THE COMPLETE
TECHNICAL PAPER PROCEEDINGS
FROM:



CABLECASTING SESSION NO. 2:
Studio Equipment for Local Origination

Session Chairman:
Greg Liptak

Participants:

Frederick Haines and Gerald Hobbs
"A Low Cost Color Camera for Cablecasting"

Keith Y. Reynolds
"A High Quality, Low Cost, Color VTR"

Glen R. Southworth and Carl J. Wenzinger, Jr.
"Local Origination for CATV Systems
Using Slow-Scan TV Techniques and Electronic
Character Generation Systems"

FREDERICK HAINES AND GERALD HOBBS

A significant reduction in the cost of an item, whether it's a color camera or an automobile, implies compromise. I will be frank with you and admit at the start that the design to be described in this paper involves compromise; however, I think you will see as the paper progresses that the compromises we have made have a minimal effect on picture quality, and in fact, result in a design which offers significant advantages in reliability, maintainability, and portability over its big brothers.

Not a single essential performance feature has been sacrificed. IVC engineers have simply taken advantage of the high stability of the solid state circuitry, and eliminated a number of costly and sophisticated trimming circuits. The number of controls on the control panel has been reduced to about one third of the normal complement. Electronic controls that have been dropped include skew, shading, and gamma. A major cost reduction has been achieved by eliminating a separate camera control unit, which normally houses the video processing circuitry and power supplies. With these circuits built into the camera, the camera requires only a 120 volt AC power cord and a single coaxial cable which supplies NTSC compatible video to any cable system. Despite the extreme simplicity of the self-contained version of the color camera, however, all studio accessories are available and can be added at nominal cost at any time. A studio camera cable in that case, links the color camera to a junction box and a remote control panel, both of which mount in a standard studio control console. In the studio version an external NTSC color encoder and an external master synchronizing generator are employed. This differs from the self-contained version of the camera in which the encoder and synchronizing generator are miniaturized, and built into the camera. The foregoing points up the extreme versatility of the IVC 100 color television camera. That is, it can be used as a self-contained camera for the single coaxial cable feeding the CATV system; or in the largest and most complex of television studios of the broadcast type employing switching systems and master synchronizing generators.

A number of important innovations have been made in the optical system to allow more light to reach the image tubes. Standard silver-surfaced reflecting mirrors have been replaced by dichroic mirrors with thin-film coatings. The chemical formula for these coatings was calculated with the aid of a computer which factored in the dispersion of the materials. By using expensive precision tooling to achieve extremely close manufacturing tolerances, it was possible to set mirrors in slots in the base casting, and then seal them in place permanently with optical grade epoxy, eliminating any need or possibility of adjustment.

The net result is a camera that can be used with image enhancers, standard gear in most television studios, to produce quality color pictures which compare quite well with those turned out by the more expensive studio cameras. And the price of the new camera is only $14,500 compared with an average of about $75,000 for most studio units. Despite its compactness, the International Video Corporation's camera is quite versatile. For cable television it can produce an NTSC picture for display on a monitor or for transmission to the home receivers through the modulator. It also can be used with studio cabling, junction boxes, remote control panels, external encoders, and master sync generators. In the latter application the camera is completely equipped with system capability. That is, it has professional intercom circuits, tally lights, and standard broadcast signal levels.

Special low-noise pre-amplifiers are needed to boost the low level red, green, and blue signals from the vidicon pickup tubes to a usable level. The vidicon tube does not generate its own noise to any noticeable extent, so the signal-to-noise ratio of the camera will be primarily set by the entrance noise of the video amplifier system. Since junction transistors act as noise generators at lower frequencies, and since noise is most objectionable at low television frequencies, an FET stage is used at the amplifier input for the best possible S/N ratio. Following the special low noise pre-amplifiers there are three processing amplifiers which provide gain control, clamping (to eliminate bounce), add system blanking, and remove voltage spikes and other irregularities that might be introduced into the vidicon signal.

The IVC 100 in its self-contained form employs a greatly simplified NTSC encoder. The IVC encoder accepts separate outputs from the red, green and blue vidicon tubes, and combines them into a NTSC compatible color signal. As the most complex circuit in the camera system, the NTSC encoder represents a major cost factor in the conventional color television camera channel. Since the decision was made at the outset of development to eliminate the camera control unit, it was necessary to devise an encoder circuit small enough to fit into the camera package. The result is a built-in encoder mounted on a double sided printed circuit board measuring approximately 6 x 7 inches. Of course, when the camera is used in a more sophisticated studio system with an external broadcast style encoder, the built-in miniaturized encoder may be removed.

The miniaturized built-in encoder uses the R-Y and B-Y signals rather than I & Q signals used in more complex encoders. Surprisingly the greatly simplified encoder circuitry does not seriously degrade the reproduced color information, because all available viewing devices including studio monitors and home receivers employ R-Y, B-Y (or equivalent bandwidth) decoders, and the higher potential resolution promised by the I & Q systems is never fully achieved in practice.

The built-in encoder employs aperture correction in the luminance signal to enhance horizontal components of the higher frequency information attenuated by the camera pickup components and the optical system. The aperture correction may be adjusted if desired for optimum correction with good signal-to-noise ratio.

A separate input has been provided in the encoder so that the green signal can be used as luminance, but the color difference signals are still created as previously described, and the composite color video output signal is entirely compatible with the NTSC signal. Use of the optional "luminance from green" circuit provides a measure of image enhancement though it does introduce errors in color saturation. In the self-contained camera a closed circuit type of synchronizing generator is built in for use in cable television where NTSC standards presently need not be followed to the letter, the built-in sync generator produces all the pulses needed for sweep, blanking, color burst, and synchronization. These are added to the encoder video signal. For those who may be concerned about possible new requirements in the future that will force cable television local origination equipment to follow broadcast technical standards, the IVC 100 can be used with a built in EIA synchronizing generator. The built in optional EIA synchronizing generator provides FCC standard synchronization. In addition it allows the built in encoder circuit to operate with locked color, thus meeting all standards of the FCC broadcast specification to be met. Regardless of how the camera is used, however, the color produced by the built in generator is almost indistinguishable on a color monitor from that produced by the color locked generator.

Many innovations introduced in the optical system are aimed at significantly cutting the cost of the camera package without seriously degrading the overall performance of the camera. For example, rather than adopt the widely used and very costly image orthicon taking lens, IVC engineers specified a 35 mm single lens reflex format design that can be purchased off the shelf. These lenses with an image diagonal of about 43 mm are very similar to the broadcast variety, but because of volume production less expensive.

The exact zoom lens employed is an auto-nikkor f4.5 50 to 300 millimeter zoom lens, the type used in Nikon F film cameras. The relatively slow speed of this lens is effectively increased at the vidicon to f1.9 by using demagnification. That is, the ratio of the image diagonal of the 43 mm taking lens to the image diagonal of the vidicon tube face plate, which measures 15.88 mm, is approximately 2.73 to 1. Therefore, both the f stop and the zoom range are altered by that factor (in the direction of improved performance) by the demagnification of the image size. The optical paths from the zoom lens to the vidicons have been greatly simplified to insure that all of the available light from the scene reaches the tube target surface. To this end the usual color trimming filters and the neutral density filters for

the red and green channels have been left out. Instead highly efficient dichroic trimming reflectors are used with the main dichroic beam splitters to shape the red and blue light transmission characteristics. And because more light can pass through to the target, overall sensitivity is greatly improved and lag is reduced significantly.

Besides the 6:1 Nikon zoom lens, lenses with fixed focal lengths are available. Where a 10:1 zoom lens is required, the slower monochrome image orthicon variety can be used with apertures as slow as f5.3 and still produce a vidicon equivalent aperture of f1.9 as described earlier.

During assembly the relay lenses are set precisely and permanently locked in place. The three image tube yoke assemblies are likewise aligned and locked into position. The entire optical system is held in the camera by precision dowell pins and can be removed in a matter of minutes for replacement of the vidicons. After a tube is replaced the optics are reinstalled with the aid of the indexing pins to achieve precise realignment, and unlike other systems which must be realigned on occasion, it needs no further adjustment. Because the dichroic mirrors are epoxied in place, adjustments to them are not only unnecessary, they are impossible.

The IVC 100 low priced color camera has put locally originated color cablecasts within the reach of even the smallest CATV installations. Larger systems appreciate the flexibility these light and inexpensive units offer, and now for the first time reasonable color capability is available to cable TV originators throughout the world.

KEITH Y. REYNOLDS

Color helical scan videotape today is a great tool for both originating and delaying CATV programs. However, as with any TV equipment, reliability is extremely important. The IVC-800 Series Helical Scan Color VTR has proved, during the past 2 years, to be extremely reliable in many CATV installations. In other words, the IVC-800 Series Color VTR has proven to be "cable-stable."

There are several reasons why this is true. The first reason is the IVC Tape Format. A short 12-inch video head scan is used to record the video information onto the tape. This very short scan line allows far easier, less critical tracking adjustments. In addition, the 6-mil wide scan is separated from the next video scan by a 3.6 mil guard band. This wider guard band prevents pickup from adjacent tracks if the head is misaligned

due to tape stretch or other factors. For these reasons, the IVC-800 can operate in any physical position, even upside down. Once tracking is set during the playback of a given tape, it can safely be left unattended during the remainder of the program. IVC uses the Alpha Wrap, in which the tape is wound 360° around the video head drum. This allows 100% of the picture information to be recorded, utilizing the full width of the tape. The cross-over interval (the only missing information) is positioned to occur during the vertical blanking interval, after the equalizing pulses. This allows all the TV receivers on a cable system to positively lock on the vertical sync pulse. Many of the competing helical scan VTR's lose several lines of picture information, due to the fact that tape and head lose contact during this period and that the edges of the tape are used for audio and control track information. IVC devised a unique method that allows the recording of the control and audio information in the same area as the video information without any interference or crosstalk between signals.

The horizontal sync pulses line up on each adjacent video tape scan line by the careful selection of tape speed and scanner RPM. Although not usually a consideration for CATV applications, this provides adequate stop motion and allows for the option of slow motion operation.

Time base stability is extremely important, particularly for stable color operation. Since the color burst occurs only at the rate of one per scan line, any velocity change during one line will produce a hue shift in the color.

To achieve this time base stability in the recorder, it was necessary to use an air bearing to make the tape flow smoothly around the drum. The air bearing is generated by a rotating member of the scanning assembly which carries the video head. Without this air cushion, the tape would tend to stick to the drum surface, providing intermittent motion instabilities. Needless to say, reliable color reproduction then would not be possible. Mechanical instabilities (a major source of horizontal jitter) are reduced by careful design of the scanner assembly. Horizontal jitter is consistently less than 0.5% of picture width with monitors of 7.5 millisecond horizontal afc time constant. This means that horizontal jitter is virtually unnoticeable on home color receivers.

Another key to cable television's wide acceptance of the IVC-800 VTR is the capability it has of recording and successfully reproducing a wide bandwidth with a high signal to noise ratio. The IVC-800 is capable of reproducing 30Hz to 4.2 MHz with a signal to noise ratio of 43 dB. This also means that it is possible to record and reproduce color without resorting to pilot tones and receiver modifications.

We have briefly described some of the built-in features of the IVC-800 VTR. Initially, however, we mentioned that reliability is important in any television equipment. What makes the IVC-800 VTR more reliable than competing helical scan VTR's?

First, of course, the IVC-800 utilizes solid state electronics throughout. In the case of any electronic failure, plug-in replacement of the printed circuit board will quickly restore the VTR to normal operation. Solid state electronics have been proven highly reliable by others as well, so that no exclusive claim can be made by IVC except for the fact that the electronic components are carefully selected for reliability. Exclusive claim can be made, however, for mechanical reliability.

All five basic operational modes of the VTR are controlled by momentary electronic push button switches. An interlocked system of relays insures smooth tape handling and virtually eliminates the possibility of tape damage due to improper operation. The five operational modes are: Rewind, fast forward, play, stop, and record.

Safe dynamic braking of the reels is achieved automatically simply by pushing the stop button. (Incidentally, as strange as it may seem, efficient dynamic braking is not incorporated on the very expensive broadcast quadruplex VTR's as it should be, but can be found on reliable instrumentation recorders.) Pushing the stop button also initiates a tape tension release after the tape has safely stopped. This relaxes the tape around the video scanner so that the head is not in contact with the tape when the VTR is in standby.

When the end of the tape comes off either reel, the tape tension arm relaxes and activates an end of tape switch. This quickly removes the power to the brake solenoids and brakes are applied to the reel tables. Power is also removed from the supply, takeup and capstan drive motors and also from the capstan idler solenoid. This effectively stops all tape motion automatically, eliminating damaged tape or damaged VTR components.

The IVC-800 VTR has been carefully designed to take advantage of as many electronic controls as are necessary to eliminate mechanical functions since electronic controls have proved to be much more reliable than similar mechanical controls. Because all electronic controls are used, it is also extremely simple to completely remote control the entire VTR. A second audio or cue track is provided along the bottom edge of the tape and this is used to trigger tape motion remotely as in applications for dial or random access systems. In these applications, the VTR is often housed in a central area physically removed from the viewing area and comes in contact with human beings only for routine cleaning, preventative maintenance, or periodical program tape changes.

It can be seen that because of the electrical interlocks and electronic sensors incorporated in the tape transport, the tape always is safely handled regardless of any possible pushbutton combinations. The tape transport cannot run wild or jam. Recordings are protected from accidental erasure due to the push-button arrangement and the fact that the record relay cannot be energized unless both the PLAY and RECORD buttons are pressed simultaneously, since the RECORD switch receives power through a portion of the PLAY switch.

The tape path alignment is set once at the factory and will stay perfectly aligned during the life of the VTR, assuring tape interchangeability for the life of the recorder.

The IVC-800 employs a single ferrite video head. Ferrite heads provide much better frequency response and wear characteristics than metal heads. The IVC head is guaranteed for a life of 1000 hours. Replacement, when necessary, can easily be performed in less than 60 seconds without expensive tools or jigs and can be done in the field by inexperienced personnel.

It is not unusual to listen to a manufacturer boast about his products. Naturally, he believes in them and wants to tell the world about them. Therefore, when an unbiased, respected, independent agency runs a scientific competitive evaluation of commercially available helical scan VTR's, the manufacturers of these VTR's are eager to know how he stands up to his competition. IVC and others in competition with IVC recently had this opportunity when the Swedish Government undertook a helical scan VTR evaluation.

Sweden is a world leader in several technologies, but particularly in the use of audio-visual aids in her highly sophisticated system of education and training.

Recently, the Swedish Government appointed a special committee to objectively evaluate video equipment, since they plan to spend many millions of dollars in the near future equipping the Swedish schools with cameras, video tape recorders, and monitors.

The government contracted to have an objective evaluation made of all helical scan video recorders, and eleven were submitted by various manufacturers throughout the world. IVC submitted 3 VTR's: an 801, an 851 with electronic editing, and the then prototype, low-cost IVC-601 helical scan VTR.

The tests extended over eight working weeks, with strict security to prevent suppliers from altering the settings of their machines after they were delivered to the Swedish Committee. In addition to an exhaustive examination by engineers, the evaluation was based on the recording and playback by the competing machines of a master tape prepared by the Swedish Committee in cooperation with educators, psychologists, and technicians. The overall

quality of the reproduction was then judged on monitor receivers by a representative panel of 320 people.

A crucial aspect of this test was that the video recorders feeding the monitors were in a separate room to prevent members of the panel from knowing which VTR was responsible for the video picture. Their unbiased personal assessments, later subjected to mathematical analysis and computerized accurately, reflected the most important criteria of VTR performance--the acceptability of the picture to a typical audience.

Numerous scientific tests were run to determine which of the 11 VTR's had the best resolution and reliability, and a report was generated. Except for those tests that showed no basic difference between recorders, the three IVC VTR's "clearly appeared to be the best." After ranking the performance of all the VTR's for each test, a final grouping was made.

Group (1) is the top group. This group consisted of 4 VTR's. "These four have based themselves above any discussion when it comes to suitability for educational purposes." Three of the 4 recorders in Group (1) were the 3 IVC VTR's.

Group (2) consisted of 2 VTR's. "No doubtful values have been noted during the test for either of these two."

Group (3) consisted of 3 VTR's. "The limitations of these machines in respect to suitability for educational purposes is commented on below."

Group (4) consisted of 2 VTR's.

The final notes of the report stated that: "The machines in Groups (1) and (2) can be recommended as suitable for educational purposes whilst the machines in Groups (3) and (4) cannot be recommended as suitable."

Complete transcripts of the Swedish report should be available this fall, at which time you can see for yourself the superior performance of the IVC VTR's. Our representative in Sweden assures us that the Swedish Committee, in giving such an authoritative endorsement, recognized the inherent reliability and also that the monochrome VTR could be converted to NTSC, PAL, or SECAM color by field addition of a printed circuit color board. Another influencing fact is that the IVC VTR's require 30% less tape per hour of program than competing VTR's. This would lead to substantial economies in educational projects where many hundreds of tapes will be needed to give a sufficient supply of recorded materials flowing to schools in Sweden.

CATV systems utilizing the IVC-800 series VTR, as well as the Swedish Government, have proved to themselves that the IVC-800 VTR provides high quality and reliability at low cost.

GLEN R. SOUTHWORTH AND CARL J. WENZINGER, JR.

The normal television signal is highly redundant in information content, primarily from the necessity of repeating virtually the same image thirty times a second. If motion is not an essential requirement in the information transmission process, then very large reductions in video bandwidth can be achieved, allowing the use of conventional "voice grade" circuits and "audio type" tape recorders. Program preparation is relatively simple, involving essentially a series of still images with accompanying sound.

The use of narrow-band video technology leads to some interesting possibilities in CATV operations. First, in some instances the "front end" of the CATV system may be on a mountain top or other remote location, making it an expensive proposition to transmit live video from downtown studios for injection into the overall system. Narrow-band video transmission is not only less costly than wide-band microwave or coaxial cable facilities, but in some instances existing voice-grade communications circuits can be used, thus minimizing time required for an installation.

Programming with narrow-band video is, however, necessarily somewhat limited in scope because of the inability to reproduce motion. Typically, a new picture may be transmitted every 10 seconds and would appear on the viewer's screen as a succession of still images. Nevertheless, this seems acceptable for announcements, advertising, messages, weather maps, time, temperature, barometer, and other readings as well as still photographs or slides.

Conversion of normal real-time video signals from either broadcast or closed-circuit type television cameras to narrow-band format may be readily accomplished with high fidelity by means of a relatively low-cost device, using data sampling techniques. In an instrument of this kind, a small segment of each television line is examined for its brightness content and the video data point "stretched" for 63.5 microseconds after which another sample is taken on the next TV line. When looking at a normal television image, you might visualize an imaginary vertical row of dots or data points which moves slowly across the television raster from left to right with the complete transmission of an 8 kHz narrow-band video image taking place in approximately 7 seconds.

The video output signal obtained by the sampling process is very similar in nature to conventional "slow-scan TV", but the method of its generation has some important advantages. First, virtually any conventional camera can be used as a video source, thus making practical extensive use of existing "real-time" equipment, facilities, and techniques. Second, the sampling converter is a relatively simple and reliable device requiring a minimum of maintenance

and adjustment, while at the same time providing narrow-band output signals of essentially the same quality as the real-time input. Third, color images may be relatively easily trnasmitted in narrow-band format by either sequentially sampling the R-G-B outputs of a broadcast color camera or by simply interposing color filters between the subject and the lens of a monochrome camera, providing a form of "field sequential" color slow-scan TV.

Narrow-band video signals do require some special handling during transmission as they are subject to essentially the same distortions as real-time video signals in terms of frequency and phase distortion as well as noise susceptibility. The transmission channel used should, when practical, have DC response and a bandwidth extending to approximately 10 kHz for optimum image reproduction. Narrower bandwidths, even "dial-up" voice-grade phone lines, can be used, but essentially involve increasing the transmission time per picture, so that as much as 2 minutes per monochrome image may be required.

For normal picture distribution it is necessary to have some means of converting the 7 seconds per frame narrow-band video back to normal 525-line 30-frame-per-second standards. This may be accomplished by means of a unique form of scan converter which is remotely related to the "instant replay" video disc recorder. With a device of this nature, incoming narrow-band video information is first translated into a series of narrow amplitude modulated pulses with an interval between pulses of 63.5 microseconds, thus essentially reversing the process used to obtain the narrow-band video signal at the transmitter. These pulses are then used to record information on a magnetic disc memory rotating at 1800 rpm build up an image at standard TV rates.

When the recording process is observed, an image appears on the TV monitor growing from left to right in very much the same manner as a slow horizontal "wipe," with the viewer being aware of the mechanics of the image recreation. Alternately, the addition of a second record/playback head to the disc memory allows one image to be displayed while a second image is being recorded, with the result that instantaneous switching from one scene to another may be accomplished without the viewer becoming aware of the recording process. Similarly, the usage of three heads allows the synthesis of color signals through R-G-B recording, although the outputs of the three disc channels must be subsequently properly encoded to approximate NTSC standards.

In addition to the origination of programs for general viewing, narrow-band video technology makes possible interesting potential activities for the CATV operator, such as specialized services to hotels, motels, and convention centers as well as for industrial uses. The utility of a given wide-band television channel can be greatly expanded by means of multiplexing a series of narrow-

band video signals for cable distribution with both transmitting and receiving scan converters being located at appropriate locations in the CATV system.

GLEN R. SOUTHWORTH AND CARL J. WENZINGER, JR.

The many requirements of CATV Systems for origination of public service announcements, local news, weather and advertising has opened a new area of application for television scan compatible character generation systems.

Computer system requirements for alphanumeric displays have caused the development of many types of character generating systems. Many of these are quite specialized and are either not compatible with television scanning systems or the characters are too small and between-character spacing too close to provide good readability on a standard television receiver. However, the Visual display system is specifically designed to be compatible with standard TV scan systems and provides character size and spacing which is easily readable on any standard TV receiver.

The heart of the system is the DISPLAY CONTROL UNIT (DCU), which is an electronic character generator combined with a core memory of sufficient storage capability to store data equivalent to one television frame or "page" of alphanumeric information. The DCU accepts standard USASCII coded data input and converts that input directly into a composite video output meeting FCC and EIA standards. The DISPLAY COMPOSER which consists of a Keyboard and one or two video monitors, provides the normal manual data input. The keyboard contains all the alphanumeric and special character keys. In addition, a separate group of control keys is included on the right hand side of the keyboard. These control keys provide for control of the "cursor", which is a half-white spot which appears on the DISPLAY COMPOSER MONITOR ONLY and indicates where the operator is "typing" on the screen.

The output "page" is made up of up to 16 horizontal rows of 24 characters per row. The standard character set consists of 63 different block-style symbols and includes the alphabet, the numerals one through zero plus numerous standard symbols and punctuation marks. Thus, practically any alphanumeric message, filling one frame may be manually composed by use of the DISPLAY COMPOSER. The keyboard portion of the DISPLAY COMPOSER in this case provides the ASCII coded data input.

The DISPLAY CONTROL UNIT by itself is not very flexible due to the single "page" information storage limitation. To fully utilize the capability of the basic character generator, peripheral units must be added to provide storage and retrieval of information or to interface with other information sources.

In addition to the keyboard data input, the VISUAL DISPLAY CONTROL UNIT has a second data input which permits interfacing with other data sources including storage devices. The DISPLAY CONTROL UNIT provides a data output, in addition to the video output. This data output permits interfacing with data storage devices or data lines.

In CATV origination, it is many times desirable to program local news, weather, financial information, announcements, national news or other information on different channels, while maintaining normal program activities on other channels. Electronic character generation can become uneconomical if a separate DISPLAY CONTROL UNIT is required for each channel to be programmed.

To relieve this economic problem, Visual Electronics has developed the VISUAL MULTI-CHANNEL ORIGINATION SYSTEM. This system consists of the DISPLAY COMPOSER, THE DISPLAY CONTROL UNIT, and THE VISUAL PAGEFILE combined with a storage unit such as the VISUAL READYFILE or MASTERFILE. These modular subsystems make up a composite system which will permit precomposing and storage of information for instant retrieval and for multi-channel display of up to 70 different messages simultaneously.

Locally originated messages are manually composed through the DISPLAY COMPOSER Keyboard. The message is then edited and upon completion of editing, the "page" is "filed" in the data storage unit for later retrieval. The READYFILE will store 62 "pages" of information, in data form, on each plug-in magnetic tape cartridge.

The MASTERFILE is a data storage unit which utilizes a magnetic disc on which over 700 "pages" of information may be stored in data form. These messages may be instantly retrieved by electronically addressing the disc utilizing a simple 5 digit code. Upon retrieval, the data is instantly "copied" into the DISPLAY CONTROL UNIT and converted to video. The original data stored in the MASTERFILE is not disturbed until new data is purposely recorded on the disc to replace previous information. The "page", or frame of video from the DCU is then routed to one of up to 70 channels of the PAGEFILE.

The PAGEFILE is also a magnetic disc unit; however, the information is recorded in the form of one frame of Television Video on each of up to 70 tracks. The basic PAGEFILE is equipped with one sync track and seven video tracks. Video tracks may be added in groups of eight. Since each video track includes its own head and amplifier, any or all outputs may be used simultaneously. The video output from each track is then fed to the input of a modulator. Therefore, one track or channel may be used for local weather, another for general public announcements, another for sports scores and so on.

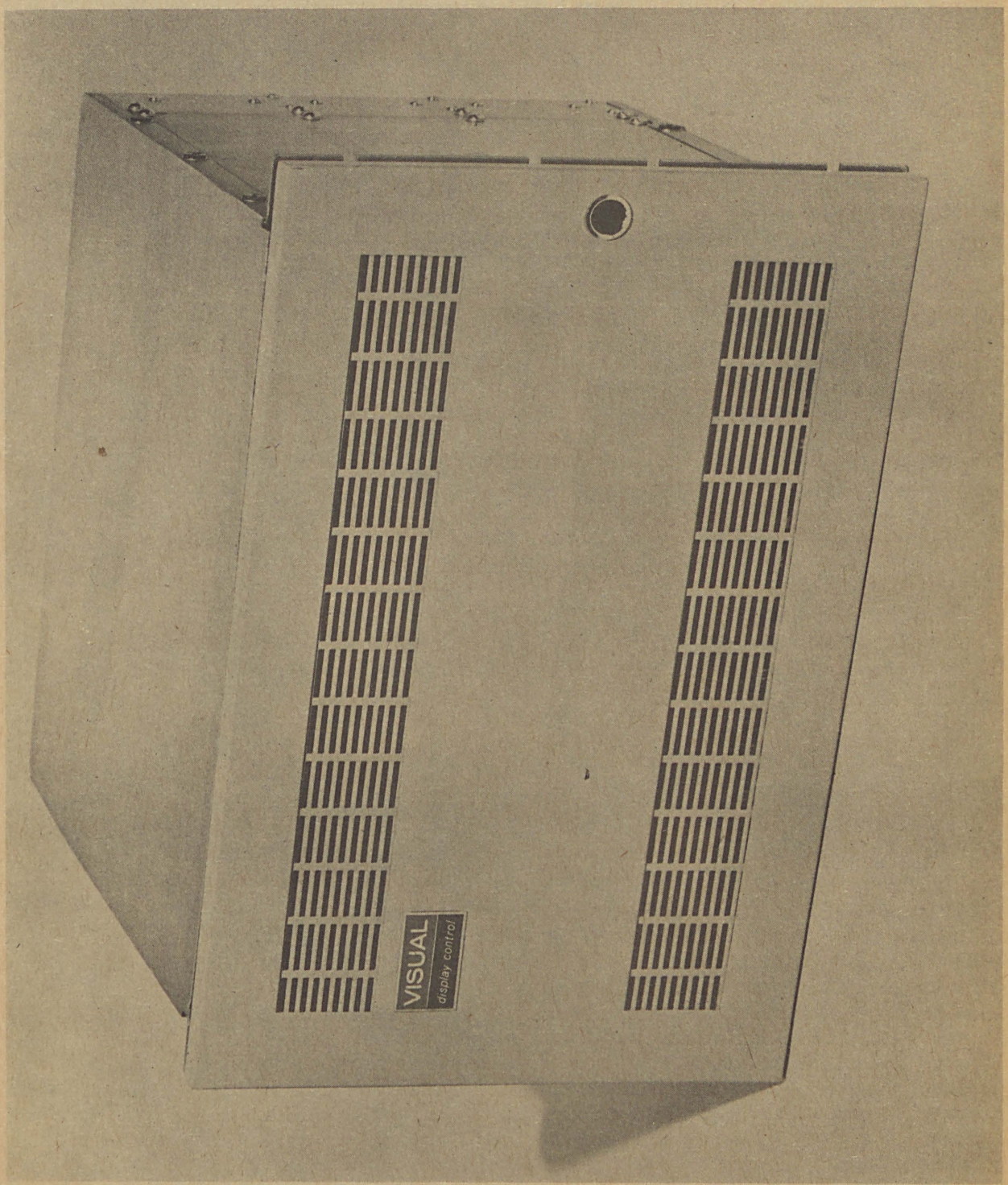
In some instances more than one "page" may be required to fulfill the requirements of any given r-f channel. Typical of this would be a civic announcement channel, displaying local meeting schedules, school bulletins, adult education course schedules and other general public announcements. In such cases, multiple PAGEFILE channels may be assigned to that r-f channel. An automatic sequencing switcher then periodically and automatically changes the display on that channel providing practically unlimited automatic programming.

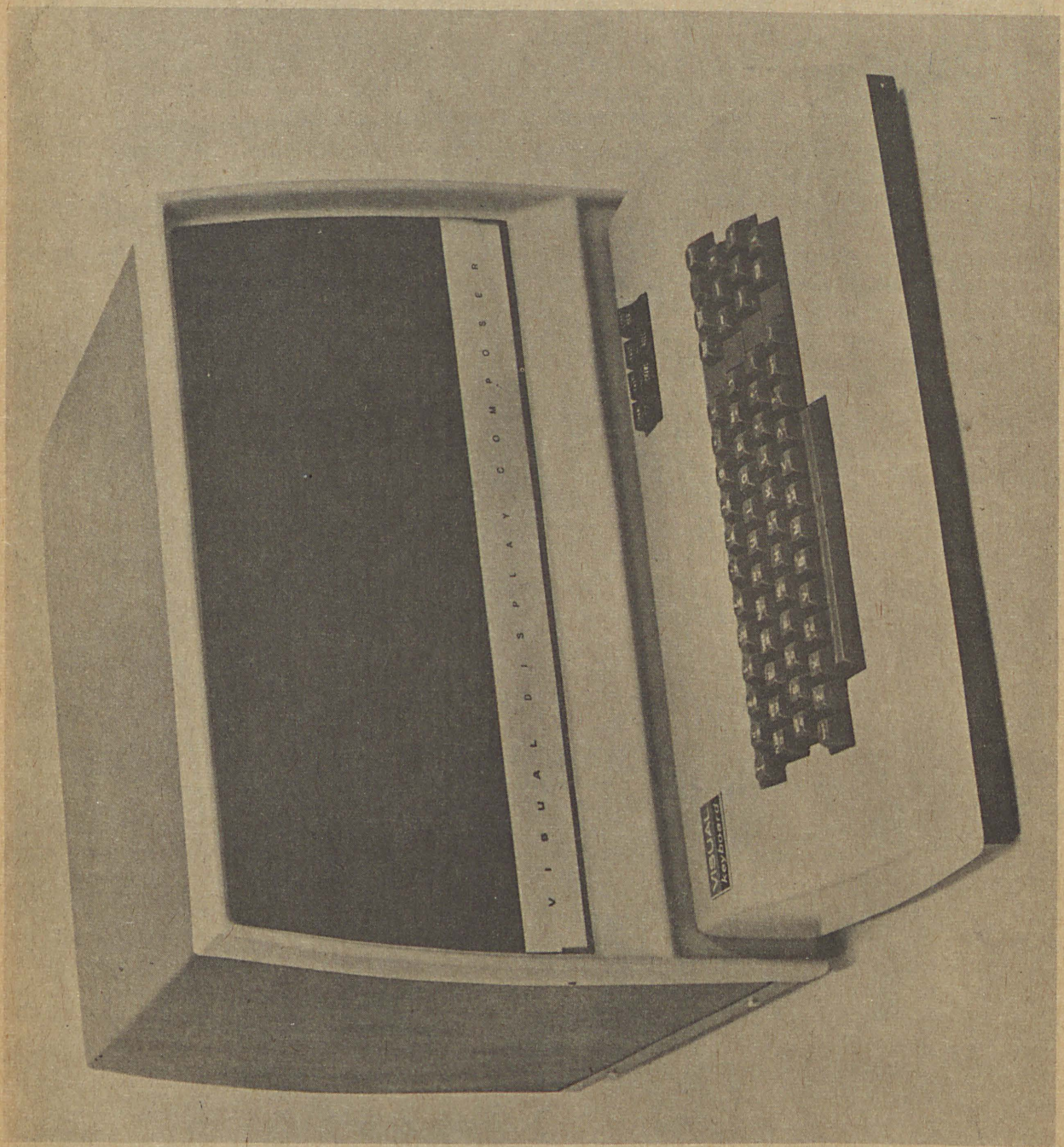
Other uses of the MULTI-CHANNEL ORIGINATION SYSTEM include a local news and sports channel, a Recreation channel listing current movies, plays, concerts and the like.

So far we have only considered the display of pure alphanumeric information. The Visual DISPLAY CONTROL UNIT also features a separate video input to a built in non-additive mixer. This permits feeding a video signal, derived from a slide or film chain into the DCU and mixing same with electronically generated alphanumerics as would be required for titling. This, however, ties up the DCU during the period that particular display is "On air".

On the other hand, an external non-additive mixer may be used as indicated in Figure 4 to provide titling of film or slides, or live pick-ups. In such a system configuration, one DISPLAY CONTROL UNIT is used to program the MULTI-CHANNEL MESSAGE ORIGINATION SYSTEM, yet can also be used for "on air" titling of live, film or slide programs. This provides maximum utilization of a single character generator.

As the Cable Television Industry expands into local program origination, the need for more flexible production and programming becomes obvious. The electronic character generator, when integrated into a MULTI-PAGE ORIGINATION SYSTEM offers a very flexible, easy to operate and economical system for the composing and display of alphanumeric messages.


VISUAL
display control


VISUAL DISPLAY COMPOSER
VISUAL
KEYBOARD

63-ASCII CHARACTER SET

1 2 3 4 5 6 7 8 9 0

! " # $ % & ' ( ) `

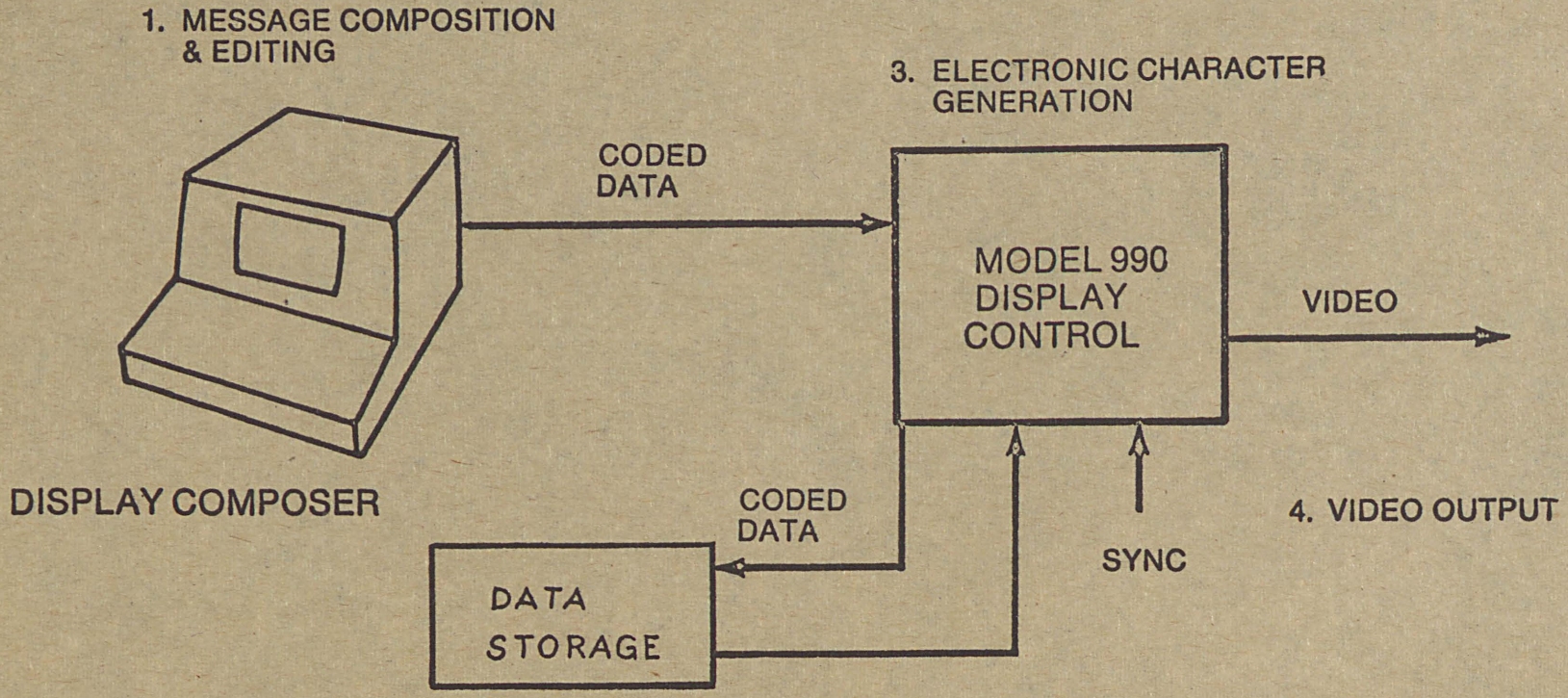
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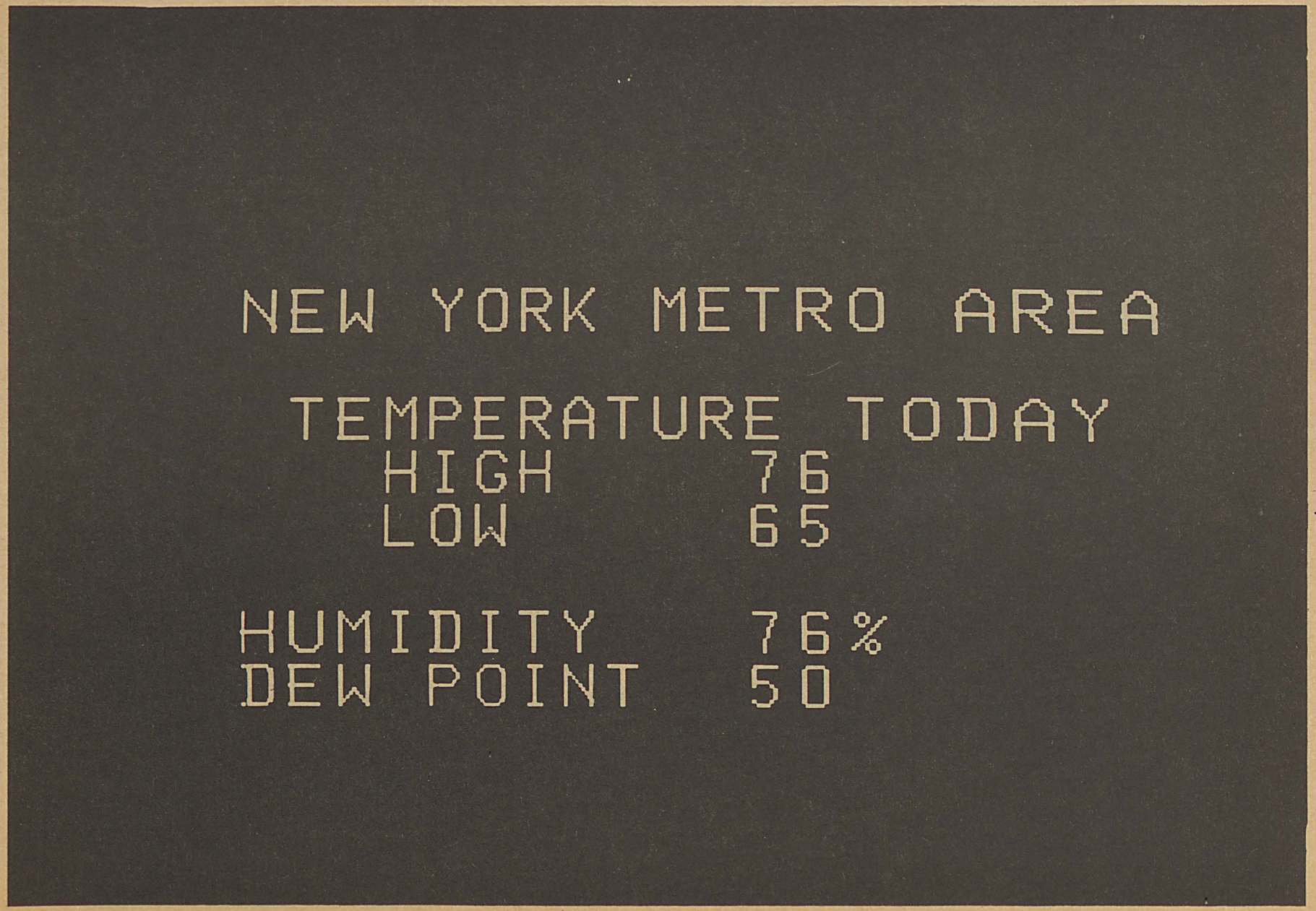
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A B C D E F G H I J

K L M N O P Q R S T

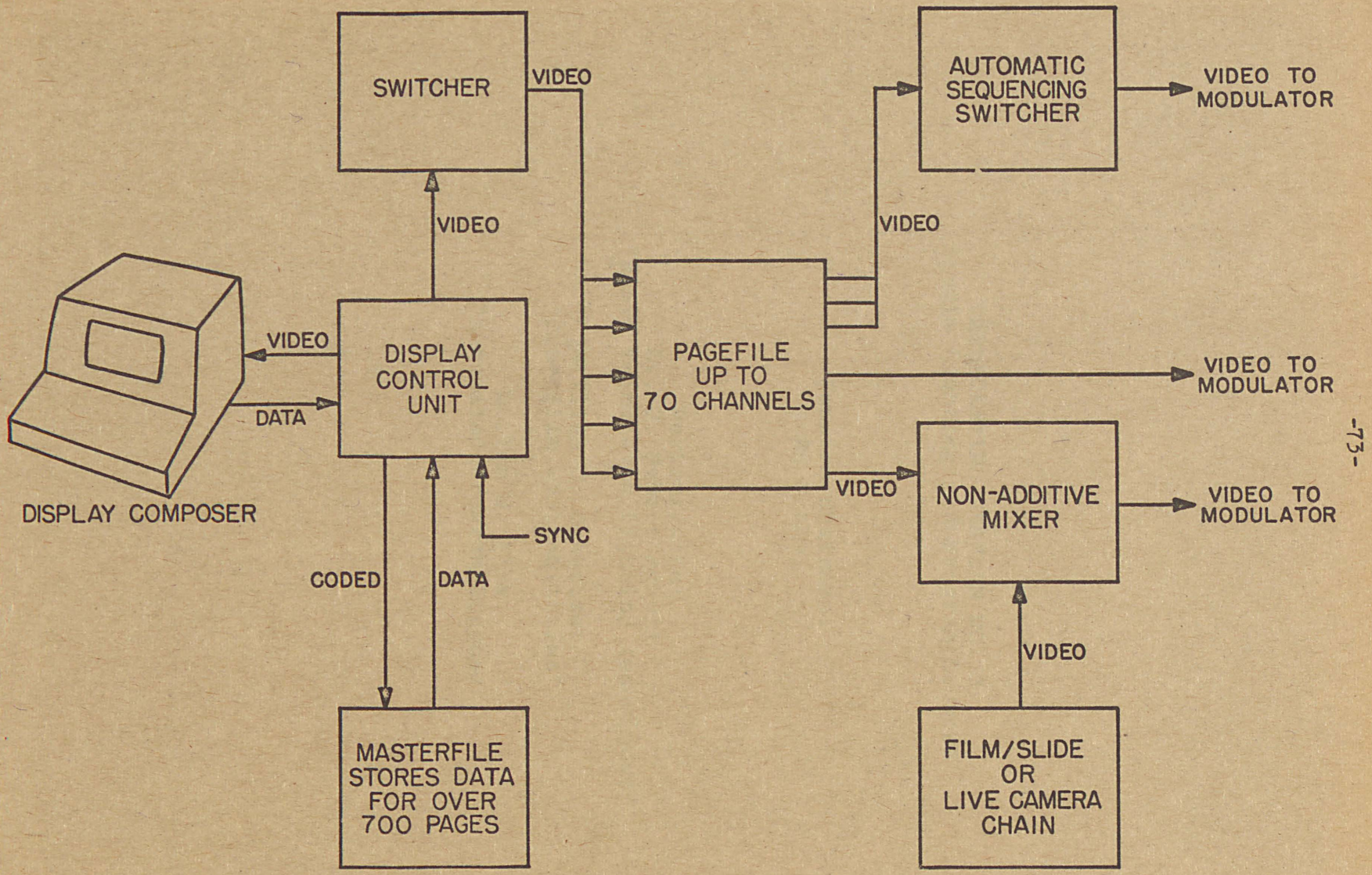
U V W X Y Z


1. MESSAGE COMPOSITION & EDITING
3. ELECTRONIC CHARACTER GENERATION
CODED DATA
MODEL 990 DISPLAY CONTROL
VIDEO
DISPLAY COMPOSER
CODED DATA
4. VIDEO OUTPUT
SYNC
DATA STORAGE
2. STORAGE OF MESSAGE IN DATA FORM


NEW YORK METRO AREA
TEMPERATURE TODAY
HIGH 76
LOW 65
HUMIDITY 76%
DEW POINT 50

A.P. VIGNETTE

(NIAGARA FALLS)--- PART OF THE TRADITIONAL MECCA FOR HONEYMOONERS IS GOING TO BE TURNED OFF FOR EIGHT MONTHS. ENGINEERS AND GEOLOGISTS WILL DIVERT WATER FROM



TYPICAL MULTI-CHANNEL MESSAGE ORIGINATION SYSTEM

HUBERT J. SCHLAFLY

The concept of a local distribution multi channel microwave link to serve as a means of delivering CATV signals from advantageously located head ends or central offices to distribution substations was proposed in early 1965 and implemented through design, FCC licensing on an experimental basis, propagation testing, and now limited commercial use, in a few selected areas.

The system of which I am speaking is the joint TelePrompTer-Hughes Aircraft Company experiments now known to the industry as AML, which is the short identification for the multi channel microwave Amplitude Modulated Link.

The purpose of this paper is to deliver to the industry a current status report on AML.

A very excellent technical review on AML was delivered at last year's NCTA convention in Boston. A rather elaborate demonstration of the working equipment was presented on the exhibit floor, at the 1967 convention in Chicago. And a thorough report on over one year of propagation testing of AML at 18 GHz was delivered as a technical paper in spring of 1967 at the IEEE Convention in New York. Reprints of all of these papers have been widely distributed and are available on request.

It is therefore not my intent to repeat that information here. I do want to tell you where the project stands, to discuss why it is not in common use in the industry today and to project some thoughts on the future course of this most interesting technique of broad band multiple addressee delivery.

There are two very essential ingredients for the success of any electromagnetic radiation device.

1. The technical development of practical working equipment.

2. The authorization of the designated governmental regulatory body for the use of such equipment to provide a desired service.

With regard to the technical development - AML has been working since 1966. A transmitter has been operating under an experimental license in New York City most of the time since that date. Today, the present version of this AML Transmitter is operating 24 hours a day 7 days a week, carrying 12 channels between a cable head end near the George Washington Bridge and two sub-distribution head ends. In accord with a commercial waiver on the experimental license which stipulates certain limitations for its use, AML is actually delivering CATV signals to many thousands of subscribers in New York on a daily basis. At the moment each of these "sub-distribution head-ends" are also complete normal CATV head ends and as part of the continuing

experiment we are able to instantly switch over service from the normal to the AML signal. I do not believe that any of our subscribers can tell the difference in the signal. A trained eye could distinguish a difference with an "A" - "B" test at the head end because the input to our AML system is from a receiving location that has slightly better reception quality than the reception at the sub-distribution head ends. You may be interested to know that one of these sub head end locations does not have direct line of sight to the transmitter. We are using a "bounce" shot from a 6'x 8' reflector mounted on a building in a block adjacent to the receiver site.

Similar experimental licenses with a commercial waiver have been granted at 18 GHz for operation with existing CATV systems in Farmington, New Mexico and in Eugene, Oregon. On February 17, 1969, the FCC authorized such operation in these two locations. Transmitters and a limited number of receivers are available. We are currently in the process of developing the transmitter sites. This includes leasing land, preparing access roads bringing in power and signal and all of the things that those who are experienced in CATV operating systems work on daily. This is an aggravatingly slow process, but we are making progress at both locations.

Here I want to reemphasize that the original intent of AML and the major benefit to the public and to the industry is not "big city" operation but rather rural operation. Delivery of processed multi-channel signals through the air to a relatively simple receiver which then cable feeds small home clusters, possibly even individual subscribers, located within a radius of 10 or more miles from an established cable system - greatly extends the service potential of the whole industry.

The technical operation to date has been successful. We have learned much which would beneficially influence to a commercial production design. As evidence of practicality, an AML transmitter was delivered here in San Francisco last week and is delivering full cable service approximately one mile through the air under a "Special Temporary Authorization" to a receiver in a room of this hotel--through the window and the fiber glass curtains. The VHF output of the receiver is feeding a number of exhibitions at this convention. This is not a demonstration, it was simply done as a service to the industry and as a protection, in the event that local broadcast reception at this building was not adequate for this convention.

Let's now consider the second of those two "essential ingredients"--the regulatory ingredient.

In order to give no false impression or misinterpretation of what I am about to say--I state that I am totally in accord with the power of a federal regulatory body determining the Rules and Regulations for the proper use of the radio spectrum in the

public interest convenience and necessity. This statement is not said tongue in cheek--it is a simple recognition of the fact that without such regulation there would be chaos.

If I have a complaint on this point, it is just that it takes a tremendously long time to determine what is in the public interest--particularly when other respected, but certainly partisan interests play the fear game of "lets don't do anything now because who knows what our needs may be tomorrow?"

At the start of the AML project we selected the 18 GHz band--approximately 2000 MHz of virgin spectrum, without a single license outstanding, which had already been assigned, by international agreement, to industrial use, fixed and mobile.

We sought specific Rule Making, to allocate a small portion of this band to local terrestrial distribution of Multi-Channel, Broad band signals, originally asking that 448 MHz be allocated to permit opportunity for nation-wide competitive services. Later this request was reduced to approximately 250 MHz, allowing for two 20 channel competitive systems in the same geographic area and relying on technical means, cross polarization, beam directivity, shielding and other means for permitting multiple operations in immediately adjacent geographic areas.

Here let me digress a bit to make a technical point. One of the principle features of AML is its economy in the use of Radio Spectrum. The system employs single sideband, suppressed carrier Amplitude Modulation--not the most sophisticated modulation method--but for the purpose of local distribution of Broad band signals where relay operation beyond one or two repeats is not contemplated--is quite adequate for the job. The beauty of this feature of AML is that the ratio of the modulating frequency band to the RF spectrum occupied is 1:1. Thus a 6 MHz television channel does not require more than 6 MHz of the Microwave spectrum. More sophisticated methods of modulation undoubtedly can boast of greater fade margins and lower noise--but they pay for this by occupying radio spectrum which is 5 to 10 times greater than the modulating band width. If these extra performance features are not required for normal local distribution service, why, we reasoned, jeopardize the possibility of obtaining FCC authorization for the service.

But even the 1:1 modulation ratio of AML was not sufficiently persuasive. In May 1968 the FCC, without prejudice, denied the Corporation's petition for rule making to allocate permanent frequencies for the AML Equipment. The basic reason for such action, as I understand it, was not opposition to the service but rather a desire to review the possible international needs and broad service category allocation of the entire 18 GHz band for satellite transmission. The time table for this review included suggesting the subject be part of the agenda of the World Radio Conference which is scheduled to be held in late 1970 or early

1971. While I believe that that conference will give due recognition to necessary terrestrial services as a vital adjunct to space communication, I do comment that that is a terribly long time to wait to find out if we can satisfy a demonstrated present day need.

That is a dark picture--but I am happy to end this report on an optimistic note. When it became apparent that allocation action at 18 GHz might be long delayed--we carefully examined other portions of the spectrum where AML might be successfully applied. We had earlier examined the band from 12.7 to 12.95 GHz where CATV operation had already been approved and rejected it. We rejected it on the basis that the band was too narrow, too fragmented and with rules too directed towards inter city service, to be useful for our purpose. I believe the thought of that beautiful 2000 MHz of unused spectrum at 18 GHz may have clouded our vision.Now we re-examined that the CARS band and on November 26, 1968 Hughes Aircraft on behalf of Theta Com filed a request with the FCC for an advisory opinion as to whether AML equipment could be licensed under existing rules in the 12 GHz band. On Feb. 14, 1969 the FCC proposed rule making and invited the filing of comments looking toward the modification of the applicable rules to permit use of AML equipment in the 12 GHz band. Comments supporting and opposing the proposed rule making were filed March 14, 1969. Reply comments were filed by April 14, 1969 - Now it is up to the Commissioners. At last we are getting action--and we are very optimistic.

J. WALTER JOHNSON

It is the objective of this paper to give CATV managers and technicians alike a better understanding of microwave in general and CARS Band in particular. A secondary objective is to explore the potential uses of CARS Band microwave as an invaluable tool for the CATV operator.

The CATV industry is unique in that it is populated by people with a broad range of backgrounds. Often it is the cable system manager who has had limited experience in microwave that must decide on path lengths and weigh system performance against economics. Therefore I hope no one is offended by the simplicity of the analogies used in this presentation.

In general, microwave is that segment of the radio spectrum above UHF and below light. (Figure 1) The majority of TV microwave in use today is concentrated in the area between 2 and 13 GHz, with some experimental work being done at 18 and 40 GHz.

CARS Band (Community Antenna Relay Service) is that segment of the microwave spectrum from 12.7 to 12.95 GHz. This segment of the spectrum was set aside by the FCC for TV microwave relays operated by cable systems under Part 74 subpart J, Community Antenna Television Relay stations of the FCC rules and regulations. Under this subpart, ten, 25 MHz primary channels were allocated along with nine secondary channels interspaced between the primary channels. Either AM or FM modulated microwave signals may be used with power outputs not to exceed 5 watts. Directional antennas must be displayed with a beam width less than 3°.

Microwave is very similar in characteristics to light. Microwave radiation can be focused into a beam with a parabolic dish or reflected off a billboard which acts as a plate mirror. Just as light is refracted or bent as it moves through media of varying density, microwaves are bent as they move from dense cool air to less dense hot air in an inversion layer. This bending effect is a major contributor to fades. The beam is simply bent out of alignment. Microwave can also be obstructed by solid objects or by fog and rain much the same as clouds attenuate the sunlight.

The microwave carrier can be changed in amplitude or shifted in frequencies by an amount directly related to the video or other intelligence which is transmitted over the beam. A microwave carrier can be likened to another carrier, the railroad. (Figure 2) The video we wish to transmit is like a box of information which we can place on flatcar, the microwave baseband. We can also load on a box of stereo FM and a third box of computer data. The flatcar travels along the carrier and is unloaded at the receiving dock. Information is loaded on a microwave carrier with a modulator and unloaded with a demodulator. Just as a flatcar has size and weight limitations, a microwave baseband has bandwidth and information density limitations.

At the head-end of a CARS system, off-air TV signals are detected as a composite signal consisting of 4.2 MHz of video information along with the 4.5 MHz audio carrier. (Figure 3) This composite signal is modulated directly on the baseband of the microwave at the transmit terminal and delivered to the output of the receive microwave terminal where it is converted up to one of the VHF TV channels. Some microwave systems carry an additional FM subchannel above the TV. Others carry a third channel of data, remote distribution, switching or alarm.

Currently it is practical to diplex all ten of the (primary) CARS Band channels on one antenna system. This is achieved through the use of dual-polarized feeds at the focal point of the parabolic reflectors and highly stable crystal controlled equipment. For example, the odd numbered channels are transmitted in vertical polarization and the even channels are transmitted in horizontal polarization. Figure 4 shows a multi-channel system layout.

The ways in which a CATV operator may utilize CARS Band are far greater than one might first imagine. When we think of CARS Band the first thought that comes to mind is the importation of distant TV, FM, and data signals. More and more we are seeing the CARS Band used in place of a trunk line between the mountain top head-end and the local distribution point down-town.

A CARS Band link can provide 10 simultaneous channels over a single hop and eliminate pole lines, rights-of-way, construction problems and years of pole rental. With the advent of 100 percent solid state modular microwave, the maintenance associated with a ten channel microwave system is not substantially different than an equivalent number of trunk line amplifiers.

The terminals of a microwave system are usually located in an air-conditioned building, where test equipment and facilities are readily available. A trunk line is subject to icing, salt air corrosion, and other destructive forces. Moreover, the line amplifiers must be maintained in this environment. A well-designed CARS Band microwave system is no more susceptible to outages than a buried cable.

On paths of ten miles or more, the cost of a microwave system and trunk system is very competitive. But most important, the signals on a microwave system can be delivered from the mountain top to down-town in perfect condition. Differential phase and gain will be less than 1^{o} and 1 dB respectively on the microwave system.

CARS Band microwave also makes it convenient to construct the local distribution point at the geographical center of the community. Trunk lines can be constructed like the spokes on a wheel. This type of system offers shorter trunk lines, lower construction and maintenance costs along with a more uniform

picture to all subcarriers. If a main trunk line fails, it affects only a pie section of the city and not the entire system.

Economics is always a key consideration in the determination of whether it is practical to provide CATV service to a given community. Often the investment in a single high-quality head-end can be distributed among several communities by splitting the output of the CARS Band microwave system and directing this split signal to a microwave receiver located in these communities. Small nearby communities which cannot afford an adequate head-end can take advantage of a common CARS Band feed. (Figure 5)

Another potential application for CARS Band which is in accordance with FCC policy but in conflict with letter of FCC law at this time is local origination. Potentially, CARS Band could be utilized for head-end studio, or remote pickup links to originate on-location community affairs, educational, and entertainment programming. As you are all aware, yesterday's news is history. Live color coverage of controversial city council meetings, today's sporting events, and local news can develop community spirit and subscriber hook-ups.

Historically, the state of the art has not made 13 GHz remote pick-up equipment too practical. At these frequencies, microphonics, frequency instability, and temperature sensitivity have often times made a TV remote into an ordeal. Today's crystal-controlled total solid-state portable units have made such remotes an everyday occurrence in the broadcast industry. For example, the network coverage of the Democratic Convention in Chicago and also the coverage of the Kennedy funeral train from New York to Washington, D. C. was accomplished in the 13 GHz region. The wireless backpack color cameras used at the Mexico Olympics were operated in the CARS Band frequency region.

The question most asked by a prospective CARS Band user is "How far can I reliably transmit?" If you ask two experts, you will likely get two answers. CARS Band is a relatively new frontier and there is a limited history of operation in this band. Experience in the last few years indicates that the initial gloomy outlook was somewhat pessimistic.

I think the best way to understand the range limitations of any microwave system is to evaluate a system. Figure 6A shows a CARS system over a 20 mile path and Figure 6B shows a similar system over a 40 mile path. Each system has approximately a 40 dB fade margin which relates to a 99.99 percent reliability.

Figure 7 shows the video signal-to-noise versus signal input to the CARS Band receiver. Fade margin is the difference between the signal received under ideal conditions and the minimum signal input necessary to produce an acceptable picture.

If the fade margin is divided into the path length, the 20 mile path can withstand 2 dB per mile of rain attenuation while the 40 mile path fails with only 1 dB per mile of attenuation.

On the 40 mile path, performance can be improved by using a transmitter which is 10 times as powerful as the first. This gives a 50 dB fade margin, but only 1.25 dB per mile safety margin. At the same time, overall system reliability may be reduced by using high voltage power supplies and high power transmitting devices which are less reliable than a system working at moderate power levels. Larger antennas, such as 10 food dishes, would add another 4 dB to the system fade margin, but when this is distributed over a 40 mile path, it does little to help the system reliability. Also consider that a 10 foot dish concentrates the microwave beam into a narrow sliver only 0.5^{o} wide. A slight atmospheric bending can move the beam off the receive dish. Mechanical stability of the dishes becomes a significant problem when the beam is this narrow.

Therefore, there must be a point of diminishing returns where bigger dishes and more powerful transmitters no longer improve the basic system reliability. This point seems to occur over path lengths between 20 and 30 miles long. Beyond this point, it becomes a value judgment on the part of all concerned whether an occasional outage warrants the expense of another repeater system. In dry mountain areas where turbulence keeps the air homogenized, 60 mile paths have been found to be as reliable as a 15 mile path in flat lands where the air stagnates and inversions are common.

Figure 8 shows the relative effect moisture will have on path attenuation. Maps such as Figure 9 can help determine the effect local weather might have on a particular path. The experience of other microwave users in your area at lower frequencies is an invaluable indication of your potential success at CARS Band. If you factor-in rain attenuation based on local weather, success at CARS Band will follow very closely the success of neighboring 7 or 11 GHz systems.

Figure 1 FREQUENCY SPECTRUM

Figure 2 MICROWAVE COMPARED TO RAILROAD CARRIER

Figure 3 COMPOSITE OFF-AIR TV SIGNAL

Figure 4 CARS BAND MULTICHANNEL SYSTEM

Figure 5 COMMON HEAD-END SERVING MORE THAN ONE COMMUNITY

Figure 6 COMPARISON OF A 20 MILE AND 40 MILE CARS SYSTEM

Figure 7 VIDEO SIGNAL-TO-NOISE VERSUS SIGNAL INPUT

Figure 8 EFFECTS OF MOISTURE ON PATH ATTENUATION

Figure 9 ATMOSPHERIC ATTENUATION MULTIPLIERS FOR U.S.

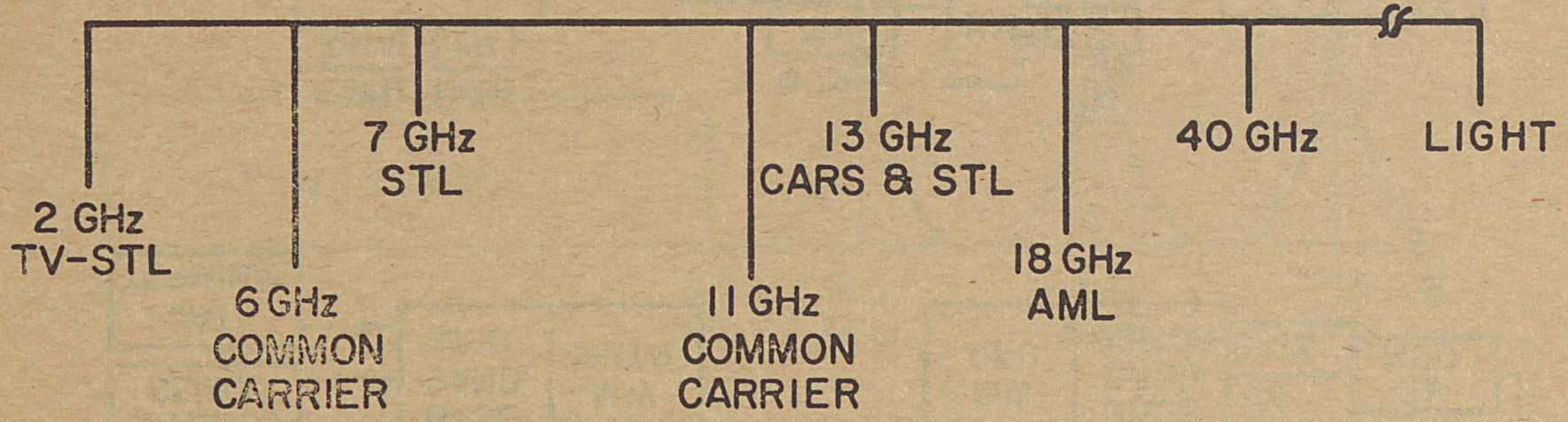

2 GHz
TV-STL
6 GHz
COMMON
CARRIER
7 GHz
STL
11 GHz
COMMON
CARRIER
13 GHz
CARS & STL
18 GHz
AML
40 GHz
LIGHT

Figure 1

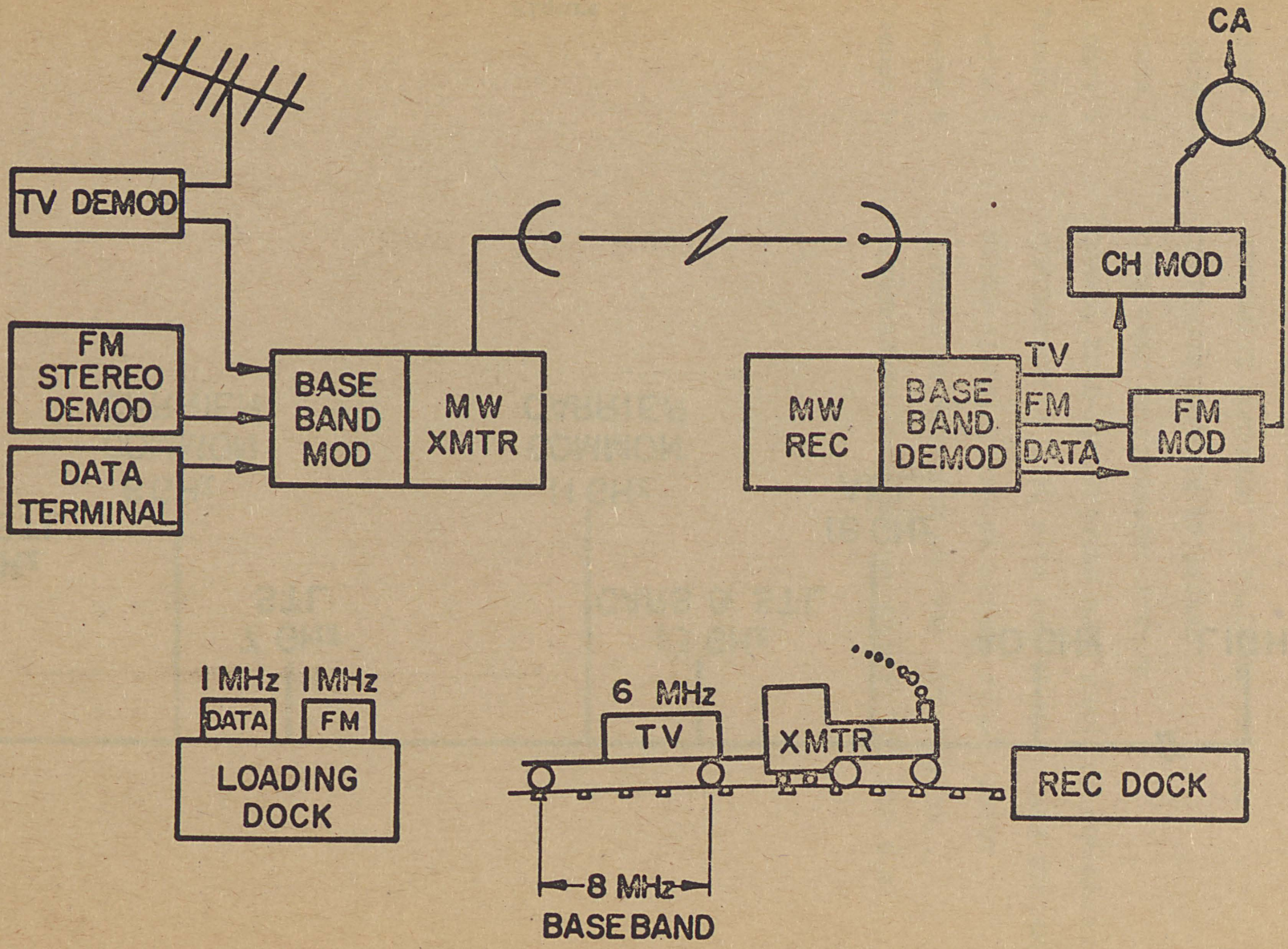

CA
TV DEMOD
FM STEREO DEMOD
DATA TERMINAL
BASE BAND MOD
MW XMTR
MW REC
BASE BAND DEMOD
TV
FM
DATA
CH MOD
FM MOD
1 MHz
DATA
1 MHz
FM
LOADING DOCK
6 MHz
TV
XMTR
REC DOCK
8 MHz
BASEBAND

Figure 2

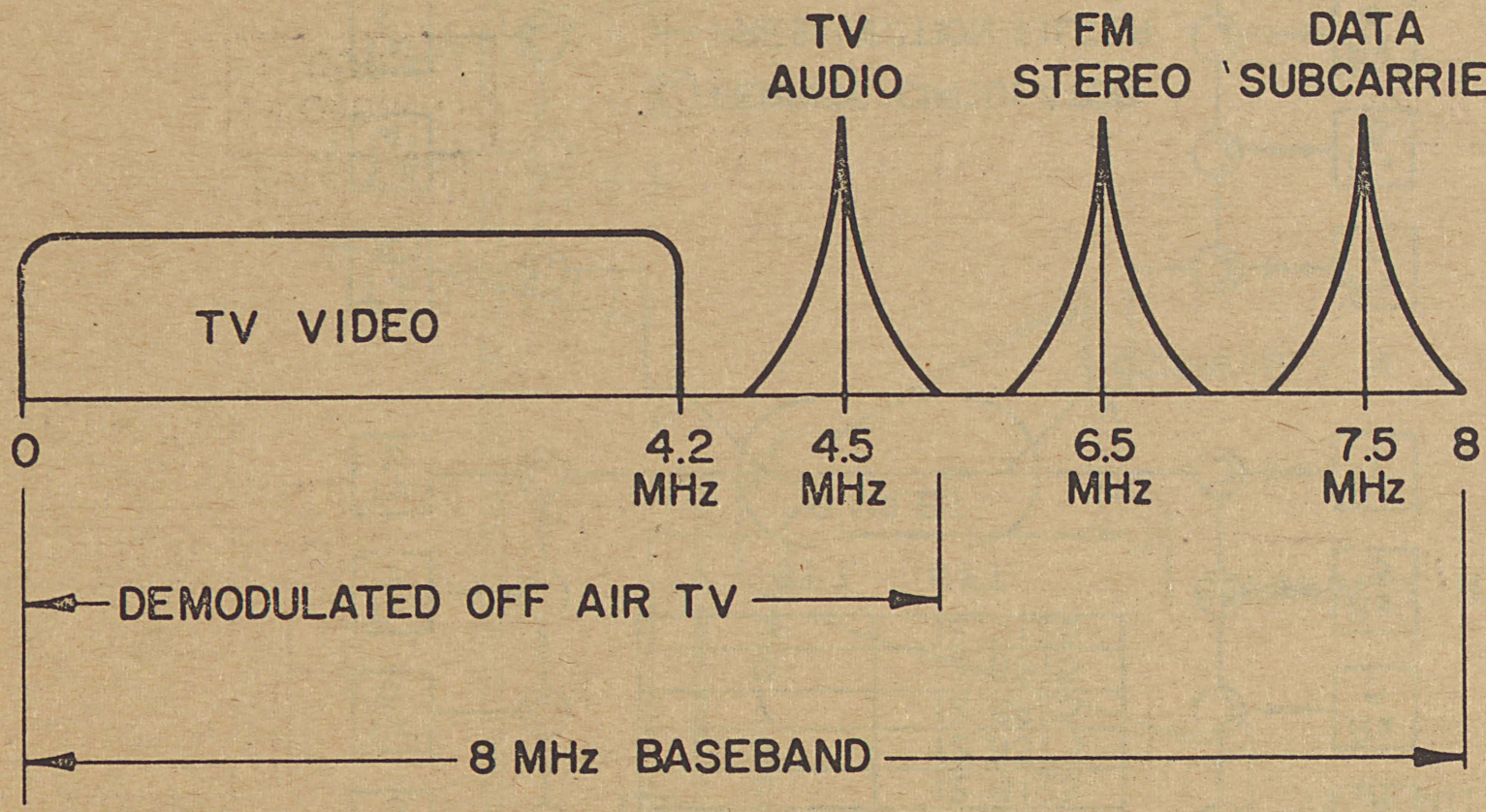

TV
AUDIO
FM
STEREO
DATA
SUBCARRIER
TV VIDEO
0
4.2
MHz
4.5
MHz
6.5
MHz
7.5
MHz
8
DEMODULATED OFF AIR TV
8 MHz BASEBAND

Figure 3

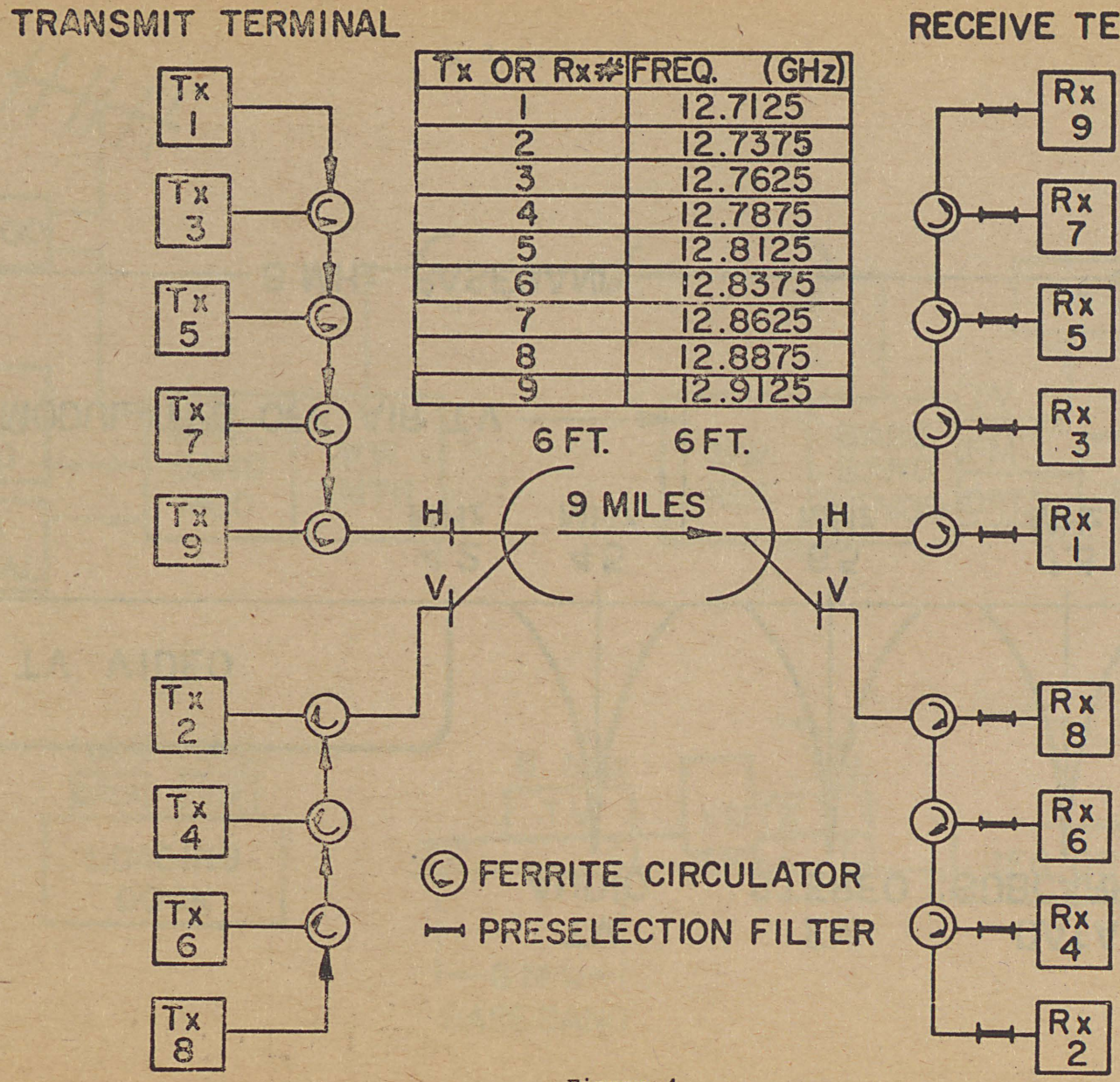
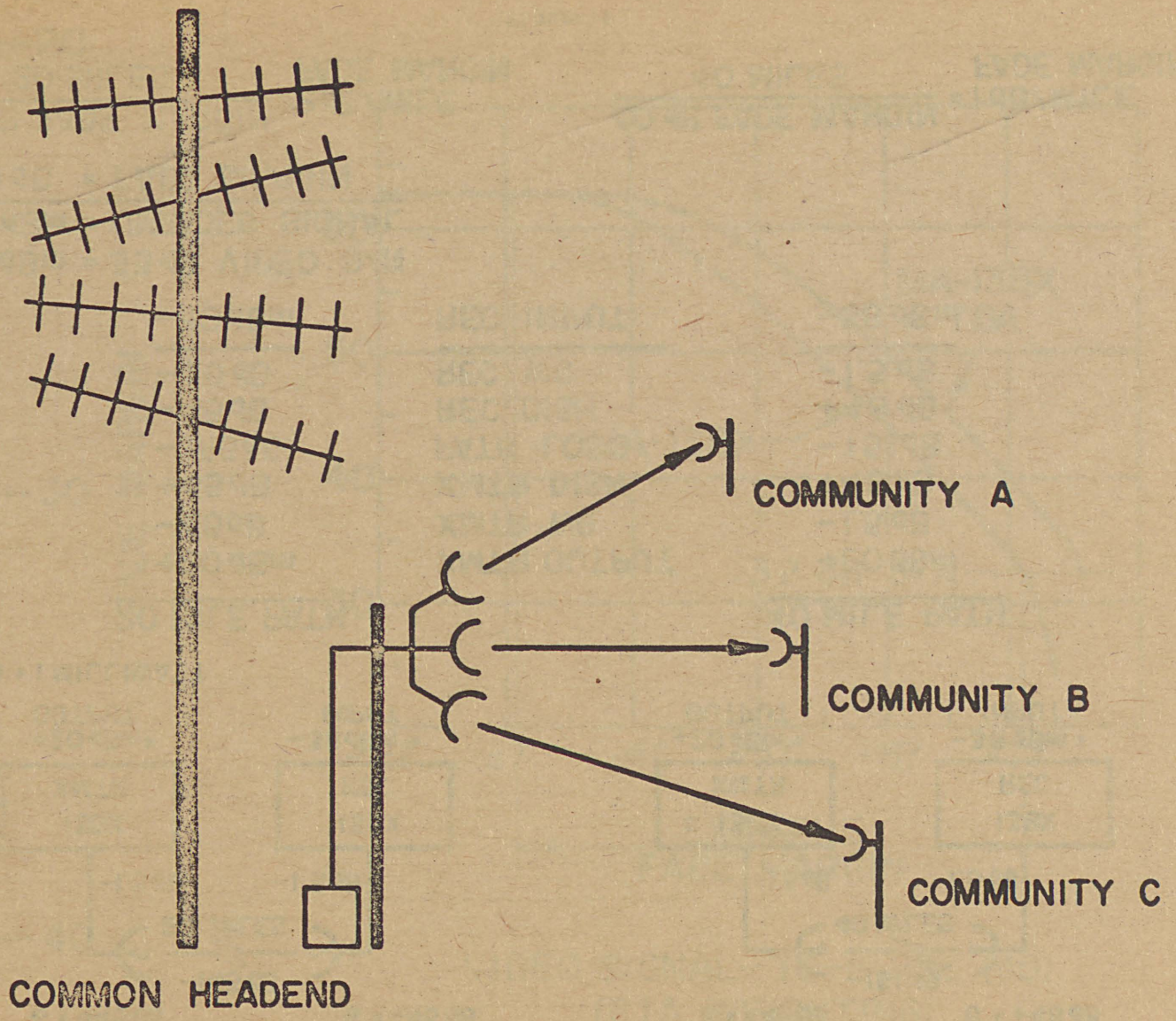
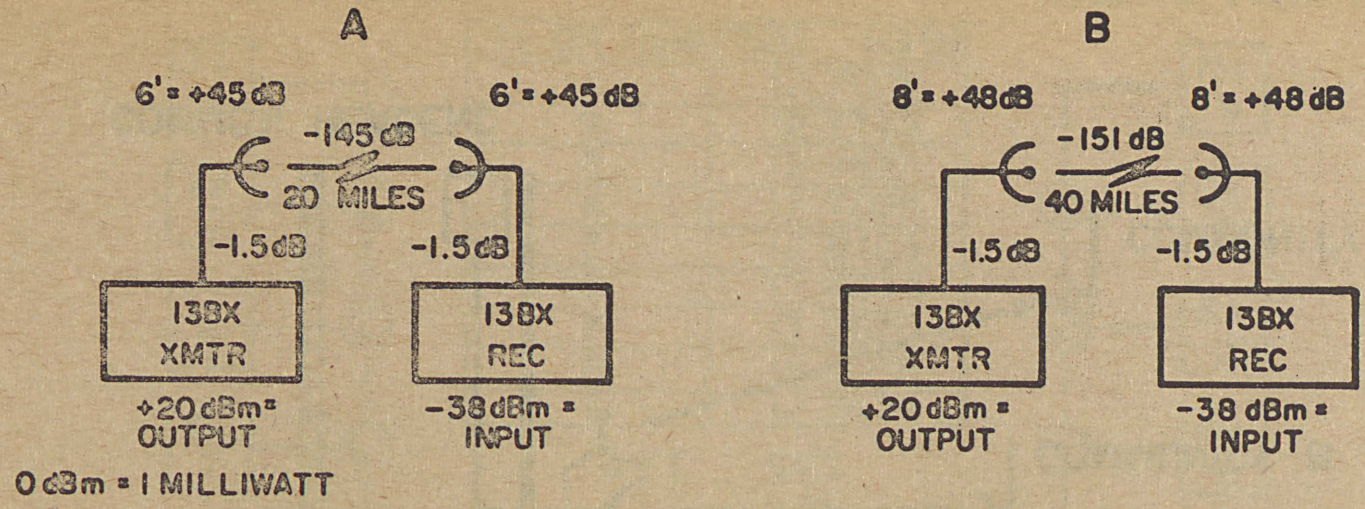

TRANSMIT TERMINAL
RECEIVE TERMINAL
Tx OR Rx# FREQ. (GHz)
1 12.7125
2 12.7375
3 12.7625
4 12.7875
5 12.8125
6 12.8375
7 12.8625
8 12.8875
9 12.9125
Tx 1
Tx 3
Tx 5
Tx 7
Tx 9
Tx 2
Tx 4
Tx 6
Tx 8
Rx 9
Rx 7
Rx 5
Rx 3
Rx 1
Rx 8
Rx 6
Rx 4
Rx 2
6 FT.
6 FT.
9 MILES
H
H
V
V
FERRITE CIRCULATOR
PRESELECTION FILTER

Figure 4


COMMUNITY A
COMMUNITY B
COMMUNITY C
COMMON HEADEND



20 MILE PATH		40 MILE PATH
+20 dBm	XMTR OUTPUT	+20 dBm
-1.5 dB	XMTR WG	-1.5 dB
+45 dB	XMTR DISH	+48 dB
-145 dB	PATH LOSS	-151 dB
-45 dB	REC DISH	+48 dB
-1.5 dB	REC WG	-1.5 dB
-38 dBm	REC INPUT	-38 dBm

-78 dBm = 33 dB VIDEO S/N
-38 dBm = UNFADED SIGNAL
40 dB = FADE MARGIN

$\frac{40\text{ dB FADE MARGIN}}{20\text{ MILES}}$ = 2 dB/MILE FADE MARGIN

$\frac{40\text{ dB FADE MARGIN}}{40\text{ MILES}}$ = 1 dB/MILE FADE MARGIN

Figure 6

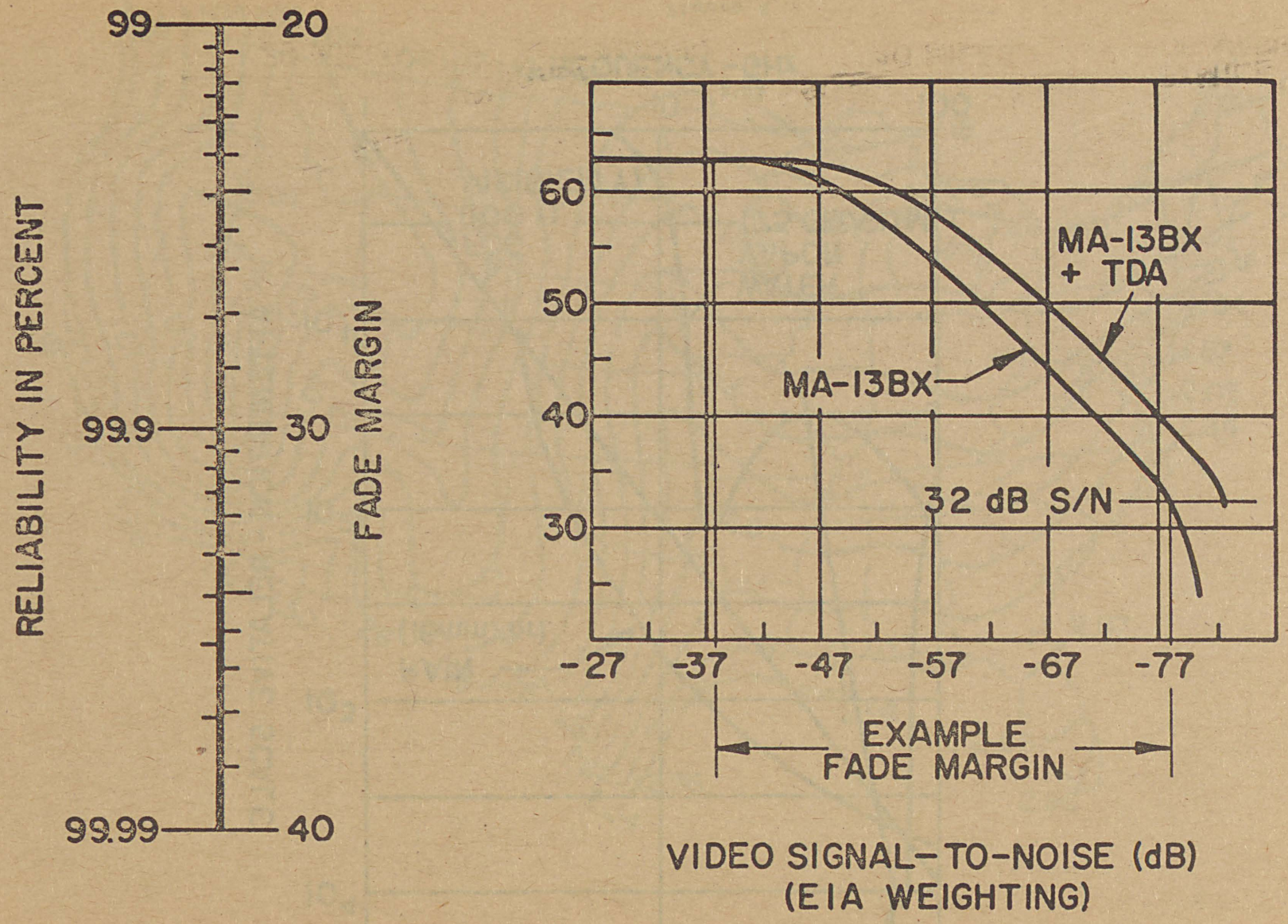

99
20
99.9
30
99.99
40
RELIABILITY IN PERCENT
FADE MARGIN
60
50
40
30
MA-13BX
+ TDA
MA-13BX
32 dB S/N
-27
-37
-47
-57
-67
-77
EXAMPLE
FADE MARGIN
VIDEO SIGNAL-TO-NOISE (dB)
(EIA WEIGHTING)

Figure 7

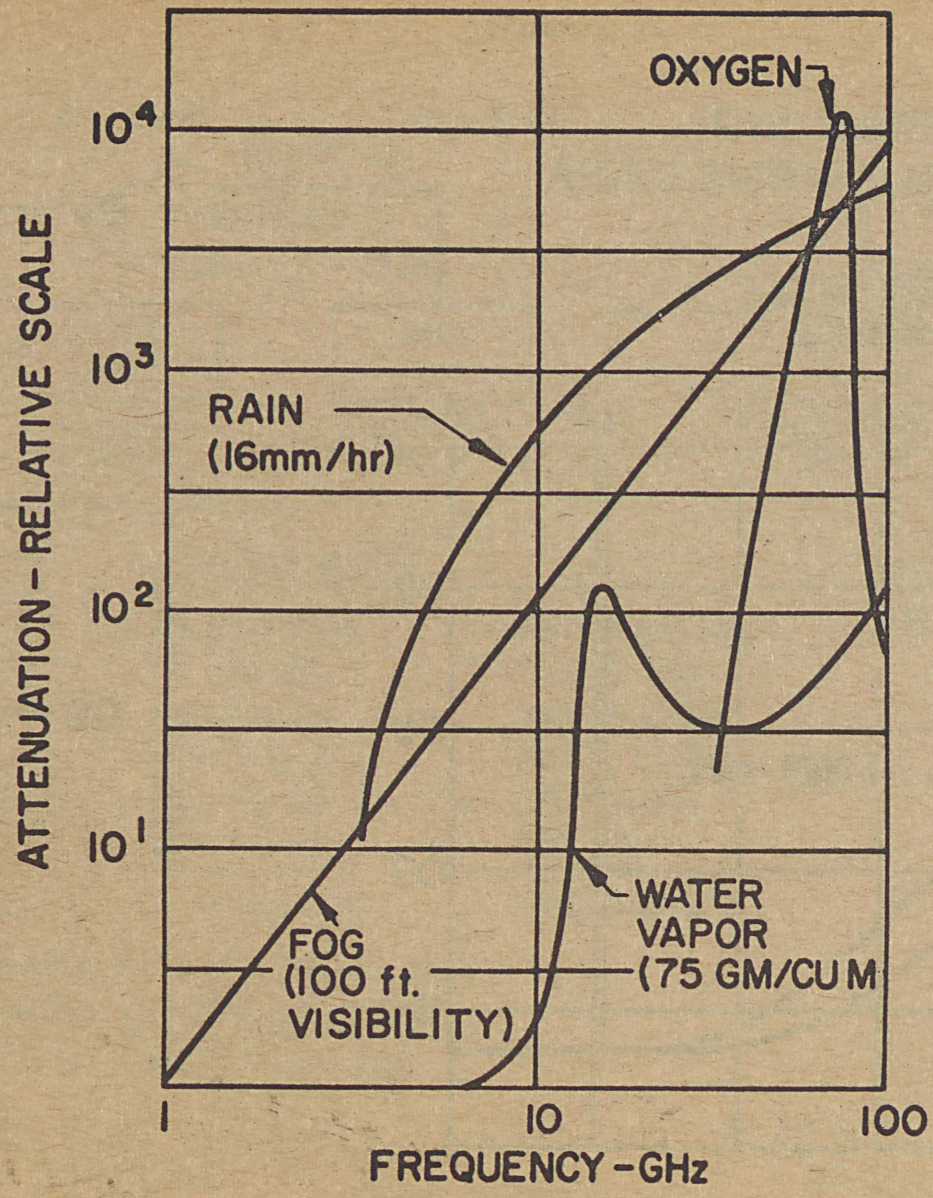

OXYGEN
10^4
10^3
10^2
10^1
RAIN
(16mm/hr)
ATTENUATION - RELATIVE SCALE
FOG
(100 ft.
VISIBILITY)
WATER
VAPOR
(75 GM/CU M
1
10
100
FREQUENCY - GHz

Figure 8

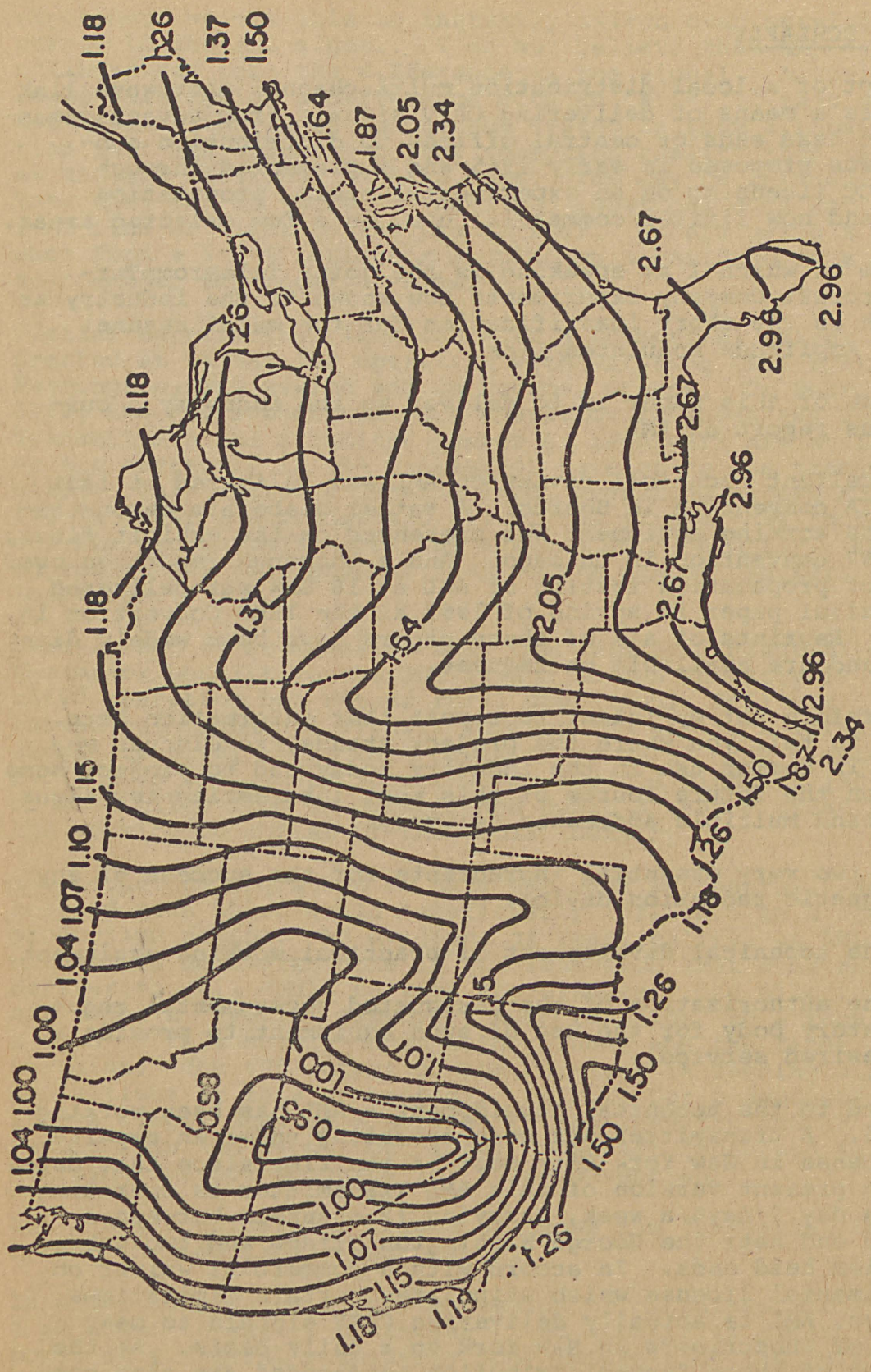

1.18
1.26
1.37
1.50
1.64
1.87
2.05
2.34
2.67
2.96
1.15
1.10
1.07
1.04
1.00
0.93
1.01
1.07
1.26
1.50
1.87
2.34

Figure 9

CATV AMPLIFIER DESIGN

Session Chairman:
Perry L. Schwartz

Participants:
Brian Jones
"Some Technical Problems in UHF CATV"

Gaylord G. Rogeness
"CATV Repeater Amplifier Design Utilizing Digital Computer"

Daniel Lieberman
"Cross-Modulation Figure of Merit for
Transistor Amplifier Stages"

Larry F. Roeshot
"A Lossless Transmission Line"

William H. Lambert
"Design Philosophy of Broadband Push-Pull Amplifiers"

BRIAN JONES

INTRODUCTION

Why should we be interested in UHF CATV? The most obvious reason is the need for more channel space. There are 70 channels between 470 MHz and 890 MHz. A capacity of 20 channels is becoming fairly common in new CATV systems, and if you want to provide more than twelve some of the channels must be converted to UHF. If there is to be a further increase above 20 in the future, the UHF octave is the only place to go.

ADVANTAGES OF UHF DISTRIBUTION

There are other reasons for using UHF. These are:

1. All second-order distortion products fall outside the band.

2. The design of passive circuits is simpler over a single octave.

3. Less equalization is required than in a VHF system where the spectrum covers more than two octaves.

Of course, there are disadvantages to UHF distribution. Cable loss is greater so we need more output from the amplifiers or more amplifiers. Clearly the cost is higher in a UHF system; but I do not think the cost per channel would be higher when you take into account the extra 58 channels.

Now instead of getting more output from UHF amplifiers we are likely to get less. The transistors available for UHF amplifiers are necessarily smaller, operate at lower bias currents, and produce more third-order distortion. Included in these distortions is that plague of the CATV industry cross-modulation.

The devices exist to provide adequate noise figure and gain over the UHF band. How far are we from providing adequate cross-modulation performance? First, how much power do we need?

AMPLIFIER PERFORMANCE REQUIREMENTS

The typical VHF system uses 12 channels driving a 75-ohm cable at a power level of about +50 dBmV per channel. The low-frequency channels are, of course, operated at a lower level due to the lower cable loss; but let us ignore that for the purpose of these calculations. Along the cable the signal is allowed to fall to about +20 dBmV before another amplifier is inserted to maintain the signal-to-noise ratio. About 10 dB of the 30 dB attenuation is caused by the through-loss of the directional couplers feeding the subscribers' receivers. There is no reason why this part of the attenuation should increase at UHF.

A cable having 20 dB of attenuation at 200 MHz will have 40 dB loss at 890 MHz. Unless we use more expensive cable we have to overcome 50 dB total loss with an amplifier. The output needed at channel 83 is 50 + 20 or +70 dBmV. This is a lot of power. In fact, if we had 70 channels at that level we would have a total r-f power of nearly 10 watts, most of which would merely heat up the cable! These figures are summarized in Figure 1.

PRESENT-DAY AMPLIFIER PERFORMANCE

We built a single-stage amplifier at Fairchild to measure the cross-modulation performance of some typical microwave transistors. The schematic is shown in Figure 2. The output circuit is a two-pole matching network[1] which gives a broadband match to 75 ohms. The input capacitor provides equalization as the transistor gain falls at higher frequencies.

The power gain of this circuit between 75 ohms terminations is shown in Figure 3. The total ripple is about 3/10 dB.

Although cross-modulation is the most important form of third-order distortion there is also intermodulation distortion to consider. This distortion produces a spurious signal at a frequency, $2f_1-f_2$ and $2f_2-f_1$, when signals at f_1 and f_2 are applied to the amplifier. Both forms of distortion are sometimes cancelled in a complicated manner, particularly in multi-stage amplifiers. For this reason a spectrum analyzer was used to examine the whole UHF spectrum. This test setup is shown in outline in Figure 4. Cancellations usually occur only at single frequencies and certain bias levels. By using the spectrum analyzer we were able to see if the intermodulation products were of substantially the same amplitude across the band. A value at one frequency which was much lower than at other frequencies would lead us to suspect a cancellation phenomenon.

For two channels we could achieve an output of 38 dBmV for a cross-modulation level of -60 dB. We did not have enough test equipment available to measure the cross-modulation with more than two channels. Let us assume that the output must be reduced in proportion to the power of added channels and further assume that we want to distribute 50 UHF channels. For 50 channels the output must be reduced 14 dB and becomes 38-14 = 24 dBmV. far short of the 70 dBmV we said was needed.

Actually if you decrease the bandwidth and use only the lower part of the UHF band it is possible to get more output. Some MATV systems use this technique for a few UHF channels over short distances.

A technique I have tried which merits more investigation is one originally suggested by Englebrecht.[2] In Figure 5 twin amplifiers are driven 90° out of phase by a quadrature hybrid. The

output signals are combined again in another hybrid. The primary advantage of this technique is that if the input and output impedances of each amplifier are the same the reflections will cancel in the terminations. The amplifier will thus have low VSWR at both input and output regardless of what is inside the amplifiers. The amplifiers have only to be identical.

Englebrecht remarked, however, that his intermodulation distortion was lower than expected. You would expect a 3 dB increase in output power over an amplifier using only one transistor in the output. I have found that broadband cancellation of third-order distortions is possible by adjusting the phase difference between the two amplifiers. The adjustment is quite critical, but at least it is broadband which is more than you can say for most distortion cancellation phenomena.

Since hybrid-coupled amplifiers of this type work best over an octave (the amplifiers are 1/4 wavelength apart at the center frequency), they are well suited to the UHF TV band.

At any rate it seems possible that in the near future we will be able to build UHF amplifiers carrying, say, 25 channels at 50 dBmV. I have made some calculations which show that, in order to obtain 70 dBmV output, we would have to operate at a collector current of 0.5 amperes. So we will probably have to make do with 50 dBmV.

With 50 dBmV output we will either have to use more expensive cable or more amplifiers--at least twice as many. However, they would be simpler amplifiers and, eventually, cheaper to manufacture. The technique of coupling similar amplifiers in parallel with 90° hybrids makes it possible to make single gain stages which have 75-ohm input and output impedances (see Figure 6). This would enable a manufacturer to assemble the whole amplifier with modules having 75 ohms characteristic impedance. AGC and equalization modules could be added between stages without upsetting the response of the individual amplifier modules. At UHF all of the modules could be made in the form of microstrip integrated circuits which would make the amplifier light, compact and inexpensive.

Such are future possibilities; but, in the meantime, what is to be done?

ALTERNATIVE APPROACH

The present method of carrying more than 12 channels on a CATV system is to use frequencies in the VHF region either above channel 13 or between channels 6 and 7. Conversion to UHF is accomplished with a converter located at the customer's receiver, an approach no one seems to be happy with.

An alternative technique would be to convert the high-band VHF signals to UHF with a converter on the distribution cable. In that case all the high-band VHF signals are converted to UHF starting with channel 14.

Let us look at a block diagram of how this would work (Figure 7). The signal on the distribution cable is sampled by the directional coupler where the output is split between two filters; one to separate the VHF channels and the other to separate the frequencies above channel 13 which are to be converted to UHF.

The high-band frequencies are converted to UHF in a mixer and the residual VHF products are filtered out by the high-pass filter. Finally the VHF and UHF channels are combined and the signals are sent to the subscriber.

There are two problems in this arrangement:

1. Mixers are by nature non-linear and produce distortion in the form of intermodulation and cross-modulation.

2. The local oscillator must be very stable and at 253 MHz cannot be a simple crystal oscillator.

Problem 1 can be solved by: (a) Using a double-balanced mixer, and (b) operating it at a low level. This means adding an amplifier as shown in Figure 8. This amplifier feeds only the house drop so it need not have the huge output capability referred to earlier. 20 to 30 dBmV would be sufficient.

Problem 2 is not so easy. If the local oscillator is not stable the tuning of the customer's set will have to be continually adjusted. This is particularly critical during a color transmission. A stable crystal-controlled oscillator would be expensive at 253 MHz.

One solution would be to move the frequency stability problem back to the head-end by carrying a 253 MHz signal throughout the system derived from a stable source. It would cause no cross-modulation since it would have no modulation, and it could also be used for AGC. Now our converter-tap box looks like Figure 9. The local oscillator signal must be large for efficient operation so we need to amplify it or use it to lock an oscillator. The last approach is the one I favor.

Now, how much would all this cost? One advantage of the high frequencies used in this system is that the circuits could be conveniently integrated in the form of thin-film circuits. For those of you not familiar with thin-film integrated circuits a typical example is shown in Figure 10. This is an amplifier made by the Fairchild Microwave Products Division.

Figure 11 shows how much of the converter could be fabricated as a single integrated circuit. Perhaps the high-pass filter could be integrated also. Figure 12 shows the same diagram with the components in the integrated circuit shown as a single block. You can see that the complexity of the conversion process is considerably reduced. This is important since you would be using one of these boxes for approximately every four subscribers, and reliability and low cost would be critical.

Notice also that simple removal of the integrated circuit reduces the subscriber to receiving only standard VHF channels. The extra UHF channels could be sold for a premium.

CONCLUSION

In summary, I have proposed a system of bulk conversion of VHF signals to UHF at the tap-off point in the distribution cable. Everything I have proposed uses present-day devices and techniques, and the use of integrated circuits should make the system economically feasible.

REFERENCES

1. Matthaei, George L., "Tables of Chebyshev Impedance-Transforming Networks of Low-Pass Filter Form", Proceedings of the IEEE, Vol. 52, pp. 939-963, August, 1964.

2. Englebrecht, R. S. and Kurokawa, K., "A Wide-Band Low-Noise L-Band Balanced-Transistor Amplifier", Proceedings of the IEEE, Vol. 53, pp. 237-247, March, 1965.

	VHF	UHF
TAP BOX LOSS	10 dB	10 dB
CABLE LOSS	20 dB	40 dB
TOTAL ATTENNUATION	30 dB	50 dB
AMPLIFIER OUTPUT REQUIRED	50 dBmV	70 dBmV

FIGURE 1

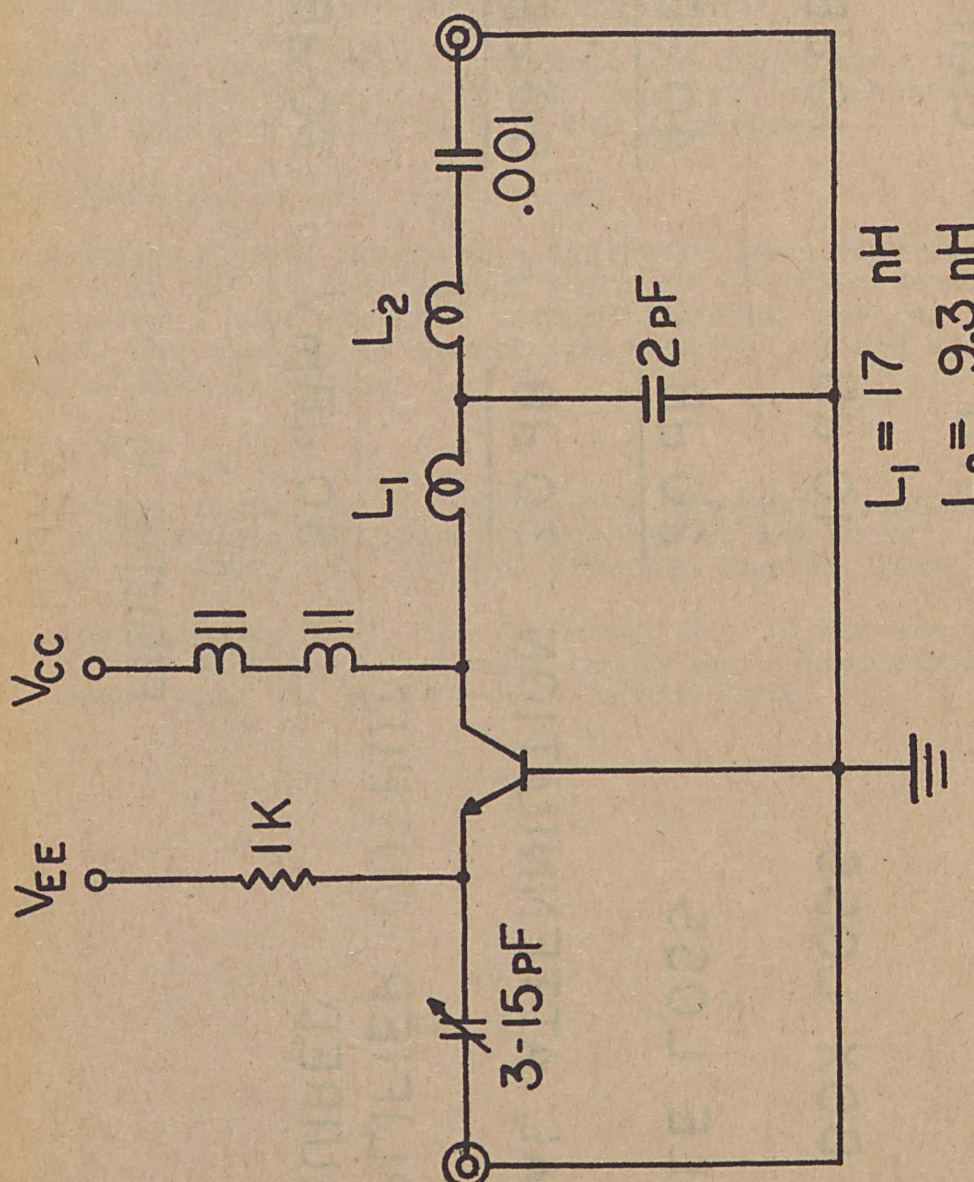


FIGURE 2

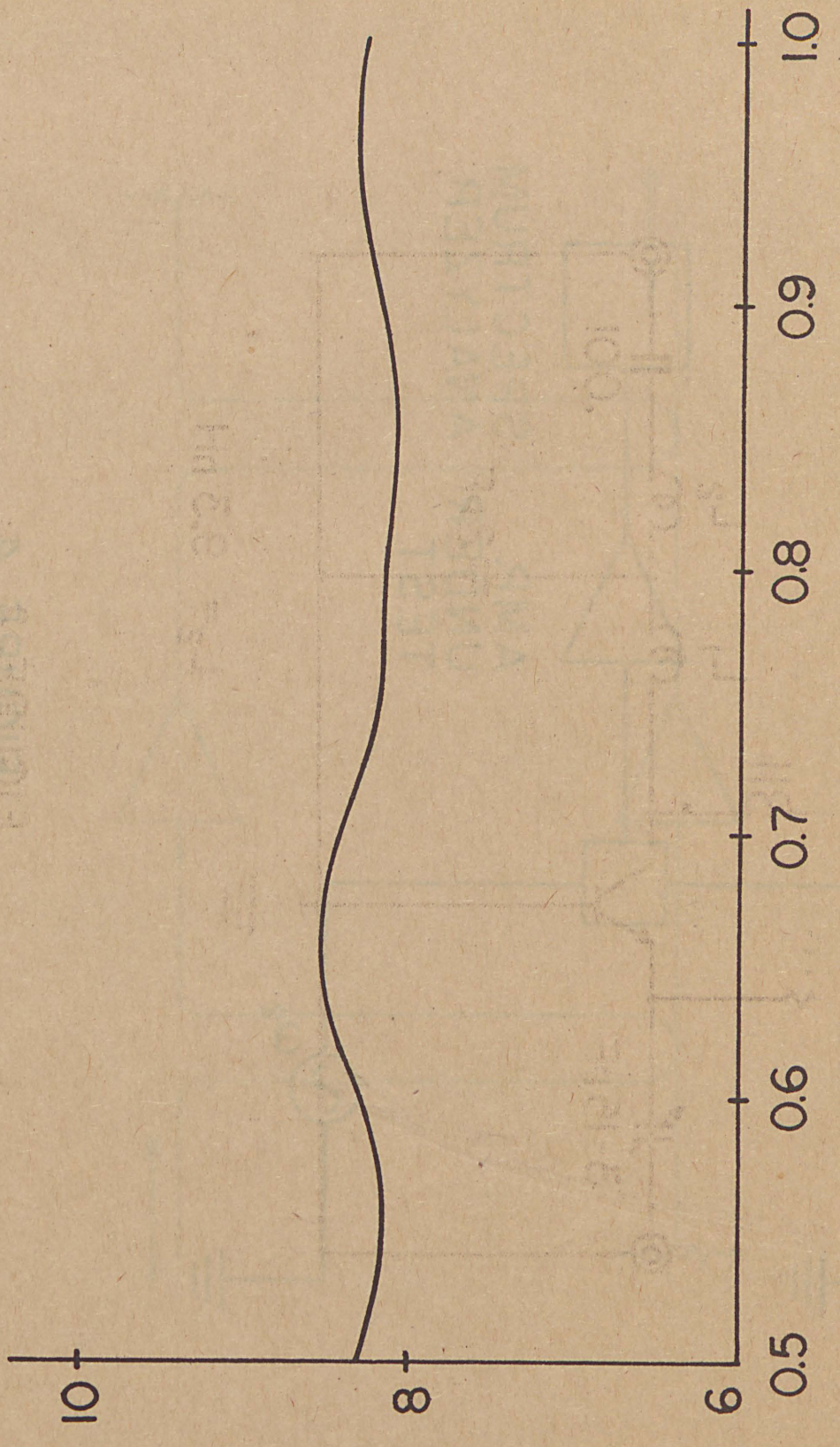


FIGURE 3

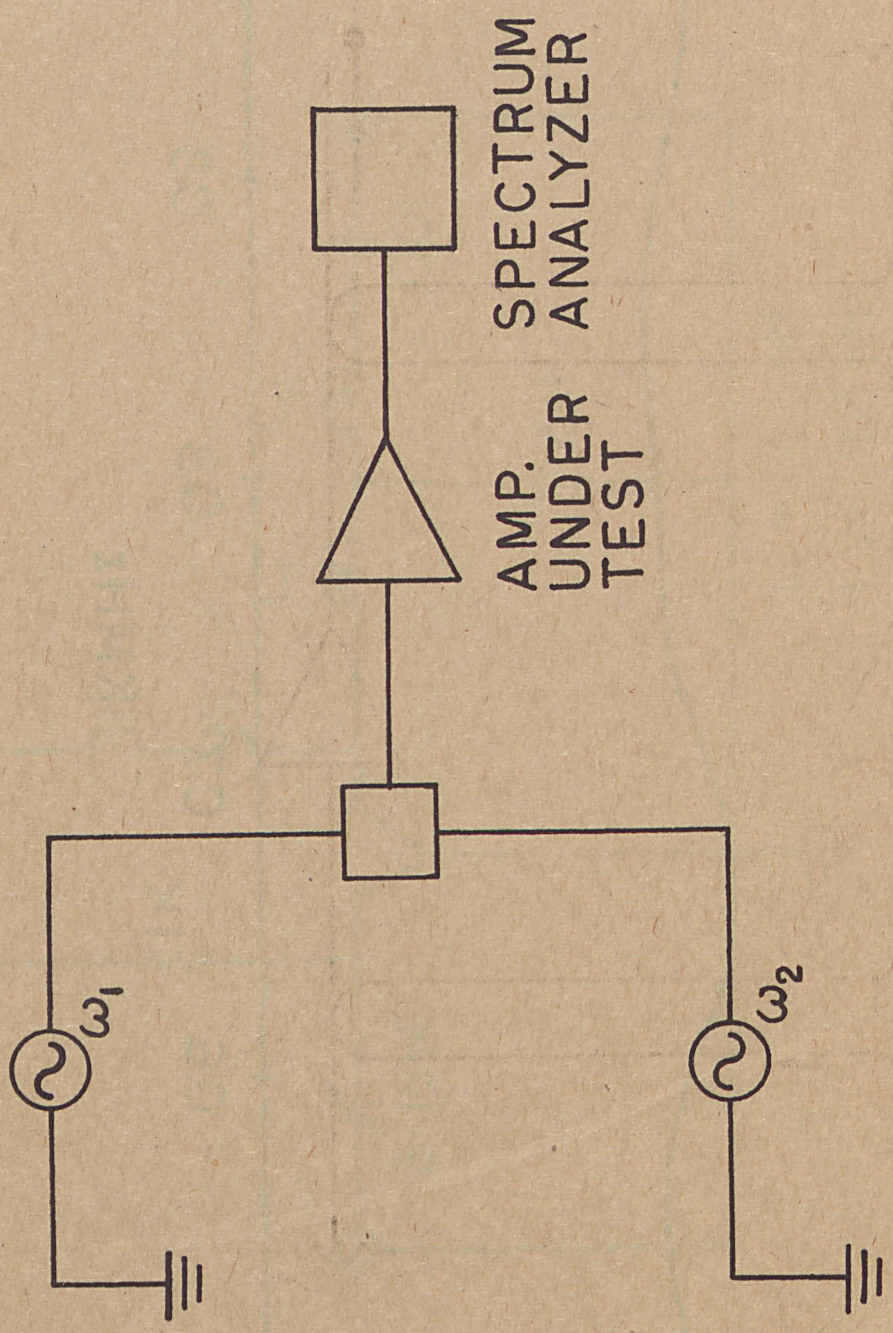


FIGURE 4

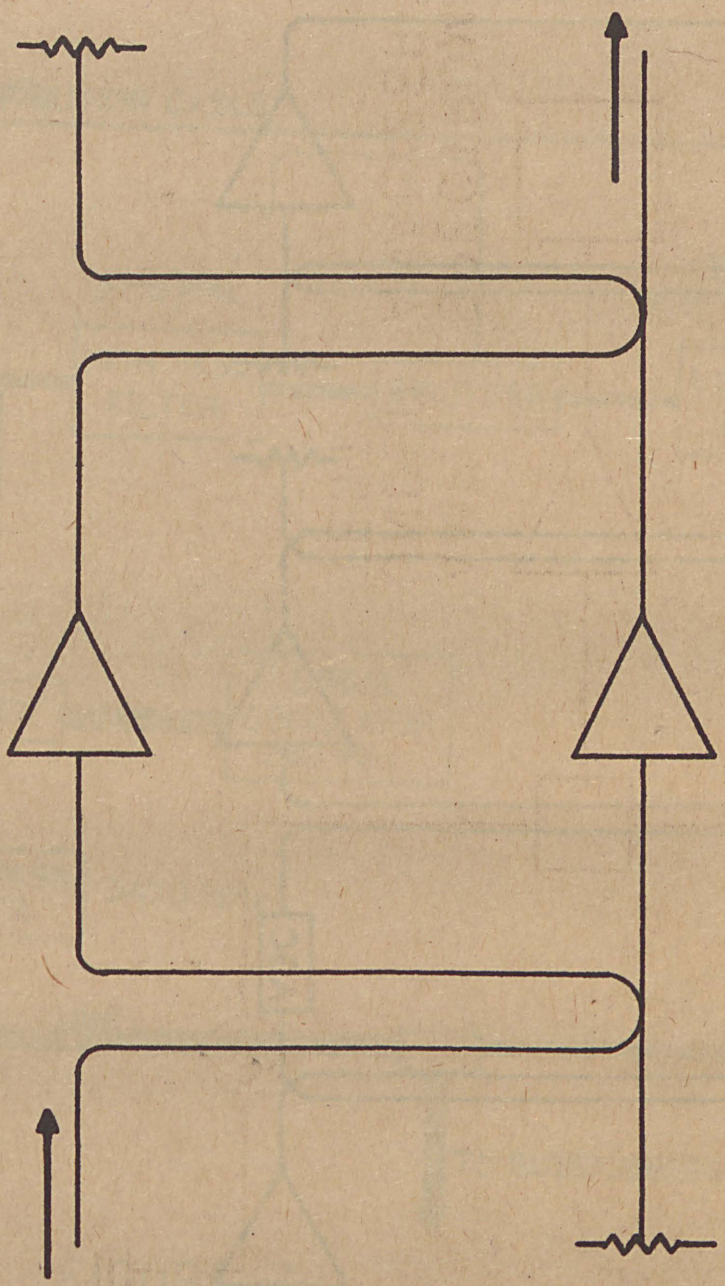


FIGURE 5

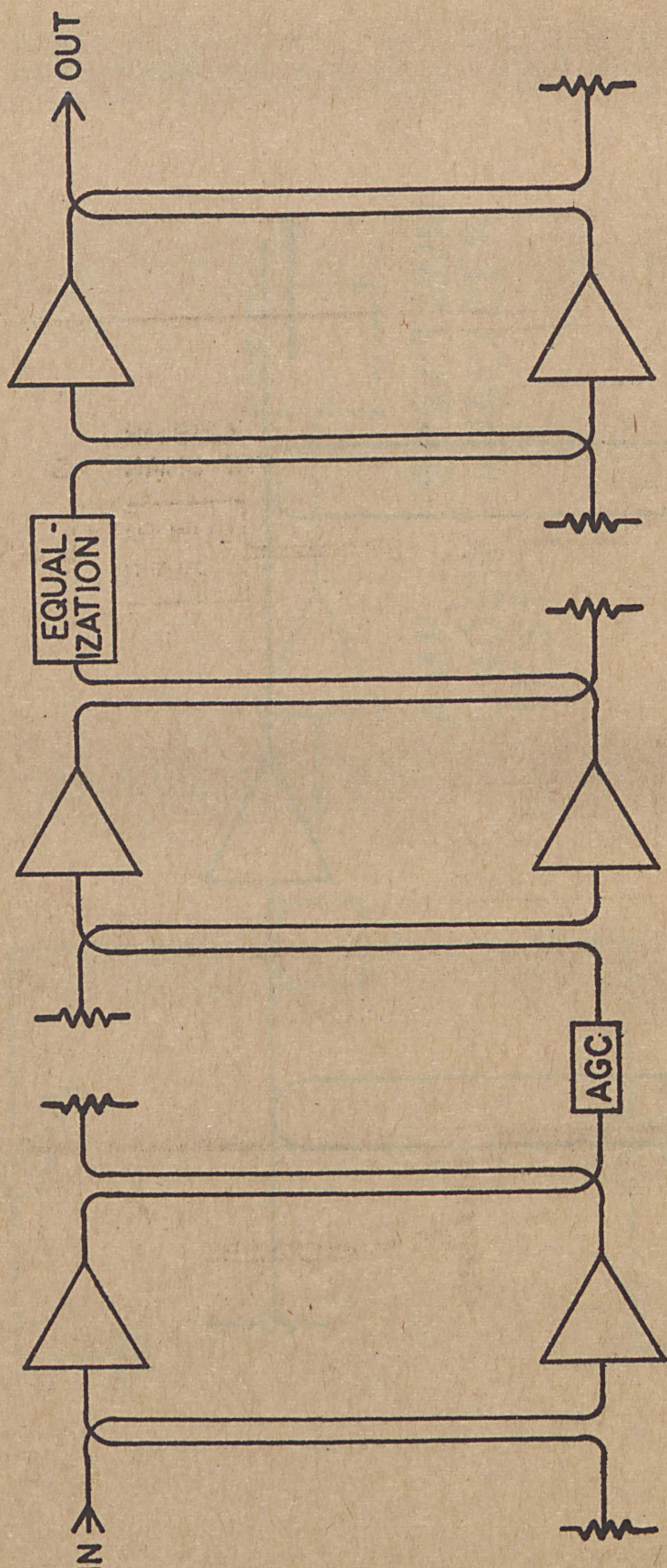


FIGURE 6

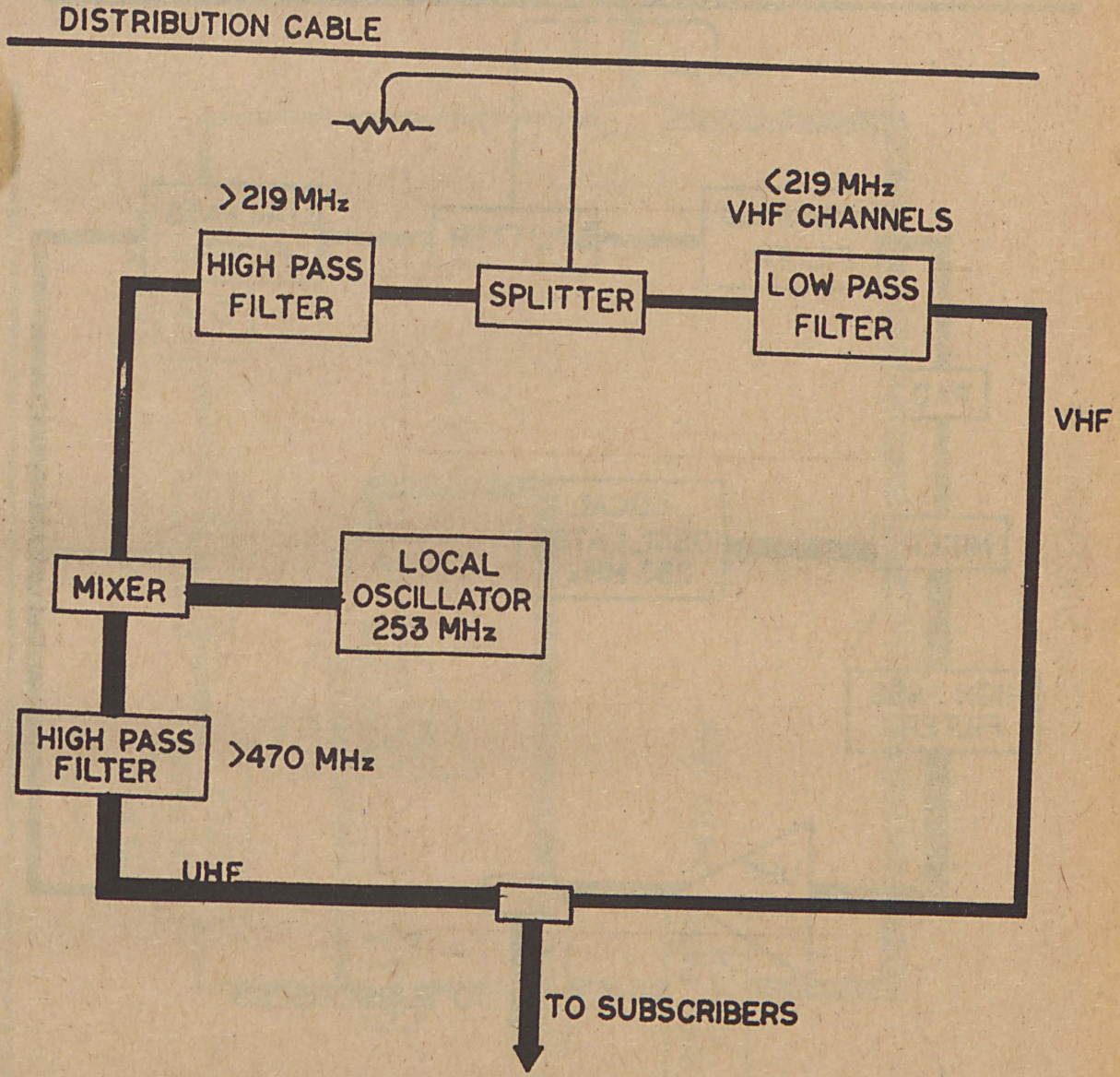

DISTRIBUTION CABLE
>219 MHz
HIGH PASS FILTER
SPLITTER
<219 MHz VHF CHANNELS
LOW PASS FILTER
VHF
MIXER
LOCAL OSCILLATOR 253 MHz
HIGH PASS FILTER
>470 MHz
UHF
TO SUBSCRIBERS

FIGURE 7

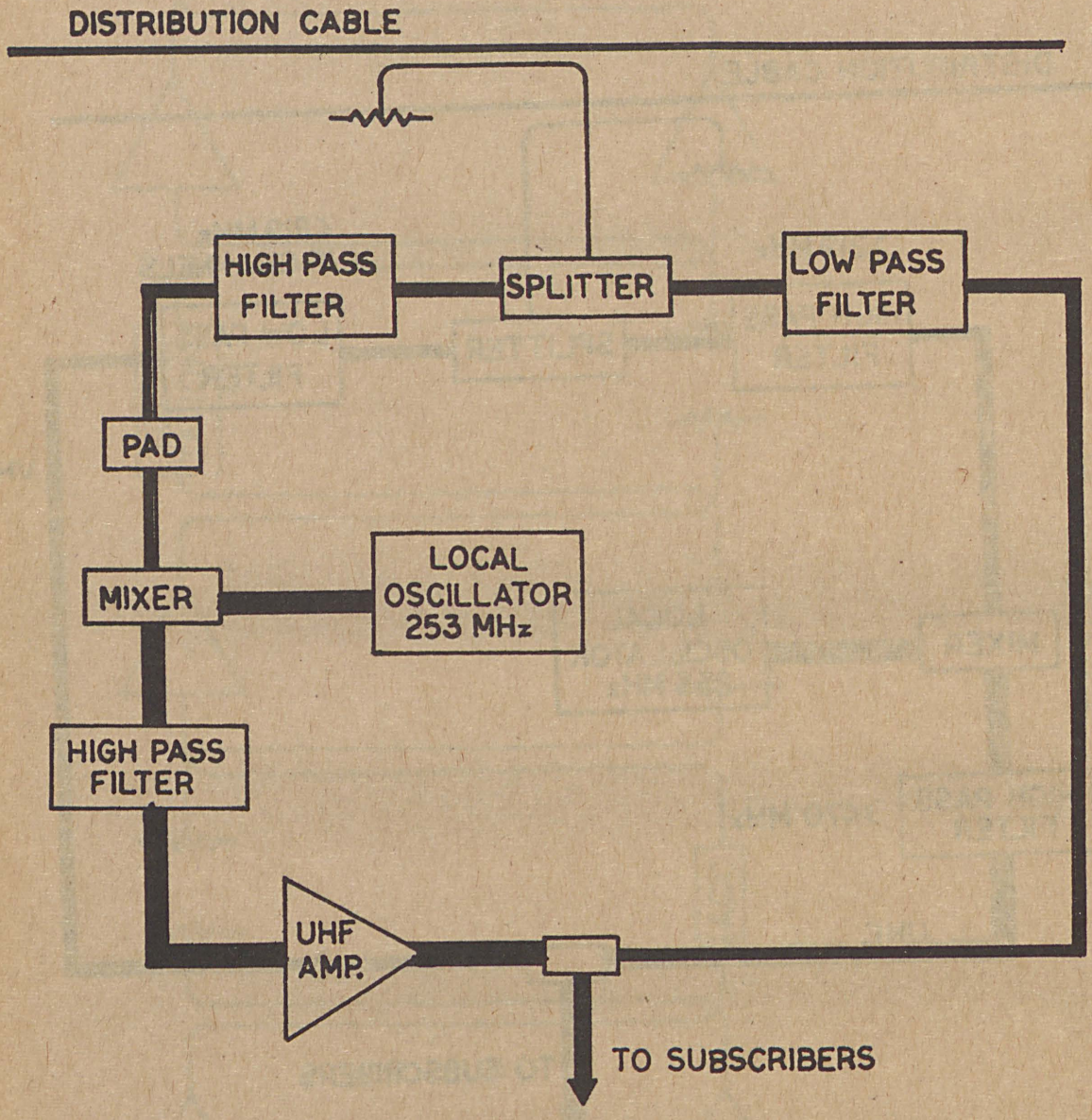

DISTRIBUTION CABLE
HIGH PASS FILTER
SPLITTER
LOW PASS FILTER
PAD
MIXER
LOCAL OSCILLATOR 253 MHz
HIGH PASS FILTER
UHF AMP.
TO SUBSCRIBERS

FIGURE 8

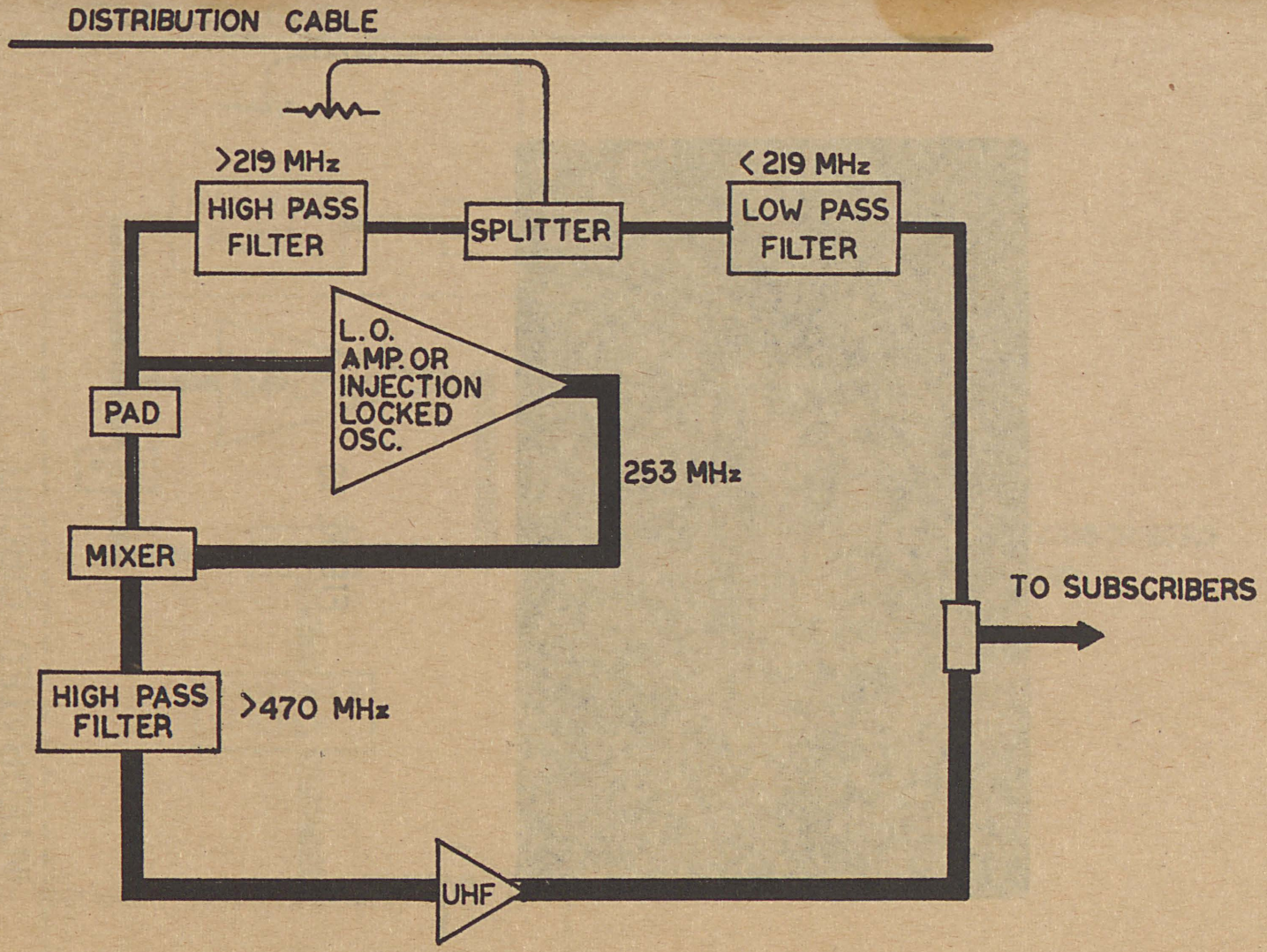

DISTRIBUTION CABLE
>219 MHz
HIGH PASS FILTER
SPLITTER
<219 MHz
LOW PASS FILTER
L.O. AMP. OR INJECTION LOCKED OSC.
PAD
253 MHz
MIXER
TO SUBSCRIBERS
HIGH PASS FILTER
>470 MHz
UHF

FIGURE 9

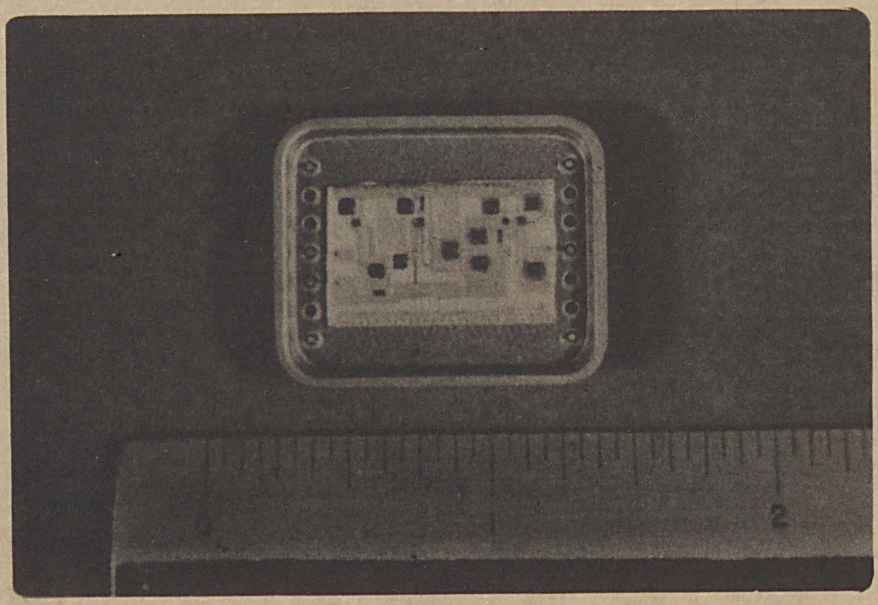


FIGURE 10

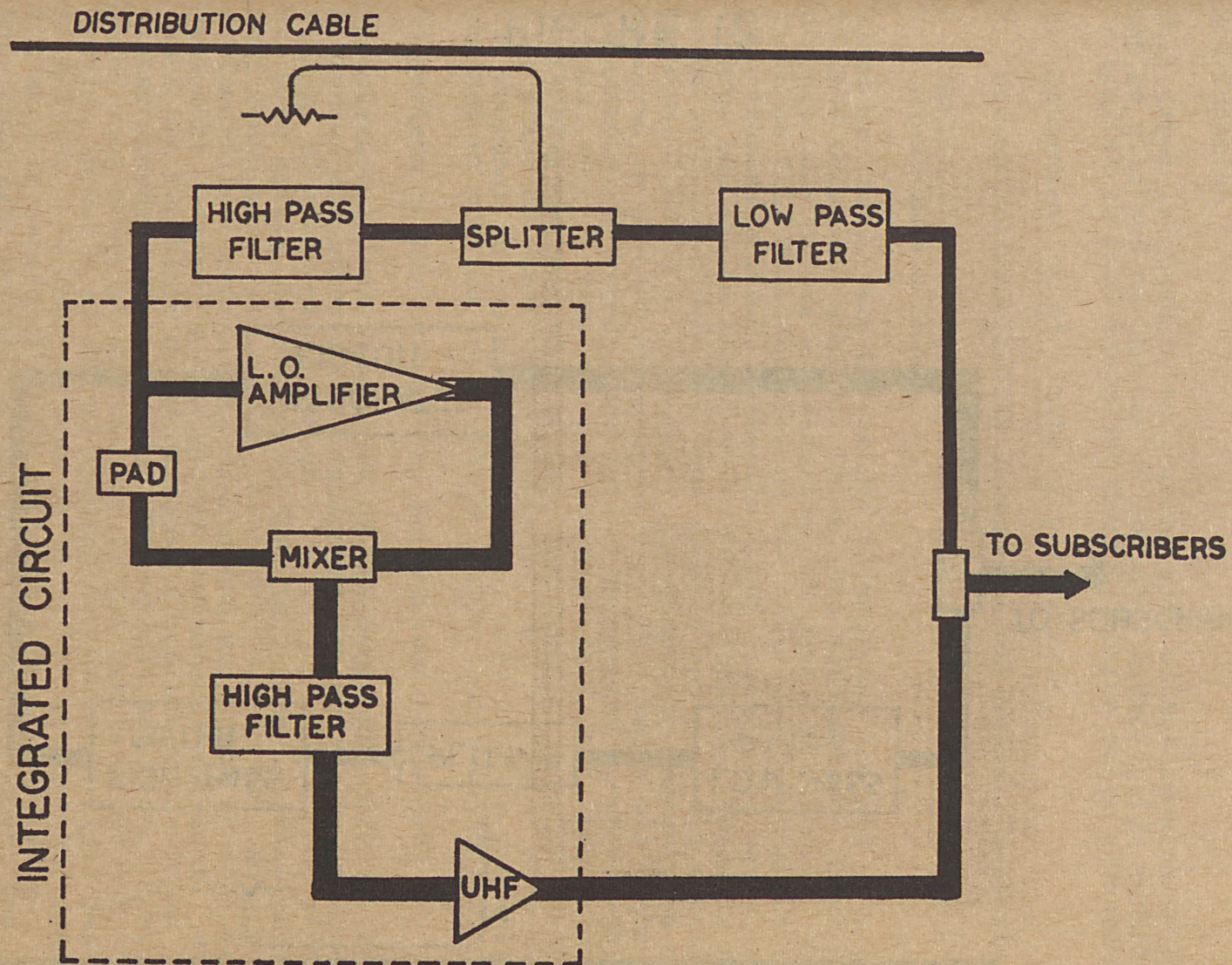

DISTRIBUTION CABLE
HIGH PASS FILTER
SPLITTER
LOW PASS FILTER
L.O. AMPLIFIER
PAD
MIXER
HIGH PASS FILTER
UHF
INTEGRATED CIRCUIT
TO SUBSCRIBERS

FIGURE 11

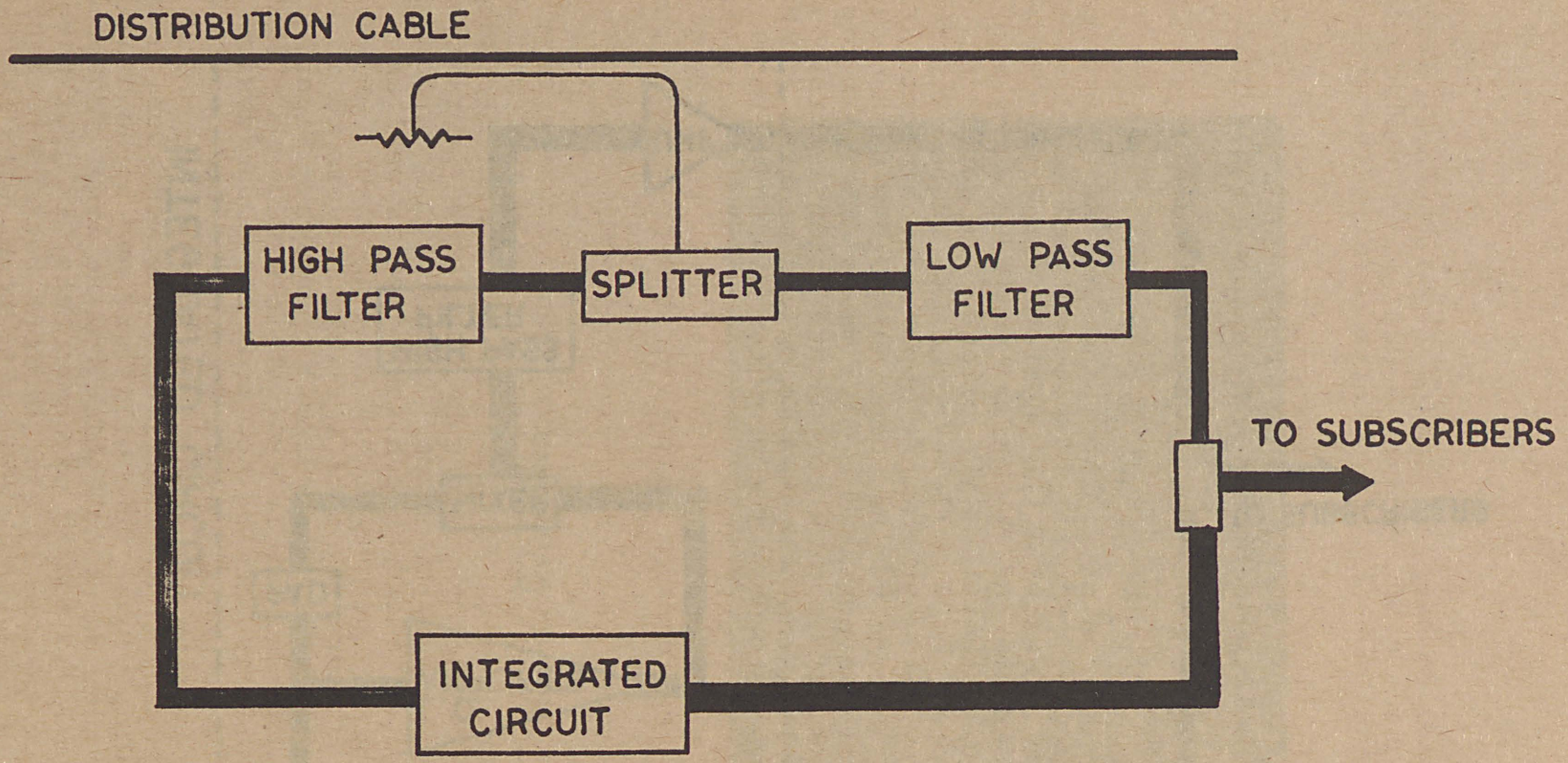

DISTRIBUTION CABLE
HIGH PASS FILTER
SPLITTER
LOW PASS FILTER
TO SUBSCRIBERS
INTEGRATED CIRCUIT

FIGURE 12

GAYLORD G. ROGENESS

Introduction

This paper is intended to present some of the advantages which may be attained by the use of computer aided design techniques as applied to CATV equipment design. Three major advantages are:

1. Determination of limits of performance.

2. Design reproducibility (component variational analysis).

3. Application to hybrid and integrated circuit design (minimum adjustments allowed).

There are three very key points in applying the aid of a computer to CATV equipment design. First, the mathematical model of the circuit must accurately describe the physical circuit. This includes full consideration of the parasitic inductances and capacitances present. Otherwise, the cliché, "It works in theory, but not in practice", will be sounded. There is nothing wrong with the theory, it just doesn't apply to the particular physical situation. Secondly, the component values used must be measured as accurately as possible. This means all resistors, capacitors, inductors, and active components (transistors, diodes, etc.). Finally, the computer is only a machine and must, therefore, be told what to do. The computer does not automatically print out answers to problems. The key point here is that the computer can be an expensive toy unless it is properly programmed to provide a systematic analysis of the problem.

Comparison of Theoretical Vs. Screwdriver Adjustment

The classical design approach of the broadband circuits required in active and passive CATV equipment has generally included a minimum of theoretical design. In general, equipment produced has been mainly the result of designs by the screwdriver-adjustment techniques used by "on the bench" designers. Note that equipment designed in this manner can work just as well as equipment designed by the purest theoretical approach. However, there are two basic disadvantages of equipment developed in this manner compared to a detailed theoretical approach. First, after many hours of cut and try in the lab to produce a workable design, there is no way of knowing how near the final design is to optimum. Secondly, it is difficult to predict and control the ease of reproducibility using this design approach. One very important reason why the screwdriver-adjustment design approach has been so widely used (and will continue to be used) on CATV products is that manual calculations at many frequencies for a circuit with a large number of components, is just not possible. The simple example of the constant resistance equalizer, which follows, demonstrates this. However, with the high speed problem solving ability of the digital computer, these calculations can now be made.

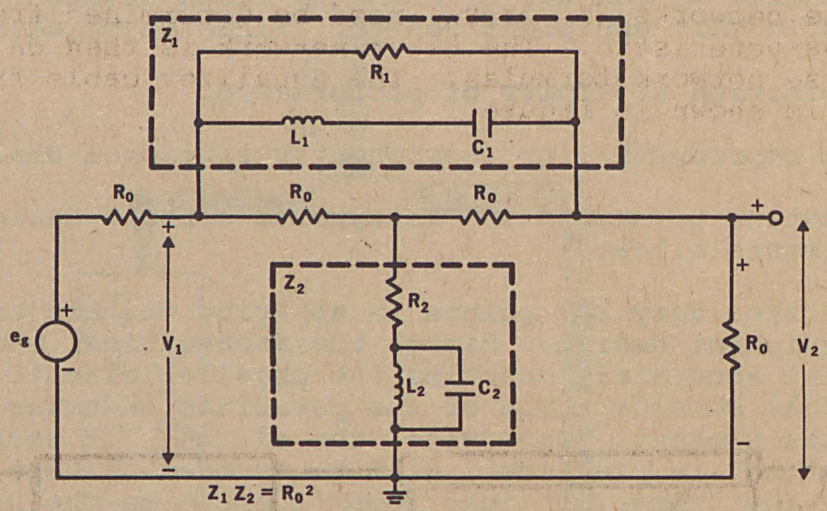


Figure 1. Bridged-T, Constant Resistance Equalizer Circuit Schematic

Design Example

To illustrate the differences between a computer aided design and a screwdriver-adjustment design, the classical constant resistance equalizer design example is given. A schematic of the bridged-T constant resistance equalizer is shown in figure 1.

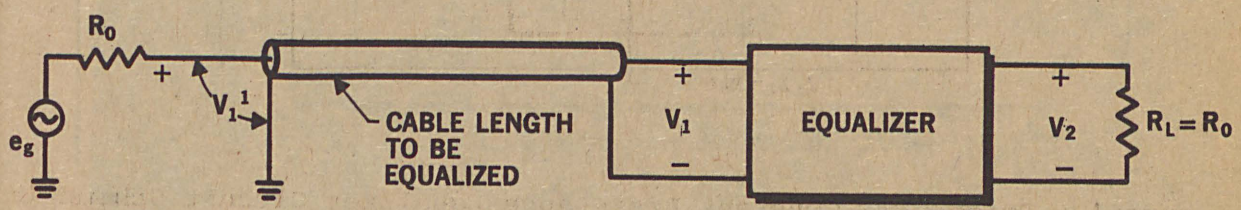
The transfer function of the bridged-T equalizer is:

$$\frac{V_2}{V_1} = \frac{1}{1 + Z_{1/R_o}} \tag{1}$$

$$\text{Insertion Loss (dB)} = 20 \log \frac{V_1}{V_2} = 20 \log \left| 1 + Z_{1/R_o} \right| \tag{2}$$

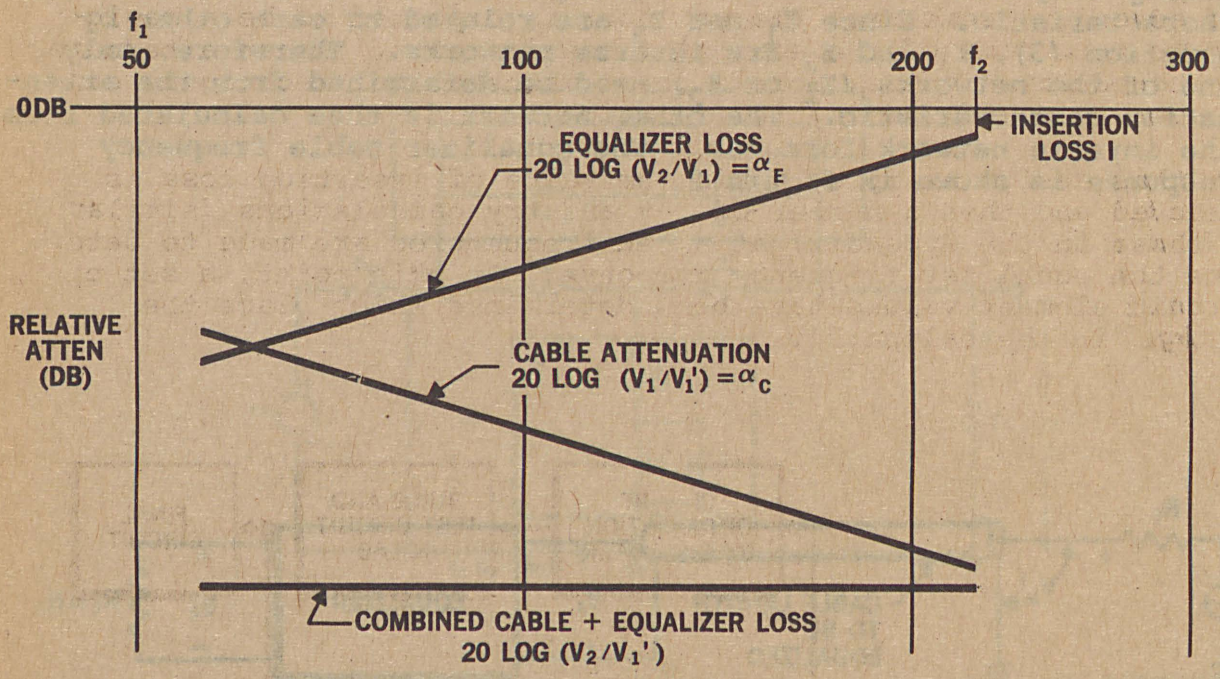
$$Z_1 Z_2 = R_o^2 \tag{3}$$

The quantity R_o is equal to the characteristic impedance of the coaxial cable and Z_1 is a complex impedance which shapes the frequency response of the circuit to equalize the cable attenuation characteristic. Since Z_1 and Z_2 are related to each other by equation (3), Z_1 and Z_2 are inverse networks. Therefore, only one of the networks (Z_1 or Z_2) need be determined from the attenuation characteristic. The other network is then calculated from the inverse network formulas. The equalizer cable frequency response is shown in figure 2.



(a) Functional Diagram

Figure 2. Equalized Cable Problem



(b) Frequency Response

Figure 2. Equalized Cable Problem

The equalizer loss at each frequency (loss is a minimum at the highest frequency of interest), when added to the cable attenuation at each frequency, results in a total attenuation which is made as constant as possible across the frequency band $f_2 - f_1$. The insertion loss at f_2 would be ideally 0 dB, but in practice is on the order 0.2 to 1 dB. The quantity $\alpha_E + \alpha_C$ should ideally be constant for all frequencies between f_1 and f_2 (in practice it would be within $\pm$.25 dB to $\pm$.5 dB).

The designer's task is then to design an equalizer circuit with a minimum insertion loss at f_2, and a circuit whose attenuation, when added to the given cable attenuation for frequencies from f_1 to f_2 will result in the flattest possible frequency response. As long as $R_o = R_L = R_g$ and $Z_1 Z_2 = R_o^2$, the return loss of the equalizer at the input and output port is infinite (or in other words $Z_{in} = Z_{out} = R_o$). The circuit design begins by starting with known generator and load impedance assumed equal to R_o and a known cable attenuation characteristic. The initial design is made for the nominal cable characteristics.

This initial design can be "conjured up" by pulling a rabbit from a hatful of experience, which may not be as far fetched as it sounds for two reasons. First, we actually do this on occasion, and secondly, sometimes the engineer is expected to be a magician to meet some of the equipment requirements. As an alternate to the educated guess, more elegant mathematical techniques can be used to yield the initial solution.

For this design example, a minimum value of insertion loss is selected and then a number of cut and try calculations (similar to those in the appendix) at a few frequencies are made to determine the equalizer frequency response. At this point, a set of circuit element values have been determined which place the design "in the ballpark".

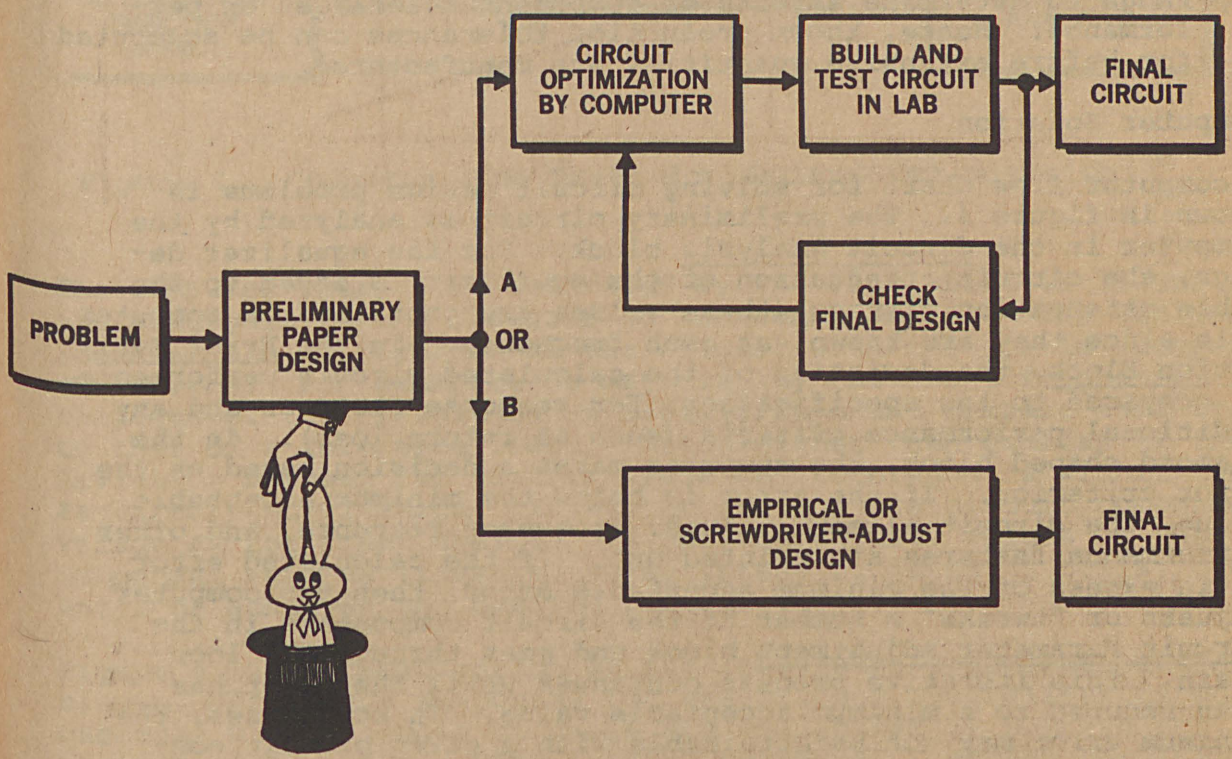


Figure 3. Block Diagram of Design Procedure

In referring to figure 3, the designer now has a choice of paths on which to proceed. The lower path represents the laboratory adjustment design optimization route leading to the final circuit.

The designer adjusts component values until he has a combination which meets the specifications.

The upper path, in figure 3, leads to circuit optimization by allowing the computer to adjust the element values to obtain the optimum design. Note that the circuit determined by the computer must still be built and tested in the lab. However, the designer knows what the best performance from the computed circuit should be. He does not have to spend hours of tweeking, "hoping" to obtain a better result. Minor adjustment of component values should lead to the final circuit which meets the given specifications. The advantages of the computer design approach are:

1. Optimum performance of circuit configuration is known before the circuit is built. Therefore, no need to spend hours of "tweeking" in lab trying to get better performance.

2. Circuit design can be checked by computer over frequency range to determine effects of component tolerances on performance. Hence, known production tolerances can be accounted for before extensive quantities are manufactured.

Computer Solution

A computer flow chart for solving circuit design problems is shown in figure 4. The preliminary circuit is analyzed by the computer in the Circuit Analysis block. For the equalizer design, the circuit attenuation of the equalizer is added to the cable attenuation figures (these values are contained in computer file since they are known) at each frequency. In the Error Evaluation Block, the deviation of the calculated circuit performance is compared to the specifications for response flatness and any additional performance criteria (such as return loss). In the diamond shaped block, the computer makes a decision based on the error criterion. If the error is below the minimum acceptable value, the circuit element values, frequency response, and other performance features are printed out. If the calculated error is in excess of the minimum acceptable error, then the computer adjusts or "tweeks" a number of the circuit components in the Circuit Parameter Adjustment block and goes through the loop again. This iterative process continues until the error has been reduced to a minimum acceptable value. In some cases, the minimum error may not be attainable with a given circuit configuration and the designer must then alter the circuit configuration.

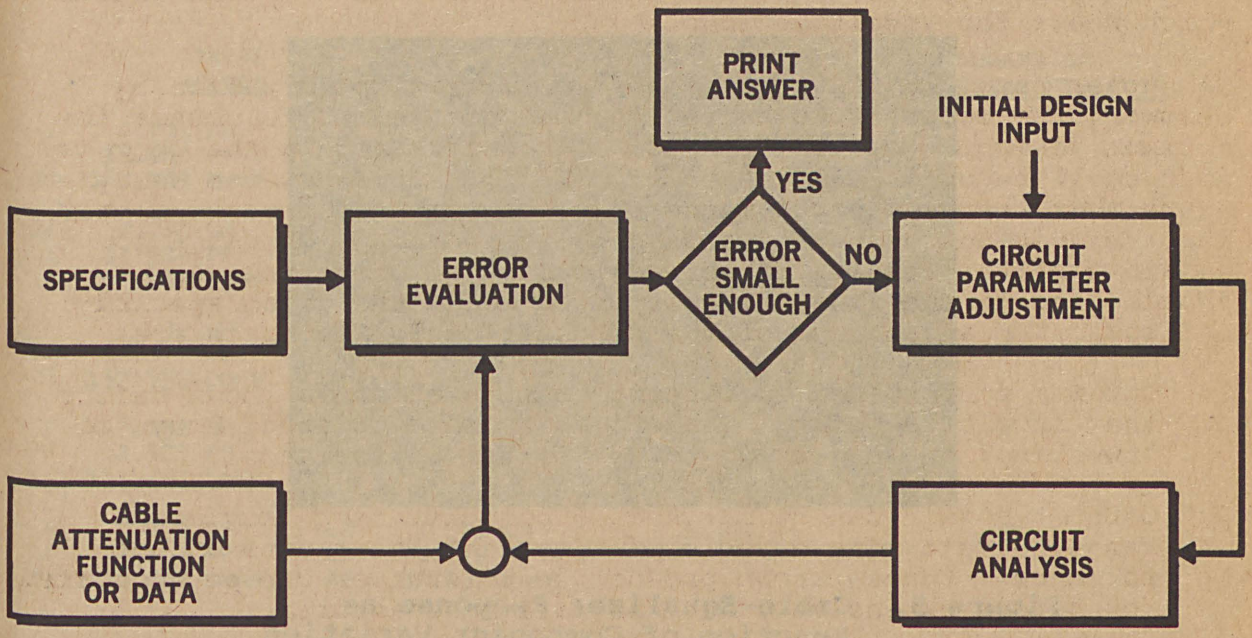


Figure 4. Computer Flow Chart for Network Optimization

The computer operations described by the flow chart in figure 4 are analogous to the designer on the bench in lab. The designer looks at the performance of the circuit with the initial component values. For example, he may display the swept frequency response of the circuit on an oscilloscope and compare this trace to that of a reference trace. The designer then decides if the deviation between the circuit trace and reference is within the required specification. If so, he records his circuit component values as the final design. If not, he adjusts values of the component such as trimmers, pots, spreading turns on coils, etc., until he achieves the desired response.

Figure 5 is a dramatization of the laboratory optimization techniques. Frequency responses for the bridged T-equalizer network cascaded with a length of cable are designated by numbers for various values of C_2. The initial value of C_2 chosen resulted in response numbered 2. The designer then adjusted the value of C_2 until response number 4 was obtained.

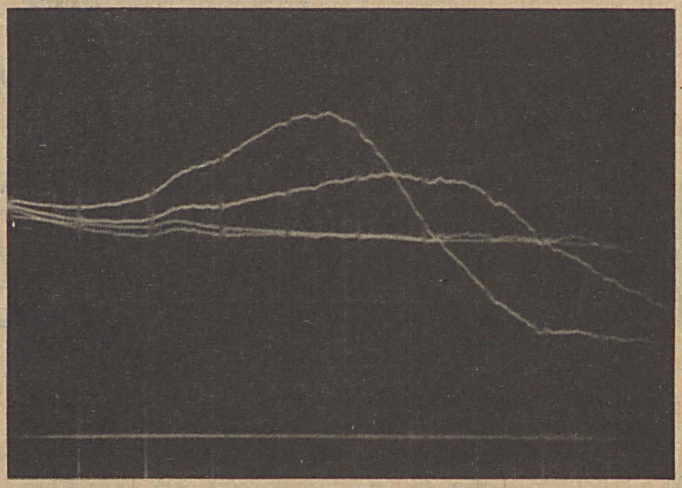


Figure 5. Cable-Equalizer Response as Function of Component Variation

Figure 6 is a computer print out for an equalizer which equalizes a length of cable equivalent to 12.5 dB of attenuation at 220 MHz for SLM-500 cable. The initial values of R_1, L_1, C_1 are 160 ohms, 0.033 uh and 13 pf, respectively. The circuit is as shown in figure 1. The values of R_2, L_2 and C_2 are listed in figure 6. In this particular program, the computer calculates the sum of the cable and equalizer attenuation values in 20-MHz increments from 40 to 260 MHz. The sum in dB is compared with the ideal flat response. The deviation in dB between the sum and flat response at each frequency is squared and summed over the range from 40 to 260 MHz. This sum is printed in the column entitled SUM OF SQUARED ERROR. Each time the computer calculated the "sum of squared errors" the number in the "NUMBER OF COMPUTER TWEEKS" column is advanced by one. The column should more scientifically be entitled "Number of Iterations". The number of iterations tabulates the number of times the component values are adjusted.

TRIAL VALUES				SUM OF SQUARED ERROR	NUMBER OF COMPUTER "TWEEKS"
L1	0.033 UH	L2	0.073 UH	68.825	1
C1	13.000 PF	C2	5.867 PF		
R1	160.000 OHMS	R2	35.156 OHMS		
L1	0.033 UH	L2	0.070 UH	3.527	2
C1	12.524 PF	C2	5.788 PF		
R1	160.414 OHMS	R2	35.065 OHMS		
L1	0.032 UH	L2	0.071 UH	3.193	3
C1	12.577 PF	C2	5.749 PF		
R1	157.952 OHMS	R2	35.612 OHMS		
L1	0.032 UH	L2	0.070 UH	3.222	4
C1	12.528 PF	C2	5.726 PF		
R1	157.263 OHMS	R2	35.768 OHMS		
L1	0.032 UH	L2	0.071 UH	2.931	5
C1	12.562 PF	C2	5.712 PF		
R1	156.262 OHMS	R2	35.997 OHMS		

L1(NH)	C1(PF)	R1(OHMS)	L2(NH)	C2(PF)	R2(OHMS)
32.131	12.562	156.262	70.659	5.712	35.997

FREQUENCY (MHZ)	CABLE ATTENUATION (DB)	EQUALIZER PLUS CABLE LOSS (DB)	DEVIATION FROM FLAT RESPONSE (DB)
40	4.82382	13.72936	0.527679
80	7.04698	13.90863	0.706944
120	8.85067	13.34456	0.142880
160	10.40268	12.71403	-0.487652
200	11.84284	12.56164	-0.640046
220	12.50000	12.75331	-0.448369
240	13.15716	13.18553	-0.016151

Figure 6. Computer Print-Out of Iterative Circuit Design

The program prints out the frequency response when the sum of the squared error (summed from 40 to 260 MHz in 20-MHz steps) is less than 3 dB. The program was written to print the response at 40-MHz increments plus the 220 MHz reference frequency. By reducing the error constraint to a number less than 3 dB, the computer would go through additional iterations until this error criterion was satisfied. This would result in a flatter frequency response. By monitoring the computer print out, the designer can recognize if his circuit design will allow the error to converge to an acceptable value or whether or not he must change the circuit configuration.

Once the circuit has been optimized for a set of nominal cable parameters, an interesting set of calculations can be made for

this particular design problem. In addition to the performance variation of the circuit due to component tolerances, performance variation of the cable-equalizer cascade as a function of cable parameters can be calculated.

The dissipation factor, D, is often the cause of the largest manufacturing variation in the production of foamed polyethylene coaxial cable. Figure 7 represents plotted frequency responses of the cable plus equalizer loss as a function of frequency and three different dissipation factors (D).

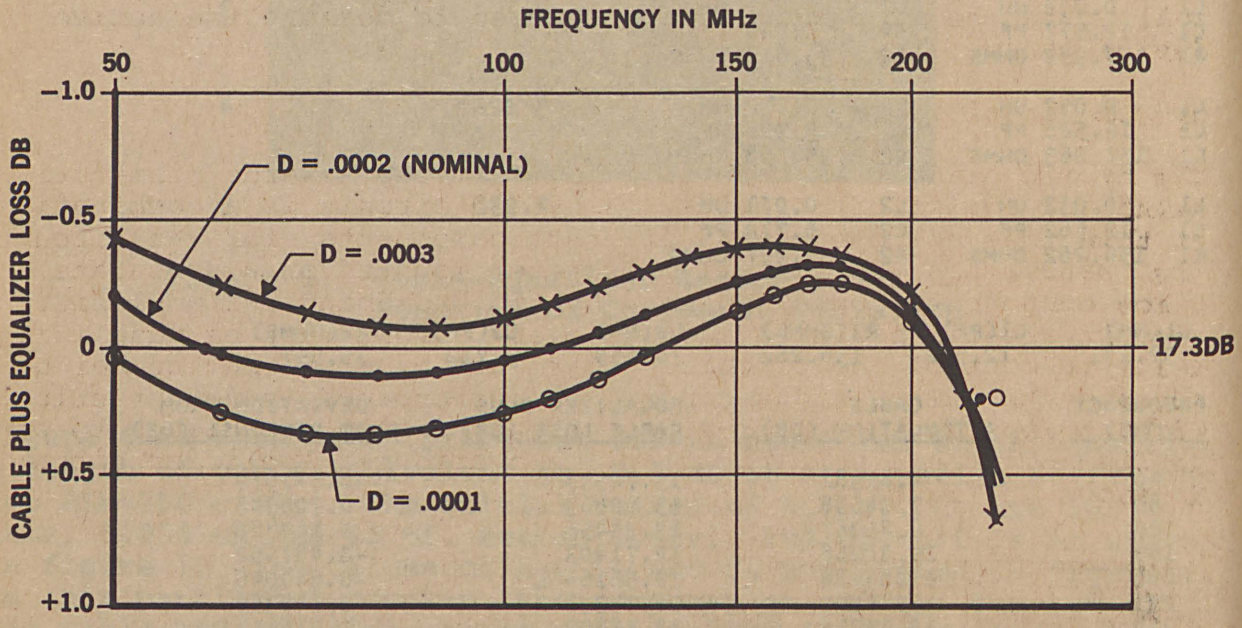


Figure 7. Cable Plus Equalizer Loss Vs. Frequency as Function of Cable Dissipation Factor. Equalizer Designed for Nominal D.

The cable attenuation was calculated from equation (6) of reference 2. The equalizer was designed for coaxial cable with a dissipation factor of 0.0002.

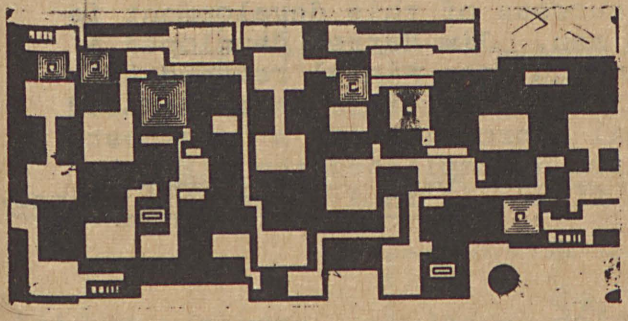
The Circuit Parameter Adjustment block in figure 4 is a key step in the application of computer aided circuit design. Without a systematic method of adjusting circuit parameters to achieve the desired circuit performance, the design process degenerates into a computer-aided cut and try method, the equivalent of the screwdriver-adjustment technique used by "on-the-bench" designers. Much work has been done in this area of circuit or network optimization by computer in the last five to ten years. There are many references available describing optimum circuit design methods and procedures.

Amplifier Design

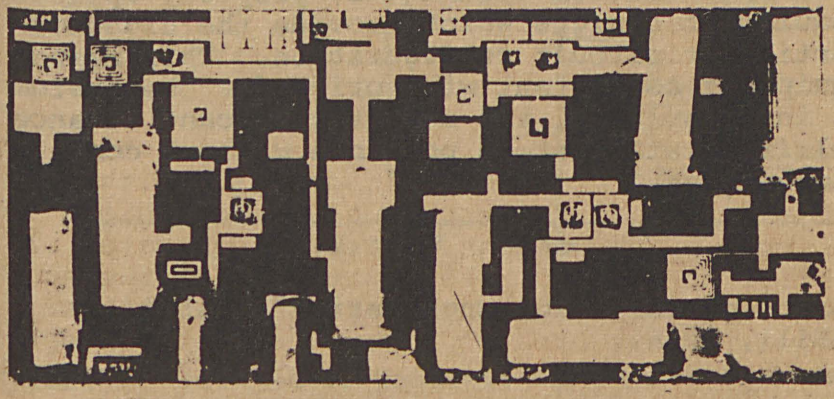
The design techniques and computer programs which solve equalizer problems can be made general enough so that they may be applied to amplifier designs, and many other circuits used in CATV equipment. A practical problem in employing the aid of a computer for broadband amplifier design is the characterization of the active devices (transistors, diodes, FET's). Characterization meaning measuring a set of y-parameters or other four-terminal parameters necessary to describe the device over the frequency range of interest. However, the results obtained are well worth the time and effort required to measure the active device parameters.

Hybrid Circuits

The hybrid circuit is the first logical step towards miniaturized broadband amplifier circuits. A hybrid circuit is a combination of thin film components and discrete components (for r-f circuits the transistors are normally discrete) mounted on a substrate. Since components contained in a hybrid broadband r-f amplifier circuit are difficult to adjust, every effort must be made initially to control the circuit performance by a minimum number of adjustments. This tight control of performance is not practical without applying computer-aided circuit design techniques to establish component sensitivities. A hybrid r-f amplifier circuit is shown in figure 8.



(a) Thin Film Circuit



(b) Hybrid Circuit, Thin Film Plus Addition of Discrete Components

Figure 8. Hybrid Circuit Example

There is little justification for miniaturizing the CATV repeater amplifiers for smallness' sake alone. However, one benefit of a smaller amplifier means more amplifier(s) in the same physical volume as occupied by discrete component amplifiers. Such features as redundant amplifiers, push-pull amplifiers and reverse transmission amplifiers can be contained in housings no larger than those now on the market.

An additional advantage of a smaller circuit made possible by a hybrid circuit technique is that circuit stray inductance and capacitance can be minimized. Lead inductance, especially in the emitter circuits of the discrete component amplifiers, reduces the available stable high-frequency gain. The hybrid circuit design realizes the full capabilities of the transistor chip before they are degraded by the parasitic inductance and capacitance of the transistor package. Hence, higher performance can be obtained from the same transistor chips now in discrete packages operating in today's repeater amplifiers.

Because of production techniques for hybrid amplifier circuits, more consistent and reliable performance can be anticipated. As the state of the art related to production technique advances, higher performance amplifiers can be expected at today's prices.

Acknowledgements

Computer aided circuit design at Anaconda Electronics has been developed for practical problem solving using the IBM-SBC Call/360 Time Sharing Service. The success of this development is due mainly to the effort of two men. Jim Harrer developed a complex matrix inversion program and John Kinkel refined this program to reduce its running time. John Kinkel also reduced to practice and wrote a practical subroutine for a "steepest descent iteration" technique which accomplished the circuit parameter adjustments, shown in figure 4, in a systematic manner.*

Conclusion

Computer-aided network optimization techniques, properly applied, can result in CATV equipment designs which provide the highest performance for a particular circuit configuration. This means better performing equipment consistent with price for the system operators. Finally, in my opinion, the next significant advance in CATV repeater amplifiers will not be possible without computer aided design techniques.

References

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*The key to computer-aided network optimization

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Appendix

An example of an insertion loss calculation at one frequency, 40 MHz follows. The circuit element values of the equalizer circuit were selected to equalize a length of SLM-500 cable equivalent to 6 dB o attenuation at 270 MHz.

A few manual calculations provide the starting point for a circuit to be built in the lab as shown in figure 9. The circuit is then optimized on the bench. However, it is obvious that more than a few manual calculations become impractical and, because of this, the theoretical performance limits of the circuit cannot be determined by manual calculation.

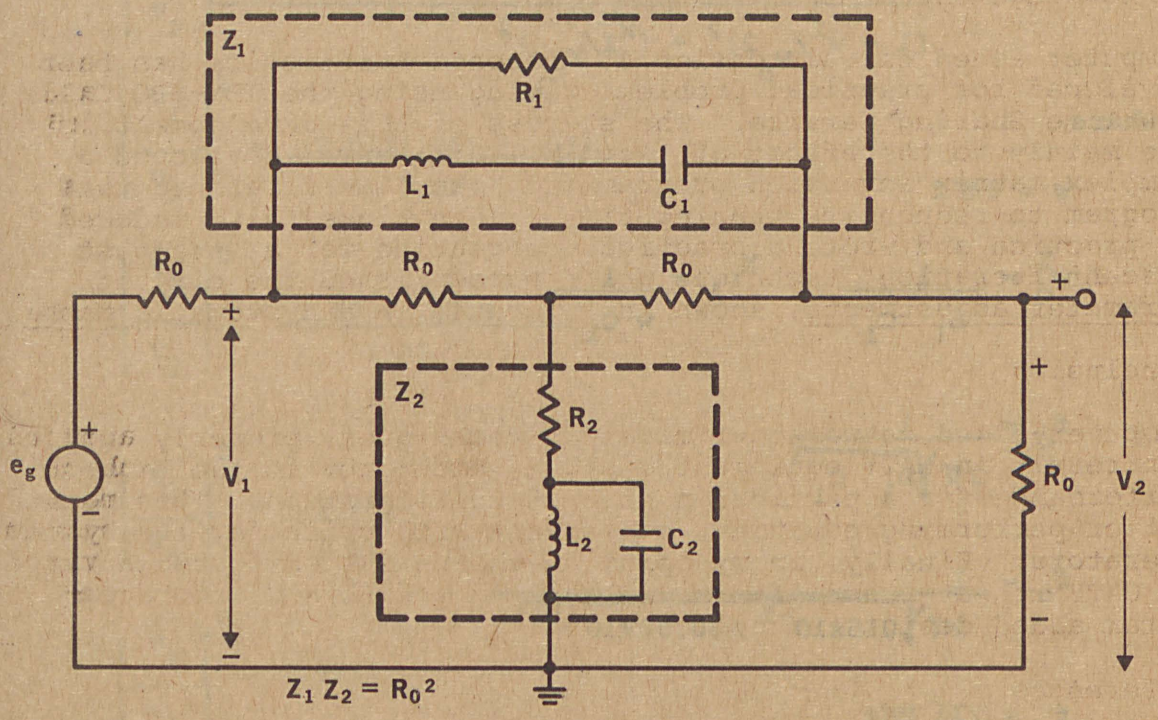


Figure 9. Bridged-T, Constant Resistance Equalizer Circuit Schematic

For this example, component values are as follows:

$R_1 = 34.8$ ohms $\qquad R_o = 75$ ohms $\qquad Z_1 Z_2 = R_o^2$

$L_1 = 15.0$ nH

$C_1 = 30.58$ pf

The insertion loss of the equalizer is defined by the equation:

$$\frac{V_1}{V_2} = \left| 1 + \frac{Z_1}{R_o} \right|$$

Substituting in the symbols for Z_1 and after some algebraic manipulation:

$$\left| \frac{V_1}{V_2} \right|^2 = \frac{(1 + R_1/R_o)^2 \quad (1 - (w/w_o)^2)^2 + (R_1/X_{C_1})^2}{(1 - w^2/w_o^2)^2 + (R_1/X_{C_1})^2}$$

where

$$w = 2\pi f$$

$$w_o^2 = \frac{1}{L_1 C_1} \qquad X_{C_1} = \frac{1}{w C_1}$$

$$f_o = \frac{1}{2\pi \sqrt{L_1 C_1}}$$

$$f_o = \frac{1}{2\pi \sqrt{.015 \times 10^{-6} \times 30.58 \times 10^{-12}}}$$

$$f_o = 231 \text{ MHz}$$

$$\frac{w}{w_o} = \frac{f}{f_o} = \frac{40}{231} = .17$$

$$\left(\frac{w}{w_o}\right)^2 = (.17)^2 = .03$$

$$1 - \left(\frac{w}{w_o}\right)^2 = 1 - .03 = .97$$

$$(1 - (w/w_o)^2)^2 = .94$$

$$X_{c_1} = \frac{1}{2 \quad x40x30.58x10^{-12}} = 130$$

$$R_1/X_{c_1} = \frac{34.8}{130} = .268$$

$$\left(R_1/X_{c_1}\right)^2 = (.268)^2 = .0718$$

$$R_1/R_o = 34.8/75 = .465$$

$$\left|\frac{V_1}{V_2}\right|^2 = \frac{(1 + .465)^2 \ (.94) + (.0718)}{((.94) + (.0718))^2}$$

$$\left|\frac{V_1}{V_2}\right|^2 = \frac{(2.01)(.94) + .0718}{1.02}$$

$$\left|\frac{V_1}{V_2}\right|^2 = \frac{1.89 + .0718}{1.02}$$

$$\left|\frac{V_1}{V_2}\right|^2 = \frac{1.962}{1.02}$$

$$\left|\frac{V_1}{V_2}\right|^2 = 1.925$$

10 log(1.925) = 2.86 dB ; Insertion Loss = 2.86 dB

CALCULATION FOR ONE FREQUENCY USING ONE SET OF CIRCUIT VALUES

DANIEL LIEBERMAN

INTRODUCTION

Cross-modulation is a phenomenon due to third order non-linearity in which the modulation of an interfering carrier is impressed upon another carrier. The latter carrier can contain its own modulation or be a CW signal. Cross-modulation is expressed as a precentage of the modulation of the interfering carrier which is "crossed-over". Both carrier levels must be equal in this case. In other words, if the interfering carrier has 100-percent modulation, and if the modulation upon the desired carrier which is due to cross-modulation is determined to be 1 percent, then the cross-modulation is 1 percent. If the percentage modulation of the interfering carrier is 50 percent, and if the modulation upon the desired carrier which is due to cross-modulation is ascertained as 0.5 percent, then the cross-modulation is still defined as 1 percent. Cross-modulation can also be expressed as a dB ratio, where the percent modulation of the interfering carrier is again the reference. In this case, 1 percent cross-modulation would be expressed in an equivalent manner as 40 dB below 100-percent modulation.

Several investigators have analyzed the non-linear mechanisms which contribute in causing cross-modulation in transistor amplifiers [1], [2]. In order of most significance these are listed below with measures for lowering the distortion:

1. Base-emitter junction non-linearity - Increasing the bias current through the junction reduces the non-linearity.

2. Current gain (beta) change with AC signal - Operation at an optimum emitter current, which is at the flat, or peak portion of beta curve, minimizes the effect of the AC signal on the beta value.

3. Avalanche Multiplication - Operation much below collector break-down voltage limits this non-linearity.

4. Collector-base capacitance - This is a cube root function with applied voltage. Increasing the collector voltage reduces the collector base capacitance.

5. Collector output impedance non-linearity - Class A operation, with a small voltage swing condition, limits the collector impedance non-linearity.

Minimization of cross-modulation, therefore, requires a compromise operating condition of collector current and voltage, since operating conditions which most linearize each parameter are in conflict with each other.

This article concerns itself with comparison of transistor amplifier configurations in relation to their cross-modulation distortion characteristics. Only the base-emitter junction non-linearity is considered, since this non-linearity is considered to be the most significant contributor to cross-modulation distortion. For this case investigations have shown that since cross-modulation occurs because of a third order non-linearity, the cross-modulation distortion is therefore proportional to the square of the interfering voltage which appears across the base-emitter junction [3].

In this article the cross-modulation of the transistor stage is analyzed from its equivalent circuit rather than from the theoretical device characteristics. It is assumed that the transistor stage gain and input impedance remain relatively constant with small signal voltage excursions. Using these hypotheses, a figure of merit factor is derived for comparison of transistor and transistor amplifier configurations with respect to their cross-modulation distortion characteristics.

This figure of merit factor is then used to compare the relative cross-modulation susceptibility of the common collector, common emitter, and common base configurations. All three configurations are compared in the hypothetical voltage generator and short circuit load case. The derivation of the equations is shown in Appendix 1. The latter two configurations are then analyzed and compared for the more practical matched input and matched output (maximum power transfer) case. Familiar formulas for transistor gain and input impedance in the low-frequency equivalent model are used for this analysis. Derivations of the equations are shown in Appendix II.

A plot of the analyzed relative figures of merit for the common emitter and base configurations, as a function of the device current gain, is then shown in Figure 4. The plot for the common emitter connection is substantiated by measurements shown in Figure 8.

The effect of feedback on the cross-modulation figure of merit is then analyzed using both degenerative and regenerative types of feedback.

It is then shown that by use of the analysis of the low frequency model, together with the analyses of the effects of feedback, a high frequency analysis of cross-modulation figure of merit can be made. This analysis is most applicable to wideband VHF amplifiers, such as used in Community Antenna Television trunk cascades. A convenient means for analyzing cross-modulation in the more complicated high frequency circuit is thus described.

Other types of stages, such as push-pull and parallel outputs, are also discussed in regard to the defined cross-modulation figure of merit.

A set of conclusions concerning the defined cross-modulation figure of merit is then reached.

FIGURE OF MERIT

Figure 1 represents a transistor amplifier stage in which the common junction is placed physically at ground. A valid comparison can be made between amplifiers using the same transistor relative to their cross-modulation characteristics for a given power output of the interfering carrier and the interfered carrier. In this case, both carriers will be considered to be of equal output levels and with frequencies within the flat bandpass of the amplifier.

The interfering voltage square, e_i^2, is expressed as:

1) $$e_i^2 = P_i R_i$$

where P_i is the input power, and R_i is the input impedance. Since $P_i = P_o/A$, where P_o is the designated output power, and A is the power gain,

2) $$e_i^2 = P_o R_i/A$$

For a designated power output, the square of the interfering voltage across the base-emitter junction will therefore be proportional to the quantity R_i/A. Since cross-modulation is proportional to the square of the interfering voltage across the base-emitter junction, the cross-modulation will also be proportional to R_i/A. Therefore, the inverse of this ratio, i.e., the power gain, A, divided by the input impedance, R_i, can be defined as a figure of merit in comparing amplifier configurations with respect to their cross-modulation characteristics in those cases where the input voltage appears entirely across the base-emitter junction. A higher inverse ratio implies lower cross-modulation and, therefore, a higher figure of merit. The figure of merit is then defined as:

3) $$F_M = A/R_i = \text{power gain/input impedance}$$

An amplifier, in order to achieve a high figure of merit, would then tend to use a transistor which has increased power gain and low input impedance. The latter characteristics are additional device requirements to that of low third-order non-linearity for all device parameters; they complement the operating characteristics of optimum current and voltage for reduction of third-order non-linearity.

For those cases where the input voltage does not appear entirely across the base-emitter junction, i.e., where the common side of the junction is not grounded, such as in an emitter follower, another term is needed to proportion the voltages between that

which actually appears across the base-emitter junction and that which appears across any resistor in series with it. Since this is straight voltage divider action, the voltage, e_{be}, which appears across the junction will be:

4) $$e_{be} = \frac{e_i R_e}{R_i}$$. Therefore

5) $$e_{be} = \frac{e_i^2 R_e^2}{R_i^2}$$ where R_e is the contribution to the input impedance of the intrinsic emitter resistance. This includes any multiplying factor due to current feedback, such as occurs in the common emitter stage.

Therefore, equation 2) would be modified as:

6) $$e_{be}^2 = \frac{P_o R_i}{A} \cdot \frac{R_e^2}{R_i^2}$$. For a given P_o the figure of merit, F_M, would become:

7) $$F_M = A \cdot \frac{R_i}{R_e^2}$$

UNMATCHED AND FIXED IMPEDANCE CASE

Figure 2 shows the three different single-stage transistor amplifier configurations, together with their low-frequency, two-generator equivalent circuits. Commonly used approximate formulas for the low frequency voltage gain, current gain, and input impedance of these circuits are given. These approximations appear for the case where the load resistance (fixed as R_L in each configuration) is much smaller than the output impedance (but is larger than the intrinsic emitter resistance r_e), and where the generator impedance is much smaller than the input impedance. This is equivalent to the voltage-generator, short circuit load case. It is a purely hypothetical case, but one which is suitable for analysis.

Using the previously defined figure of merit, each of the configurations can be compared. Power gain will be ascertained as the product of the voltage and current gains. The derivations are shown in Appendix I. The results are given in the following:

Common Emitter

8) $$F_M = \frac{A}{R_i} = \frac{\alpha^2 R_L}{(1-\alpha)} \cdot \frac{1-\alpha}{r_e} = \frac{\alpha^2 R_L}{r_e^2}$$

Common Base

9) $$F_M = \frac{A}{R_i} = \frac{\alpha^2 R_L}{r_e} \cdot \frac{1}{r_e} = \frac{\alpha^2 R_L}{r_e^2}$$

Common Collector

For this case the figure of merit is derived from Equation 7, since the emitter is not grounded. Therefore,

10) $$F_M = \frac{A \cdot R_i}{r_e^2} = \frac{\alpha^2 R_L}{r_e^2}$$

Figures of merit for the unmatched case (voltage-generator, short circuit load) are equal for all three configurations. The higher power gain advantage of the common emitter stage is offset by the lower input impedance of the common base stage. The common collector stage introduces degenerative feedback, which lowers its power gain and raises its input impedance; however, the effective interfering voltage across the junction is also lowered, thereby maintaining a cross-modulation figure of merit equal to that of the other configurations. In all three cases, use of transistors with a higher α and a lower intrinsic emitter resistance would tend to yield higher figures of merit.

MATCHED CASE

In the matched case the output impedance of the transistor amplifier is matched to a specified load impedance, while the input impedance of the transistor amplifier is matched to a specified source impedance. Maximum power transfers from source to amplifier input and from amplifier output to load are thus obtained. The load and source impedances can be assumed to be equal. Perfect non-dissipative matching devices are used, as shown in Figure 3. Power gain of such stages is thus the transducer gain of the active element. A formula for this type of power gain is given in the literature[4].

The following description will compare the common emitter and common base configurations with respect to their relative cross-modulation figures of merit in the matched case. Formulas from the literature will be used for each of the power gains and each of the input impedances. Derivations of the formulas are shown in Appendix II. The results are listed in the following:

Common Emitter

11) $$F_M = A/R_i = \frac{\alpha^2 r_c}{r_e^2 \sqrt{1+\beta}}$$

Common Base

12) $$F_M = A/R_i = \frac{\alpha^2 r_c}{4r_e^2}$$

Plots of relative figures of merit, F_M, as a function of α where r_c/r_e^2 = constant, are shown in Figure 4 for the matched case of common base and common emitter amplifiers. It is noted that the merit figures are equal for $\sqrt{1+\beta} = 4$ or beta = 15. At this value $\alpha = .94$. For values of $\beta > 15$, the common base is advantageous in the matched case in regard to the cross-modulation figure of merit, while below the value $\beta = 15$ the common emitter amplifier appears advantageous.

Also note that while the figure of merit in the common base connection increases monotonically as a function of alpha, in the common emitter connection it has a maximum value for a specific value of alpha. This value can be computed from Equation 11):

$$F_M = \frac{\alpha^2 r_c}{r_e^2\sqrt{1+\beta}} = \frac{K\alpha^2}{\sqrt{1+\frac{\alpha}{1-\alpha}}} = K\alpha^2\sqrt{1-\alpha}$$

where $K = r_c/r_e^2$

$$\frac{dF_M}{d\alpha} = 2K\alpha(1-\alpha)^{1/2} + \frac{K\alpha^2}{2\sqrt{(1-\alpha)}} = \frac{4k\alpha(1-\alpha)+K\alpha^2}{2\sqrt{(1-\alpha)}}$$

To find the value of α for the maximum value of F_M, set $\frac{dF_M}{d\alpha} = 0$

$$\frac{dF_M}{d\alpha} = 0 = \frac{4K\alpha(1-\alpha) - K\alpha^2}{2\sqrt{(1-\alpha)}}$$

$$4\alpha(1-\alpha) - \alpha^2 = 0$$

$$4\alpha - 4\alpha^2 - \alpha^2 = 0$$

$$5\alpha = 4$$

$$\alpha = .8$$

Therefore, $\beta = 4$ for the peak figure of merit.

Also note that the cross-modulation figure of merit for both the matched and unmatched cases is of similar form in the common base configuration, but that matching results in an optimum

figure of merit at an alpha value less than theoretical peak of unity in the common emitter configuration.

This analysis has assumed a base resistance which is small compared to the intrinsic emitter resistance. It will be shown later that a finite base resistance which is linear in nature does not change the figure of merit in either configuration.

DEGENERATIVE FEEDBACK

Several types of feedback used in amplifiers are shown in Figure 5. The operational feedback shown in Figure 5A has as its feedback point the base-emitter junction, which is the defined third-order distortion producing point. This configuration, therefore, cannot improve the figure of merit. This is easily shown by the fact that operational feedback reduces the open loop gain, A, by $\frac{1}{1 + bA}$ where B is the feedback factor, while it also reduces the input impedance by $\frac{1}{1 + bA}$. Therefore,

13) $$F_M = A_F/A_{iF} = \frac{A}{1 + bA} \Big/ \frac{R_i}{1 + bA} = A/R_i$$

The closed loop figure of merit is, therefore, the same as that of the open loop.

The current feedback shown in Figure 5B also maintains the same figure of merit regardless of the feedback factor. In this case the emitter resistance, r_e, of the common emitter configuration can be replaced by $r_e + R_f$, since both resistors are reflected to the input by the common multiplying factor of β. In the case of the common base circuit, the physical resistance, R_F, in the base is reflected back in series with r_e as $r_e + (1 - \alpha) R_F$. Since current feedback divides the effective interfering voltage between r_e and its series impedance, R_F, Equation 7) (with R_e equal to the resistance, r_e, modified by a feedback factor) must be used for calculating the figure of merit.

Using the increased effective resistance of $r_e + R_F$ for r_e, and with $R_e = r_e\sqrt{1 + \beta}$ (the normally effective impedance of the emitter resistance) in the calculated formulas shown in Appendix II for power gain and input impedance of the common emitter matched case, yields:

14) $$F_M = \frac{AR_i}{R_e^2} = \frac{\alpha^2 r_c (r_e + R_F)\sqrt{1 + \beta}}{(r_e + R_F) r_e^2 (1 + \beta)} = \frac{\alpha^2 r_c}{r_e^2\sqrt{1 + \beta}}$$

Similarly for the common base matched case, using the modified impedance $r_e + R_F$ substituted for the emitter impedance r_e in

the formulas of Appendix II for power gain and input impedance, and with $R_e = r_e$, yields:

15) $$F_M = \frac{AR_i}{R_e^2} = \frac{\alpha^2 r_c (r_e + R_F)}{4 (r_e + R_F) r_e^2} = \frac{\alpha^2 r_c}{4 r_e^2}$$

These figures of merit are the same as derived previously for the case with no current feedback. Therefore, current feedback, as shown in Figure 5B, does not modify the figure of merit of common emitter or common base amplifiers.

Another type of degenerative feedback, although rarely used, is shown in Figure 5C. This type of feedback lowers the power gain and raises the input impedance. However, as in current feedback it changes the total interfering voltage across the base-emitter junction so that the figure of merit remains constant.

The conclusion reached from this analysis of single stage amplifiers is that operational and current feedback do not change the cross-modulation figure of merit. This can also be realized from the fact that if the summing point of the feedback path is the distortion-producing point, then feedback cannot reduce the signal distortion.

REGENERATIVE FEEDBACK

Regeneration is most often an accidental occurrence, since it is sometimes difficult to compute exact transfer functions of transistor amplifiers without sufficient and exact knowledge of all the transistor parameters, especially at high frequencies.

One type of regenerative feedback is shown in Figure 6A. This is similar to the circuit of Figure 5C except that the phase of the feedback circuit is reversed 180 degrees to ensure regeneration instead of degeneration. For this type of regenerative feedback, the power gain is increased, while the apparent input impedance is decreased. However, the total interfering voltage across the base-emitter junction is raised proportionally so that the figure of merit remains constant, when compared to the circuit without regenerative feedback.

Another type of regenerative feedback is shown in Figure 6B. This is similar to the feedback circuit of Figure 5A, except that the phase of the feedback circuit is reversed 180 degrees to ensure regeneration instead of degeneration. For this type of regenerative feedback the power gain is increased, while the apparent input impedance is equally increased. Therefore, this type of feedback does not change the cross-modulation figure of merit from the open loop value. The conclusion reached from this

analysis of regeneration in single stage amplifiers is that regeneration does not change the cross-modulation figure of merit.

HIGH-FREQUENCY AMPLIFIERS

The power gain at higher frequencies is lowered due to:

1. Increase in degenerative feedback in collector-base impedance path.

2. Decrease of current gain as frequency increases.

3. Decrease of output impedance.

4. Secondary effects, such as increased effects of base-emitter capacitance, emitter inductance and base spreading resistance.

The input impedance is primarily lowered by:

1. Decrease of current gain as frequency increases.

2. Increase in degenerative feedback due to lowered collector-base impedance.

3. Also, secondary effects, such as that of the base-emitter capacitance, serve to lower the input impedance, while increased effects of base spreading resistance and emitter inductance serve to increase the input impedance.

Changes in the high frequency power gain and input impedance, which are due to feedback, therefore serve to modify the low frequency cross-modulation figure of merit at higher frequencies, according to analysis made previously for the feedback cases. Therefore, the high frequency figure of merit can be derived from analysis of the low frequency figure of merit and the feedback factors which cause changes in high frequency gain and input impedance.

In addition, the low frequency example can be used for high frequency analysis by modifying the value of the parameters as they change with frequency. The high frequency value can then be substituted in the low frequency example. The parameters which most modify the high frequency transfer function of the transistor amplifier stage are stated in the following paragraphs, together with their effects on the cross-modulation figure of merit.

Increase in Degenerative Feedback due to Collector-Base Capacitance

If the base is grounded, this affects only the common emitter configuration. As shown previously, this type of feedback,

since it affects both power gain and input impedance equally, does not change the figure of merit in the common emitter configuration. If the base is not grounded, there will be feedback in the common base configuration. As stated previously, this type of feedback does not modify the figure of merit in the common base configuration.

Decrease in Current Gain with Increasing Frequency

In the unmatched case where the load impedance remains small compared with the collector output impedance, the figures of merit for both the common emitter and common base show that they remain equal, but fall as the square of the current gain. Therefore, in the unmatched case, since the current gain decreases with increasing frequency, both figures of merit will decrease also with increasing frequency.

Further, in the matched case, the common base figure of merit depends upon alpha in the same manner as in the unmatched case. Here again the figure of merit will therefore decrease monotonically with increasing frequency. The common emitter state in the matched case has the factor $\sqrt{1+\beta}$ in the denominator and the factor α^2 in the numerator for its figure of merit. Since α, and therefore also β, fall with increasing frequency, the figure of merit will change according to the change of the factor $\alpha^2/\sqrt{1+\beta}$ as a function of frequency. The change in the figure of merit as a function of alpha is shown in Figure 4.

Since the value of alpha at any particular frequency depends upon the F_T ($\beta = 1$) of the transistor, and on the low frequency alpha, the relative value of the figure of merit at any frequency will also depend upon the F_T and the low frequency alpha of the transistor. Since the figure of merit of the common emitter stage, in the matched case, does not increase monotonically as a function of alpha, an alpha can be reached which corresponds to a particular frequency in which the common emitter figure of merit is higher than that of the common base. For VHF amplifiers, the frequency of advantage for the common emitter stage would be the frequency at which $\alpha = .94$ or $\beta = 15$. This value was derived in previous paragraphs. For a VHF transistor with an F_T ($\beta = 1$) of 1500 MHz, the frequency above which the common emitter configuration could exhibit a higher figure of merit than the common base would be at $f = F_t/15 = \frac{1500}{15} = 100$ MHz.

Figure 4, together with knowledge of the f_t of the transistor being used, can serve to show how the common emitter figure of merit in the matched case changes with a decrease in beta and, therefore, with an increase in frequency. Figure 4 shows that the figure of merit will peak at the frequency in which $\alpha = .8$.

Decrease in Output Impedance

This affects both the common emitter and common base figures of merit equally. Therefore, the two figures of merit will decrease equally with increasing frequency as the collector impedance decreases.

Base-Emitter Capacitance and Emitter Inductance

If these are assumed to be properly tuned out at all frequencies, no change in figure of merit for either configuration will occur as a function of frequency because of them.

Base Spreading Resistance

The intrinsic base resistance usually increases with frequency. With voltage gain being defined as

$$A_V = \frac{I_{out} R_{out}}{I_{in} R_{in}} = \frac{A_i R_{out}}{R_{in}}$$

and with R_{in} increasing as the base resistance increases, the figure of merit would appear to decrease with frequency, since power gain is decreasing and input impedance is being raised. However, r_b, while raising the input impedance, also serves as a voltage divider for the signal, thereby lowering the effective voltage across the intrinsic emitter resistance. As an example, in the unmatched common emitter case the input impedance is more accurately $R_i = r_b + \frac{r_e}{1-\alpha}$. Therefore, the effect of r_b on the total input impedance is $(1 - \alpha)$ times the effect of r on the total input impedance. This is similarly true in the unmatched common base case. In the matched cases, the input impedance formula is more complicated when $r_b = 0$, but here, too, it is obvious that the effect of r_b on the input impedance is proportional by some factor in relation to the effect of r_e on the input impedance. If we then define $R_i = r_b + kr_e$, the voltage gain will be reduced for a finite r_b, when compared to a circuit where $r_b = 0$, by a factor

$$\frac{A_v \ (r_b > 0)}{A_v \ (r_b = 0)} = \frac{kr_e}{r_b + kr_e}$$

The power gain will be reduced by the same factor. The input impedance ratio will in turn be increased by the reciprocal of this factor. Using equation (5) the effective interfering voltage across the base-emitting junction is shown to be divided so that

16) $$e_{be}^2 = \frac{e_i^2 (kr_e)^2}{(r_b + kr_e)^2}$$ where $R_e = kr_e$ and $R_i = r_b + kr_e$.

R_e of Equation 5) will not change with the change in value of r_b, since R_e is only a function of r_e. Using Equation 7) to determine the relative change in cross-modulation figure of merit as a function of base resistance results in

17)
$$\frac{F_{M\,(r_b>0)}}{F_{M(r_b=0)}} = \frac{A_{rel}\ R_{i\,rel}}{R_{e\,rel}^2} = \frac{kr_e}{r_b+kr_e} \cdot \frac{r_b+kr_e}{kr_e} = 1$$

where each factor is the relative ratio between the value of some $r_b > 0$ and the value at $r_b = 0$. Therefore, a linear base spreading resistance has no effect on the cross-modulation figure of merit.

Conclusions which can be reached concerning the cross-modulation figure of merit for high-frequency amplifiers from this analysis are:

1. In the common base configuration the figure of merit decreases with increasing frequency. The decrease is proportional to changes in α^2 and the collector impedance in both the matched and unmatched cases.

2. In the common emitter configuration, the figure of merit of the unmatched case changes similar to that of the common base configuration as a function of frequency.

3. In the common emitter configuration, the figure of merit of the matched case will probably decrease with increasing frequency, since the collector impedance will probably decrease faster than $\sqrt{\beta + 1}$ as a function of frequency. However, the high frequency figure of merit will probably be higher than that of the common base configuration after the frequency of $F_T/15$. Figure 4 indicates that an optimum β exists which maximizes the figure of merit. Therefore, an optimum transistor f_t for maximizing the figure of merit could exist at a particular operating frequency.

4. The collector base capacitance has no effect on the figure of merit in the common emitter configuration, since it only serves to increase the degenerative feedback.

5. A linear base spreading resistance has no effect on the figure of merit in either the common emitter or common base configurations.

6. The base-emitter capacitance and emitter inductance will have no effect on the figure of merit if they are properly "tuned out" at any particular frequency.

Measurements of cross-modulation of a common emitter stage at VHF frequencies indicate correlation with the previous analysis and conclusions.

A broadband, well-matched amplifier stage (40-250 MHz flat ± 0.2 dB) of the configuration shown in Figure 7 was examined for its cross-modulation characteristics as a function of the frequency of the interfering carrier. The interfering carrier was modulated by a 15-kHz square wave which keyed the interfering carrier "on" for 50 percent of the time. The desired signal, which was unmodulated, was set at 210 MHz.

The detected modulation on the desired signal was measured with a highly sensitive, phaselocked voltmeter. In all measurements the output levels of the undesired signals were the same.

The results of the measurements are shown in Figure 8. Also shown on the graph is the theoretical inverse of relative cross-modulation figure of merit vs frequency of the transistor according to the previous analysis of the high frequency model. Power gain measurement of the amplifier indicated an F_t ($\beta = 1$ value) of about 1500 MHz for the transistor.

The measured values indicate the trend, when the transistors are operated at a frequency such that their high frequency beta is greater than four, for the cross-modulation distortion to decrease as the interfering frequency increases in the same manner as predicted by the inverse of the derived relative cross-modulation figure of merit.

FIGURES OF MERIT FOR OTHER CONFIGURATIONS

Paralleling of transistor stages, or class A push-pull operation of them, can result in increased figures of merit. This is shown by the following:

Parallel Outputs

In paralleling stages, the input impedance is reduced to 1/2 of its single value, while the power gain remains the same. Therefore, the figure of merit of the parallel connection is:

18) $$F_{MP} = A/R_{i/2} = 2A/R_i = 2F_M$$

Push-Pull Output

In class A push-pull operation, the input impedance is doubled while the power gain remains the same. However, the interfering voltage is divided across the two series push-pull stages. Therefore, the figure of merit, using Equation 7) for push-pull operation, is:

19) $$F_{MPP} = \frac{AR_{is}}{R_e^2} = \frac{2AR_i}{R_i^2} = \frac{2A}{R_i} = 2F_M$$

CONCLUSIONS

A cross-modulation figure of merit for transistor amplifier stages can be defined in terms of the power gain and input impedance of the amplifier for a fixed power output level and transistor type. By use of this figure of merit, it has been shown that for the case where the distortion is produced at the base-emitter junction:

1. In the unmatched case, where the load impedance is small compared to the collector output impedance, the figure of merit and, therefore, cross-modulation distortion of all three transistor configurations can be made equal.

2. In the matched case, the common base figure of merit is greater than that of a common emitter for alpha greater than .94. For a lower alpha value the common emitter tends to have a higher figure of merit.

3. Degenerative feedback in a single stage amplifier cannot change the defined cross-modulation figure of merit.

4. Regenerative feedback in a single stage amplifier cannot change the defined cross-modulation figure of merit.

5. The low frequency equivalent circuit of a transistor stage together with knowledge of feedback effects on cross-modulation distortion can be used to predict the relative cross-modulation figure of merit at VHF frequencies.

6. In the matched case, circuit use of transistors with high collector impedance and low intrinsic emitter resistance would tend to yield higher cross-modulation figures of merit. Higher alpha transistors would also be beneficial in the common base circuit, whereas an optimum alpha of .8 at the operating frequency would be most desirable for a transistor used in a common emitter circuit.

REFERENCES

1. Lee C. Thomas, Eliminating Broadband Distortion in Transistor Amplifiers, Bell System Technical Journal, March 1968.

2. S. Narajanan, Transistor Distortion Analysis Using Volterra Series Regeneration, Bell System Technical Journal, May-June 1967.

3. Brian L. Jones, Cross-Modulation in Transistor Amplifiers, Solid State Design, November 1962.

4. Lo, Endres, Zawels, etc., Transistor Electronics, Prentice Hall, 1953.

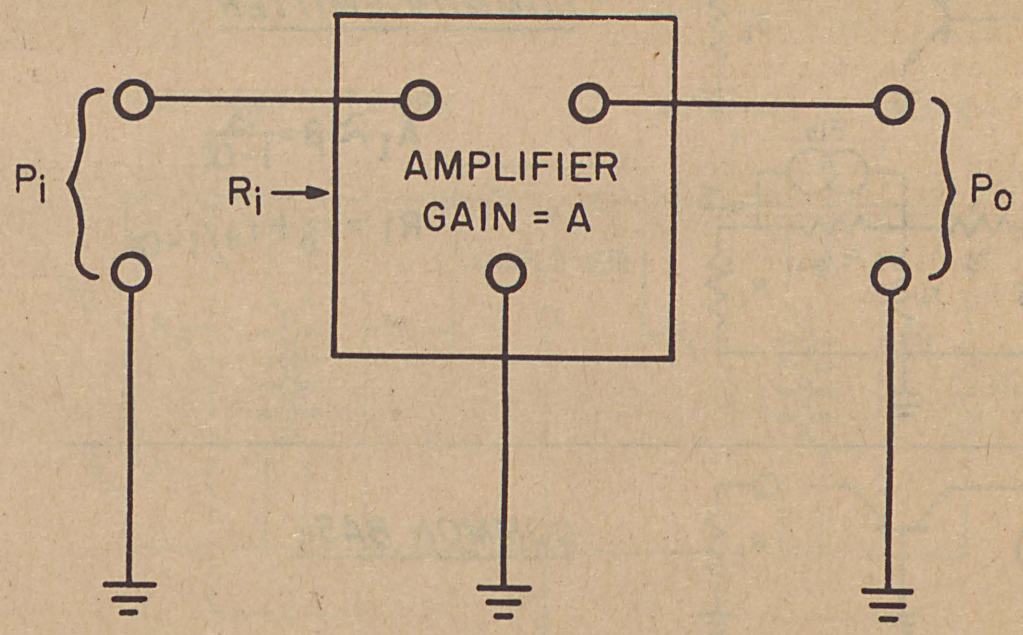
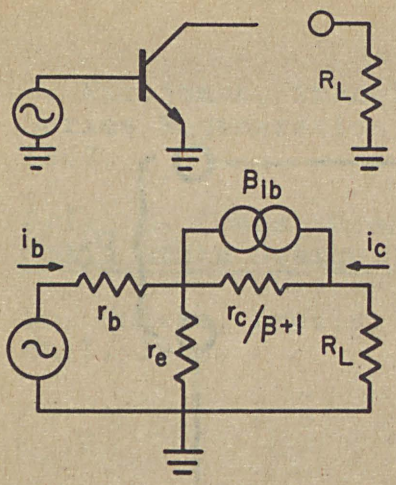


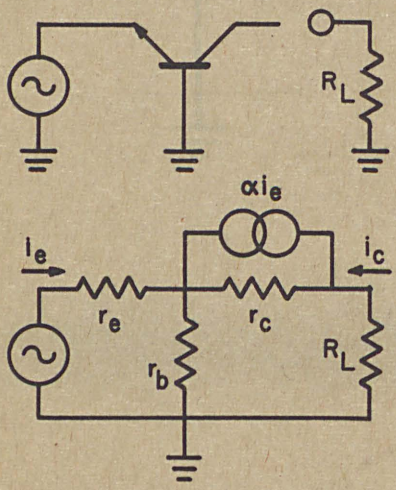
Figure 1. Amplifier Model



COMMON EMITTER

$$A_I \approx \beta = \frac{\alpha}{1-\alpha}$$

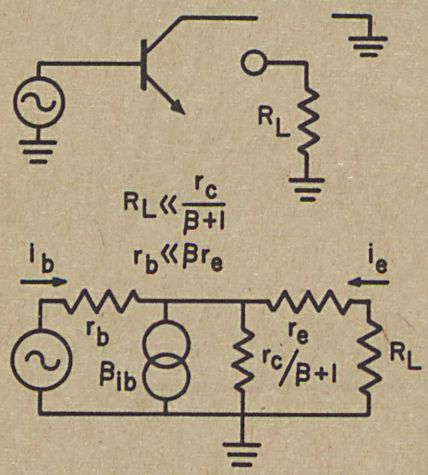
$$R_i = r_b + r_e/1-\alpha$$



COMMON BASE

$$A_I \approx \alpha$$

$$R_i = r_e + (1-\alpha)\, r_b$$



COMMON COLECTOR

$$A_I = \beta = \frac{\alpha}{1-\alpha}$$

$$R_i = r_b + \frac{[r_e + R_L]}{1-\alpha}$$

Figure 2. Low Frequency Equivalent Circuit

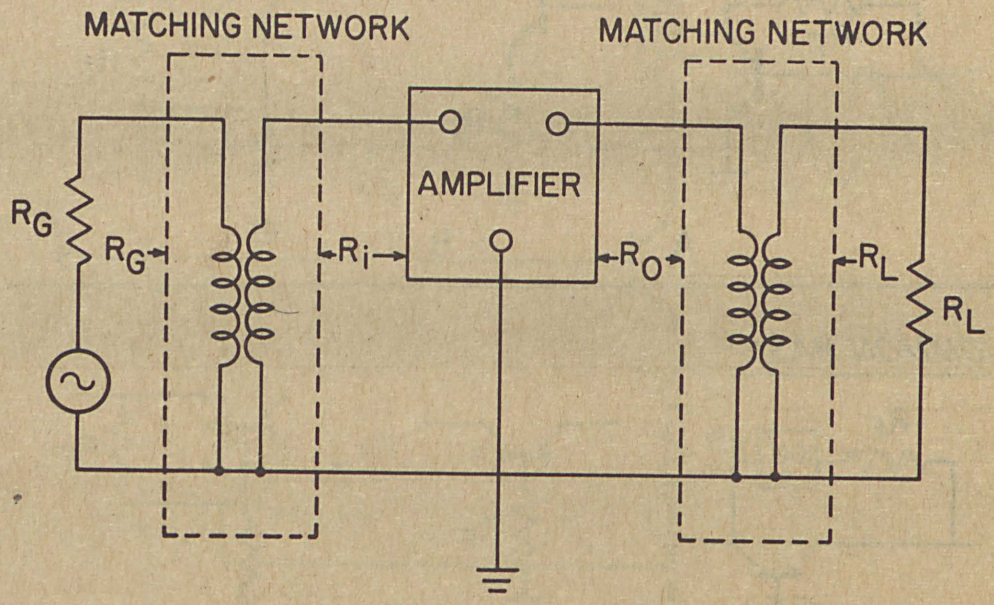


Figure 3. Matched Case

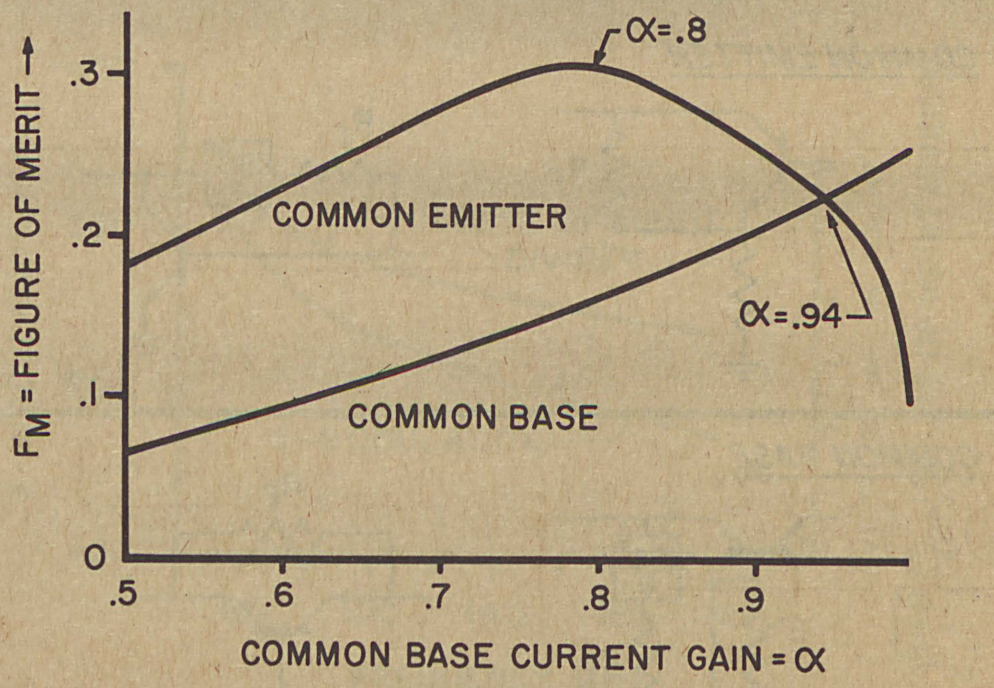


Figure 4. Figure of Merit Vs Current Gain

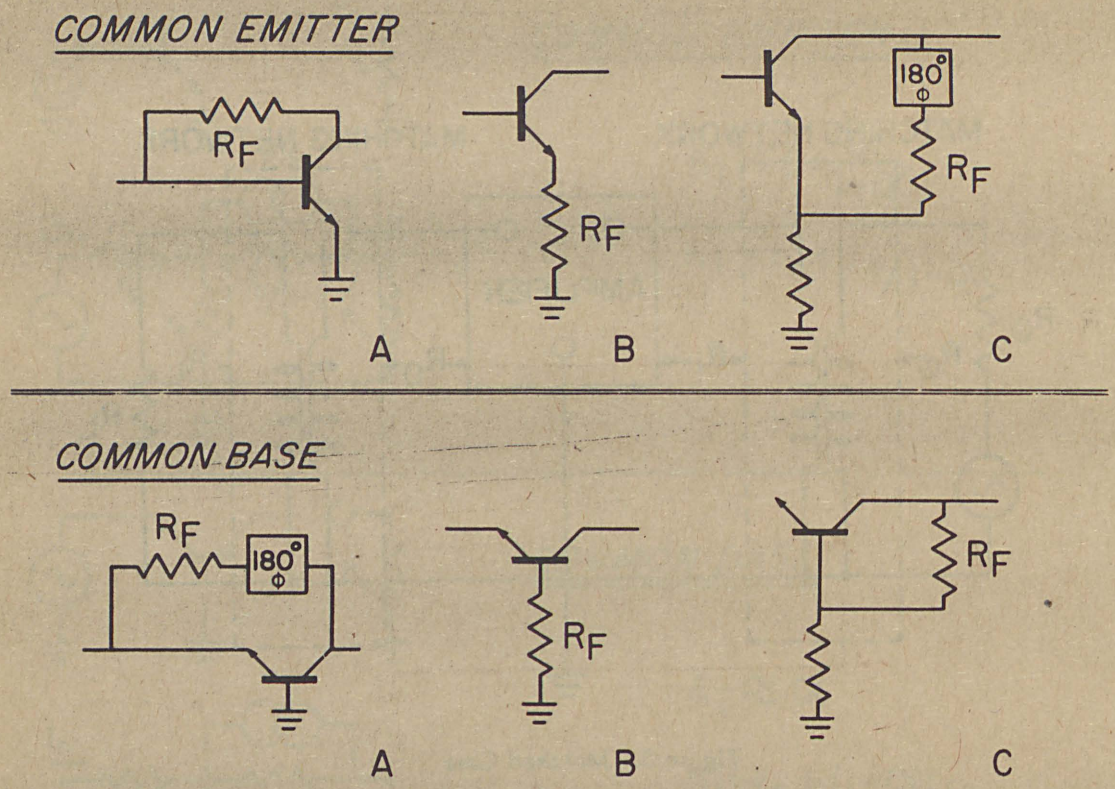


Figure 5. Types of Degenerative Feedback

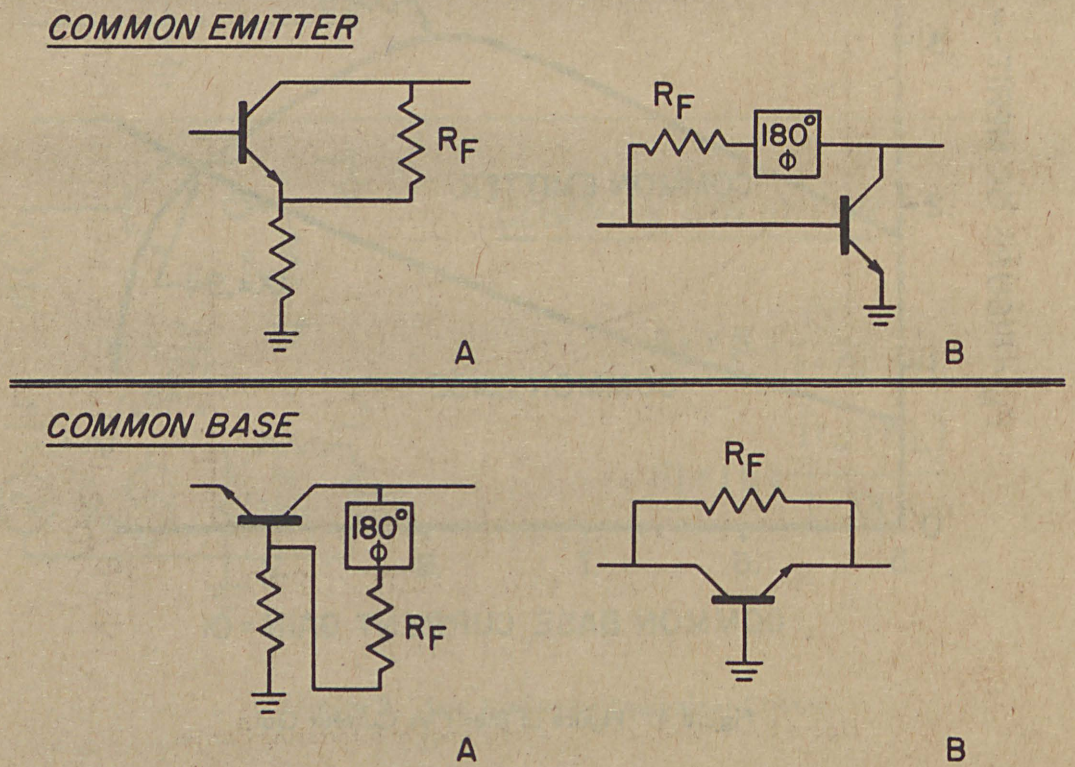


Figure 6. Types of Regenerative Feedback

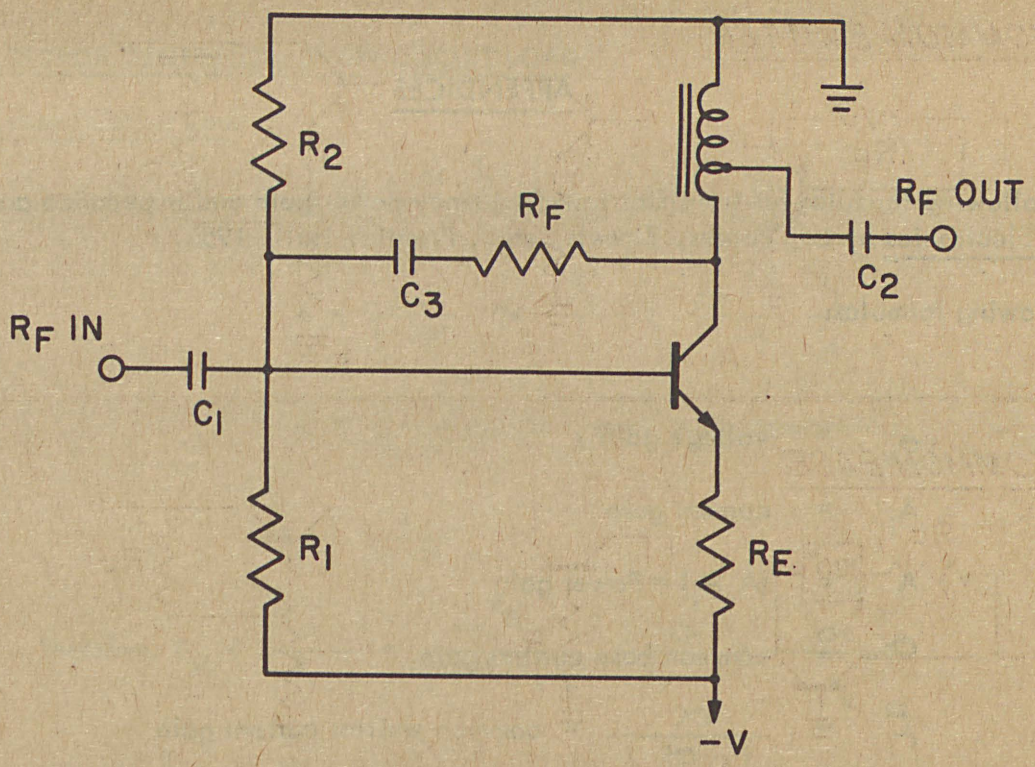


Figure 7. Broadband Amplifier

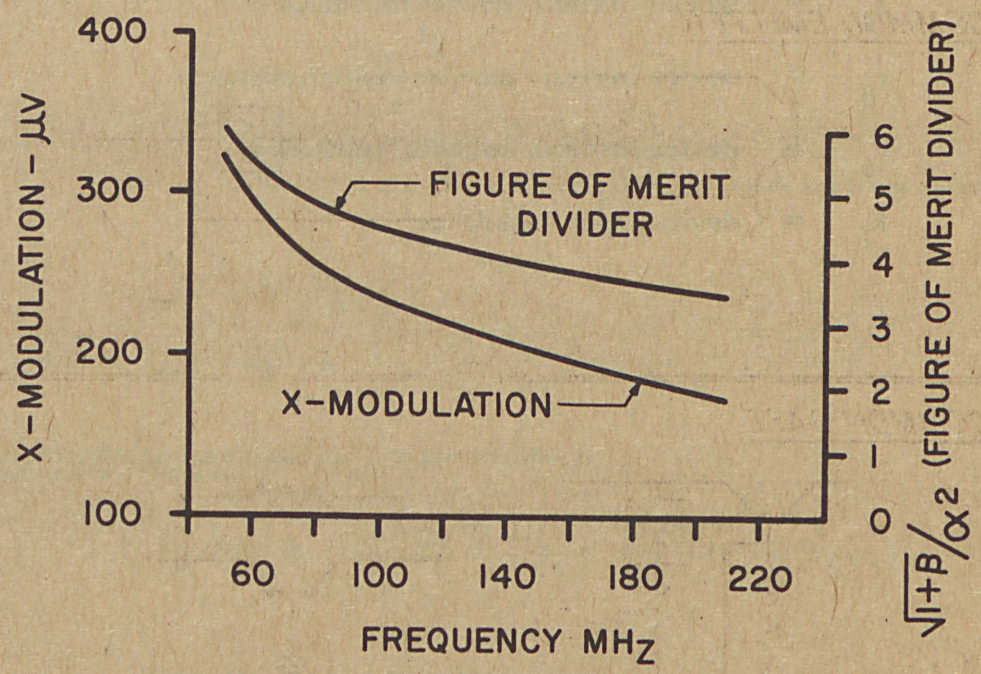


Figure 8. X-Modulation Vs Frequency of Interfering Carrier

APPENDICES

The following formulas for transistor low-frequency power gain and impedance are from Transistor Electronics by Lo, Endres, Zawels, etc., Prentice Hall, 1953.

In the following formulas:

A_v = voltage gain

A_i = current gain

A = $(A_v A_i)$ = Power gain

α = common base current gain

β = $\frac{\alpha}{1 - \alpha}$ = common emitter current gain

R_L = load impedance

r_e = device intrinsic emitter resistance

r_b = device intrinsic base spreading resistance

r_c = device intrinsic collector resistance

R_i = device input impedance

APPENDIX I

VOLTAGE GENERATOR, SHORT CIRCUIT LOAD

Common Emitter Case

$$A_v = \frac{\alpha R_L}{r_e} \; ; \; A_i = \beta = \frac{\alpha}{1-\alpha}$$

$$A = \frac{\alpha}{1-\alpha} \cdot \alpha \cdot \frac{R_L}{r_e} = \frac{\alpha^2}{1-\alpha} \cdot \frac{R_L}{r_e}$$

$$R_i = r_b + \frac{r_e}{1-\alpha} \; ; \text{ For } r_b \text{ made small compared to } r_e/1-\alpha$$

$$R_i = \frac{r_e}{1-\alpha}$$

$$\text{Therefore, } F_M = \frac{A}{R_i} = \frac{\alpha^2 R_L}{(1-\alpha) r_e} \cdot \frac{1-\alpha}{r_e} = \frac{\alpha^2 R_L}{r_e^2}$$

Common Base Case

$$A_v = \frac{\alpha R_L}{r_e}; \; A_i = \alpha$$

$$A = \frac{\alpha^2 R_L}{r_e}$$

$$R_i = r_e + (1-\alpha) r_b \; ; \text{ For } r_b (1-\alpha) \text{ made small compared to } r_e$$

$$R_i = r_e$$

$$\text{Therefore, } F_M = \frac{A}{R_i} = \frac{\alpha^2 R_L}{r_e} \cdot \frac{1}{r_e} = \frac{\alpha^2 R_L}{r_e}$$

Common Collector Case (Equation 7 of previous text)

$$F_M = A \cdot R_i \cdot \frac{(1-\alpha)2}{r_e^2} \; ; \; A_v = \frac{\alpha R_L}{R_L + r_e + r_b (1-\alpha)} \; ;$$

For $r_b (1-\alpha)$ made small compared to r_e

$$A_v = \frac{\alpha R_L}{R_L + r_e} \quad ; \quad A_i = \frac{\alpha}{1 - \alpha}$$

$$A = \frac{\alpha^2 R_L}{(1 - \alpha)(R_L + r_e)}$$

$$R_i = r_b(1-\alpha) + \frac{r_e + R_L}{1-\alpha} \quad ; \text{ For } r_b (1 - \alpha) \text{ made small campred to } r_e$$

$$R_i = \frac{r_e + R_L}{1 - \alpha}$$

$$F_M = \frac{A R_i (1 - \alpha)^2}{r_e^2} = \frac{\alpha^2 R_L}{(1 - \alpha)(R_L + r_e)} \cdot \frac{r_e + R_L}{1 - \alpha} \cdot \frac{(1 - \alpha)^2}{r_e^2}$$

$$F_M = \frac{\alpha^2 R_L}{r_e^2}$$

APPENDIX II

MATCHED INPUT AND MATCHED OUTPUT CASE

$$A = \frac{r_c \beta^2}{(1+\beta)(r_b + r_e)\left(1+\sqrt{\frac{r_b + (1-\beta) r_e}{r_b + r_e}}\right)^2} = \frac{r_c \beta^2}{(1+\beta)\left(\sqrt{r_b} + \sqrt{r_e} + \sqrt{(1+\beta) r_e}\right)^2}$$

For $r_b \ll r_e$ and $(1+\beta) r_e \gg r_e$

$$A = \frac{r_c \beta^2}{(1+\beta)^2 r_e} = \frac{\alpha^2 r_c}{r_e}$$

$$R_i = (r_b + r_e)\sqrt{\frac{r_b + (1+\beta) r_e}{r_b + r_e}} = \sqrt{r_b + r_e}\ \sqrt{(1+\beta) r_e + r_b}$$

For $r_b \ll r_e$

$$R_i = r_e \sqrt{1+\beta}$$

$$F_M = A/R_i = \frac{\alpha^2 r_c}{r_e^2 \sqrt{1+\beta}}$$

Common Base

$$A = \frac{r_c \alpha^2}{(r_b + r_e)\left(1+\sqrt{\frac{r_e + (1-\alpha) r_b}{r_b + r_e}}\right)^2} = \frac{r_c \alpha^2}{\left(\sqrt{r_b + r_e} + \sqrt{r_e + (1-\alpha) r_b}\right)^2}$$

For $r_b \ll r_e$

$$A = \frac{r_c \alpha^2}{4 r_e}$$

$$R_i = (r_b + r_e)\sqrt{\frac{r_e + (1-\alpha)r_b}{r_b + r_e}} = \left(\sqrt{r_b + r_e}\right)\sqrt{r_e + (1-\alpha)r_b}$$

For $r_b \ll r_e$

$$R_i = r_e$$

$$F_M = A/R_i = \frac{\alpha^2 r_c}{4 r_e^2}$$

LARRY F. ROESHOT

Abstract

The feasibility of fabricating miniature amplifiers within the outer sheath of coaxial cables is examined. The reliability of such a system is recognized as being very important since the amplifying sections are not readily accessible. Circuit considerations are reviewed and illustrations of present day amplifiers approaching the requirements are shown. A computer aided fabrication process is described along with some practical methods of providing bridging and customer taps in the CATV system.

Introduction

Over the past four years the advances in cable technology have reduced cable losses and improved uniformity to such an extent that the practical limit is nearly achieved. Turning to a different approach, VHF and UHF hybrid integrated circuits are proposed to be used as active elements housed in the cable to compensate for cable losses and approach the ideal "lossless transmission line."

The lossless transmission line (LTL) as described here would be supplied in continuous lengths of one mile or more. Access stations to house power and AGC equipment are spaced one to two miles apart. Fewer connectors simplify the field installation and results in less cable abuse and in few discontinuities. Since the hermetic seal is maintained the contamination possibilities are also reduced.

There are many instances where clusters of homes located a few miles from the rest of the system makes service impractical. Although cable costs are high, the system has the potential of lower overall costs to permit service to such remote areas. With the trend toward underground systems and the associated problems of pedestals, tunnels and access manholes, the LTL system is attractive.

Reliability

The effectiveness of the LTL system is largely dependent on the overall reliability of each amplifying section. The Bell Telephone Lab's transoceanic cable installed nearly 20 years ago operates with a reliability of one failure in 10^9 hours. Our space program is vivid proof of the high degree of reliability attainable in current microelectronic equipment. Computers used in the Apollo program containing 13,000 circuits, have been put on life tests by the Massachusetts Institute of Technology.[1] Over 33 million circuit hours have elapsed without a failure. The failure rate for present day integrated circuits and hybrid systems is .04 failures per 100,000 hours, or approximately 1

failure per 200 years. With 10 amplifying sections per mile of cable, a 20 mile system can expect about one failure per year. When a failure does occur the procedure is to simply replace the faulty LTL section.

For a conventional buried system using pedestal housings it has been estimated that installation costs for a mile of cable is $1,325.[2] This is equivalent to about 1/5 mile of faulty LTL replacement (or one full-time technician per 100 miles of plant). The reader is invited to compare this cost with the annual maintenance cost for 20 miles of an existing cable system.

Since the attainment of this high degree of reliability is costly, a sizable market is needed to warrant such a development program. The 2,000 existing cable systems growing at the rate of 25% annually, represent a market potential of more than 100,000 amplifiers per year (estimated: 20,000 miles/year).

High reliability is based on an analysis described by the Weibull Distribution theory. This proven theory states simply, that after an initial burn-in, or debugging period, the failure rate is constant. At the present state of the art. Amplifiers subjected to 100% mechanical, electrical, and temperature testing, and burned-in for about 200 hours can attain the required liability.

Amplifier Circuit Considerations

Coaxial amplifier enclosures for transistors are not new.[3] Early designs were developed for microwave use in an attempt to obtain gain closer to the theoretical cutoff frequency f_t. The design philosophy in using a miniature coaxial structure is an effort to maintain the radial fields set up in the coaxial cable. Tracing the signal path from the coaxial cable to the first active device in a conventional CATV amplifier reveals the discontinuities and extraneous circuit effects introduced. Additional circuit elements are then required to compensate for these effects as well. Coaxial amplifier design, installed in the cable as shown in Figure 1 along with miniature hybrid circuitry reduces the parasitic capacitance and inductance so that the theoretical transistor model is more nearly realized.

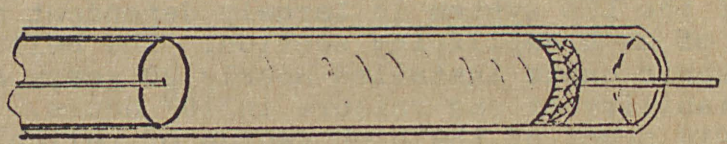


Figure 1. The coaxial amplifier showing compensation discs (to the right).

The approximate high frequency equivalent circuit of a bi-polar transistor is shown in Figure 2. The output power is dependent on the voltage developed across V_{BE}, hence follows a 6 dB per octave slope, i.e., a 12 dB gain difference between channels 2 and 13. (Figure 3.) With carefully designed test jigs in which the parasitics can be measured this theoretical gain can be measured. Cascading two stages gives 24 dB more gain at channel 2 than channel 13, and with cable attenuation additional amplifier slope is required. The simplest form of negative feedback emitter degeneration can trade gain for bandwidth with amplifier slope provided by the collector-to-base RLC network, as shown in Figure 4.

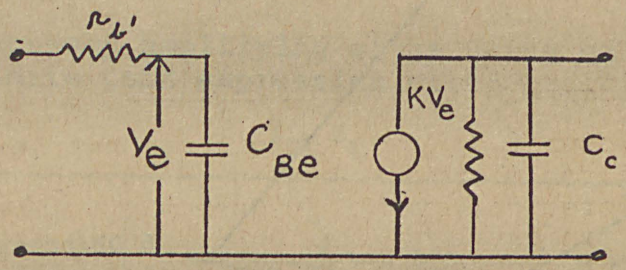


Figure 2. Approximate high frequency equivalent circuit.

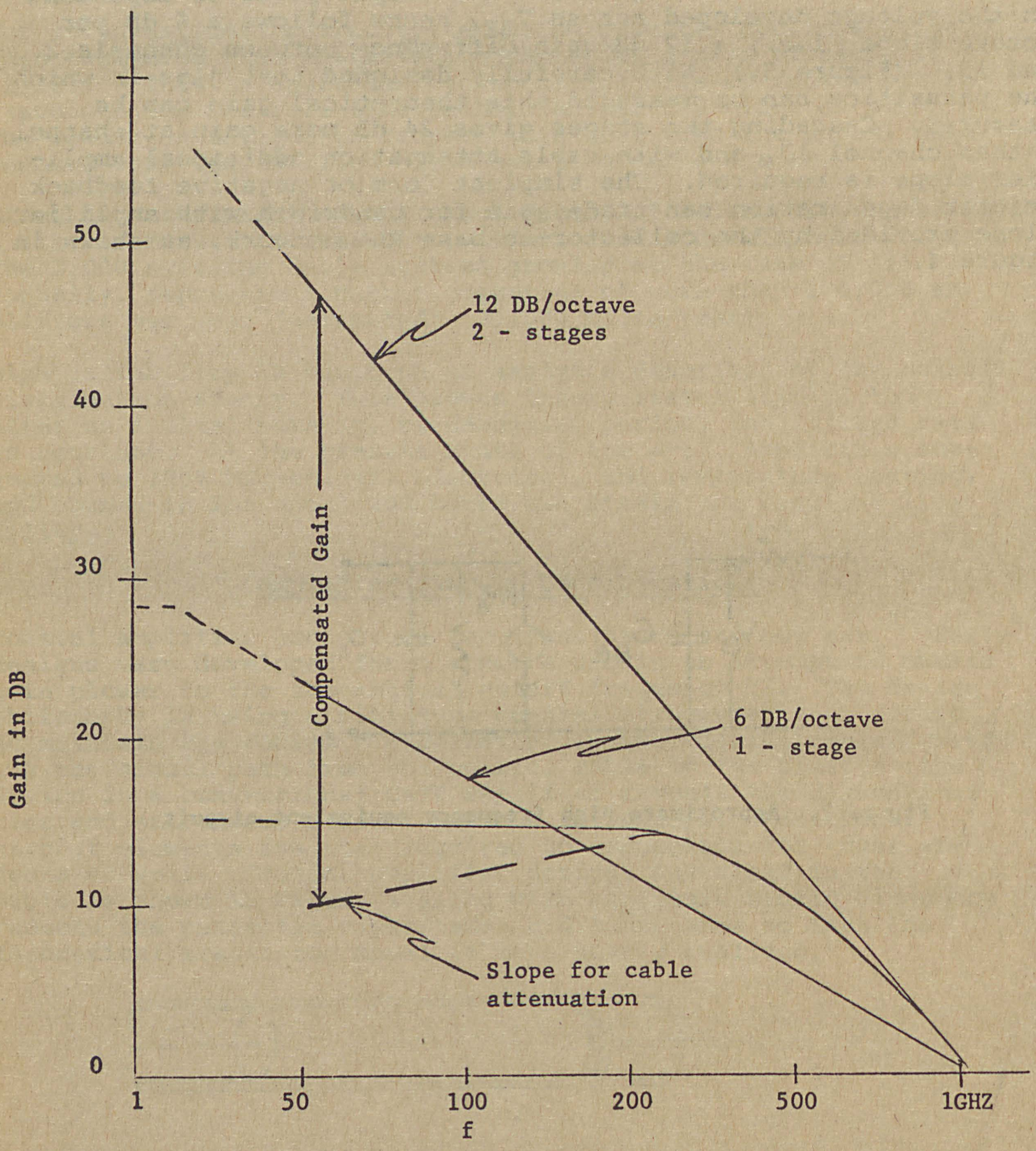


Figure 3. Gain response

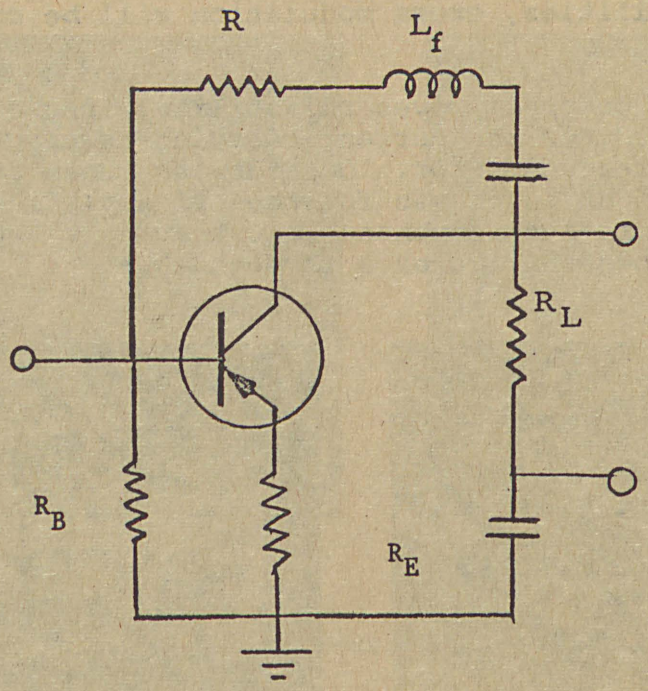


Figure 4. Emitter degeneration and collector-to-base feedback.

A high frequency amplifying stage using emitter degeneration has an approximate gain expression of:[4]

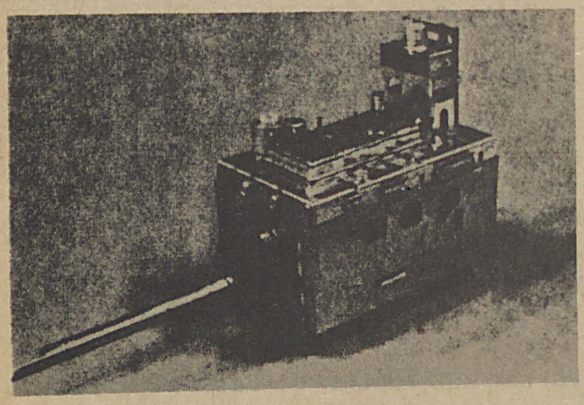
$$A(s) = \frac{Y_{21} Z_L}{1 + \frac{a_o g_m r_b}{B_o}\left[1 + \frac{SFB_o}{w_a}\right] + a_o g_m Z_e \left[1 + \frac{S}{a_o w_a}\right]}.$$

It is evident that using this expression for two stages along with the collector-to-base feedback represents an impractical approach for broadband CATV amplifier design. Expressions for other broadband circuit configurations are even more unyielding.[5]

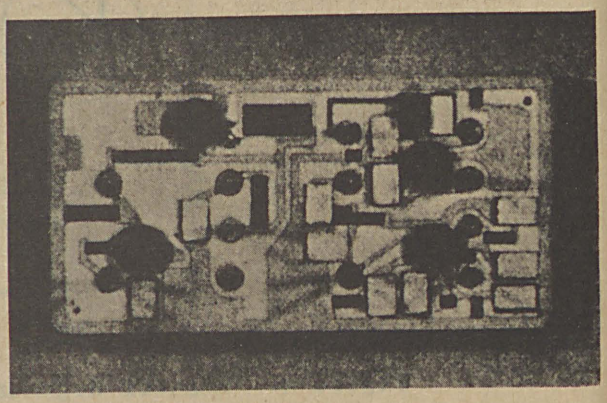
In considering the gain required for each amplifier in the LTL many of the practical constraints requiring present day CATV amplifiers to depart from the optimum value of 8.7 dB are removed. With less overall gain, the gain differential between channels 2 and 13 is easier to compensate, and with fewer circuit elements the reliability is improved. In addition the signal level at any point along the distribution line is within input level requirements of the TV receiver. The output power of the amplifiers need not be higher than those presently found in CATV amplifiers, and since the operating levels will be well below

the maximum capabilities, cross modulation will be correspondingly reduced.

Finally, low lias power improves reliability, increases amplifier efficiency, and reduces the current carrying requirements of the coaxial cable center conductor. Considering these factors a nominal gain of 15 dB is chosen for the LTL amplifier. Some miniature amplifiers and responses illustrating the present state of the art are shown in Figures 5 through 10.



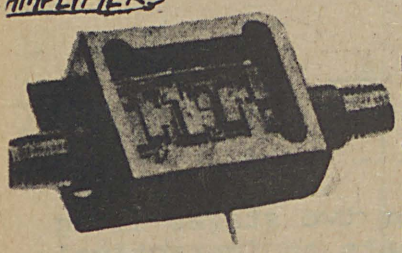
VHF TUNER WITH THICK FILM MODULE



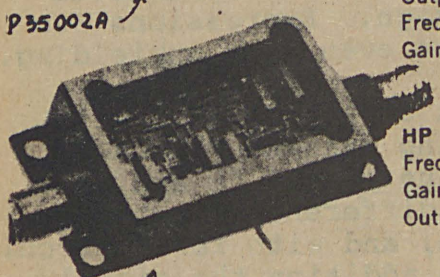
TOP VIEW SUBSTRATE ASSEMBLY

Figure 5. Oak Mfg. V.H.F. tuner with thick film module and substrate assembly.

AMPLIFIERS



P35002A



P35003A

HP 35005A (six-stage amplifier)

Frequency:	0.1–2 Gc
Gain:	40 dB ±3 dB
Output:	16 dBm at 1-dB gain compression

HP 35004A

Output:	0.01–1.3 Gc
Frequency:	25 dB ±2 dB
Gain:	16 dBm at 1-dB gain compression.

HP 35003A

Frequency:	0.01–400 Mc
Gain:	20 dB ±0.5 dB
Output:	23 dBm at 1-dB gain compression

HP 35002A

Frequency:	0.01–400 Mc
Gain:	20 dB ±0.5 dB
Output:	10 dBm at 1-dB gain compression

HP 35001A

Noise:	5 dB
Frequency:	0.1–100 Mc
Gain:	20 dB ±2 dB
Output:	20 dBm at 1-dB gain compression

HP 3500A

Frequency:	0.1–100 Mc
Gain:	30 dB ±1.5 dB
Output:	5 dBm at 1-dB gain compression

Figure 6. Chips are characterized before being placed in the circuit.

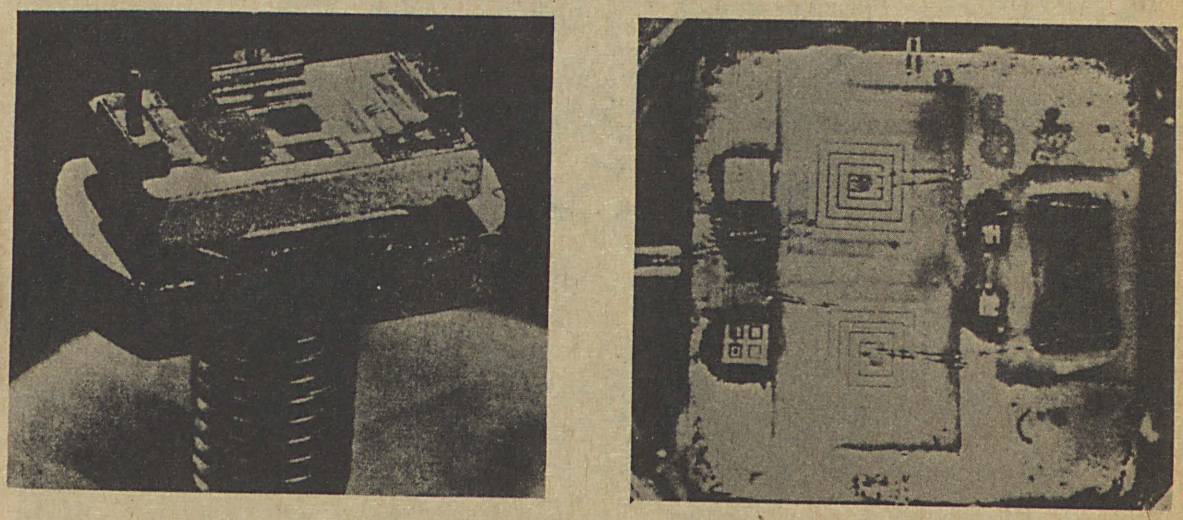


Figure 7. 7 Watt Power amplifier 265 to 400 MH_z. Size is about 1/2 inch square. (RCA)

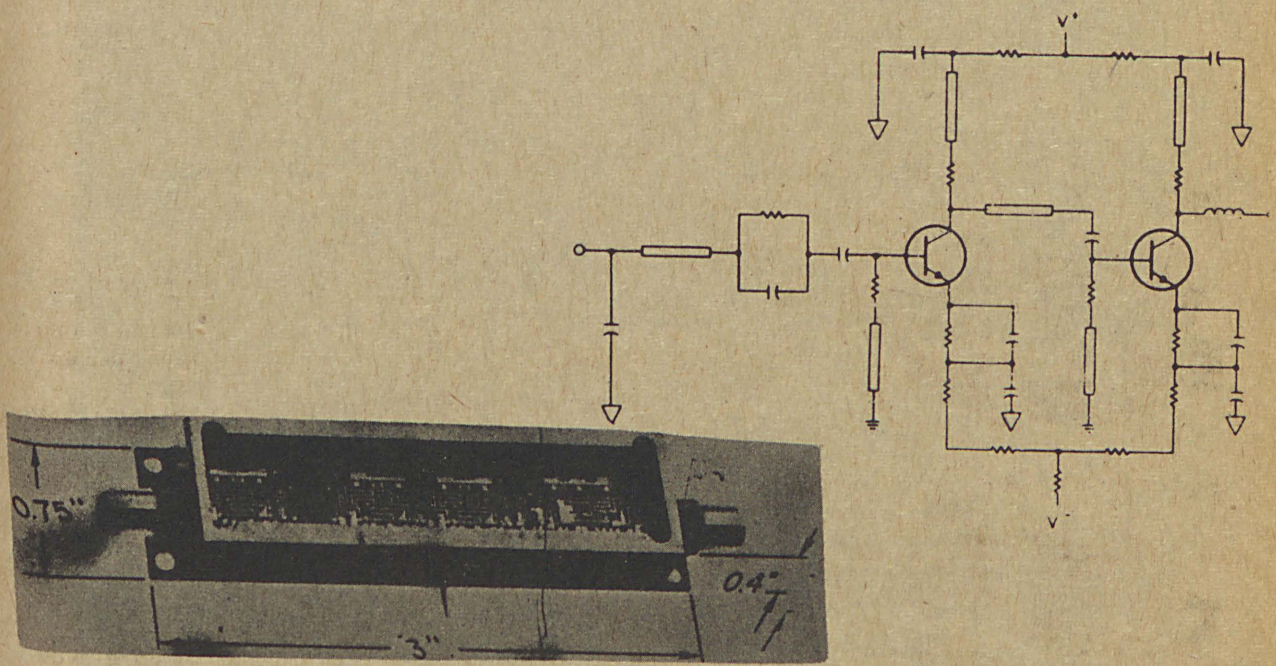


Figure 8. Computer designed T1 amplifier, Flat to 2 GH_z.

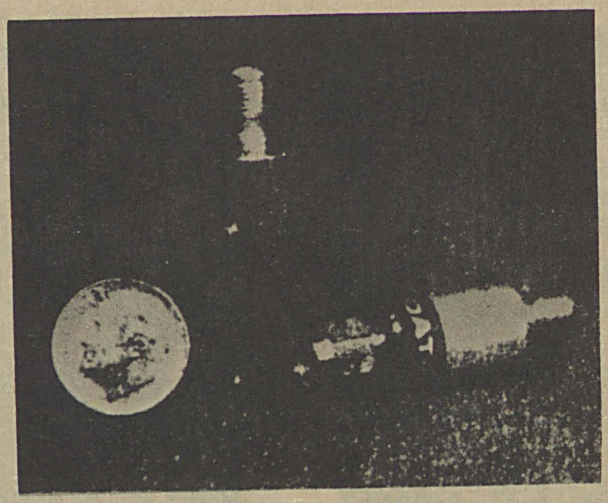
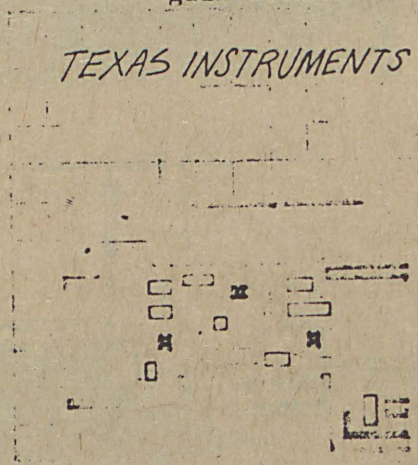
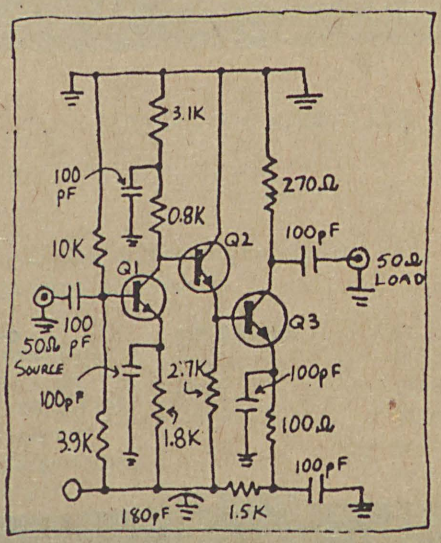


Figure 9. Coaxial Broadband Amplifier .18 DB gain from 50 to 850 MH_z. (Electro Data)

TEXAS INSTRUMENTS



MIC-035A VIDEO AMPLIFIER



• BANDWIDTH (3dB pts):	100-800 MHz
• 500 MHz POWER GAIN ($R_g = R_L = 50$ ohms):	22dB NOMINAL
• 500 MHz NOISE FIGURE ($R_g = 50$ ohms):	4 dB MAXIMUM
• OUTPUT IMPEDANCE @ 500 MHz:	50 ohms NOMINAL
• GAIN SLOPE (400-600 MHz:	<2 dB
• GAIN COMPRESSION @ 500 MHz	<0.5dB @ -30 dBm INPUT LEVEL
• OUTPUT VSWR:	1.5:1 MAXIMUM
• PACKAGE:	14 PIN 0.375 INCHES HERMETICALLY SEALED FLAT PACK

Figure 10. T1. Hybrid VHF-UHF Amplifier.

The Fabrication Technique

The amplifiers for the LTL are inserted periodically in the coaxial cable as shown. Using low loss cable such as Superior 6030A or AL 75-750J the LTL requires 5 amplifiers per mile. In fabricating the LTL extensive use if made of scattering matrices and a computer.

S parameters are a powerful tool in analyzing complex networks under actual circuit conditions.[8] The technique is used to measure the complete amplifier as a "black box" regardless of what is inside. All parasitic effects are included.

The amplifier is represented by the network as shown in Figure 11. a_1 and a_2 are the incident voltages, while b_1 and b_2 are reflected waves. From these variables simultaneous linear equations are written.

$$b_1 = s_{11}a_1 + s_{12}a_2$$

$$b_2 = s_{21}a_1 + s_{22}a_2$$

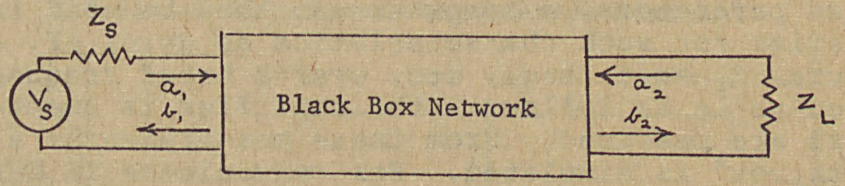


Figure 11. An amplifier as a "Black Box" showing incident and reflected waves.

The s-parameters are then:

$$s_{11} = \left.\frac{b_1}{a_1}\right|_{a_2 = 0} = \text{Input reflection coefficient with output matched.}$$

$$s_{22} = \left.\frac{b_2}{a_2}\right|_{a_1 = 0} = \text{Output reflection coefficient with input matched.}$$

$$s_{21} = \left.\frac{b_2}{a_1}\right|_{a_2 = 0} = \text{Forward gain with output matched.}$$

$$s_{12} = \left.\frac{b_1}{a_2}\right|_{a_1 = 0} = \text{Reverse gain with input matched.}$$

Stated in terms of power quantities:

$$\left|s_{11}\right|^2 = \frac{\text{Power reflected from the network input}}{\text{Power incident on the network input}}$$

$$\left|s_{22}\right|^2 = \frac{\text{Power reflected from the network output}}{\text{Power incident on the network output}}$$

$$\left|s_{21}\right|^2 = \frac{\text{Power delivered to a } Z_o \text{ load}}{\text{Power available from } Z_o \text{ source}}$$

$$= \text{Transducer power gain with } Z_o \text{ load and source}$$

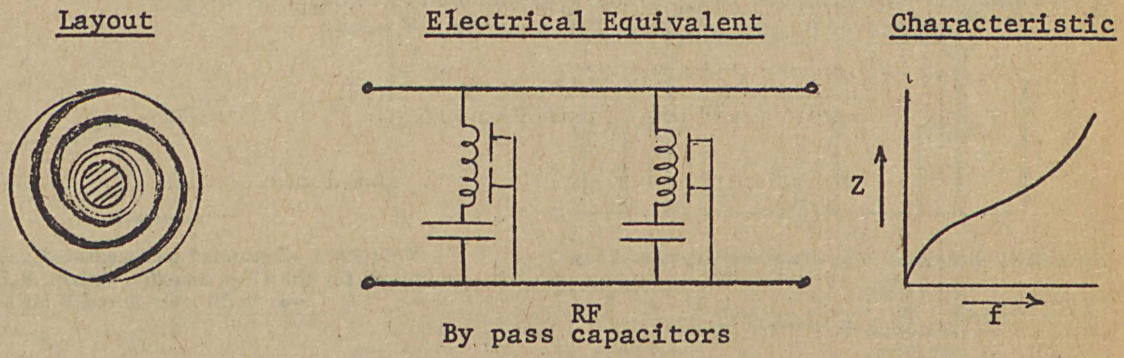
$$\left|s_{12}\right|^2 = \text{Reverse transducer power gain with } Z_o \text{ load and source.}$$

With these parameters, a computer can then be used in optimizing the amplifier for such characteristics as gain, NF, slope with temperature, dynamic range, etc. over a broad frequency range. The procedure is as follows: the amplifier is swept and the s parameters are measured. From these measurements, a model of the "black box" is simulated. For convenience in handling, it is then converted to a series of h, y, or ABCD parameters by the computer. The amplifier is now accurately represented by the selected parameters. This seemingly complicated procedure would take days if computed by hand. Once the computer conversion program is written, however, all except temperature tests can be made in a matter of minutes. All that remains to be done is to match the amplifier with its proper complement. Suppose the impedance of the cable was 72 ohms at 120 MHz and 78 ohms at 168 MHz. For maximum power transfer and minimum reflection a load would be required identical to the impedance at those frequencies. (Any reactances would have to be opposite for cancellation.)

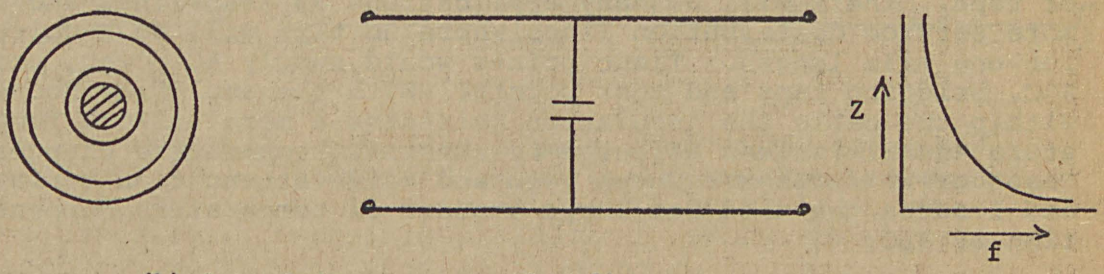
In a like manner, a cable having "suck-out" at a certain frequency could be compensated by an amplifier having a peak response at that same frequency. This gain complimenting process is similar to that used by CATV amplifier manufacturers[9] to obtain overall flat response.

The amplifiers to be installed in the cable are characterized and the information is stored in the computer memory. For amplifiers having a nominal 15 dB gain, about 1,000 feet of cable represents the "black box" and is characterized as previously mentioned. The computer searches its memory bank to find the amplifier best suited to optimize the combination of cable and amplifier section (perhaps one of ten categories). Another 1,000 feet of cable is added and the 2,000 feet LTL now becomes the "black box".

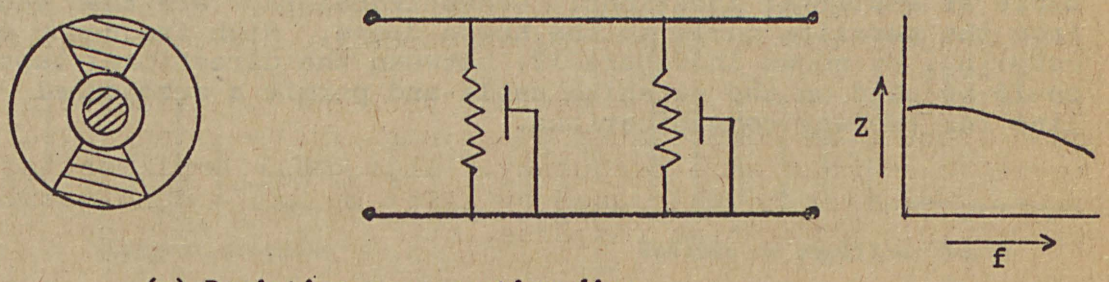
While the computer selection of the appropriate amplifier is being made, "compensation discs" as shown in Figure 12 may be added. These discs function as a distributed shunt elements and have the electrical equivalents as shown. While the line is being swept during the fabrication process, disc elements can be adjusted using abrasive techniques.



(a) Sprial inductance compensation disc



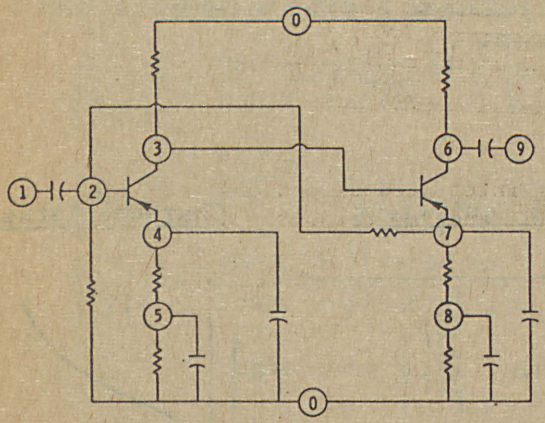
(b) Capacitive compensation disc



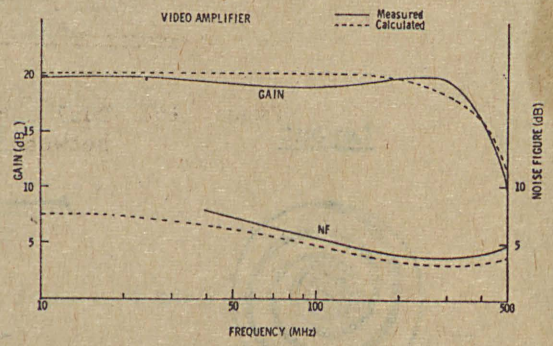
(c) Resistive compensation disc

Figure 12. Compensation discs showing the approximate electrical equivalent and impedance characteristic.

The broadband amplifier shown below and in Figure 14 has been designed by H. Cooke of Texas Instruments using a computer technique. The schematic shown is a rather simple resistance coupled circuit, but in reality, it is quite complex.



FIGURE/4—Schematic of a two-stage video amplifier.



FIGURE/5—Calculated and measured gain and noise figure for the video amplifier circuit. Reference gain was 20 dB from 10 to 500 MHz.

Since there is much advantage in maintaining a hermetic seal for the LTL, special consideration must be given for bridge output or taps. There will be many applications as trunklines and remote service distribution lines where no taps will be required for one mile length. These points would supply AC power, provide ALC, bridging taps and test points. With the amplifier housed within the cable the insulation maintains a more uniform temperature and it is less affected by external temperature changes. Deep burial further reduces gain and cable attenuation variations and lessens the need for large amounts of temperature compensation or ALC.

For cases where many taps are required, Figure 16 illustrates a possible solution--a dual cable. The hermetic seal of the main cable is unaffected. Directional couplers, feed the parasite cable at amplifier locations. Conventional taps are then made from the parasite cable to the house drops. High frequency decoupling, as shown in Figure 17, between the directional taps could be used on the parasite cable and permit a subchannel line for two-way communications.

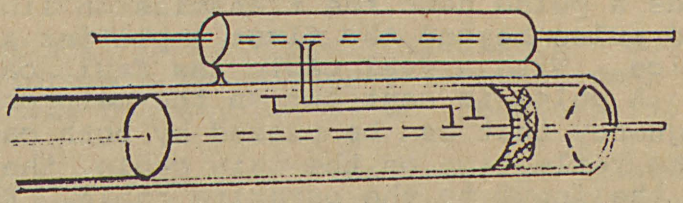


Figure 16. Dual cable showing integrated directional coupler between the main LTL and the parasite cable.

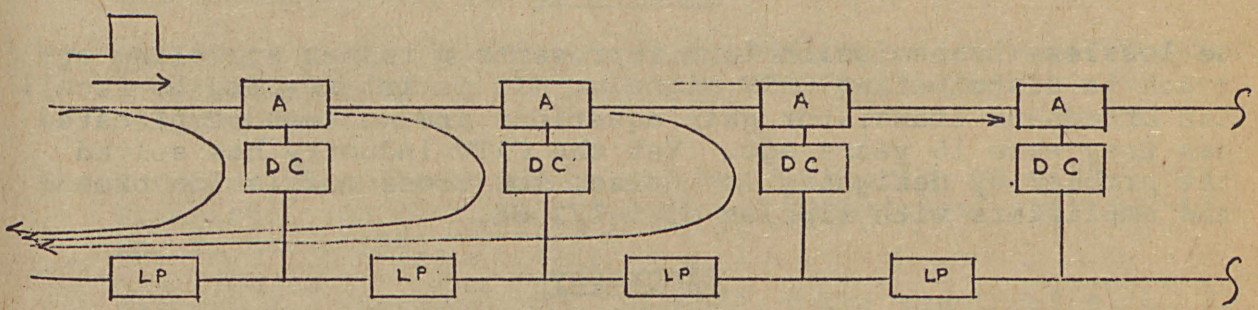
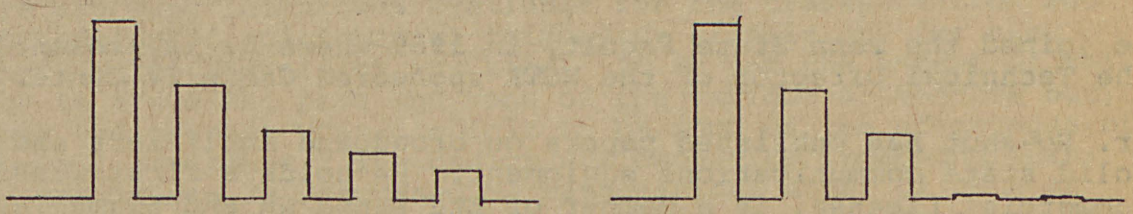


Figure 17. Fault location using a TDR. Pulses add in the parasite line only when an amplifier is operating.



Correct Response

Failure in amplifier No. 4

Figure 18. Pulse response. Different pack lengths cause pulse delays.

ɔcating a faulty amplifier within the LTL is accomplished by the
ɜe of a time domain reflectometer. In conventional usage, as
ıe TDR sends a pulse down the transmission line, there will be
ɔ reflected pulse beyond the first amplifier since it is a uni-
ıteral device. With a dual cable the fault can be determined
ɜ follows. A pulse is sent out on the main cable at some sub-
ıannel frequency that can be passed by both cables. Rather than
ɜasuring the reflection on the main cable, the pulse would be
ɔserved at the input to the parasite cable. For each pulse sent
ıt a composite of 5 pulses will be observed in decreasing magni-
ıdes, representing contributions from each of the 5 directional
ɔuples along the cable pair. When an amplifier fails no signal
ıll be passed between the cables beyond that point. The number
ɛ pulses displayed would simply indicate the number of active
mplifiers.

Conclusion

ıe lossless transmission line represents a rather startling ap-
roach to distributing CATV signals. It is interesting to recall
ıat broadband transistor gain equations are no less complicated
ıan they were 10 years ago. Yet the CATV industry has solved
ıat problem by designing low noise, low cross-modulation broad-
and amplifiers with ripples of ± 1/2 dB.

Biography

Larry Roeshot

r. Roeshot graduated from The Pennsylvania State University with
B.S. in Electrical Engineering in 1958. After working at
hilco and RCA he attended The University of Pennsylvania and
eturned to Penn State where he received his M.S. in Electrical
ngineering in 1960. Appropriately for CATV, his thesis topic
as "Broadband Transistor Distributed Amplifiers." He worked at
RB-Singer, Inc. in State College, Pennsylvania as a staff en-
ineer and was Director of the R-f Laboratory.

e joined the Penn State Faculty in 1969 where he is presently
he Technical Director of the NCTA sponsored Cable TV Center.

r. Roeshot has published papers on broadband amplifiers and
olid state communications equipment. He holds a First Class
ommercial License, is a member of Eta Kappa Nu and Sigma Tau,
registered Professional Engineer in Pennsylvania and a CATV
:onsultant.

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WILLIAM H. LAMBERT

INTRODUCTION

There are many techniques available for the transportation and distribution of multichannel television signals or, for that matter, multicarriers of any kind. It is not the intent of this paper to argue the pros and cons of the various approaches but, rather, to present what are felt to be some of the advantages of push-pull equipment. The design philosophy of broadband push-pull amplifiers is discussed, a mathematical model of such an amplifier is derived and various manipulations performed on the model to determine the expected behavior of such an amplifier.

GENERAL

Techniques previously presented to the CATV industry for carrying multichannel television signals include the octave system,

plit-band system, push-pull system and the two-cable system. ome of the advantages of a system designed with push-pull equipent can be described as:

a. Full spectrum availability

b. Increased output capability

c. Low group delay distortion (advantage over split-band)

d. Two classes of service are readily available

e. Converter required only for premium service

hese are only some of the advantages of a system designed with ush-pull equipment. Perhaps the only disadvantage that could e attributed to a push-pull system would be the apparent complexity of the equipment design. However, if the problem areas re properly outlined at the outset of the equipment design effort, proper attention can then be given to detail such that a eliable and well designed equipment is readily attainable which ill yield the desired system performance.

FFECTS OF 2nd ORDER DISTORTION

econd order distortion in broadband push-pull amplifiers is not new thing. The distortion has always been there, and the beats nd 2nd harmonic components resulting from the 2nd order nonlinearity of the amplifier have always been with us. However, ntil the advent of mid-band channel usage this type of distortion has never been of any concern. When it becomes necessary o use parts of the spectrum that are not octavely related, it ecomes necessary to have low 2nd order distortion in the amplifiers.

o the question, "How does 2nd order distortion show up in a TV icture?", the answer is not simple. The degree to which the eat is objectionable is a function of many things. For instance, 2nd order beat that falls below the visual carrier is much ess objectionable than one that falls above the carrier but elow the aural subcarrier. Also, the actual frequency of the eat itself is a factor in that if the beat frequency is harmonically related to the horizontal line frequency, the beat pattern ill show up as vertical lines on the screen, the number of lines eing determined by the harmonic relation to the horizontal rate. f the interfering beat is an odd multiple of half the line rate, he beat loses itself in the interlace and is not visible. Any ombination in between will show up as diagonal lines.

HAT LEVEL OF 2nd ORDER DISTORTION

n order to design a system using push-pull amplifiers, a design imit on 2nd order distortion is needed. How much beat will a

viewer tolerate? In an attempt to answer this question, we have made many subjective tests. It was found that a 2nd order beat, generated from modulated carriers, that was down at least 60 dB was barely perceptible to most people. The most critical condition occurs when the picture includes a large area of constant tone, such as the background often seen on a typical panel show.

In performing the tests, channels 2, 13 and a carrier at 157.25 were passed thru amplifiers with channel 13 being observed on a color TV set. The sum beat of the video carriers in channels 2 and G falls into channel 13, 1.25 MHz above its video carrier. The example above is one of a sum beat with the three channels given. There are also other 2nd order distortion components; namely, difference beats, an example of which would be 13-G, the beat falling into channel 2 and 13-2, the beat falling into G. In the case of the difference beats into 2 and G, the interference is 1.25 MHz below video carrier. This will provide no visible distortion whatever.

Also present at the output of the amplifier was the 2nd harmonic of each of the above channels. These were not considered, in that, the 2nd harmonic is inherently 6 dB down from the sum and difference beats. [1] [2]

Many other conditions must be attached to any subjective testing. However, for sake of simplicity, suffice it to say, that as a result of subjective tests it was found that if the sum or difference beat, generated from CW carriers, delivered to the customer was in no case worse than -60 dB, the interference on the screen would not be perceptible to most people. It should, however, be pointed out that if the 2nd order distortion is allowed to increase by only 6 dB, the visible interference becomes quite objectionable. Except as noted, the carriers used in all the tests were modulated with normal video signals.

From these tests it was determined that a signal with a 2nd order beat of -60 dB (as generated from CW carriers) was the minimum that we wanted to deliver to customers.

HOW MUCH PUSH-PULL

Having ascertained that the worst 2nd order distortion that can be tolerated in the system is 60 dB down, the question of how much reduction of 2nd order by push-pull techniques is required in the various components of the system must be asked. In order to answer this question properly, it is necessary to know how the 2nd order "builds up" in a system of cascaded amplifiers.

From extensive tests performed in the field and in the Lab. it was determined that holding the second order beat in each trunk amplifier below -66 dB at an output of +50 dBmV, resulted in a trunk cascade in which the 2nd order distortion was worse than -66 dB at normal system operating levels. [3]

Similarly, the feeder amplifiers must also be designed with individual amplifier performance of -66 dB 2nd order distortion at their rated output. When this is done, any combination of trunk and feeder will provide 2nd order distortion to any tap in the system that is at least -60 dB down. It must be emphasized that the 2nd order build up in a short cascade (2 or 3 amplifiers, typically found on feeders) is such that if the 2nd order distortion of the distribution amplifiers is not at least -66 dB down at their rated output, it is impossible to deliver signals to the customer anywhere in the system with a 2nd order distortion specification of -60 dB.

In this way we arrive at a 2nd order performance requirement in each amplifier of -66 dB at +50 dBmV. The details of amplifier design follow per this requirement. Figure 1 illustrates the block diagram of an arrangement found adequate in this respect. Three stages are used, a single ended input amplifier followed by two stages in push-pull. The single ended stage has 7 dB of gain. The gain control and thermal compensation introduce 4 dB of loss and the push-pull stage provides 20 dB of gain. Thus, the entire amplifier has an operational gain of 23 dB.

Individual transistor stages of the type used in this amplifier generate beats below -55 dB at an output of +50 dBmV. The beat level relative to the output, is reduced 1 dB for each dB decrease in output. If the amplifier is designed as shown in Figure 1, this means that the first stage output level will be 16 dB below the amplifier output level. Thus, at +50 dBmV output, the 1st stage level is +34 dBmV and its second order distortion will be -71 dB. If proper care is taken in designing the push-pull stage, it is possible to achieve at least 20 dB of improvement due to push-pull. Then the 2nd order distortion of the push-pull section will be at least -75 dB at +50 dBmV output. Adding the 2nd order distortion of the push-pull stage and single ended stage will yield a worst case beat for the total amplifier that is no worse than -66 dB at +50 dBmV.

This shows how the desired second order performance is delivered by the circuit arrangement illustrated.

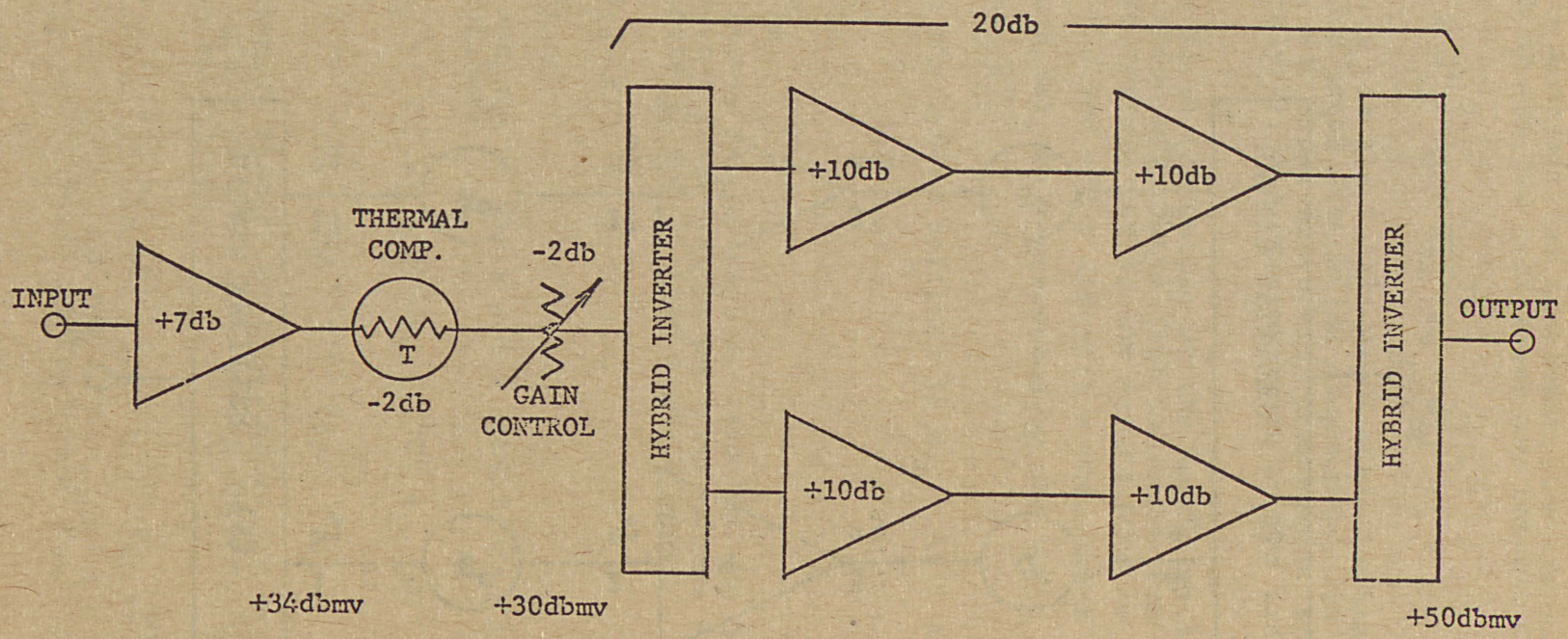
THE MATHEMATICS OF PUSH-PULL

I. Mathematical Model:

The object here is to derive a mathematical model for push-pull amplifiers so that the reduction of 2nd order distortion can be calculated. The push-pull amplifier performance is evaluated as a function of gain and phase balance. Figure 2 shows a block diagram of a possible configuration for a push-pull amplifier. The amplifier consists of two hybrid splitters (S), two phase inverters (ϕ & θ) and two amplifiers.

Figure 1

Block Diagram
SMM-P Amplifier



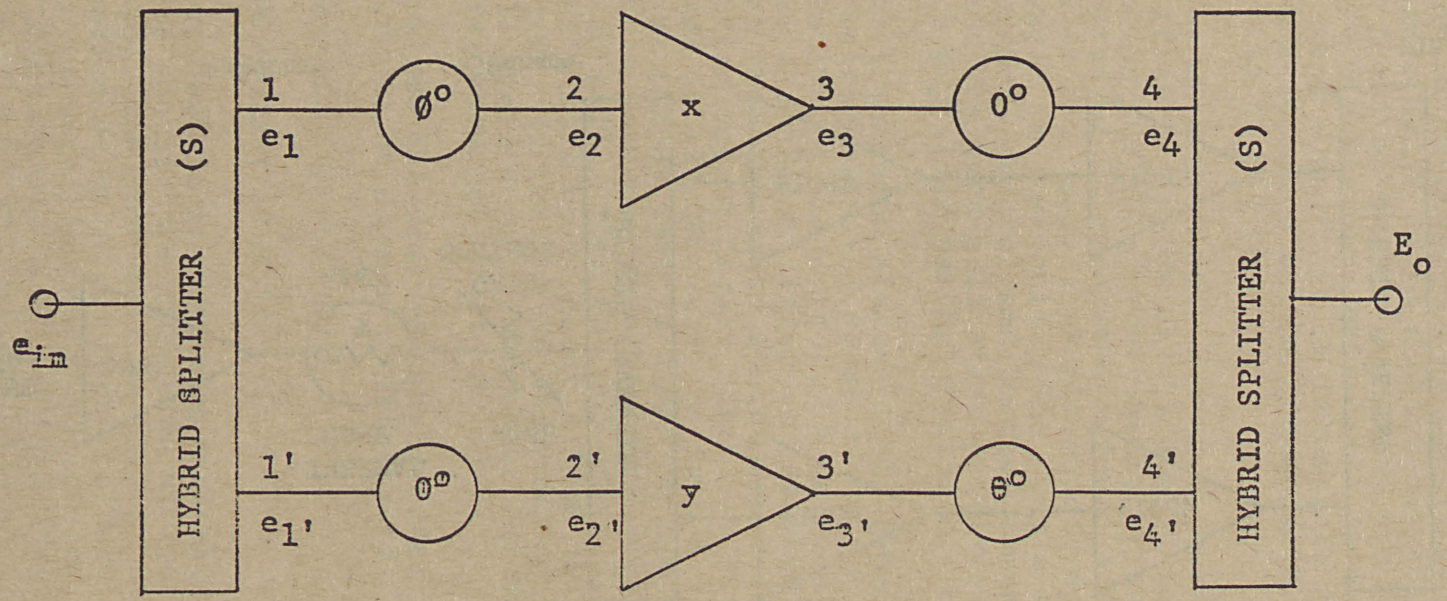


FIGURE 2

BLOCK DIAGRAM
PUSH-PULL AMPLIFIER

For purposes of this mathematical treatment, the transfer characteristics of each of the two amplifiers are described by the Taylor expansion.

$$e_o = e_{in}a_1 + \overline{e_{in}}^2 a_2 + \overline{e_{in}}^3 a_3 + \overline{e_{in}}^4 a_4 + \ldots$$

In this expression, e_o is the total output signal containing the fundamental, with 2nd order distortion components, 3rd order distortion components, 4th order distortion components, etc. For purposes of this analysis, all components above 3rd order will be ignored.

The fundamental signal at the output of the amplifier is $e_{in}a_1$. The 2nd order distortion components (2nd harmonic, sum beat and difference beat) are represented by the second term in the expression, $\overline{e_{in}}^2 a_2$; the 3rd order distortion components (compression, Xmod, triple beat and IM) are represented by the third term of the Taylor expansion, $\overline{e_{in}}^3 a_3$.

The input signal to the hybrid splitter is e_{in}. At 1 and 1' the signals are:

$$e_1 = .707\ e_{in}$$

$$e_{1'} = .707\ e_{in}$$

where the .707 represents the voltage division of the 3 dB splitter. The phase inverter reverses the polarity of one signal. At the amplifier inputs (2 and 2') the signals are:

$$e_2 = .707\ e_{in} \angle\phi$$

$$e_{2'} = .707\ e_{in}$$

The signals at the outputs of the x and y amplifiers (3 and 3') can be written as follows:

$$e_3 = .707\ e_{in} \angle\phi a_{1x} + (.707\ e_{in} \angle\phi)^2 a_2 + (.707\ e_{in} \angle\phi)^3 a_{3x}$$

$$e_{3'} = .707\ e_{in}a_{1y} + (.707\ e_{in})^2 a_{2y} + (.707\ e_{in})^3 a_{3y}$$

(As previously mentioned, distortion terms above 3rd order will be ignored.) The signals at the input to the summing hybrid inverter are written as follows:

$$e_4 = .707\ e_{in} \angle\phi a_{1x} + (.707\ e_{in} \angle\phi)^2 a_{2x} + (.707\ e_{in} \angle\phi)^3 a_{3x}$$

$$e_{4'} = .707\ e_{in} \angle\theta\ a_{1y} + (.707\ e_{in})^2 \angle\theta\ a_{2y} + (.707\ e_{in})^3 \angle\theta\ a_{3y}$$

The output of the push-pull amplifier is the sum of signals e_4 and $e_{4'}$ as processed by the hybrid splitter.

$$E_o = .707\ e_4 + .707\ e_{4'}$$

where the factor .707 accounts for the 3 dB splitter. As mentioned above, the amplifier output contains many components (the fundamental, 2nd order distortion components and 3rd order distortion components). This is written as:

$$E_o = e_{o1} + e_{o2} + e_{o3} + \ldots$$

The fundamental output of the amplifier e_{o1} is therefore:

$$e_{o1} = \overline{.707}^{2}\ e_{in}\ \underline{/\phi}\ a_{1x} + \overline{.707}^{2}\ e_{in}\ \underline{/\theta}\ a_{1y}$$

simplified

$$e_{o1} = .5\ e_{in}\ (a_{1x}\ \underline{/\phi} + a_{1y}\ \underline{/\theta})$$

The second order distortion component at the amplifier output is:

$$e_{o2} = \overline{.707}^{3}\ (e_{in}\ \underline{/\phi})^2\ a_{2x} + \overline{.707}^{3}\ (e_{in})^2\ \underline{/\theta}\ a_{2y}$$

or

$$e_{o2} = .354\ e_{in}^{2}\ (a_{2x}\ \underline{/2\phi} + a_{2y}\ \underline{/\theta})$$

The third order distortion component at the amplifier output is:

$$e_{o3} = \overline{.707}^{4}\ (e_{in}\ \underline{/\phi})^3\ a_{3x} + \overline{.707}^{4}\ e_{in}^{3}\ \underline{/\theta}\ a_{3y}$$

or

$$e_{o3} = .25\ e_{in}^{3}\ (a_{3x}\ \underline{/3\phi} + a_{3y}\ \underline{/\theta})$$

The total output of the amplifier is then seen to be:

$$E_o = e_{o1} + e_{o2} + e_{o3}$$

$$E_o = .5\ e_{in}\ (a_{1x}\ \underline{/\phi} + a_{1y}\ \underline{/\theta}) +$$
$$.354\ e_{in}^{2}\ (a_{2x}\ \underline{/2\phi} + a_{2y}\ \underline{/\theta}) +$$
$$.25\ e_{in}^{3}\ (a_{3x}\ \underline{/3\phi} + a_{3y}\ \underline{/\theta}) + \ldots.$$

1. Amplifier Gain

The gain of the push-pull amplifier is given as follows:

$$\text{Gain} = a_1 = \frac{e_{o1}}{e_{in}}$$

from above

$$e_{o1} = .5\, e_{in}\, (a_{1x} \angle\phi + a_{1y} \angle\theta)$$

therefore

$$a_1 = .5(a_{1x} \angle\phi + a_{1y} \angle\theta)$$

expressed in decibels

$$A_1 = 20 \text{ Log } a_1$$

$$= 20 \text{ Log } .5(a_{1x} \angle\phi + a_{1y} \angle\theta)$$

2. 2nd Order Distortion Component

The magnitude of the second order distortion is expressed as: (from above)

$$e_{o2} = .354\, e_{in}^{\,2}\, (a_{2x} \angle 2\phi + a_{2y} \angle\theta)$$

where a_{2x} and a_{2y} describe the second order curvature of the x and the y amplifier transfer characteristics respectively. For effective second order cancellation in a push-pull amplifier, it is necessary that a_{2x} and a_{2y} be nearly equal. This is one of many factors that determine the second order performance of the finished amplifier.

From the above expression, it can be seen that the phase balance of the two inverters also plays a part in determining the second order performance of the push-pull amplifier.

Mathematical expressions have been derived that describe the Gain and 2nd order distortion of a push-pull amplifier.

II. Effects of Gain and Phase Variation on Amplifier Gain

The Gain of the push-pull combination has been described as:

$$\text{Gain} = A_1 = 20 \text{ Log } .5(a_{1x} \angle\phi + a_{1y} \angle\theta)$$

rom this, it is seen that the Gain is a function of the gain of ach of the two individual amplifiers and the phase relationship f the input and output inverters.

o study the behavior of the push-pull amplifier gain as a func- ion of gain balance, a_{1x} Ø is arbitrarily assigned the value of 180°. That is, the "x" amplifier is unity gain (0 dB) and its hase inverter (Ø) is perfect with a value of 180°. The gain of y" amplifier a_{1y} is then varied by ±20 dB from unity gain, with also held constant at 180°.

he results of this exercise are shown in Figure 3. Note that ith Ø and Θ equal to 180° and the x and y amplifier gains nearly qual, the total gain varies only 0.5 dB for each 1 dB change in ndividual amplifier gain. The possibility of gain increase by n individual amplifier of 20 dB is not likely. However, note hat if one amplifier fails (y = -20 dB) the total amplifier ain will be reduced by 6 dB.

o study the Gain behavior of the push-pull amplifier as a func- ion of phase variation, the x and y amplifier gains were set qual to each other and Ø assigned the value of 180°. Θ was then aried from 180° to obtain a total amplifier gain reduction of dB. The results are shown in Figure 4. It can be seen that arge phase variations are required in order to degrade the total mplifier gain by 1 dB.

III. Effects of 2nd Order Balance and Phase Variation on The Total Amplifier:

1. Perfect Balance, Gain and Phase

he second order distortion component was expressed as:

$$e_{o2} = .354\ \overline{e_{in}^2}\ (a_{2x} \angle 2\emptyset + a_{2y} \angle \theta)$$

est performance of the push-pull amplifier is attained when $a_{2x} = a_{2y}$, $\Theta = \emptyset = 180°$. Under these conditions:

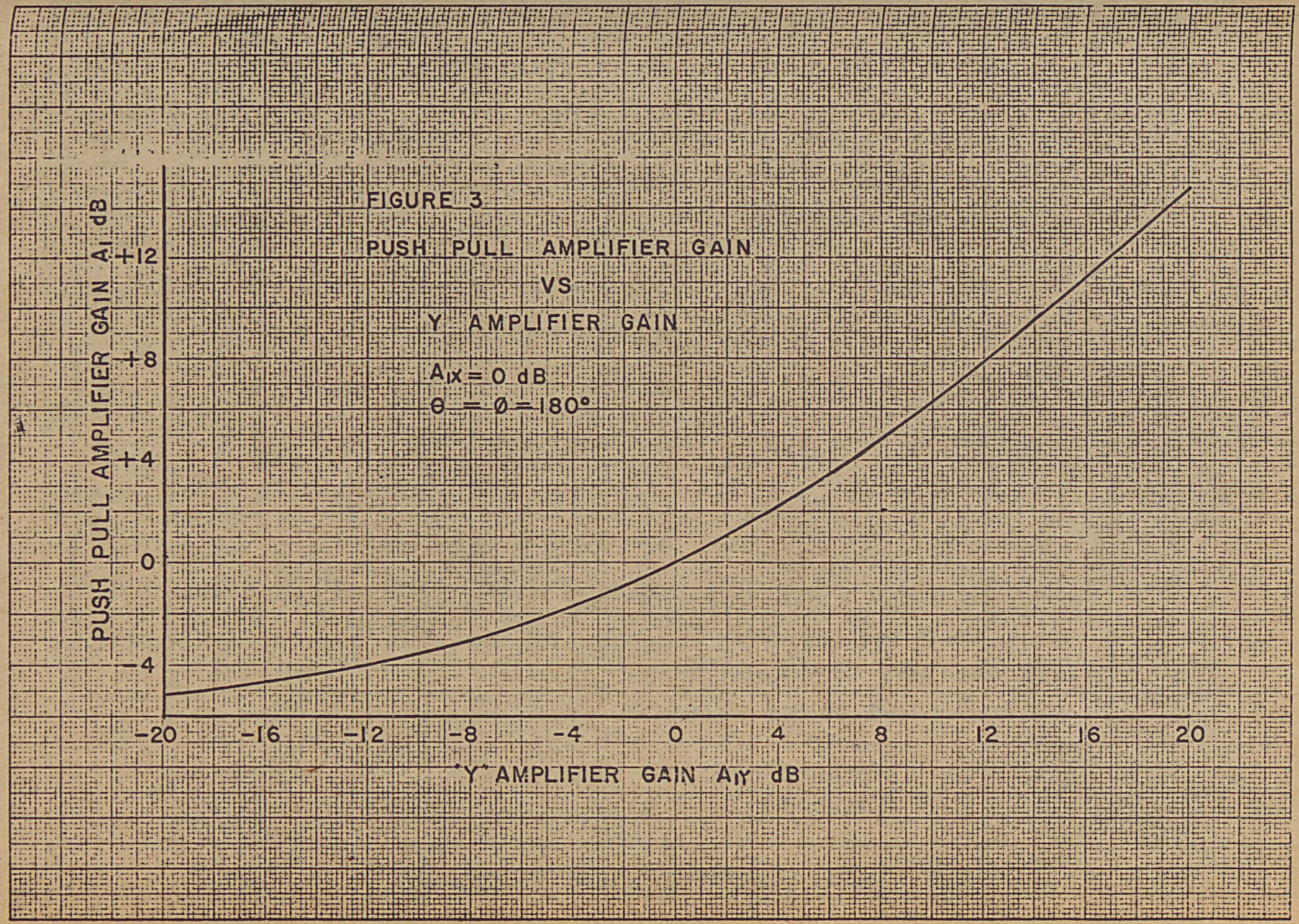
$$e_{o2} = .354\ \overline{e_{in}^2}\ (a_{2x} \angle 360° + a_{2y} \angle 180°)$$

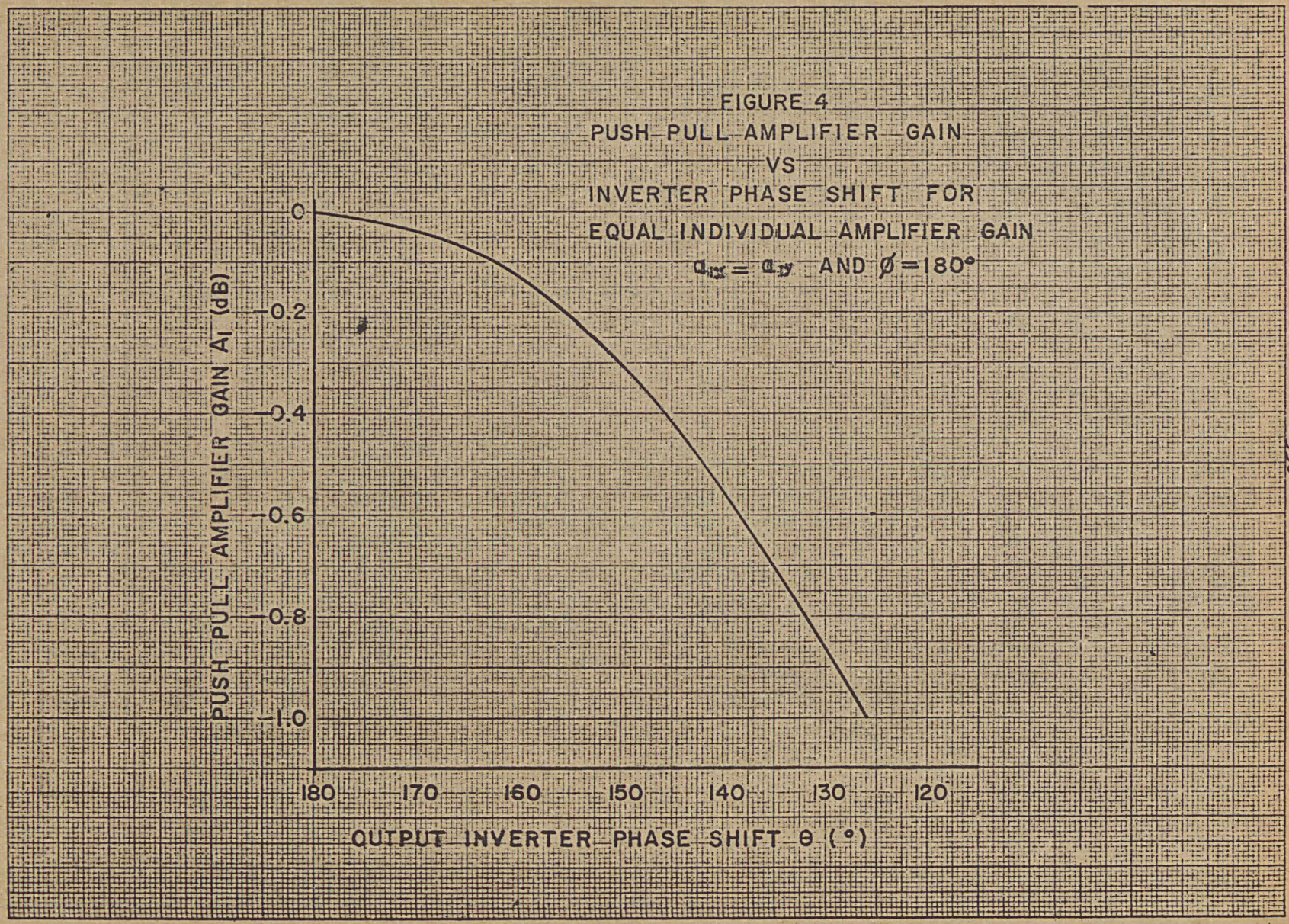
$$= .354\ \overline{e_{in}^2}\ (a_{2x} - a_{2y})$$

\ block diagram showing an ideal push-pull amplifier (perfect econd order cancellation) is shown in Figure 5.

2. Variations Due to 2nd Order Component Unbalance, Θ and Ø Constant

In order to study the behavior of a push-pull amplifier as a function of all the above mentioned variables, the following


FIGURE 3
PUSH PULL AMPLIFIER GAIN
VS
Y AMPLIFIER GAIN
A_{1X} = 0 dB
θ = Ø = 180°
PUSH PULL AMPLIFIER GAIN A1 dB
+12
+8
+4
0
-4
-20
-16
-12
-8
-4
0
4
8
12
16
20
"Y" AMPLIFIER GAIN A_{1Y} dB


FIGURE 4
PUSH-PULL AMPLIFIER GAIN
VS
INVERTER PHASE SHIFT FOR
EQUAL INDIVIDUAL AMPLIFIER GAIN
$a_x = a_y$ AND $\phi = 180°$
PUSH PULL AMPLIFIER GAIN A_I (dB)
0
-0.2
-0.4
-0.6
-0.8
-1.0
180
170
160
150
140
130
120
OUTPUT INVERTER PHASE SHIFT θ (°)

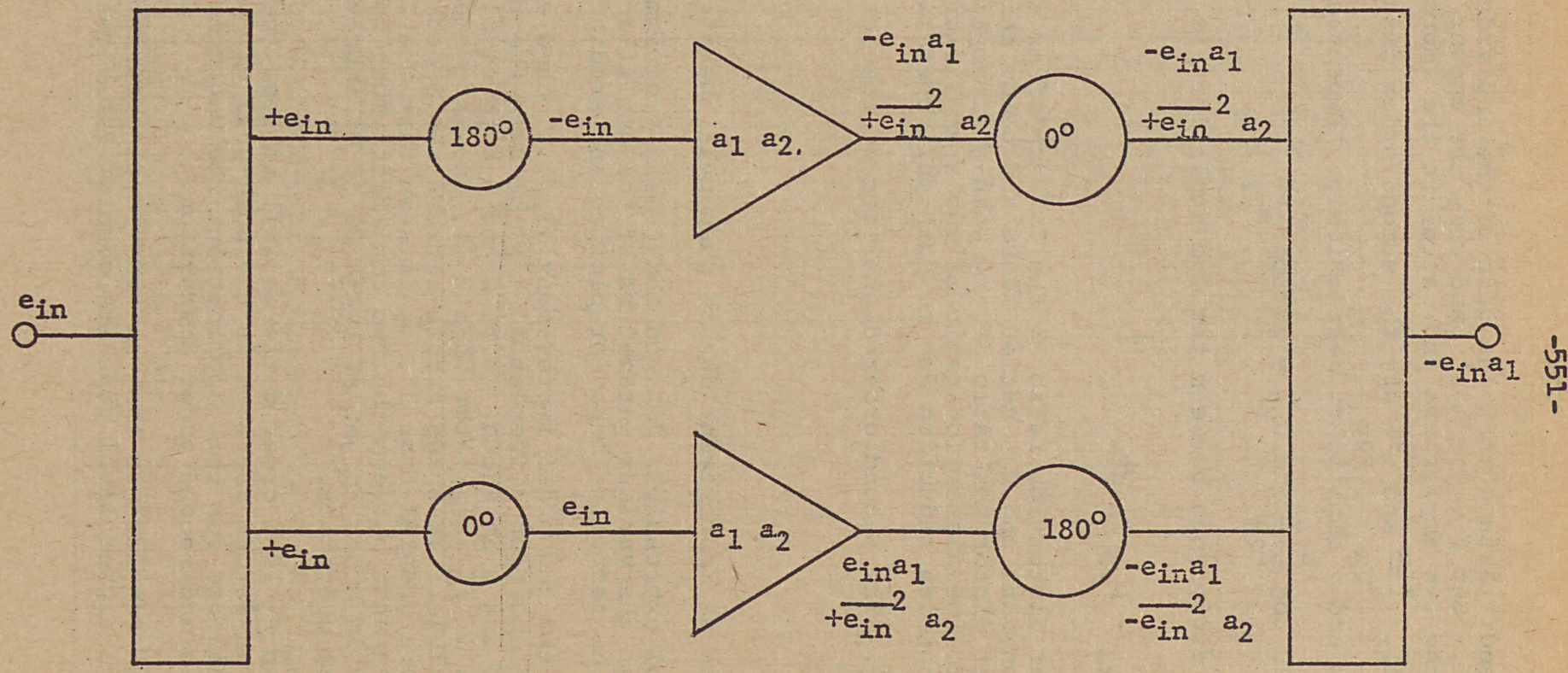


FIGURE 5

BLOCK DIAGRAM

PERFECT PUSH-PULL AMPLIFIER

procedure is used: Assume that the gain of the individual amplifiers are equal. Set $\emptyset = \theta = 180°$, and vary the amount of distortion in the two amplifiers and calculate the improvement due to push-pull. $\frac{a_{1x}}{a_{2x}}$ and $\frac{a_{1y}}{2_{2y}}$ are the second order distortion ratios of the x and y amplifiers respectively. Expressed in dB.

$$D_{x2} = 20 \text{ Log } \frac{a_{1x}}{a_{2x}} \text{ and } D_{y2} = 20 \text{ Log } \frac{a_{1y}}{a_{2y}}$$

The distortion difference between the two amplifiers is expressed as follows:

$$\triangle = D_{x2} - D_{y2} \text{ in dB.}$$

The second order distortion ratio of the "x" amplifier is arbitrarily held constant and D_{y2} varied above and below this value. The second order distortion ratio of the push-pull amplifier is then compared to the distortion ratio of the x amplifier for a measure of distortion reduction due to push-pull operation.

$D_2 = 20 \text{ Log } \frac{e_{o1}}{e_{o2}}$. The second order distortion of the total amplifier.

$$I_{pp} = D_2 - D_{x2}$$

where I_{pp} is the dB improvement due to push-pull operation.

The mathematical expressions derived above were programmed on a computer so that the various parameters of the amplifier could be varied and the resulting behavior plotted and studied.

Figure 6 shows the 2nd order improvement (I_{pp}) plotted against the 2nd order distortion differential ($\triangle$) between the two amplifiers with $\emptyset$ and θ as shown. With $\emptyset$ and θ both equal to 180°, it is seen that if $\triangle$ is greater than 2 dB, an improvement of 20 dB is impossible. If phase errors between the input and output inverters are greater than 5°, it is seen that the 2nd order distortion difference between the two amplifiers must be kept to under 1.5 dB in order to get at least 20 dB of improvement due to push-pull operation.

In order to keep $\triangle$ (2nd order differential) to less than 2 dB, matched pair transistors are used in the push-pull circuit. In selecting transistors for this application, the matching must be done for gain and second order distortion.

Gain matching is required so that an individual transistor does not operate at a higher level than its counterpart. Matching

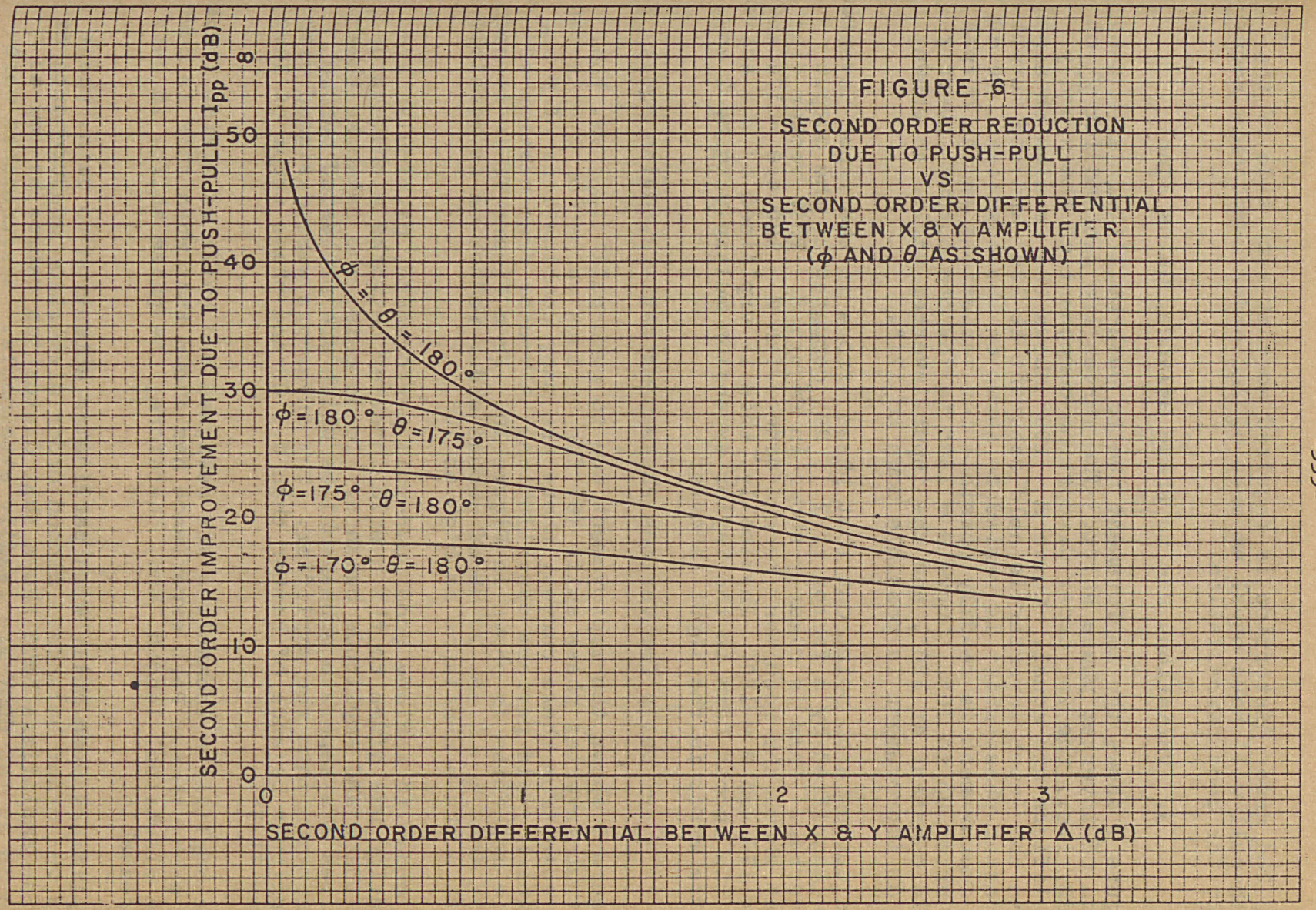


FIGURE 6

SECOND ORDER REDUCTION
DUE TO PUSH-PULL
VS
SECOND ORDER DIFFERENTIAL
BETWEEN X & Y AMPLIFIER
(ϕ AND θ AS SHOWN)

for 2nd order distortion is required so that each side of the push-pull will have equal amounts of 2nd order components necessary for good cancellation.

3. Variations Due to Phase Balance, Gains Equal

Figure 7 shows the improvement due to push-pull (I_{pp}) as a function of inverter phase shift. The curves are plotted for $\triangle$ of 0 dB; i.e., the 2nd order distortion component of the x and y amplifiers are equal. Curve $\phi = 180°$ shows the results obtained when the input inverter is held constant at 180° and the output inverter phase shift is varied as shown on the abscissa. 20 dB of improvement is readily possible for variations in the output inverter up to 10°. Curve $\theta = 180°$ is for the output inverter held constant at 180°, and the input inverter varied as shown. 20 dB improvement is possible down to 171°.

The curves also point out that phase errors in the input inverter are magnified by a factor of 2 (6 dB) compared to the output inverter. This is clearly shown in Figure 8. This vector diagram shows the resultant second order with $\phi = 180$ & $\theta = 170$ and $\phi = 170$ and $\theta = 180$. Physically, this is explained by the action of the second term in the Taylor expansion multiplying by 2 any phase error in the input inverter.

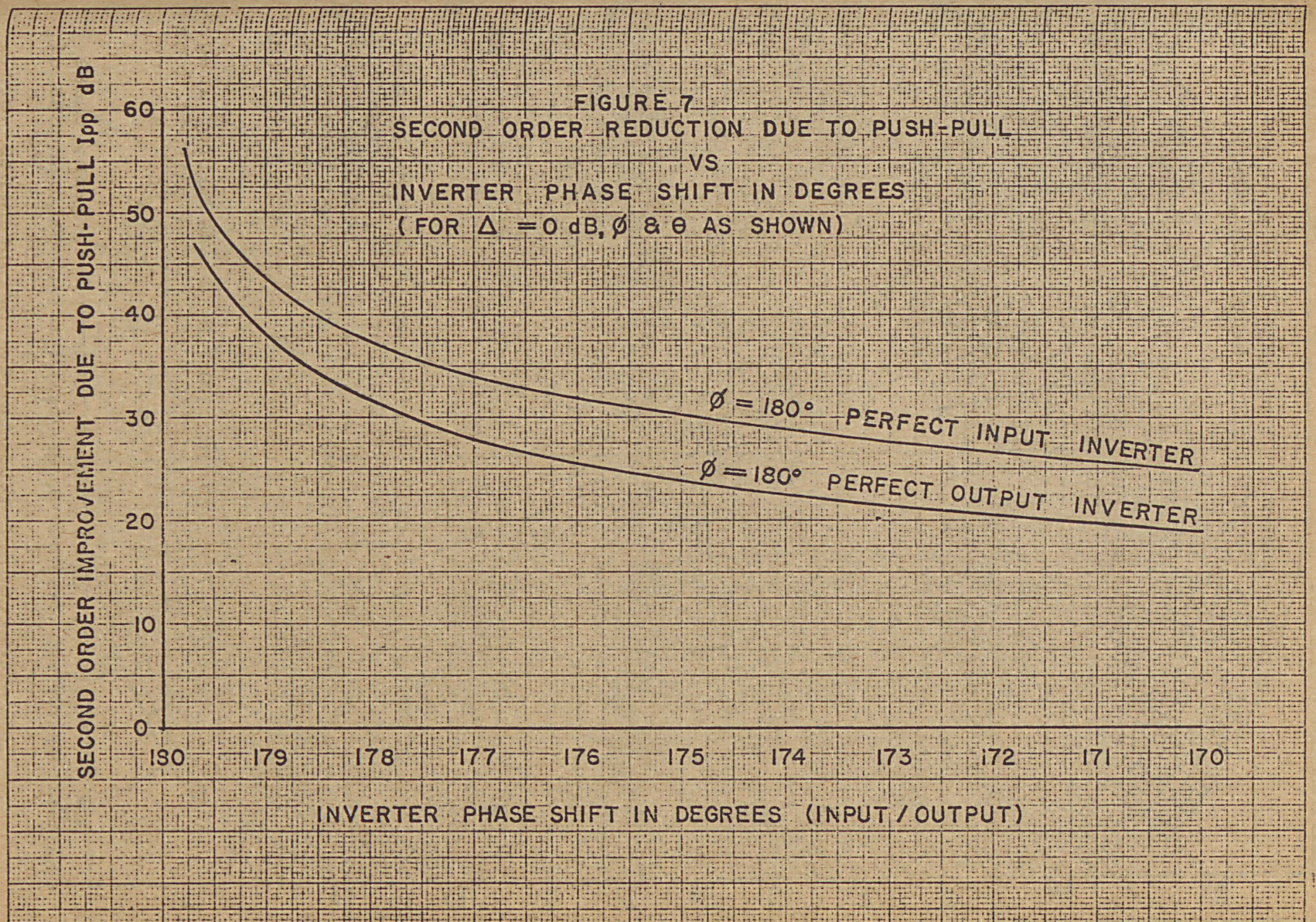
4. Nulls for Various Phase Combinations, Gains Equal

Figure 9 shows the improvement due to push-pull (I_{pp}) vs. the output inverter phase shift (θ) for various values of ϕ. As can be seen from these curves, there are many combinations of ϕ and θ which yield perfect cancellation. A vector presentation of this mechanism is shown in Figure 10. From Figure 9, it is seen that for $\triangle$ = 0 dB, 20 dB of second order reduction is possible with a phase unbalance as high as 10°.

In order to achieve good push-pull performance, particular attention was given to the hybrid inverter networks with regards to phase and amplitude balance. To do this, the networks themselves are separate subassemblies which are pretested before insertion into the amplifier. The inverters were designed with amplitude balance of better than 0.3 dB and phase error of less than $\pm 1.5°$.

The amplifiers themselves are designed and built as mirror images of each other. Past experience has shown that when this is done the electrical length, and, therefore, the phase shift, is very repeatable.

Amplifiers were built with particular attention to gain, phase and 2nd order balance. Second order distortion measurements of these amplifiers have shown that distortion ratios as low as -80 dB at +50 dBmV are readily attainable. Measurements were


FIGURE 7
SECOND ORDER REDUCTION DUE TO PUSH-PULL
VS
INVERTER PHASE SHIFT IN DEGREES
(FOR Δ = 0 dB, Ø & θ AS SHOWN)
SECOND ORDER IMPROVEMENT DUE TO PUSH-PULL Ipp dB
60
50
40
30
20
10
0
Ø = 180° PERFECT INPUT INVERTER
Ø = 180° PERFECT OUTPUT INVERTER
180
179
178
177
176
175
174
173
172
171
170
INVERTER PHASE SHIFT IN DEGREES (INPUT / OUTPUT)

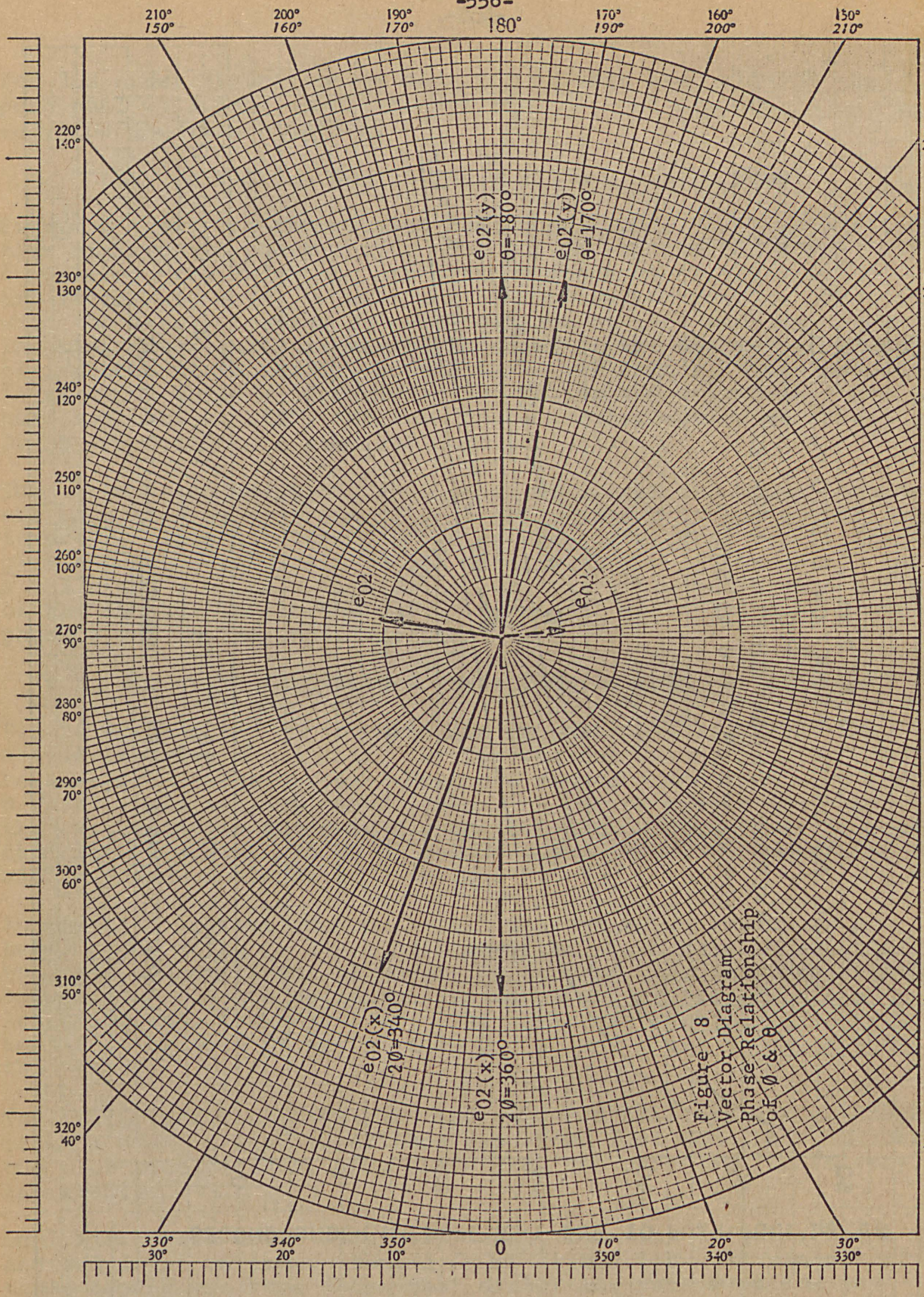


Figure 8
Vector Diagram
Phase Relationship
of Ø & θ

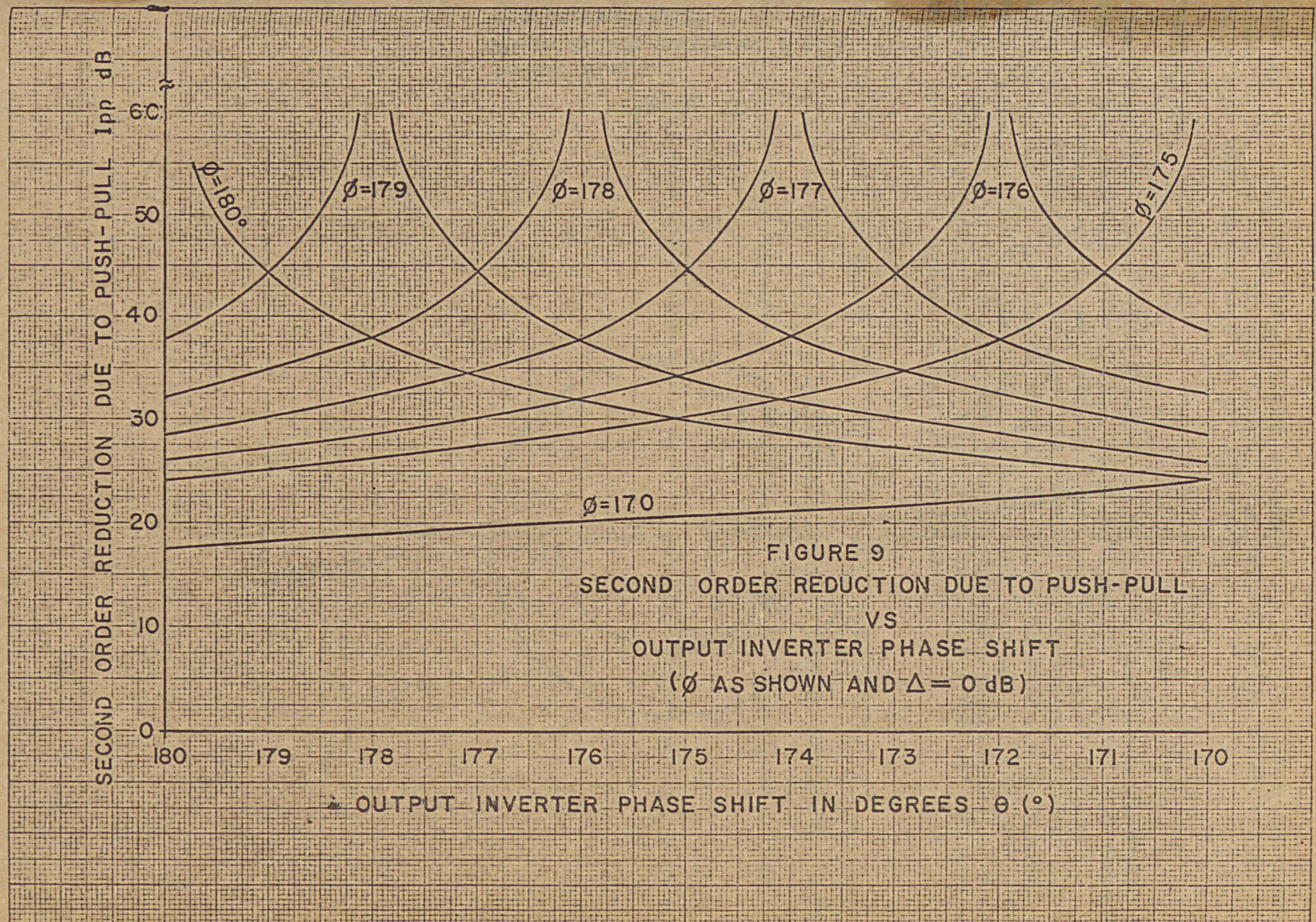


FIGURE 9
SECOND ORDER REDUCTION DUE TO PUSH-PULL
VS
OUTPUT INVERTER PHASE SHIFT
(Ø AS SHOWN AND Δ = 0 dB)

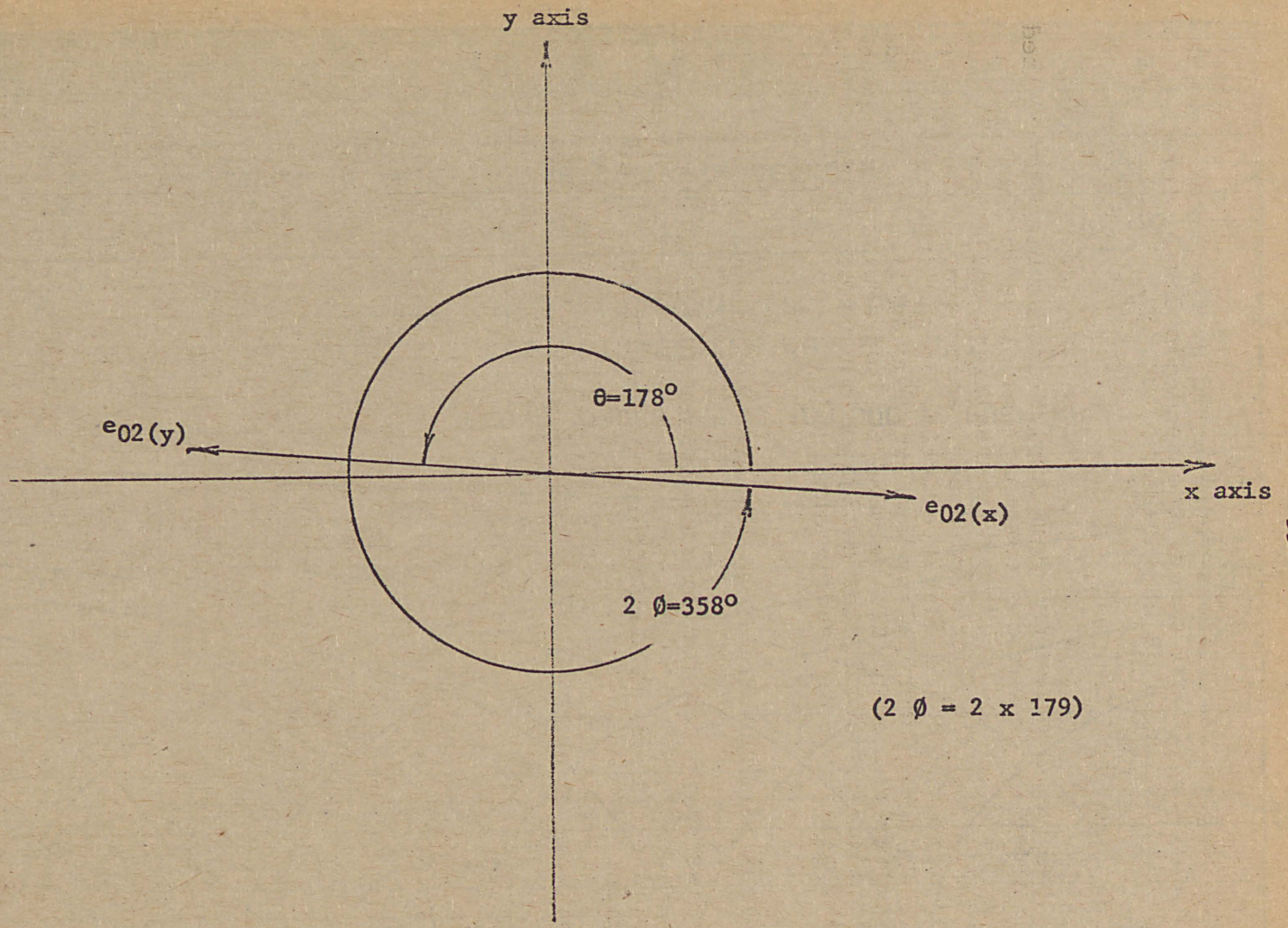


Figure 10

Vector Diagram
Phase Relationship of Ø & θ
For Cancellation

made on the complete amplifiers represented by the block diagram shown in Figure 1. In all cases, the second order distortion ratio was well below -66 dB at +50 dBmV.

CONCLUSIONS

A mathematical model of a Push-Pull Amplifier has been formulated and curves plotted for various combinations of variables. From these, it can readily be seen that to realize a well behaved broadband amplifier with good 2nd order performance, minute care must be given to the phase characteristics of the inverters and amplifiers, gain differential between the two amplifiers and 2nd order distortion differentials between the two amplifiers. With proper attention to detail, the design objective of -66 dB second order distortion ratio is readily attained.

[1] Technical Handbook for CATV Systems; Ken Simons.

[2] Transmission System for Communication; Staff, Bell Tel. Labs.

[3] Unpublished Paper; M. J. Jeffers, Jerrold Electronics Corporation.

TECHNICAL SESSION NO. 5:
CATV Antenna Design and Selection

Session Chairman:
Herbert Michels

Participants:
Albert K. Fowler
"Antenna Performance Data and Antenna Selection"

Mark H. Ronald
"Antenna Design, Using Scale Models"

ALBERT K. FOWLER

INTRODUCTION

The problem of selecting the proper type of antenna is a continuous one in an ever changing technology. The antenna is the heart of the system; and as such, every effort has to be made to assure the use of the proper antenna for a particular application. Past technology has been to select an antenna based on a manufacturer's advertised performance characteristics or on the general acceptability and reputation of the product. This is no longer a satisfactory method of antenna selection. Each antenna system requirement has to be considered in terms of its technical requirements. Each requirement should be analyzed and a logical selection process used to select the proper antenna. If a marketed product is not available to fill the need, an antenna may be designed to perform the needed function. The purpose of this paper is to discuss the performance characteristics of different antenna types so that the reader will be in a better position to evaluate and select the proper antenna for his particular requirements.

FACTORS GOVERNING ANTENNA SELECTION

Some of the more important ones are:

1. Performance
2. Environmental conditions
3. Economics
4. Political considerations
5. Appearance
6. Geographic considerations
7. Site location
8. Contractural requirements
9. Other business considerations

We concern ourselves in this paper only with antenna performance. We list some of the other considerations as it will be evident to the reader that performance may not always be the sole criterion for selection. However, the meeting of minimum performance standards is mandatory.

PERFORMANCE CRITERIA

The most significant electrical performance criteria are:

gain
directivity
bandwidth

Other related factors are:

VSWR
side lobes
back radiation
noise generation

The most significant mechanical performance criteria are:

wind load
ice load
mounting provisions
ease of assembly
packaging configurations

Other factors are:

temperature
humidity
shock and vibration
appearance (aesthetic qualities)

Antenna Types

Before discussing the performance criteria of the various antenna types, it will be useful at this point to review the different antenna types that we will discuss. Please refer to the enclosed chart (Chart No. 1). This lists different antenna types and some of their salient characteristics. For example, in referring to the different antenna types, you will note that the yagi is a narrow band, somewhat directive high gain antenna. The log periodic antenna is a broad band, somewhat directive intermediate gain antenna, etc. You can see by referring to the chart the various characteristics.

As seen from the above chart, we may set the antennas down in two very broad categories. The first being narrow band and the other being broad band. These two basic divisions are shown in Chart No. 2. Notice that in the above division, the parabola has the capability for narrow band or broad band operation depending upon the feed type used. Also, notice that we are talking about the parabola in a very broad sense to include all reflector type antennas.

Beam Characteristics

How do the various beam characteristics of the foregoing antenna types differ? Please refer to Chart No. 3. This chart shows the generalized beam shapes of the various antenna types. It must be recognized that these beam shapes will vary somewhat within a rather broad range depending upon the number of elements on the antenna, the aperture size of the antenna, or other factors. A definition of directivity is needed, and the chart sets about to define directivity of the various antenna

CHART 1

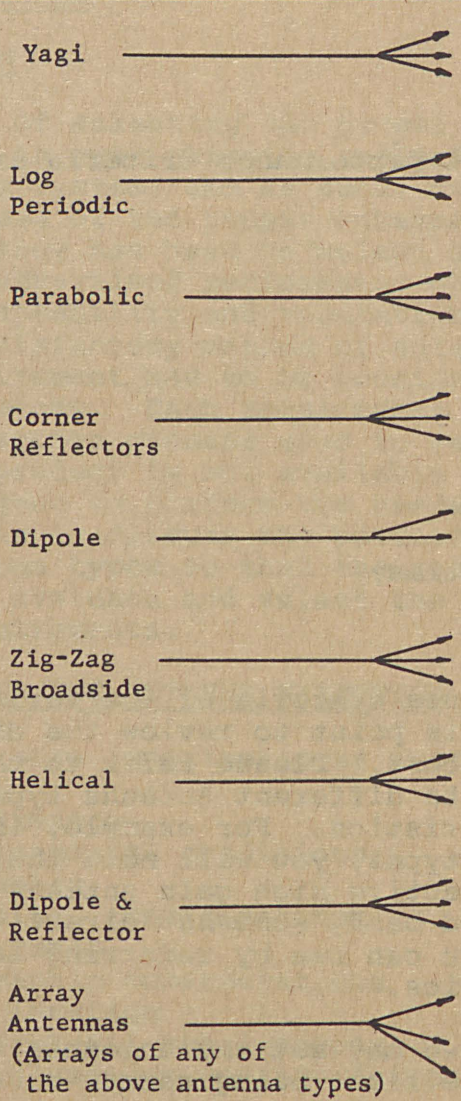


CHART 2

Narrow Band Antennas

Yagis
Dipole and Reflector
Corner Reflectors
Zig-Zag
Parabolas with Narrow Band Feeds

Broad Band

Log Periodic Antennas
Helical End Fire Antennas
Dipoles
Parabolas with Broad Band Feeds

CHART 3

PATTERN SHAPE	 1	 2	 3	 4	 5
DIRECTIVITY DESCRIPTION	Somewhat	Moderately	Very	Extremely	Ultra
BEAMWIDTH	50°-100°	30°-50°	15°-25°	Less than 15°	Less than 5°
ANTENNA TYPES FOR SPECIFIC PATTERNS	Yagis less than one wavelength long (generally up to 10-elements)	Yagis greater than one wavelength long (generally 10-elements or more)			
		Array of 2 yagis			
	Corner Reflector	Array of 2 corner reflectors			
	Zig-Zag	Array of 2 Zig Zags			
	Low Periodic Low Band	Log Periodic High Band			
	Log Periodic (All Band)	Array of 2 LP's (All Band)			
	Dipole & Reflector	Array of 2 Dipoles & Reflectors			
		Quad Array	4 Antenna Diamond Array	9 Antenna Diamond Array	
			Parabolas with apertures of 2 to 4 wavelengths	Parabolas with apertures greater than 4 wavelengths	Parabolas with apertures greater than 12 wavelengths

Arrays of 3 antennas in horizontal plane

Arrays of 4 or more antennas in horizontal plane

Arrays of 12 or more antennas in horizontal plane

types. Notice here that we have established definitions of directivity, and it is our hope that these can be used to an extent that they will become a common type descriptive term in our technology.

Comparison of Beam Characteristics

How do the above described generalized beam characteristics compare to actual measured antenna patterns of various antennas? I am going to show several slides of various antenna patterns taken on the R-F Systems, Inc. antenna test range. These antenna patterns cover just about every type of antenna I have described to you; therefore, it will be possible for you to see how these antenna patterns actually compare with our generalized types. You will notice in looking at these antenna patterns that some of them do have deficiencies in one way or another.

Such deficiencies are either caused by faulty quality control or may be due to poor design.

The patterns referenced are shown in the following pages of this paper, Figure 1 to 22.

One very important conclusion that can be drawn from the data is that the antenna desired and the antenna purchased may not always have the pattern anticipated. For a very critical antenna pattern requirement, it is important that the antenna pattern characteristics of the antenna be measured. Also, it behooves the user to assure himself that any surrounding antenna support structure does not modify the antenna pattern.

ANTENNA PATTERNS OF YAGIS AND LOG PERIODIC ANTENNAS

FIGURES 1 TO 15

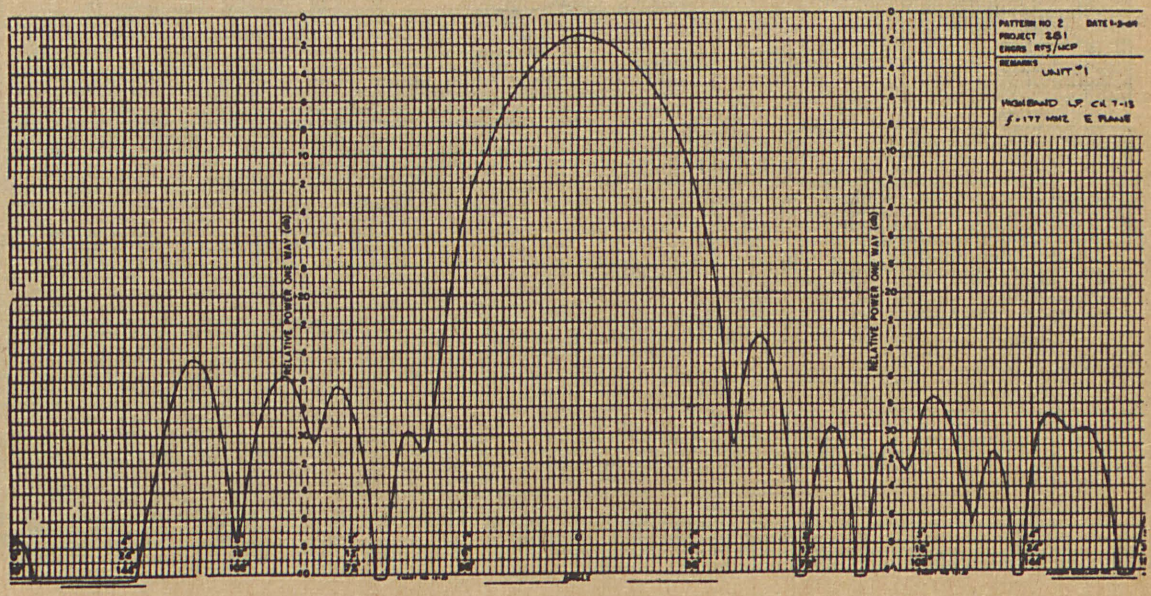


FIGURE 1

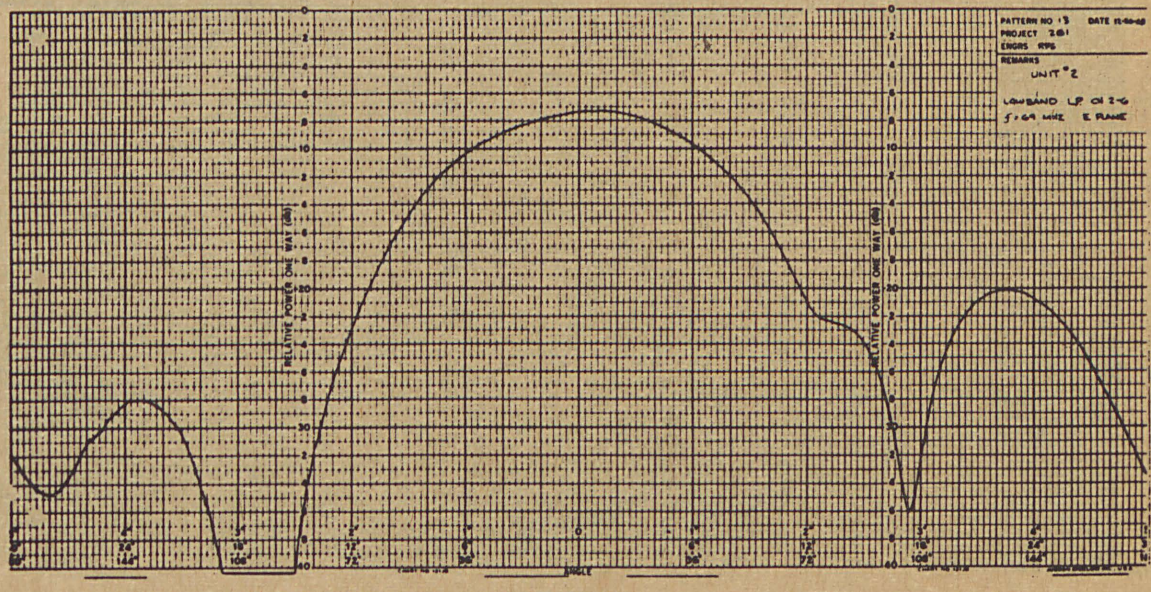


FIGURE 2

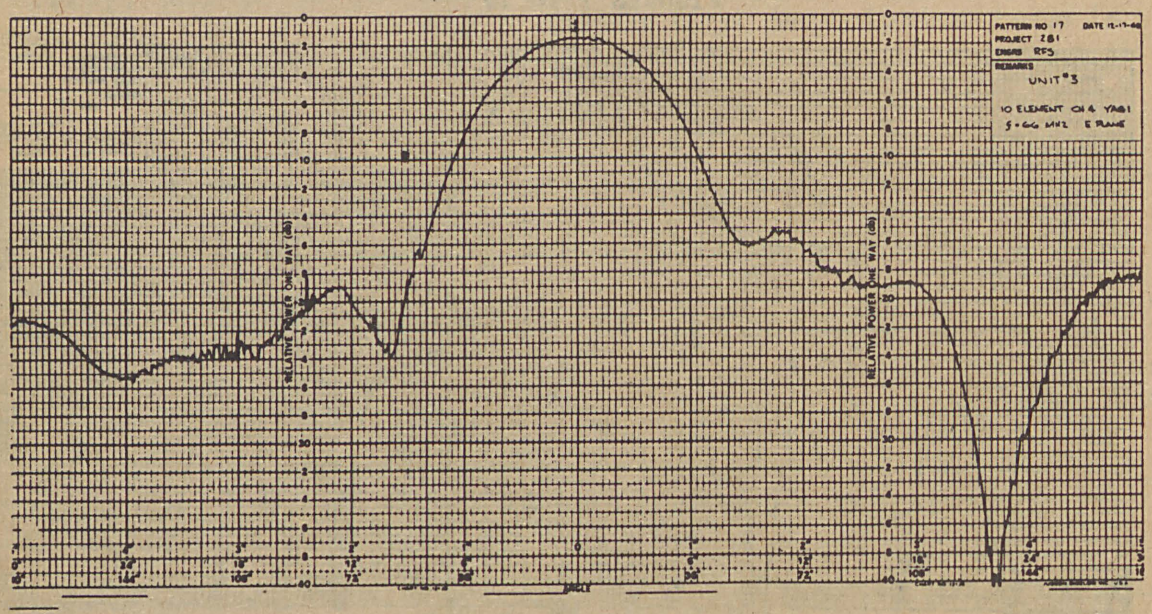


FIGURE 3

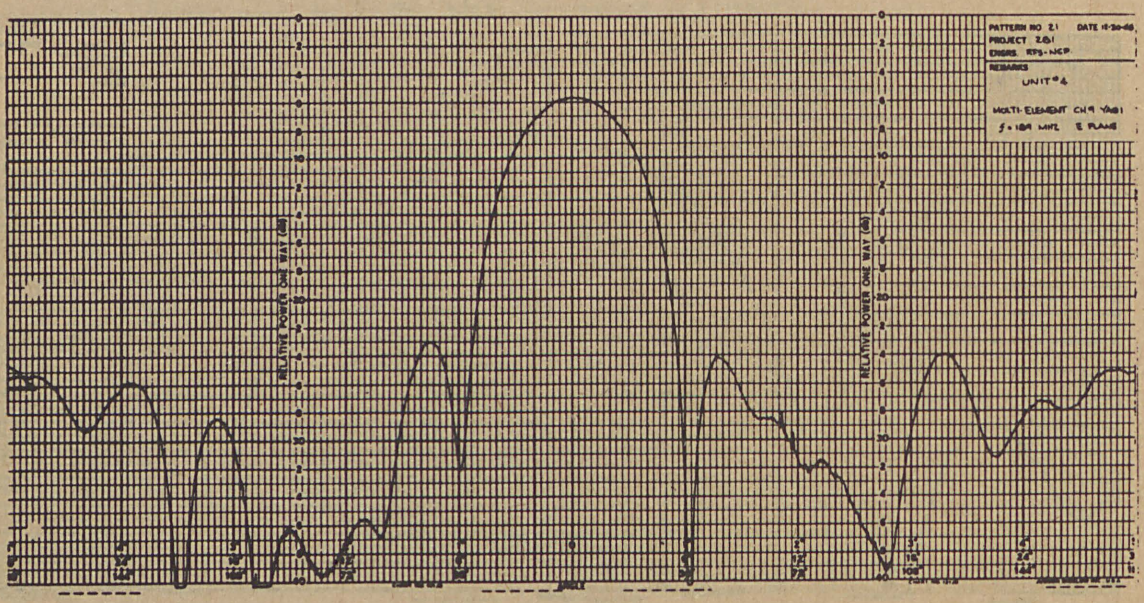


FIGURE 4

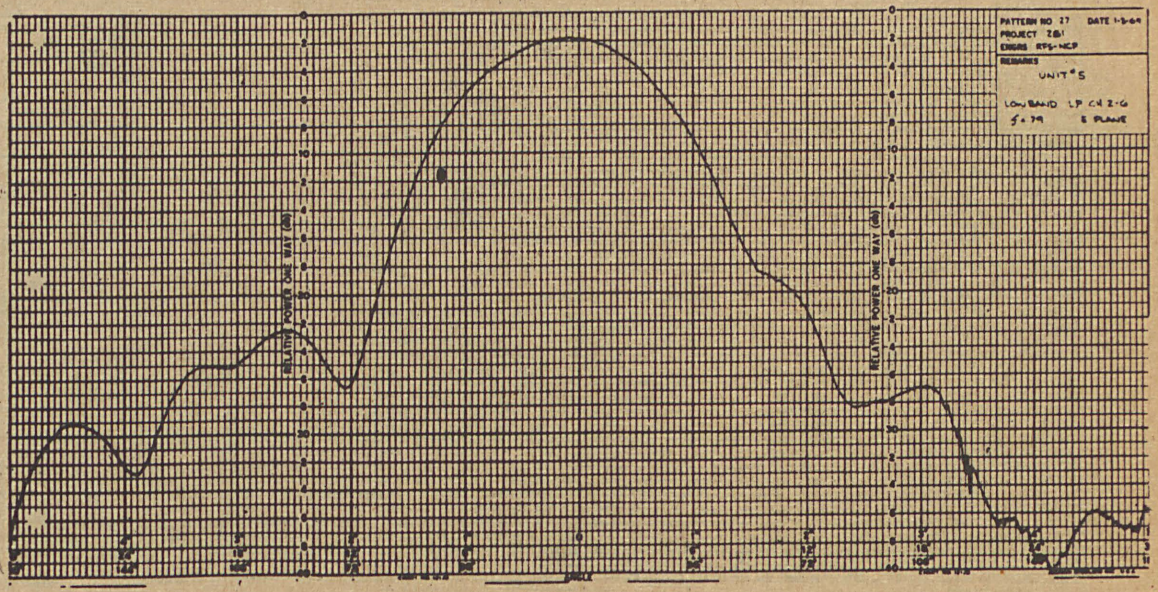


FIGURE 5

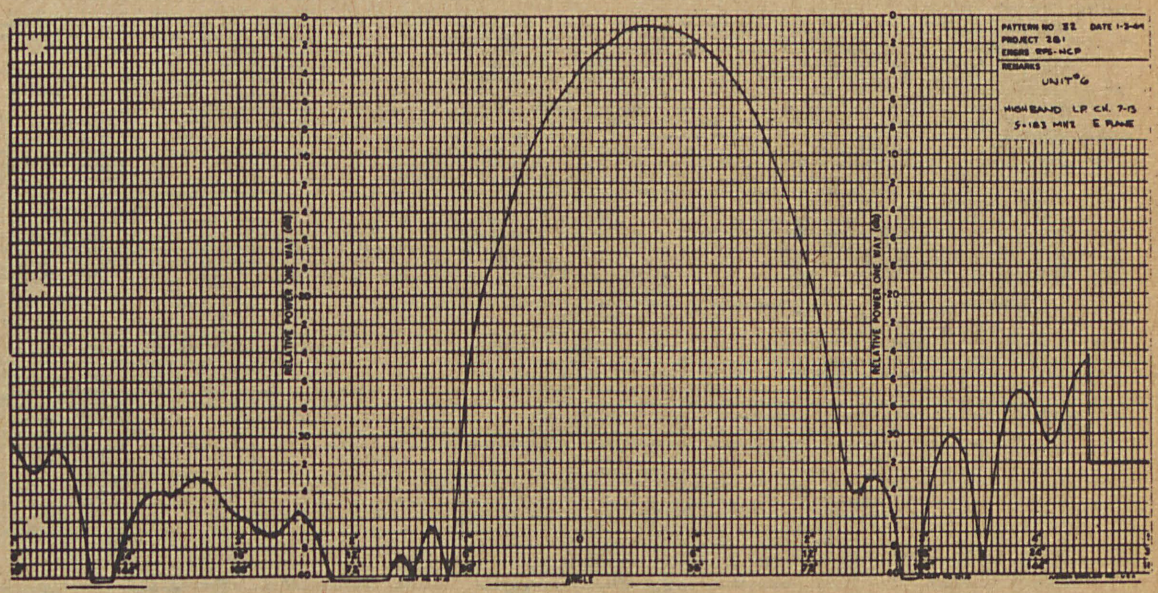


FIGURE 6

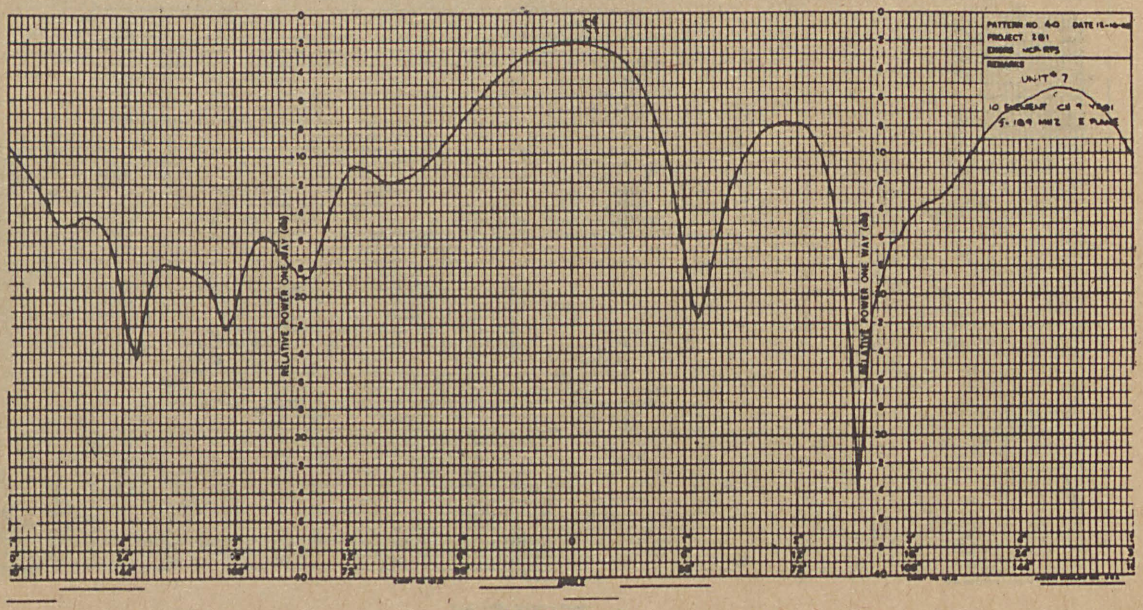


FIGURE 7

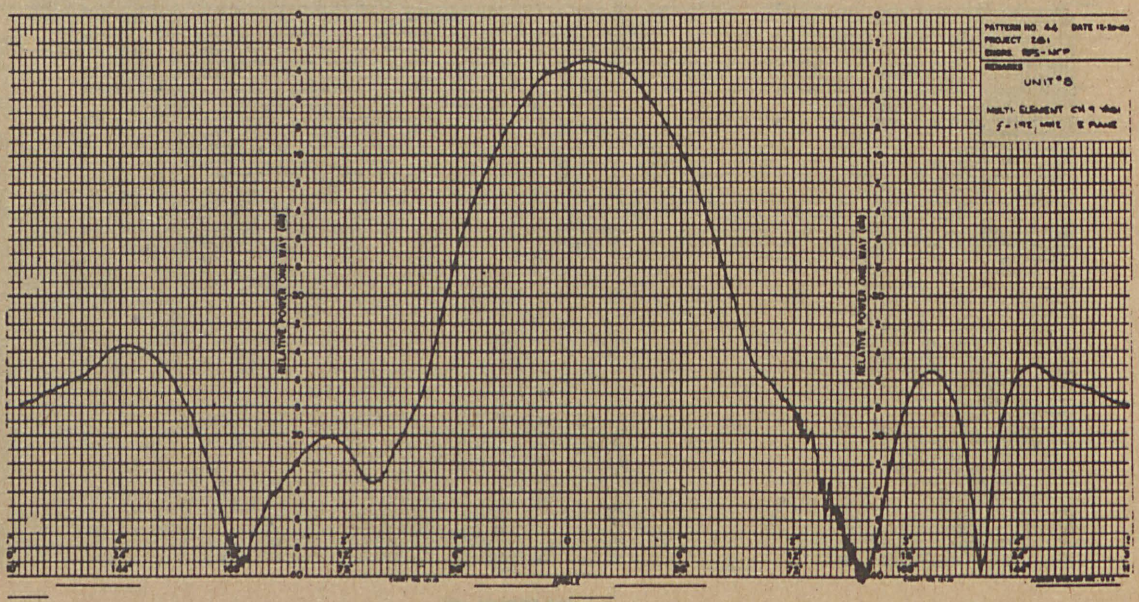


FIGURE 8

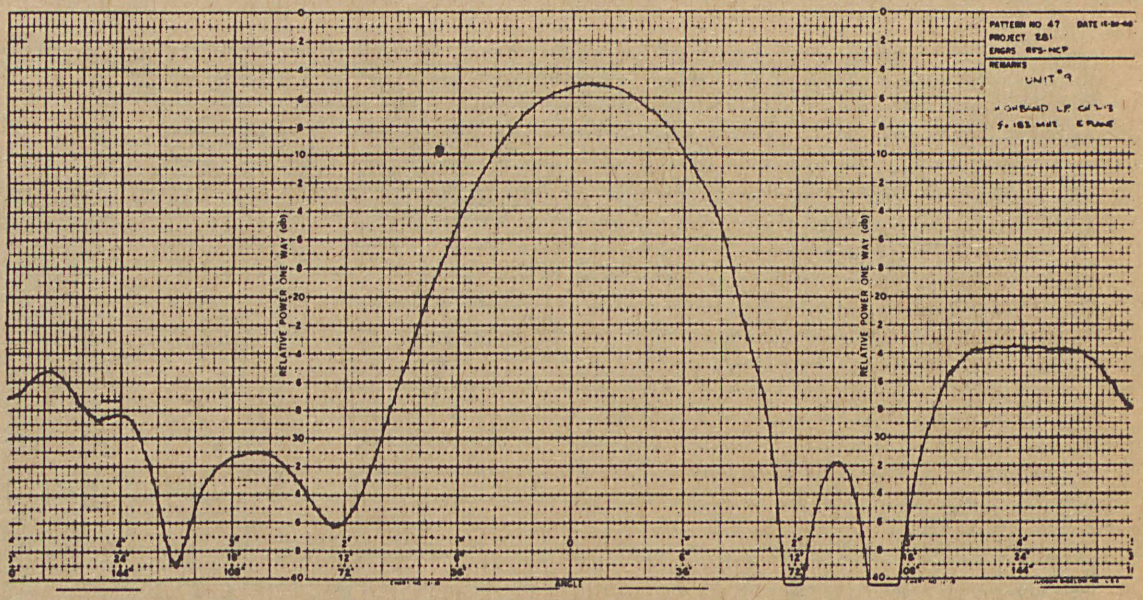


FIGURE 9

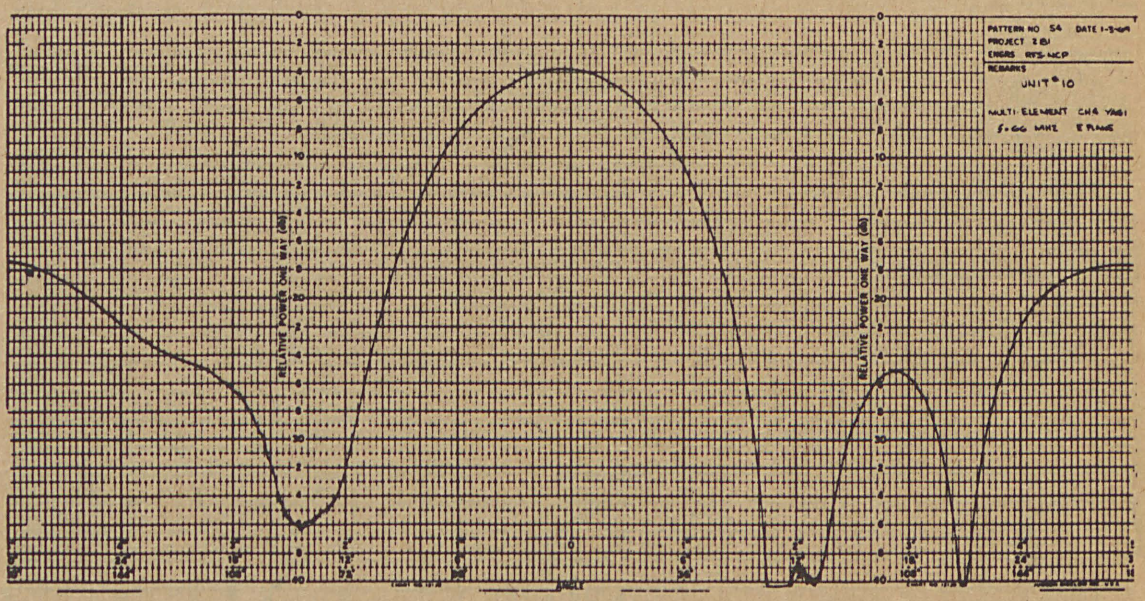


FIGURE 10

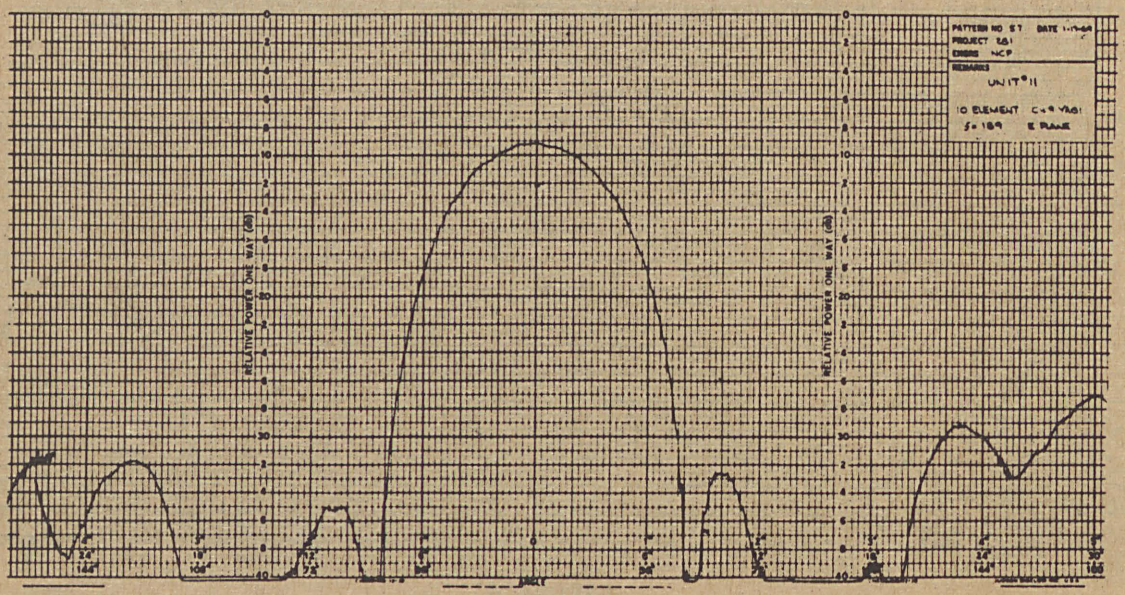


FIGURE 11

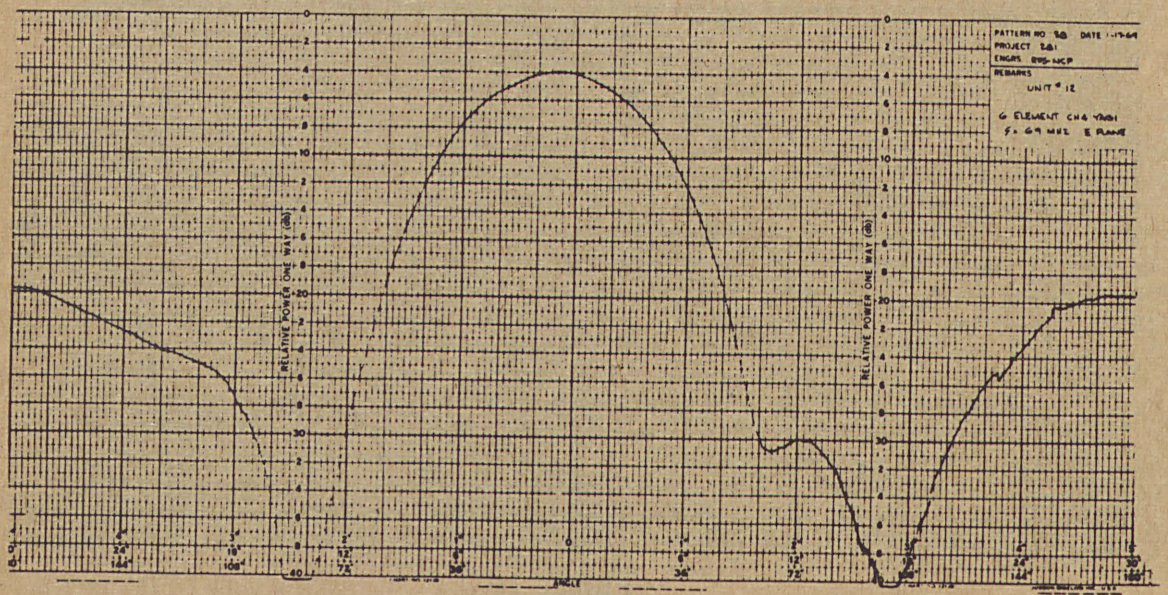


FIGURE 12

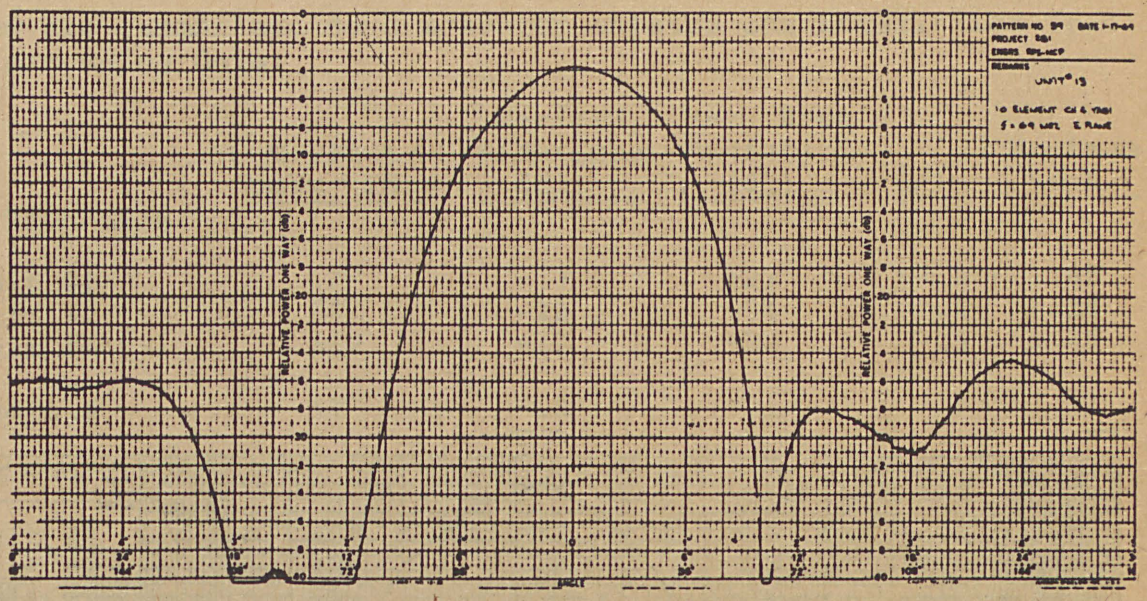


FIGURE 13

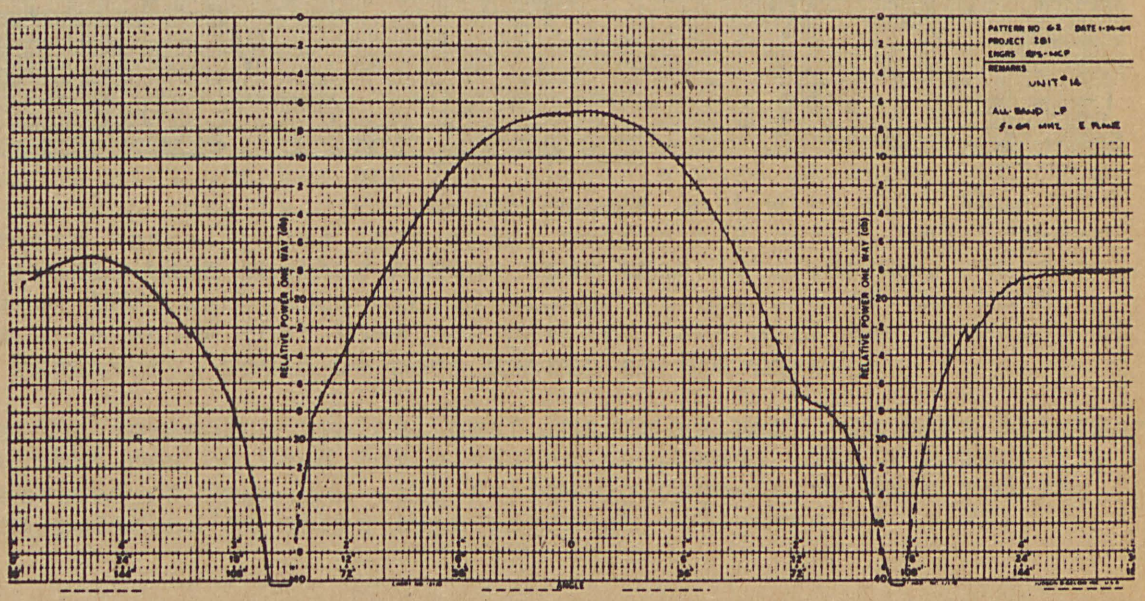


FIGURE 14

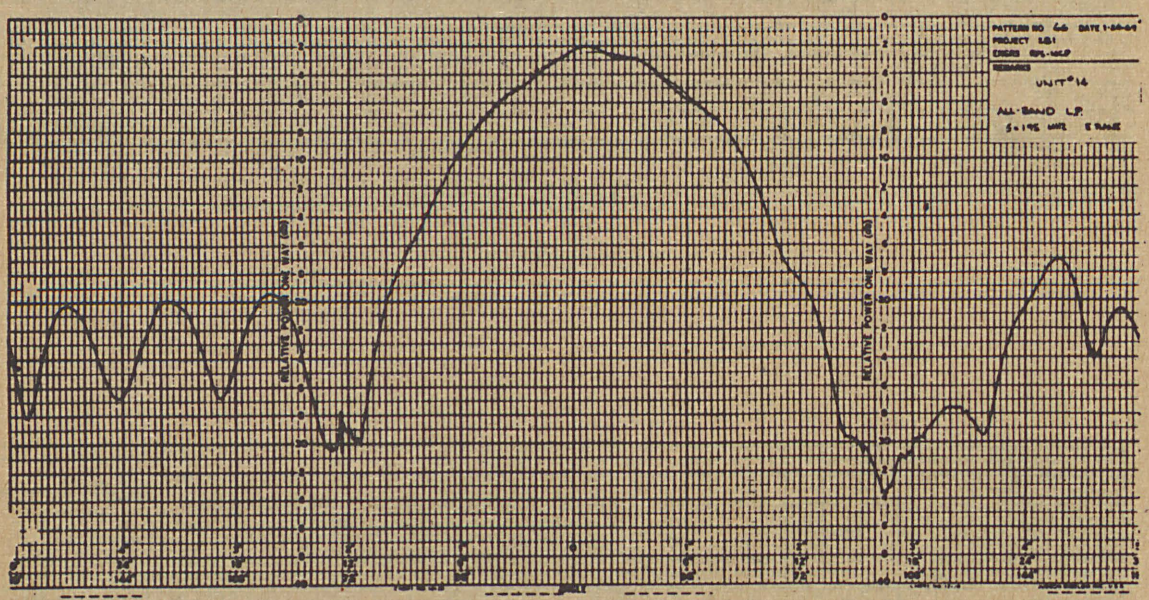

PATTERN NO 46 DATE 1-26-64
PROJECT LB1
UNIT #14
ALL-BAND L.P.
RELATIVE POWER ONE WAY (dB)
RELATIVE POWER ONE WAY (dB)

FIGURE 15

Summary of Measured Antenna Characteristics

Below are summarized some measured antenna characteristics from the preceding data:

	E Plane Beam Width	Maximum Side Lobe (dB)	Max. Back Radiation (dB)	Gain	Maximum VSWR
Low Band LP's					
Unit #1	62°	-17	-27	7.2	1.48
Unit #2	54°	-20	-34	7.8	1.34
Unit #3	56°	-18	-32	7.5	1.40
Average	57°	-19	-31	7.5	1.41
High Band LP's					
Unit #1	40°	-24	-24	7.0	1.5
Unit #2	48°	-26	-33	5.6	2.2
Unit #3	52°	-20	-21	6.5	2.2
Average	47°	-23	-26	6.4	1.9
10 Element Yagis					
Unit #1	48°	-6	-17	10.0	2.40
Unit #2	48°	-21	-24	10.6	1.48
Unit #3	47°	-10	-13	8.2	1.90
Unit #4	44°	-24	-19	10.8	1.36
Average	47°	-15	-18	9.9	1.83

The foregoing measurements are taken on similar antennas. Yagi antennas with greater and less elements were measured with some interesting results. For example, one unit with more than 10 elements actually had less gain, poorer F/B ratio, and broader beam width than another having less than 10 elements. On some models, VSWR was particularly higher at one end of the band. This data shows that VSWR and pattern data with the antenna, if not mandatory, would be most useful to the user.

From the foregoing typical performance values, you have information that can be used for planning purposes. The averages are summarized on Page 154. The following pages show measured antenna patterns of other type antennas, (Figures 16 to 22).

PATTERNS OF 30 FT. ASTROSCAT PARABOLIC ANTENNA

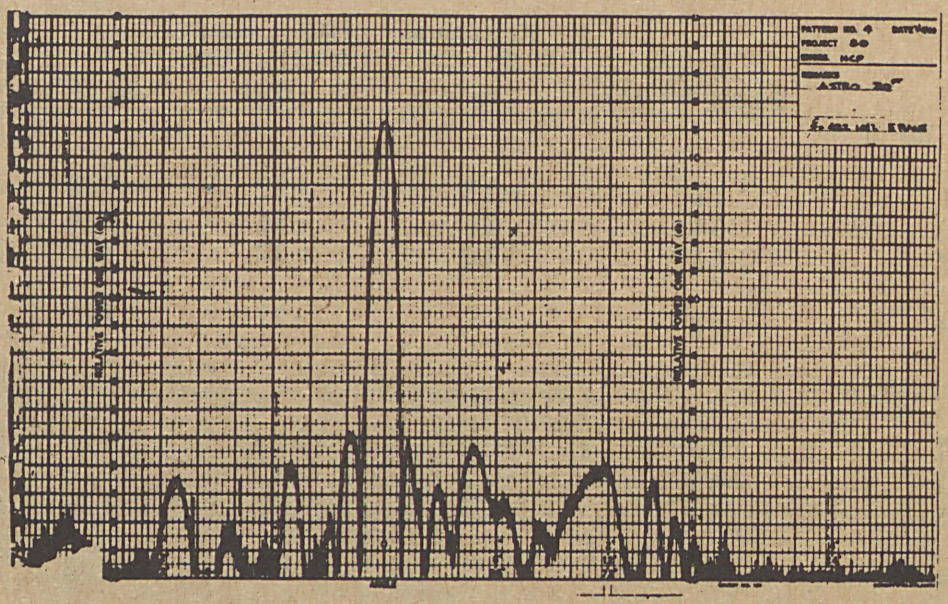


FIGURE 16

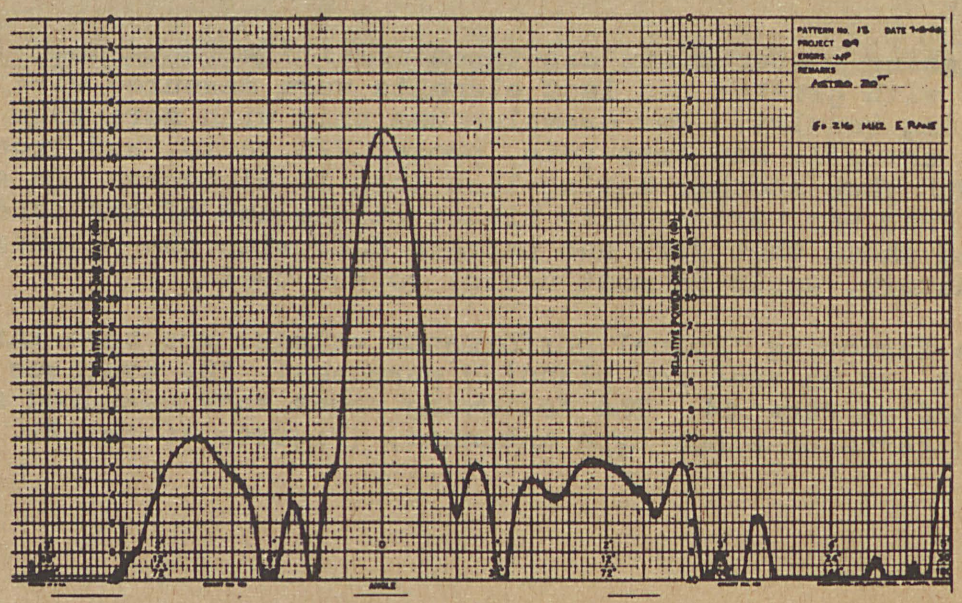


FIGURE 17

PATTERN OF ZIG-ZAG ANTENNA

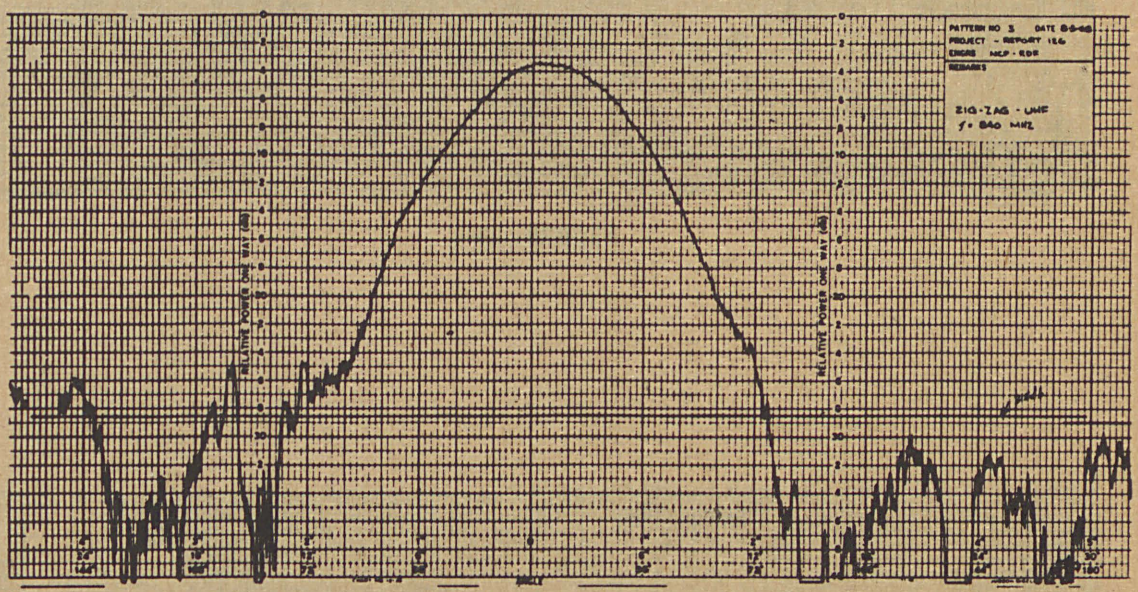


FIGURE 18

PATTERNS OF VHF CORNER REFLECTOR ANTENNA

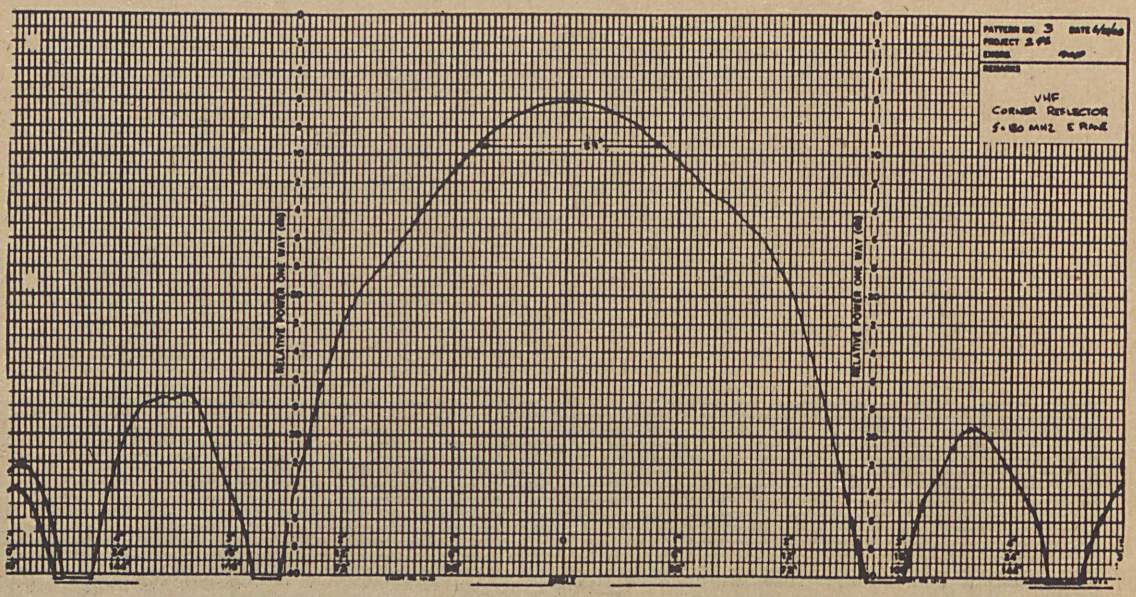


FIGURE 19

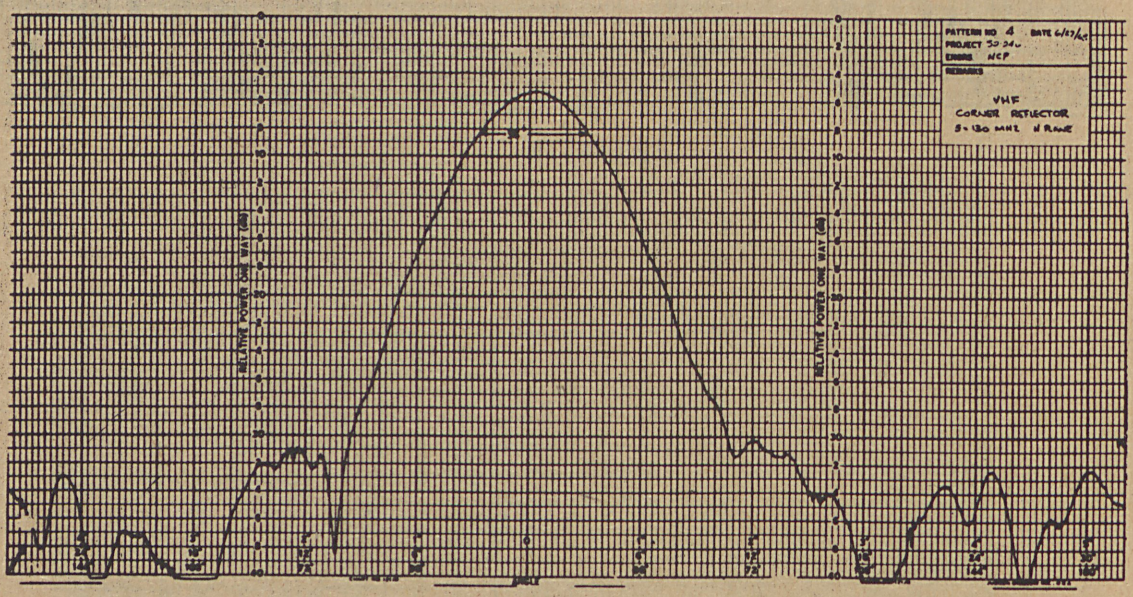


FIGURE 20

PATTERNS OF UHF CORNER REFLECTOR ANTENNA

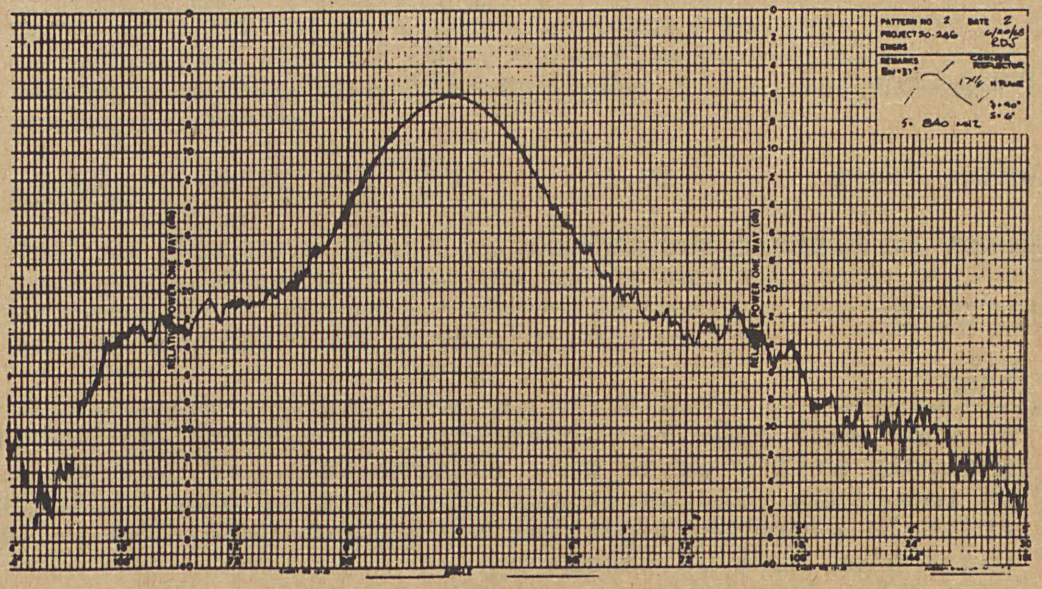


FIGURE 21

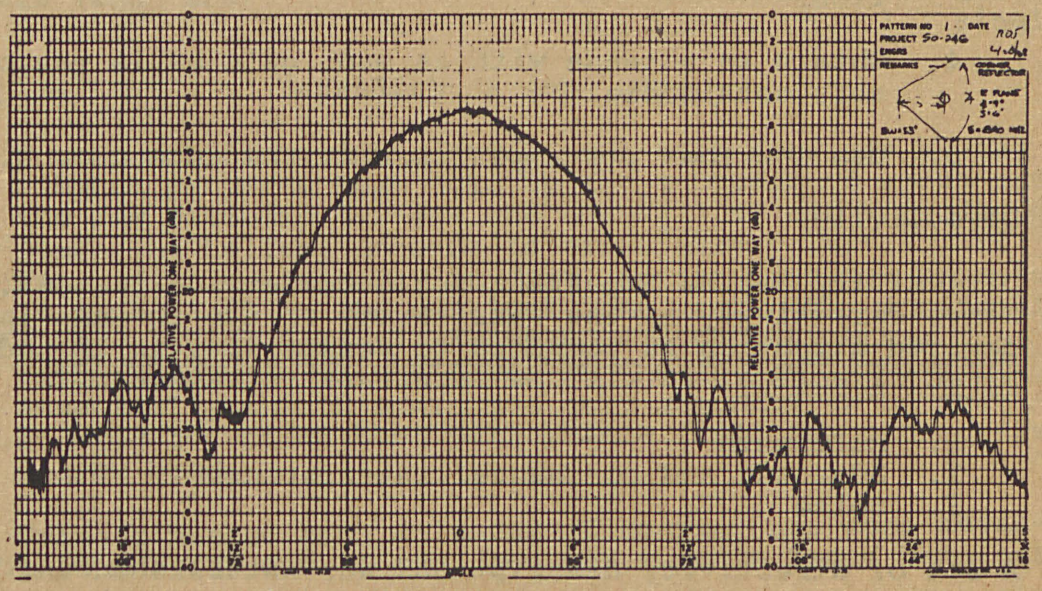


FIGURE 22

	Gain (dB)	Beam Widths	Front to Back Ratios	VSWR
Low Band LP's	7.5	57°	-27 dB or better	<1.5
High Band LP's	6.5	47°	-21 dB or better	<1.5
10 Element Yagis	10.0	47°	-18 dB	<1.5

Discussion of Performance Criteria

Electrical

Gain

We know when gain is important. A competent preliminary analysis will provide this information. If gain is not an important consideration, there may be many alternates. If it is a problem getting sufficient gain, the following action must be taken:

1. Minimize all line losses by selecting line with lower loss characteristics.
2. Use individual channel pickups to eliminate splitting losses.
3. Make site measurements to pick the best site location.
4. Obtain an antenna with as much gain as is reasonably obtainable.
5. Use low loss pre-amplifiers at the antenna end.

Directivity

Directivity may be important for a variety of reasons. Since directivity is the sensitivity of the antenna in a desired direction as compared to sensitivity in an undesired direction, it will be important in regard to:

1. Multipath
2. Adjacent and co-channel interference
3. Noise

A set of directivity descriptions was established in Chart No. 3. To effectively use directive antennas, the problem must be defined. Once it is defined, you may set about to obtain an antenna to do the job. If one is not

available, a special array of antennas may be designed to solve the problem. In antenna requirements of this type, measured antenna patterns are highly recommended.

Refer to some of the antenna patterns already presented to obtain an idea of their directive properties. Also refer to the section of this paper on the Use of Arrayed Antennas.

Bandwidth

From an impedance point of view ideally we would like to have an antenna that was perfectly matched over our band of interest. However, this is impossible, so we strive to get the match as good as possible.

Below we have listed what is considered to be reasonably attainable VSWR's for various antennas.

	VHF		UHF
	Low Band	High Band	-
Yagis	1.5 single Ch.	1.3 single Ch.	Not applicable
Log Periodics	1.5 over 2-6	1.3 over 7-13	1.5 14-83
Zig-Zags	-	1.2 single Ch.	1.1 single Ch.
Corner Reflectors	1.4 single Ch.	1.2 single Ch.	1.1 single Ch.
Helicals (end-fire)	-	1.4 all band 1.1 single Ch.	2.0 all band 1.1 single Ch.
Parabolas	Depending on feed type		

From a pattern point of view, the only antennas having antenna patterns that hold up for a broadband width are the log periodic designs and the helical end fire designs. Since the helical antenna is circularly polarized, it finds little use today in CATV, as one does not wish to lose the 3 dB in the vertical component. The possibility of developing helical antennas of a unique nature for CATV is perhaps in the cards in the future. Therefore, essentially the LP's are the only antennas to be considered for broad band performance. All the others are narrow band.

Using a narrow band antenna, of course, has some advantages of its own if one does not require broad band usage.

VSWR

Typical VSWR's are listed in the preceding paragraph.

Side Lobes

Side lobes in antennas for CATV normally do not present problems unless they are oriented in the direction of an undesired signal. The actual loss and gain for an antenna having high side lobes is not very great, and one could readily tolerate side lobes on the order of 10 dB.

On the other hand, it is much better to use an antenna with lower side lobes as the chances for co-channel or adjacent channel interference would be minimized.

Back Radiation

Back radiation has to do with the lobe structure of the antenna pattern in the back direction. Similar comments apply to back radiation as apply to side lobes.

Back radiation becomes a problem where an undesired station is coming in from the back direction or where there are potential interference problems in back of the antenna due to the tower mounting and other obstructions.

For certain antenna requirements, it becomes vital to obtain very high front to back ratios in order to eliminate undesired stations. Normally, 20 dB front to back ratio is considered to be a good ratio for a typical antenna; however, much higher front to back ratios are available utilizing special antennas.

Noise Generation

Noise generation is usually caused by loose contacts within the antenna structure or loose elements. It is mandatory that all electrical connections on an antenna be completely solid and noise-free. This is particularly true where the center conductor connects into the antenna structure. Loose and sliding contacts must be examined closely to assure that they are not a noise generating problem.

Noise generation from external sources can be a problem in the near vicinity of an antenna. In these cases, it is extremely desirable that the antenna have a high directivity to eliminate pickup from any of these local noise sources.

Mechanical

Windload

There are no antenna specifications for windload for use in CATV. However, most manufacturers utilize EIA Standard

222 which is the standard EIA Specification for microwave towers and structures.

Windload designs then normally are based upon the different zones which include 30, 40 and 50 pound per square foot windloading areas, as classified in the EIA Specification. Normally it would not be good design practice to design for under a 100 mile per hour windload. This is equivalent to a 40 pound per square foot windload on a flat surface. Normal designs for CATV consider the structural survival of materials of the antenna. This is usually sufficient since the beamwidths are quite broad on most antennas.

If there is a very special application in which we are dealing with ultra directive antennas with beamwidths of less than 5^{o}, particular attention must be taken to the deflection of these antennas under windload. In such circumstances, the desired operating windload should be considered in calculating these values. The antenna should not be allowed to deflect more than one-half of the beamwidth under the desired operating windload.

Ice Load

Most antennas will handle the ice loads under moderate windload conditions. Usually antennas are not designed to take ice loads simultaneously with maximum windload because such conditions hardly ever exist. It is usually good design practice, however, to design for a normal amount of ice at the survival windload, usually one-half inch. This, however, is not vital.

It is recommended that the antennas be designed for a maximum survival windload in accordance with the EIA Specifications and be designed to take moderate ice loads depending upon the prevailing conditions in the area at the operating windload.

Mounting Provisions

It is important that mounting configurations be rugged and easily handled in the field. These mounting provisions, of course, have to take the same wind and ice loads as the basic antenna. It is extremely important that these mounting configurations be assembled in an easy manner as they frequently have to be assembled at high altitudes in the air.

Ease of Assembly

An important aspect of antenna design is the assembly process. For the simpler antennas, this usually does not

represent much of a problem, and most manufacturers are submitting equipment which is readily assembled in the field. Some of the more sophisticated antennas may become a little complicated in their assembly; however, usually if the assembly instructions are followed to the letter, little difficulty will be encountered.

Usually the manufacturer has had considerable experience with the particular product he is submitting; and with the benefit of this experience has gone to some detail to come up with assembly instructions for his product. Therefore, it behooves the user to follow his instructions to the letter, at least until satisfactory experience has been attained with the product.

It is a good practice to bring to the attention of a manufacturer assembly defects in writing because he is more likely then to take corrective action on such defects.

Packaging Configurations

The reason packaging configurations are important in antenna design for CATV is because of the cost of shipping such products. Usually products that are shipped assembled cost considerably more to ship than disassembled products. Therefore, it is important to determine by product investigation the precise packaging configuration requirements.

Temperature

Normally temperature is not considered extensively in the design of CATV antennas. Most manufacturers design their products using commonly used materials which will withstand normal temperatures in the temperate United States.

The same may be said to apply to humidity. Most CATV equipment is subjected to some shock or vibration testing. This is usually a test conducted by the manufacturer in his plant over an extended period of time to determine the effects of vibration on his product.

Appearance is usually not an important factor in CATV antenna design since the antennas generally are far from any area where they come under extensive local scrutiny. This is particularly true where they are mounted high in the air. There are occasions, however, when a particular product type may be either located in a populated area or near to the ground, and then appearance becomes important. This may be particularly true where an existing building structure is being used to house the antennas.

The important thing about appearance is usually that an installation is rated by its appearance; therefore, it behooves the operator to maintain a site, including the antennas, as neat as possible at all times.

The Use of Antennas in Arrays

The technique of arraying individual radiators to obtain desired beam characteristics is not being utilized as fruitfully as it can be.

I wish to spend a few minutes to demonstrate the tremendous value of array techniques when properly utilized.

Array Fundamentals

The antenna pattern of a radiator can be expressed as a function of the antenna angle. This can be expressed mathematically as follows: $E = f(\theta)$ where E is the field voltage, and f is a function of the angle θ. One can define this mathematically for common pattern characteristics, or he can determine the value of E for any particular angle from the actual measured antenna pattern of the antenna he will use in the array. For example, here is a typical pattern:

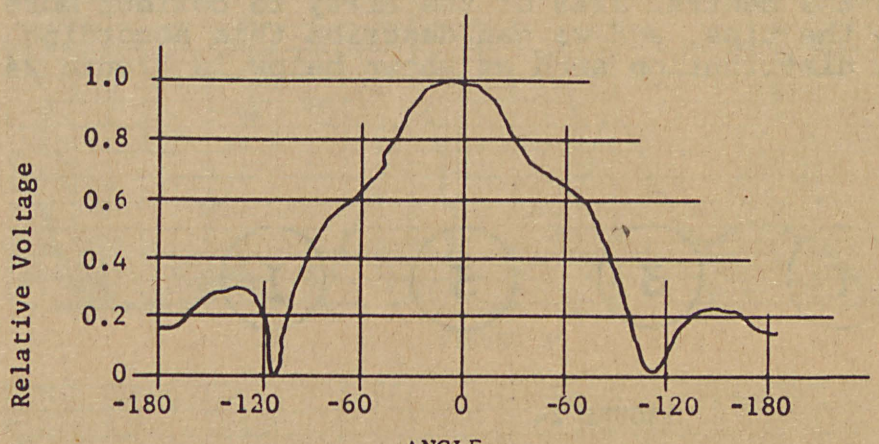


FIGURE 23

We can take values of E for any angle we desire in our calculations; however, we must take a sufficient number of points.

What happens when we place these antenna elements in an array? Any array of elements regardless of the individual element pattern can be described mathematically as if each was a point source (isotropic radiator). For example, the mathematical expression for a two element array of point sources is:

$$F(\theta) = 2 \cos\left(\frac{S^\circ}{2} \sin\theta\right)$$

For a four element array:

$$F(\theta) = 4 \cos\left(S^\circ \sin\theta\right) \cos\left(\frac{S^\circ}{2} \sin\theta\right)$$

In each case above, $F(\theta)$ is the array factor. How do we obtain the pattern when we use an individual radiator that is not a point source? We simply multiply the array factor by the individual element pattern. E of the array is equal to E of the element times E of the array factor.

Let us suppose we are going to put the relatively poor antenna pattern characteristic, similar to that shown in Figure 23, in an array of four antennas. It is a relatively easy matter to calculate these patterns, and I think you would be astonished to see the rather nice antenna pattern characteristic achieved by using a rather poor antenna shape for the individual radiator.

An even more dramatic improvement can be obtained by using a different distribution of energy to the antennas by using a so-called tapered distribution. What do we mean by a tapered distribution? We simply mean that we use a combining network that allows the central area of the array to collect more energy than the tips, and we can describe this according to a numerical distribution such as shown below in Figure 24.



FIGURE 24

The particular distribution shown is a binomial distribution for four elements. However, other mathematical models of distribution can be used.

Array Illustration

To demonstrate the principles above, we have constructed a simple array of four log periodic elements. The array consists of four very inexpensive domestic LP antennas. The

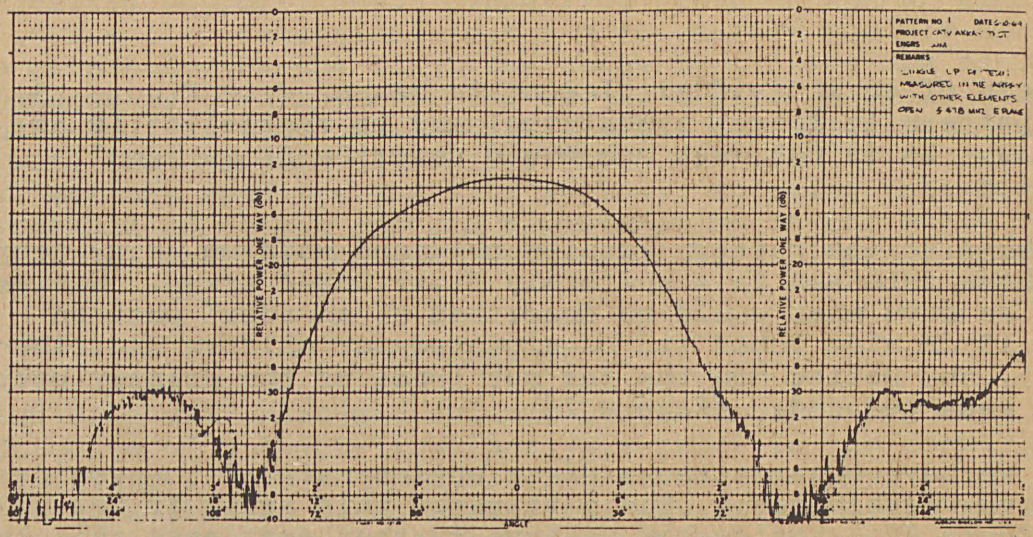


FIGURE 25

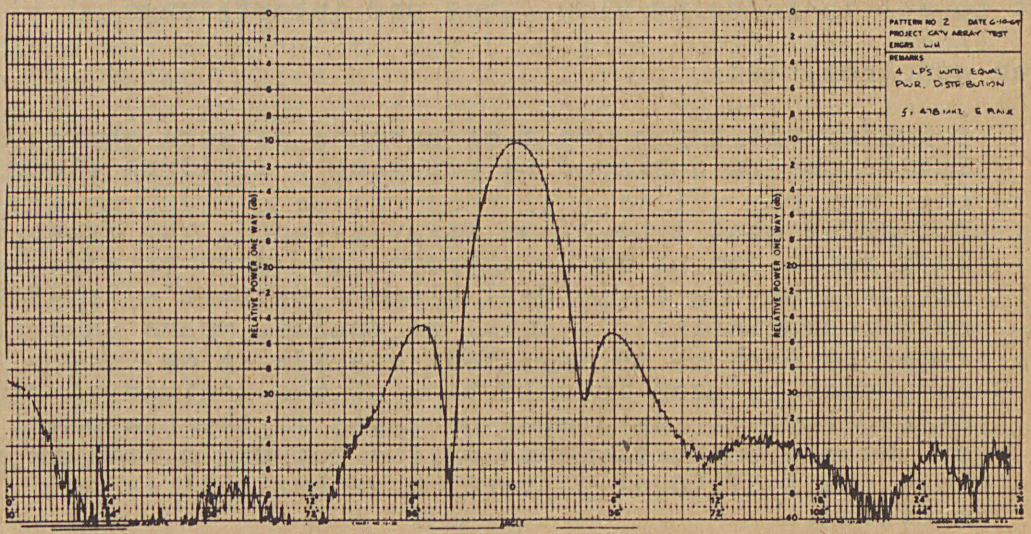


FIGURE 26

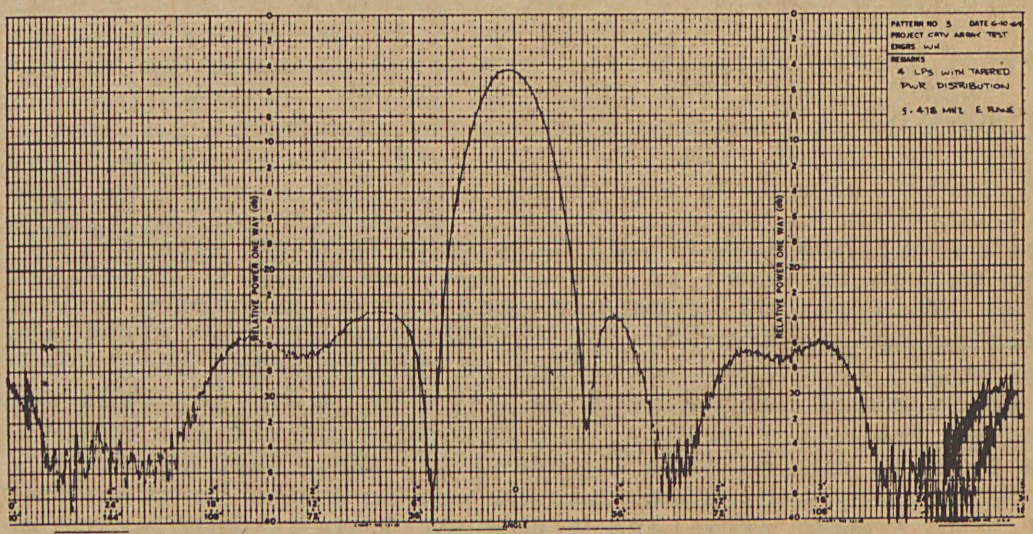


FIGURE 27

pattern of an individual element is measured in Figure 25. The pattern is fairly symmetrical and is typical of LP antennas. It is not what one would describe as an ideal pattern.

Now observe the pattern results obtained when we array four of these antennas in a uniformly distributed array. Notice that we have what could be described as an ideal pattern with 13 dB side lobes (to be expected for uniform distribution), and notice how the far out lobes of the primary pattern have been reduced. (Figure 26)

Next we have constructed a distribution network to provide a tapered distribution. The pattern of this array is now shown in Figure 27. Notice how we have further decreased this lobe structure. The power of this technique, I am sure, is obvious to all in reducing side lobes and interference.

We can conclude that:

1. Considerable improvement of antenna pattern characteristics can be achieved by arraying individual elements.

2. No matter what type of an array is used, the front to back ratio can never be improved any more or made any better than the individual element pattern's front to back characteristic. This, of course, means that, if front to back is an important consideration, great care must be used in selection of the individual radiating element. Care must be taken in the placement of these antenna elements on the support structure so that the individual pattern characteristic is not modified.

MARK H. RONALD

Summary

Scale model antenna techniques have been applied to CATV head-end design in order to obtain optimum antenna system performance. This method, commonly used by the aerospace industry for checking the performance of antennas mounted on missiles, satellites and airplanes, consists of constructing an electrical scale model of the antenna and then measuring this model at a scaled frequency range. A computer analysis was used for the initial design of a head-end for Long Island, New York. This study indicated that it was possible to colocate a channel 2 to 6 quad array and a channel 7 to 13 quad array on a

single crossarm support, thus, conserving space on the antenna tower. It was also determined that a more uniform performance could be obtained over the frequency range by tilting the antenna elements in toward the center of the array. A scale model of the head-end was then constructed and the test results agreed closely with the computed data. The model was used to select the final antenna spacings and tilt angles. By using this model, it was possible to obtain important information on the whole head-end structure at a cost far below that of full scale experimentation.

Introduction

The design of a CATV head-end antenna system usually consists of the performance of a theoretical analysis prior to the construction and testing of the individual antennas and arrays. This paper discusses the use of an additional design procedure which often results in an optimized head-end system. An extra step is included after the completion of the required calculations, consisting of the construction of a scale model antenna system. Measurements and adjustments are then made, using this model, prior to the construction of the final full scale assembly. This technique has the advantage of providing a relatively inexpensive device which is easy to modify and test before committing funds for a final unit. A more significant advantage is that it is possible to build a scale model of a fairly complex head-end antenna system and test this total structure. Using this method, data can be obtained on the effect of the support structures and on the effect of coupling between arrays. Due to the size and weight of most head-end antenna systems, it is normally not possible to obtain this important information on a full scale basis. This paper presents an example of how model measurements were used in conjunction with theory and full scale measurements in the development of a unique head-end antenna system.

Theory

The use of scale model antennas in order to determine the overall system performance is not a new technique. As early as 1919, scale model antennas were used for measurements of large communication antennas. By the late 1940's this method had gained widespread acceptance as the best means of determining the response of antennas mounted on airplanes. Today, sophisticated modeling techniques are used by the aerospace industry for checking the performance of antennas mounted on airplanes, missiles and satellites.

Model measurements in electromagnetic systems are based on the principle of electrodynamic similitude - a direct consequence of the linearity of Maxwell's equations. If one electromagnetic system is derived from another system by dividing all dimensions by a constant factor n, then both systems will have geometrically

similar fields if the following relationships are maintained:

$$\epsilon_M \mu_M f_M^2 = n^2 \epsilon_F \mu_F f_F^2 \quad (1)$$

$$\sigma_M \mu_M f_M = n^2 \sigma_F \mu_F f_F^2 \quad (2)$$

where

ϵ = dielectric constant
σ = conductivity
μ = permeability
f = frequency
n = arbitrary scaling constant

The subscript M refers to the parameters of the scale model and F to the parameters of the full scale system.

In the construction of scale model antennas, one generally must have $\epsilon_F = \epsilon_M$ and $\mu_F = \mu_M$ due to the fact that the measurements will be made in air. It, therefore, follows from equation (1) that frequency at which the model measurements are taken must be n times the frequency of the full scale antenna. It follows from equation (2) that $\sigma_M = n\sigma_F$. This requirement is impossible to satisfy, since the full size units are constructed of aluminum which is a good conductor. However, since the conductivity of the metal is high, the error in simulation is small if a good conductor such as copper is used in the model.

Example

Scale model antennas were used in conjunction with computer calculations and full scale measurements in the development of a head-end for Long Island, New York. The various steps in the design cycle are outlined below as an example of how scale model measurements are employed in CATV antenna development. The Long Island head-end incorporates several unique design features which are discussed below.

In the design of the particular head-end being considered here, there was a requirement to pick up channels 2, 4, 5, 7, 9, 11, and 13 from New York using a minimum of space on the tower. For this reason the basic concept selected consisted of two diamond quads, with one mounted inside the other as shown in Figure 1. In order to determine the optimum antenna spacing for each quad, a computer program was generated which plots the principle plane patterns of the array. The antenna elements selected were log periodic dipole antennas. This antenna type has significantly lower sidelobes than yagis. The particular log periodics used have an average sidelobe level 50 dB down from the main beam and worst sidelobe or backlobe 30 dB down from the main beam. For this reason, a cosine approximation can be used for the element pattern in the array calculations.

The element pattern in a principle plane is:

$$E = \cos^n \theta \qquad (3)$$

Table 1 shows the beamwidth and corresponding values of n for the antenna elements.

TABLE 1

	Beamwidth		n	
Channel	Hor	Vert	Hor	Vert
2 - 6	60°	95°	2.41	0.88
7 - 13	50°	60°	3.52	2.41

In the principle plane the diamond array can be reduced to an array of three antennas with twice the power in the central unit. This yields a Dolf-Tchebyscheff taper of 1:1.4:1 and, therefore, the sidelobes are reduced. The normalized array pattern is:

$$E_a = \cos^n \theta \quad (1 + \cos \Psi) \qquad (4)$$

where $\Psi = \frac{\pi d}{\lambda} \sin \theta$

This equation was used to calculate the antenna patterns for various values of spacing, d.

As a result of these calculations a particular problem became apparent. If the spacing is optimized at the low end of the band, then high sidelobes appear at the high end of the band due to grating lobes. These are caused as a result of an in-phase condition being created at a point other than the main beam due to an excessively wide antenna spacing. If the spacing is optimized at the high end of the band, then there is a significant increase in beamwidth and a corresponding reduction in gain at the low end of the band. In addition, consideration of the desirability of mounting one quad within the other made it necessary to restrict the available range of spacings to reduce the possible antenna interaction.

In order to resolve this problem, a computer program was written for the case of antennas tilted in toward the center of the array as shown in Figure 2. This produces a more uniform electrical spacing since the phase center of a log periodic antenna moves toward the front of the antenna as the frequency is increased. The new equation for the normalized antenna pattern became:

$$E_a = \frac{1}{2}\left[\cos^n\theta \pm \frac{1}{2}\sqrt{\cos^{2n}(\theta+\alpha) + \cos^{2n}(\theta-\alpha) + 2\cos^n(\theta+\alpha)\cos^n(\theta-\alpha)\cos\psi}\right] \qquad (5)$$

where α is the tilt angle.

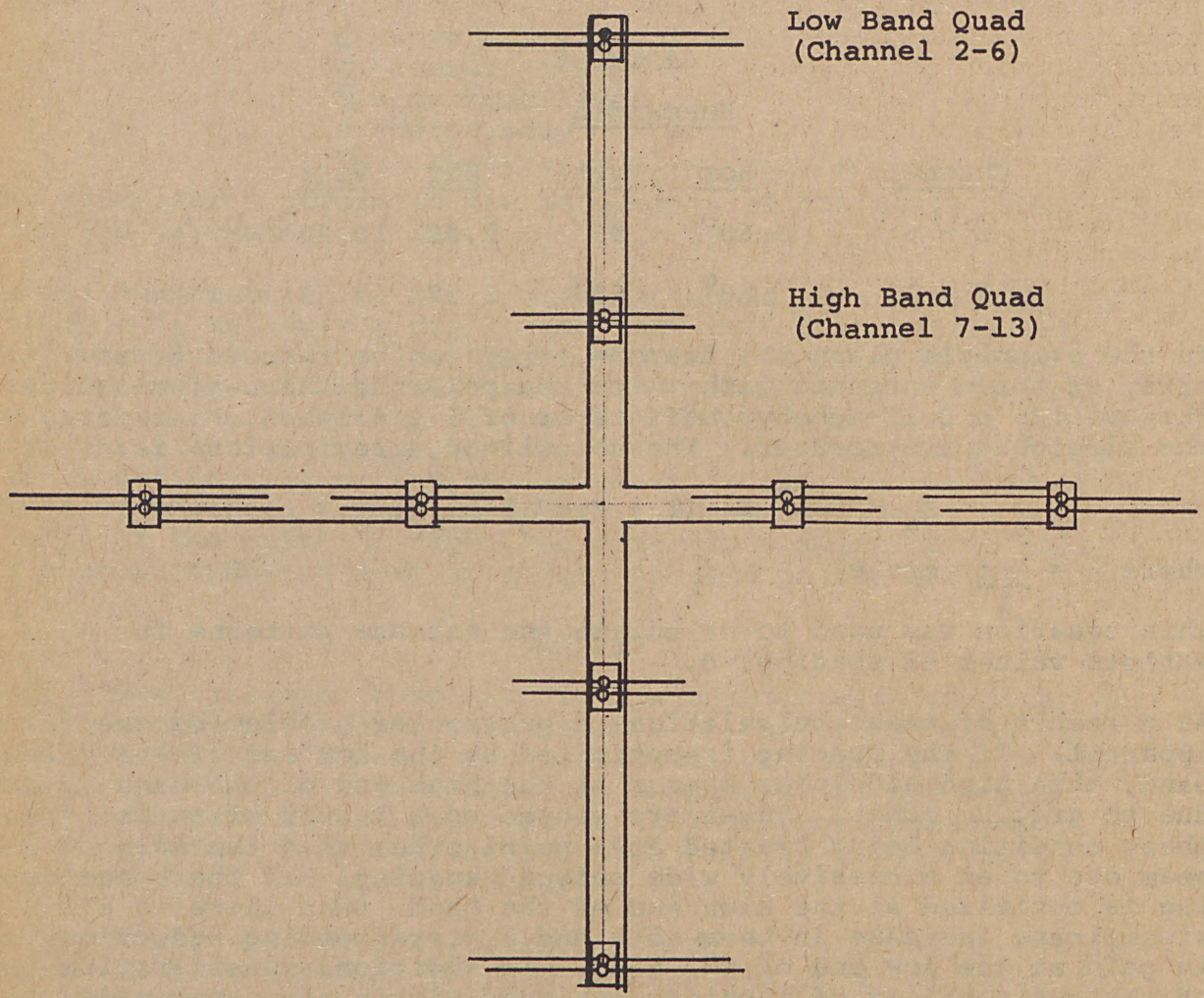


FIGURE 1: Dual Quad Configuration

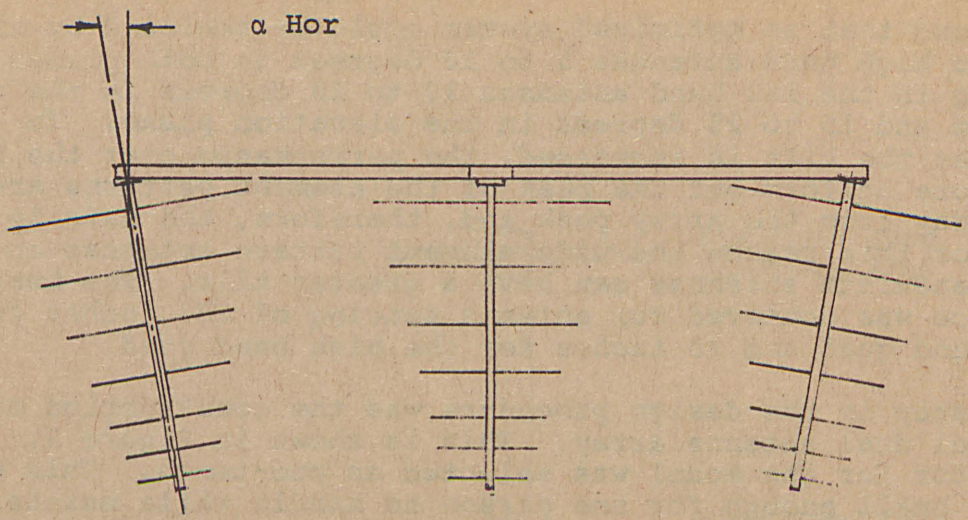
It was found that an optimized system could be achieved by tilting in the high band antennas 5 to 10 degrees in both planes and by tilting in the low band antennas 10 to 20 degrees in the azimuth plane and 15 to 25 degrees in the elevation plane. In general, as the tilt is increased, the performance over the band becomes more uniform but the peak of the element patterns are shifted away from the array peak and, therefore, the gain is reduced. For this reason the wide element pattern antennas and broader bandwidth antennas can have a greater tilt. The best performance was achieved for antenna spacing of 280 inches for the low band quad and 90 inches for the high band quad.

The next step in the design procedure was the construction of a scale model dual antenna array. This is shown in Figure 3. The scale factor for the model was selected as one-tenth. This made the model small enough for one person to handle while maintaining a low enough scale frequency to be convenient. The model dimensions are approximately 38 inches wide by 30 inches high by 16 inches deep. The antenna booms and dipole arms were constructed of copper tubing and copper rod. Although it was not possible to accurately scale the connectors and cables, a reasonable approximation was obtained, using OSM connectors and RG 187/U. The scale model antenna was constructed with adjustable antenna locations so that the antenna spacings could be readily changed. In addition, each element was hinged at the base to provide for an adjustable tilt angle.

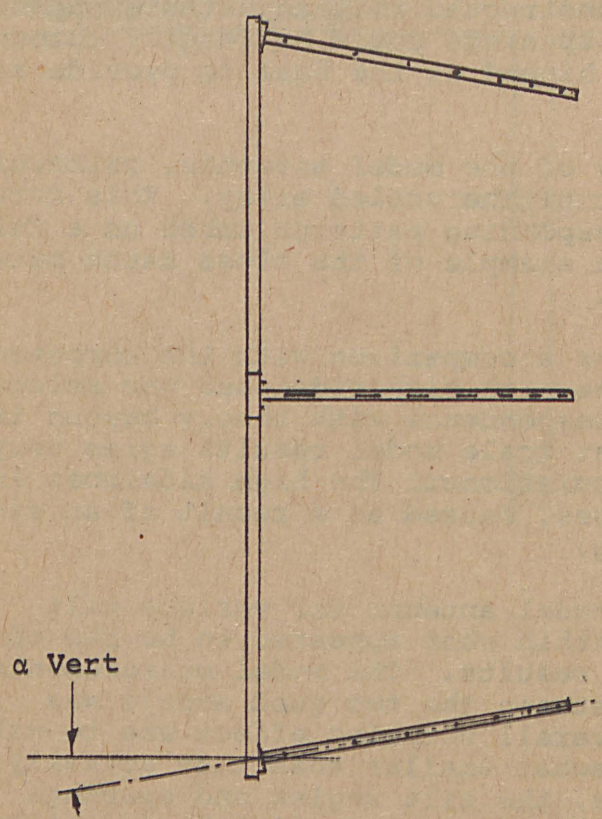
In order to check the validity of the model antennas, patterns were taken on a single element of the scaled array. This data was then compared to the corresponding patterns taken on a full scale unit. Figure 4 shows an example of the close match between the full and scale model data.

The next check on the model was a comparison with the computed patterns. For this test a case with high sidelobes was selected in order to determine the correspondence with theory beyond the main beam. Figure 5 shows that scale model results agree very closely with the computer calculations. The high sidelobes in these patterns are grating lobes, caused as a result of an excessively wide antenna spacing.

Data was recorded, using the model antenna for various tilt angles and antenna spacings within what appeared to be the optimum range from the computer results. The model measurements indicated that the coupling between the two quad arrays was small, but noticeable. The overall coupling effect was to make the array spacings appear somewhat smaller than they actually were. After a series of tests, the tilt angles and spacings that yielded the best pattern shape, lowest sidelobe and highest gain were established. It was, also, determined, based on these tests, that it was indeed possible to mount one quad array within another without sacrificing performance.



TOP VIEW



SIDE VIEW

FIGURE 2: Quad Array Showing Tilt Angle

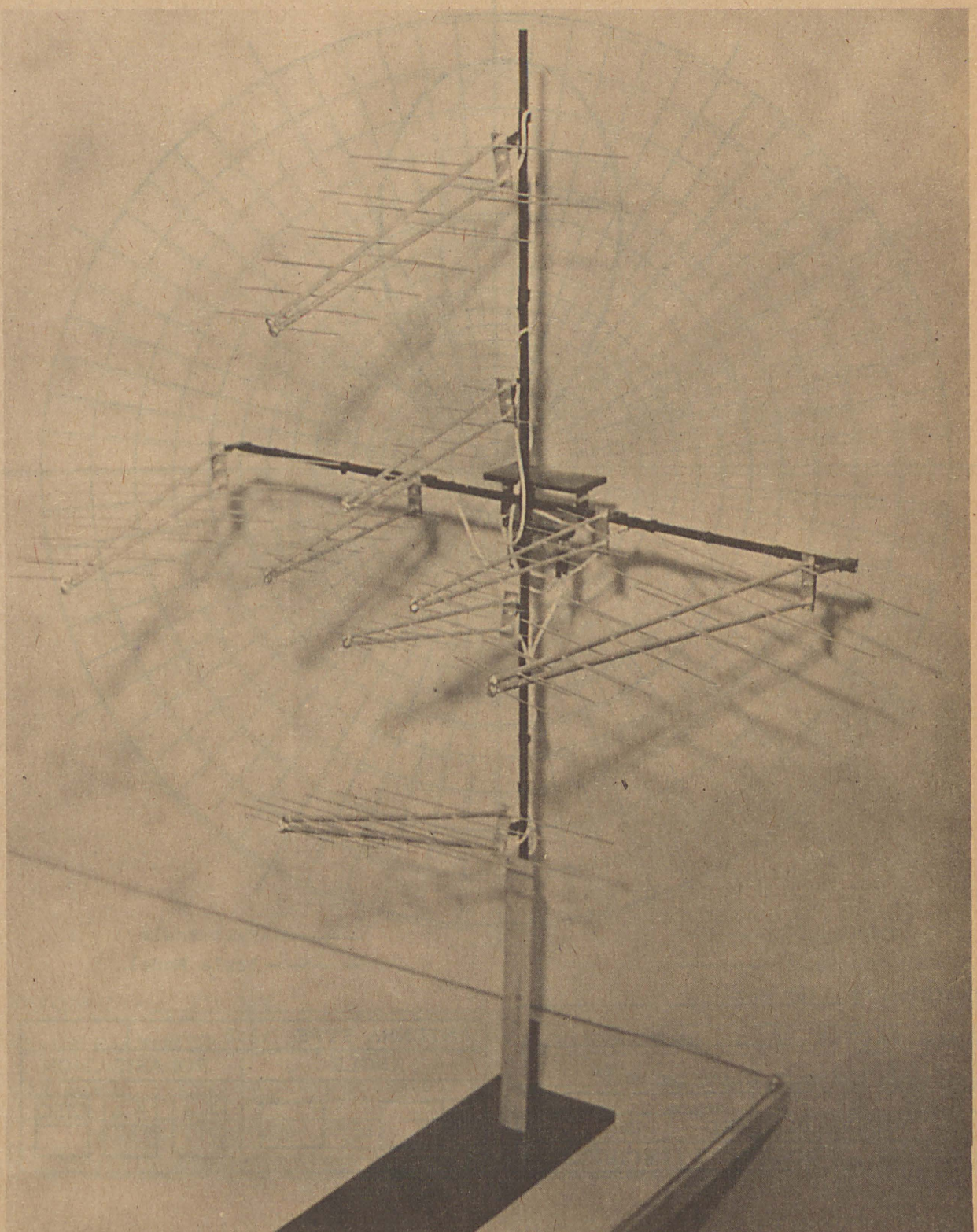
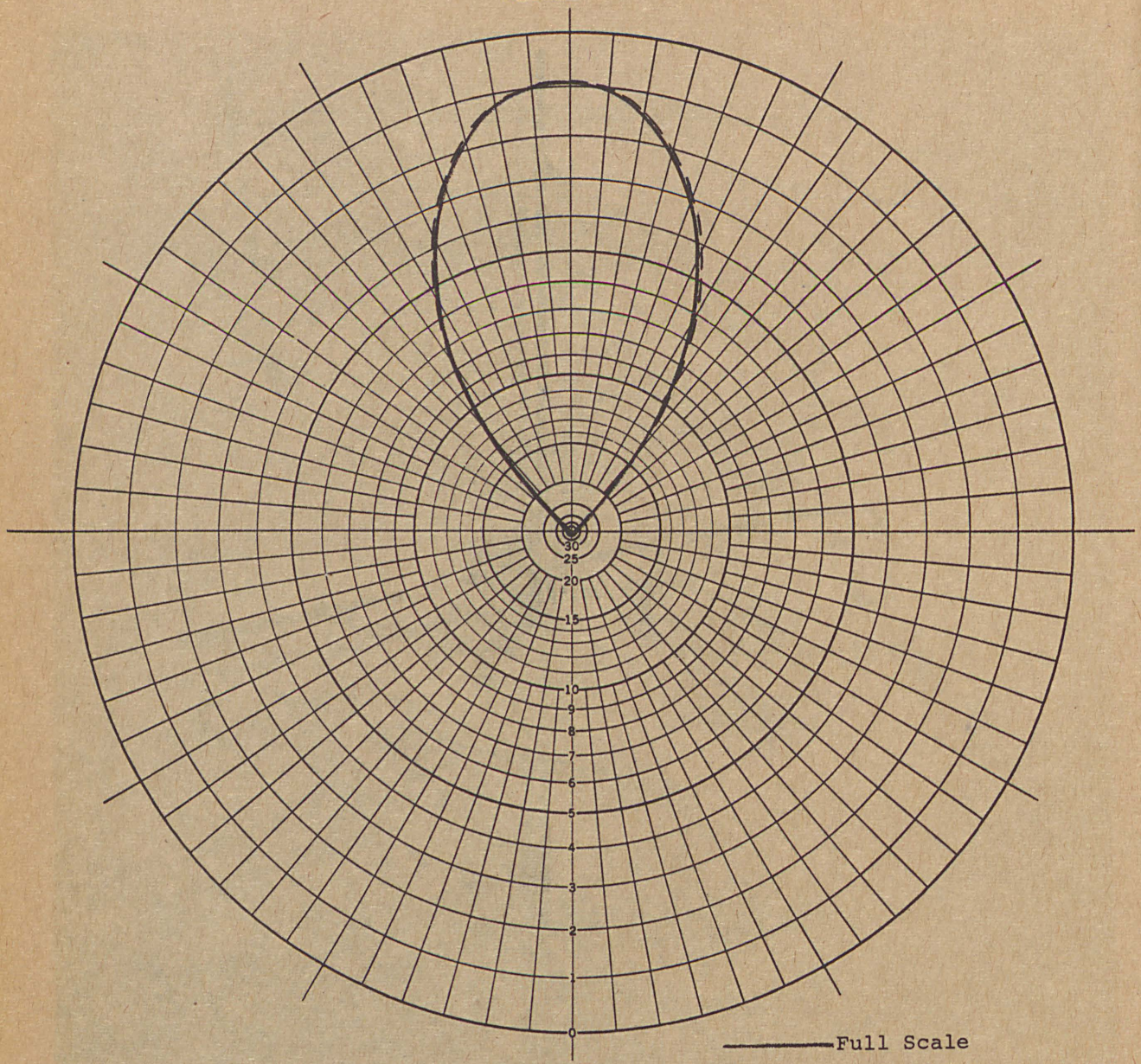


FIGURE 3: Scale Model Antenna

ELTECH LABORATORIES, Inc.

FIGURE 4



FREQUENCY 189 MHz

SCALE FACTOR 10

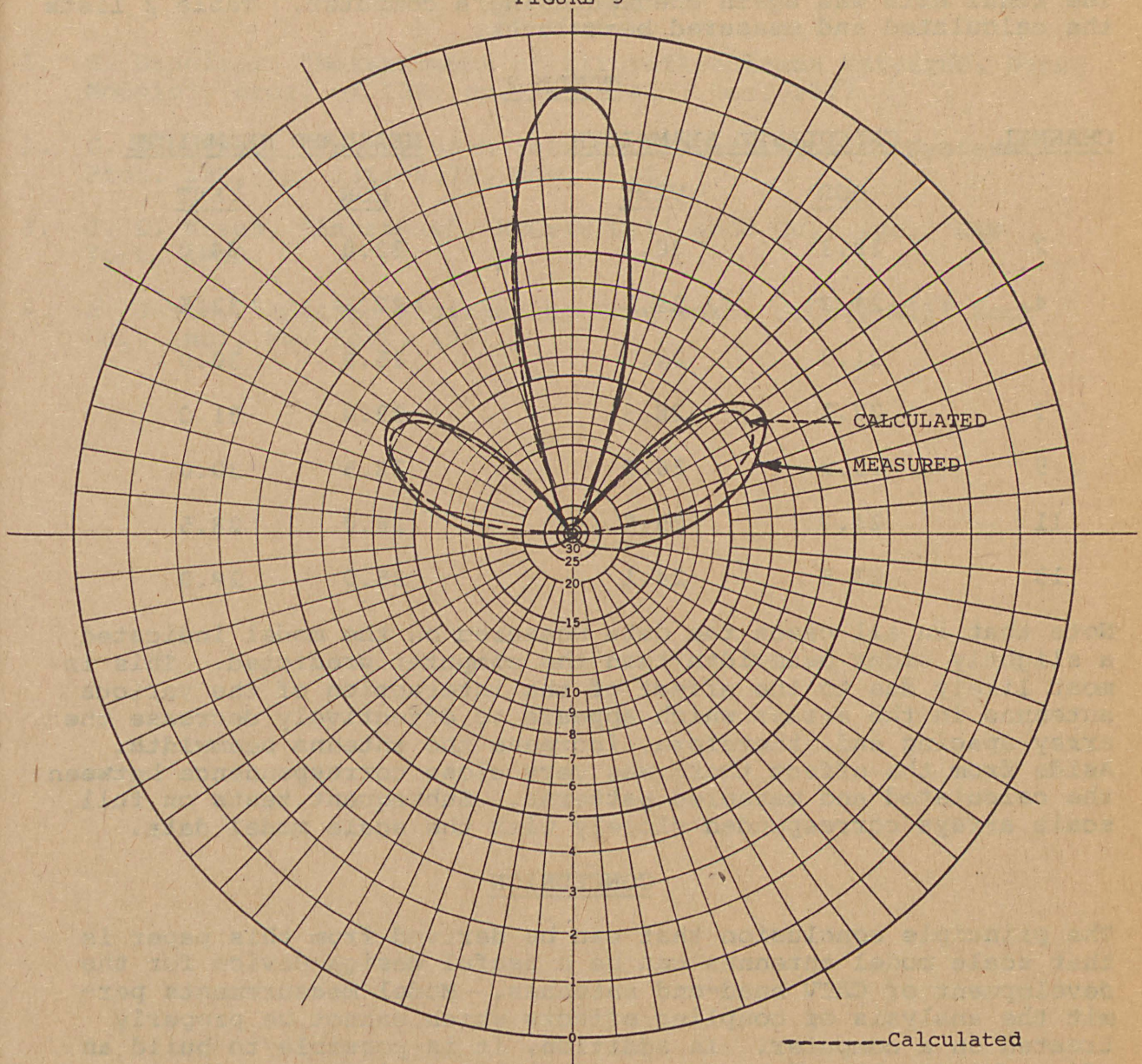
REMARKS azimuth plane pattern

CURVE PLOTTED IN		
VOLTAGE( )	POWER( )	DECIBELS( )

ANTENNA TYPE 1300			
ANGLE		POLARIZATION	
Eϕ:	Eθ:	E_ϕ	E_θ	CIRC

ELTECH LABORATORIES, Inc.

FIGURE 5



FREQUENCY 850 MHz

SCALE FACTOR 10

REMARKS elevation plane pattern

CURVE PLOTTED IN		
VOLTAGE( )	POWER( )	DECIBELS(X)

ANTENNA TYPE 1100	
ANGLE	POLARIZATION
Eϕ: Eθ:	E_ϕ E_θ CIRC

The final data was again checked using a computer. Table 2 lists the calculated and measured beamwidths.

TABLE 2

CHANNEL	CALCULATED BEAMWIDTH		MEASURED BEAMWIDTH	
	HOR	VERT	HOR	VERT
2	29.1	30.7	32.0	34.0
4	24.7	25.5	27.5	32.5
5	21.9	22.3	25.0	30.0
7	27.1	28.3	29.0	31.0
9	25.9	26.7	28.5	30.0
11	24.7	25.5	28.0	28.5
13	23.5	24.1	25.0	28.0

Note that in all cases the data measured on the model indicated a slightly wider beamwidth than the computer predicted. This is most likely due to the effect of the interaction of the various antennas in the arrays which appears to effectively decrease the array spacing and, therefore, increase the antenna beamwidth. Aside from the effect there was very close correspondence between the calculated and measured patterns. Subsequent tests on full scale arrays corresponded closely with the scale model data.

CONCLUSION

The principle conclusion that can be derived from this paper is that scale model antennas can be a useful design device for the development of CATV head-end antennas. Model measurements permit the analysis of coupling effects which cannot be properly treated on a computer. In addition, it is possible to build an adjustable scale model structure so that various antenna configurations can be tested in a short period of time and at a minimum expense. Scale models are particularly important for complex head-end systems where the total antenna array is too large to test on a full scale basis. The integrated quad array structure consisting of two diamond quads co-located on a single cross arm was developed by using a model antenna. This model permitted the determination of optimum antenna pointing angles and spacings at a cost far below the cost of full scale experimentation.

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CATV DISTRIBUTION PLANNING

Session Chairman:
Milford Richey

Participants:
Wayne R. Hauser
"Problems and Solutions in Buried CATV Plant"

Preston Spradlin
"A Review of Taps for CATV"

WAYNE R. HAUSER

Objectives

Plans and organization are essential elements in any type of construction. This is especially true in building an underground CATV System in any community. Underground plant construction extends into every neighborhood utilizing most every street, alley and occasionally other public and private right-of-ways. Each potential subscriber is personally involved in this construction. His exposure may be a minor delay to work because of trenching operations along his normal route; or he may be exposed to strangers cutting a small trench through the parkway in front of his home causing damage to the flora and fauna. A potential subscriber is more involved in underground construction than aerial construction because our facilities inadvertently trespass his accustomed habits.

There are four objectives to this paper. They are:

1. Highlight the problem areas of organization and planning as it relates to underground CATV construction.

2. Suggest sound methods of solution.

3. Stimulate thinking on the subject matter.

Philosophy

In order to have a successful image in the community and to have a successful business, we believe that the underground system should be built as quickly as possible with the minimum inconvenience to potential subscribers and the city at large. The construction and operation of the plant should provide maximum service at a minimum of cost.

Major Problem Areas

The major problem areas that you are likely to encounter during construction are:

I Escalating construction costs

II Incomplete plans and specifications

III Inadequate organization

IV Part-time supervision

V Subject of Relationships

I. Escalating Cost--How to Minimize

Aerial construction is relatively simple. Hardware and cable are placed between poles A and B, then messenger and cable are installed. They are relatively few variables. By contrast, underground construction has many variables; and these variables drastically affect the per mile cost of the system. The location of the trench, whether it is in the street or in the parkway, affects cost; likewise, soil conditions, rock conditions and whether or not the surface material (asphalt or concrete) will also force the expenditure of more money than anticipated. The situation is further complicated by the varying conditions throughout the community. Therefore, the creation of a defined construction area becomes important for a number of reasons, most important of which is project control. The construction area should have several common denominators, such as: more or less uniform soil conditions, street construction or alley construction or a geographical area in the community lends itself to a definable unit.

In our Newport Beach System, the construction area is defined by the distribution system extending from a system "bridger-converter". In Phase I of the Newport Beach System, there are 23 converter areas. Work is assigned and inventory is controlled by these converter areas. Likewise, our direct sales marketing program is organized on a converter area basis so that system construction, cabling, splicing, proof of performance, house drops, house wiring, sales and customer hook ups can be coordinated on an area by area basis. We have termed this the "batch flow method" of construction. Without utilizing the batch flow method of construction, the assignment of priority tasks or inventory control problems seem to increase.

CATV construction contracts are basically unit contracts. Normally, contractors press to complete as many units per day in order to offset their high overhead and construction costs. A defined area approach forces the contractor to complete one portion of the system before skipping to the next. Some contractors have been known to work through a general area of the community skipping through and completing all the easy construction and then doubling back and gearing up for more difficult construction problems. This situation leaves gaps and voids in the system which can delay energizing the plant and obtaining revenue from subscribers.

Establishing starting and completion dates for each phase of construction, focuses the attention of all parties on priority tasks.

II. Incomplete Plans--Avoid It!

The lack of complete and approved construction plans undoubtedly will become the most costly mistake encountered in building an

underground system. The competitive climate in which CATV franchises are pursued forces the CATV operator to make commitments to the city well ahead of any thoughtful consideration for system design and construction practices. Operators, especially multiple operators, have a tendency to rush the strand mapping, field engineering and design phases in order to initiate construction in accordance with the time requirements of the city franchise; hence, inaccuracies and voids appear and the critical area of system construction plans.

I suggest that you check with the city public works department to determine the type of map which would be most acceptable for the construction and electronic layout. The standard procedure of obtaining city maps and retracing them excluding superfluous detail, was not a good practice for our Newport Beach System. The city public works department determined that they would rather have the same maps used by the utility companies, so that page 17 of the City Water Plans corresponded to sheet #17 of the CATV Plans. Had this request been determined prior to developing the plans, many hours and quite a few dollars could have been saved.

Each sheet of plans should be complete with the name, address and telephone number of the owner along with the official date that the plans were first circulated and used by several contractors, the city and our own company representatives. Without the official date appearing on each sheet of the plans, it is conceivable that your contractors may be building different systems. Each set of plans should be complete with a page devoted to typical construction practices of vaults, cross sections of streets, the location of other underground utilities, complete with a legend and standard specifications which have been approved by the City Department of Public Works.

A key sheet should be submitted to reveal the precise area in the community that the work is to take place.

Taking these suggestions to mind does not eliminate all of the conflict. The City Department of Public Works is primarily interested in the location of the trench; therefore, they want simply a trench diagram. Because many utilities are located underground, most cities require that plans should be dimensioned showing the precise location of the proposed CATV facilities. The city, at least our city, was not interested in the electronic layout which reveals the number of cables and electronic devices which are required. In order to eliminate the need for two types of plans, i.e. a set of construction plans and a set of electronic layout plans, I suggest that you bring this to the attention of city officials and negotiate a reasonable compromise.

A civil engineering consultant is a most handy person to have available prior to and during the course of construction. This consultant is able to talk "turkey" with his civil engineering

counterpart in the city government; also, the consultant is able to save many dollars by advising the cable tv operator of streets and alleys which are already severely congested with underground facilities. I recommend the addition of a civil engineer on a consultant basis without qualification.

In many areas of our country, cities are separated by imaginary boundary lines. You may find yourself in a situation in which I found myself. While constructing the system within the city of Newport, crews inadvertently placed several hundred feet of distribution system within the adjacent city of Costa Mesa, California. At first the city manager of Costa Mesa was delighted to hear about my mistake, for he though he had found a way to balance the city budget; however, a very equitable solution resolved the problem.

III. Organization

To connect a subscriber to a CATV System on the day that proof of performance and system acceptance has been completed is the objective of good organization. This organization necessarily includes every function from the time the franchise was accepted to the installing crew connecting a subscriber to the system. "He who has the gold makes the rules" is the guiding principle of the organizational structure. It is the project manager who represents the stockholders who have the gold. The project manager, unequivocally, should have the entire responsibility and commensurate authority over the creation of the underground system. Key personnel in the areas of engineering, finance, marketing and public relations, serve as staff functions to the project manager and the civil engineering consultant should be available to him as needed. There is line authority between the project manager and the superintendents of construction, splicing, house drops, wiring, customer connections and testing and proof of performance.

System construction involves several processes; namely, sign surface removal, trenching, removal of back fill, placing of conduits in vaults, refilling with slay or a natural fill and finally patching. If a contractor has three complete crews performing these functions at different locations within the city, the project manager should have his superintendent follow each crew each day. The construction superintendent is responsible for quality control of his crew. He should be able to make decisions on the spot which will keep the job moving and to insure the project manager that each aspect of the job is being done properly.

When the contractor submits his invoice and worksheets for payment, the construction superintendent will verify the quantity and quality of work accomplished. Upon the superintendent's approval, the invoice is forwarded to the project manager for

payment. The splicing superintendent conducts his operation in the same manner and procedures. If underground house drops and house pre-wiring are handled by contractors for testing and proof of performance, the person in charge of these activities should exert quality control and advise the project manager of any irregularities.

Ideally, construction, splicing, house wiring and house drops should be done by a single prime contractor; however, having two contractors on hand provides some flexibility for the project manager.

Unfortunately, not all underground contractors are equally experienced and/or well-financed. Therefore, it may seem prudent to accept bids for certain defined areas of your system and based upon performance of the contractor, amend the contract to extend the construction into adjacent new areas.

IV. Supervision

The organizational chart reveals that the cable TV operator provide field personnel supervising each phase of construction and that an individual should ideally be provided with each construction or installation crew. This practice results in quality control of the work being performed.

The job of the field supervisor is to make on the site decisions which will implement construction insuring a high quality of work being performed and to advise the project manager of the status of the project daily. With daily status information, the project manager can adjust the work load enabling him to meet the predetermined target date for completion. Anticipating these needs is much less expensive and easier to accomplish than correcting faults and mistakes during construction.

V. Relationships

In order to see a project through a successful completion, there must exist good relationships between and among the city, contractors, utility companies, potential subscribers and your company. Wholesome productive relationships exist for two reasons, (1) character of the individuals involved, and (2) the communication which exists among them. To begin with weekly meetings should be established with representatives from each company involved in the project. At these meetings, the procedures should be established to correct any damaged utility line or subscriber's property with the minimum inconvenience to all. After the project is underway, the meeting time could well be extended to twice each month. Memorandums, with copies to each company representative, aid in informing people of the result of the meeting and in communication.

Operators should be equally concerned with the relationships that exist within their own company. The perpetual conflict between the technical and marketing areas can be resolved by a blanket of complete understanding of the problems involved. Marketing is dedicated to saturate the system with subscribers pressing the technical people to rush their work so that salesmen can keep promises to the potential subscribers. Frequent and regular communication between the marketing and technical personnel tends to alleviate sticky problems.

Summary

Five basic points were presented in this paper. They are:

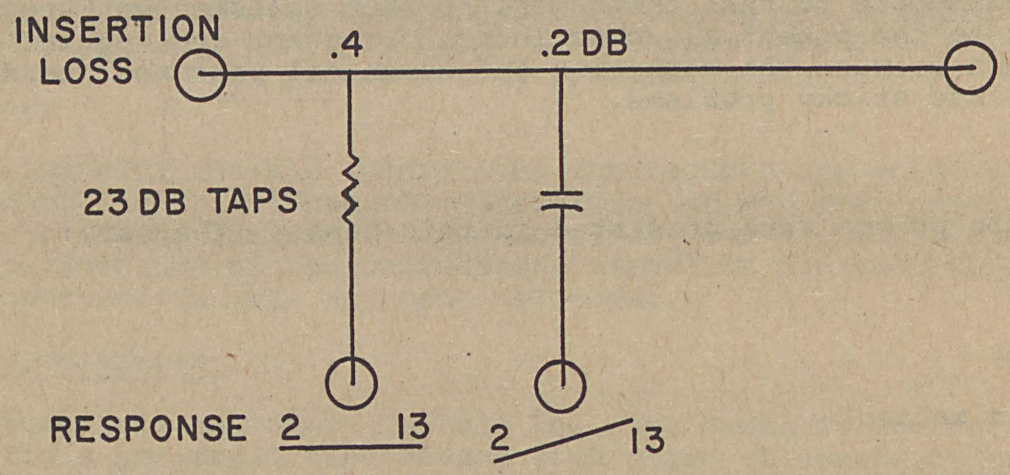
1. Cost
2. Plans
3. Organization
4. Supervision
5. Relationships

It is believed that cost can best be controlled by the batch flow method under the supervision of field personnel responsible to the project manager.

Plans complete in all details are fundamental for a successful project. Operators should work closely with their municipal jurisdiction to establish the ground rules prior to beginning construction. Frequent and regular meetings among all aspects of the construction organization contribute to the understanding of the other fellow's problem.

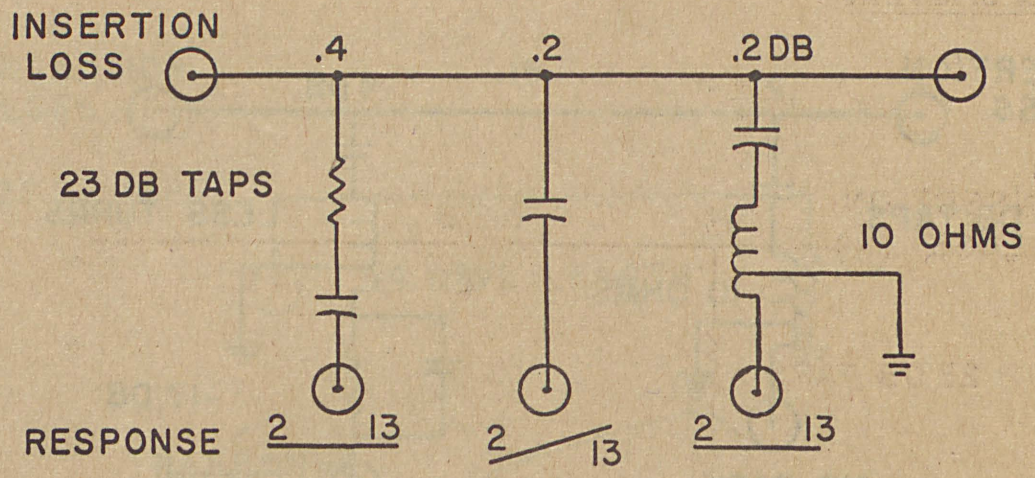
Will there be any risk if operators put into practice all the suggestions in this paper? Yes, there will be. But we wouldn't have America today if Columbus didn't risk a little. Good luck.

PRESTON SPRADLIN



NO BACK MATCH 1

In the very beginning of CATV, two taps were used extensively. First, a resistive tap as shown and followed by the capacitive tap. Each were acceptable in a low bank system (channels 2 to 6). The capacitive tap was more popular because it has less insertion loss and, with its built-in tilt, helped compensate for cable losses. Being a capacitor, it naturally provided AC isolation, although a capacitor could be inserted in series with the resistor. Neither unit was backmatched but this was not too important before the coming of color. For our discussion, we will consider a tap value of 23 dB.

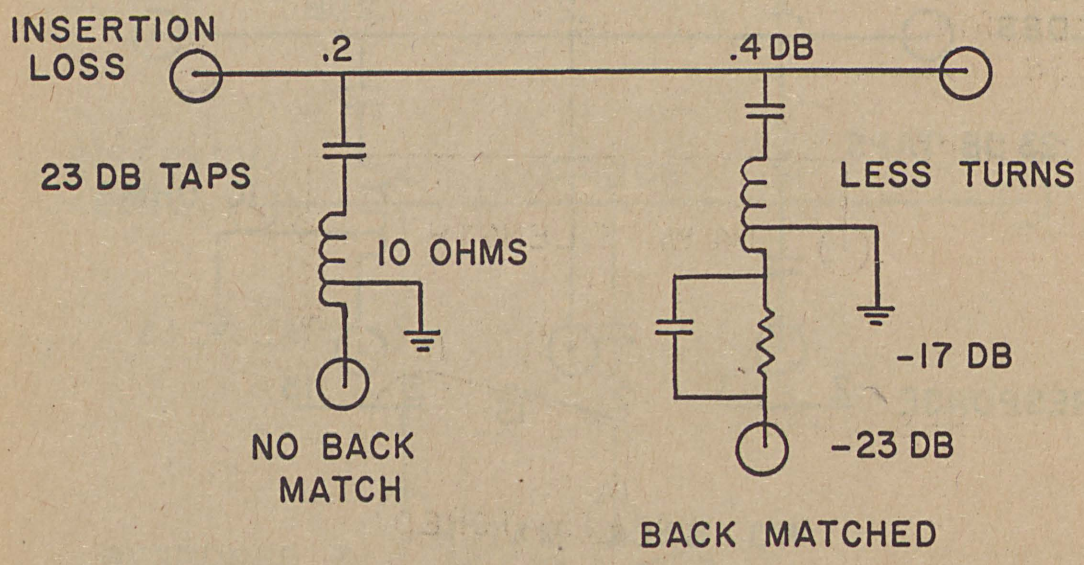


NO BACK MATCH

2

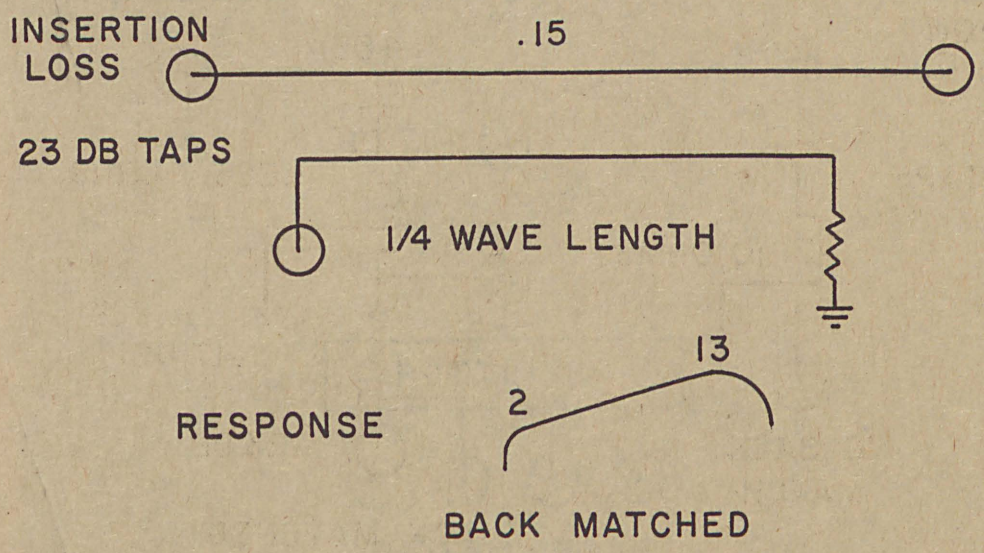
The next type of tap to come into popular use with the event of all-band systems was the transformer tap as shown. It featured low insertion loss and flat response. The capacitive tap was unacceptable in all band systems because of its extreme tilt and resulting low tap loss at Channel 13. The big disadvantage of the transformer tap was that it too wasn't back-matched.

In some color situations, it was necessary to use a pad preceding the TV set transformer to keep down standing waves.



3

A modification of the transformer tap made it a back-matched unit but brought about a strong disadvantage, which was more insertion loss. The first transformer tap shown has a back-match impedance of approximately 10 ohms, depending on frequency. To back-match this, a resistor was merely inserted in series with the output lead to match it. A small shunt capacitor was used to compensate for high frequencies. This resistor resulted in an additional 6 dB loss to the tap. In order to keep our tap value at 23 dB, we must use less turns on the transformer so that our junction point (Series resistor & transformer) is -17 dB -6 dB through the resistor which = -23 dB at output. This change in the transformer brought about more insertion loss to the thru line or .4 dB. This approximately equals the resistor tap insertion loss, but it has the additional feature of being back-matched. To this point we have not mentioned VSWR (return loss,) - but we can expect that more insertion loss will result in lower return losses, which brings us to our next consideration.

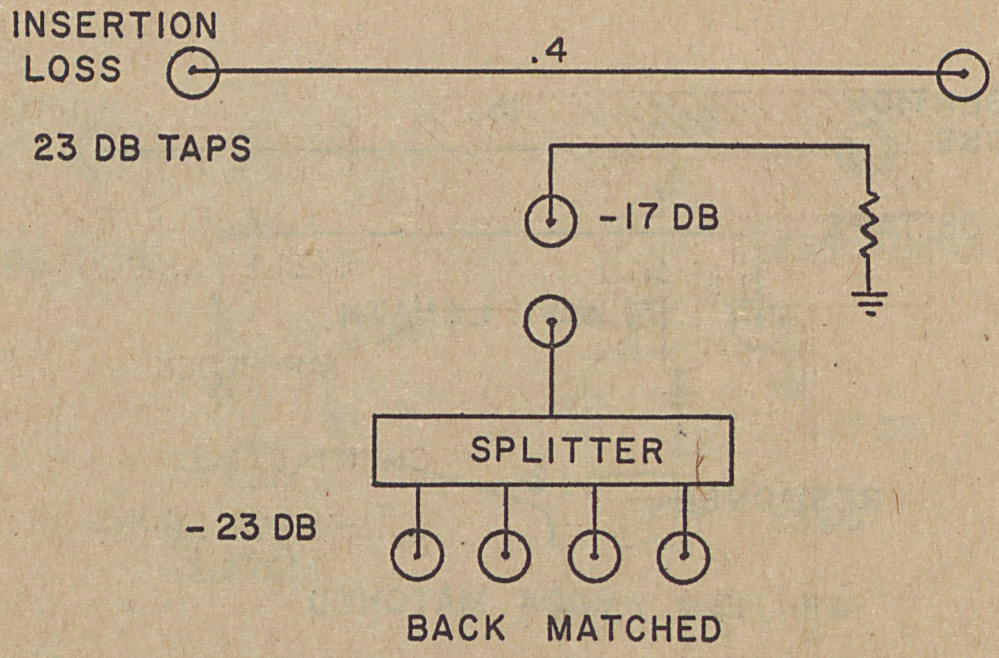


4

Directional Coupler

The Directional Coupler - or in-line tap - has come into extreme popularity because it provides several advantages over the previous units. (1) Low insertion loss (2) A flat to slightly tilted response (dependent on design) (3) Directivity (4) Back-match without series resistors resulting in less insertion losses. You might say it is the ultimate to date. It does have the disadvantage that the cable must be cut at each tap with resulting additional costs in labor and the increased cost of the basic unit - it also gives us additional possible trouble points due to the connectors involved.

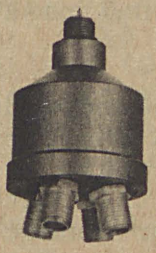
The directional coupler can also provide a better VSWR (return loss) if properly designed than the pressure tap because it goes in series with the coaxial cable and a certain amount of compensation can be done to maintain this match, while the pressure tap can only parallel the center conductor and as the insertion loss increases the return loss goes down.



5

The type of tap shown is the strip line version utilizing a 1/4 wave length principle.

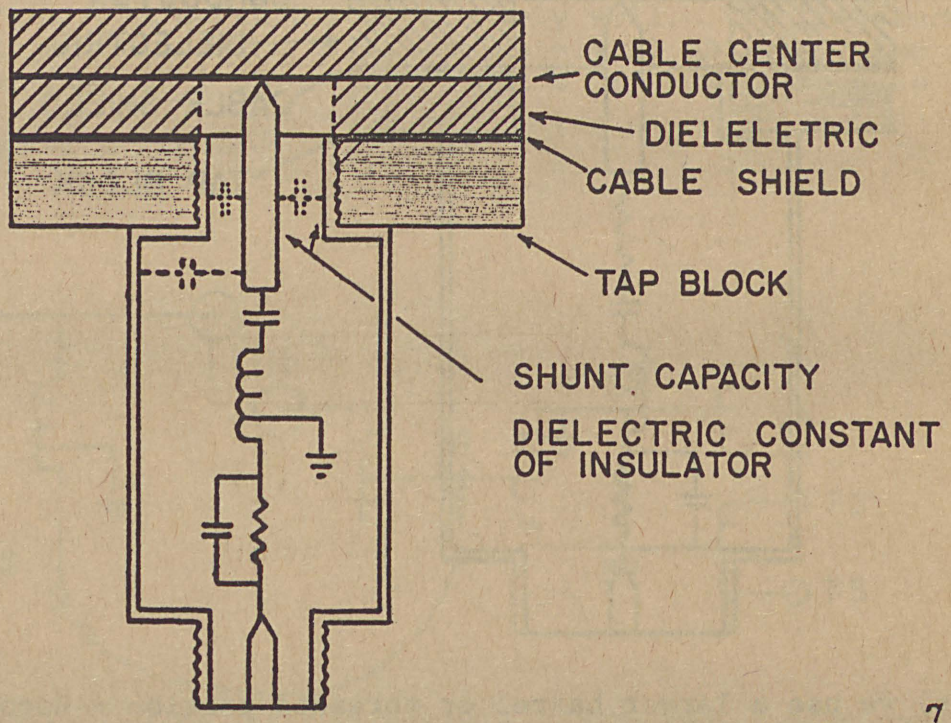
The directional coupler can also provide 4 outlets with only the expected increase of insertion loss - many units give an option of single, -2, or 4 outputs.



6

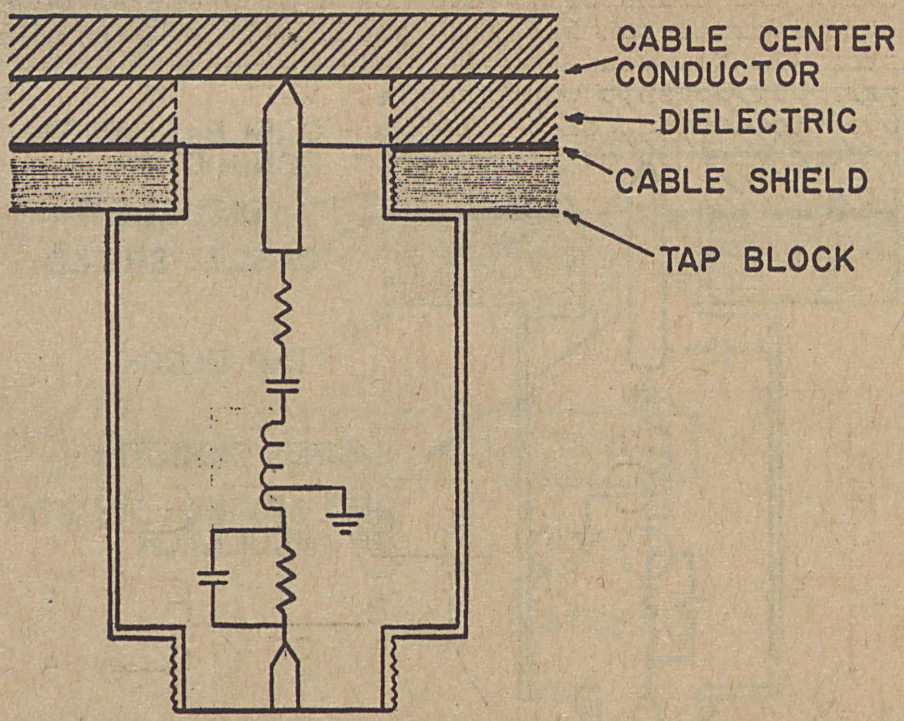
What we will attempt to do is design a multi-tap with as many features of the directional coupler as possible, yet stay with the old school - of not buying a thousand-foot reel of cable, hang it in the air, and then cut it into 8-10 pieces. In short - in existing systems, we like the pressure tap principle.

The tap units discussed are circuits built into a pressure tap which has several factors we must consider.



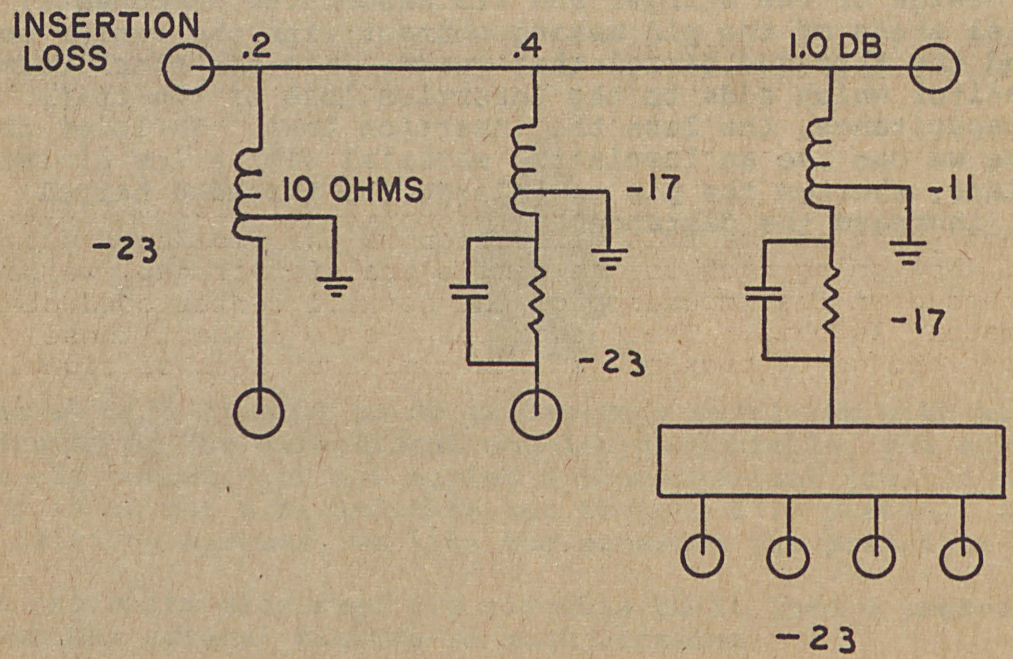
7

The cut-away view of the pressure tap shown is typical and must receive several considerations in its design. The most important being the design of the Stinger and its associated components. The parallel areas of the pin making contact with the center conductor, and the threaded barrel that screws into the block form a small capacitor which adds to the insertion loss of the unit. So the less capacitance, the less the insertion loss. To lower the capacitance we can use an insulating material with a low dielectric constant, shorten the pin or enlarge the threaded barrel which will increase the distance.



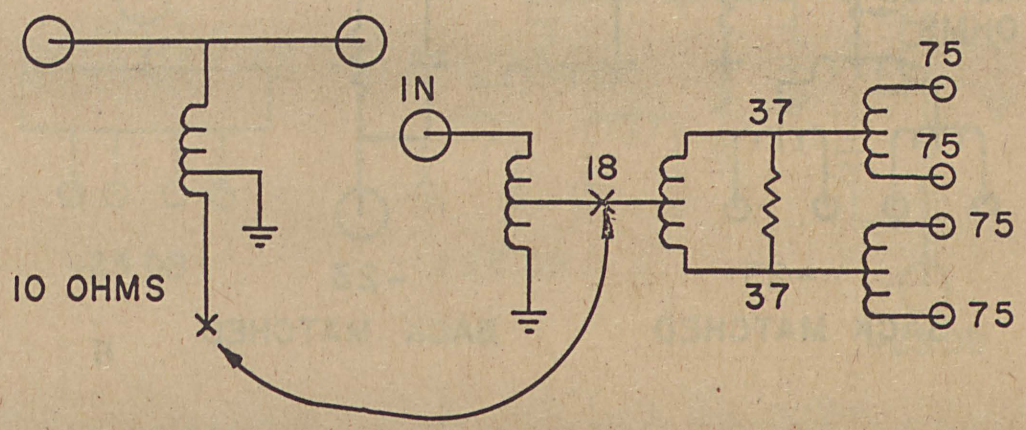
8

First, we use a larger barrel or threaded portion - Second, we use a low dielectric constant material and Third, we insert a small resistor in the immediate lead shortening the pin - all these factors lessen the capacitance, lower the insertion loss and improve the return loss.



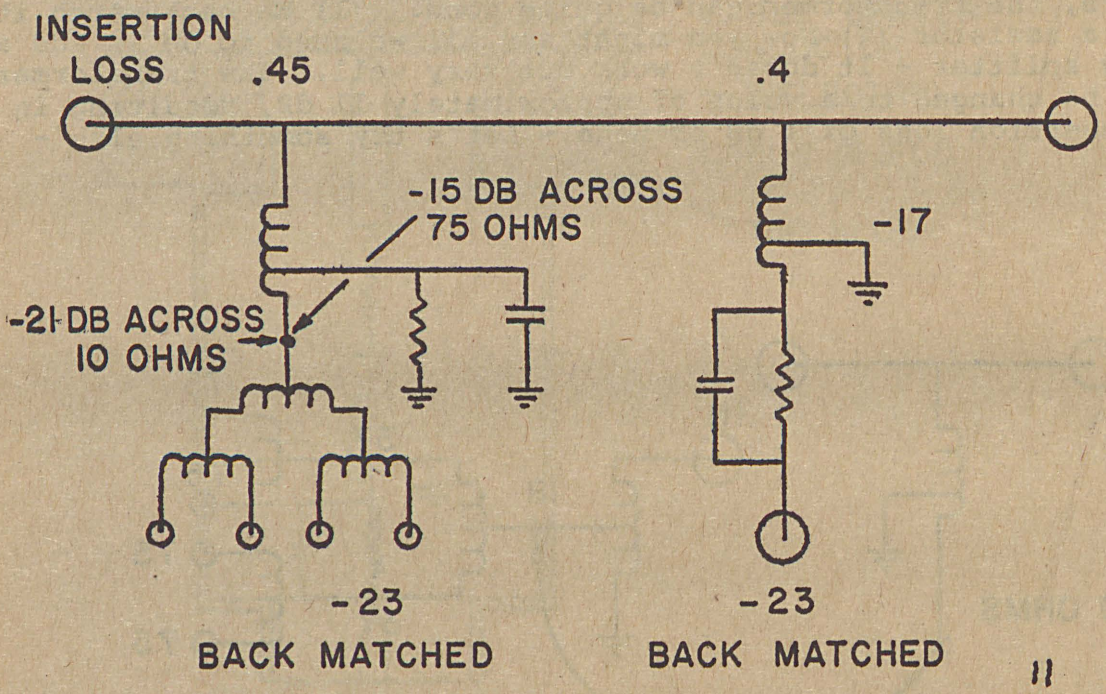
9

Let's now review the transformer tap for a minute - as we said before, the transformer can be quite good. (1) We back-match it with a resistor (2) Now you might say all we need to do is add a 4-way splitter - It doesn't work out very well. The transformer must be changed to a value of approximately 11 dB, resulting in an insertion loss of 1 dB or none - Let's try something else -

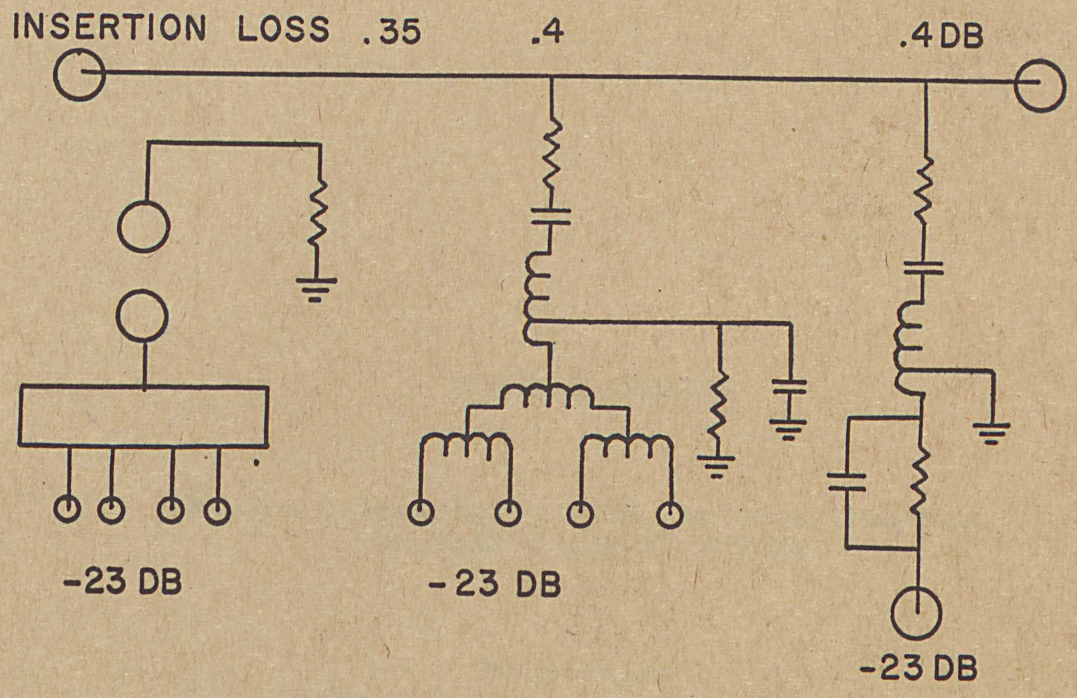


10

Here is shown a 75 ohm 4-way splitter. The input is 75 ohms and the first coil steps the impedance down to approximately 18 ohms (it varies with frequency). The second coil steps it up to 37 ohms and the next pair of coils brings the impedance up to 75 ohms with an overall theoretical loss of 6.5 dB - capacitors (not shown) are used on the coil junctions to compensate for frequency. The important junction for this discussion is the impedance point of 18 ohms. Now going back to the simple transformer tap, we see the coil steps down the impedance of the coaxial center conductor to approximately 10 ohms. The answer then is to connect these two junctions and get a back-match with a minimum loss of signal.



Here we show the second portion of the 4-way splitter matched to the 10 ohm point on the transformer tap. The transformer coil was adjusted to provide a -15 dB across 75 ohms, but if we could read it at 10 ohms it would be a -21 dB junction - The impedance is then stepped up to 75 ohms across four outputs with only 2 dB of loss. The unit with 4 outputs then compares favorably with the single tap.



12

We can now favorably compare the four-way multi-tap with the directional (in-line tap) especially in the values over 20 dB. It is made in 16-20-25-30 & 35 dB values. The VSWR can compare to a directional coupler in all values over 16 dB value.

CATV HEADEND ENGINEERING

Session Chairman:
Walter S. Wydro

Participants:

Steven I. Biro
"Minimum Acceptance Testing of CATV Head-Ends"

George C. Kanen
"In-System Conversion 24 Channels"

Philip D. Hamlin
"Converters and Television Sets as CATV Terminal Devices"

Patrick R. J. Court
"Considerations in the Design and Use
of CATV Converters"

Floyd O. Vincent
"The Converter's Place in Today's Modern Cable System"

B. R. Carter
"Solid State Headends"

STEVEN I. BIRO

It is my objective to start a useful dialogue between CATV operators and engineers on the Acceptance Testing Procedures for CATV Head-Ends.

A block diagram of an average (10 channel) CATV Head-End is presented on Figure 1. The ideal Head-End acceptance procedure would encompass the testing of all components shown in this schematic and checking all specifications. It is doubtful that many CATV operators could afford the time, instrumentation and the engineering support required for a thoroughly conducted Acceptance Test.

For all practical purposes, a one-day testing of the Head-End should be satisfactory, demonstrating both Performance of the Antenna System and Performance of the Signal Processing Network. For each of these:

A. PERFORMANCE OF THE ANTENNA SYSTEM

1. Proper orientation of the antenna-arrays.
2. Checking antenna-array gain.
3. A co-channel protection test. (Optional)

B. PERFORMANCE OF THE SIGNAL PROCESSING NETWORK

1. Comparing off-the-air and Head-End test point pictures.
2. Demonstrating the absence of interference beats.
3. Triggering of the substitution oscillators.
4. AGC action of the receiver.

In order to perform above tests, the following minimum test-instrumentation and equipment is required:

1. Field strength meter (FSM)
2. 17" color TV receiver
3. Coaxial switch
4. 3 dB hybrid splitter
5. Step attenuator
6. Search antenna
7. 10/20 kHz tunable B.P. filter (Optional)
8. Audio millivoltmeter (Optional)

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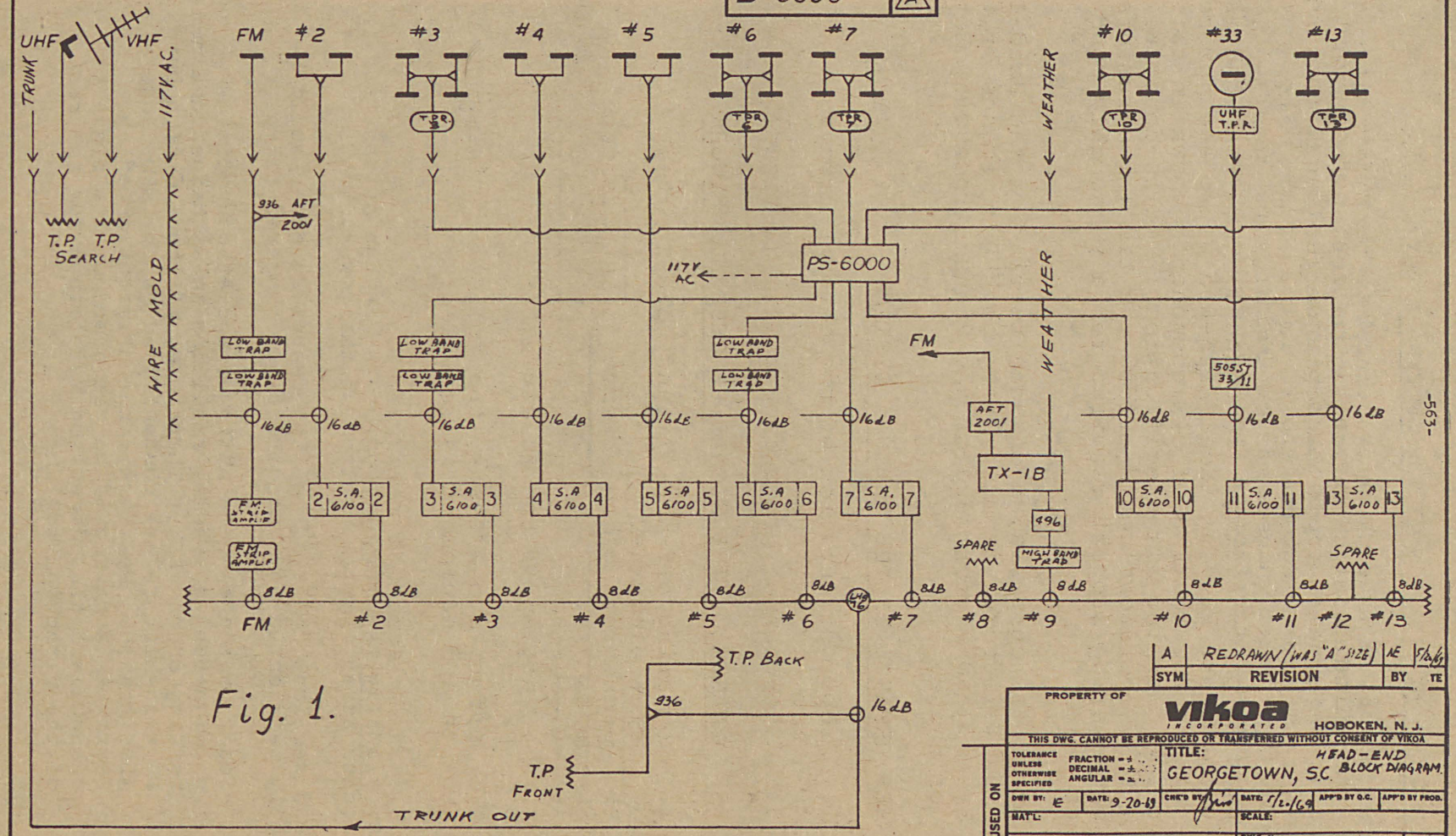


Fig. 1.

-563-

SYM	REVISION	BY	TE
A	REDRAWN (WAS "A" SIZE)	NE	5/26/69

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TOLERANCE UNLESS OTHERWISE SPECIFIED: FRACTION = ±, DECIMAL = ±, ANGULAR = ±

TITLE: HEAD-END BLOCK DIAGRAM GEORGETOWN, S.C.

DWN BY: E	DATE: 9-20-69	CHK'D BY:	DATE: 12-16-69	APP'D BY Q.C.	APP'D BY PROD.

MAT'L: SCALE:

FINISH: DWG. NO. 5639 SIZE B A

USED ON

CHECKING THE ORIENTATION OF THE ANTENNA ARRAY

The testing of the antenna arrays cannot be performed without a rotor mounted Search Antenna at the top of the CATV tower. Arranging the proper connections according to Figure 2., the search antenna shall be rotated until the field strength meter shows a maximum reading, and the TV receiver a good, interference free picture.

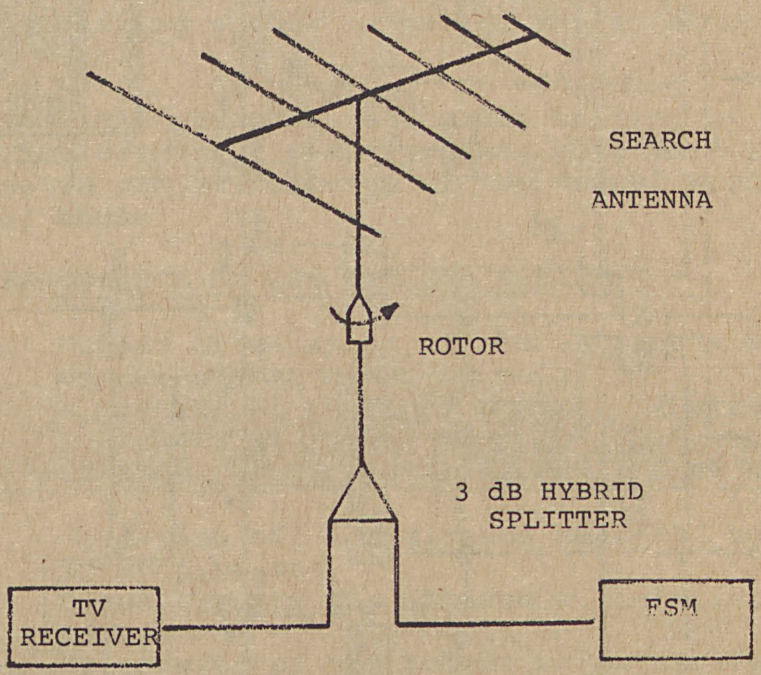


Fig. 2

Compare visually the orientation of the Search Antenna and the antenna array from the bottom of the tower.

If the directions don't agree, the search antenna should be carefully reoriented and the directions compared again.

NOTE: Search antennas have narrower radiation patterns on high-band channels, resulting in a sharper maximum reading on the FSM. Therefore, if low and high-band TV transmitters are concentrated on the same tower (Los Angeles, New York), the orientation of the Search Antenna should be performed on the highest channel and that direction maintained for the rest of the direction testing.

COMPARING THE ANTENNA ARRAY WITH THE SEARCH ANTENNA

Using the Search Antenna as a reference, the signal level and picture quality of the Antenna Array shall be checked channel by channel, using the instrumentation of Figure 3. In this set-up, the coaxial switch has a very important function: It eliminates the time factor when rapidly fading signals of distant TV stations have to be compared. (Switching of the coaxial switch requires only a fraction of a second.)

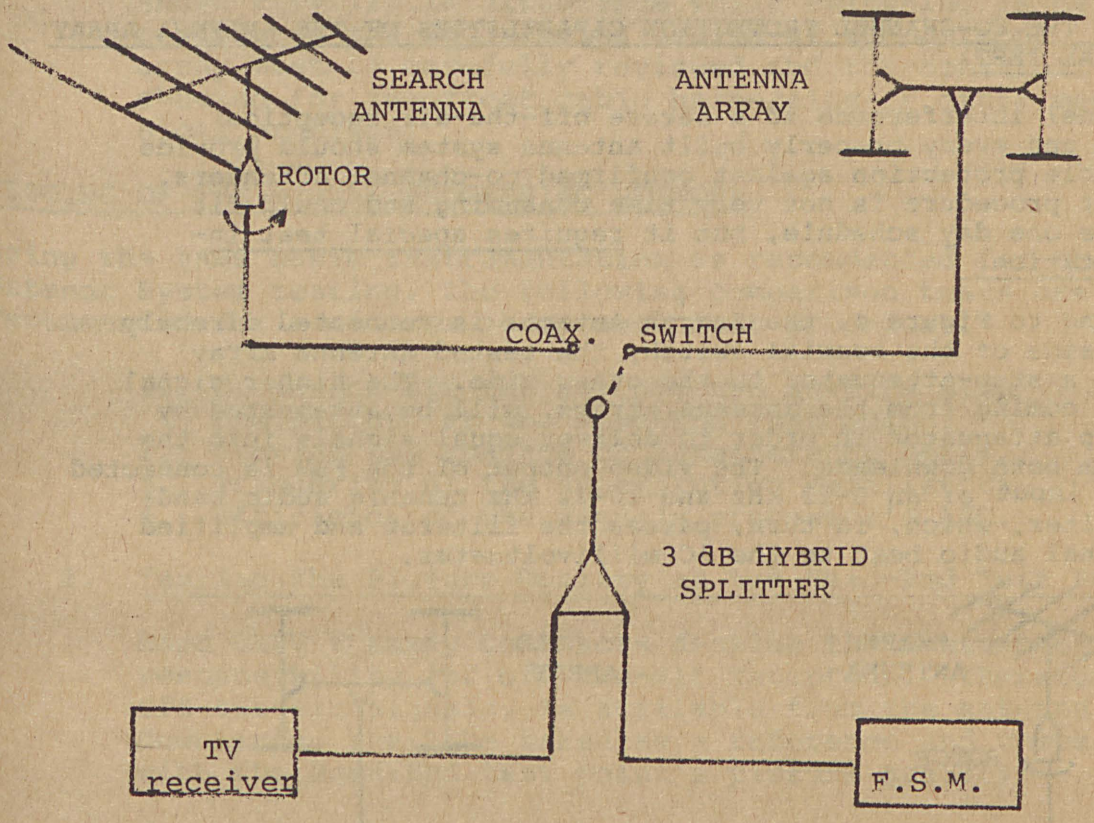


Fig. 3.

Antenna Array Gain testing can be accomplished by switching from the Antenna Array to the Search Antenna. Knowing the antenna gain of the Search Antenna, while compensating both for the difference in the antenna height and for downlead attenuation, the Antenna Array gain can be evaluated. A single channel, several hundred dollar CATV Antenna should out-perform by several dB gain the all-band $ 40 to $ 50 Search Antenna.

The test set up of Figure 3 may be also used for checking off-the-air picture quality and interference protection. Using the Color TV receiver as a reference, and switching from the properly oriented Search Antenna to the Antenna Array, the latter should provide superior color fidelity, more contrast and better picture resolution. At the same time, picture quality may be also judged for absence of interfering signals. The antenna arrays should clearly demonstrate less co-channel beats and less AC or r-f interference. This quantitative testing is fast, straight forward and the required instrumentation makes it feasable even in the less instrumented CATV systems.

TESTING THE CO-CHANNEL PROTECTION CAPABILITIES OF THE ANTENNA ARRAY (OPTIONAL TEST)

Co-channel interference is a severe off-the-air reception problem and every properly built antenna system should provide reasonable protection against confirmed co-channel offenders. The test procedure is not very time consuming and could fit into the one day schedule, but it requires special test instrumentation.

According to Figure 4, the Search Antenna is connected directly to one side of the coaxial switch, the tested Antenna Array through a step-attenuator to the other side. The higher signal levels, coming from the antenna arrays, will be attenuated by the step attenuator in order to deliver equal signals into the FSM from both downleads. The video output of the FSM is connected to the input of an 8-12 kHz and 18-22 kHz tunable audio bandpass filter, which, in turn, passes the filtered and amplified co-channel audio beat to the AC millivoltmeter.

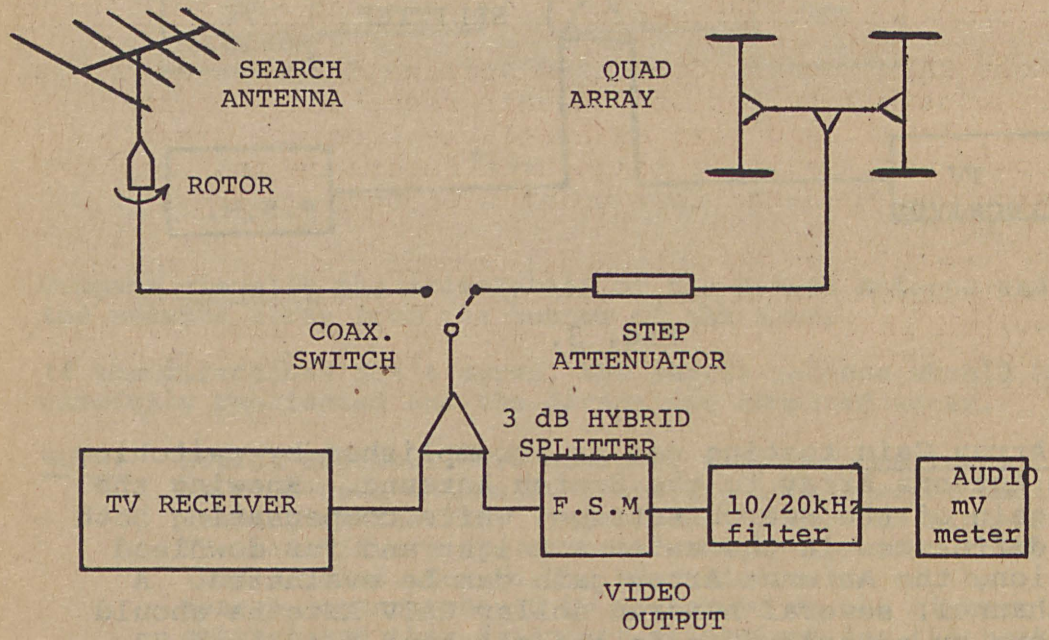


Fig. 4.

Provided the Search Antenna is pointing in the right direction, we obtain a quantitative reading of the co-channel interference from both antenna types. When distant channels are to be checked, the comparison test must be repeated several times to obtain an average value under rapidly fading signal propagation conditions.

NOTE: It is reasonable to expect a 6 to 10 dB improvement in co-channel protection from an antenna array over an all channel search antenna, but 15dB additonal protection should be called excellent. If this test shows very little difference while switching is being performed, the engineering design of the antenna array must be carefully reviewed and the construction checked for incorrect cable harnessing or other mechanical problems.

TESTING OF THE SIGNAL PROCESSING NETWORK

Using the same basic instrumentation as recommended for the Antenna System testing, the following comparison tests are recommended for a minimum acceptance test procedure.

1. Comparing off the air picture quality with the picture at the Head-End Test Point.
2. Proving the absence of interference beats.
3. Triggering of the substitution oscillators.
4. Efficiency of the signals processor's AGC.

1. Testing the Picture Quality at the Head-End Test Points

Most CATV Turnkey Contracts decline the contractors' responsibility for off-the-air reception. Therefore, off-the-air signals, as available from the antenna downleads, shall be taken as a reference and compared with the Head-End test point's picture quality.

Figure 4 shows the block diagram of the recommended test instrumentation. The left side of the coaxial switch is connected to the antenna downlead, the other side, through a step-attenuator, to the Head-End test point.

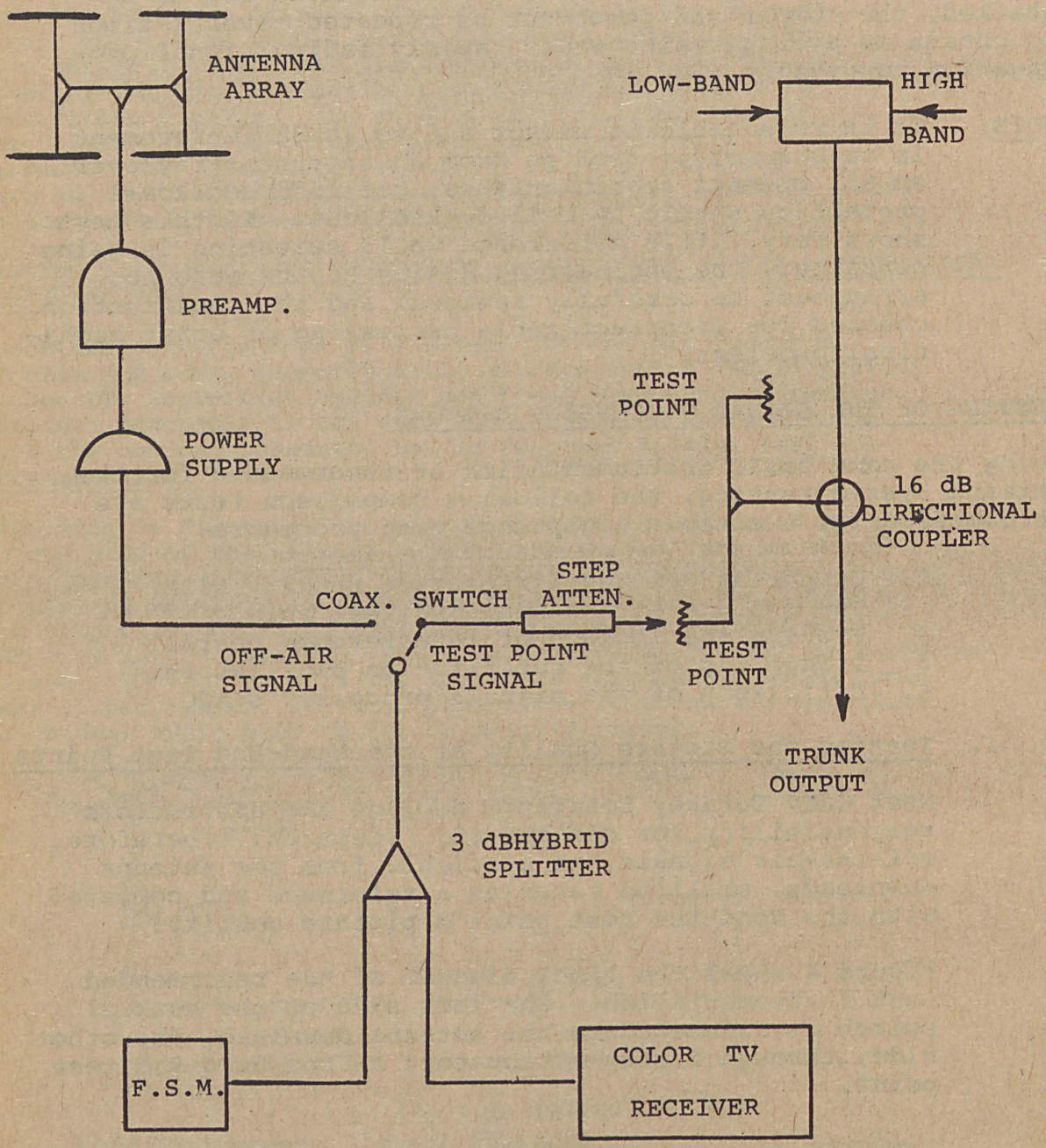

ANTENNA ARRAY
LOW-BAND
HIGH BAND
PREAMP.
TEST POINT
POWER SUPPLY
16 dB DIRECTIONAL COUPLER
STEP ATTEN.
COAX. SWITCH
OFF-AIR SIGNAL
TEST POINT SIGNAL
TEST POINT
TRUNK OUTPUT
3 dBHYBRID SPLITTER
F.S.M.
COLOR TV RECEIVER

Fig. 5.

The step-attenuator must be manipulated to feed the TV receiver with equal signal levels in both modes of operation.

Feeding the TV receiver from the antenna downlead, the TV receiver shall be carefully tuned and adjusted to provide the best off-the air color picture quality. Then, switching the TV receiver to the Head-End Test Point, but without touching it's fine tuning, the picture should not demonstrate any deteoriation in color fidelity or in picture resolution. This procedure must be repeated on every channel and the observations entered into the log-book.

Although this test is quite simple and requires very limited instrumentation, it reveals a great deal about the critical electrical parameters of the signal processing networks, such as frequency response, differential gain and differential phase conditions. The testing of these parameters would otherwise necessitate extremely precise and expensive laboratory type instrumentation, normally not available for CATV field testing.

2. Checking the Absence of Interference Beats

Maintaining the test set-up of Figure 4, the TV receiver shall be properly tuned for best off-the air signal, then switched to the Head-End test point. First, the adjacent channel signal processing units will be turned off, followed later by other units. The TV picture should not demonstrate any change in the background (random) noise, hash or interference beat contents. If there is a sudden change (disappearance) in the interference level, we have evidence that it has been generated within the Signal Processing Network and proper steps shall be taken for the elimination of this problem.

3. Demonstrating the Performance of the Substitution Carrier Oscillators

In the absence of off-the air signals the signal processor should switch automatically into the substitution mode of operation and stay in that mode until the desired TV signal returns on the air. The demonstration should begin with a disconnect of the antenna downleads. The substitution oscillator should trigger within 10 to 20 seconds. Reconnecting the antenna downlead, the signal processor should return instantly to its regular mode of operation.

The measured video carrier levels should not change more than ±1/2dB between the regular and substitution mode of operation. This condition can be easily checked with a FSM at the Head-End test point.

4. Testing the Signal Processor's AGC Action

The specifications of better quality signal processing units call for a ±1/2dB change in the output level if the input signal varies from -14 dBmV to +26 dBmV. For testing the efficiency of the AGC, off the air signals may be used.

A FSM shall be connected through a 20dB pad to the signal processor's output test point. The antenna downleads shall feed the input through a step-attenuator. Reducing the input signal level to the minimum -14 dBmV level or below, the output must be carefully monitored and recorded by the FSM.

Although this testing procedure may not cover the full 40dB dynamic range of AGC action, it will clearly demonstrate the performance of the AGC under practical anticipated fading conditions.

For a full scale AGC testing the application of calbrated signal generators are mandatory.

SUMMARY

It is the author's opinion that a one day testing, using generally available test instrumentation, is only the first but the right step before accepting any Head-End.

Recommendations for a more sophisticated Head-End Acceptance Test will be published in a later presentation.

GEORGE C. KANEN

The desire for increased channel capacity in a CATV distribution system--spurred by the addition of locally originated signals as well as off-air available stations--has created a whole new area of problems for the system operator as well as equipment manufacturers.

Many of us have seen the industry go from a two or three channel system using "strip type" amplifiers as distribution units to the so-called "broadband amplifiers" that boosted the low-band channels allowing carriage of the grand total of five channels, to the now standard twelve channel amplifiers for what was called the "ultimate in CATV equipment." We were barely used to the vagaries and additional techniques required with the twelve channel amplifier when the first twenty channel equipment became available from the suppliers.

The new twenty-plus channel equipment, whether it adds the additional channels in the mid-band between 120 MHz to 174 MHz, the octave approach with twenty channels carried between 120 MHz and 240 MHz, or whether it be a combination of the previous two, the basic problem still is that some or all of the channels carried on the system are non-standard TV frequencies, necessitating that these be converted to standard channels for the individual TV subscriber's set.

A method that exists, and several manufacturers offer this device, is the top of the set converter. This unit, probably familiar to all of us, incorporates a switch and a tuner to by-pass standard channels to the TV set or alternately to convert the non-standard channels to one standard one. Required, quite obviously, is one of these units per television set--a cost that quite rapidly becomes great, particularly if there are quite a few two and three set homes in your community.

If converters or conversion of some form are to be eliminated then, we must of necessity, build a full dual cable system--that is, build two, twelve channel systems side by side, run a drop cable from each feeder to the TV set and use an A-B switch at the set to select one 12 channel system or the other twelve channel system. This, although expensive, certainly does away with conversion. Let's look for a moment at another way to accomplish twenty-four channels, exploring the how and the relative costs involved.

In our system in Newport Beach, we are carrying a full twenty channels of TV signals and employ a specially designed conversion unit placed in the CATV system ahead of the subscriber, to convert back to standard channels.

The system design, with this approach looks like Figure 1.

The trunkline is a single cable carrying all signals basically in an octave configuration. At trunkline locations, where bridging stations would occur, is placed the System Converter. This unit accepts the octave frequency TV signals and electronically converts them to two outputs with up to 12 standard TV channels per output. For example, 24 signals carried on the trunk are converted to separate, isolated outputs for distribution --12 standard TV channels per output. (Figure 2)

Since the converter unit is placed at the trunk amplifier where a bridger would occur in the system, then the In-System Converter functions as a "bridger-converter" and requires the same number of distribution leg outputs as the standard bridger i.e. four except that in this case, because of conversion within the unit, there are eight outputs, two per distribution leg.

A basic block diagram of the in-system converter will serve to clarify the operation of the unit. (Figure 3)

The input from the octave trunkline is coupled to the converter, split through quality and exact filters, combined in mixers with local oscillators to produce standard TV channel frequencies, amplified in separate 12 channel amplifier sections and then four-way split to provide both an "A" and a "B" output--four outputs from the "A" side and four outputs from the "B" side. Distribution legs then from the converter throughout the distribution are dual--one feeder for the "A" side and one feeder for the "B" side.

Let's look at the total configuration from the trunk through a distribution section and analyze costs involved with this method. The next illustration (Figure 4) would be that of a typical bridger/converter distribution section--further assuming that we have a good design, that all four feeder sections from the bridger/converter are utilized, and that we have two (2) cascaded line extenders in each leg. The cost analysis to do then is to calculate the extra cost involved (above the basic 12 channel system) for this method.

Now let's take the individual items which go to make up the second or dual part of the distribution system and see what the additional costs are.

Feeder Cable (10,000')	$ 900.00
Directional Taps (80)	960.00
Line Extenders (8)	1,120.00
Converter (less bridger credit)	1,300.00
Tap splicing labor (80)	200.00
Total Additional Cost	$4,480.00

Now let's count the customers that we can serve from this design using an average of 3.2 customers per tap location--we then have a potential of 256 subscribers. On a dedicated plant basis (service to all subscribers), our per dwelling unit cost is $17.50.

The dwelling unit cost with the top of the set converter system would be $25 per dwelling unit (the cost of the set top converter) if each dwelling unit served had only one TV set. Since our industry average appears to be 1.5 TV sets per home our top of the set cost per dwelling unit would average $37.50 as compared to the $17.50 for the in-system method.

In summary, the in-system conversion method has been proven in our system operation in Newport Beach, the principle and operation of the device is straight forward and relatively simple from a system design and technician maintenance standpoint, and the additional costs above basic 12 channel operation are substantially lower than other existing methods.

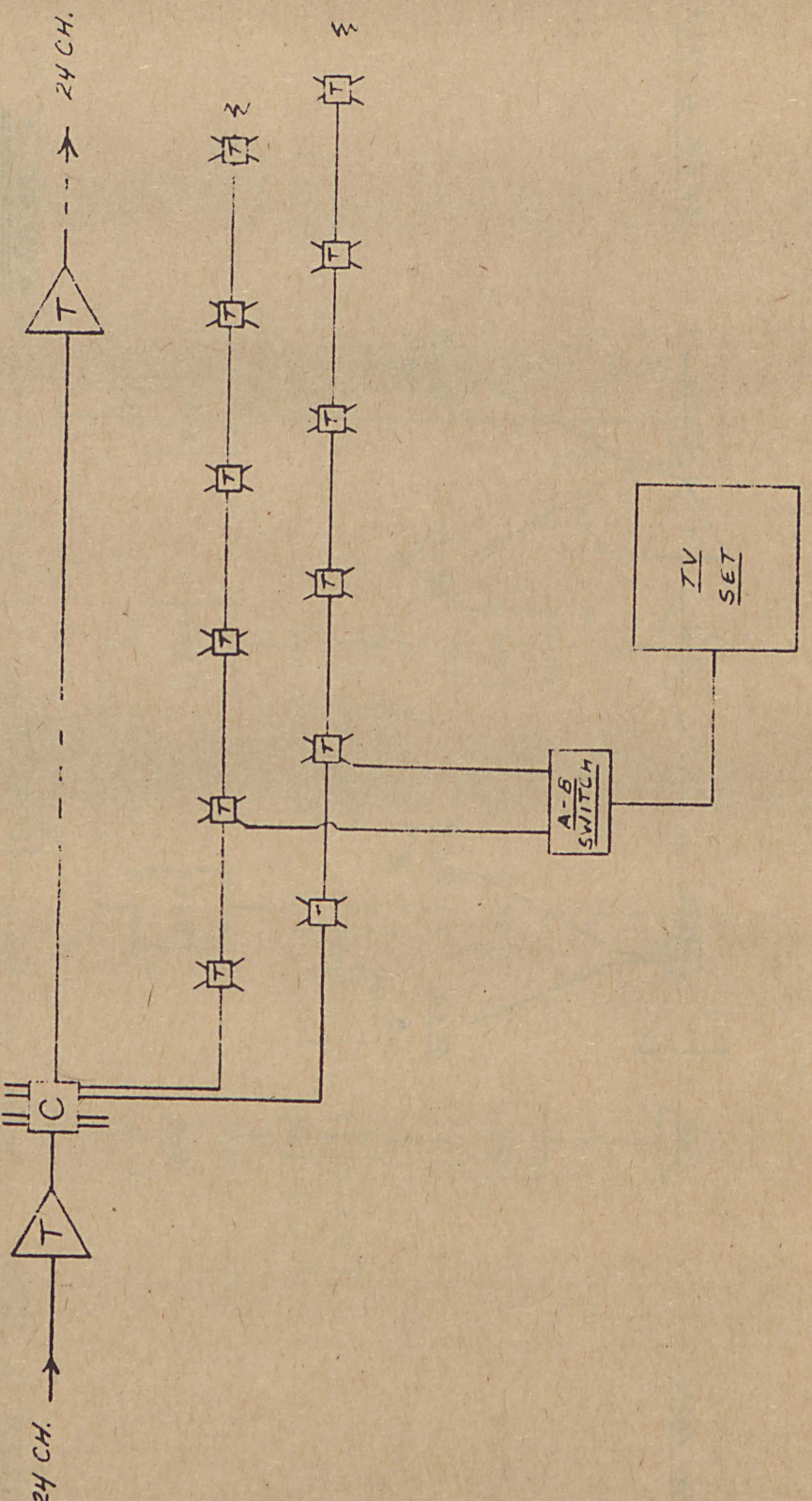


FIGURE 1

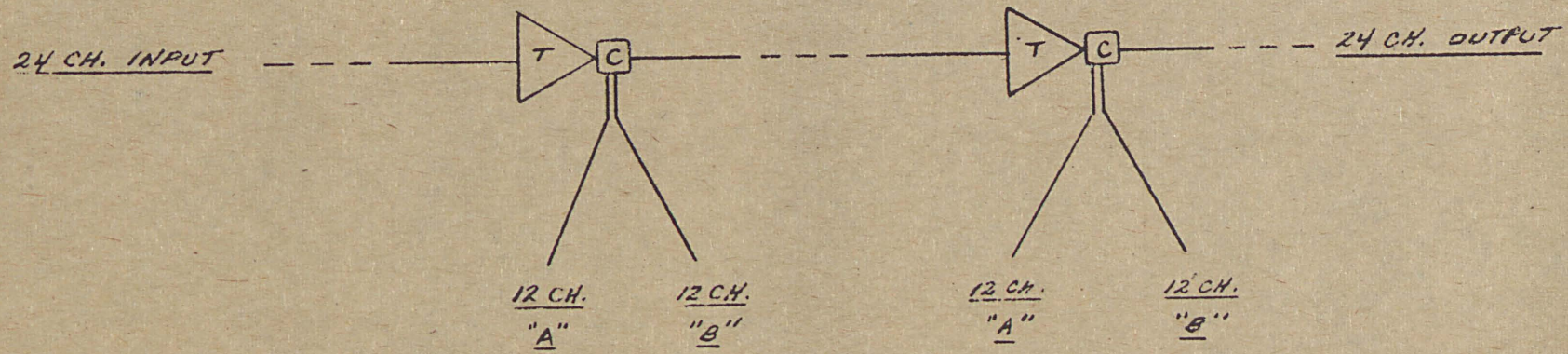


FIGURE 2

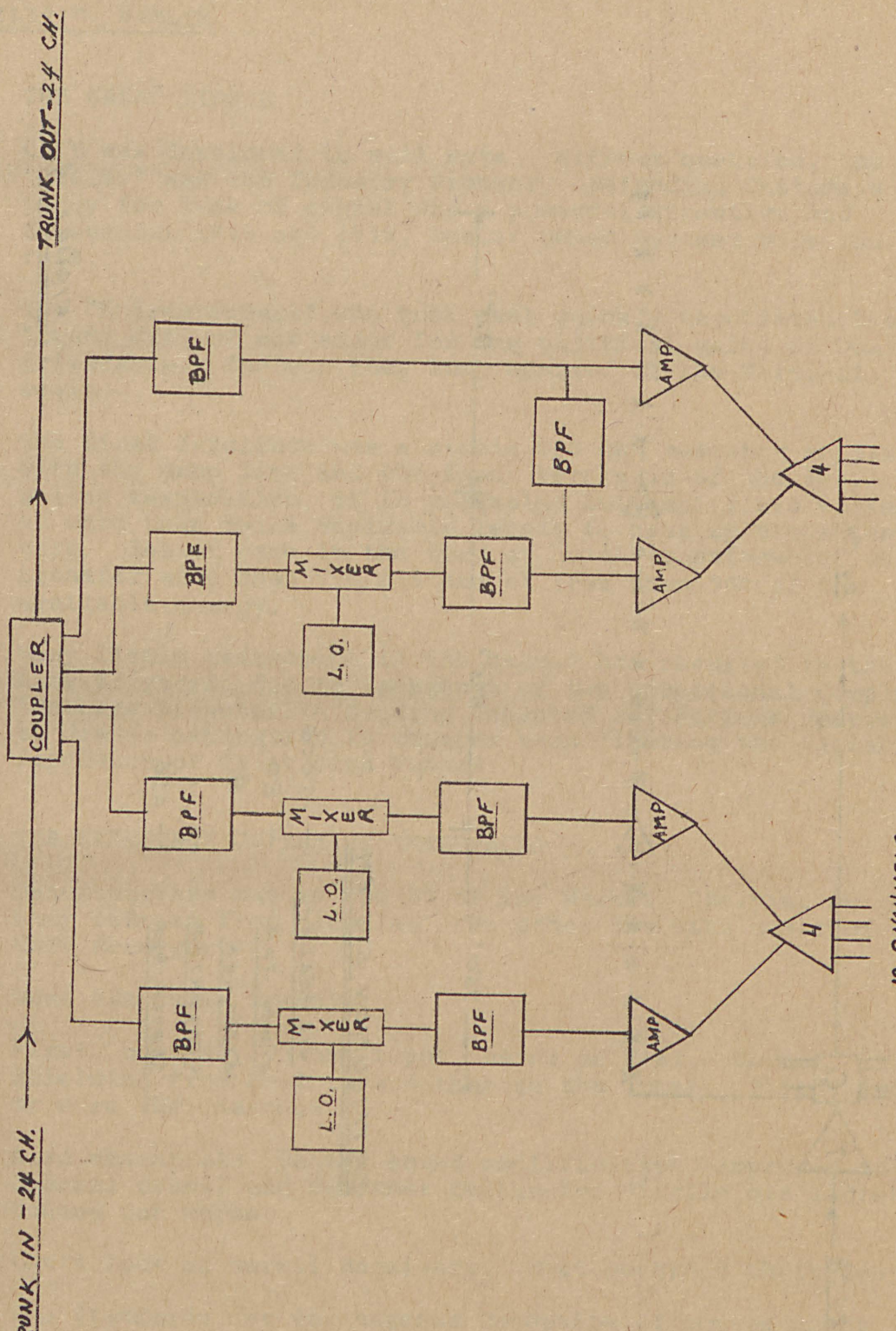
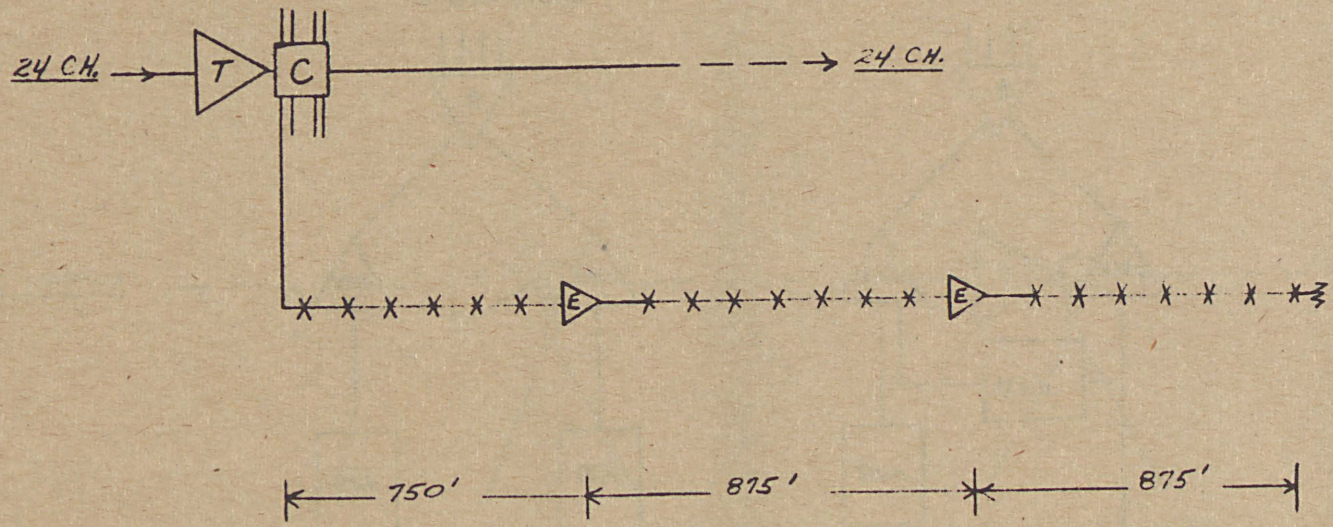

TRUNK IN - 24 CH.
TRUNK OUT - 24 CH.
COUPLER
BPF
MIXER
L.O.
AMP
4
12 CHANNELS
2 - 13

FIGURE 3



DISTRIBUTION SYSTEM

.412 FEEDER	— 10,000'
4-WAY TAP	— 80
EXTENDER	— 8
CONVERTER	— 1
SUBSCRIBER	— 256

FIGURE 4

PHILIP D. HAMLIN

I. THE GREAT CIRCLE

CATV was developed to sell sets. Without question, the "Dealer" was the Industry Pioneer. Refunding Customers' money for lack of signal was a powerful incentive and throughout 1948 and 1949, Dealer Owned Systems were the rule.

The "Entrepreneurs" who took over quickly negotiated the "trade off" of set sales for the political gains of Dealer friendship. Therein they lost control of the Terminal Device.

The first Interface was a simple 100 ohm resistor in parallel with the drop line and the input terminals of the Set. As a line termination, it is unequaled but amplifiers worked at more than twice desirable levels to heat up those resistors. Relief came in the form of balun transformers, which transfer more than 90% instead of less than 50% of the available energy.

Very little refinement in the baluns has occurred in the last 15 years, due to emergence of the Directional Coupler "Garbage Disposer." Sending unwanted reflections upstream to die of exhaustion is cheaper than fighting the variable impedance of Television Tuners.

II. THE EMERGENCE OF ACTIVE INTERFACES

Manufacturers say we are 2% of the Market. Relying on that, they refrain from "loading" the other 98% with costs of a CATV Receiver.

What are those costs?

First, coaxial, 75 ohm input, using an F-61. Second, 100 dB Shielding from F-61 to-and-through the Tuner. Third, twenty or more VHF Channels.

Also essential: Better sound amplification, improved adjacent channel traps, and smoother tuning for "little old ladies" tuning out worms.

Let's look at normal Receivers. What governed their design?

The Standards set for Antenna Reception of non-adjacent channels.

.....so let's look at the Antenna.

The standards dictate horizontal dipoles, with or without parasitic elements for directivity. This energy collector must be broad band over at least the channel of interest and frequently over two octaves. This encourages folding the dipole and gives a 300 ohm nominal impedance.

Twinlead is a cheap and efficient downspout for this energy, and is readily made 300 ohms.

A problem develops at the set. Single ended Tuners require unbalanced lines. To match the Tuner, a balun transforms 300 ohm twinlead to 75 ohms.

Easiest mounting for the balun is the Tuner. The Tuner is behind the Knobs, on the front of the Set, necessitating more twin lead from balun to screw terminals on the back of the set.

This arrangement is satisfactory for Antennas. The folded dipoles intercept lots of energy and pour it down the efficient twin lead. Reflected energy from indifferent to very bad match at the Tuner input is squirted back up and reradiated to oblivion by the reciprocal antenna.

.....but connect the same set to a CATV System.

The nominal 75 ohms we want is buried inside the cabinet. Between our 75 ohm cable and that Tuner is the barrier of the 11¢ balun. Hurdling this obstacle requires a $1.00 transformer, carrying our impedance upstairs to 300, from whence the set balun brings it back down to 75.

Losses are multiplied and reflections abound. Far worse, the 15 to 30 inch interconnecting twin lead is an exposed jugular, vulnerable to all ambient signals and a positive guarantee of "direct pickup."

III. UNDERSTANDING DIRECT PICKUP

Assume two signals traveling a parallel course for 20,000 feet. One travels by air, the other by cable paralleling the air path.

Arriving at the Television Set, the Air Signal cuts across twinlead from set back to balun, the balun itself, and the almost wide-open Tuner. This develops a signal.

The Cable signal also arrives. It develops a picture too .....but there is a difference. The difference is time. Assume the Cable to have a velocity factor of .6666 that of free space. Assume the Air Signal travels 900 feet per microsecond, giving the Cable Signal a speed of 600. For

every 1000 feet the Cable Signal is delayed .5 microseconds and accumulates 10 microseconds of delay.

Assume again the Tuner "sees" a +20 Signal from the Air Signal, which arrives first. The Cable Signal hits the same input with +15.

The horizontal sweep line is visible for 53 microseconds. It syncs on the first signal. The second signal, with identical information arrives later and weaker. Its sync is not enough to "seize" the horizontal oscillator but all mathematical sequences of the first signal are duplicated.....ten microseconds later. It therefore appears about one fifth of the screen to the right.

In practice, there are many differences. Airplanes provide "dancing ghosts", in which the flutter makes the direct pickup alternately stronger or weaker than the cable and control leaps from one to the other. The "direct pickup" is also plural, with numerous air paths via reflections, making variable delays visible as extra smears and ghosts.

There is infinite variety but all degrade reception.

IV. CURES FOR DIRECT PICKUP

Ghosts are invisible if down 30 dB from the desired signal. They are occasionally unnoticed at -25 dB and even tolerated close to -20.

Propagation conditions vary throughout day and night, and with weather. The objective should be -30.

This is achievable with an even start. Let the Direct Pickup be +15 and the Cable Signal +15. Wire the drop directly to the Tuner, ground braid, by-pass powerleads, pray a little, and you can barely see the ghost.

Often they come back to haunt you.

Cure depends upon degree. If System Layout permits hitting the Set Terminals with +15 dB, and Direct Pickup is +15 before the cure is attempted, success is barely possible. The undesired signal must be reduced to -15 dB for complete cure but -10 is generally acceptable. Elaborate bypassing of the balun, soldering calle to the Tuner, and other expedients will effect the cure.

In many areas, no cure can be effected at reasonable cost. This led to the "active interface."

V. CONVERTERS AS "ACTIVE INTERFACES"

Converters are the oldest active device in CATV. Most 1948 Systems converted a single channel to i-f, through a modified Television Tuner, then ran high level 25 Megacycle signals directly to sets, without intermediate amplification. The first amplifiers were developed for this i-f distribution.

Later Systems converted the available signal to Channel 2, for least line loss. With the advent of three channel Systems, all were heterodyned to Channels 2, 4, and 6. "Direct Pickup" was cured on a single channel Seattle System I constructed in 1949 by Home Convertors, converting the single channel 5 to i-f, then back to Channel 2. "Block conversion," heterodyning 5-6, later solved the problem at the Head End.

All Big City Systems solved this problem at the Head End until they ran out of channels.

The next move was from Head End to Home. Using a scaled down Channel Commander permits delivering the set any convenient "clear channel." One hundred dB Shielding permits processing the clean cable signals to i-f and back to the channel chosen for delivery.

VI. PROBLEMS IN DESIGNING AND MAINTAINING CONVERTORS

First, the problem. We need a thousand dollar Signal Processor, sized for the home, priced at $25.00.

The budget necessitated some deletions. Stricken are AGC, AFC, and Crystal Control.

AGC is sorely missed. With manual gain control, we adjust the potentiometer for best compromise between Noise Figure and Cross Mod. It controls the voltage at the base of the r-f Stage and what is best for one is not healthy for the other. AGC would permit setting the minimum signal condition for best noise, then provide the necessary voltage to improve the overload when the signal was high enough that Noise Figure was not the item of interest.

AFC and Crystal Control elimination has simply forced the design of more stable oscillator circuitry. Mrs. Jones, if she likes the Network's Offerings, can cry her way through a full day of Soap Operas in Color, without retuning her Converter.....assuming the necessary stability in the Television Set.

Maintenance is not a problem. Our Twenty Five Channel Tuner has been independently tested by three Laboratories. It withstands accelerated life tests of 25,000 complete cyclings. Neither discernible contact wear nor appreciable oscillator shifting resulted. More than 32,000 have been manufactured.

Pilot Error is a serious problem. The Subscriber lines up two holes to hit a bullseye. Frequently he forgets and tunes the set, shifting the bullseye out of range. A Service Call results. Corrective action in the form of a "feed through" switch is under consideration. When the Set is "detuned," the Subscriber can throw the switch and by-pass the Converter. Using the same channel in the Cable, he can "retune" his own set.

Biggest problem with installation is dynamic range. Large City Systems are laid out with very high signals at Subscriber Terminals. Converters are built for the range 0 to 12 dB.

Our original units provided no access to the manual gain control. The Operator had to pad where signals exceeded 12 dB.

A screwdriver adjustment with easy access through the case eliminated this problem.

A Public Relations problem is Remote Control. Few Installers can "field" the angry reaction of a Subscriber who has paid fifty dollars or more for a "Pinger".....but a really good salesman can teach him to fine tune subtle color changes with the remotely placed Converter, using the "Pinger" for other controls.

VII. THE ULTIMATE TERMINAL DEVICE

The Customer Owned Set is a "Terminal Disease." We pamper its deficiencies and when the going gets too rough, feed it "Pablum" through the Converter. Always we sustain the frustration of delivering a product without control over its final display.

The Subscriber owned 19" Color Set costs him more than $18.00 monthly to buy, finance, and repair. In addition, he pays for the Cable.

An Operator can Lease a CATV Color Receiver of better quality, with multi-channel capability, 100 dB Shielding, and periodic preventive maintenance, for $12.00. Present Operating Margins can be maintained or equalled.

Both Parites to such an arrangement stand to gain. I predict the "ultimate terminal device" will revolutionize our Standards and enhance our Service to Subscribers.

VIII. SECONDARY SERVICES POSSIBLE WITH LEASED RECEIVERS

The twin problems of the Newspaper Industry are Paper Supply and Delivery. Disposal of the discarded waste is a headache to the Homeowner.

Delivery of all Printed Media is within the grasp of CATV. Storage devices can receive entire newspapers and circuits are within reach to permit scanning a whole page, then "zooming" in to fill the screen with a paragraph or a single picture.

The passing of the indifferent, affluent Newsboy, and the Mother who drives him around his route, will not long be mourned.

Dual payment plans are entirely practical, with the "free television" advocates suffering "fade-in fade-outs" of intermittent advertising superimposed on the copy. Subscribers would pay for the privilege of uninterrupted News.

IX. HOTEL/MOTEL SERVICES

Hotels provide a unique opportunity for "in house" programming. If your field of interest lay in the next speaker and you wanted to relax in your room until he appeared, a channel tied to a Camera aimed at this stage would be a genuine convenience.

Cameras showing the wares of local Department Stores could likewise fill vacant channels and permit shopping by telephone, with same day delivery to your Hotel Room. All equipment utilized could generate Lease Revenue and someone would, of course, derive income from the Advertising.

X. CATV TELEVISION SETS OF THE FUTURE

The form of present Television Signals guarantees the addition of noise and distortion on each successive reamplification. Encoding signals to pulse modulation and using amplifiers that regenerate the pulsed input without noise is prevented by the necessity for decoding back to the standard form for Television Set processing.

Under the Wired City concept, the CATV Receiver can be built to accept superior methods of distribution.

END OF AN ERA

Obviously we have completed the "Great Circle." The TV Dealer started the business to sell Sets. He passed the torch to us, we built a better mousetrap, and vast new areas were opened to Set Sales. In twenty years we have exceeded the capabilities of the Terminal Device. We need more channels. We need shielding. Most importantly, we need control of the Quality of the final picture.

To accomplish this we must offer the "Ultimate Terminal Device" .....The CATV Receiver!

Thank you.

PATRICK R. J. COURT

INTRODUCTION

The basic purpose of any CATV converter is to allow an increase in system channel capacity, either by eliminating direct pick-up problems or by permitting the utilization of additional spectrum space on the cable (which is normally beyond the reach of a standard TV receiver), or both. Despite the fact that these devices perform a valuable function, and do it very efficiently, they remain the subject of much controversy within our industry. The author hopes that a full discussion of the considerations in their design and utilization will help dispel some of the misunderstandings and misgivings which presently surround them.

SOME EARLY HISTORY

The invention of the CATV converter was stimulated by the movement of cable TV into the major U.S. metropolitan markets, in particular New York City. It came as an unpleasant surprise to the operators who were developing these markets, to discover the phenomenon of the "Right Handed Ghost." In central Manhattan, for example, there are seven powerful VHF transmitters and the local radiated field strengths are phenomenal, being measured in volts per meter. While it is possible to build a cable distribution which is adequately shielded against these powerful radiations, nobody had previously reckoned with the amount of signal that can be picked up by the exposed antenna circuits, or induced by ground currents, within the TV receiver itself. The receiver, under these circumstances, is presented with two signals on each of seven channels -- one direct from the transmitter and the other, somewhat later, through the cable. Hence

the right handed ghost. In view of the fact that the basic motivation for building CATV in New York in the first place was to offer service free of the familiar and distressing left handed, multipath ghosts which had haunted New Yorkers for so long previously, the discovery was a depressing one indeed. A right handed ghost is no more saleable than a left handed one!

The stratagem of connecting the coaxial cable directly to the tuner was not very successful in New York, invalidated the UL approval of the receiver and, furthermore, presented the operators with the prospect of a less than satisfactory relationship with their subscribers in the matter of future responsibility for his receiver maintenance.

Necessity is the mother of invention and the concept of the shielded VHF to VHF converter to eliminate ghosting arose in the West in response to the anguished cries from the East. The converter was born, in fact, in the laboratories of International Telemeter Corporation in Los Angeles in late 1965. It was born not entirely for altruistic reasons, but in the hope that an honest dollar might be made from so elegant a solution to so vexing a problem. Sterling Information Services and Television Presentations have since acquired the exclusive patent and marketing rights to this invention with the same reasonable expectation.

Almost coincidental with the emergence of metropolitan CATV came the pressure for more channels and it was logical to incorporate additional tuning capacity within the converter enclosure, and hence the evolution of the non-standard frequency converter.

DESIGN CONSIDERATIONS

In spite of its inherent simplicity the design considerations of a CATV converter, if not complex, are quite diverse. As with any other consumer-type product, the requirement of low cost (and where else can one buy so much for so little these days?) complicates the design problem. Let us first consider the standard 12 channel VHF to VHF converter. Its purpose is to remove the tuning function from the TV receiver and to enclose it within a heavily shielded environment which is immune to direct pickup. All channels are then converted to intermediate frequencies and thence to a single VHF channel, not shared by a local station, to which the TV receiver can then be tuned and lo -- the ghosting problem is solved.

Dual Conversion

Implicit in the conversion of all twelve standard VHF input channels to a single one of these is the use of dual conversion. Single conversion results in an impossibly difficult range of oscillator frequencies and almost insurmountable image problems.

At one particular channel, single conversion becomes mathematically impossible.

Dual conversion implies the conversion of all input channels to i-f and the use of a second mixer to convert the i-f carriers to the chosen output channel. The frequency inversion which occurs in the first mixer must be canceled by a second inversion in the output mixer. Thus the output oscillator is "high-side," as indeed is the input oscillator.

Choice of Intermediate and Output Channel Frequencies

Whenever multiple conversion is employed, great care must be taken in design to avoid spurious interferences. Certain combinations of carrier and oscillator frequencies can give rise to problems if not guarded against. Potential third order problems also exist when considering that a third conversion occurs in the TV receiver itself. At one particular channel, for example, all three oscillators are operating at the same nominal frequency. Note nominal, not actual.

The choice of i-f was largely dictated by economic considerations. In order to make the converter economically feasible in a then uncertain market, it was decided to employ a basically standard, high quality, television tuner. These are manufactured in huge volume from unbelievably costly tooling and have been refined over years of engineering and manufacturing experience. They are consequently available at relatively low cost. It was a sound decision, because the market was not only unpredictable, but the total potential could not possibly justify anything radically different from a standard tuner. Even if every known CATV subscriber eventually had a converter, this would represent less than half the annual tuner production of Oak Manufacturing Company, which was selected as the source of the TPI converters.

For excellent reasons, the TV industry has standardized the band from 41 to 47 MHz for i-f and all tuners are currently manufactured this way. It therefore made all the sense in the world to retain this i-f for converter use.

The choice of output conversion channel frequency was not so circumscribed, but again economic considerations precluded offering a wide choice. Technical considerations excluded the use of the low VHF band, particularly channel 6 which happens to encompass the second harmonic of 41.25 MHz (i-f audio). The other low band channels make it difficult to achieve adequate "feed-through isolation," which will be reviewed later.

It is desirable to restrict the choice of output channels to two frequency-adjacent ones, the logic being that in any one city, one or the other will be unoccupied by a local channel. At locations midway between two adjacent frequency transmitters, their field strengths will not pose a co-channel interference problem.

From an economic standpoint it is preferable to use frequencies as high as possible so that the ratio of bandwidth to center frequency is small, then the same physical components can be used for both channels. The only difference at the factory is then one of alignment and tracking. Alternative channels 12 and 13 were therefore chosen.

Choice of Tuner and Modification for CATV Use

A systematic evaluation of available tuners led to the Oak four-circuit incremental switch type, largely because of its excellent characteristics, dependability and low oscillator radiation. As good a tuner as it is, it is not suited, without modification, to CATV use. For example, it is designed with 300 ohm input, has substantial gain and is optimized for use with agc. It is economically unfeasible to provide agc in a converter, and with adjacent channel operation the normal transistor tuner does not fare too well without it, largely because of cross-modulation. With the collaboration of Oak engineers, its electrical characteristics were carefully tailored for CATV use with fixed bias operation. In particular the input was redesigned for 75 ohms, and the gain was reduced from 40dB to 10dB by the use of degenerative feedback and other techniques. A compromise was found between noise, gain and cross-modulation which ideally suits CATV adjacent channel requirements. The resultant noise figure of 12dB maximum yields scarcely perceptible noise at -6dB input, while cross-modulation is better than -57dB at +6dB input. In practice this means that cross-modulation is invisible at input levels up to +12dB and scarcely visible with normal picture content at levels up to +18dB. In addition the gain taper across the spectrum was confined to less than plus or minus 3dB. All of this was accomplished without degradation of any of the excellent mechanical and other design characteristics of the generic tuner.

Beyond this, a further refinement was added, to overcome an intrinsic problem which exists when receiving channels 5 and 6 adjacently, and which many CATV engineers have undoubtedly observed with standard receivers. When tuned to channel 5, the tuner oscillator frequency is 123.00 MHz. The second harmonic of adjacent channel 6 video is 166.50 MHz, and the difference frequency is 43.5 MHz which happens to fall in the i-f band as a highly visible beat. The tuner was modified to incorporate a special switched trap which attenuates channel 6 video when tuned to channel 5 and the beat is thereby eliminated.

Adjacent Channel Rejection

Many receivers in the low to medium price class, particularly the transistorized variety, do not operate comfortably with adjacent-channel CATV input. Many exhibit cross-modulation and every CATV engineer is familiar with the adjacent sound beat and the need to reduce audio levels on the system, to the point where some marginal receivers can scarcely reproduce audio at all! In

spite of the extra cost, the TPI converters incorporate adjacent channel traps, with minimum attenuation of 20dB. These completely overcome both problems at the receiver, and in fact if every receiver were equipped with a converter, the audio levels in the system could be raised to the normal FCC specified level of -10dB instead of the meager -15 to -20 which most systems struggle with.

Output Channel Filter and Attenuator

As the converter bandshaping is principally governed by the tuner and i-f circuits, the output filter can be relatively broadband. The principal consideration is attenuation of the output oscillator, both to meet FCC radiation specifications and to avoid a possible beat with the receiver oscillator, which operates at nominally the same frequency. A triple tuned filter provides the desired bandwidth and skirt selectivity and reduces oscillator output to less than 1000uv. A 3dB, L-attenuator helps maintain output VSWR at better than 2:1.

Fine Tuning

The considerations surrounding fine tuning are quite complicated and the arrangements provided in the TPI units, while they add to the cost, are in the judgment of the author the best that can be provided. In theory, if the converter oscillators were perfectly stable, there would be no need to provide fine tuning in the converter at all. However, this does not take into account the fact that most TV receivers themselves have a warmup drift or the differences in transmission from channel to channel, particularly with color. The situation therefore arises that the subscriber is selecting channels at the converter and fine tuning at the receiver -- not a particularly convenient arrangement, especially if the converter is installed as a remote control device.

At the other extreme it is possible to furnish a conventional front-end fine tuner in the converter and thus avoid the problem and expense of providing highly stable oscillators and a fully-regulated power supply. This is the inexpensive way out and unfortunately the results are consistent with the old adage "you get what you pay for." The subscriber is now confronted with two, wide-range, fine tuning adjustments and can get totally lost in his attempts to correct one with the other. The i-f carriers can become completely misplaced with respect to the passband and traps and in fact, both receiver and converter can become totally misaligned. Bear in mind that on some channels, the fine tuning range can exceed one channel width, so the prospects of difficulty are considerable.

This situation has been roundly and justly criticized by CATV operators and probably represents one of the basic reasons for resistance to the use of converters at all.

The approach taken in the TPI converters was to take the best and reject the worst of both alternatives. Both oscillators are designed to have excellent long-term stability (combined drift less than plus or minus 200 kHz over 30°C rise above ambient). A fully regulated power supply completely eliminates dependence upon line voltage between 100 and 130 VAC. The tuner incorporates a high quality memory detent tuning mechanism with re-set accuracy within plus or minus 50 kHz. Thus the overall frequency dependability is within about plus or minus 150 kHz and it is possible to withhold the tuner oscillator adjustments from the subscriber entirely -- even the installer. The memory tuning adjustments are intended for factory and service use only and all frequencies are precisely adjusted at the factory with crystal controlled calibrators, using the audible beat method (therefore within plus or minus 10 kHz). We are therefore assured that the i-f carriers remain correctly positioned within the passband.

For the convenience of the subscriber a fine tuning adjustment is provided which affects only the output oscillator over a limited range (plus or minus 0.75 MHz), and which compensates for TV receiver warmup drift and transmission variations. This is accomplished through a 300° rotation potentiometer, which electronically controls the output oscillator. The subscriber can now precisely fine tune the channel at the converter without getting lost and it is rarely, if ever, necessary for him to touch his TV receiver tuning controls once they are set. It is also very easy for him to do so should it become necessary, as he merely has to visually index the converter tuning knob to approximate mid-range and then fine tune the receiver. Thereafter he is in business.

Gain

Many people seem to be under the misapprehension that a figure of merit for a converter is overall gain and wonder why our units have only 6dB plus or minus 3dB. This is not a consequence of poor design; in fact the figure was deliberately chosen. With too much gain, some receivers will overload with maximum input from the drop cable. With too little gain or a loss, the noise contribution from the TV receiver can be significant when the input is at a minimum. The gain figure of 6dB plus or minus 3dB assures that neither of these things will happen.

Bandwidth and Bandshape

CATV people are of course calibrated to the idea of plus or minus 0.25dB from 50 to 250 MHz, and wonder why a typical converter does not meet this standard. Well, plus or minus 0.25dB is necessary for amplifiers which have to be cascaded and is to be expected in a unit costing $500/800 per copy. At the prices people expect to pay for converters, however, it is economically unfeasible to achieve such a specification, and at the same time meet

all of the other requirements, including satisfactory phase response. As a practical matter there has to be a compromise and we have found the best to be the "3dB rectangle" whereby all points in the response curve between picture and sound are within 3dB. No visible picture degradation results, even to the most critical trained observer; in fact the picture quality is usually improved because of elimination of cross-modulation and adjacent sound beats.

VSWR

Here again, CATV engineers have grown accustomed to figures like 1.2:1 and 1.5:1, and are not happy with the idea of 4:1 which is the design figure for the current TPI converters. Until now the state of the art has not permitted an improvement without consequent degradation of noise performance.

Frankly we have not been happy with this figure either, although it is better than most receivers which operate on CATV, apparently successfully. We have also yet to be shown a situation in which improved VSWR would perceptibly improve the end result. However we recognize this figure should be reduced, if just to avoid any argument, and are looking to improved technology to achieve this.

Shielding

The shielding requirements are severe and should not be less than 100dB. This means that in a field of one volt/meter the output of the converter, with its input terminated and shielded, should not be greater than 10 uv. This would put any potential ghost signal approximately 46dB below the desired converted signal output, with input at 0dB, and is substantially better than the best drop cable currently available.

To accomplish this, the r-f circuits are totally enclosed in a rugged, plated steel compartment, and the power supply circuits are mounted externally to this compartment. The only connection other than the coaxial input and output cables, which enters this compartment is B+, and this is through a filtered terminal. Thus there is no prospect of pickup on the power cord being induced inside and no need for complex power line filtering. Figure 1 shows the chassis construction of the TPI Focus 12 VHF to VHF twelve channel converter.

Power Supply

Some economy might have been effected by the use of a transformerless supply, but in the interests of absolute subscriber safety a transformer-type supply is used. Also in spite of the extra cost, a fully regulated supply is used rather than simple zener

stabilization in order to maintain oscillator stability. Twelve volts B+ is used and there is no measurable change of B+ with line voltage.

Miscellaneous

The internal circuits of the converter tend to offer a natural, direct path to the output channel frequency. Hence a phenomenon known as "on channel feedthrough" whereby channel 12 on the cable input can possibly interfere with the converted channel 12 at the output, particularly if the converter is tuned to channel 12. The direct channel will differ slightly in frequency from the converted channel, so careful attention to the internal layout and circuit design is necessary to avoid the problem. Feed-through isolation must be maintained at 70dB minimum.

To assure absolute subscriber safety, the converter should be fully approved and listed by Underwriters' Laboratories. In some cities it is illegal to install such equipment in the home without the UL seal or city equivalent.

Devices of this kind must also be certified to meet Part 15 of the FCC Rules and Regulations regarding direct and line-conducted radiation.

Aesthetics

With a single design you cannot please all of the people all of the time, but if you try hard enough, you can please most of them most of the time. Economics presently weigh heavily against offering too much choice of style or color, so a conscientious effort must be made to achieve something which is aesthetically pleasing to most people. As with the familiar telephone, clean contemporary styling and color appear to be the best choice. Figure 2 shows the TPI Plus 13 converter.

Non-Standard Channels

The development of converters for non-standard channel frequencies has consistently been ahead of the distribution equipment for transporting them. While the amplifier people are still lagging, they are catching up fast.

In the early state of development of expanded channel operation, it was quite out of the question to commit the elaborate and costly tooling and engineering required for a tuner having more than 13 positions, and retaining the same proven mechanical and electrical properties. (The 13th position is of course for UHF.) The approach taken therefore was to design a 13 position tuner using the same mechanical parts as used in the standard 12 channel unit, and retaining the same basic circuit design except for the

inductive tuning elements. Historically, that is how the 25 channel concept began -- a converter containing a 12 channel tuner and a 13 channel tuner can obviously receive up to 25 channels. The VHF allocation plan also helped because it is possible to arrange nine new frequency-adjacent channels between the aircraft navigation band (which it is prudent to avoid) and channel 7. Four more can be positioned above channel 13 with only a 10% increase in total bandwidth. These 13 new channels were designated A through M (to avoid confusion with the UHF channels), which terminology has become standardized. It is also remarkable that if we momentarily forget the five low band V's and consider only the remaining 20, we find them contiguously arranged from 120 MHz through 240 MHz which happens to be one octave. The converter people foresaw the probable earlier development of single-octave distribution equipment, which is inherently free of second harmonics and second order beats, and the later development of mid-band techniques followed by all band equipment, perhaps using push-pull. In any event the converter itself could care less and was prepared for any eventuality.

The Gamut 25 converter therefore contains two tuners and a function switch to select either the number channels or the letter channels. It affords full shielding against direct pickup in all of them.

The Plus 13 contains only the non-standard tuner and a bypass switch to permit tuning the regular twelve channels at the TV receiver. It was devised as a more economical method of adding up to 13 new channels in areas not particularly bothered by direct pickup from local TV stations.

The same basic design considerations applied to these two units as to the Focus 12, with a few additional tricky problems thrown in.

RELIABILITY

A considerable amount of misinformation has circulated around our industry concerning converter unreliability, instability and so forth. As a result many operators are reluctant even to consider using them. Some of this misinformation is based upon experiences with very early models, since discontinued, some made by people no longer in the business. Perhaps the best rebuttal to this is the experience of Manhattan Cable Television which is by far the largest user of converters in the business. MCTV has substantially more than 15,000 Focus 12 converters in operation and is experiencing a trivial annual failure rate. It is therefore in no way discouraged from its conviction that converters offer the only practical solution to its problems.

USES FOR CONVERTERS

Apart from simply allowing increased channel capacity, converters offer the prospect of additional revenues for operators who can now consider offering a dual class or even a multiple class service. In fact, in the long run, this seems to be the only way of justifying the provision of an ever-increasing number of channels. Using the same cable, it is possible to offer up to 12 channels for one price and beyond 12 for a higher price. Beyond that, it is possible to direct specific channels to selected business communities, schools, doctors, etc., in return for additional separate monthly fees. It is not particularly difficult to arrange for converters to be inoperative at specific channels, thus denying say the doctors' channel to the schools and vice versa, and both of them to the public at large.

Converters can be installed as remote control devices, perhaps not as elegant as wireless remote control, but functional. At least two systems are doing this as an inducement to obtain additional subscribers and have many satisfied customers as a result.

ALTERNATIVES

Alternatives of course exist to the problem of providing more than 12 channels, the most notable being the two cable system. The main disadvantage seems to be higher cost and certainly higher initial investment. The dual plant has to be installed even if there is only one subscriber, whereas investment in converters is proportional to the number of subscribers. Furthermore, many buildings are difficult to wire with two cables, particularly high-rise apartments. The dual cable system, moreover, does not have inherent protection against direct pickup at the receiver and each local TV transmitter can now knock out two channels instead of one, one with a simple ghost, the other with co-channel beats, dual images and venetian blind effects.

Another method is the hybrid system employing pole-top converters. In this arrangement a single trunk cable is used carrying say 20 channels, single octave. Elaborate converters then manipulate the channels around so that they can be carried the rest of the way dual cable, standard frequency. The economics of this arrangement would seem to be not too far different from the all-dual system and the problems of dual wiring in homes, direct pickup, etc., seem to be the same.

Block converters from VHF to UHF have also been proposed both for indoor and outdoor installation. Unfortunately, block converters are prone to all kinds of beats and UHF receivers don't take too kindly to adjacent channel operation. It is almost impossible to find the channel one is looking for on the average UHF dial, and nearly impossible to tune it when it is found. Direct pickup from UHF stations can disable certain channels and many receivers are still around which cannot receive UHF anyway.

WHAT OF THE FUTURE?

Many operators have expressed the view that the TV receiver industry will soon come forth with shielded multi channel receivers which will make converters unnecessary. This may happen over the very long range but the fact is that the total number of subscribers now served by CATV represents but a fraction of the 60/70 million television homes in the U.S. This does not presently justify the attention and investment required by the industry to manufacture special CATV receivers or to increase the cost of all receivers sold so that they are compatible. Even if they started today and sold nothing else but these ideal sets, it would take at least ten years to turn over the present inventory of sets in use. Clearly the CATV industry is not going to wait that long to furnish the additional channels and services that are presently possible through the use of converters.

What of a special CATV receiver to be leased to subscribers as part of the service? The problem here is to convince the owner of a $500 color set which matches his French Provincial or Danish Modern decor, and which has the features and screen size he likes, to accept some kind of standardized CATV receiver instead, presumably at extra cost. Such an arrangement was tried in Montreal, Canada, in the early 50's and it fell flat on its face. Besides, does the CATV industry really wish to get into the receiver business, and does it really wish to alienate the dealers?

Many operators hope for some dramatic breakthrough or miraculous development which will eliminate the need for converters entirely. Miracles are unlikely but there will undoubtedly be breakthroughs in price, although they may not be as dramatic as we would all like to see. Prices must eventually bottom out as they have with TV sets and autos, once maximum advantage can be taken of volume production. Already, mass production techniques are being used as much as possible, designs are economical and markups are modest. Improved technology will gradually enhance performance even beyond present standards and at the same time allow prices to remain competitive.

For our company's part, we expect converters to find increasing acceptance and are examining every avenue to improve the product and reduce prices. Our new model Gamut 26, just announced, embodies the results of an 18 month program wherein radical new techniques have achieved these two conflicting objectives. Perhaps the Gamut 26 qualifies as a "breakthrough."

Varactor tuning may eventually supersede present methods, when the economics of the interface mechanisms have been resolved. Here the converter manufacturers are largely dependent upon the technologies developed by the receiver and tuner industry which presently enjoys a much larger volume over which to amortize the considerable investment in engineering and tooling involved.

The converter as we see it today, or even tomorrow, may be only a forerunner of more sophisticated subscriber terminal equipment of the future. Future devices may allow for many different kinds of service, beyond simple television entertainment. Some of these services may involve two-way transmission, may allow purchases to be made in the home in response to advertising messages, rating services, surveillance systems in conjunction with outgoing burglar and fire alarms, two way facsimile, etc., etc. The horizons are unlimited -- who knows they may one day dispense Green Stamps.

CONCLUSIONS

The CATV converter is here now, today, in practical, reliable, economical form and with a proven track record. The distribution equipment manufacturers are hot on our heels. The pressure for more channels is with us and additional revenues are waiting to be gathered through their use. What are we waiting for?

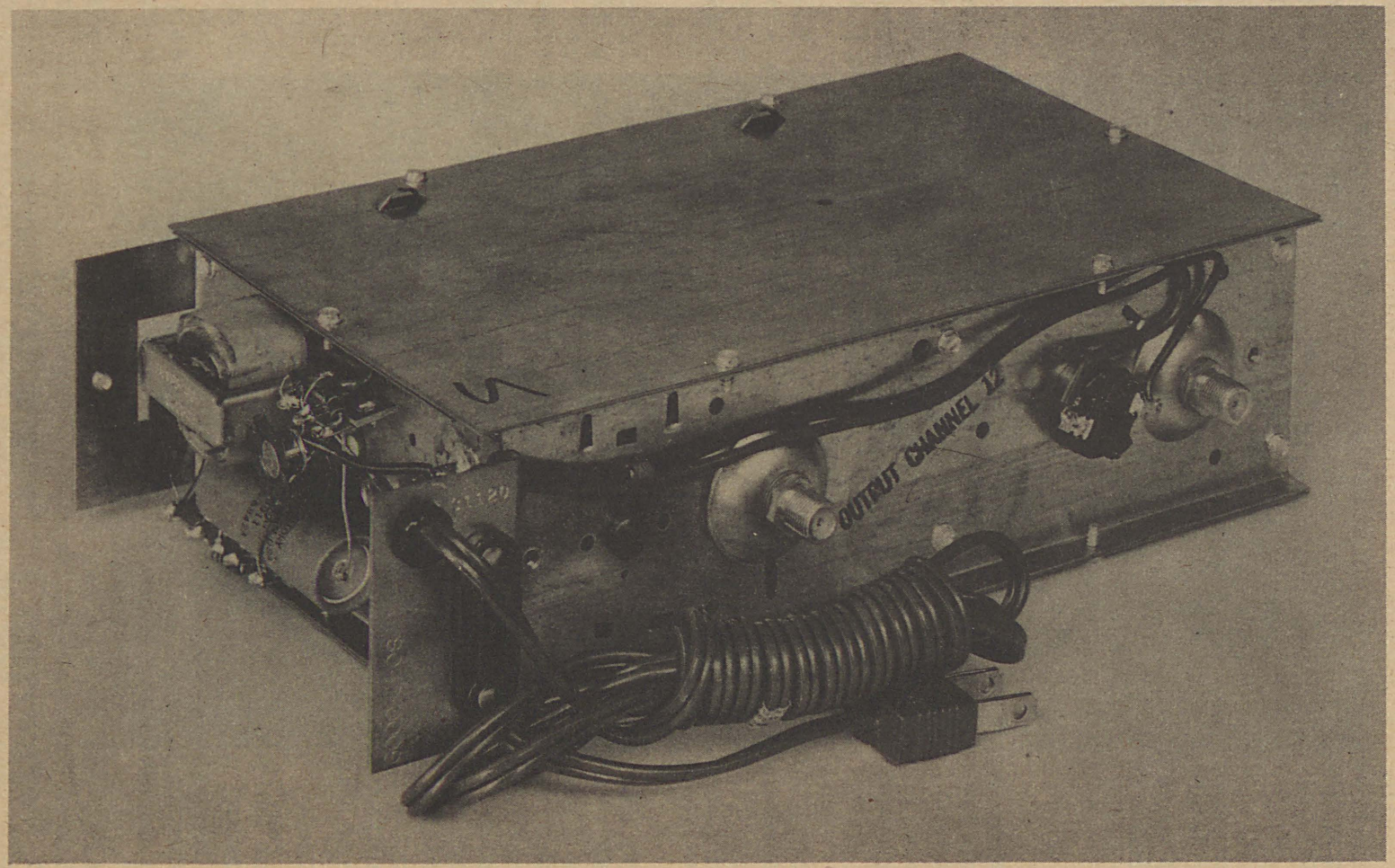


Figure 1. Chassis Construction of the TPI Focus 12 Converter.

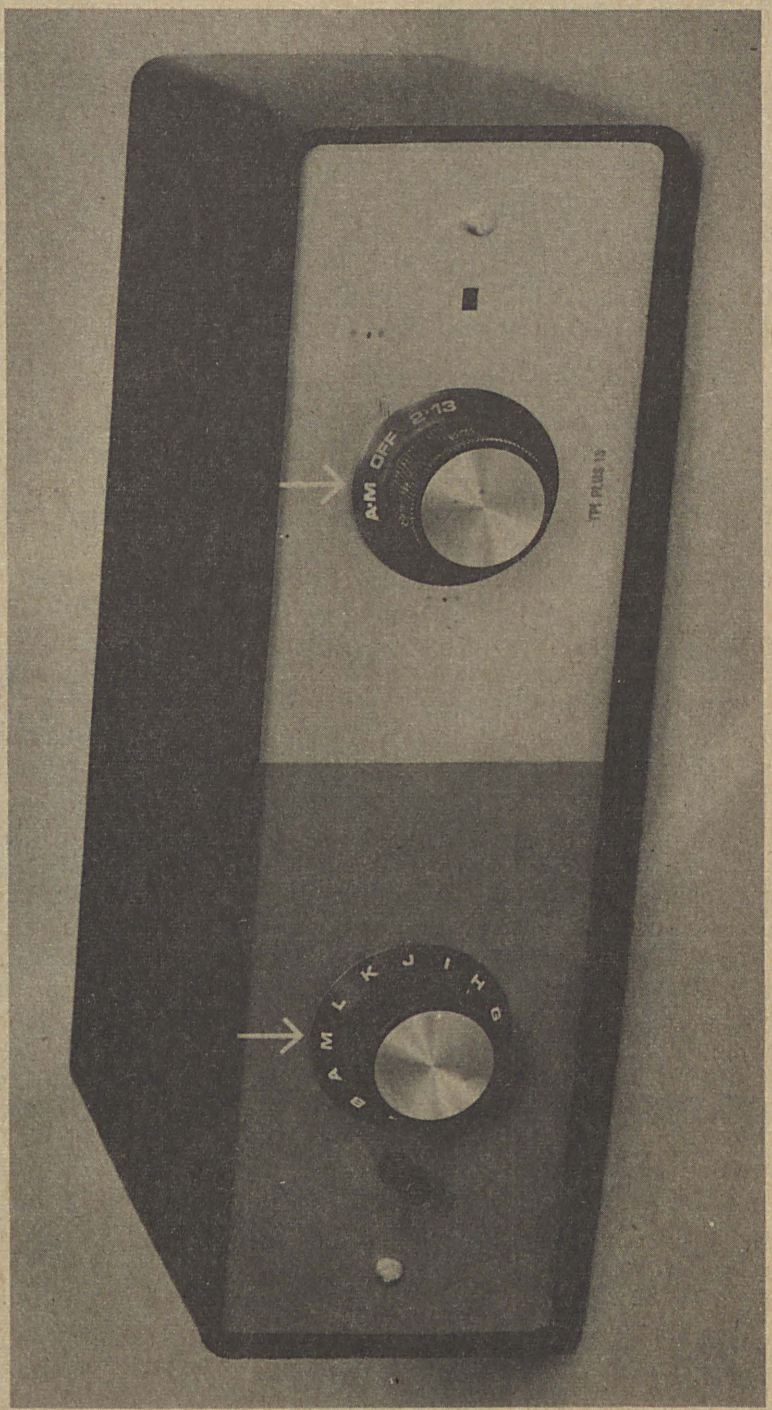


Figure 2. TPI Plus 13 Converter.

FLOYD O. VINCENT

The need for a multichannel system has created the need for a converter. The converter in today's modern systems must accomplish many things in addition to producing more channels. It must be a compatible partner of the cable system.

When I say "compatible partner", I refer not only to today but with an eye to the future expansion and growth of the CATV industry. Right now many persons are busting their brains trying to figure how additional services and, I might add, additional revenue can be utilized by the system and the system operator. It is upon this premise that I say, "Keep your system clean."

The only clean system is a set-top converter. It is an appendage not an integral part; therefore, 2-way communications are still possible all the way from the customer's house. Another point of fact, there are no other parasite frequencies generated in the system. The only other clean system is two cables or systems all the way from the head end.

In the dual cable case, a cursory glance at cost may be illusionary and the costs would be in labor, due to extra care needed to avoid leakage or cross talk between the two systems which would have to be in the order of 60 dB all the way from the head end, plus the fact that a switch would be needed at the customer's set.

Any new devices on the drawing board now or in the future could not possibly be compatible with all the schemes that have been broached forgetting more than 12 channels to the customer; and, if the various schemes I have heard of do take place, we have lost what is now known as the basic system concept and created something which would limit future growth or expansion, except to get more than 12 channels on a one-way path to the customer in which case each system would become a unique entity in itself and components for some would be custom-designed. With no possibility of a future device being compatible with all systems economically or practically, no system or supplier could survive this expense.

The set-top converter does not alter the basic concept of any system now in existence and will not impair its future growth. It will, in fact, enhance the operation of any basic system now operating as far as selectivity, direct-air pickup rejection, and return loss causing ghosts by double travel on lead-in.

The set-top converter has the additional feature of not being exposed to the elements which include high temperature excursions, humidity, and corrosion which should overshadow the fact that it could be stolen or there would be service calls, plus the additional cost factor of producing more than 12 channels any other way.

The set-top converter is the only scheme that will increase the selectivity of the TV set. Any other scheme can only place the frequencies at the right place in the spectrum, and the adjacent channel selectivity will be at the mercy of the TV set. Even a behind-the-TV-set converter cannot do this.

Let me further expand this concept. Any converter, no matter where it is placed in the system, unless the customer tunes it to select his channel, will only place a specific channel at a specific place in the spectrum with equal amplitude, and the TV set alone has the job of selection of this channel while the converter that the customer tunes essentially preselects a channel and therefore has the additional selectivity of the converter and the TV set combined for adjacent channel rejection.

The ideal set-top converter has these additional qualities:

(a) Gain - It has gain which will help to avoid direct-air pick-up problems. No other converter can put this gain on a specific channel of the TV set, the AGC of the set thereby helping to reject a direct-air pick-up channel.

Let me further clarify. While a behind-the-TV-set converter could presumably also have gain it would not have the selectivity plus gain function for adjacent channel selectivity.

This preselect quality would be of necessity if we are going to hit the almost barefoot r-f amplifier of the TV set with a +30 dBmV signal level to avoid crossmod being generated in the r-f amplifier of the TV set.

(b) This converter has a better input match than any standard TV set -- in fact a return loss in the order of 10:1, while most TV sets are in the order of 3:1 or worse. This means that no ghosts can be produced on the input lead-in cable from the tap which could be produced from a poorly matched TV set. How this comes about is, when the TV set has a very poor match and the lead-in cable exceeds 40 to 50 feet, the signal is reflected back up the cable, re-reflected from the tap and back to the TV set, producing a displaced image. With a well-matched intervening converter, this would not be possible. Since the line from the converter to the set is fairly short, no noticeable ghost could be produced there even with a poor TV set match. Let me add here that this feature could also be maintained by a behind-the-set converter.

In addition to the above, the well-designed converter should exhibit the following qualities which would allow it to be coupled to any system and be an asset to same.

(a) Constant gain from 50 to 250 MC

(b) Ability to handle a fairly large input dynamic range -10 to +10

(c) Exhibit a good noise figure

(d) And have output attenuator pads for the sets that have limited AGC

Let's take a look at the system and see what the converter at the set can do or has to do. In the first place the noise power in a 4 MC bandwidth in dB referenced at 1 Milliwatt is -107.57, or 10 log KTB = -107.57 dBm.

On top of this basic number, the system noise figure must be subtracted. For instance 32 amps cascaded with 10 dB noise figure each would yield a 25 dB system noise figure at the output of the 32nd amp.

If we subtract (with all signal levels referenced to dBm)

```
-107.57 = 10 log KTB
  25.00 = Noise figure of 32 amps in cascade
- 82.57 = Effective system noise level
- 48.75 = 0dBmV signal level
  33.82 = Signal-to-noise ratio at the set if the set were to
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receive an 0dBmV signal level, or 43.82 dB if the set were to receive a +10 signal level.

The above numbers assume no other adverse system conditions like temperature on the cable which is not completely cured with equalizers and AGC. In such case the signal-to-noise ratio is further degraded.

If the amps had been 8 dB noise figures, we would only have increased the signal-to-noise ratio by 2 dB.

Therefore, the signal would have to be at least +10 for an acceptable picture.

Earlier in the system after 16 amps the same signal-to-noise ratio would be achieved with a +7 dBmV signal at the customer's set.

This means that the converter so placed in a system after 16 or 32 amplifiers must be able to handle a +7 to +10 dBmV input signal without saturation in order to preserve the signal-to-noise ratio and not produce crossmods at this signal magnitude.

Most TV sets would be able to handle this plus the converter's gain due to the AGC action within the set; however, the converter's output stages must be able to cope with a +30 dBmV signal linearity.

The converter's gain would have to be fairly constant from channel to channel, otherwise there would be either noise figure or saturation problems. Where the gain dropped, the noise level would raise. Extremely high level excursions would limit in the TV set.

With an ideal signal input level of +10 dBmV and 10 to 20 dB of gain the converter will help suppress most direct-air pick-up problems.

However, if the converter does not receive an adequate S/N ratio, there is no way it, or any device, can recover the S/N ratio. Gain in a converter can only help suppress direct-air pick-up problems, and its noise figure can only help minimize the noise contributed by the converter to the system. No matter what the noise figure of the converter, it cannot recover a degraded signal-to-noise ratio.

Conclusion:

The converter will not only eliminate off-the-air pick-up, but with constant gain across the band will truly give your system a 25-channel capacity.

B. R. CARTER

Advantages of Solid-State Circuitry

The many advantages of solid-state circuitry are commonly known. Among these are low power requirements, low maintenance due to long life of transistors, and small physical size.

The physical size of transistor circuitry lends itself favorably to modular construction. Let us examine the versatility of this type construction.

On Channel Conversion

The simplest requirement of a CATV heterodyne type head-end is an on channel conversion. This requires a down conversion to i-f, an i-f band pass, i-f amplifier with AGC, a standby carrier, up-converter and power supply.

Referring to Figure 1, Channel A is fed to the down converter where it is mixed with the oscillator and converted to an i-f. For on channel conversion, the oscillator is common to both the down converter and up converter. It is then passed through a bandpass filter to the video i-f amplifier where an AGC voltage is developed to control the i-f amplifier. The AGC voltage is also fed back to the down converter in the form of a delay AGC voltage to keep the AGC amplifier in the center of its dynamic range.

A sound trap should be provided in the i-f amplifier to adjust the sound level. The i-f is fed from the i-f amplifier to the up converter where it is mixed with the oscillator frequency and converted back to Channel A.

There should also be a means of switching to a standby carrier when the off-air signal is lost. This can be accomplished by switching between two supply voltages, utilizing a Shmitt trigger to sense the AGC voltage level. When the standby carrier is turned on, signal from the i-f amplifier should be blocked by turning off the output stage. The AGC stages must remain on in order to develop an AGC voltage when the input signal is restored.

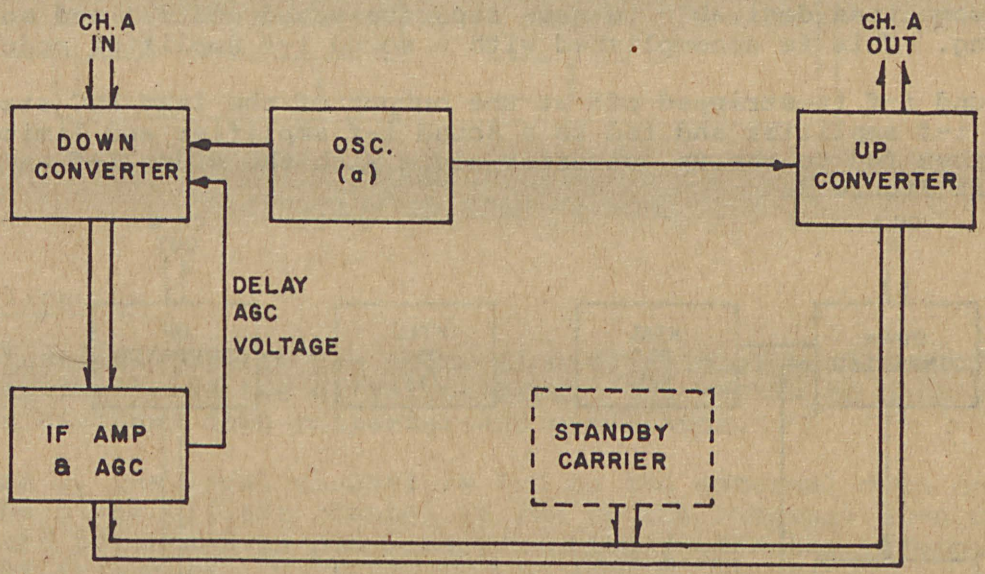


FIGURE 1

ON CHANNEL CONVERSION

Off Channel Conversion

For off channel conversion, (Ch. A. - Ch. B) another crystal controlled oscillator is required to drive the up-converter. (Figure 2)

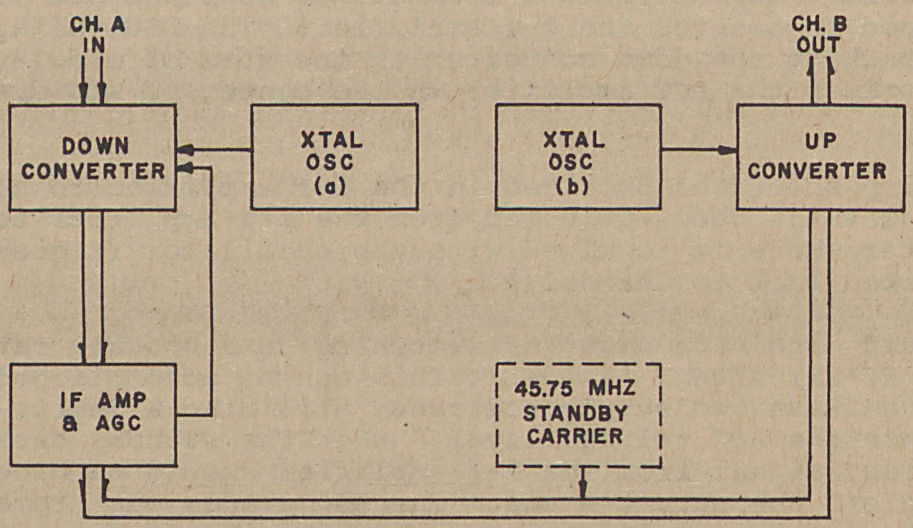


FIGURE 2
OFF CHANNEL CONVERSION

Sound Control

It is sometimes desirable to have separate sound control and sound limiting. This is accomplished with a sound i-f amplifier module.

The sound i-f is stripped off at the output of the last AGC stage in the i-f amplifier and fed to a sound i-f amplifier and limiter. It is then fed to the up converter along with the video i-f as shown in Figure 3.

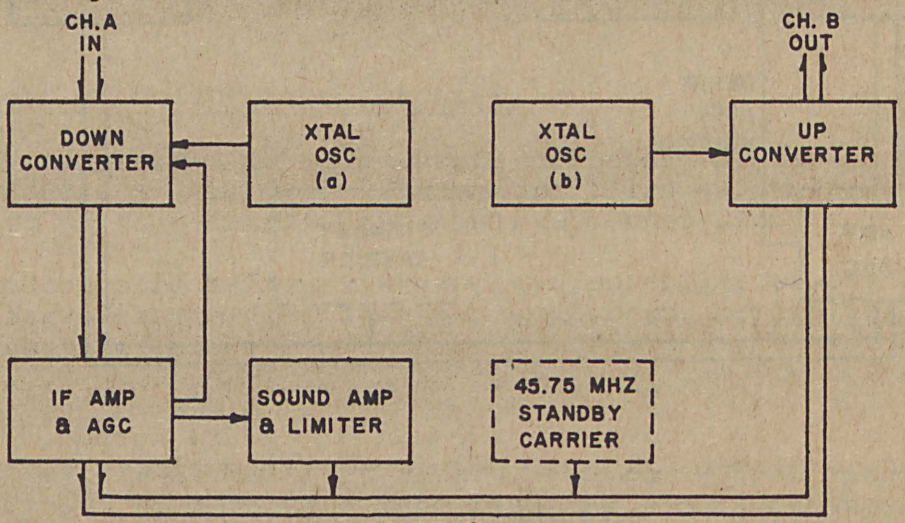


FIGURE 3
SEPARATE SOUND CONTROL

Origination

By adding a video modulator and vestigial side band filter to the standby carrier module, we have the capability of originating video. (Figure 4)

With an addition of an FM modulator to the sound i-f amplifier (Figure 4), we have provisions for local origination in the standby mode of operation. The output of the video i-f amplifier is cut off and the FM modulator and video modulator are enabled. The modulated i-f carriers are fet to the up converter and converted to the desired channel.

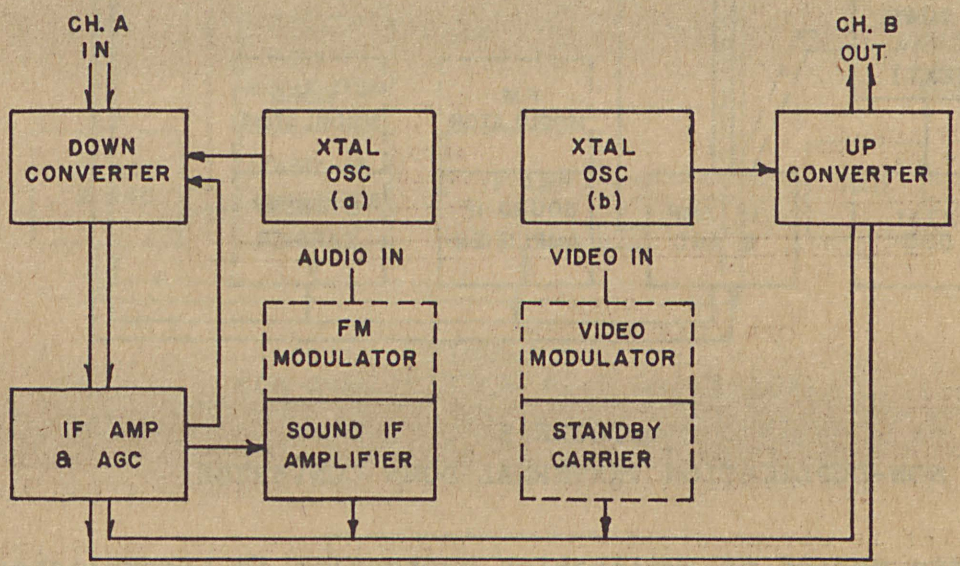


FIGURE 4
ORIGINATION IN STANDBY MODE

Non-duplication

Some situations require the protection of a local station. This can be accomplished two different ways. One way is to have a separate external down converter and oscillator.

In Figure 5, the local channel is fed to the external down converter. The other off-air channel is fed to the internal down converter and processed as previously mentioned when the internal down converter is active.

When the external down converter and oscillator are turned on, the internal down converter and oscillator are turned off.

The i-f is then fed from the external down converter to the i-f amplifier and is processed as previously described.

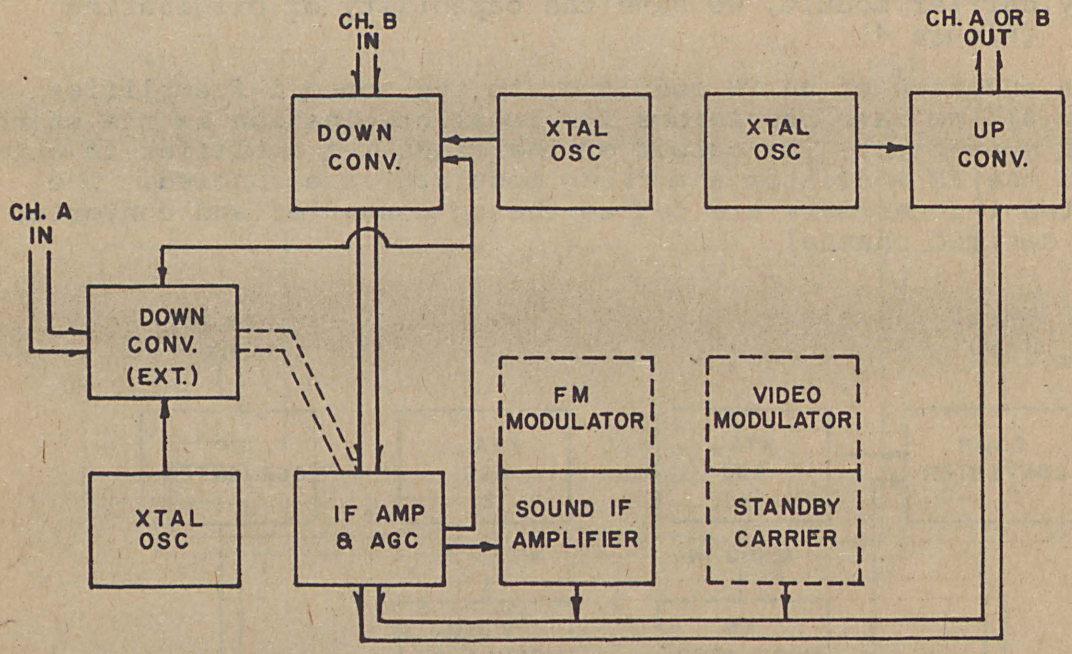


FIGURE 5
NON-DUPLICATION (EXTERNAL DOWN CONVERTER)

An alternate method of duplication protection is accomplished by substituting an i-f amplifier for the standby carrier and feeding the i-f from another head-end unit to the i-f amplifier input as shown in Figure 6. A pad is used to provide isolation between the two i-f's when the units are operating in their normal modes.

When Channel B is switched to standby (Figure 7), the i-f amplifier is enabled and the i-f from Channel A is fed to the up converter of Channel B. Then, when Channel A goes off the air and the standby carrier comes on, it feeds both the Channel A and Channel B up converters.

This switching may be accomplished remotely. This is also useful in situations where an educational channel or some independent channel has a limited broadcast schedule. Rather than having a blank carrier on the channel, another channel can be substituted.

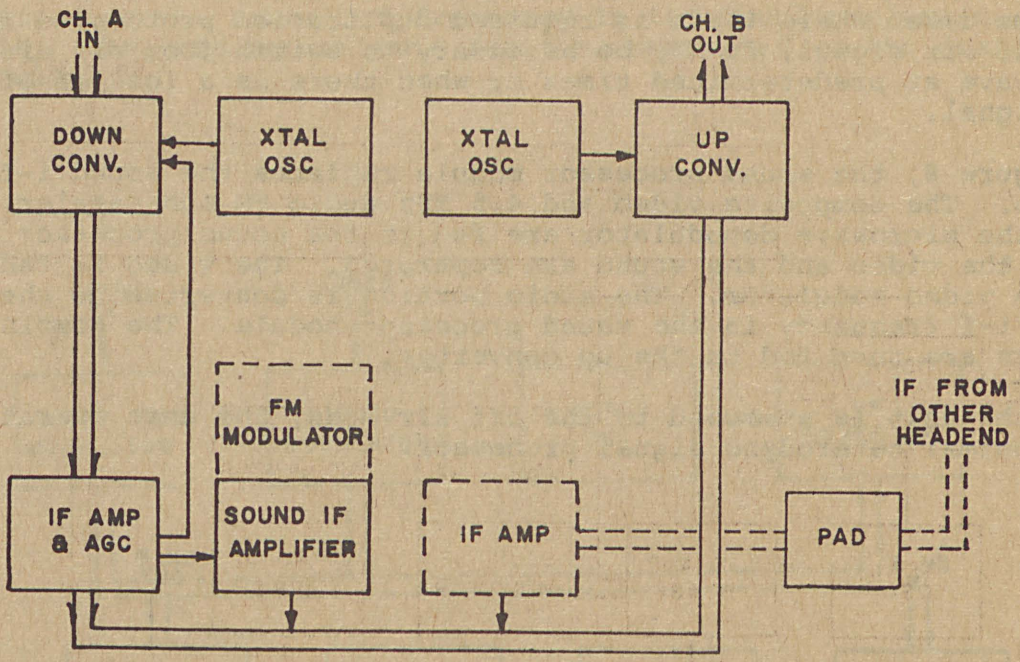


FIGURE 6
NON-DUPLICATION (i-f AMPLIFIER)

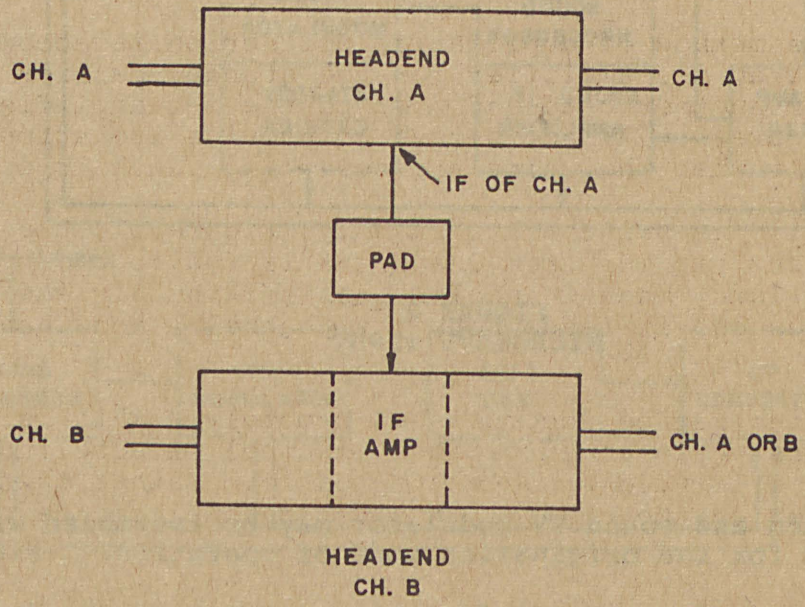


FIGURE 7
NON-DUPLICATION (i-f AMPLIFIER)

Switching From Off Air to Microwave

In some cases where there is required duplication protection from the off air signal, it may be necessary to switch from off air to microwave at predetermined times or when there is a loss of off air signal.

In Figure 8, the sound processor module replaces the sound i-f module. The composite video and 4.5 MHz audio FM sub-carrier from the microwave demodulator are fed to the sound processor where the video and the sound are separated. The video is fed to the video modulator. The audio portion is converted to the sound i-f frequency in the sound processor module. The combined outputs are then fed to the up converter.

When the unit is switched to the off air mode, the unit operates as a normal heterodyne signal processor.

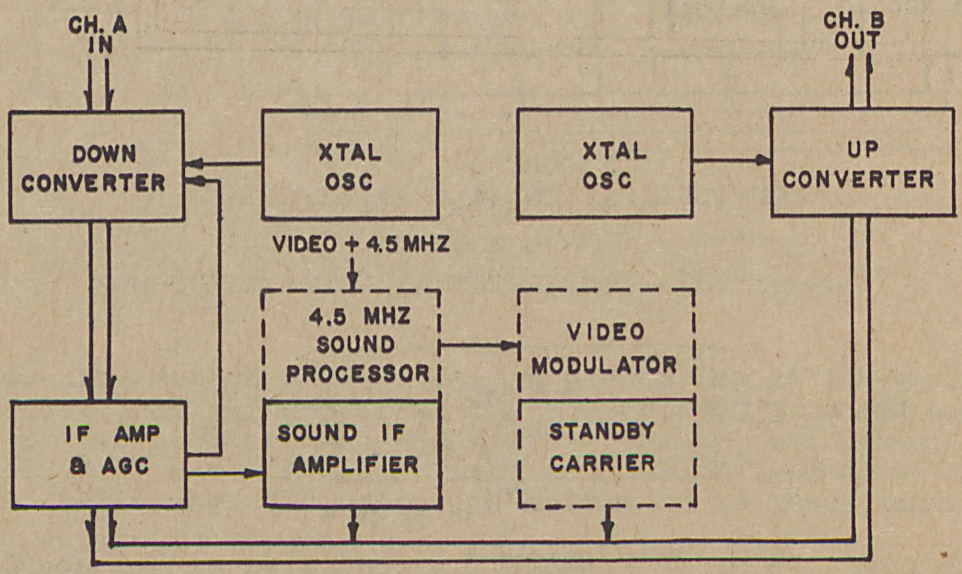


FIGURE 8
MICROWAVE INPUT

TV Modulator

A normal video and sound TV modulator may be assembled with the modules used for the origination mode of operation. (Figure 9)

When the source of program information is a microwave feed, (Figure 10) the composite video and 4.5 MHz audio FM sub-carrier from the microwave de-modulator are fed to the sound processing unit where they are separated. The video is fed to the video

modulator where it generates a video i-f. The audio portion is converted to the sound i-f frequency in the sound processing module. The combined outputs are then converted to the desired channel.

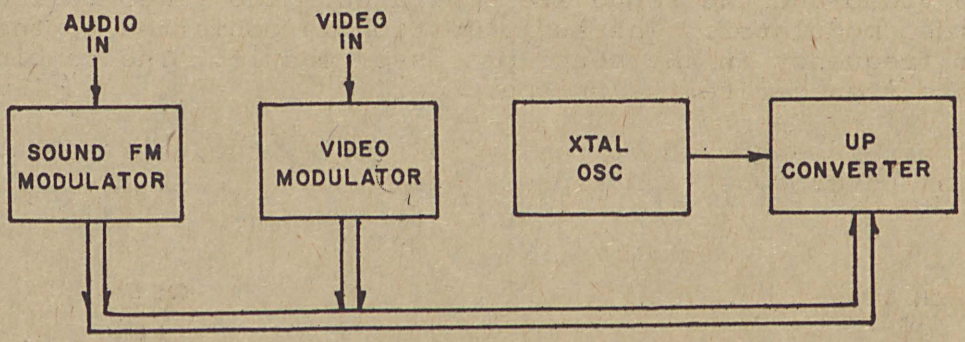


FIGURE 9
TV MODULATOR

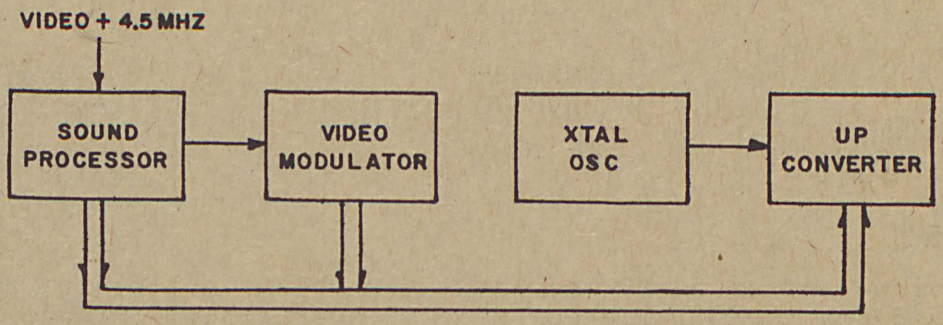


FIGURE 10
TV MODULATOR MICROWAVE FEED

CATV TECHNICAL STANDARDS

Session Chairman:
Hubert J. Schlafly

Participant:
Walter S. Wydro
"CATV Picture Performance Standards"

WALTER S. WYDRO

The tremendous growth of the cable industry has placed increased demands on the technical quality of the picture signals carried by a cable system. Simultaneously, a technical "renaissance" has been occurring in both the Broadcasting technology and in home receiver performance.

Much has been said about inadequacies of the NTSC Color Television Standards, but the significant fact is that most problems for which the system is blamed are equipment or hardware limitations not remotely related to the transmission standards.

Let us review, in a broad sense, some of the progress that has been made recently.

Transmission Equipment

New color cameras having a far better signal-to-noise ratio, with increased resolution and increased sensitivity are now being heavily used by the Broadcasters. The color from these cameras is much more natural and the total picture tonal and chromatic content made much more pleasing than ever before. Even the Monochrome signals from these new cameras have excellent tonal quality. Transmitters and studio signal processing equipment have been greatly improved, particularly the signals from the major networks and from the new UHF or Educational stations.

Receiving Equipment

Here as in the transmission equipment, noteworthy improvements have been made in the color shadow mask cathode ray tube available Brightness and in the rendering of more accurate colors. Other areas of improvement for the receiver have been in more accurate tuning, often fully automatic in nature, AGC of the Chroma circuits, and better overall color stability.

With the increased public acceptance of color television, there has been a corresponding increasing clamor for better picture quality which is now being felt by the cable industry. To progress a cable system must keep pace with this technical upsurge. The large technical burden of supplying high quality cable television is rapidly becoming the principal factor by which the large market areas can continue their growth.

Need For Better Standards

The Long Lines department of AT&T and the Networks have at various times used a variety of test signals that could be passed along with video signals to enable continuous transmission system performance monitoring. Most Engineers are familiar with the standard picture test signals or patterns. These test

signals are broadcast either before or after normal programming. This of course limits their usefulness to record keeping and transmitting facility checks that are useful only to the Broadcaster.

For on the air performance checking, the VITS (Vertical Interval Test Signal) is becoming indispensable. These test signals are switched into Lines 18 and 19 of both Fields #1 and #2. They are useful to us as cable test signals since they are transmitted simultaneously with the program to be viewed and are therefore subject to the same distortion as the standard picture signal. Both networks and the intercity carriers make extensive use of these test signals. Comparison of these VITS signals can be made at various points along a cable system, from Head End to the furthest subscriber drop. Since these signals are so readily available their basic parameters will be briefly reviewed.

Figure #1 Multiburst Signal

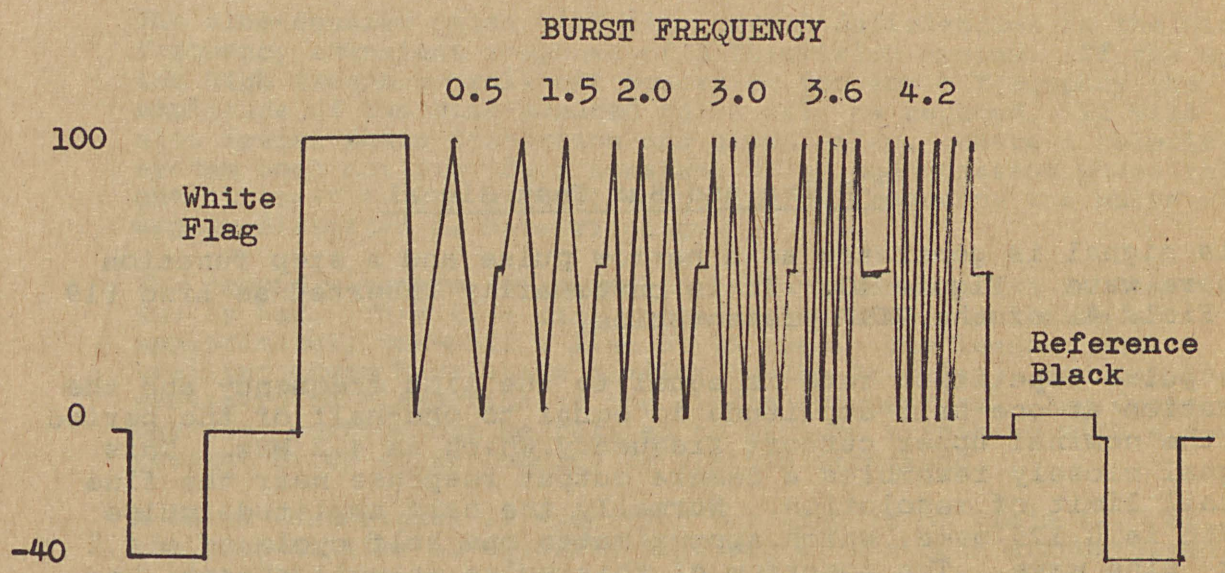


Figure #1

Multiburst Test Signal

The Multiburst signal usually occupies Line #18 of Field #1 and consists of; reference white level, a series of signals equal to reference white levels having the following frequencies: 0.5, 1.5, 2.0, 3.0, 3.6, 4.2MHz , and reference black level.

The Multiburst signal will test frequency response as well as show areas of frequency selective distortion. A low pass filter

is often used at the measuring oscilloscope to filter out the high frequency burst signals leaving the average value or burst base line, Figure #2. If amplitude non-linearity exists at any of the burst frequencies, the filtered base line will shift since the net value is no longer zero.

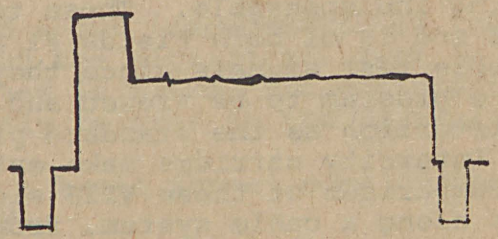


Figure #2 Multiburst Test Signal Passed Through a Low Pass Filter After Detection

T-Pulse and Bar Test Signal

This signal is generated as a narrow pulse and a step function square wave. Figure #3. It is customarily inserted as Line #19 of Field #1 of the VITS presentation.

The pulse repetition rate is equal to the line frequency and the duration at one-half amplitude is equal to one-half of the period of the nominal upper cut-off frequency which is 4.2 MHz. This signal closely resembles a camera output response near the fine detail limit of resolution. Normally the half amplitude pulse width is 0.125 usec. which approximates one half cycle of a 4.2 MHz sine wave. The spectrum of this pulse is well chosen, being half amplitude at 4 MHz and diminishing to almost zero at 8 MHz. Most of the spectral energy is contained in the higher video pass band near the color sub-carrier frequency. The pulse width is set at 2T with half amplitude width of 0.25 usec. for evaluation of the region between 0.5 and 2.0 MHz. A T/2 pulse of 0.625 usec. is used to observe the low frequency region although the accompanying bar pulse normally will provide the same results.

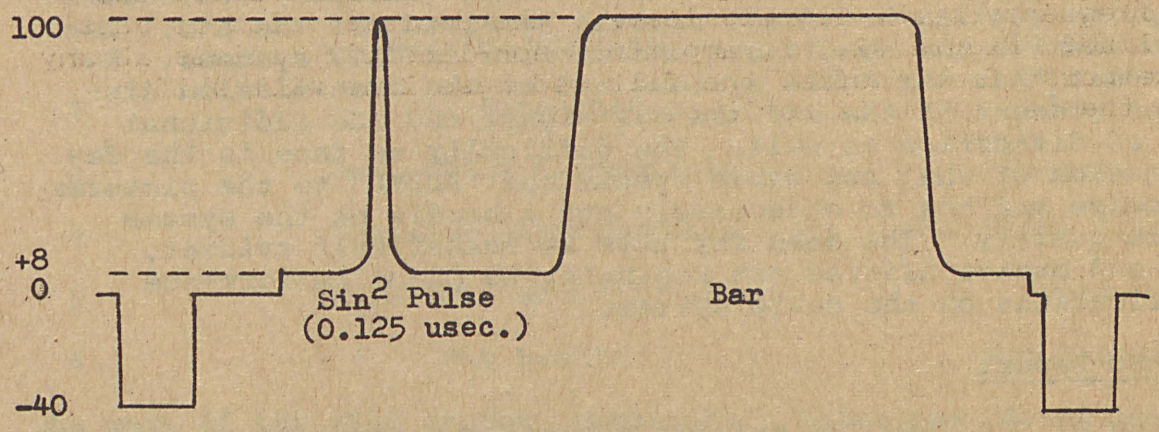


Figure #3 SIN ^{2} PULSE and BAR TEST SIGNAL

The sine-squared pulse will also reveal deficiencies in the high frequency transient response of a television system. If the system high frequency roll-off occurs at too low a frequency the amplitude of the sine-squared pulse will be reduced. It will also reveal phase distortion and group delay. Where a television system does not provide a constant delay and constant phase shift out at least to the highest transmission frequency the pulse will appear distorted or have ringing.

The second waveform following the sine-squared pulse is the window or bar. This is a flat topped pulse with a duration of approximately one-half a line or 25 usec. The leading and trailing edges have shape similar to the 2T pulse. The bar is sensitive to distortion at the middle frequencies. Any droop of the flat portion can be related to picture streaking with a few percent droop corresponding to visible streaking.

A color test signal is specified for Line 18 of Field #2. At the present time no specific test signal has been standardized. Various fixed phase color sub-carrier frequencies providing reference I, Q, R-Y, B-Y and alternating phase signals have all been used.

The last signal of the VITS series is the stair-step. This signal is used as a standard stair-step and with 20% 3.58 MHz modulation on each step. With the 3.58 MHz modulation the signal provides a test of the small signal gain variation as the luminance component is stepped from black to white. Any fault in the differential gain characteristics will result in a change of either the amplitude of the stair-steps or of the impressed 3.58 MHz modulation.

We have examined the built in test factors generally associated with prime quality broadcast signals received off the air. Let us now examine the conditions encountered in CATV systems. We must admit that our cable systems add to the transmission distortion present in the off the air signal and add additional forms of distortion as well. The difficulty we face is the determination of what our cable system has "ADDED" to the pictures we receive and how to objectively put a handle on the system picture quality. The need for this is rather self evident, towns and municipalities are beginning to place performance specifications on the cable systems.

The TASO Report

A review of the TASO (Television Allocations Study Organization) report of Panel 6 entitled "Levels of Picture Quality" indicates that the psychophysical aspects as well as the technical tests were considered important to the objectives of the panel. As part of the test run and reported on by this panel a total of 63 different test conditions were used.

Of these 49 test conditions were for single sources of interference and 14 were for two or more sources. The following general grouping can be made for the 63 tests:

Test Type	Number of Tests Made	Elements Varied Between Tests
Adjacent Channel	12	Upper and lower adjacent channel, interfering frame rate, scene.
Co-channel	29	Offset frequency, interfering frame rate, and scene.
Random Noise	8	Scene.
Co-channel and Random Noise Simultaneously Present	14	Offset frequency, level of random noise, frame rate, and scene.

A total of four receivers, two monochrome and two color receivers were used for the foregoing tests. The two color receivers were "good" chassis table models.

A six number rating scale was established for these measurements:

Grade	Reception Faults	Merit of Reception
1	Not Perceptible	Excellent
2	Just Perceptible	Good
3	Definitely Perceptible	Passable
4	Somewhat Objectionable	Not Quite Passable
5	Definitely Objectionable	Poor
6	Not Usable	Not Usable

The work of the TASO groups represents a milestone of achievement in the art of television. What is needed now is an extension of this fine work with more of the cable television parameters.

Conclusion

Good subjective Picture Quality standards are sorely needed by the cable industry. Accordingly, I make the recommendation that the cable industry through the NCTA, set up an Ad Hoc committee to determine the specific standards needed and make recommendations how such a series of standards might be implemented. If field tests are required, these too should come from the recommendations of this committee.

Thank you,
Walter S. Wydro

CATV SYSTEM DESIGN AND OPERATION

Session Chairman:
Earl Hickman

Participants:
C. Bailey Neal
"Television Receiver and CATV System Interface Problems"

Archer S. Taylor
"Direct Pickup"

Donald W. Levenson
"New Technique Permits Summation Sweeps Without Interruption of CATV Subscriber Service"

Orville D. Page
"CATV Transmission Systems for Reliable Year-Round Operation and 20-Year Life"

J. D. Cauldwell, P. Knight and E. R. Mertz
"RFI Considerations in CATV"

John Campbell and Joseph P. Gleason
"Design Parameters for Integrated Urban Communications"

C. BAILEY NEAL

The function of a CATV system is to provide its subscribers with good television service where, for one reason or another, only unsatisfactory and/or limited off-the-air reception is possible. A good CATV system should approach, as closely as possible, a distortionless link between broadcaster and viewer. Less than optimum performance can result from deficiencies in the system, the receivers or both.

CATV system characteristics and television receiver characteristics related to use with CATV systems, which to a noticeable degree limit overall performance, may be considered interface problems. Receiver performance not specifically related to use with CATV systems will not be considered.

Characteristics of television receivers which can influence overall performance include:

1. Adjacent Channel Rejection

Most present-day television receivers can satisfactorily separate a relatively weak desired signal from relatively strong undesired signals on the adjacent channels. This is a probable worst-case condition for off-the-air reception, based on channel allocations. Since the weaker signal is somewhat noisy, low-level adjacent channel interference, if present, is masked. The situation is quite different when the receiver is connected to a CATV system which provides, for example, full 12 channel service at relatively equal signal levels of 0 dBmV or higher. Low-level adjacent channel interference, if present, can be perceptible.

Adjacent channel rejection is a function of both adjacent channel selectivity and receiver cross-modulation performance. The effectiveness of extreme adjacent channel selectivity is limited by present-day tuner cross-modulation characteristics and suppression of pass-band side-lobe response substantially beyond 40 dB attenuation produces diminishing returns. The projected significant increase in percentage of television receivers used with CATV systems may make it desirable to improve tuner cross-modulation performance by increasing r-f selectivity at the expense of increased noise figure.

Receivers which provide good off-the-air adjacent channel rejection should provide satisfactory performance when connected to a CATV system which maintains adjacent channel signals relatively equal in level and essentially at broadcast channel frequencies. Receivers with marginal adjacent channel sound rejection have led to the common CATV system practive of attenuating sound carrier level 15 to 18 dB below accompanying picture carrier level. This can result in noisy sound in some older receivers.

High adjacent channel rejection is obtained by using very selective trap circuits which have minimum adverse effect on pass-band skirt selectivity. At the trap frequency, 60 dB or greater rejection may be attained but at frequencies 200 kHz away, especially toward the pass-band, rejection may be reduced by 20 dB. The effectiveness of adjacent channel traps, when a receiver is correctly tuned for the desired channel, obviously depends on the adjacent channel frequencies being as expected.Viewer difficulty with color signal fine tuning has led to the incorporation, in many color television receivers, of AFC systems which tend to maintain correct desired channel tuning. Some error, dependent on receiver design, accuracy and stability of alignment and accuracy of viewer tuning with AFC off, can be expected.

Pilot carriers at various frequencies are used for CATV system AGC. The commonly used pilot carrier at 73.5 MHz can cause a beat in channel 5 color by intermodulation with channel 5 picture carrier. Adjacent channel rejection characteristics determine the extent to which this interference is generated in the receiver. Other pilot carrier frequencies in use do not appear to cause such problems. CATV system operators can help the situation by keeping the pilot carrier level low - perhaps 10 dB or more below picture carrier channel signal levels.

2. Immunity to Direct Pick-up

Direct pick-up of desired channel signal, by other than the antenna system, is not usually considered a problem for off-the-air reception. In areas where the radiated field strength is high, contamination by direct signal pick-up can substantially degrade the quality of subscriber pictures from a CATV system. Since most television tuners provide substantial (14 to 20 dB or more) rejection of in-phase signals applied to their balanced input terminals, the problem should be minimized by using a well-balanced balun transformer from CATV system house drop to receiver antenna terminals. Direct pick-up problems have, in some instances, caused CATV system operators to provide subscribers with a set-top converter, converting incoming signals to a single, locally unused, channel. This circumvents rather than solves the problem and is incompatible with television receivers having remote control systems, a feature desired by many. It appears that the direct pick-up problem requires further attention by both CATV and television receiver industries.

3. Picture Quality vs. Input Signal Level

Subjective evaluation of receiver color picture quality versus input signal, by several experienced observers, resulted in the following consensus:

(a) Picture signal to noise ratio does not significantly improve with input signal levels above about +4 dBmV.

(b) Pictures show visible but not objectionable snow with a -6 dBmV input signal level.

(c) Picture signal to noise ratio visibly degrades fairly rapidly as input signal level is reduced below -6 dBmV. A reduction of signal input level from -6 dBmV to -8 dBmV is quite evident.

The receiver used for this subjective evaluation was a top-of-the-line model with solid state tuner and i-f amplifier. The test was not repeated with a variety of receivers but differences should be small, at least at signal levels above 0 dBmV.

The ultimate performance of a CATV system is limited by its head-end equipment, which must produce television signals as free as possible from noise and cross-modulation. Other characteristics of head-end equipment which can influence overall performance include:

1. Amplitude and Group Delay Response of Selective Circuits

In order to approach a distortionless link between broadcaster and viewer, the CATV system must maintain all desired channel frequency components (except for the sound carrier which is usually separated and reinserted at a controlled level) essentially unaltered in amplitude and time relationship.

Specifications for reconversion and remodulator CATV head-end equipment suggest that relatively flat amplitude response over the required frequency range is not too difficult to achieve. R-f band-pass filters, sometimes required to attenuate out-of-band spurious output from modulators or to provide additional r-f pre-selection, may introduce objectionable frequency discrimination toward the band edges. Frequency response should be symmetrical or have little tilt at least ±0.5 MHz around the chroma carrier. Unequal upper and lower side-band energy can introduce quadrature distortion (color transients) when the color signals are recovered in a receiver.

An important characteristic of any transmission system is its ability to transmit a complex signal with minimum distortion. One form of distortion results when related components of the signal, occupying different parts of the frequency spectrum, do not pass through the system uniformly delayed in time. Specification of a system's group delay variation over a frequency range, is a specification of variation in time delay through the system at different frequencies through this range. Degradation of the transient response of the video signal recovered by the receiver will occur if group delay is not relatively flat through the range of frequencies corresponding to the video modulation. Group delay time in the vicinity of the picture and chroma

carriers should be closely matched to minimize relative displacement of luminance and related chrominance on the color television receiver screen. Most CATV head-end equipment specifications do not include specification of group delay characteristics.

2. Differential Gain and Differential Phase Distortion

In order to approach a distortionless link between broadcaster and viewer, the CATV system must maintain picture carrier luminance and chrominance modulation essentially unaltered. Viewers are much more critical of errors in color saturation and hue of color television pictures than of errors in grey scale of monochrome television pictures.

Distortion of color saturation between light and dark parts of a picture is a function of amplitude linearity, since the chrominance signal is superimposed on the luminance signal. Differential gain is defined as the deviation from linearity. Significant differential gain distortion through the luminance range makes it impossible for the viewer to set color saturation correctly for both high luminance flesh tones and lower luminance background colors. Differential gain distortion must be low from white level through the region occupied by the color burst, so that the burst to chrominance amplitude relationship, relied on for color AGC operation, is not altered.

Distortion of color hue between light and dark parts of a picture is a result of color subcarrier phase-shift as a function of luminance signal level. Differential phase in color television is defined as the phase shift incurred by a constant phase chrominance signal as a function of low frequency (e.g., luminance) signal amplitude. Differential phase distortion must be very low from white level through the region occupied by the color burst, since the latter at blanking level provides a phase reference for color demodulation and the most critical colors, flesh tones, generally are relatively high in luminance.

Differential gain and differential phase specifications for some CATV head-end equipment do not appear sufficiently stringent to avoid perceptible, and perhaps objectionable, distortion of color television signals. Viewers are unhappy with present off-the-air color signal variations from program-to-program and station-to-station, and the need for more stringent broadcast specifications is being reviewed. The projected substantial growth of CATV systems may be inhibited unless any additional color signal distortions introduced are reduced to an imperceptible level.

3. Carrier Frequency Accuracy

In order that a receiver's adjacent channel trap circuits function as intended, the adjacent channel signal frequencies must

be such that they are converted to the i-f trap frequencies when the desired channel is correctly tuned. The increasing use of AFC systems and the limited fine tuning range for color television signals do not permit appreciable compromise between tuning for desired channel and for minimum adjacent channel interference. When a desired channel is misplaced in frequency between two correctly place channels, either the adjacent sound or adjacent picture carrier (dependent on direction of frequency error) will be too close to the pass-band when the desired channel is correctly tuned. Channel frequencies must be maintained as close as possible, preferable with ±.02% or better, if best receiver performance is to be expected.

The characteristics of CATV distribution systems which influence overall performance are generally well known, and except for a comment on control of subscriber signal level, will not be discussed further. It appears advantageous that, with present state-of-the-art limits on television receiver cross-modulation performance, adjacent channel signal levels should be relatively uniform, and probably between about +3 dBmV and +10 dBmV, for best overall performance.

SUMMARY

1. Interface problems have been defined as characteristics of television receivers and CATV systems which limit the ability of the latter to serve as an essentially distortionless link between broadcaster and viewer.

2. Television receivers could benefit from improvement in adjacent channel rejection and in immunity to direct pick-up, to function more effectively with CATV systems.

3. CATV head-end equipment could benefit from improvement in amplitude and group delay characteristics and in channel frequency accuracy.

4. CATV distribution systems are a vital link in the chain but were not discussed because they are generally well understood.

5. Appropriate standards must be developed, and equipment built and maintained to such standards, to permit the CATV system to function as an essentially distortionless link between broadcaster and viewer. This could be a significant factor in achieving the extensive expansion which has been projected for CATV over the next 5 to 10 years.

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ARCHER S. TAYLOR

In the early days of Cable TV there were no strong TV signals in the community under cable. Even when cable was installed in one and two-station markets, the increased choice of programs which the cable provided tended to outweigh the inconvenience of learning to receive certain channels at different numbers on the selector dial.

The interference problem first arose when CATV tried (voluntarily or under duress) to mitigate the adverse effect to the local broadcaster of carriage on other than the assigned channel. Now, with the development of CATV in larger markets the CATV operator often cannot afford dead channels. Thus, the broadcaster's need to preserve identification with a channel number now coincides with the Cable TV operator's need to utilize all available channels.

And so, the question arises increasingly: "How can we successfully carry local signals on channel?"

Interference occurs whenever the TV signal arrives at the signal element of the first detector of the TV receiver by more than one route. The desired signal arrives by cable, we hope, but undesired signals arrive by a process we will call leakage, either into the cable or into the receiver itself. The undesired signal is delayed one microsecond for each one thousand feet of airline distance from the transmitting antenna to the customer's receiver. The desired cable signal is delayed one microsecond for each thousand feet airline distance from the transmitting antenna to the CATV antenna plus 1.2 microseconds for each one thousand feet of coaxial cable (not strand feet) including the drop cable. Thus, any Cable TV customer receives the desired (and paid for) cable signal a few (or several) microseconds later than the ambient direct signal.

It takes roughly 40 microseconds for the electron beam to scan

from the left side of the picture screen mask to the right, representing about 7.5 miles difference in path over the air, or about 9 miles of cable. It is therefore apparent that direct signal will arrive early, but almost never more than one line early. AGC, sweep, and clamp circuits will be locked to the stronger signal. Since sync is "blacker than black" the horizontal sync pulse of the weaker signal appears as a vertical black bar on the screen. If the direct signal is strong enough, a phantom picture will appear, generally to the left of the desired picture.

If the head-end is a baseband system (demod-remod), or if different local oscillators are used for down and up conversion, the slight and unavoidable frequency difference between the cable signal and the direct pickup signal produces an effect much like co-channel interference. Heterodyne signal processors avoid this by using the same L.O. for down and up conversion.

As will be seen later, there are so many uncontrollable variables that it has not been possible to describe a reliable threshold field intensity for direct pickup. As a rough rule of thumb it appears that with heterodyne or strip processors, you can expect to find vertical black bars on some TV sets anywhere within the Grade A Contour. With baseband type processors, you can expect venetian blind interference all the way to the Grade B Contour, and even beyond. Distinct phantom pictures will appear up to perhaps 10 miles.

At this point, we must distinguish between direct pickup ghosts which are leading, to the left of the desired cable image; and multipath propagation ghosts which are lagging, to the right.

Then there are two circumstances which may contradict the rules I have just given:

1. If the difference in travel time exceeds 63.5 microseconds, the ghost or vertical black bar may appear on the right because it is leading by more than a full line. This is quite unusual, but it can happen.

2. In another rare case, the direct pickup is actually stronger than the cable signal. Since the TV set locks to the stronger signal, the cable picture becomes the "ghost", lagging behind the direct pickup signal.

It is really not correct to say that "direct pickup" is caused only by poor receiver shielding. Before the receiver problem can be corrected, it is essential that there be no direct pickup leakage into the cable distribution system itself. This can and does happen. The most obvious reason is inadequately shielded drop cable. Braided cables of the RG-59/U type may have as low as 70% coverage, leaving a great deal of space for

leakage. But leakage may also take place at any loose or corroded connector or splice on trunk or feeder cable as well. Careless use of a knife or stripping tool may have caused a cracked aluminum sheath which can leak a direct pickup signal. Pressure tap contact with the aluminum sheath may have become loose or corroded, allowing leakage into the feeder and drop.

Thus, in new systems, routine use of high coverage drop cable such as double shielded braid, nylon foil tape, or solid aluminum sheath is good insurance. But before any other step is taken on a direct pickup problem, the drop must be tested for freedom from interference. Several broadcaster types drawing up rules for Cable TV have proposed test methods requiring removal of the desired signal from the system. Any experienced operator will recognize immediately that this cannot be done as a routine test because of the flood of customer complaints about interruption of service.

The most practical method we have found is to connect a carefully shielded TV set to the drop. A small-screen, battery operated, portable receiver can easily be mounted in a sheet metal box with the picture screen only partly uncovered. The balun transformer is arranged so that the drop cable shield connects firmly to the shield box. If any direct pickup effects are seen on this receiver, it is almost certainly due to cable system leakage. This must be isolated and corrected before proceeding further.

If the shielded test receiver produces a picture free of direct pickup, it may be safely concluded that any direct pickup interference observed on the customer's TV set is in the receiver itself, or its interface with the drop.

When the cable itself is free of direct pickup, there is a rather simple but effective way to measure roughly the vulnerability of a particular drop installation. Connect a switchable attenuator in the drop serving the customer's set. Increase the attenuation until the picture on the customer's set begins to tear because it can't tell whether to sync to the cable or to the direct signal. At this point, it may be assumed that the undesired leakage signal presented to the horizontal sync circuits is approximately equal to the attenuated desired signal delivered by the cable, which can be measured. This level is the equivalent direct pickup signal level characteristic of the particular TV set in its particular environment.

We have not yet collected a great deal of data, but we have a tentative opinion that the cable signal level at the drop terminal should be about 30 dB greater than the equivalent direct pickup level for freedom from leakage interference.

The signal level at the drop terminal may be raised by using a

different tap value, lower loss drop cable, or a booster amplifier at the subscriber's terminal. The upper limit of signal level is determined partly by system design and partly by the receiver overload characteristics.

The effect of the balun transformer on direct pickup frequently seems to be a mystery, but it is really very simple. First, the balun itself may pick up ambient signals if not adequately shielded both electrically and magnetically. The twin lead jumper adds to the length of the twin lead in the receiver as antennas of small but finite effective length.

Another mechanism which must be considered, however, is that the drop cable shield itself is exposed to the strong ambient field, acting as a long wire antenna of pretty good efficiency. If the shell of the F-fitting on the balun transformer could be connected to the receiver ground, the currents picked up by the shield would not produce any signal voltage at the tuner input. But this is usually not practicable.

It is important to note that grounding at VHF radio frequencies is not as easy as grounding dc or power or lightning. A ground at the service entrance usually has no effect on the direct pickup signal, because the ground wire itself is long enough to be an antenna. Similarly, a ground connection from the transformer to the receiver chassis may not be short enough to be effective. So, unless you go inside the set and ground the balun with a 1/4 inch lead at the same point to which the tuner itself is grounded, there will be a significant impedance between the drop shield and the tuner ground.

In the absence of an external path, the drop cable shield currents are returned to the tuner ground through the two baluns, one external, the other in the tuner. If the baluns are accurately balanced, the currents pass equally through the two sides of the 300 ohm windings, thereby cancelling and coupling little or no leakage current to the tuner input.

The cable technician cannot usually do anything about the internal balun. But it is sometimes helpful to use a well balanced external unit, and it should be tried. As a matter of fact, it would seem prudent to use a well balanced balun in all installations in systems suffering from direct pickup interference. Attempting to ground the balun to the receiver chassis is not likely to help much when it is realized that a #20 ga. wire three inches long has approximately 50 ohms of impedance at 100 MHz.

Another trick for reducing the common mode current resulting from direct pickup on the drop cable shield is to insert a choke or trap at the end of the drop. The drop cable can be wound into a coil of 4 or 5 turns held in place with tape, or

the drop cable can be formed into a hairpin shaped quarter-wave trap.

If the direct pickup signal in the receiver is primarily a result of coupling to the internal twin lead or other set wiring, neither the balanced balun or the drop cable choke will help significantly. We have found that they do help, but certainly are not cure-all remedies.

Where cable subscribers are located less than about 10 miles from a local TV transmitting antenna, it is probably that nothing short of modification of the TV receiver will cure some cases of direct pickup. There are apparently some cases where even the most elaborate but practical TV set modifications cannot completely eliminate the problem.

When TV set modifications appear to be necessary, and are acceptable to the cable operator, the first and most effective step is to provide 75 ohm unbalanced coaxial cable right down to the tuner balun input, grounding the cable shield with a very short low impedance lead directly to the tuner input ground.

In order to maintain compatibility with 300 ohm balanced antenna inputs, it may be satisfactory to use shielded 300 ohm balanced cable. We have not tried this, however.

In extreme cases, where the TV transmitting antenna is much closer than 10 miles, it appears that more extensive shielding may be required. Perhaps the entire tuner will need to be enclosed in foil or sheet metal; perhaps the power supply needs to be decoupled for r-f; perhaps the AGC bus conducts direct signal to the first detector; perhaps there are other sensitive circuits which must be identified and properly shielded.

In all this discussion I have avoided mention of the set-top converter. This device works. If the cable itself is free of leakage pickup, the converter is completely effective in eliminating interference, because the customer's TV set is tuned to a channel on which there is no strong ambient field. There are, however, a number of problems besides cost which are beyond the scope of this paper. I believe I would recommend the assistance of competent consultants in evaluating the complex factors associated with the use of converters.

Likewise, our good friend Mac Ferguson has pioneered the dual cable concept which avoids direct pickup interference by conversion to open channels, but nevertheless provides customers with more than 12 channels by means of an A/B switch at the set.

There are a number of adaptations and combinations of conversion and dual cable which make a certain amount of sense in particular cases. Hardware is not yet adequate, in my opinion.

ARCHER S. TAYLOR AND DONALD W. LEVENSON

In any case, conversion schemes are all the same insofar as they assume that TV channels on which there is a strong ambient signal will be wasted. Can we afford to "waste" cable spectrum in this way?

In the final analysis, the best answer is a redesign of TV receivers so that they are isolated from ambient fields. Work on this is in progress. We stand a better chance of success when we have 20 million subscribers than we do with 3-1.2 million. It is as simple as that.

In closing, let me summarize. A systematic approach to the problem of direct pickup should eliminate most of the mystery of what has often seemed an inscrutable problem.

First: Test for and eliminate interference on the drop or or cable system.

Second: Measure the equivalent direct pickup signal level.

Third: Work for a 30 dB spread between desired and undesired signal levels by:

(a) Raising the desired signal level as much as possible.

(b) Decreasing the undesired signal level with balanced baluns, drop cable chokes, or shielded tuner input levels.

I believe that at distances more than 10 miles or so from a full power TV transmitting antenna, 90% or more of the direct pickup cases can be corrected without modifications to the TV set. At closer distances, some set modification will be necessary; and at very close range, it may not be possible to solve all the problems.

Demod-remod and sub-low type system designs are especially vulnerable and should be avoided.

DONALD W. LEVENSON

The installation of a well engineered CATV system to bring superior pictures to your subscribers is today a well defined science. The maintenance of the original high standards of performance as the system ages is another matter.

This paper describes a method of making a summation sweep of the entire TV and FM spectrum of an operating CATV during the subscribers' viewing hours without receiving complaints from them.

The design criteria for our system were:

1. No annoying interference with TV pictures
2. No interference with system operating levels
3. No interaction with system AGC
4. No breaking into system or cabling
5. The remote receiving equipment must not require any power or synchronizing with the city power mains. It must be capable of operating entirely from a truck with only the truck battery or a portable power source

The system described in this paper removes only a few lines of one TV field by using a rapid sweep coupled with a short duty cycle, that is, the sweep time to operating time ratio. This technique solved the problem of interference with TV pictures, operating levels and AGC. An operating time of 2 to 10 m sec. with an off-time of 12 to 20 sec. creates no problems either for the technician or the viewer.

A simplified block diagram of the equipment at the head-end is shown in Figure 1.

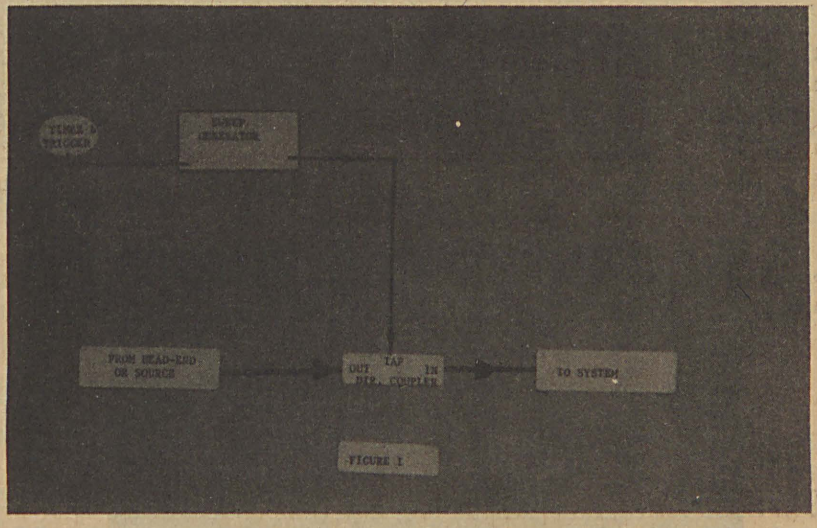
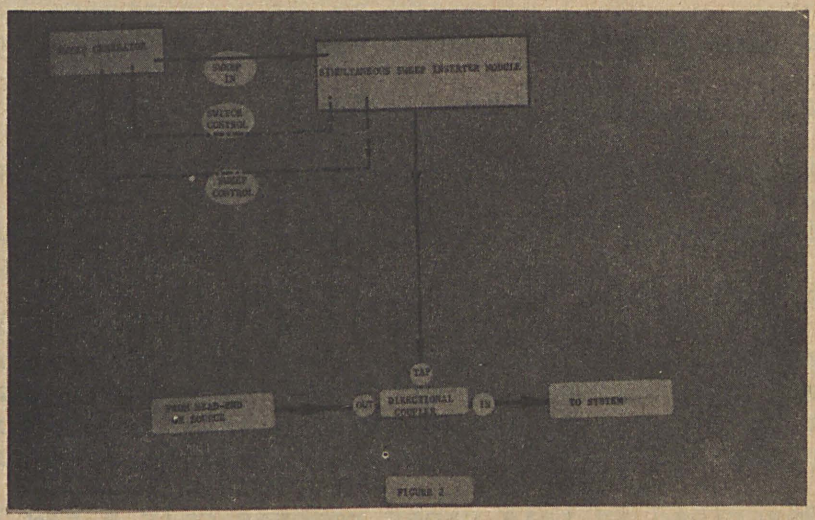


FIGURE 1

The timer-trigger controls the sweep operation. A directional coupler is used to insert the sweep into the system. The sweep r-f level in the trunk line should be 10 to 20 dB above the video carriers.

A block diagram of one commercial version of the equipment is shown in Figure 2.

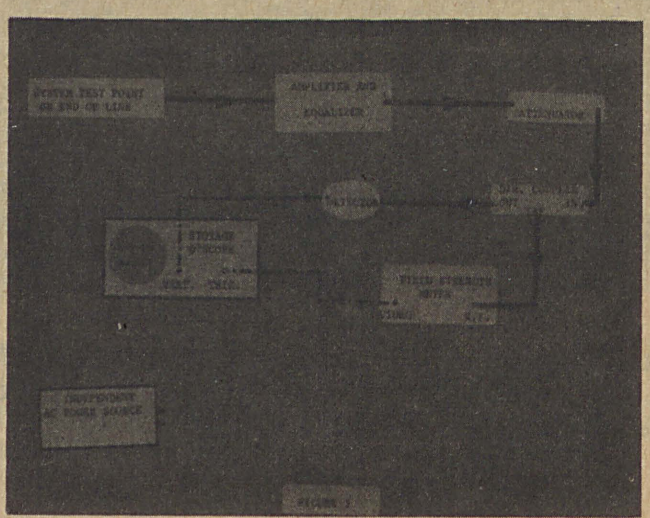


The commercial simultaneous sweep inserter module contained the variable timing and sweep modulation control circuits as well as a solid state switch. The solid state switch is necessary to prevent noise and extraneous signals from getting into the system. For a plant to be maintained properly, the sweep and inserter units should be left permanently installed and made a part of the head-end equipment. In this way, the system is always ready for rapid emergency trouble shooting as well as for routine preventative maintenance.

The signal from the system amplifier output test point or the cable end is fed into the truck, amplified, and detected.

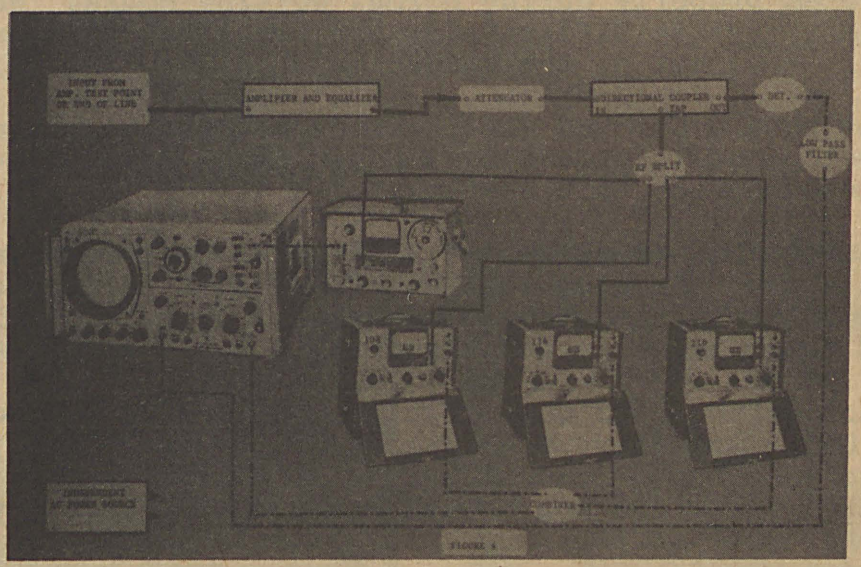
The amplified r-f signal is sampled with a directional coupler and fed into a field strength meter.

A block diagram of the basic receiving system is shown Figure 3.



Two of the unique features of this system are the method of viewing the pulse, and the method of triggering the oscilloscope time base. The detected sweep signal is introduced into the vertical circuits of a storage oscilloscope. To control the triggering of the time base, a field strength meter was set slightly below the lower limit of the lowest frequency channel. When the sweep traverses the lower skirt of the system the pulse developed in the field strength meter is used to trigger the oscilloscope time base. The time base on the oscilloscope is set to give a full sweep in the same time span as the sweep generators' time base. Hence the sweep and remote viewing locations are in synchronism with only the r-f sweep in the system as the control.

Markers may be provided with other field strength meters.



To view the detected pulse we use a 141A Hewlett-Packard oscilloscope whose persistance or storge time we can vary. This allows us to preserve a single trace for photographing or analysis or permits the trace to fade between sweeps if system adjustments are made simultaneously.

Before we discuss some actual maintenance situations, note that Figure 4 is a pictorial representation of the equipment in the mobile van when many of the following oscillograms were made. The Jerrold 727 field strength meter pictured furnishes the trigger pulse for the oscilloscope. We use a dual trace vertical amplifier on the Hewlett-Packard 141A. The wide band detector is fed into channel A through a low pass filter that removes the 15,750 h_z horizontal sweep components. The B channel furnishes our zero signal base line for the sweep. We also feed markers that are under control from the additional field strength meters into Channel B.

Some problems familiar to everybody in the industry include such things as an intermittent connection in the center conductor of a splice, a crack in the outer sheath of the cable, deterioration of the cable, or a bad fitting on either the input or output of electronic equipment connected to the cable.

The following figures were taken on operating CATV systems.

(See figures 5, 6, 7, 8, 9A, 9B, 10)

The emphasis of CATV has now moved from the rural to the urban communities. The CATV's financial success depends on its ability to bring with continuity a better pciture to subscribers.

The techniques described in this paper make it possible to maintain the system properly during normal working hours. What is more important, system difficulties can often be diagnosed before they are apparent to the subscriber.

We hope that this paper and the techniques described stimulate further development into methods and equipment for improving the on-line maintenance of CATV systems.

The emphasis of this paper has been on system maintenance. However, these techniques also save considerable time in placing a new systems in operation because the r-f output and tilt may be measured simultaneously and adjusted as needed.

I wish to acknowledge the contribution of Messrs. Lee Zemick, Sid Fluck, Henry Arbeiter, Mike Jacobs and Caywood Cooley of the Jerrold organization. Without their vision, the simultaneous sweep synchronizer would not be available to the industry today.

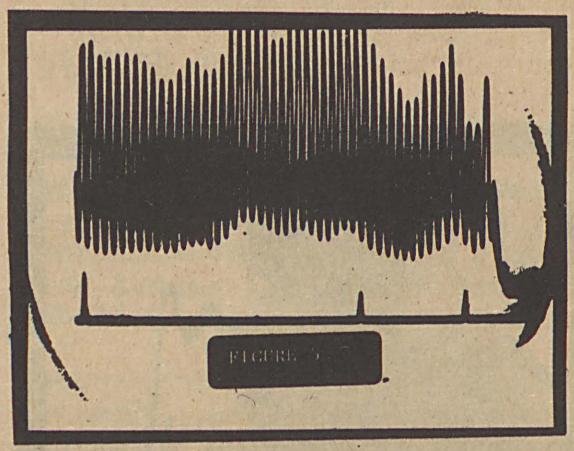


Figure 5 shows a defective splice about 160 feet from the amplifier. The solid trace shows the splice repaired.

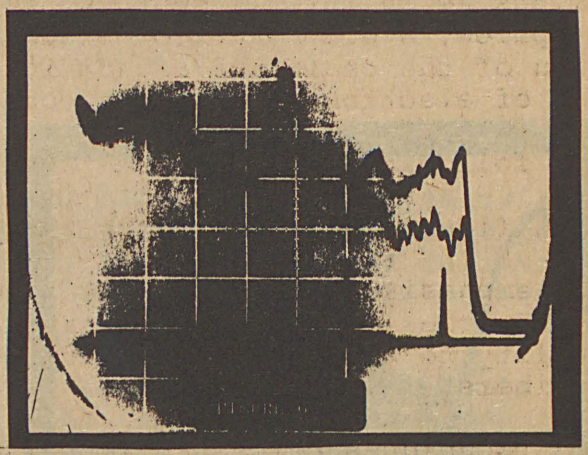


Figure 6 is the response from a hairline crack in the outer conductor of coaxial cable.

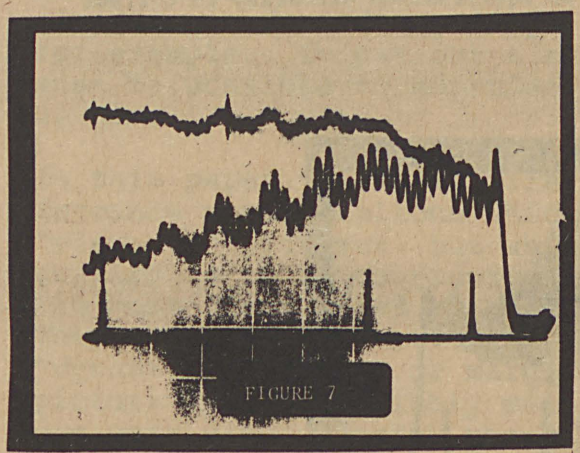


Figure 7 is a poor connection on center conductor at splice feeding the amplifier.

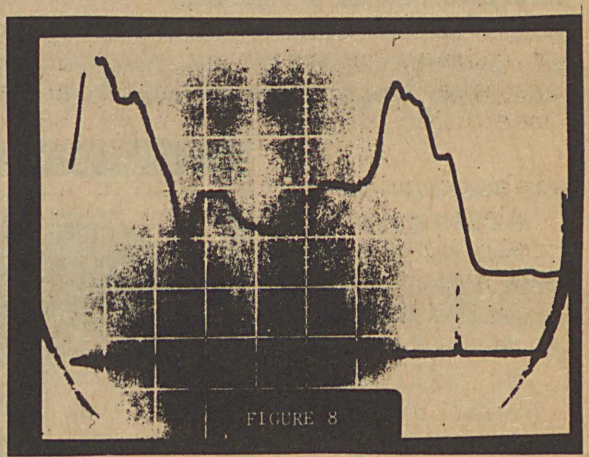


Figure 8 is loss of signal at specific frequency.

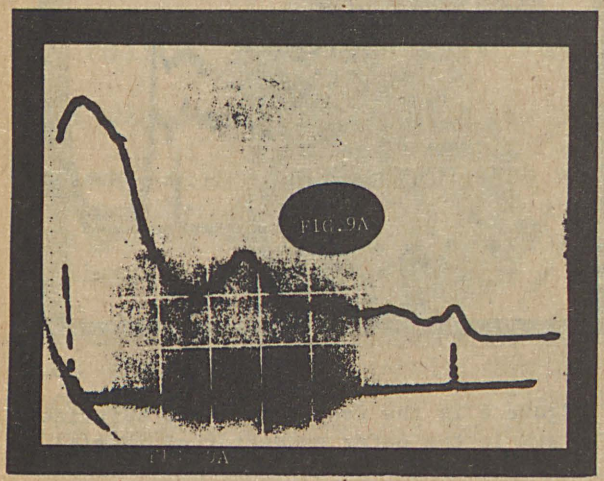


Figure 9A is response of cable that deteriorated over a period of approximately 6 years.

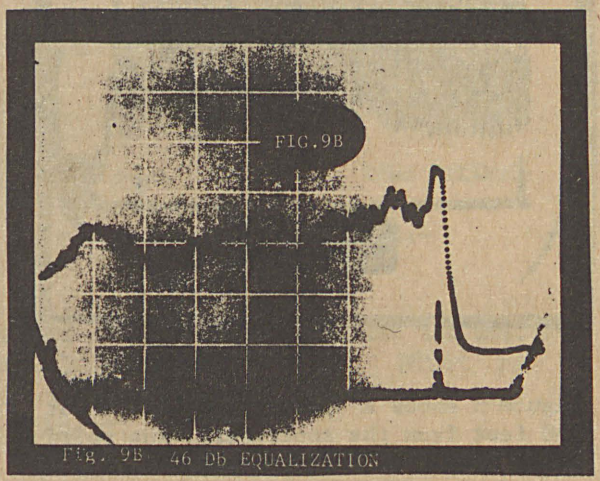
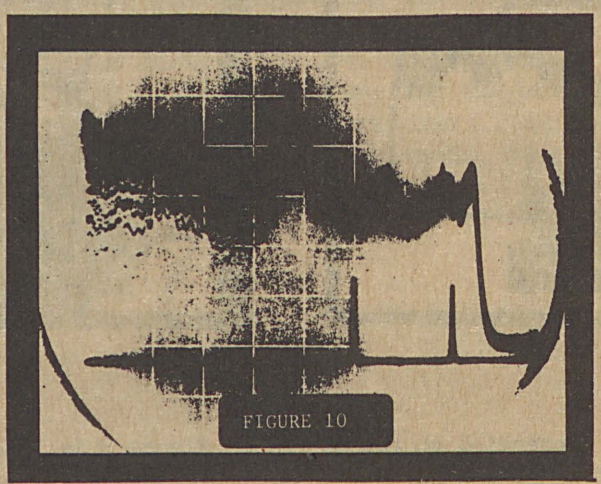


Figure 9B is the same cable with 43 Db of equalization necessary to correct response.



The flashing picture syndrome is familiar to all of you. Figure 10 is an oscillogram taken at the output of an amplifier as the wind was blowing. The large change at low frequencies indicates probably center conductor intermittance.

ORVILLE D. PAGE

I. INTRODUCTION

New equipment becoming available for broad-band cable television systems is capable not only of greatly improved electronic performance but also of a significantly higher degree of reliability and longer life, plus greater ease of installation and maintainability.

Not-so-coincidentally perhaps; (a) the Cable TV industry is entering an explosive growth era; (b) CATV system operators are becoming much more sophisticated and knowledgeable of their technical problems, operating problems, and costs; and (c) the subscribers are becoming more critical and demanding of the type and quality of services offered. Additionally, CATV is moving into many areas where off-the-air pictures are generally quite good, so that pictures off the cable must be not just "acceptable" but of very high quality.

And, finally, CATV systems are becoming much more expensive - by almost an order of magnitude where large cities are being wired, for example. To pay out a reasonable return on investment, it must be possible to amortize these systems over longer periods of time.

In this paper, we shall first of all assume a set of system performance specifications which will give not just "acceptable" or "viewable" pictures, but which should result in such picture quality as to be considered quite enjoyable viewing by all but the most disgruntled subscriber (and perhaps a few competitors). Then we shall attempt to define or design a system with such a "dynamic range" (1) or margin of safety that this quality of picture will be reliably maintained over a period of at least one year without major resetting of levels or realignment of equipment.

Following this are brief discussions of reliability, maintainability, and cost considerations.

II. SYSTEM PERFORMANCE REQUIREMENTS AND OPERATING CONDITIONS

A. Signal-to-Interference Ratios

Test programs relating subjective picture quality to signal-to-interference ratios are sufficiently well-known to the serious reader, and little if anything will be gained here by again summarizing the results of these tests. (2), (3), (4) et al.

The objective here is to list a set of signal-to-interference ratios which will result in pictures acceptable to a great majority (90% or more, 90% of the time) of the critical subscribers -

pictures which will in general compare well with off-the-air pictures, in most any urban area. For the purposes of this paper, we shall assume that the picture will meet these requirements if the system delivers signals to the TV set with the following ratios:

Signal-to-noise Ratio (4 MHz)	40 dB
Cross-modulation Ratio	50 dB
Intermodulation Ratio	50 dB
Hum modulation Ratio	45 dB

Other types of interference, such as co-channel and adjacent-channel, are not generated in the transmission system, and are not considered here.

If our system is to meet the criterion of year-round operation we must then insure that the signals at almost all (say 90%) of the subscriber's terminals shall be maintained at, or better than, these ratios or quality levels (say 90% of the time) for at least a year without major adjustments, resetting levels, or any general realignment of the system.

B. System Bandwidth and Frequency Response

Today's CATV equipment will be obsolete at some time in the future. This is natural and unavoidable in any industry where the "State-of-the-Art" is changing - and it is changing rapidly in our industry. The need for selecting the best and most versatile equipment becomes obvious. To do so will then insure that your system does not enter early obsolescence. If we are to design a system for 20-year life, it must not only function after 20 years, it must perform a useful function at that time.

Transmission equipment is now available which will cover a frequency range of 50 to 280 MHz (±0.25 dB) in the trunkline and in excess of 50 to 270 MHz in distribution lines. Passive devices cover frequencies between 5 and 300 MHz or better. Cable is now being furnished to cover frequency ranges in excess of 5 to 300 MHz. This provides for 20 or more channels of TV without worrying at all about second-order products, and still allows plenty of unused spectrum for other ancillary service signals, which could be transmitted at considerably lower signal levels. Furthermore, the equipment is now modular, so increasing r-f bandwidth and other capabilities in the future would depend only on replacing modules.

In careful design of r-f equipment and amplifier circuits, provision is made for circuit adjustments which can be made in the field to compensate for slight variations in response of cable and passive devices. This is accomplished during sweep-alignment of the trunkline, which should always be a part of any new system installation, and further should be made a part of regular maintenance procedures.

Experience indicates that frequency response at the end of a trunkline can be within ±2 dB for most systems of reasonable length (32 to 50 amplifiers), by careful alignment of amplifiers and by use of high quality cable and passive devices. Bridging amplifiers normally have a specified frequency response of ±0.5 dB, and good-quality extenders should not exceed ±1.0 dB. These irregularities would tend to add, so if distribution is not swept, and up to 2 high-quality line amplifiers are cascaded off a bridger (see below), response at the tap should be held linear within ±5 dB across the band, with not more than 0.5 dB variation between adjacent channels. Sweep-alignment of distribution amplifiers (not normally necessary) would be expected to improve this further.

C. Subscriber Levels and Tilts

As of approximately 1959, TASO reported to the FCC (2) that the poorest noise figure available in a VHF set was about 12.2 dB. Presumably, TV sets are no worse today; surely they are better. Assuming a 12.0 dB noise figure in the receiver, the level of a clean signal coming into the set would have to be, for a 40 dB S/N:

S = 40 dB + N (N = noise level in dBmV at 75 ohms)
40 dB + (-59 dBmV + 12 dB)
-7 dBmV

However, the signal coming in is not clean due to the noise contribution of the system itself. Furthermore, as we enter larger cities and areas of higher population, we are going to encounter greater noise levels and appreciable pick-up from local TV stations (which will for the time being still be broadcasting signals). Accordingly, we shall select a higher signal level, +3 dB, at the set, and the set noise figure will not be limiting after all. (Increased level at the set has been found to be very effective in reducing or eliminating degradation by local pickup. In one urban system, where local signal levels are quite high, the need for converters was eliminated in 90% of the cases, by designing for a level of 10 dBmV at the set).

For best TV set performance, levels should not vary excessively at the set. Although AGC performance is generally quite effective in most all color and black and white sets available today, nevertheless, it is possible to overload the set. The set will perform better if signal variation is held to a minimum. A maximum level of 15 dBmV is probably a good compromise.

D. Environmental Considerations

CATV systems must operate in all parts of the country - and throughout the world - over all extremes of weather and associated environmental conditions. The service must be of the

highest quality and reliability - and often the demands for service might be highest during the worst conditions such as during rainy seasons, severe cold weather, etc. To the extent that reliability is not designed into the equipment and the system, greater maintenance effort and customer dissatisfaction will increase costs and reduce revenues.

A good beginning reference point for equipment performance requirements as a function of environmental conditions would be the general specifications for surface military equipment, such as the current versions of MIL-E-16400 and MIL-E-4158. These represent many years of experience of the military services in attempting to design equipment for operation under all weather and environmental conditions, throughout the world. The following conditions should be anticipated for reliable operation in the domestic United States:

1. Temperature

   Reference to U.S. Weather Bureau records indicate of course a wide difference in temperature ranges in different parts of the country. For example, in Los Angeles, California the total temperature change over a year's time might not be more than 80°F or so. In Great Falls, Montana, however, the temperature change might be 130° over a year's time. Equipment is now available which will function over temperatures considerably in excess of these - i.e., from -40°F to +140°F or a total range of 180°F.

   To insure additional safety factor in our design we shall require that our CATV system operate reliably over at least a range of 170°, or ±85°F.

2. Corrosion

   Of all the environmental problems encountered in operating CATV systems, probably temperature is the best-known and therefore of the most concern to everyone. This is probably due to the rather unfavorable circumstances experienced when CATV went to transistors (the same thing appears to have happened in all other industries), and partly due to the fact that temperature problems tend to manifest themselves immediately and urgently; they cannot be ignored.

   From an economic standpoint, however, corrosion is a deadly enemy of CATV systems, particularly such areas as coastal cities, and cities where the air contains a high degree of corrosive air pollutants. Reference to the above-mentioned MIL Specs will be

helpful again here. Specifically, guidelines for use of dissimilar metals must be followed. All metal surfaces must be passivated and/or coated for corrosion resistance, or must be reliably protected from the elements, such as polyethelyne jacketing on cable. Aluminum housings used on amplifiers and passive devices should be iridited or chromate-dipped, and then painted with a long-life paint such as one of the epoxies. This procedure must be followed where corrosive elements are known to exist in the atmosphere, and for all buried plant.

3. Moisture

Moisture entry into cable, fittings, and equipment has been one of the most troublesome and expensive problems in the industry, and proof remains to be seen that it has been economically and reliably solved.

For practical purposes, it would appear that none of the fittings available today will offer trouble-free, moisture-proof performance for more than a year or two (although great progress has been made over the past few years in designing good, high-quality fittings). Regular maintenance-cleaning, tightening, replacing is required.

Today's high-quality cable is a very great improvement over what was available to CATV even a few years ago. However, it too is being subjected to more stringent demands, as for example in underground plant, where corrosion and moisture will combine to cause early degradation.

Equipment and devices, too, are still much too susceptible to moisture entry. Much has been done, largely perhaps as a result of Bell Telephone's KS Specs, toward design of sealed, gasketed, bolted enclosures for CATV transmission equipment. Problems of gasket setting, porosity, and the ever-present technician/serviceman who must be depended on to carefully seal and torque the housing each time it is opened, all combine to almost guarantee that at any given time there will be some type of moisture in some number of equipment housings. A rather interesting approach to the problem admits to the fact of water entry, and proposes the use of a self-regenerating dissicant in the equipment. (5) Another approach is to pressurize the system.

4. Mechanical

Aerial-mounted equipment is subjected to three general types of vibrations:

a. 60 Hz from the power line transformer and associated equipment.

b. Resonant vibrations of the utility systems, triggered by the winds.

c. Vibration caused by moving vehicles on streets and highways.

Now to relate this to detrimental effects on the CATV System, let us add two other factors.

a. Aluminum is subject to cold flow.

b. Contraction and expansion of aluminum with temperature changes.

The above conditions can cause cable fitting nuts to loosen and/or the pressure on the ferrule to be reduced. At any location where movement of the cable is restricted, the cable can fatigue, causing the shield to separate.

Either of the above conditions will result in a high-resistance ground circuit, with resulting radiation interference and/or ghosting.

Minimization of these matters begins with good construction, e.g.: (a) properly lashed cable, (b) strain relief loops; (c) tight, lubricated, weather-proof fittings, and then continued with conformance to a regular, careful inspection and maintenance program.

Other mechanical environmental conditions are primarily limited to those encountered in shipping, handling and installation. Solid-state equipment and devices are quite immune to mechanical shock and vibration; however, care is required in shipping and handling of cable.

5. R-f Interference

Proper mechanical and electrical design and installation will insure performance superior to FCC specifications, and will eliminate pick-up by the transmission system.

6. Reflections and Ghosts

Reflections must be held below levels which will produce ghosts on TV screens. The reflection ratios, or return losses necessary to accomplish this are directly related to cable length, cable attenuation, and time delay (1). These factors can be related to determine necessary return loss ratio and directivity at the input and out of each amplifier and passive device. Generally, return losses as listed in Table 1 will eliminate ghosting, and normally return losses of equipment and devices will not change appreciably with age, except where fittings will become defective.

III. SYSTEM DESIGN CONSIDERATIONS

The "Transmission System" discussed here will only include that portion of the CATV system from the combined output of the head-end to the output of the tap-off device in the distribution system. Specifically, subscriber plant (drops, etc.) is not within the scope of this paper, except to remark that much attention is needed there, which is being given by many manufacturers.

To simplify matters here, we shall assume that the subscriber drop plant is virtually perfect, (a very unrealistic but necessary assumption at this time), and that the drop cable has attenuation of 7 dB at Ch 13, varying linearly to 3.5 dB at Ch 2. In the limited time and space left we shall now consider the design of the total CATV transmission system.

A. General Considerations

It would be ridiculous, economically and otherwise, to build a home or factory with an electrical system capacity based on average usage. Overloads and growth factors must be included. Then why design a CATV system to normally operate at performance factors which are actually borderline between "acceptable" and "Objectionable"? If the system is to be reliable and profitable, we must design for the majority of "worst cases". (Since many of the factors included are subjective, economic feasibility does stop short of "100% satisfactory").

A safety factor must be applied to all important electrical parameters of the transmission system which are likely to change, most notably: crossmodulation, intermodulation (2nd and 3rd order "beat"), noise, hum, and levels. Then under changing condition of temperatures, equipment aging, misadjustment, replacement of modules, etc., we can insure satisfactory performance for a large majority (90%) of our customers for a reasonable length of time: one year or more without minor adjustments or general realignment.

With respect to spurious interference (crossmodulation, intermodulation, noise) a quality factor for equipment has been derived by Jones (6). A similar or identical factor for equipment and systems has been discussed by Rheinfelter (1) as "dynamic range", and to this we must add a perhaps very arbitrary factor to allow for equipment alignment, system aging, etc.

B. System Signal Level and Interference Variation

1. Trunkline Signal Variations

Consideration of dynamic range and other factors related to level changes and system adjustments must be preceded by a discussion of ALC methods, since all level variations in the system start with level variations in the trunkline. First of all, use of the term, "level control" is not realistic unless levels indeed are being controlled. Specifically, a device which senses temperature and then hopefully changes gain and slope, of another device in an attempt to make a signals remain constant, just isn't going to give adequate level control in the trunkline. Acceptable ALC will only be obtained by sensing the level of one or more signals which are being transmitted along the coax. Automatic, closed-loop circuitry then controls the levels at the amplifier output. Pilot-carrier control provides cumulative correction; each amplifier picks up the error at the output of the previous unit. Temperature-sensing "ALC" is not cumulative; errors are additive.

Then, since we want "level control" across the band, we really must also use a feedback system which will control the frequency response of the devices in such a way that all levels are controlled. In a sense, then, we really don't have "level control" unless we control all levels, and this is best accomplished by dual-pilot carrier control, or by use of automatic level control/automatic tilt control (ALC/ATC) devices in the system (7). The system can then indeed automatically control levels regardless of the ratio of cable loss to flat loss in any section of trunkline. The use of the term "Automatic Level and Tilt Control" to describe an amplifier which is really "tilt compensated" for a fixed length of cable, and operates only on one pilot carrier, is nothing but misleading.

With respect to the still somewhat prevalent use of manual gain amplifiers in the trunkline, interspersed with an ALC/ATC amplifier or, worse still, an ALC

amplifier every third station or so, it does seem to be a bit inconsistent to design a precision ALC or ALC/ATC system which is capable of holding amplifier output level to within ±0.5 dB, and then space these amplifiers 60 dB or more apart. This allows for (60 dB x 1.0%/10°F x ±85°F) or up to 5.1 dB increase or decrease in input to the ALC amplifier, and up to 3.4 dB increase or decrease in output of the non-ALC amplifier. In case an ALC station fails, the above variations are then doubled at the next station.

For reliable, high-quality trunkline control, we contemplate the use of pilot-carrier ALC (Tilt-Compensated) at every trunkline station, and dual-pilot-carrier ALC/ATC at every fourth station for aerial plant and every sixth station or so for underground. Under these conditions, and 22 dB spacing, the average cable run between amplifiers would be perhaps 18 dB and trunkline amplifier output levels will hold to better than ±1 dB with modern dual-pilot-carrier ALC/ATC control. Input levels will accordingly hold to better than ±1 dB ±(85° x 1.0%/10°F x 18 dB cable) = ±1 dB ±1.5 dB or ±2.5 dB or better. (Neglecting signal variation in the head end). This input variation is further reduced by designing temperature-compensating gain changes into the ALC loop in the amplifier, so that the output levels tend to vary directly with temperature - a rather elegant combination of temperature equalization in the circuit plus automatic pilot carrier control in the system. A level stability of ±1.5 dB any place in the trunk is not exactly uncommon with such systems.

With allowance for aging, we can undoubtedly expect average variations at the input of the amplifiers of ±2.0 dB or so. However, once the ALC/ATC circuits are properly adjusted, output levels should never vary more than ±1 dB, again neglecting head end variations.

2. Distribution System Signal Variations

Input to the Distribution system is derived from the trunkline, and we start with an input variation of ±2.0 dB maximum. A new line amplifier is now available with a temperature-sensing gain-control device in the circuit. (See Table 1). This unit has a maximum operational gain of 30 dB, and for temperature-caused input level variations up to ±3 dB, will hold output levels +1 dB. With noise

figure well under 10 dB, two or more of these units can be cascaded in distribution. The length of loaded cable at the output of each extender will be approximately 16 dB and level variation will be $(85^{\circ} \times \frac{1\%}{10^{\circ}} \times 16) = 1.36$ dB. The AGC circuit will reduce this to one-third, per amplifier, so two amplifiers will allow a variation of less than 0.91 dB at the end of the last feeder.

The bridger will drive approximately 10 dB of loaded cable (at approximately 35 dB output) which will vary $\pm(85^{\circ} \times \frac{1\%}{10^{\circ}F} \times 10$ dB) or 0.85 dB in attenuation. Bridger gain will vary a maximum of ±1.0 dB over the temperature range.

Total variation (under worse case conditions) at the end of Distribution Line and at the set will be:

Bridger output level variation	±3.0 dB
Distribution cable off bridger	±.85 dB
Two line amps and cable	±0.91 dB
Sub-Total (Distribution)	±4.76 dB
Drop cable $\pm(85^{\circ} \times \frac{1.0\%}{10^{\circ}F} \times 7)$	±.60 dB
Total at set	±5.36
or less than	±6.0 dB at Ch 13

In extended range systems, variations will be higher by the square root of the frequency ratios. For a system operating up to 270 MHz for example, the variation would be less than -6.0 dB $\times \sqrt{\frac{265.26}{211.25}}$ or 6.72 dB. Variation will be much less in underground installations, where temperatures change perhaps only $\pm 20^{\circ}$ or less.

3. Variations in Noise and Distortion Ratios

Under iii A.2.a. above, we calculated worse case signal level variations in the trunkline as:

Amplifier Input	±2.0 dB
Amplifier Output	±1.0 dB

Corresponding interference ratio variations in the trunkline would be:

S/N Variation	±2.0 dB and
Intermod. and crossmod variation	±2.0 dB

Signal variations at amplifier outputs in distribution, are tabulated in Table II:

Table II
Output Signal Variations of Distribution Amplifiers

Amplifier	Output Level Variation (dB)
Bridger (Intermediate)	±3.00
Line Amp. No. 1	±2.95
Line Amp. No. 2	±3.41

The following sketch illustrates the computation:

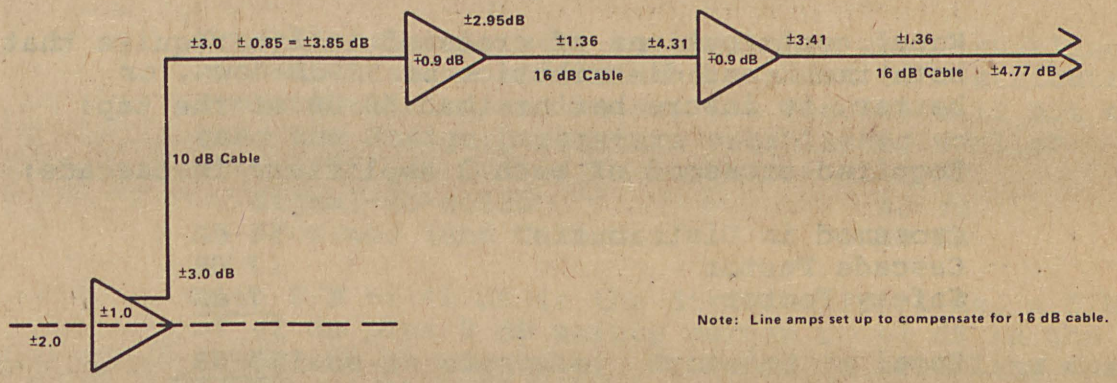


Figure 1

Averaging these will give a variation which is accurate enough: ±3.1 dB in level and ±6.2 dB in distortion.

Input level changes will affect signal-to-noise ratio in distribution. From Figure 1 above, the input level variations will be:

Bridger	±2.00 dB
Line Amp. No. 1	±3.85 dB
Line Amp. No. 2	±4.31 dB

Average line amp input level variation: ±4.08 dB, which will approximate the average signal-to-noise variation in 2 cascaded amplifiers. (We must assume equal signal input to both amplifiers). Signal-to-noise variation in the bridger will vary ±2.0 dB.

C. System Design Levels

Calculation of required system operating levels will be based on the assumption that trunkline length is to be maximized, consistent with practical amplifier gains. Equal contribution of interference from trunkline and distribution is desirable.

1. Distribution Levels

Equal contributions of crossmodulation require that both trunk and distribution be 56 dB down, or better, to insure better than 50 dB at the tap:

Required crossmod of each 3 amplifiers in cascade:

Crossmod in Distribution	56 dB
Cascade Factor	10 dB
Safety Factor	7 dB
Total	73 dB

Referring to Table 1: Bridging amplifier must operate at 43 dBmV - $\frac{73-57}{2}$ = 35 dBmV out.

Two line amplifiers must operate at 50 dB - $\frac{73-57}{2}$ = 42 dBmV out.

Multitap charts are shown (for .412 cable) in Figure 2.

Signal-to-noise in Distribution is:

Bridger:	Minimum input to Directional Coupler	13 dBmV
	Directional Coupler	-6 dB
	Pad	-5 dB
	First stage input level	+2 dBmV

S/N = 2-(-59 + 10) (Noise Figure = 10 dB)
S/N = 51 dB

Subtracting input variation of 2 dB gives 49 dB S/N worse case.

Two Extenders: Noise Figure = 10 dB
Cascade Factor = 3 dB

Input Level = 17 dB
Pad = 5 dB

First stage input 12 dB

S/N = 12 -(-59 + 13) = 58 dB less 4 dB safety factor or 54 dB worse case.

Combined 49 dB/54 dB; S/N $\approx$ 48 dB in distribution line using power addition tables.

2. Trunkline Levels and Cascades

Trunkline levels must be such that when trunkline crossmodulation and noise are added to Distribution crossmodulation and noise, the results will not exceed the design parameters established earlier:

Signal-to-noise	40 dB
Crossmod (and Intermod)	50 dB

With S/N of 48 dB in the distribution line, a S/N of 41 dB plus 2 dB safety margin or 43 dB in the trunkline is adequate. Crossmod in trunkline must be better than 56 dB down, plus 2 dB safety margin, or 58 dB down.

Entering values for trunk amplifier from Table 1 in Figure 3, we derive the relationship (for 22 dB gain):

49.5 -C = C -6 +22 (output level = input level + 22 dB)

from which

C = 16.75 dB = 10 log N, where N = maximum number of amplifiers in cascade
$\therefore$ N = 47 amplifiers

Assuming an average of 18 dB of cable between amplifiers and new 3/4" polystyrene foam cable with 0.68 dB/100 ft. at Ch 13, we can transport 12 channels of TV a distance of:

$$\frac{18 \text{ dB} \times 47 \text{ amplifiers}}{0.68 \text{ dB}/100 \text{ ft.}} = 124.400 \text{ feet}$$

or

21.7 miles

and then distribute high-quality signals at the end.

Input level would be 16.75 - 6 = 10.75 dBmV.

Output level would be 49.5 - 16.75 = 32.75 dBmV.

D. Hum Modulation

Assuming power addition, (3-phase 60 cps power) hum modulation in the trunkline would be:

$$65 - 10 \log 47 = 48 \text{ dB}$$

and in distribution:

$$60 - 10 \log 4 = 54 \text{ dB}$$

The combined total is approximately 47 dB. (Power Addition).

IV. RELIABILITY

System life of 20 years or so implies high reliability of equipment and components. Solid-state equipment, properly packaged, heat-sinked, and derated, is capable of useful life well in excess of 20 years. MTBF (mean time between failure) has been calculated for the distribution line amplifier (LA 20) listed in Table 1, utilizing Mil-Hdbk-217 and allowing for temperature ranges of -40°F to +140°F. The result was one failure in slightly more than 8 years. Trunkline stations and bridgers will exhibit comparable MTBF, allowing for increased complexity, of from 2 to 4 years.

Passive devices will, of course, enjoy considerably longer life.

Cable may be a problem, however. Some manufacturers are willing to at least talk about 20 years in aerial plant, for jacketed aluminum foam-dielectric cable, with a 5-year guarantee. For underground plant, much needs to be learned about cable life. Underground systems must be designed for easy replacement of cable and fittings, and for longest life. Gas-filled cables are another possibility, with the added advantage also of pressurization of equipment. This becomes eminently feasible with the availability of sealed, cast housings, for all distribution equipment. Cost trade-off vs. life will govern.

V. COST CONSIDERATIONS

Cost considerations cannot be addressed in detail here; the presentation is already too long. A separate paper will be in order.

A system of the type described in this paper is not inexpensive to build. Cost trade-offs are many and varied. Initial installation costs are only part of the problem, although perhaps often paramount at the time. A few dollars more for good reliable, maintainable equipment will constitute an investment with a fat return. Long life of equipment and plant will further greatly increase return in future years. Each situation demands special analysis.

VI. CONCLUSION

More stringent demands on CATV systems performance, plus higher initial construction costs, require systems to be designed and built which will offer almost an order of magnitude longer life and higher reliability. Equipment is becoming available with performance, reliability, and life which will soon make 20-year systems feasible. Cost recovery and return on investment will depend on longer life, reduced maintenance, ease of installation, quick troubleshooting and repair, and higher performance with resulting increased revenue.

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   Page 121 Table III - Receiver Performance

   Pages 448-468 - Subjective Test on Levels of Picture Quality

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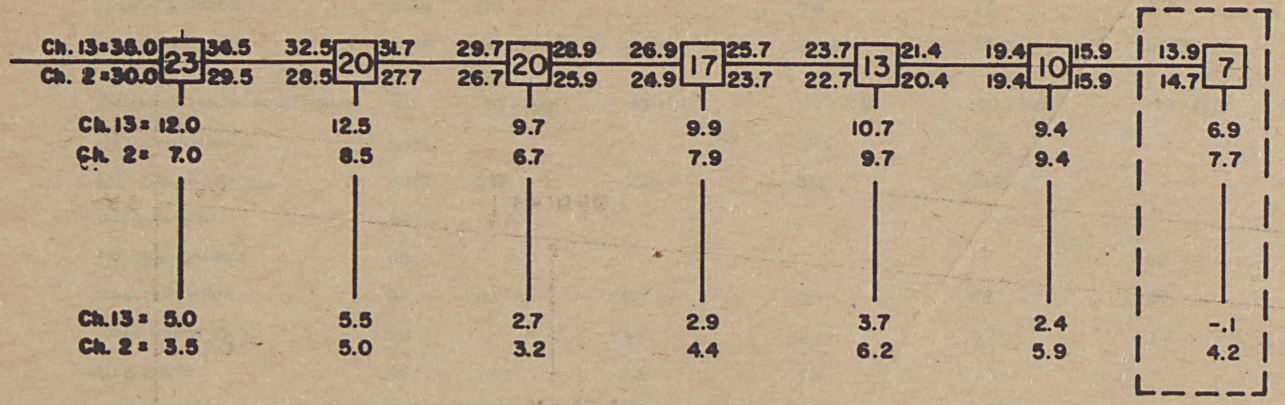
TABLE 1

		STA-225 Trunk-ALC	STB-225 Trunk-Bridge ALC	STA-73.5/225 Trunk ALC/ATC	STB-73.5/225 Trunk-Bridge ALC/ATC	SBA Intermediate Bridge	LA-20 Multipurpose Line Amplifier	SLS, SDF SRPU, SS/U Passive Device	SMT Multitaps
Frequency Range	mHz	50-280	50-280	50-280	50-280	50-270	50-270	10-300	50-220 10-300
Frequency Response	dB	±0.25	±0.25	±0.25	±0.25	±0.5	±0.5	±0.25	±0.25
Operating Gain	dB	22	22	22	22	30	30		
Noise Figure	dB	10	10	10	10	16	10		
Cross Modulation Ratio:	dB	93	93	93	93	-57	-57		
Output - Ch 13	dBmV	32	32	32	32	43	50		
Tilt Ch 13/ Ch 2	dB	9	9	9	9	8	13		
Amplifier Slope Ch 13/Ch 2	dB	9	9	9	9	4	13		
No. TV Channels		12	12	12	12	12	12		
Input Level Ch 13	dBmV	10	10	10	10	13-29	20		
Input Tilt Ch 13/Ch 2	dB	0	0	0	0		9		
Return Loss In	dB	18	18	18	18	18	16	20	20
Return Loss Trunk Out	dB	18	18	18	18	18		20	20
Return Loss Dist Out	dB					16	16	20	20
ALC Stability	dB	±0.5	±0.5	±0.5	±0.5		±1		
ATC Stability	dB	TC*	TC*	±0.5	±0.5		TC*		
ALC Range	dB	±4	±4	±4	±4		±3		
Slope Adjust Ch 2	dB	±4	±4	±4	±4	±4	±4		
Hum Mod Ratio	dB	65	65	65	65	60	60		
Isolation-Outputs	dB					20			26-30
Isolation-Taps	dB								20
Pilot Carrier No. 1**	mHz	225	225	225	225				
Pilot Carrier No. 2	mHz			73.5	73.5				
Operating Temperature Range	°F	-40 +140	-40 +140	-40 +140	-40 +140	-40 +140	-40 +140	-40 +140	
Operating Voltage	volts	20-30	20-30	20-30	20-30	20-30	20-30		
Current Required	amps	0.8	1.1	0.9	1.2	0.5	0.4		

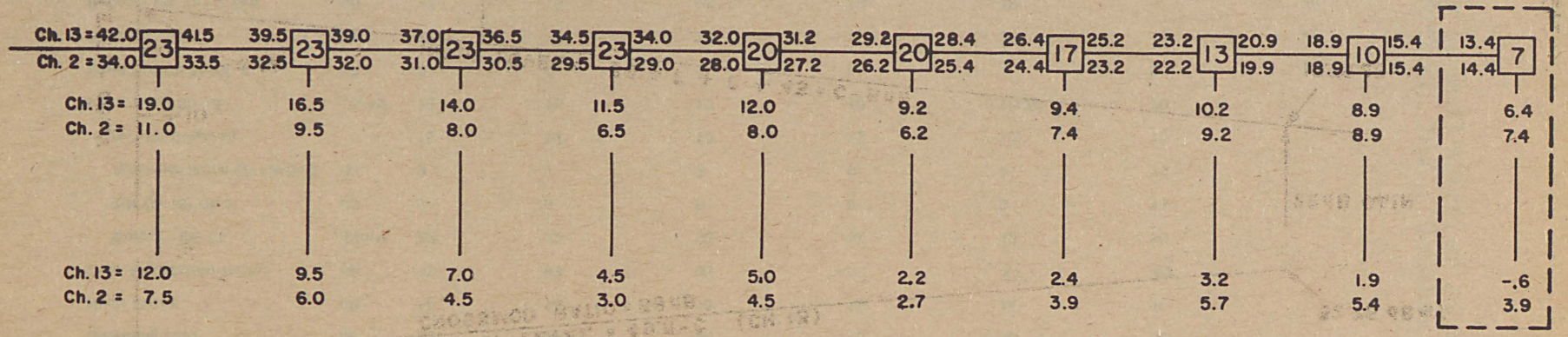
*TC – Tilt Compensated

**Alternate Pilot Carrier at approximately 275 mHz

750' = SBA Distribution Line



1125' = LA-20 Distribution Line



NOTE: 1. 412" distribution cable, with attenuations of .86 db/100' at Ch. 2 and 1.65 db/100' at Ch. 13.

2. 125' between multee taps.

3. 125' of RG-59/U drop cable, with attenuations of 2.7db/100' at Ch. 2 and 5.8 db/100' at Ch. 13.

FIGURE 2

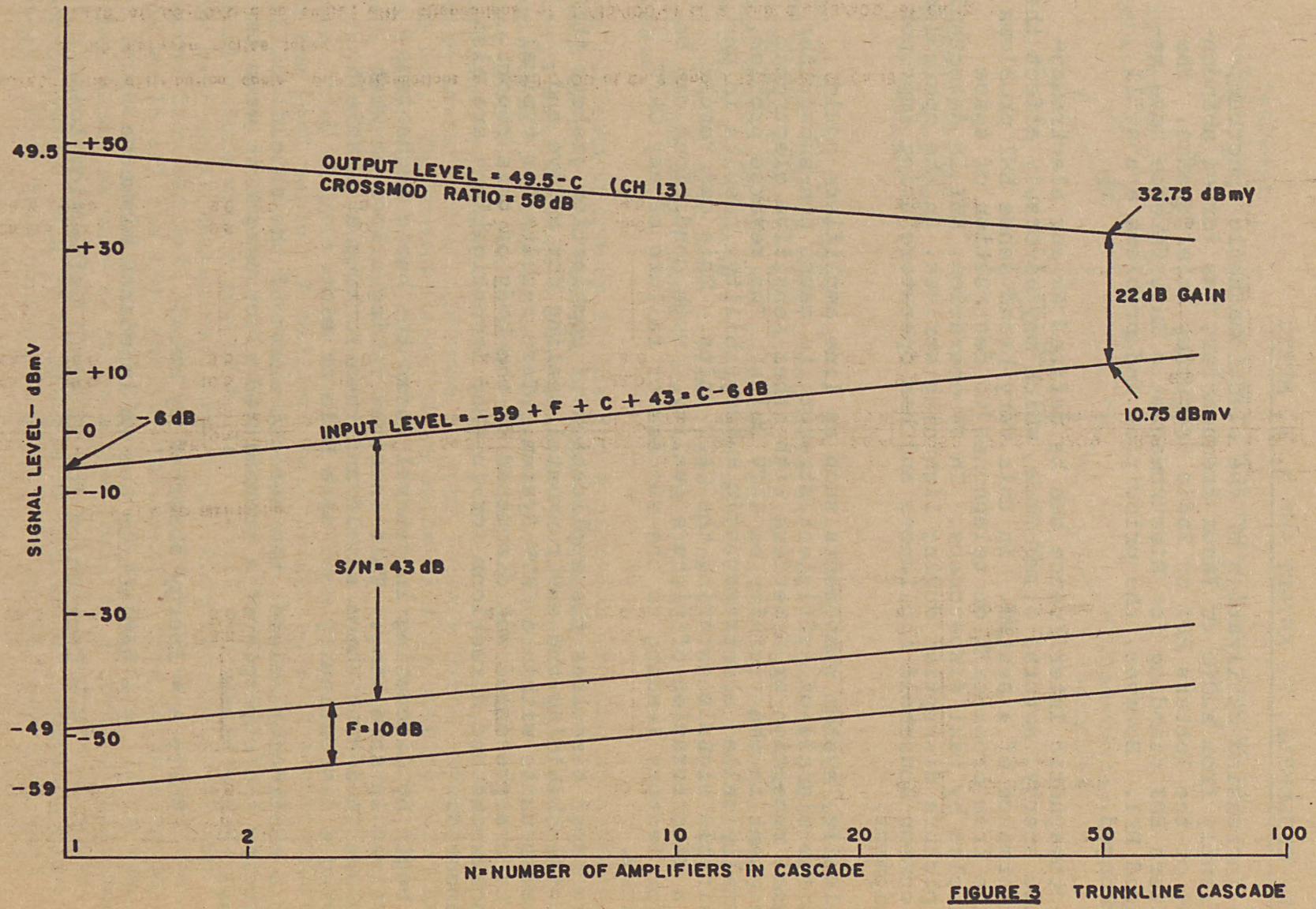


FIGURE 3 TRUNKLINE CASCADE

J. D. CAULDWELL, P. KNIGHT AND E. R. MERTZ

The increasing utilization of the electromagnetic spectrum, currently from audio to laser frequencies, has forced abandonment of the letters RFI or Radio Frequency Interference. The letters EMI standing for Electromagnetic Interference have replaced RFI. However, the principles and problems are still unchanged.

Electomagnetic Interference can be defined as any electromagnetic energy, natural or man-made, which may adversely affect the performance of a system. In this very broad sense EMI problems range from cross-talk on telephones to destruction of space vehicles by taxi dispatchers. In TV operation, EMI is detectable in picture disruption during lightning strikes, in the operation of common household appliances and ham operators using improper equipment.

Typically, system components such as line amplifiers could radiate signals of sufficient strength to cause non-subscriber signal reception or interfere with other sensitive electronic equipment in the vicinity of CATV units. The reverse problem, normally called electromagnetic susceptability, results in undesirable signals entering the CATV units. This can result in a deterioration of picture quality. Both conditions can be major factors leading to the success or failure of any CATV System.

This paper discusses the application of combination gaskets that provide shielding and environmental sealing for active and passive units within a CATV System. Test results for typical units are presented and discussed in the body of this report. Conclusions and directions for further investigations are also presented.

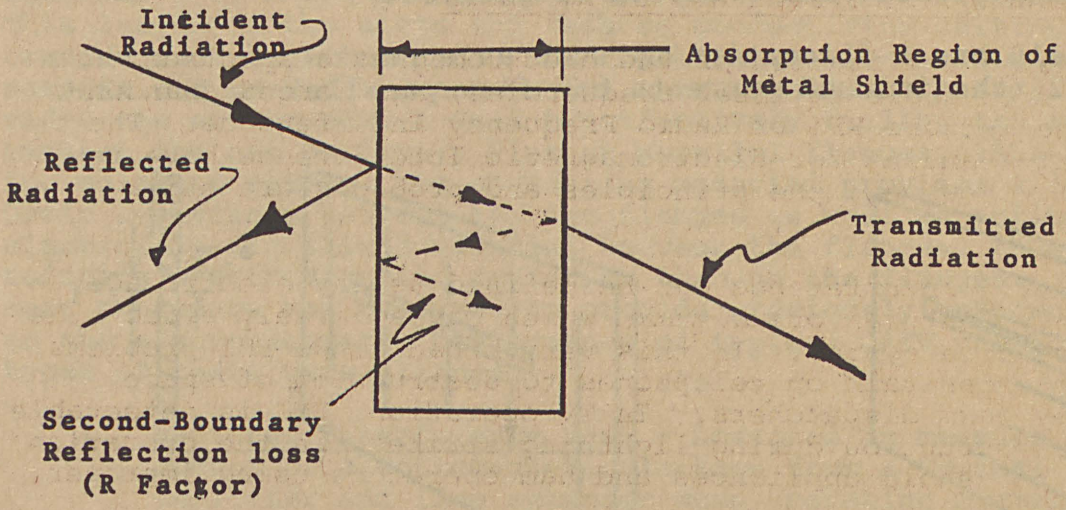
We begin by discussing in general terms the basic mechanisms involved in shielding. This involves taking a look at what happens in a continuous shield and then looking at a shield having a discontinuity such as a hole or slot.

For a continuous shield, the effectiveness of the shield in reducing the strength of a transmitted electromagnetic wave is equal to $S = A+R+B$

Where A = Energy absorbed by metal

R = Reflection due to impedance mismatch

B = Correction for internal reflection loss.



The absorption losses in the above terms can be understood by realizing that an electromagnetic wave is a combination of alternating electric and magnetic fields. You will remember that when these fields move relative to a conductor, currents and voltages are induced in that conductor. Since any practical shield will have some finite resistance, the flow of current will result in an energy loss in this shield in terms of I^2R losses.

The reflection losses in the above equation are due to impedances mismatching. The concept of impedance matching is one that has always been difficult to understand. Yet, we will often match impedance in a mechanical sense without knowing it. Any system that involves a mechanical advantage can be thought of as an impedance matching device. When you use a wrench, you are in a sense matching the impedance of your forearm to the impedance of the nut. The transmission of an automobile is nothing more than an impedance matching device. It matches the mechanical impedance (torque-to-speed ratio of the motor) to the mechanical impedance of the wheels (torque-to-speed ratio of the wheels). Another more vivid example of mechanical impedance matching will be found on the pool table. A billiard ball colliding with a stationary billiard ball will transmit its momentum to the previously stationary ball. In a classic physics' experiment, this is usually done with a row of balls. If all the balls in the row have equal mechanical impedances, then the energy is imparted from one ball to the next and the last ball leaves the row while all the rest remain stationary. This is an example of impedance matching, and there is no reflection. If on the other hand, we were to throw a golf ball at a bowling ball, most of the energy would be returned to the golf ball and it would bounce away. This is an example of mechanical impedance mismatch. With this concept in mind, it can be seen that the

greatest reflection will result when the mismatch between an electromagnetic field and a shield is greatest.

When a shield has a discontinuity such as a narrow slot as shown in Figure 2, the induced currents can flow parallel to the slot

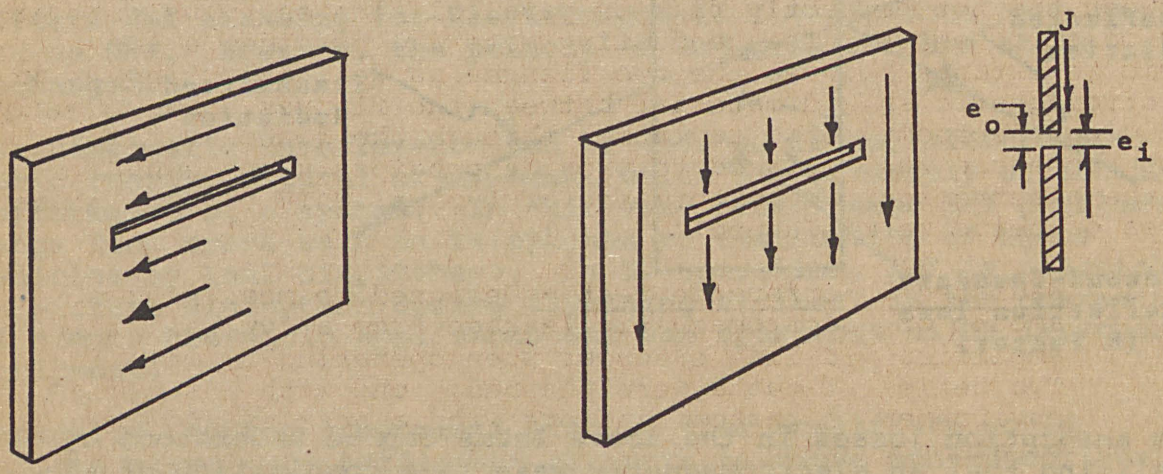


FIGURE 2

in which case the slot has little effect on the free flow. When the current flow is perpendicular to the slot, however, a very definite impedance exists. By simple Ohms Law, a voltage equal to IR or IZ will appear across this impedance. Since the shield normally is a good conductor, the voltage on the outside of the shield E_o will be equal to the voltage on the inside of the shield E_i except for series impedance through the shield and shunt impedance across the slot. In other words, an r-f voltage now appears on the outside of the shield due to a current J flowing on the inside of the shield. This voltage on the outside represents leakage.

The aluminum castings of active and passive units used in the CATV industry are in fact shields containing discontinuities such as cable ports, fault lights, thermistor mounts and, of course, the gasketed joint between the box and its cover. Theoretically, there is no leakage of signals from this joint if direct metal-to-metal contact is made along its entire length. To achieve this, however, the two contacting flanges must be absolutely clean, perfectly flat and highly conductive. While such a joint is physically realizable, it is economically unfeasible. Furthermore, using only a non-conducting environmental gasket between flanges, it is more difficult to make this joint continuous without the long narrow slots that will cause electromagnetic leakage. In addition, as the contacting areas are exposed to

weather, the surfaces begin to corrode, causing electrical discontinuity at those points that did make contact originally. This lengthens the slots and reduces conductivity causing increased radiation leakage. For these reasons, a combination seal/shield gasket is most useful. The resilient material provides the environmental seal by effectively filling the space between the not perfectly flat or parallel flanges, thus preventing moisture entry. The conducting material provides a low Ohmic resistance between the two flanges as well as acting as an electromagnetic shield material between the flanges, thus greatly reducing electromagnetic radiation through the flanges. The test procedure was designed to provide previously unknown data on the electromagnetic performance of typical CATV units. Three types of tests were planned:

1. Radiated Interference Test - Designed to measure the amount of electromagnetic leakage from a typical line amplifier and line extender when operating normally. Two series of tests were planned: one with a standard environmental gasket, and one with a seal/shield combination gasket.

2. Electromagnetic Susceptibility Test - Designed to determine the external field strengths required to deteriorate the signal in a typical line extender and line amplifier. Again, two series of tests were planned: one with a standard environmental gasket, and one with a seal/shield combination gasket.

3. Sensitivity Tests - For a Typical Color Receiver - These tests were planned to yield results which might be applicable to the data obtained in the Radiated Interference Test.

Unfortunately, there was not sufficient time to make the Electromagnetic Susceptibility Test. However, it is intended that these data will be obtained in the future. Instances of picture deterioration due to high ambient interference in the vicinity of CATV units are not unknown. Our intent is to obtain quantitative data on this problem.

For the Radiated Interference Test, the limits called out in Western Electric Specification #KS-19925, Issue 3, Par. 3.08 were used as a guide. This paragraph reads as follows:

"RF Radiation

3.08 Sufficient shielding shall be provided by the closure assembly so that the radiated signal strength at a distance of ten feet is less than 2 micro-volts per meter for channels 2-6 and less than 5 micro-volts per meter for channels 7-13 when a signal level of 48 dBmV is present at the amplifier output."

The test set-up to determine radiated interference is shown in Figure 3. A power inserter was used to mix the 24 volts AC with high frequency supplied by the signal generator. A 50-75 Ohm L-Pad was used for impedance matching. The output level of the test units was determined with a Jerrold Model 727 tunable voltmeter. Appropriate adjustments were made on the signal generator so that the output signal from the amplifier was 48 dBmV and the output of the line extender was 42 dBmV. All input equipment was outside of the shielded enclosure. An aluminum sheath coaxial cable brought the signal from the shielded enclosure bulkhead to the test units.

The original test receiver selected was the Singer-Metrics model NF-105 and associated antennas. After running a few tests, it became evident that the receiver noise level, in combination with antenna factors, was too high to obtain measurements. We then looked for a new system and found that the second generation electromagnetic interference tests instruments typified by the Fairchild Electro-Metric EMC-25 did have the necessary sensitivity.

Measurements were made via a broadband dipole located adjacent to the geometric center of each test item at a distance of 10 feet. The antenna was rotated for a polarization check, and left in the plane of maximum received signal strength. Prior to orienting the units for the test, the housings were probed to find points of maximum radiation. Upon determination of this point, the antenna was oriented to face this side of maximum radiation. The test item, during test was isolated physically from the ground plane to simulate, as close as possible, actual installation conditions. In addition to absolute measurements being performed at the test unit's operating frequency, automatic spectrum scans were made to determine if frequencies other than the fundamental were being radiated by the test unit.

The test units were a main line bridger amplifier model L-20 and a line extender model #E-20 supplied by HTV Systems of East Rochester, New York. As standard equipment, these units include a combination seal/shield gasket of silicon rubber and monel mesh part number 80-9864, originally supplied by Technical Wire Products, Inc., Cranford, New Jersey. A plain silicon rubber gasket was used as the environmental seal.

Tables I and II show results of tests run on the main line amplifier and extender:

TABLE I

Leakage in μv/m

Trunk Line Amplifier

Channel	Combination* Seal/Shield	Rubber Seal
2	Less than .3	2.5
6	Less than 1.0	1.6
7	Less than 3.2	22.5
13	Less than .56	31.5

* These figures are ambient noise and represent the minimum discernible signal of the receiver.

TABLE II

Leakage in μv/m

Line Extender

Channel	Combination
2	.56
6	1.6
7	2.8
13	3.2

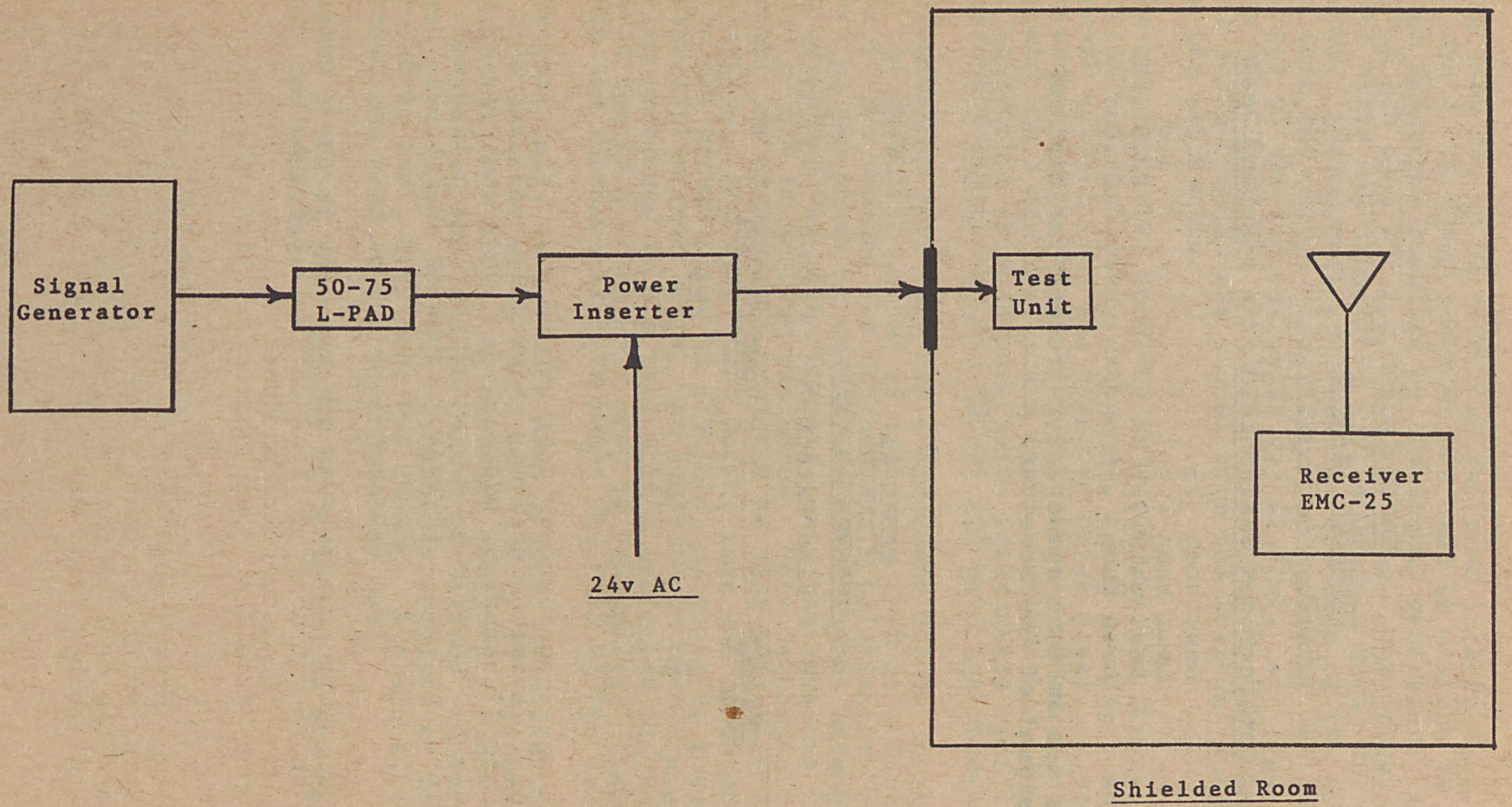
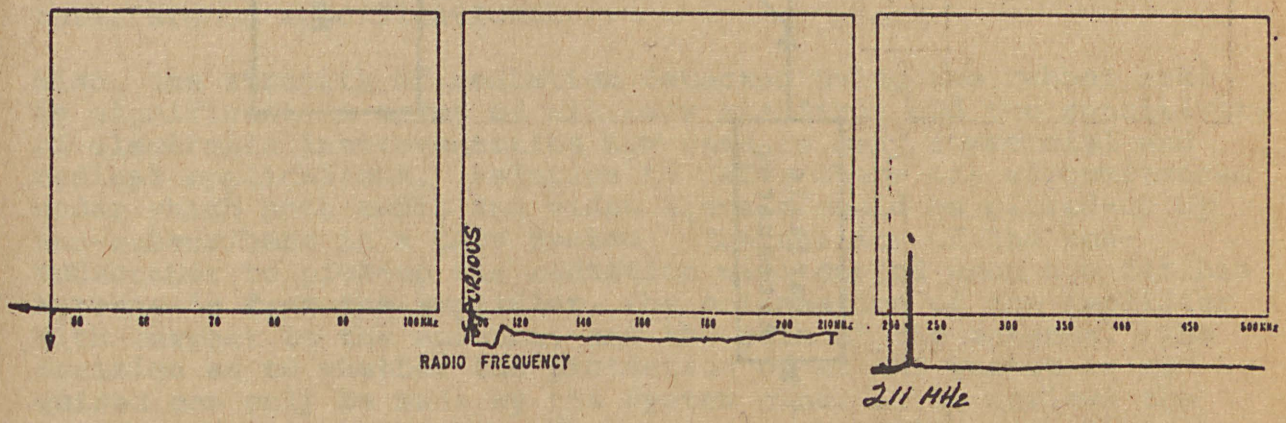


FIGURE #3

ERM 5/28/69

Table I first shows the field strength for the combination mesh-rubber gasket installed in the line amplifier. This seal/shield gasket was then replaced with the silicon rubber gasket and the test was repeated. Table II shows the results of the same test performed on a line extender with the seal/shield gasket installed.

Graph #1 is a recording made with the Fairchild FSS-250 System of relative signal strength vs. frequency when the amplifier was operating at Channel 13 with the rubber gasket installed. Any radiation present from 100 MHz to 500 MHz would have been picked-up. No frequency other than the operating frequency can be attributed to the amplifier. We did pick-up a local FM station operating at about 101 MHz. Our point in bringing this up is that many electronic enclosures radiate at harmonics above and below their fundamental frequencies. This does not appear to be present in CATV amplifiers.



GRAPH #1

Figure 4 shows the set-up that was used to determine the sensitivity of a color television receiver. Basically, the signal from a local channel (Channel 9) was picked-up and converted to an unused channel, (Channel 7). The signal level was reduced by a variable attenuator and then split for measurement and reception.

This test shows that a "watchable picture" could be obtained with a 25 micro-volt signal to the television set. The picture contained a lot of snow, but most of the detail was present. A signal level of only 10 micro-volts produced a picture that was almost all snow, but excellent sound characteristics were present.

In relating the two tests above, that is the sensitivity of the TV and the radiation emitted from the amplifier, one must be careful to compare the data on the same basis. The leakage on Channel 13 with the rubber seal was 31.5 micro-volts/meter.

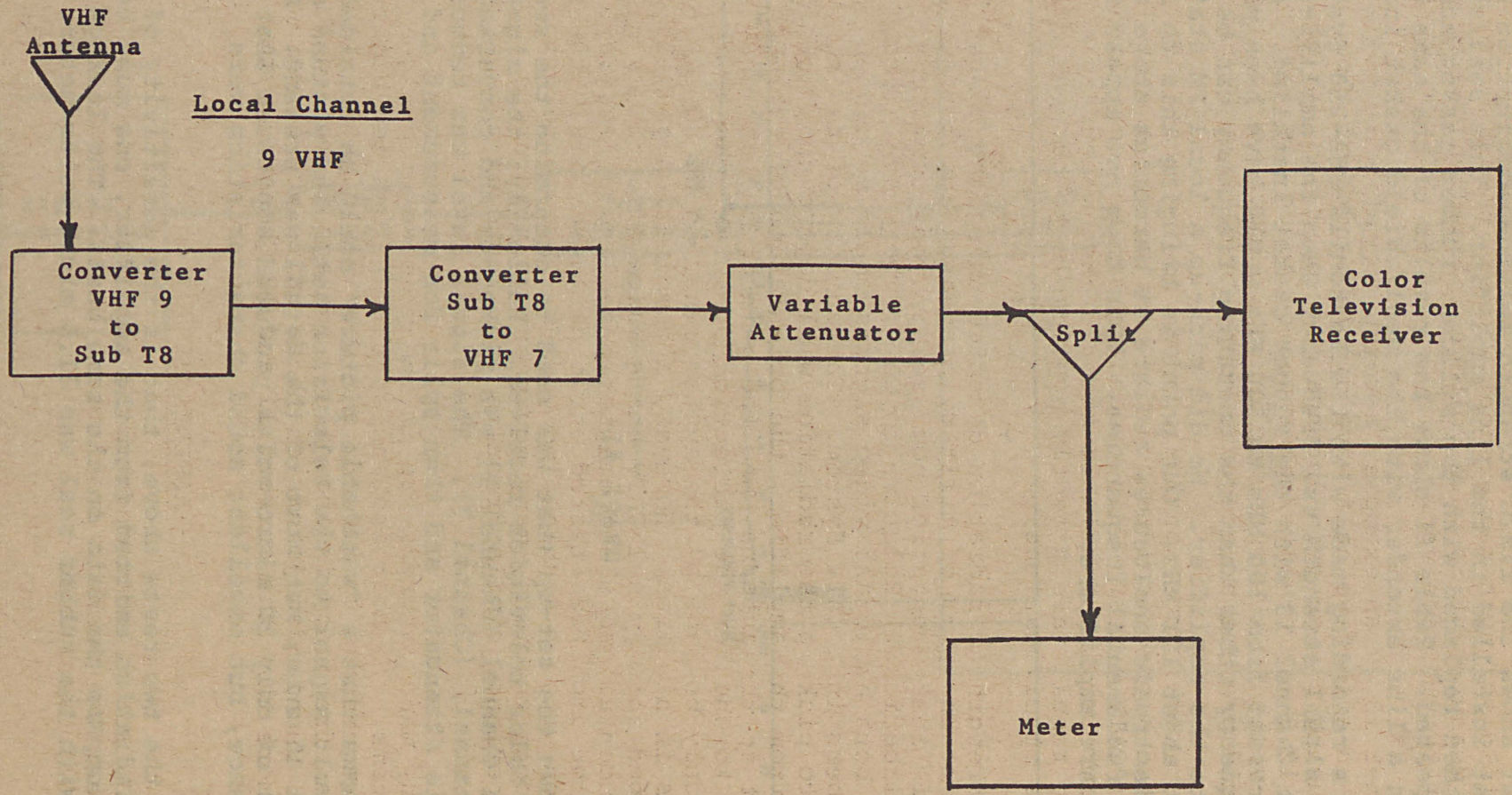


FIGURE #4

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This is a field strength measurement whereas the 25 micro-volts sensitivity measurement is pure voltage induced in the antenna terminals of the TV receiver.

Taking Channel 13 as an example, a rough comparison can be made by assuming an effective half wave dipole length of about .5 meters and using a high gain antenna, say of 12 dB. A field strength of 12.5 micro-volts/meter would induce a signal voltage of 25 micro-volts at the receiver input. A much lower field strength would produce an adequate sound level in a TV receiver.

Reviewing our work, some conclusions can now be made. First we have presented a practical method for testing the energy leakage from typical CATV units. This procedure can be accomplished utilizing commercially available interference measuring equipment and the results are directly applicable to current military interference specifications.

Also, the strength of radiation detected using the rubber seal is significant in terms of military standards and the sensitivity of electronic instrumentation now used in many commercial and medical applications. Relative to CATV, there are circumstances under which both audio and video signals could be picked-up by non-subscribers in a CATV System. The ability of the non-subscriber to pick-up the radiation will depend upon how far his antenna is from the amplifier, the orientation of the amplifier with respect to the antenna, and the gain of the antenna. The decision as to whether the protection of an EMI gasket is required can only be made by the system owner as he reviews the requirements in his area. However, a combination gasket has been developed for typical CATV units which effectively provides both environmental and electromagnetic sealing at moderate cost. Of course, the amplifier tested would not have passed the KS specification without a shielding gasket. Due to the similarity of housing constructions, many equipment manufacturers would probably experience similar results from tests on this type of amplifier.

Finally, many manufacturers are in the process of designing 20 channel systems. In most instances, this raises the highest operating frequencies to 240 MHz and possibly higher. Table I shows that as frequency is increased, leakage is more difficult to contain. Unshielded joints on these units would leak substantially more than the current 11 and 12 Channel systems in use.

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JOHN CAMPBELL AND JOSEPH P. GLEASON

A few years ago, Mr. David Sarnoff, RCA Board Chairman, predicted the home would become a "communications center" from which would be conducted much of the daily household business including shopping by TV and paying by computer.

In a recent issue of the Journal of the Society of Motion Picture and Television Engineers, a new concept of cable television was proposed, which should greatly interest CATV operators, because it shows how some of these things envisioned by Mr. Sarnoff can be accomplished with present-day techniques. This new concept of cable TV, called "Integrated Urban Communications", would provide for the following services:

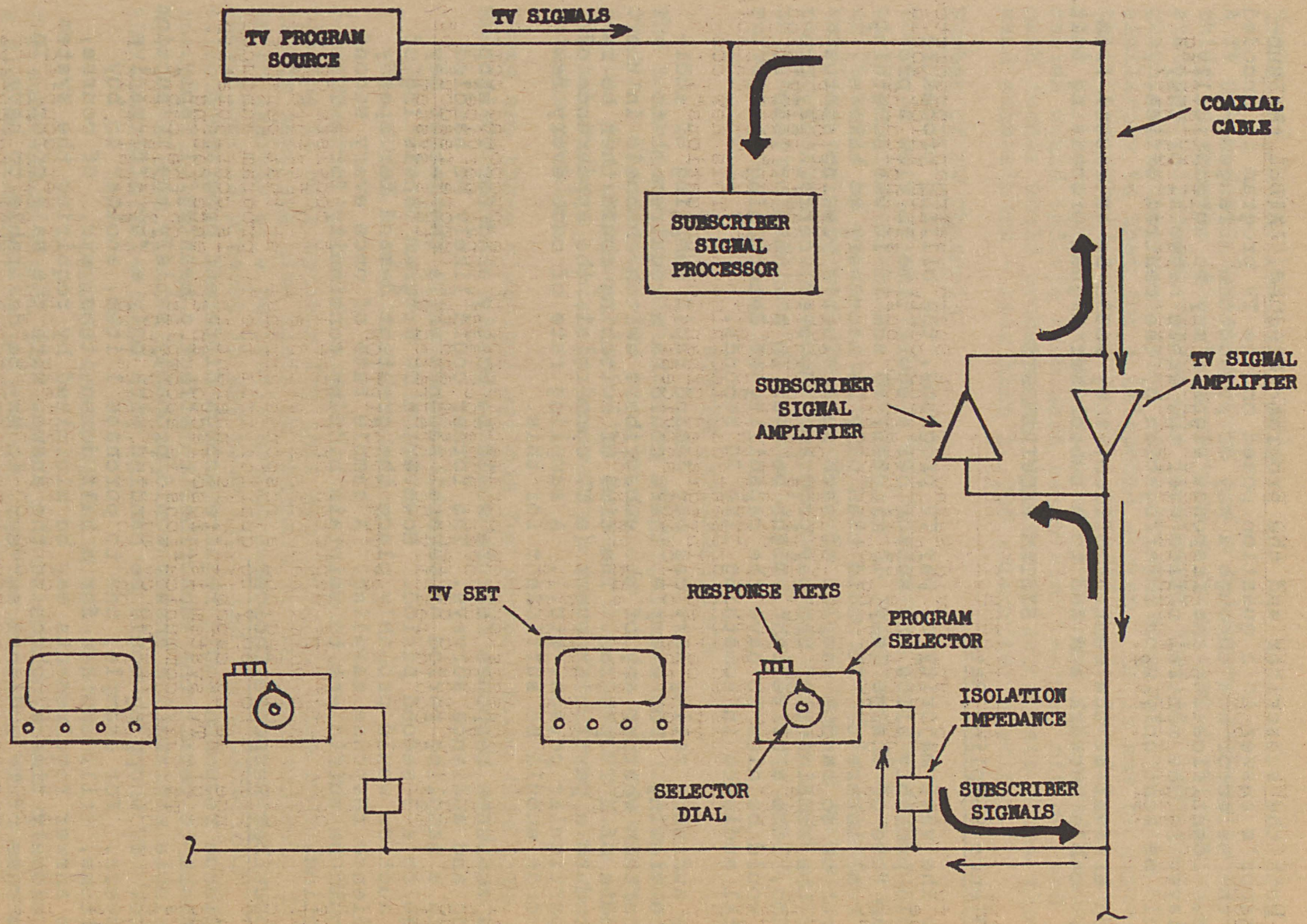
(1) Commercial TV and FM Radio
(2) Pay TV
(3) Audience Rating
(4) Audience Response

This paper discusses system parameters for these proposed communication services. However, numerous additional services such as an electronic currency system and the remote readout of utility meters could readily be integrated with this system.

SYSTEM DESCRIPTION

The proposed system is depicted in Figure 1. It consists of a CATV network into which has been inserted a pay TV feature with central office billing and a response arrangement that permits the subscriber to reply to queries from the TV program announcer. An audience rating capability is inherent in this configuration, because a pay TV system is, ipso facto, an audience rating system. Two-way communications is accomplished on the cable network by using frequency multiplexing and by designing the TV signal booster stations to facilitate two-way signal transmission.

A program selector unit connected at each home TV set couples the TV program selected, and only the selected program, to its TV receiver and at the same time generates a signal indicative



SYSTEM BLOCK DIAGRAM - FIGURE 1

of both the subscriber and the program selected. Also, the subscriber's answer to a question posed on the TV program is encoded in the selector box through a key or pushbutton arrangement. These identification and response signals may be automatically relayed to the central office over the cable network, or they could be sent only upon interrogation by the central office.

Upon arrival at the central office, they would be extracted from the cable network and fed to a subscriber signal processing unit.

SYSTEM REQUIREMENTS

Audience Sampling Rate

For the vast majority of pay TV programs, the billing procedure would probably allow the subscriber a short time to view a program free of charge (say, 10 minutes) to see if it was something of real interest. It would then only be necessary to take a dozen or so random samples of each subscriber's viewing status for the remainder of the pay program. However, certain pay programs, like a prizefight, might be over in a minute or less so it would be nice to have the capability of determining the total audience in something like 30 seconds.

The audience rating services may demand rapid sampling of audience viewing. For example, there could be a requirement to ascertain whether any of the subscribers switch channels in the middle of a TV program. The time of switching could then be related to a particular event (a TV commercial, the appearance of a particular person, etc.). A sampling rate of once every few seconds should be sufficient for this.

The audience response feature would be mostly used for TV shopping and audience surveys. The former could likely be handled with a sampling period of several seconds while the latter may require a 3 second period. However, a TV program consisting of an auction would probably place the greatest demand for speedy audience response sampling. A sample rate of once every second should be sufficient to maintain bidding continuity for a TV auction.

Subscriber Response Choices

Audience response would require enough different programmed answers to permit the subscriber to effect a meaningful reply. A single affirmative answer would probably satisfy the TV auction case. TV shopping could be handled with only a few affirmative answers. For example, one to purchase 1 item, another to buy 2 items, still another for a half dozen items, etc. Of course, the answer requirements may be minimized by requiring the system to closely time-synchronize the answer with the sale offer. In the case of TV audience surveys, it may be desirable to have several choices from which the subscriber may select an answer.

Number of Subscribers per Cable

A TV cable distribution network and a telephone network have one thing in common: they both service a great number of subscriber stations. It seems reasonable to suspect that the best geographical arrangement for a cable TV system might bear some similarity to that for a telephone system. So it may be expected that there would be many TV central offices in the larger cities just as there are numerous telephone exchanges. Several feeder cables would radiate from each television central office, and each feeder would probably be required to accomodate a few thousand subscribers - less than 10,000 subscriber stations.

Number of TV Channels

There is no rigorous formula for determining the required number of TV program channels. However, it is suggested that a total of 20 would be ample. At least 7 channels should be capable of handling pay programs and all channels should have an audience rating feature. The audience response requirements could probably be met if 10 channels could be used for TV shopping, 5 for surveys and 2 for auctions.

SYSTEM IMPLEMENTATION

The techniques for distributing TV program signals to the home over a cable network are well known. So it is only necessary to discuss the communications link between the central office and the subscribers, which is basically a multiple-access communications problem.

There are three classical methods for accomplishing this type of multiple access to a single cable with off-the-shelf equipment:

1) Frequency Division Multiplexing
2) Time Division Multiplexing
3) Coded Division Multiplexing

A parametric trade-off analysis shows that time division multiplexing is near optimum for this application. This method allots separate time slots or channels to each subscriber. It is an example of a perfectly orthogonal system since only one subscriber is present in any time slot, and the deleterious effects of power sharing and cross product modulations are eliminated. In addition, it is an ideally energy-efficient system. Also, the subscriber signals may be more easily processed at the central office since they arrive sequentially or in serial.

CENTRAL OFFICE/SUBSCRIBER DATA LINK

The subscriber signal processor at the central office could be a digital computer which sequentially interrogates the program

selector in each subscriber's home to ascertain what TV channel he is viewing. This may be accomplished by transmitting a sequence of evenly-spaced pulses on a 74 Mc carrier so they would easily travel through the cable network, along with the TV program signals, to the program selector box at each subscriber's TV set.

The program selector box would contain trap filters connected to the incoming TV cable. There would be one filter for each TV channel. These filter traps could consist of a few inches of transmission line terminated in a small capacitor. When the subscriber selects a TV channel for viewing, the trap tuned to the selected channel would be disconnected, and the selected program would pass through to the TV receiver. At the same time, the selector switch encodes a reply generator to identify the channel selected. Subscriber responses are made with push-button switches which also encode the reply generator.

The subscriber reply signals could be transmitted to the central office on a 1 Mc carrier so they would be far removed in the frequency spectrum from the signals transmitted from the central office.

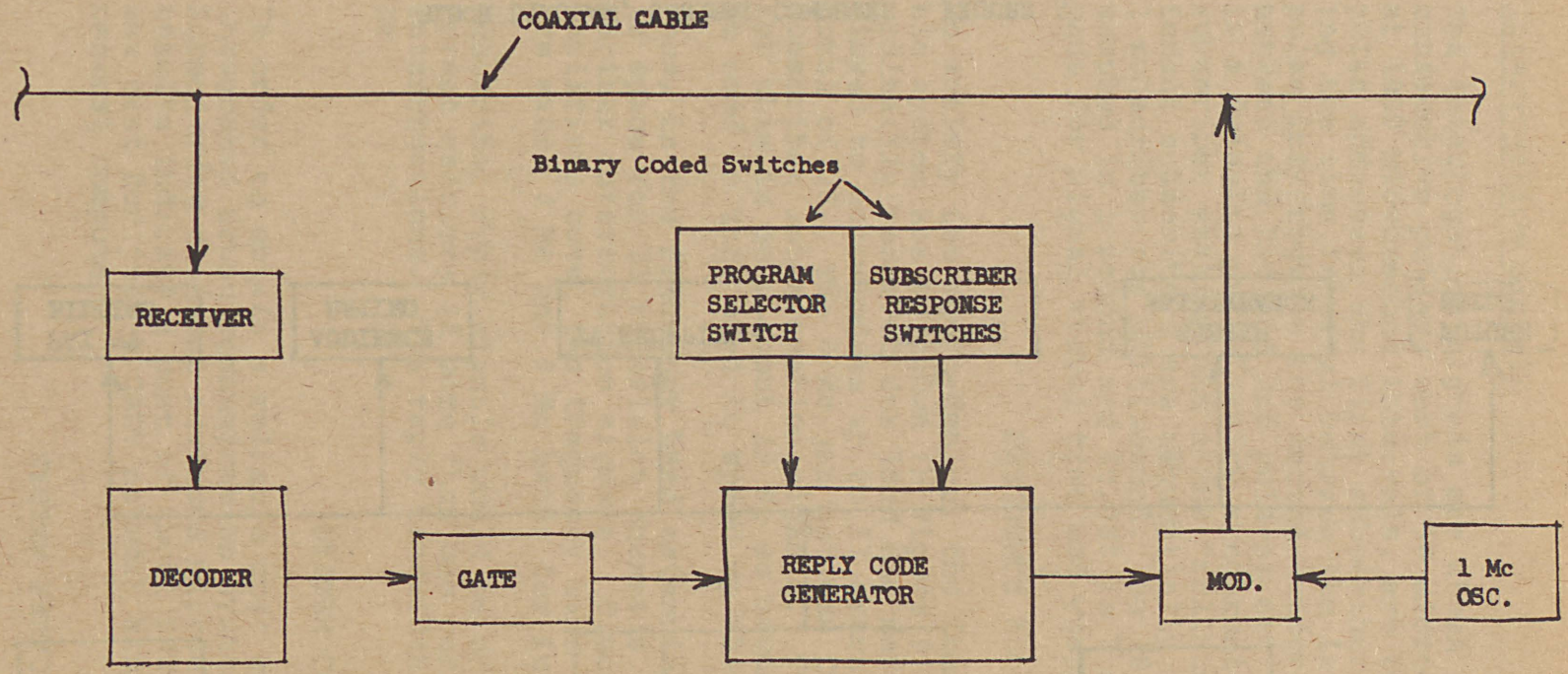
Subscriber Transponder

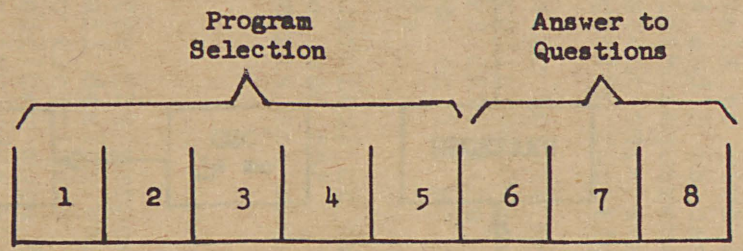
The subscriber station transponder is shown in Figure 2. The interrogation signal is received and decoded. The proper subscriber address will gate on the reply generator into which has been encoded the information identifying the TV channel selection and the subscriber's answer to a question from the TV program announcer.

The subscriber reply contains 8 binary bits, 5 of which are used to identify the TV channel selected and 3 to answer questions. Thus, up to 32 different program channels could be identified and 8 different answers are available for subscriber response.

Central Computer

The central office operation is depicted in Figure 3. A master clock synchronizes a digital computer which controls the interrogation function. The computer envisioned would be a small digital machine of the SIGMA class with a 50,000-word core memory and the capability for transferring data at the rate of 200,000 instructions per second. Thus, the computer can easily handle subscriber interrogation, pay TV billing, audience rating statistics, TV shopping, audience surveys and system maintenance checks with capacity to spare. Readout to the operator could be through a "mini-printer".

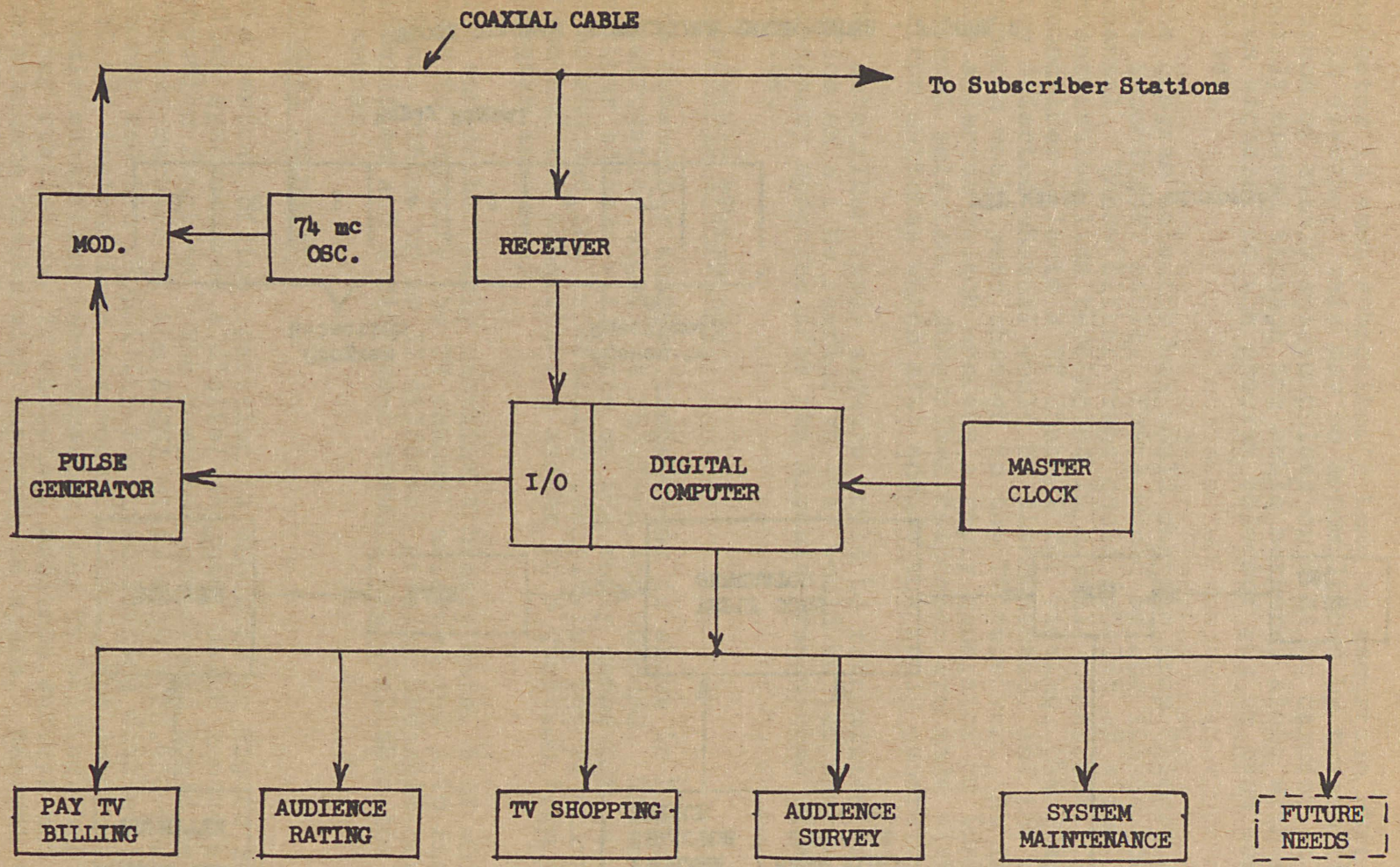




Reply Signal

BIT Width - 50 microsec.

BLOCK DIAGRAM, SUBSCRIBER TRANSPONDER - FIGURE 2



BLOCK DIAGRAM, CENTRAL COMPUTER - FIGURE 3

Interrogation Signals

The interrogation signals are shown in Figure 4. A string of N consecutive pulses, each of 50 microseconds duration and spaced at 1000 microsecond intervals, are transmitted. The first pulse addresses the first subscriber station which replies during the time interval between the 1st and 2nd pulses; the second pulse interrogates the second subscriber, and the reply arrives between the 2nd and 3rd pulses; etc. After the Nth pulse, there is a "missing pulse" which synchronizes the decoders at each subscriber station and a new "roll call" is begun. Thus, N different subscribers are sequentially interrogated at the rate of 1 subscriber per millisecond. So 1000 subscribers could be sampled in 1 second and 60,000 in 1 minute. Ample allowance is made for signal travel time and guard time.

FREQUENCY ALLOTMENTS

To satisfy the above design, the frequency allotments in the cable system are as shown in Figure 5. The frequency band ordinarily reserved for land and marine mobile usage may be employed to accommodate up to 11 extra TV channels to give a total of 23. The 4 Mc gap between Channels 4 and 5 is used for subscriber interrogation signals. The bandwidth requirement for this is only about 40 Kc so several different carriers could be used in this band to speed up the interrogation function.

Thus, in the frequency band extending from 54 Mc to 216 Mc there is space for 23 television channels, the FM radio band and subscriber interrogation signals. Since standard CATV line amplifiers cover the frequency band from 50 Mc to 225 Mc there are extra 4 Mc and 9 Mc bands for future needs.

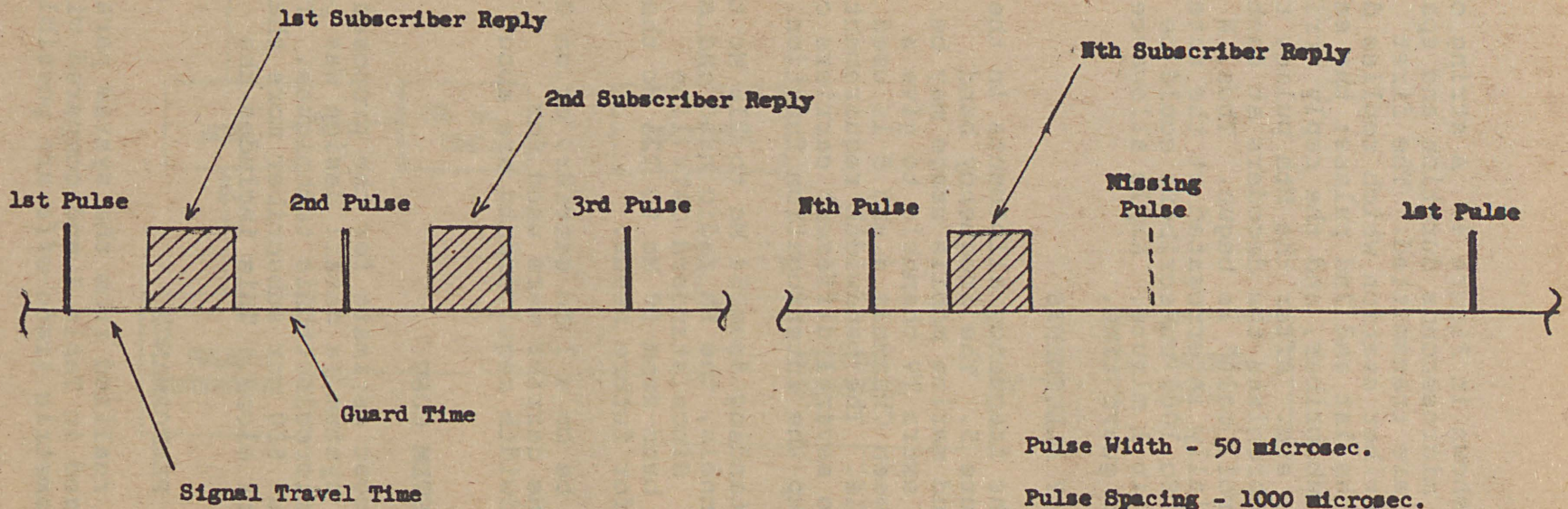
Subscriber reply signals would be on a 1 Mc carrier, or on different carriers if more than one carrier were used for interrogations. The reply bandwidth requirements are about 40 Kc.

SYSTEM COST

In order to obtain a reliable cost estimate for the proposed integrated urban communication system, a detail design was performed using the most advanced microelectronic techniques. The results indicate a cost of about $50 per subscriber more than the cost for just a CATV network alone. This includes the central computer.

SYSTEM PERFORMANCE

The performance which could be realized from the system parameters given herein is summarized in Table I and compared with system requirements. Many parametric trade-offs are possible



Pulse Width - 50 microsec.

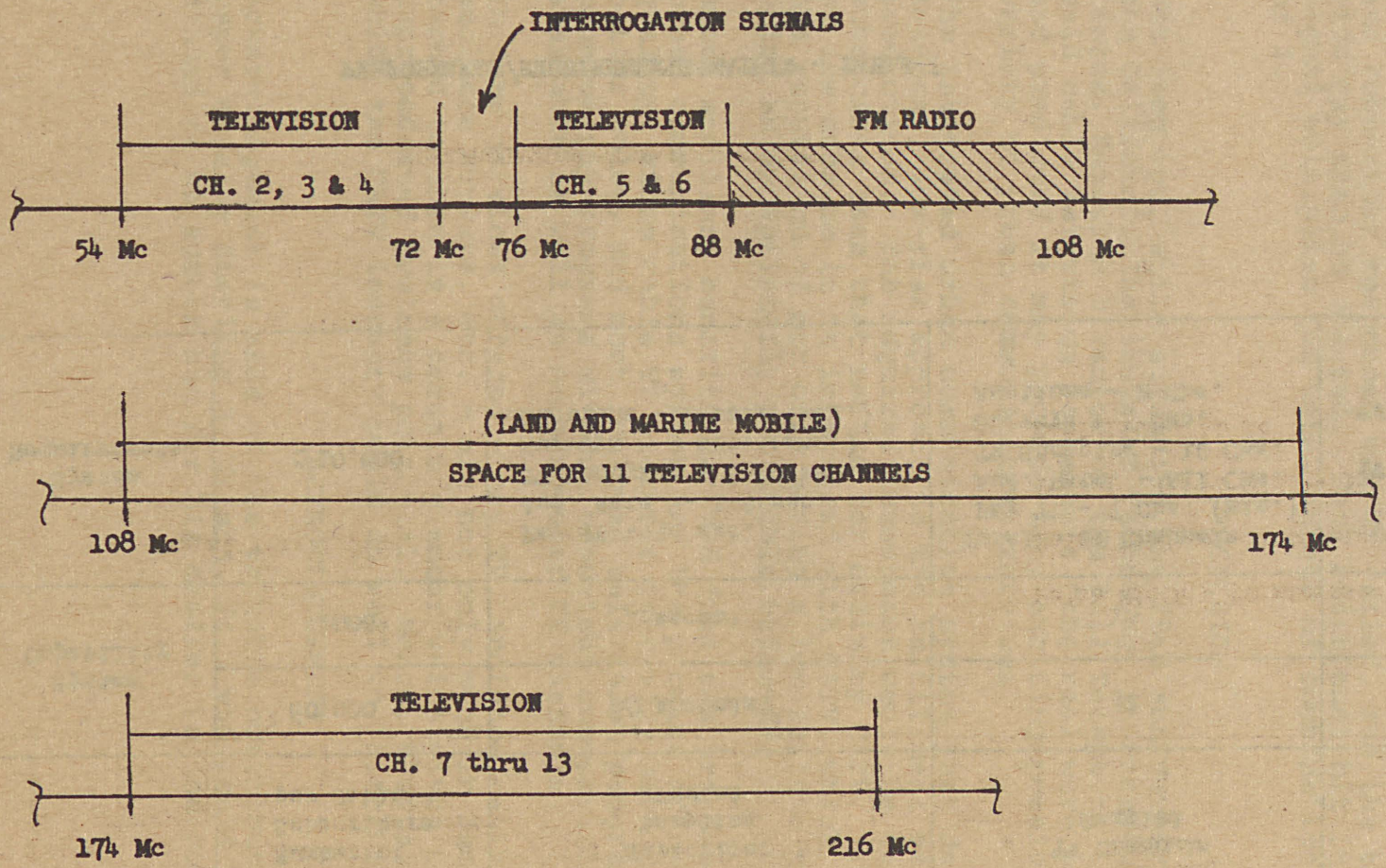
Pulse Spacing - 1000 microsec.

Travel - Guard Time - 550 microsec.

Bandwidth - 40 Kc

N Different Subscribers Interrogated in N milliseconds.

INTERROGATION SIGNALS - FIGURE 4



FREQUENCY ALLOTMENTS - FIGURE 5

	Number of Subscribers per Cable	Subscriber Sampling Period	TV Channels Sampled	Subscriber Response Choices
System Capability	60,000	60 seconds	32	8
	1000	1 second	16	16
System Requirements	< 10,000	Pay TV - 30 sec. Aud. Rate. - 1-5 sec. TV Shopping - 5-10 sec. Surveys - 3 sec. (max.) Auctions - 1 sec. (max.)	Total - 20 Channels Pay TV - 7 Chs. (min.) Aud. Rate. - All Chs. TV Shopping - 10 Chs. Surveys - 5 Chs. Auctions - 2 Chs.	TV Shopping: 1-5 Answers TV Surveys: 5-7 Answers TV Auctions: 1 Answer

PERFORMANCE/REQUIREMENTS MATRIX - TABLE I

to vary performance. For example, changing the number of pulses in the interrogation signal will change the subscriber sampling period. Furthermore, by using different carriers, the number of subscribers addressed in a given time period may be increased.

The subscriber reply signal also allows a variety of trade-offs. The division of bits between program-selection identification and subscriber responses may be varied, and the total number of bits may also be changed. Each additional bit inserted in a signal multiplies the total number of combinations by a factor of 2.

CONCLUSION

Not long ago, while attending the 75th anniversary conference at the California Institute of Technology in Pasadena, Dr. John R. Pierce, Research Director of the Bell Telephone Laboratories, said cable television represents "the real wave of the future" and predicted it may provide many exciting possibilities for a variety of urban communication services.

The integrated urban communication system just described is a low-cost, low-risk approach to the fulfillment of Dr. Pierce's predictions. The required investment would be only $50 more per subscriber than that needed for ordinary CATV. The risk would be low because it is integrated with CATV, which already enjoys the reputation of not only having a low failure rate but of also being an exceptionally profitable business.

Among ancillary benefits derived from the proposed integrated urban communications system are the promise of better TV picture quality, since cable TV pictures generally have more clarity and better color, and much improved television programming, because premium pay programs without obnoxious commercials would be available as well as more regular TV channels.

The new services offered - pay TV, audience rating, TV shopping, audience surveys, etc. - are not only much in demand but attached to them is a certain glamour which gives promise of an unprecedented business potential. Hence, they are a "star" to which the CATV industry would do well to "hitch its wagon".

ACKNOWLEDGEMENT

Acknowledgement is made of the valuable contributions to this paper made by Sterling H. Wilson, Jr., who would have been included as an author but for his desires to the contrary.

TECHNICAL SESSION NO. 4:
CATV System Level Control

Session Chairman:
G. Norman Penwell

Participants:
Mordechai Weiss
"Solving Temperature Problem Using Dual Carrier Automatic Slope and Gain (ASG) Controls"

Donald B. Gregory
"AGC Operation and System Performance"

George P. Dixon
"Temperature and the CATV System"

MORDECHAI WEISS

Mordechai Weiss in 1960 obtained a B.Sc. Degree from the Polytechnic Institute of Brooklyn. He also took graduate work in the School of Electrical Engineering, New York University, during 1961 and 1962.

For the last ten years Mordechai has been active in electronic design and engineering management of Communication Equipment and Test Instruments. He has worked for Fisher Radio Corporation, Jerrold Electronics, Bendix Radio and others.

He joined the Equipment Division of AEL as Section Head and Engineering Manager of a very sophisticated and complex digitally tuned electronically swept receiving system project over the HF-VHF-UHF spectrum. Mr. Weiss is presently a CATV Sales Specialist.

M. Weiss is a member of the IEEE.

Introduction

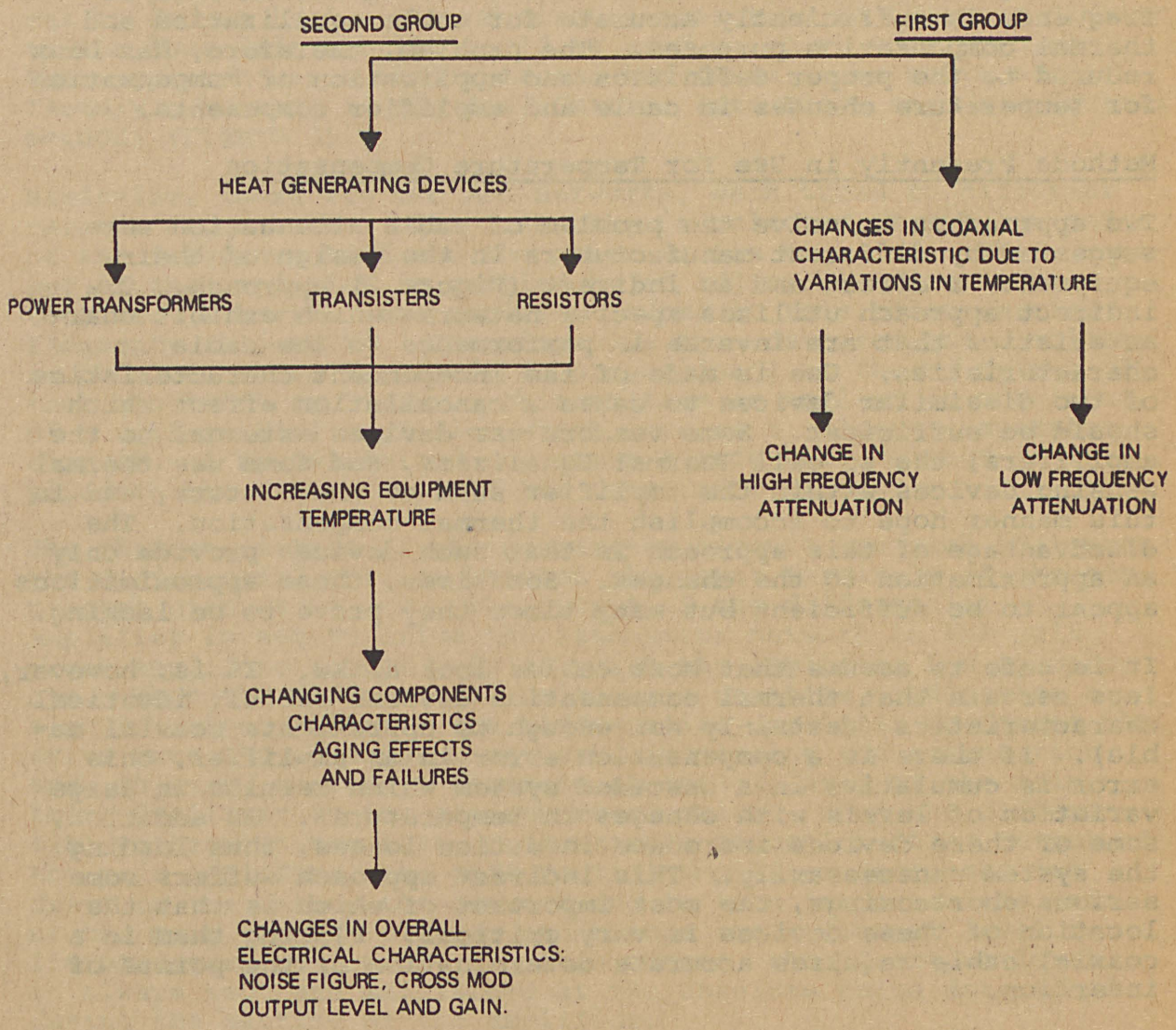
The most critical problem that can beset any CATV System owner or manager is temperature variation and the ability of the CATV plant to withstand such variations.

The effects of temperature variations are divided into two distinctly different groups; changes in characteristics of the electrical components, and changes resulting in failures of components due to excess stress. The first group concerns itself with the proper dynamic performance of the equipment within its specified parameters, while the second group relates directly to the failure rate and reliability of the equipment. (See Figure 1.) In this discussion, I will consider the problems and parameters of the first group, and only mention some factors in the second group.

Definition of the Problem

A CATV system consists of a number of amplifiers connected in cascade through coaxial cables. This system is frequently located in an environment whose temperature swings from -30 degrees F. to +120 degrees F., a spread of 150 degrees F.

Coaxial cable also changes its characteristics with temperature. The cable attenuation is changed by approximately 0.1% per 1 degree F. This change is also frequency dependent exhibiting a different change at low frequencies than at higher frequencies. These changes were analyzed and discussed in the past and it is claimed that the attenuation characteristics can be calculated and predicted. Because of different manufacturing techniques



EFFECTS OF TEMPERATURE CHANGE
Figure 1

and materials used by various suppliers of cable, there are some differences in the characteristics of the same type of cable. It was still felt, however, that one mathematical ratio relating the changes in attenuation characteristics to the inverse of frequency is sufficiently accurate for cable equalization and thermal compensation purposes. The problem, therefore, has been reduced to the proper definition and application of compensation for temperature changes in cable and amplifier components.

Methods Presently in Use for Temperature Compensation

Two approaches to solve the problem of cable attenuation were suggested by different manufacturers in the design of their equipment, a direct and an indirect (Figure 2) approach. The indirect approach utilizes special networks which exhibit characteristics that are inverse in performance to the cable characteristics. Use is made of the independent characteristics of two dissimilar devices to cause a cancellation effect which should be sufficient. Some vendors use devices external to the amplifiers, the so call Thermal Equalizers, and some use thermal sensing devices within the amplifier such as thermistors, and in this manner hope to accomplish the thermal compensation. The disadvantage of this approach is that such devices provide only an approximation to the changes. Sometimes, these approximations appear to be sufficient but many times they prove to be lacking.

It is safe to assume that most cables look alike. It is, however, less certain that thermal compensation devices exhibit identical characteristics (certainly not enough to approximate coaxial cable). If there is a compensation error in an amplifier, this error is cumulative in a cascaded system which results in large variation of levels with changes in temperatures. In addition, some of these devices introduce insertion losses, thus loading the system unnecessarily. This indirect approach suffers some serious shortcomings, the most important of which is that the location of these devices is very critical. Placing them in a coaxial cable requires accurate determination of the points of insertion.

Different component values have to be used for different lengths of cables in a system; they are very seldom interchangeable and each amplifier in the system has to be trimmed to match the cable equalizer which it follows or drives, depending on the situation. In addition, in time and under power stress, these components age and exhibit different characteristics requiring realignment or replacement. A partial solution to the problems was afforded by utilizing direct means to recognize level changes and to retain the levels at a predetermined and constant value. This was accomplished by an AGC network. This direct method did partially solve the problem, but the variation of levels was reduced, not eliminated.

The Auto-Slope and Gain Control Approach

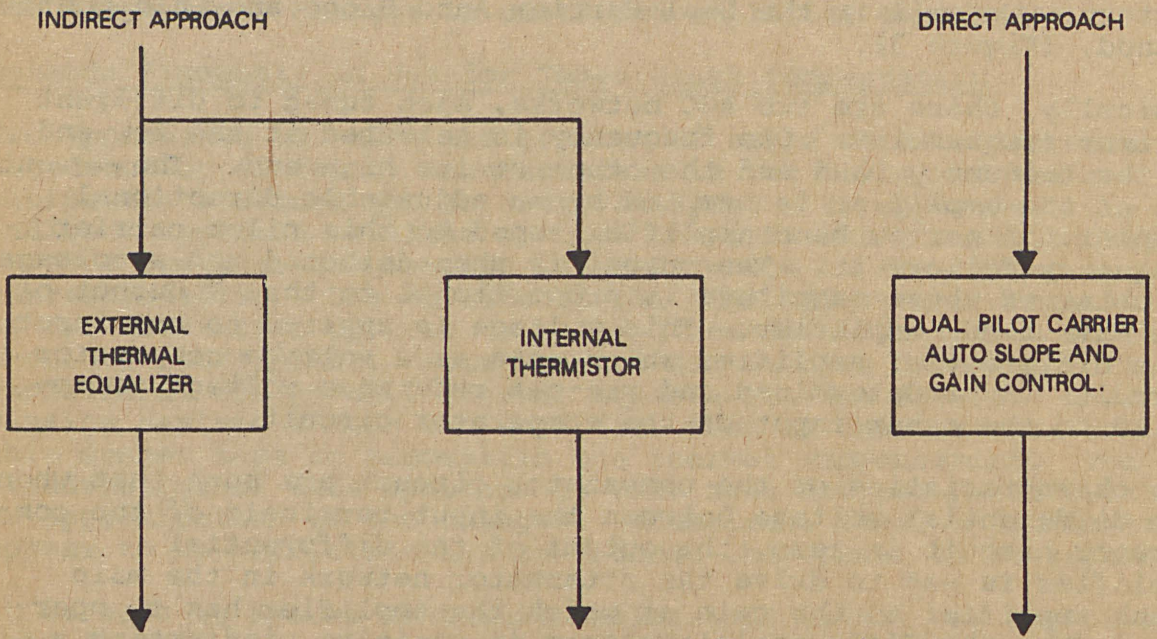
Variations in slope, however, were still significant and depended directly on the length of cable that was involved. It was logical to deduct that a second circuit operating in a manner similar to the Auto Gain Circuit could be used to solve this problem. This approach was actually tested and found to be quite satisfactory. We call it the Dual Carrier Auto Slope and Gain Control method, (Figure 3).

Basically, there are two AGC networks, each tuned to different carrier frequencies. One frequency is selected at the low end of the frequency band and the other at its high end. The r-f output of the amplifier is sampled by an adjustable directional coupler. A narrow band amplifier tuned to this pilot carrier frequency follows it. The output is then detected and a voltage is obtained whose magnitude is proportional to the r-f output of the main trunk amplifier. This voltage is applied to one input of a differential amplifier which acts as a voltage comparator circuit. A predetermined and pre-set reference voltage is applied to the other input of the comparator circuit.

The characteristics of the comparator circuit are such that when the differential voltage between the input terminals of the comparator circuit is zero, the output of the differential amplifier is set to drive the attenuator network in the main trunk amplifier to the gain at which the amplifier has to operate. When the differential voltage is positive, indicating a high r-f output voltage, the differential amplifier increases the drive into the attenuator network, increasing the attenuation and, in turn, causing a decrease at the r-f level of the main trunk amplifier to the predetermined value. When the differential voltage is negative, indicating a reduction in r-f output of the main amplifier, the differential amplifier decreases its drive of the attenuator network and in turn increases the gain of the main trunk amplifier and brings the r-f output level to its predetermined level. In this manner, the r-f output level is always kept and maintained at the absolute value determined during the setting of the amplifier.

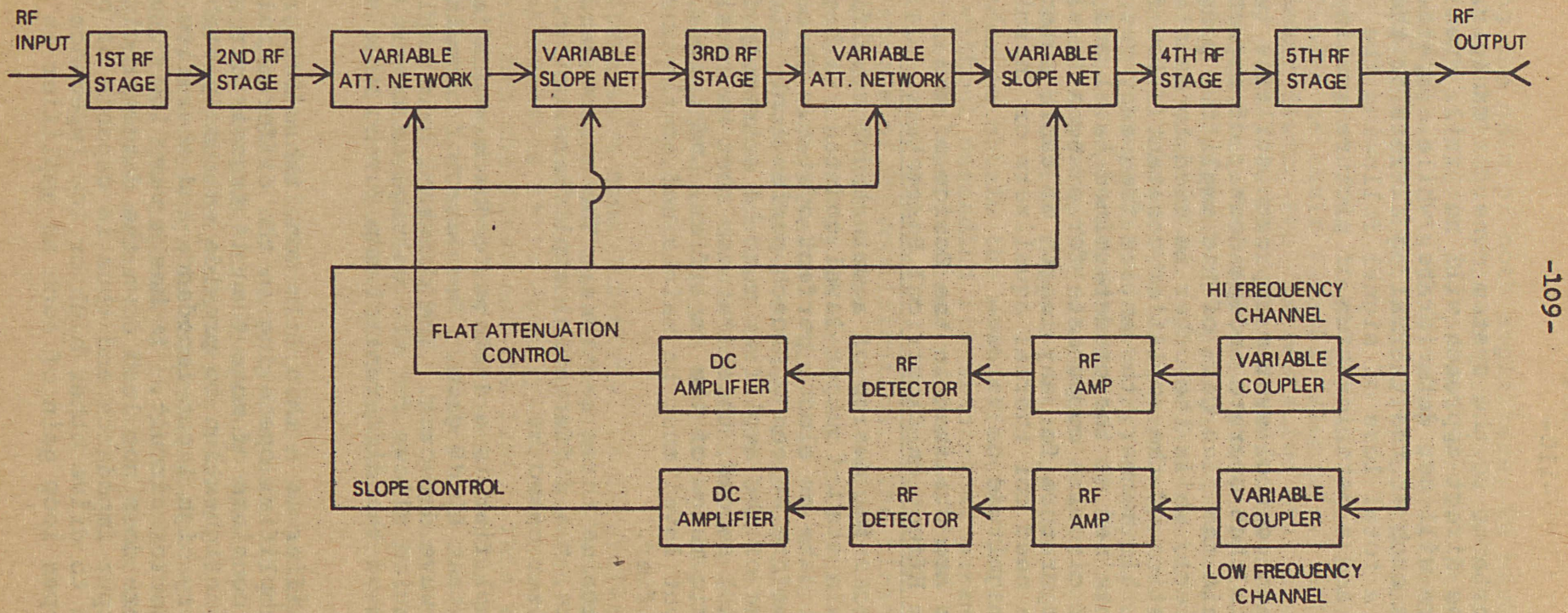
It should be borne in mind at this point that it does not matter what caused the r-f level to change at the input, and that any changes in r-f levels in preceding stages are not cumulative. For example, if 50 amplifiers are put in cascade, and the output levels of all of them change in the same direction by 1 dB, the total change at the output of the fiftieth amplifier will be whatever changes in output level a single amplifier exhibits, or 1 dB. When these numbers are used in a system having an indirect temperature compensation technique such as thermal equalizers or thermistors, the total RF output change will be 50 x 1 or 50 dB.

Let me digress for a moment! This comparison is most dramatic



POSSIBLE SOLUTIONS FOR CABLE ATTENUATION DUE TO TEMPERATURE CHANGE PROBLEM

Figure 2



AUTOMATIC SLOPE & GAIN CONTROL AMPLIFIER

Figure 3

and is of utmost importance to the system owner or manager. A system built using the direct approach will not fail, even the quality of the picture will not deteriorate, while a system using the indirect approach such as the thermal equalizers or thermistors will experience a total loss of signal following the twentieth amplifier, and a deterioration of picture quality after the tenth amplifier.

The auto-slope and gain control system approach utilizes two pilot carrier circuits that operate independently of one another. One is used to maintain the flat gain of the amplifier constant, (high frequency carrier), while the other is used to maintain the slope characteristics of the amplifier constant, (low frequency carrier). In this manner, the entire frequency response of the system is maintained at the predetermined level and tilt. The two pilot carrier circuits compensate for changes in slope due to changes in temperature for any length of cable automatically, eliminating the need for thermal equalizers or thermistor networks of various magnitude or values.

Special Circuits That Are Utilized in the Design of the ASG Network and Their Effect on Electrical Parameters.

The secret of the successful design of a main trunk amplifier is the ability to maintain its r-f output level constant; a highly stable amplifier will make an almost perfect system. Three conditions must be met before we can approach perfection. First the frequency response of the amplifier must be extremely flat (± one-tenth of one dB) second, this flatness must be retained over the entire dynamic range of the amplifier, and third, a highly stable r-f output level must be maintained at the output terminal of the amplifier.

The ASG circuitry contains three sections: The narrow band amplifiers and detectors, the differential amplifiers, and the attenuator and equalizer networks.

The narrow band r-f amplifier is a 4-stage feedback amplifier that is set at a constant 60 dB gain. The detector circuitry is a dual diode full-wave detector. The constant gain amplifier detector combination allows for the voltage to remain constant at the input of the differential amp during wide ranges of temperature.

The differential amplifier is a thin film monolithic integrated circuit operational amplifier operating in the differential mode. The circuitry consists of more than 14 transistors connected in a special configuration to provide extremely stable DC gain. It has a very high input impedance and therefore does not load down the detector circuit. It has a very low output impedance and therefore does not load down the detector circuit. It has a very low output impedance and thus is capable of being a good current source to drive other high or low impedance circuits. The typical open loop gain of such an amplifier is 90 to 100 dB.

Adding the gain of both amplifiers, we have an open loop gain in excess of 150 dB. This entire gain is used to maintain the output level stable at the preset level. Attention is drawn to this figure as it is this value of available gain that makes possible the excellent stability of the amplifier.

The attenuator (The "Diat"$_{tm}$) and equalizer networks contain PIN diodes as their variable elements. A PIN diode is a semiconductor device that is resistive over a very wide frequency range, over 1000 MHz. It is therefore frequency independent at the frequencies that are used presently in CATV equipment. By changing the current through the PIN diode, a change in resistance is accomplished. In the Attenuator network, changing the current will change the flat gain characteristics of the amplifier. In the equalizer network, changing the current will change the slope characteristics of the amplifier. The resistance value of the PIN diode can change over a wide range and as a result a wide range of attenuation is obtained.

In order to obtain the most effective performance of the amplifier without degrading its electrical parameters, it is important to design these parameters into the main trunk amplifier very carefully. The main trunk amplifier consists of five stages of r-f amplification. The first stage is designed to exhibit optimum noise figure values. It is important not to inject any circuitry in front of this stage in order to degrade its noise figure value. The last stage is designed to provide maximum r-f power level with minimum of intermodulation and crossmodulation distortions. For least distortion, it is preferred to operate this stage with as minimum an r-f level as possible. The last stage, therefore, should not be followed by any lossy components.

For distortion considerations, it is preferable to operate all stages at their minimum r-f levels. Therefore, in order to accomplish optimum performance, attenuation of signal is best accomplished if it is equally divided among all the stages rather than the first and the last. This is precisely the design approach that was followed in this amplifier. There are two identical attenuator circuits and two identical equalizer circuits in this amplifier. The attenuator and equalizer networks are placed before the third and fourth stages. In this manner, all the desired performance parameters are successfully met.

The amplifier is aligned for best frequency response and input and output VSWR. In varying the gain of the amplifier from maximum to minimum, the frequency response does not change. This is an extremely important feature as it has direct bearing on costs and savings in manpower and money to a CATV system. You all know how expensive it is to send out technicians periodically to adjust gains of the amplifiers during changes in

seasons. It is also usually necessary to check and reset the relative amplitude of the different channels as changing the gain of the amplifier changes its frequency response characteristics. Now, with a wide dynamic range gain control circuit, which is uniform over the entire bandwidth of the CATV system, this problem is eliminated.

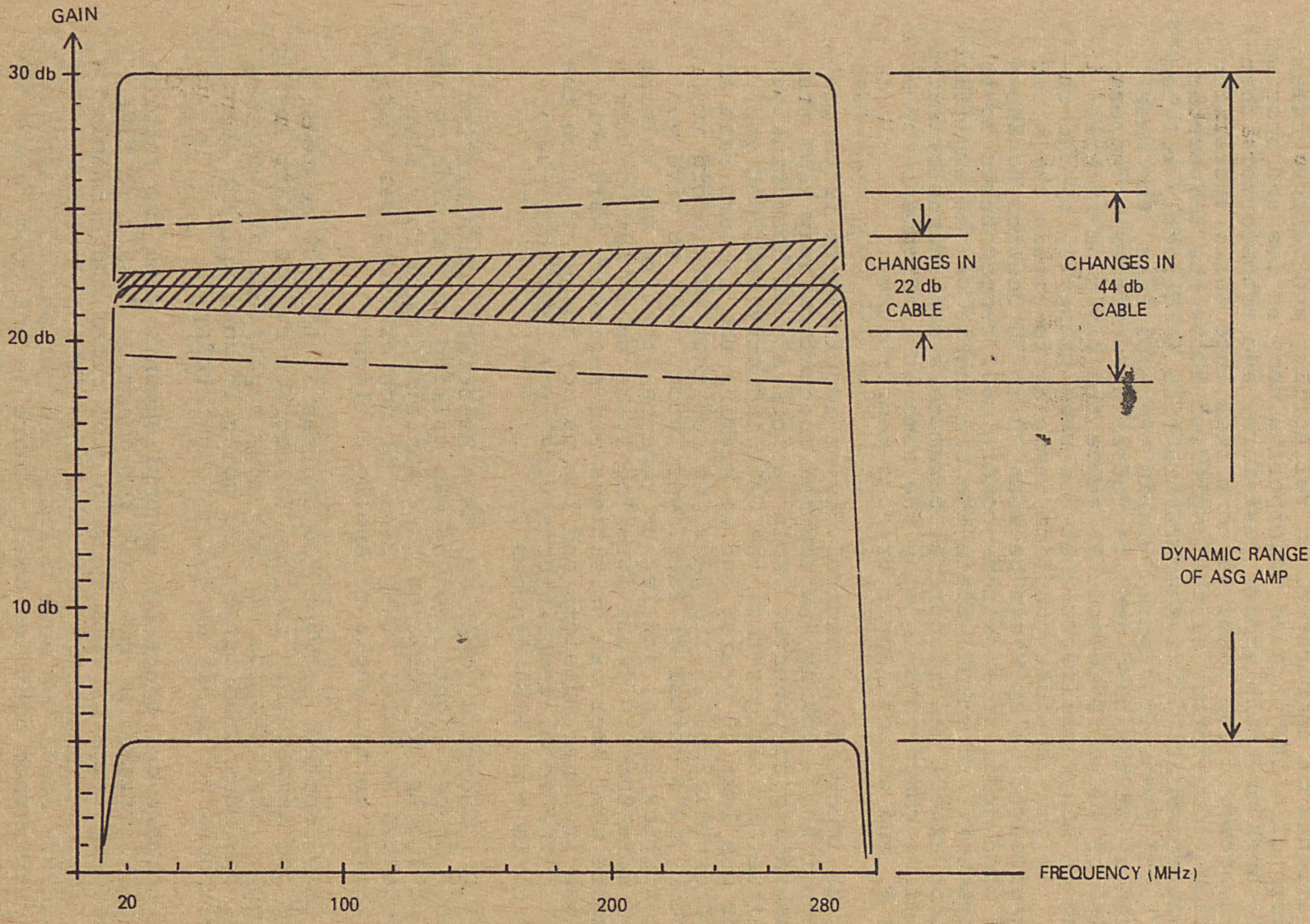
To illustrate the effectiveness of this design, I wish to mention some of the performance parameters that can be verified in the Lab, where proper test facilities are available. Maximum gain of 32-34 dB may be observed. Minimum gain of less than 5 dB were measured, 2-4 dB was typical. This means that gain variation of dynamic range in excess of 25 dB are obtained with this amplifier. The gain of the amplifier was set at a nominal 22 dB, for the 22 dB spacing that is considered generally common in CATV systems. Crossmod data was taken using a 12 channel test set. The output level of the amplifier was set at +32 dB mV output and crossmod reading below -90 dB were recorded (-98 dB). The output level was then increased in 2 dB steps up to +40 dBmV and the crossmod curve changed in steps of 4 dB indicating a linear and well-behaved amplifier. The gain was then changed by ±8 dB and data was taken in a similar way. The results were compared and it was verified that crossmod values were within less than 5% of one another as the gain was changed from 16 dB to 30 dB, (See Figure 4.)

You will recall that previously I used the example of 50 amplifiers in cascade and indicated that a change in 1 dB at the output level of every amplifier in a similar manner will not affect the system performance. Changes of 1 dB are not uncommon in existing amplifiers. However, now to illustrate my point, I am going to increase the change in level from 1 dB to 8 dB. A system utilizing this amplifier, and this amplifier only, will provide satisfactory performance under such a change. This significant improvement in performance is contributed largely to the utilization of the two stages of the PIN diode attenuator networks.

Let us now consider the meaning of an ±8 dB dynamic range on other system parameters. Let us see what it means to us in terms of temperature changes and lengths of coaxial cable. We know that the attenuation of a coaxial cable changes by approximately .1% per 1 degree F., or 10% per 100 degrees F. Let us now take an 80 dB cable and allow the temperature to change by 200 degrees F. or ±100 degrees F. The cable attenuation will vary by ±8 dB, which is the value that was tested. Remember now that 16 dB does not represent the full dynamic range of the amplifier.

Concluding Remarks

Up to now I was talking about changes in parameters due to change in temperature. I would like to make some comments as



CHANGE IN 22 AND 44 db OF CABLE VS FREQUENCY DUE TO ± 100°F TEMPERATURE CHANGE

Figure 4

to the effects of temperature on reliability and failure rates. Amplifiers of a CATV system incorporate many active and passive devices, such as transistors, resistors, and transformers that dissipate power. The power is converted into heat, increasing the ambient temperature of the amplifier above the temperature of the environment. This temperature rise is directly related to the total power dissipated within the amplifier, the mass and geometry of the case and its radiating surfaces. Temperature rise of 40 to 50 degrees F. above the environment were measured on many amplifiers that are used presently by the industry. If you consider junction temperature within the solid state devices to be anywhere between 10 to 30 degrees F. above ambient then under some extreme conditions, temperatures up to 200 degrees F. are found within the components of the amplifiers. One cannot expect the electrical parameters and characteristics of amplifier components to stay the same at environments of 70 degrees F. and at both lower or high temperatures.

One of the important mechanical design requirements is to provide proper heat sinking and thermal conduction away from the heat generating components. When we look at the heat sinking capabilities in designs that the CATV industry provided you with for the last 20 years, and we examine the failure rate that you have experienced in the past, we see that the record is quite poor, as a matter of fact, very poor. Let me give you some statistics again, and let us remember that we are talking in 1969, more than 10 years into the space age. Let us look and compare what American scientists and engineers were able to accomplish in lunar missions and let us not forget that on the surface of the moon, temperatures vary from less than -300 degrees F. to over +150 degrees F.

To quote Dr. George E. Mueller, NASA Associate Administrator for Manned Space Flight, when he was talking of the high reliability of the Apollo vehicles that contained more than five million parts, he said, "Only five (5) non-critical parts actually failed on the whole of Apollo 8 flight."

We, in CATV, operate between -30 degrees F. to +100 degrees F. Whenever the temperature reached 80 degrees F. you start losing your sleep. The question is "How many amplifiers are we going to lose, how many transistors are going to burn up, and how many telephone calls are we going to get today."

When we compare our space age accomplishments with the records of our CATV systems, we must ask the question "Isn't it time that the CATV industry come up with good clean and reliable gear?" Yes, the answer is yes, the time is long overdue. The CATV industry needs the same quality and reliability that our military and space agencies need. There is not good reason why we should not have it. We feel this amplifier is a major step in this direction.

Thank you.

DONALD B. GREGORY

A CATV trunk system is made up of cycles of components along its length. Each cycle consists of a length of cable and an amplifier which has gain that is exactly opposite the cable and passive network losses at all frequencies within the bandwidth of the system. The maximum length of cable that can be used ahead of an amplifier is limited by the lowest signal levels that can be handled by the amplifier. Signal to noise ratio performance is the limiting characteristic.

The maximum gain that can be built into the amplifier is limited by the ability of the amplifier to handle high level signal swings. Cross modulation and other spurious distortion products are the limiting factors. Any method to control system levels is limited by these required system characteristics.

No amplifier gain and tilt controls would be necessary if:

1. Amplifiers could be spaced at precise intervals along the cable (No regard to pole locations and having predictable cable losses).

2. Cable attenuation was constant (No change in cable losses such as from reaction to temperature of environment).

3. Amplifier gain would remain constant within the environment.

4. Power splitting devices employed that exhibited losses similar to cable with frequency.

Of course, these requirements are not yet met on a practical basis for CATV applications. Constant amplifier gain is the one factor that is being most reasonably controlled. In very long cascades some compensation for this variation should be considered.

To maintain constant levels throughout the system with the variation of cable length, cable loss per length, cable temperature, and power splitting loss it is necessary to build in the amplifier variable gain adjusting controls. These controls must also adjust the gain of the amplifier across the band at a different rate from one band edge to the other.

This skewing of the amplifier gain vs. frequency characteristic changes the tilt of the amplifier. It is necessary to build in the amplifier this capability since there are factors (such as passive device and cable loss) that must be compensated by skewing the amplifier's response.

A method to enable these operations to take place in the

amplifier is to place manually operated controls in the amplifier. This is practical for initial set-up of a CATV system, but as the system experiences changes in its environment, its losses change. The primary changing factor is cable loss. The rate that cable loss changes is precisely predictable as it heats and cools. A practical method to compensate for these changes is to sample at some frequency the result of the cable loss at the amplifier and adjust the gain of the amplifier by some automatic means. The response of the amplifier can be skewed at a predictable rate to compensate for the cable loss function with frequency. This cycle of cable and amplifier then has at its end points stable signal levels. The limit of the stability is then affected by the amount of interference by other factors. To overcome these unpredictable variations and the tracking error of the automatic gain controlled amplifier it is necessary to include a separate sampling function in the amplifier. This sample should be selected at a frequency removed from first frequency sample. In a practical CATV system the two sampled frequencies can be:

1. in the guard band between Channels 4 and 5 (72 to 76 MHz such as 73.5 MHz).

2. above the highest signal frequency in the system (such as 271.24 MHz).

These selections then give a "handle" on the two ends of the system which makes it practical to adjust the amplifier gain and skew the response automatically to compensate for normal smooth loss versus frequency characteristics that could arise on the system.

The location of these control functions within the amplifier is also extremely important. If the attenuator is located at an intermediate position in the amplifier the input stages will have to be capable of handling high signal levels when input signal levels are high (see figure 1). If the attenuator is located at the input of the amplifier its loss will directly contribute to the degradation of the signal to noise ratio (see figure 2). Due to recent state-of-the-art developments it is now possible to build automatically controlled attenuators at very high frequencies that exhibit extremely low minimum insertion loss. The placement of the attenuator at the input of the amplifier allows it to work over its entire gain range and deliver a constant signal to noise ratio and also a constant signal handling capability (constant cross modulation and other distortion products). Note that the signal levels at all amplifier stages in the amplifier remain constant. This means that a system designed for any particular set of conditions will maintain constant performance characteristics as normal loss variations take place on the system. This premise will hold for the following conditions:

1. AGC employed at each amplifier location.

2. the CATV system designed within the dynamic range of the AGC system.

The variable equalizer which automatically tilts the frequency response of the amplifier may be located at any convenient location in the amplifier since it has only a small effect on the overall signal swing in the amplifier (see figure 2).

An amplifier with characteristics of:

1. Operational gain: 22 dB @ 270 MHz

2. AGC range: ±4 dB @ 73.5 MHz
   ±8 dB @ 271.25 MHz

will hold signal levels constant at all points in the bandwidth over a cable temperature range of 290° F. Of course, this would be much more AGC range capability than normally needed, so a slight modification of the performance/cost trade-off is practical. The signal to noise ratio and the signal handling capability is sacrificed by only a minor amount. Figure 3 shows the effects on levels (and performance) by using manual gain control amplifiers at every other amplifier location which yield a more economical system design. This configuration will yield constant levels at each AGC amplifier output port over a 145° F cable temperature range. Nearly all CATV systems constructed in the United States will experience less than a 145° temperature swing (including cable temperature rise in sunlight) This then allows manual gain amplifiers to be used at every other location to obtain a cost saving if desired.

Investigation of the degradation of signal to noise ratio and cross modulation can be made for this application of an AGC amplifier at every other trunk location. A cycle on the trunk line is now considered as:

1. a span of cable (22 dB @ 270 MHz)

2. a manual gain control amplifier

3. a span of cable (22 dB @ 270 MHz)

4. an automatic dual pilot gain controlled amplifier (see figures 3a, 3b, 3c).

Calculations of degradation of desirable system characteristics are given in Appendix A. One amplifier pair with AGC at each location would produce a signal to noise ratio 54 dB. One amplifier pair with AGC at every other location is 53 dB, therefore, the degradation is 1 dB of signal to noise ratio.

Cross modulation degradation by use of manual gain amplifiers at every other location is calculated in Appendix B. Note that

the degradation caused by using a manual gain amplifier at every other location would be 2 dB. The cost of the system could be reduced (savings being the cost of the AGC system at every other trunk amplifier location) at the small increase of system degradation. Likewise, it is obvious for optimum system performance use of automatic gain control amplifiers at every trunk location would be necessary.

Level control of feeder lines is not as critical as the trunk system, but some method of reducing the level swing with temperature provides better system performance. Either single pilot AGC line extenders or thermal control would be adequate since these units are used in limited cascades.

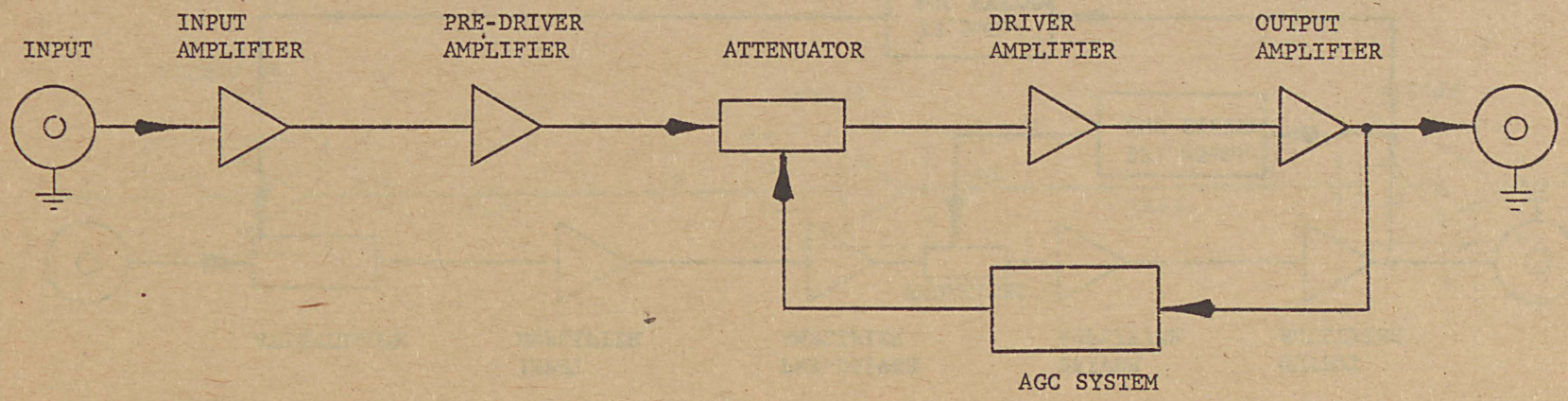

INPUT
INPUT AMPLIFIER
PRE-DRIVER AMPLIFIER
ATTENUATOR
DRIVER AMPLIFIER
OUTPUT AMPLIFIER
AGC SYSTEM

FIGURE 1

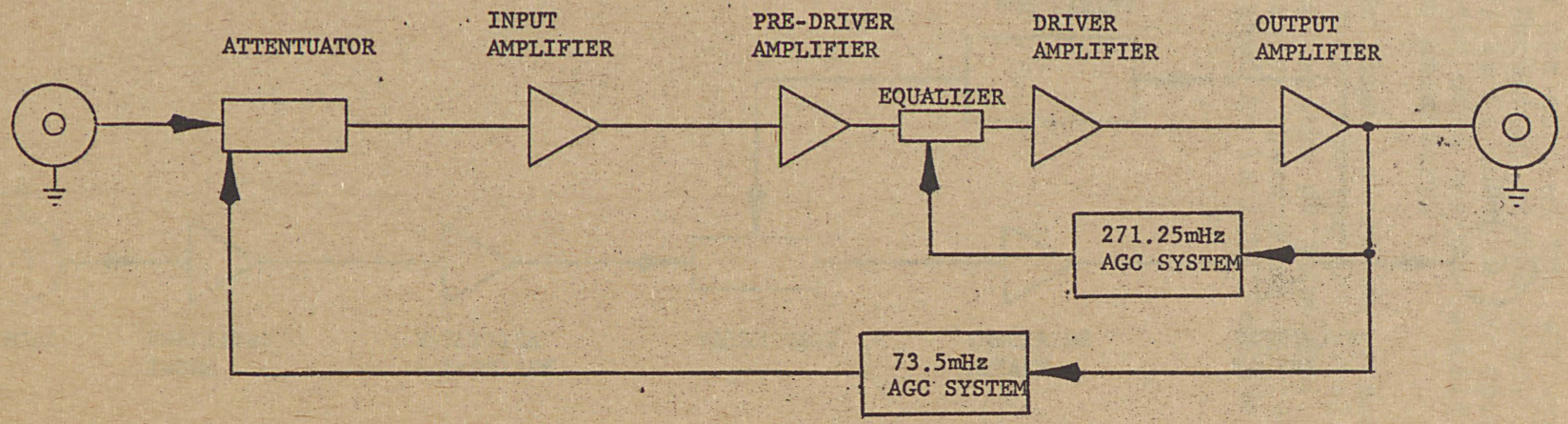

ATTENTUATOR
INPUT AMPLIFIER
PRE-DRIVER AMPLIFIER
EQUALIZER
DRIVER AMPLIFIER
OUTPUT AMPLIFIER
271.25mHz AGC SYSTEM
73.5mHz AGC SYSTEM

FIGURE 2

FIGURE 3a

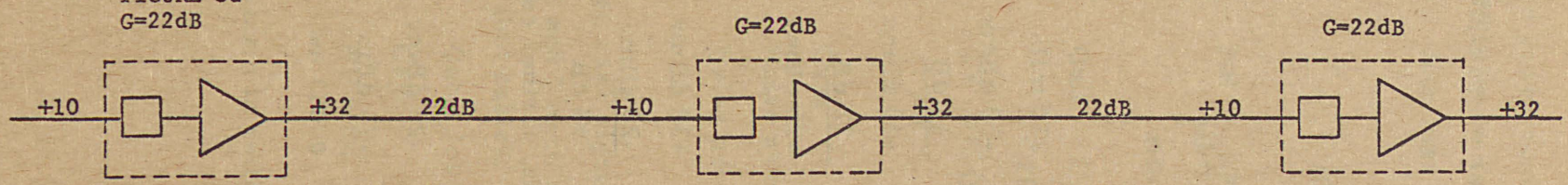


FIGURE 3b

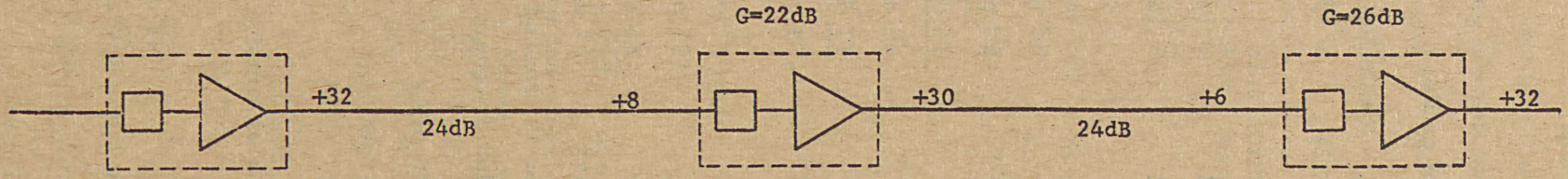
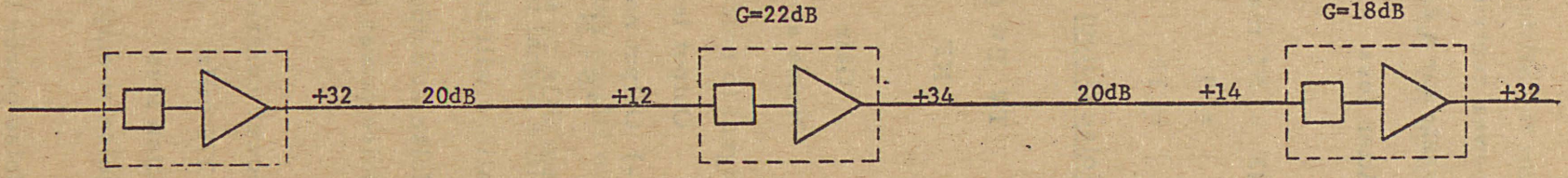


FIGURE 3c



APPENDIX A

I. Noise power contribution by one manual gain amplifier when adjusted to compensate for a 22 dB span of cable.

Atten loss = 1/2 (G_{max} - cable loss)

= 1/2 (26 - 22) = 1/2 (4) = 2 dB

NF = NF max. gain + Atten loss

= 9 + 2 = 11 dB @ 270 mHz

= 12 + 2 = 14 dB @ 54 mHz

Noise Output

	54 mHz	270 mHz
TV BW (per channel)	-59 dBmv	-59 dBmv
NF	14 dB	11 dB
	-45 dBmv	-48 dBmv
Gain	11 dB	22 dB
Noise at output port	-34 dBmv	-26 dBmv

Signal to noise ratio

Output level	+27 dBmv	+32 dBmv
(-) Output noise	-34 dBmv	-26 dBmv
S + N one amplifier	61 dB	58 dB

Since signal to noise ratio is limited at 270 mHz, further calculations will be made at that frequency only.

Noise at output port @ 270 mHz -26 dBmv

Noise power level: ref 1 mw -75 dBm

0.033 nw

II. Noise power contribution by one automatic gain amplifier at maximum gain at 270 mHz.

Atten loss = 0 dB, NF = 9 dB

Noise at output port = TV BW + NF + Gain

= -59 + 9 + 26 = -24 dBmv

Noise power level: ref. 1 mw -73 dBm

0.052 nw

Appendix A - (Continued)

III. Noise power contributed by one automatic gain amplifier at minimum gain at 270 mHz

Attn loss = 1/2 (G_{max}) - cable loss + $\triangle$cable, 1st span)

= 1/2 (26 - 20 + 2)

= 1/2 (8)

= 4 dB

NF = NF max gain + Atten loss

= 9 + 4

= 13 dB

Gain = G_{max} - Atten loss - Eq. loss

= 26 - 4 - 4

	@ 270 mHz
TV BW (per channel)	-59 dBmv
NF	13 dB
	-46 dBmv
Gain	18 dB
Noise at output port	-28 dBmv
Noise power level: ref 1 mw	-77 dBm
	0.02 nw

IV. Worse case signal to noise ratio by one pair of trunk amplifiers (1 ea. MGC and 1 each AGC). Note the worse case exists at AGC maximum gain (hot cable). (NP = Noise Power Level)

Cable loss = $\log^{-1} \frac{24}{10}$ = 25.2

Gagc = $\log^{-1} \frac{26}{10}$ = 39.8

NP total = NPagc + $\frac{\text{NPmgc x Gagc}}{\text{cable loss}}$

= 0.052 + $\frac{0.033 \times 39.8}{25.2}$

= 0.052 + 0.052

= 0.104 nw

= -70.0 dBm

= -21.0 dBmv

Appendix A - (continued)

IV.

Signal to noise ratio

Output level @ 270 mHz	+ 32 dBmv
(-) Output noise	- 21 dBmv
S + N Amp pair	53 dB

V. Signal to noise ratio of a pair of AGC amplifiers at hottest cable temperature (same conditions as example of Parts II thru IV) @ 270 mHz.

Atten loss = 1/2 (G_{max} - cable loss)

= 1/2 (26 - 24)

= 1/2 (2)

= 1 dB

NF = NF max gain + Atten loss

= 9 + 1

= 10 dB

Noise Output

TV BW	-59 dBmv
NF	10
	-49
Gain	24
Noise at Output port	-25 dBmv

Signal to noise ratio

Output level	+ 32 dBmv
(-)Output noise	- 25 dBmv
S + N each amp	57 dB
Derate for pair	3 dB
S+N Amp pair	54 dB

APPENDIX B

I. Cross modulation (CM) contribution of one manual gain amplifier at coldest cable temperature. (see figure 3c).

Rated output level (ROL): +32 dBmv @ Ch 13

Cross Modulation: -93 dB NCTA Standard

Actual output level (AOL): +34 dBmv @ Ch 13

Cross Modulation: -89 dB NCTA Standard

from CM = 2 (AOL - ROL) -93

= 2 (+34 - 32) -93

= 2 (2) -93

= -89 dB

II. Cross modulation contribution of one amplifier pair (1 each MGC and 1 each AGC amplifier)

Amplifier	CM	Voltage Factor (ref -100 dB)
MGC	-89 dB	3.5
AGC	-93 dB	2.1
	-85 dB	5.6

III. Cross modulation contribution of one amplifier pair of 2 each AGC amplifiers

CM = CM of one amplifier + 6 dB

= -93 +6

= -87 dB

CATV TECHNICAL STANDARDS

Session Chairman:
Hubert J. Schafly

Participants:
John B. Damonte
"The Role of the IEEE in the CATV Industry"

G. Norman Penwell
"The NCTA Standards Program"

Guest Panalist:
Sydney R. Lines

(Papers received after material
sent to printer.)

JOHN B. DAMONTE

I have been asked to speak to you this morning about the IEEE and how it might interface with the cable TV industry.

First of all, let me define for you what IEEE is all about. The IEEE stands for the Institute of Electrical and Electronics Engineers. It's a group of about 158,000 engineers located throughout the world who are interested in the electrical and electronics business. The organization is relatively new in one sense, in that it is a merger of two former organizations, the American Institute of Electrical Engineers and the Institute of Radio Engineers.

The 158,000 membership represents the largest engineering society in the world by a factor of about 2. What do we do? We are a scientific, literary and educational organization. We are scientific in the sense that we are interested in the development of new systems devices and proponents in the electrical and electronic area.

We are literary in the sense that we publish papers and serve as a forum for the discussion of these papers. We are educational in the sense that we sponsor conventions, conferences, symposia and other gatherings, locally as well as internationally, to disseminate the latest engineering information available to the various facets of electrical and electronic engineering.

How do we operate? Basically, we are divided into what are called regionals, and there are ten regions throughout the world. Six of these regions make up the United States. San Francisco is located in region 6 and incidentally happens to be the largest single section in the world. The seventh region is Canada. The eighth region is the western European land mass.

Region 9 is central and southern South America, and region 10 is Asia and the eastern portion of Europe.

We have approximately 200 sections, and that is the basic building block of the IEEE. The sections are responsible for establishing the local programs, meetings, local conferences and this sort of thing. In addition to the sections, we have a technical organization which is called the "Group" and this particular technical group is interested in a particular phase of electrical engineering.

For example, it might be audio or television, antennas, microwave theory and techniques, aerospace engineering -- there are 31 of these various segments (groups).

We also publish a lot of material. The IEEE has some 42 different publications covering the various technical areas of interest.

JOHN B. DAMONTE AND G. NORMAN PENWELL

When IEEE was first formed as a merger of the IRE and IEE, there were at that time three publications. And in 1947 we published some 3,000 pages of technical material. I ask you to think in your own minds what you think we might be publishing today. Today we have some 42 publications and we publish 30,000 pages of technical matter. So there is a tenfold increase in the very short period of time.

I think one thing that we are working with that might be of interest to you is the fact that we are all becoming saturated with paper. It must be true in your industry as well as in all of the others.

To try to get at the meat of the kind of material that you want requires that you go through a lot of different magazines and journals. There should be some systematic way in which you can derive the kind of information that you need to do your particular job. I think this is probably one of the reasons that you have formed your particular organization, to specialize in a particular area, to make that kind of information available to you.

In addition to our periodicals, IEEE publishes standards. These are standards set up by committees of IEEE working in conjunction with other agencies such as FCC and other regulatory bodies. These committees establish the particular limits of acceptability for various kinds of devices, operations.

And I see, just listening to the last speaker, that you too have standards for your own industry and operations in that industry. In short, IEEE is a forum for the discussion of technical problems, and I think this is where it has its greatest value. It brings together people who have common problems and gives them the opportunity to discuss these problems with the experts in the field.

We at IEEE are pleased to see the emergence of the cable TV industry, and we stand ready and willing to help you in any way that we can. I think that is the formal part of my talk, and later on, if you have questions, I will be glad to answer those that I can.

G. NORMAN PENWELL

I would like to discuss very briefly this morning the NCTA standards program and what it means to you as a CATV systems operator. Over the past few years, we have approved several standards and

recommended them to the membership of this organization. We have one standing committee, that is, the NCTA Standards Committee, which meets several times a year or as is necessary to discuss standards.

This committee relies heavily on the analysis and recommendations of an engineering subcommittee. While these two groups work jointly, the functions and charges to these two committee groups are different. I would like to emphasize the distinction between these two functions.

Membership in the Engineering Subcommittee is open to NCTA members and associates who have indicated an interest and a capability in CATV engineering analysis. It is made up largely of representatives from the engineering staffs of the manufacturers and the engineering consultants serving the industry.

It serves as the work-horse for the Standards Committee in developing the basic data and the analysis necessary for the formulation of good engineering practices and standards.

On the other hand, the Standards Committee is made up largely of representatives from the engineering staffs of CATV system operators, and it is the Standards Committee that recommends standards to the NCTA Board of Directors for final approval. There are two kinds of standards that can be developed, (1) standards that specify common methods of measurement for equipment and system parameters and (2) minimum performance standards that recommend minimum requirements for equipment or systems such as Walt has been speaking about this morning.

There is a need for both kinds of standards, but primarily and firstly, our NCTA committee has been interested in developing common methods of measurement. To the extend that NCTA standards specify methods of measurement, it is in your interest to ask that your manufacturer report equipment capability in accordance with the recommended standards.

By so doing, you are going to be able to make a meaningful one-to-one comparison between equipment from different manufacturers. The NCTA Standards Committee has five standards, and they are available in booklet form here at the convention in two boxes at the rear of the room. If you have not received a set of these, you are certainly welcome to them.

You will note, for example, that the first standard is a minimum performance recommendation for subscriber carrier level, but note that this standard was withdrawn recently for revision in the face of new data on color receiver performance on CATV systems, and it is in the process of being redrafted to reflect the current thinking in best engineering practices.

To give you an example of the kind of consideration that is going into the development of the standards, consider minimum subscriber level. For example, what might be a desirable minimum level for a metropolitan area with a rather high level of industrial and man-made noise would not necessarily be a desirable minimum level for a CATV system operating in a quiet area remote from man-made noise.

Another factor for consideration is that a CATV system is really statistical in nature. For example, is it realistic to insist that all subscriber drops be above a minimum level at all times?

Other standards include one on distortion characteristics, one on graphic systems, one on our numbering system, and most recently, one on noise measurement, which has been approved for recommendation to the NCTA Board for final approval. Apart from the subscriber carrier level standards, you will note that the standards describe common methods of measurement.

Other standards are in the process of being developed. One engineering panel, for example, is working on the relationship of subjective receiver picture quality to various types of interference, relating picture quality to an engineering measurement.

Another panel is working on the development of a set of common parameters to describe coaxial cable characteristics. A program is underway to develop a 75 ohm standard. We CATV system owners have been buying coaxial cable that is ostensibly of 75 ohm impedance. The manufacturer or system operator can not guarantee that it really is a 75 ohm coaxial cable, since there is no common standard traceable to the National Bureau of Standards.

In fact, the differences in return loss on coaxial cable that is sometimes discovered between a reported return loss and the measured return loss may in part be blamed on a lack of a common standard of reference. Therefore, the Engineering Subcommittee is working with the National Bureau of Standards with the intent of developing, under the voluntary standards program of the Department of Commerce, a 75 ohm coaxial air-line standard.

Each manufacturer or system owner would then be able to purchase an air-line standard which could then be sent to the Bureau for certification within a specified tolerance. There are needs for development of other standards too.

For example, with many systems on the threshold of expanding beyond the 12-channel cable, we are faced with the dilemma of where to allocate the non-standard channels. Are we as an industry to wait until one large manufacturer or system owner established the non-standard assignment by virtue of being the first to fully implement a workable assignment, or do we perform an in-depth study of the problem, analyze the various trade-offs involved and the various proposals, and then made a recommendation to the industry about where to allocate non-standard channels?

G. NORMAN PENWELL AND SYDNEY R. LINES

There is a further need for technical guidelines that can be used by municipalities and cities who grant franchises. As many of you are aware, we have been experiencing, as Walt mentioned, a rash of situations where cities and municipalities across the country have been granting franchises that do not properly address the problem of how to best protect the public interest.

I recall one recent franchise, for example, that specified the kind of cable to be used, the voltage to be used to power the cable amplifiers and the distortion minimums for individual amplifiers. Overlooked entirely was the fact that equipment is put together as a system and if specifications are required they ought to be on the system as a whole.

For those of you who are interested in technical guidelines, the Association had prepared several years ago a filing on an FCC Docket, Number 15971, in which technical guidelines regarding technical aspects of CATV were discussed.

That document is several years old now, and the Engineering Subcommittee is in the process of rewriting these guidelines. When you pick up your copy of the NCTA Engineering Standards in the back of the room, you will note on the back page a leaf that says, "these technical guidelines are in the process of being rewritten." I would like for you to note the future issues of the NCTA Membership Bulletin, because these guidelines will shortly be available in the Bulletin and I would like you to pick them up and insert them into your NCTA Engineering Standards. This will be the guideline that we will recommend as an association that you present to the people who are your franchisers.

SYDNEY R. LINES

It was suggested when Norm Penwell first contacted me about appearing on the panel, that I contribute a few words about the Commission's viewpoints on technical standards. But what I have to say here today represents no commission viewpoint but simply my own comment.

What the Commission ultimately may do in the way of adopting technical standards for cable systems is not yet clear. I think the best indicator of this thinking is set forth in paragraph 29 and 30 of the Notice of Inquiry and the Notice of Proposed Rulemaking in Docket 18397, which was released last December and which has since occasioned considerable comment.

I will quote quite briefly from that document. Paragraph 29: "It has been repeatedly suggested that the Commission should undertake to prescribe uniform technical standards to further high quality service to the public in both broadcast signals and CATV-originated material and compatibility among systems for purposes of interconnection. We think the time has come to start in this direction. Accordingly, interested persons are invited to make concrete and detailed suggestions as to what technical criteria might appropriately be prescribed. After consideration of the comments, the Commission may establish a committee to assist in the formulation of specific proposed criteria. In any event, it is contemplated that a further notice will be issued, proposing specific criteria prior to the adoption of any rules prescribed for technical standards."

I would like to emphasize here that the Commission is talking about technical standards to encourage, 1, high quality service to the public, and to provide for, 2, compatibility among systems for purposes of interconnection. What I will comment on here is simply standards for service to the public.

The Commission's concern for high quality service is, I think, an amplification of that concern which was originally expressed about picture degradation, and which appears in the rules in Section 74.1103(d). And that section says, "The signal shall be carried without material degradation in quality within the limitations imposed by the technical state of the art."

Now, Section 74.1103(d) was an attempt to respond to the many allegations at that time that cable systems were deliberately degrading the signals of local or competitive signals. It has been criticized as an attempt to provide a benefit for television broadcasters rather than for the viewing public.

The Commission, in Docket 18397 is now saying specifically that it has a concern for the quality of service rendered the public and that it intends to take steps to protect the cable system viewers.

I think that an evaluation of your industry, what it presently is, what it has been and what it appears soon to be suggests that here is an industry whose initiative, whose ingenuity and contribution to the public welfare has caused it to mushroom from a small and scattered and rather insignificant number of undertakings to a phenomenon which has inserted itself very squarely into the national picture and can no longer be ignored.

This same ingenuity and initiative and enthusiasm which has propelled the growth of cable television probably also is responsible for the fact that your industry has failed to establish widespread standards which might benefit you as well as your customers. In short, you have been too busy with your business.

It is true that NCTA has a functioning standards committee and it's true that the manufacturing segment of your industry, through the IEEE and also through EIA, have committees set up for generating technical standards.

But I think it is also reasonable to say that the output from these tentative efforts is relatively small. Only those who have participated in standards work can appreciate the amount of time and the effort that goes into generating just one acceptable standard.

So at this day and hour, there aren't very many acceptable technical standards already in being which the Commission might draft or draw upon for its regulation of cable systems.

In response to the Notice of Proposed Rulemaking in 18397, we received several detailed discussions which will be considered in due course. These are all public information and can be reviewed from the filing in Washington.

I should not discuss these particular things here, but I think that the first reaction that one will get from reading them is that although they originate from authorities, their approaches are different, as different as night is from day. Some suggest that the Commission should promulgate performance characteristics for each amplifier or each unit in the system.

Others suggest that with appropriate modification, we might adopt the existing television broadcast standards which were written for transmitters, and these should be applied to the cable system. Then there have been suggestions that we accept or type approve the individual units in a system. And we have also looked at what the Canadians have done with respect to technical standards.

As early as 1956 they had standards for signal levels delivered to subscribers, and they had standards for channel bandwidth, also linearity and gray scale picture characteristics, and even picture degradation. They measured these characteristics on a calibrated receiver.

The calibrated receiver, of course, they might connect at various points of the cable system. But the point I'm trying to make here is that the technical practice in the cable television industry and the actual plants that are now in existence are so diverse that early formulation of a universe of technical standards applicability to all systems is going to be very difficult.

My own opinion is that cable television is not ready for the application of universal technical standards, but that a growing segment of the viewing public is. The viewers are ready for technical standards and so are the communities who franchise your operations.

So, assuming that the Commission decides to push forward and adopt technical standards and requirements for CATV systems, what might they adopt and how might they be applied? I would like to suggest that one of the first items which might contribute toward standardization is an early adoption of a uniform set of definitions.

How does one define a "subscriber"? For example, what is a "drop cable"? How does "slope" differ from "tilt"? What is the bandwidth of an amplifier? How is signal-to-noise ratio defined and measured?

A list of these terms which are so used everyday and so simple in concept is very long, but in the cable industry there really has not been an adequate formulation of a list of these. I think that we need some central and authoritative body such as NCTA to provide the official backing that such a list requires.

Now I would like to suggest a possible approach to future Commission action with regard to technical standards. This is what I would call the "Black Box" approach. This would consider the cable system, including the antennas with the headend, simply as a "black box" which is connected between the subscriber's receiver at one end and the television broadcasting station on the other.

The Commission would not attempt to regulate specifically what goes into that black box, but the Commission would concern itself instead with the signal which comes out of it. We would insist that the signal be delivered, for example, at such and such a level. It would be adequately free of noise and distortion, and that the isolation between various subscribers is such that the subscriber does not disturb his neighbors.

So to use the "Black Box" approach, I suggest that the following parameters might be the subject of standardization for cable systems. Number 1, the minimum input signal delivered to each subscriber; Number 2, the equality of signal levels as between channels; Number 3, the isolation between any two subscriber outlets; Number 4, the frequency response on any channel; Number 5, the signal-to-noise ratio at a subscribers outlet; Number 6, the permissible compression of the sync pulse; Number 7, the radiation from a cable system.

There are several other parameters which also might be on the list; for example, one is cross-modulation or, as they say in Europe, cross-view. And NCTA already has developed a procedure for measuring and specifying this for an amplifier. But I am not certain how this would apply to a system.

During the question and answer period, if there are any questions, we possibly can elaborate on these for you.

DISCUSSION

MR. SCHAFLY: I will open the floor for questioning or rebuttals. Does anyone wish to speak? Yes. Come to the microphone, please and state your name and association.

MR. DONALD LEVENSON: Mr. Lines, I would like to know who, in the "Black Box" approach, you consider is going to be responsible for the path between the transmitting antenna and the CATV receiving. There's a problem in there. I was wanting you to comment on that.

MR. LINES: I quite think that you can't ignore the propagation problem, and I wouldn't know who could be responsible for that, who is responsible for there being a propagation problem. In the application in the administration of any technical standards, there has to be a certain amount of good faith exercised by the regulating authority as well as the regulated.

I really don't think that the propagation problem is something that prevents the adoption of technical standards applicable to CATV systems.

MR. LYLE EARN: The thing I wanted to ask is that the broadcaster has never had, as I know of, a control on the original quality. Now a drove of performers have their equipment that you can start out with, a very noisy film, a very poor resolution camera, etc., but now we are talking about CATV, not degrading a picture.

Is there any work towards improving this for the broadcasters?

MR. LINES: There are no technical standards applicable to the picture. That is transmitted by the television station. The Commission does not regulate the picture interval. The Commission applies its standards to the performance of the transmitting chain, the equipment, and it does have requirements regarding the synchronizing signal of television, but not of the picture interval.

MEMBER: I just wanted to mention, I am an old broadcaster and have been in the television business for a long time. There is a very fine committee active at the present time, which has various sections which has to do with improving film quality and transmission quality in every direction.

They have network representatives on it and others, so they are very aware of the problems, and work is going ahead on this.

MR. SCHAFLY: I would like to emphasize what these gentlemen have indicated. There are really three areas of so-called standards. There are terms and definitions, most important. I

know that the ones that Mr. Lines has indicated being desirable, at least as the first priority, and I am happy to say that some of those have at least been treated in some of our existing standards.

The second method is of measurement, approached methods of measurement using practical available test equipment.

The third is performance specifications. Now these get to be extremely touchy and almost out of the realm of a standards committee who is treating itself towards terms, definitions and measurements. I know in the IEEE, a CATV task force has been mentioned frequently, and that the IEEE as a professional society, does not want to say what is good and bad in terms of absolute numbers and attach it to something, but rather how do you measure?

I think the program of your Standards Committee, in attempting to obtain better subjective evaluation of good and bad in terms of visual perception, is an indication of our modality in that direction.

MR. KENNETH SIMMONS: I simply wanted to comment as to perhaps a word to our own standards group and also to Mr. Lines. I think it's important to underline the uniqueness of the CATV standards problem.

The specifications that fit our situation are not necessarily, and in fact, seldom are the same as those that fit the broadcast system. In Mr. Ragone's paper this morning, for example, he mentioned the required selectivity on the transmitter in a CATV system, where you have all signals at equal levels on adjacent channels as contrasted with the Buckeye situation, where you may want to receive an adjacent channel from the local town under the antenna of a local transmitter.

The requirements are not the same, and one mistake that we can make, and one that we have tried very hard to recognize in our standards work, is to assume that any of the former standards apply directly and without thought to the CATV situation.

Another example, perhaps, is the problem of direct pickup, whereas radiation from a cable system is of great interest to the FCC in the protection of the consumers who are using the radiated signals. There are diverse problems on the pickup. The CATV system is of great interest to the cable operator also and to his customers, and these matters require consideration of each standard which might be adopted and might be applied to the cable system situation, to see that we are controlling, in fact, the service delivered to the customer and not arbitrarily applying some standard which comes down to us from some other situation.

GENERAL MANAGEMENT

AND

ENGINEERING SESSION

CATV VIA SATELLITE

Panelists
Frederick W. Ford
G. Norman Penwell
Louis B. Early
Robert D. Briskman
Irving B. Kahn
Frank W. Norwood
Nathaniel E. Feldman

Moderator
Benjamin J. Conroy, Jr.

FREDERICK W. FORD

I will make a very important proposal during the course of my remarks. This proposal is for the use of space satellites for the purpose of transporting non-entertainment programs on an interconnected basis to CATV systems throughout the country. This proposal is in complete compliance with the joint proposals of the staffs of the National Cable Television Association and the National Association of Broadcasters. Those proposals provide that there shall be no interconnection for entertainment type programs.

Representatives of the Communications Satellite Corporation have accepted our invitation to hear this proposal, and to help us understand the technical and economic problems involved no matter what the information transported may be.

Space communications via satellites has been a fact since the early bird satellite began relaying signals from space in April 1965. This date marked the beginning of a new era in communications.

The Communications Satellite Corporation (COMSAT) is now entering its fifth year of satellite operation, and in this short span of time we have seen this technology leap ahead to the point where the fourth generation satellite is about to be launched. It will provide a five-fold increase in circuit capacity.

These are our questions: How does the satellite communications technology relate to the CATV industry? Is there a future for CATV in this exploding communications technology?

I began wrestling with these questions some years ago. At our Financial Seminar in New York in February of 1966 I stated, "To the extent that the Commission obtains authority and may require the industry to exhibit an interest in the origination of programming or limit the bringing in of distant independent signals it may force the CATV industry perhaps to a nationwide cable network." Later that same year, at our Annual Convention in Miami, Florida, I urged each of you, if it were at all technically and economically feasible, to immediately institute on one channel programs to serve the needs, desires and interests of the community of which you are a part. It now appears that each of these predictions for our industry may, in fact, be realized.

The answers to these questions are of concern to every CATV operator and to all potential investors in this industry. We are proposing today that the CATV industry take immediate advantage of this new technology -- that the CATV industry become involved in the satellite technology by participating with the existing framework of authorizations. The Communications Satellite Corporation is presently authorized to be a carrier's carrier. In other words, it is authorized to receive and deliver signals from other authorized carriers. We are proposing that

the CATV industry become one of the prime users of the satellite capability in order to bring more program options and a diversity of service to the television homes of the United States. We are proposing that we contract for part of the domestic satellite service to the extent that it would provide the backbone of a trunking system that would eventually interconnect several million CATV subscribers to provide a selection of program options that only CATV is designed to fulfill.

The NCTA staff began working on this project several months ago. It was our aim to develop a method whereby a CATV system could be built and operated profitably in the major television markets of the nation. The concept would be to provide subscribers all local signals plus something else. The "something else" would not likely be a distant signal -- based on a presumption that we would be held to the rules of the Second Report and Order.

The "something else" should be a package of programming available only on CATV that would, in the aggregate, be interesting enough to the potential television viewer that he would buy the service on the basis of the appeal of one or more of the program options in the total package. Perhaps no one program channel would be appealing enough by itself to stimulate the homeowner to buy, but the aggregate appeal of several channels -- providing a diversity of minority interests, that would be largely unavailable on broadcast stations, would be enough to stimulate a television homeowner to subscribe to the system.

This, then, is a proposal that will make major markets a viable CATV enterprise and the technology exists today to put the programming package and the interconnect system together, and make subscription to systems in smaller markets more attractive than ever.

We are proposing a service of 6 channels -- 6 additional channels of programming that would be designed primarily for CATV subscribers -- that would be available only as a package of programming -- that is, a system would not be able to pick and choose a channel or two of this service, but would make it all available to his subscribers. This is a necessary caveat on the proposal that the economics of the package, the monthly cost to the subscriber can be kept at a nominal level. The interconnection is necessary because of the live coverage of much of the programming that is contemplated and because of the perishability of programming that covers news, current events and public issues.

I would like to draw heavily upon the recommendations of the Carnegie Commission for the development of a national television system that will better serve the public and cultural needs of our people.

The cable industry can better serve the goals of this Commission because of the additional dimension of time availability. The

cable technology offers much greater programming flexibility than broadcast television because of the extensive excess channel capacity of cable.

A broadcaster must appeal to a mass audience with almost every program he presents. This is an inherent flaw in the present broadcast system -- since it forces the broadcast program to appeal to a mass audience -- or the greatest common denominator of interests among the people. Minority interests are subordinated to the interests of the majority.

But this need not be true in a system that has excess channel capacity. There are literally hundreds of activities that people are interested in enjoying, or learning about, or in teaching others. A service with excess channel capacity can devote time at leisure to exploring new or different subject matter such as new science, mathematics, religion, discussion of public issues, education, and so on, almost without limit.

To begin with, we propose to make two of these 6 channels available on a full-time basis to the Corporation for Public Broadcasting -- to be used to fulfill the original intent of the Carnegie Commission. Their stated intent was to program a public television channel directed toward general public and cultural interests and program, in addition, instructional television dealing primarily with formal education.

The Corporation for Public Broadcasting could now fulfill the promise held forth in the Carnegie Report by providing a public channel, that we would interconnect to several million CATV homes and the public would be better served with programming that would be free from the constraints of commercial television; the doors could be opened to greater expression and cultural richness; we could be exposed to new domains of learning, emotions, skills, human expressiveness, and physical phenomena that might otherwise be outside our ken.

The availability of a nationwide interconnect would spur both Congress and the Corporation for Public Broadcasting to an early implementation of the Commission's goals on this subject.

The other channel to be made available for CPB would be decicated to full-time use in instructional television.

It is ironic that in this nation so well endowed with natural resources such as oil, land, timber, minerals and so forth, we have overlooked, or at least slighted, that most important and most basic of any nation's natural resources, the people.

Every new invention, concept, innovation, philosophy of analysis has its roots in the educational development of the mind that

brought it forth. How obvious it should be then, that every mind be developed to the maximum potential through exposure to as much education, formal or otherwise, that is can assimilate.

Edcuation is basically nothing more than information transfer. One generation transfers information to the next. Naturally, the more efficient the information transfer process becomes, the more efficient and better is the educational system.

Transfer of information by speaking to one another (aural transmission) has been with us for thousands of years -- but it is not a particularly efficient way to transfer information. The recipient has to accept the pace of the speaker.

Reading is a more efficient information transfer mechanism. One can read at his own pace which can often be many times faster than speaking. Speedreaders sometimes read as fast as 3,000 words per minute. Even so, the English language is not very well constructed to maximize information transfer -- it is very redundant and often ambiguous.

One glance at a picture and your mind, through your eyes, will assimilate more information than can normally be transferred in several pages of English text. There can be a lot of information in a picture.-- and it can be transferred very rapidly.

When one realizes that in the television system we change the picture 30 times a second we have the capability to transfer information at a truly fantastic rate.

We, therefore, have the technical capability to educate at fantastic rates, provided we use the medium correctly. One channel devoted to instructional television can help solve the problem of getting formal education course exposure to the many persons and families who otherwise would not have the opportunity to gain such an education.

This channel should be programmed with a set of common denominator program courses such that the viewer could matriculate in college level education almost entirely via television. The homeviewer should be able to take all courses that would lead to a baccalaureate degree in, for example, liberal arts, or general education.

The typical degree work would require 120 credit hours; about 15 credit hours per semester. Thus an 18-hour daily schedule maintained from 6:00 a. m. until midnight would allow time for all the course work for all the courses for each of the four years to be presented twice per week. If the student missed the first presentation he could keep on schedule by viewing the second showing which would be programmed at a different hour the following

day. The summer months of May through September would be fully available for special or vocational instruction.

The third channel would be a full-time, 24-hour weather service. There is a need for good weather information to be available at all time, rather than just at the times the broadcast stations present their weather summaries. We, as individuals, cannot always program our time so that we are available to watch the local braodcaster or network weathercaster present his summary. We need a channel of this kind of service that would be available at any time we wanted to be brought up to date on the latest weather.

Everyone is always interested in the weather -- and as mobile as our people have become we find ourselves interested in the weather back home -- or the weather at the vacation spot we're going to next week -- and so forth.

We propse a professional group of meterologists that would put together a network quality weather summary, devoting about 10 to 15 minutes per time zone, thus covering the entire United States in an hour or less. The program would than be repeated and updated as necessary to keep the weather information as current as possible.

A centrally located service of this sort could use satellite weather pictures to best advantage. The weather stations across the nation also provide video radar data that could be used to better display local weather movements.

Commercial and private pilots have long had available to them a continual broadcast weather service, broadcast from several hundred stations throughout the country. The Environmental Sciences Service Administration (ESSA) has recently inaugurated a series of coastal VHF broadcast stations that repeat weather information for marine use. There is no reason that the general public should be denied a similar service that would be designed to meet the needs and interests of the general public. Commercial broadcast stations obviously cannot dedicate their channel to full-time weather such as this, but the excess capacity of the cable technology makes it entirely practicable and desirable.

A weather channel such as this would allow everyone to follow the important weather movements that affect large sectors of the country. In the winter time, the weather service could be augmented with special reports on skiing and snow condition reports at the nation's ski resorts. In the summer time, special advisories on beach and coastal weather would be required. Aviators and marine operators might even find themselves viewing such a channel for background information on weather movements prior to their departures.

The fourth channel would be made up of medical and health information of interest to the general public, and special programming for the medical and hospital professionals. It is becoming increasingly obvious that a serious doctor shortage is developing in this nation -- and there is no short term solution to this problem on the horizon. This creates the need for dissemination of health and medical information to the family unit. The more familiar the family unit is with proper medical care the less drain on the doctors time.

Part of the problem is the distribution of the doctors that are currently available. The Sunday, June 15 edition of the Baltimore Sun reported, for example, that in the inner city there is one doctor for every 6,600 people. The national average is critical enough -- and that is one doctor for every 1,000 persons. The lack of available professional medical personnel in such city core areas means interminable waiting periods in doctors' offices, and in hospital corridors. Discouraged by these obstacles to medical care the poor often do without. A national medical service channel could do much to lighten the doctors load by informing the family unit on how to best treat minor medical problems -- on how to distinguish between a minor or major medical problem and so forth.

On top of all of these demands on the doctors time, many states are now requiring the doctor to maintain continuing education credits in order to keep his license current. The problem is that most doctors work so hard during the day and night it is hard to schedule time for formal course work.

To make this continuing education chore somewhat easier, the doctors in the Washington, D. C. area, for example, are participating in an experiment designed to further their medical education with the least possible disruption. The local educational television station broadcasts instructional material in scrambled form during the late evening hours and the doctor's sets are equipped with an unscrambling device so they may view the program. But there are many problems associated with the scrambling process. Special sets are required to pickup the extremely low frequency heart sounds, for example. The excess capacity of the cable technology could do this job more easily and with existing receiving equipment since we could augment the video channel with high fidelity wideband FM for audio.

The cable technology has more time options available to it also and we are not constrained to broadcast only in the late evening hours. Many repeat plays could be made of each doctors or nurses instructional program to allow the individual to program his or her own time more conveniently.

The fifth channel is to be devoted to full-time coverage of congressional "Capitol Hill" activities. The basic ingredient to a well functioning democratic society is an informed electorate -- the people must know and have a right to know about all the congressional activities in which their elected representatives are involved. Complete and live coverage of congressional activities, important committee hearings and discussions should not be denied the voting public. Broadcast stations and networks must necessarily edit all congressional coverage to the constraints of their limited time news programs. A cable television channel completely dedicated to this kind of coverage can carry live and/or via tape replay all of the important congressional floor discussions and committee hearings. In this manner, the viewer becomes his own editor, and does not have to rely upon the network or the broadcast station to edit the material to what is usually on a capsule report of the event.

On some days when Congress is particularly active there may be as many as 10-15 concurrent committee hearings in process. To the extent feasible, such hearings should be made available to that part of the public that is directly involved in the legislation under consideration. For the most part, material of this kind would be of minority interest -- but the minority group affected by such legislative activities would find such proceedings of extremely high value -- the overall social and political value of such a public congressional coverage channel is obvious. The information disseminated would be an essential element of an informed and modern participatory democracy.

Besides the live coverage such a channel could devote much time to video tape replays of hearings and events that could not be covered live because of a more important event that was being presented live. Early morning and evening hours would be programmed with such material and even replays of some of the more important congressional activities. Such a channel would provide a nationwide forum for individual congressional discussion of critical legislation.

The costs of programming such a channel would not be as great as might be expected since the expensive element of editing content down to a few minutes of newscast time, as is done by the networks and the broadcasters would not be required. It would cost less to present much of this kind of material live. Even so considerable staff talent would be required to man the technical crews necessary to assure program viewability and interest. Additional video staff would be necessary to cover simultaneous events. A large reliance upon video tape and playback facilities would be in order. We estimate a hard core staff of about 80 technical persons would be required to maintain such a facility and to operate the camera taking and video playback facilities necessary to provide all day coverage every day.

The economics of such an undertaking are, nevertheless, within easy reach of the CATV industry when we relate the cost involved to the several million viewers that would be interested in subscribing to a new program package such as we are proposing.

The sixth channel of this package would consist of selected re-runs satisfactory to the owners of those programs. The newworks have produced a large quantity of non-mass-entertainment programming that is of very high quality and worthy of more than just one showing. This material could be made available through multiple exposure so that a wider audience could experience the stimulation of some of this programming.

We propose to replay much of this kind of material, if possible -- the white papers, the specials that address themselves to current events and so forth. There is much of this programming that does not get sufficient exposure, simply because it is not always available in time slots suitable for everyone.

The American Broadcasting Company did a masterful performance in its coverage of the Winter Olympics in Mexico City, but how much of that did each of us have an opportunity to view? Think how many more people could be accommodated, if all of that material could be made available for several repeat showings at different program times so that everyone would get more than one chance to view it.

One might think that the networks object to repeating programs more than once, but the precedent of syndication is already part of our system. Repeat showings of "McHales Navy," "I Love Lucy," etc. are commonplace.

I have never understood why some of the excellent documentaries that have been carefully prepared by the networks, which are highly informative and educational, are only shown once.

Broadcasters apparently conform to this type of program presentation because they are operating in a medium of scarcity. They have but one channel through which to funnel all of their program material -- each program must compete for a mass audience. In the event no mass audience is possible because of the time slot, minority interest programming is sometimes provided. The minority must view such programming at this time or not at all.

Cable technology does not have this limitation. It has excess channel capacity to offer. It would really be in the public interest to allow and coordinate rebroadcasts of all such material at several different times so that maximum exposure could be gained for some of the better cultural and documentary programs. In the event programming of this nature is unavailable, other types of

public service programs will undoubtedly be found.

I have outlined the details of an exclusive CATV service that would provide 6 channels of simultaneous programming. The interests that would be presented on these 6 channels would, in the aggregate, be of sufficient diversity and value that we believe the metropolitan television viewer would be prompted to buy the CATV service for the combined service of off-the-air local signals and the CATV 6 channel service.

To further the educational requirements of the nation, and to augment the programming of the educational television community, we would further propose that any non-commercial local educational channel would be able to use one or more of these program services at his option, paying the distribution and switching costs only to the nearest CATV outlet. Thus, a means is provided to get more of this valuable programming to more remote and rural areas of the country that are for the time being beyond the reach of economical CATV operation.

The program I have outlined offers the promise of fulfilling the Carnegie Commission's Report on Public Television. This proposal may not come into being precisely as I have proposed it, but there is no doubt in my mind that the accomplishment of its broad outline is inevitable.

G. NORMAN PENWELL

First, I want to talk about the programming costs to the CATV industry to produce this six-channel service. Illustration number 1 shows the six channels of service that Mr. Ford talked about.

As you will note in illustration number 1, three of these channels are to be programmed by agencies outside the CATV industry. It is proposed that CPB and NET, or a combination of these two agencies, with assistance from other foundations, make available the programming for the public channel and the instructional TV channel. The cost of producing the programming for the remaining three channels is the problem to which I will address myself.

The flagship operation, or program service center, would of necessity be located in Washington, D. C. The channel requiring the largest investment in staff and equipment is the full-time coverage of congressional activity.

To adequately cover these activities the minimum equipment needs would be one complete full-scale, mobile, color camera system, broadcast quality equipment. The primary mobile system would need a mimimum of three cameras for adequate coverage of live events. At least three additional single color camera systems with video tape recording equipment would be required to supplement the live coverage of Congress' activities.

Since there is so much activity to be covered, much of the program material would have to be video taped for later playback. The video recording equipment must be of standard broadcast quality -- that is, the 2" quad head, tape machines.

To fully implement this system, it is estimated that a full time staff of about 80 persons would be necessary. This would be the core staff that would also be used to support the programming activities of the other two channels of programming I will talk about later.

The estimated cost of the congressional coverage, staff, amortized equipment cost, and operating costs, including video tape and so forth, is about $2.2 million per year.

The 24 hour weather channel service will require, in addition, a staff of full time meteorologists, plus supporting technical personnel. The equipment requirements include additional broadcast quality video tape recorders since a considerable amount of this kind of programming may involve playback during periods of inactive weather movements.

Facsimile equipment will be needed to decode the satellite weather data. The U.S. Weather Bureau recently made available the cloud cover pictures transmitted by the weather satellites over the U.S. You have no doubt seen some of these fax pictures of cloud cover during some of the network or local weather newscasts.

These satellites are tracked at Wallops Station, Virginia; San Francisco, California; and Honolulu, Hawaii. The data is then piped over land lines to Suitland, Maryland where the information is put on tape. The taped reception is then played back into the forecast circuit and is made available to any user desiring the service at regularly scheduled times.

The latest satellites transmit pictures both day and night. In daytime operation, the satellite orbits the earth, special cameras take pictures of the cloud cover, sea, and land masses below. The pictures are then transmitted immediately to ground stations within acquisition range. During the nighttime hours, pictures are taken in total darkness by means of infrared sensing. The satellite senses this radiation with a lead selenide photoelectric cell and converts it to electrical signals which are transmitted immediately to ground stations within range. During each overhead pass of a weather watching satellite, a ground station can obtain two to four pictures, depending upon the satellite's

transmission characteristics and the tracking station's position relative to the satellite orbit plane.

Today there are three different sources for facsimile weather information: (1) The existing U.S. Weather Bureau land line networks, wherein three land line circuits are available with information on national network circuit weather, under 20,000 ft.; (2) The high altitude circuit weather, over 20,000 ft.; and, (3) The forecast circuit I mentioned earlier which relays pictures to Suitland, Maryland from Honolulu, Hawaii, San Francisco, and Washington.

In addition to this weather information, there are the APT satellites themselves. The APT system automatic picture transmission operates on the principle of electronic slow scan television and photographs from the orbiting weather satellite are to send to any ground station equipped to pick up and decode the picture information.

The Weather Bureau's national facsimile service network makes available a host of weather data including wind and pressure maps, snow and fog cover, ice cover on The Great Lakes, predictions of maximum wind and wind shear, and radar summaries.

Weather radar as displayed on a PPI scope is also now available from the Weather Bureau. Plans are to make available the radar data from each of about 30 stations across the country. The radar picture is taken off the PPI display, encoded into facsimile and is transmitted over land lines to anyone desiring the service. One picture every 90 seconds is available from each of the radar sites.

The CATV weather channel service would make use of all of these aids that are furnished by the U.S. Environmental Sciences Service Administration. The projected additional cost in producing the programming for this channel on a 24 hour basis, including personnel and the amortization of additional equipment required, is about $0.3 million.

The third channel of CATV programming that would require funding by the CATV industry is the network replay channel. This service would consist entirely of video tape recording of network programs so the staffing apart from network coordination administrative personnel, entirely a technical requirement. The estimated cost of this service for additional staff operating costs, largest single item of which is the cost of video tape, and for the amortization of equipment is estimated to be at $0.5 million annually.

The total costs then to the CATV industry for the six-channel service is approximately $3 million. (figure 2). This is the figure

that is going to be related to a per/subscriber cost projected to the case where we are able to serve several million subscribers through an interconnection. While this program cost may sound low, one must realize that none of these three services are of the type that require high production costs. They are of the type that take advantage of the cable technology's excess circuit capacity. Editing costs have been largely eliminated. The weather service will develop into a routine operation -- the network replays are entirely technical -- involving no production cost. Immediately one can arrive at some per/subscriber costs by taking the possibility of interconnecting our 3.6 M subscribers. The program cost would then be less than $1 per year each; or 7¢ a month per subscriber. If we begin talking about interconnection of 10 million subscribers, the costs are a third of this. What subscriber would not be willing to pay a few additional cents per month for a six-channel service such as this?

And these costs may be subject to some adjustment downward because of the availability of additional interconnect time for other services. The service we are proposing is an interconnect of six channels -- all channels would be leased from the interconnect service for full 24 hour day availability...yet not all six channels are to be programmed for a full 24 hour day.

The weather channel is a full 24 hour channel so there is no further channel time available there. The Corporation for Public Broadcasting channel would be programmed from 7 a.m. EST until midnight PST, thus making available four hours of six MHz channel time in each 24 hour period. The remaining channels would be programmed from 6 a.m. EST until midnight PST, thus releasing three hours daily per channel, or an additional 12 channel hours. Thus a total of 16 hours of six MHz channel time would be available in each 24 hour period.

One of the best uses of this channel availability would be to make it available for alpha numeric distribution to the home of published material such as newspapers, magazines, books, and so forth. Our CATV system concept is not so well adapted for household to household interconnect, but is extremely well adapted for distribution from one central source to all homes -- this is in other words a multiple address system. This additional channel availability could be used to distribute to the home, all kinds of daily newspapers, The New York Times, Washington Post, St. Louis Post Dispatch, Christian Science Monitor, and so forth. These newspapers, and much more, could be made available to all homes in the system every day.

Dr. Licklider, formerly of Harvard and MIT, writing for the Carnegie Commission report, calculated the standard newspaper column

of text contains about 4,000 characters. Thus one television channel could carry the alpha numeric contents of a 30-page newspaper every second.

As a matter of record, if one estimate is even approximately correct, one television channel could carry on a continuing basis, as it is published, every bit of text that is published in all newspapers, magazines, journals, or books that find their way into any recognized library or document room in the world. This was an estimate made by J. W. Sender and reported in Science, Volume 141, 1963, that all of this published material was generated at the rate of about 2 million bits per second.

To quote Dr. Licklider: "Evidently, if we limit the discourse to alphanumeric text, it is not lack of bandwidth that stands in the way of offering the world's fund of news and knowledge to every man in his own home!"

It is true that we do not have today a low cost terminal device for the home that would select and store the newspaper or other magazine data that we might have available in this manner, but a nationwide interconnect serving several million subscribers would be more than enough stimulus for the entrepreneurs to invest their money in design and production of homeowner devices to do just this.

Subscription to your own interests in newspapers, magazines, journals and books, would mean lowered cost for operation of the system which could be used to reduce interconnection costs or to provide more sophisticated programming.

Next we come to the cost of interconnecting and the options that are available to us for this purpose.

Let us look first at the population or television homes that could reasonably be interconnected by 1975 if the programming sources and the distribution system were made available.

We have been working with the National Bureau of Standards of Boulder, Colorado in developing some statistics on where the people of the United States are located. The Bureau has the basic data of the 1960 census in their computer and the machines have been programmed to give us the relationship of population with reference to each of 253 television market city centers. These data tell us how many people are within five miles of the city center (Post Office coordinates), how many are within ten miles, 15 miles, and so forth out to a distance of 70 miles from each of these market cities.

So, now we have a good grasp of how people are concentrated around television markets, but the data is for 1960. To bring this data into focus for 1975 we have gone to the Stanford Research Institute

to give us the population growth factors for each of these areas. Applying these individual growth factors for each of these markets has now given us the basic data to construct the potential television homes for 1975.

Illustration number 3 indicates how the population is accrued as we add markets, until we get to the total of some 334 television market cities which now includes separately the cities of the hyphenated markets.

If we look at the people within 35 miles of the city center, the top 120 markets put us in front of about 50 million homes; by the time we have added the population for all of the market cities we are in front of about 60 million homes. Note that we are in front of about 50% of the 35 mile zone population by the time we have added the population of the top 30 markets.

The next illustration (number 4) indicates how a typical large market city would look. There is the city core area that would in most cases be circumscribed by a 20 mile radius circle. The other circle is at 35 miles. Most large markets have suburbs on the periphery of the more dense city core area.

A CATV system would probably not cover from a single hub all of the area within the 35 mile circle; but it could be expected to develop a single system within the inner city core area which in most cases would not be nearly as large as the 20 mile radius indicated here. A 10 mile radius would circumscribe the core area of cities like Baltimore and Washington, for example. So, the logical extension of the system to the 35 mile zone areas would be to use short hop microwave, or perhaps the AML system when it becomes available to serve the many smaller suburban locations on the periphery of the big cities. But the point is that the population within the 35 mile radius has a pretty good likelihood of becoming CATV potential homes.

The next illustration (number 5) indicates how the population is distributed with respect to the city centers when we aggregate all of the television markets above. Note that within 10 miles of the city centers we can be in front of 30 million homes (100% curve). As we increase the radius we can reduce the penetration and still maintain the 30 million subscribers. If penetration is as low as 40%, however, it is going to be difficult to reach 30 million subscribers. For the 35 mile radiums and assuming 60% penetration we would be at approximately 30 million subscribers. In other words, if we served 60% of the population within 35 miles of the city centers of the 334 market cities we would be serving 30 million subscribers. For purposes of discussing interconnection we are going to use the figure 30 million as a reasonable CATV potential that could be served.

The first option open to us is a terrestrial interconnection provided entirely, or at least to the extent possible, by the existing carriers -- that would be primarily AT&T.

Illustration number 6 shows the AT&T and other carrier interconnect to the existing television broadcast stations. AT&T by itself does not at this time serve all of these CATV and television markets. But if we were to use the existing AT&T service this would amount to 16,400 miles of six channel service. To this we would have to add 8,700 miles of other common carrier mileage -- and in addition to this another 900 miles of new service would have to be installed. This all adds up to about 26,000 miles of interconnect required to serve the roughly 600 million homes we have been talking about. At present AT&T tariffs for video and audio lines, the cost for the six channel service would approximate $126.5 million per year. For the 60% CATV penetration figure we have been using this amounts to $4.20 per subscriber per year, or 35¢ a month for the interconnect.

But there are more economical ways in which to interconnect. Let us use AT&T as the backbone trunk system that would serve several service centers throughout the U.S. and then let us use CATV and other private microwave service from these service centers to the individual CATV headends.

As you can see in illustration number 7, there is considerable circuit mileage already available and serving CATV. The big advantage of using this service is that while it may not be satisfactory for a nationwide trunkline system it is certainly satisfactory for short distances involving three or four hops. And the tariffs that are filed for CATV service are considerably lower than the AT&T tariffs.

If we strategically locate 36 service centers about the country it turns out that we can build in front of the 60 million homes by connecting markets within 100 miles of each service center. The average microwave hop is about 25 miles, so a 100 mile extension at the most would involve four hops of CATV microwave.

The resulting distribution is shown in illustration number 8. We use AT&T trunking from Washington, D. C. to each of the 36 service centers, and we use CATV and other private microwave from the service centers to each market city or suburb.

The cost of the CATV microwave begins at about $30 per mile per month per channel, but as we add channels to the system, the overall cost comes down to about $10 per circuit mile per month per channel. This is considerable savings over the AT&T tariff.

This distribution system would now require 8,000 miles of AT&T trunking which would cost about $49 million per year for six channels plus some 20,000 miles of CATV microwave service which would cost about $14.4 million per year for six channels.

The combined cost, then for this mixed terrestrial system is about $63.3 million per year for the full six channel service System No. 2 has reduced the interconnection cost by 50%. For the 60% penetration figure we have been using, the subscriber cost is now $2.10 per year, or 17.6¢ per month.

This is about the best figure we can get if we interconnect terrestrially. What we are going to propose is that we use the satellite service to interconnect the 36 service centers rather than use the AT&T service, which will result in even lower interconnection costs (figure 9).

CATV 6-CHANNEL COLOR TELEVISION SERVICE

1.) Corporation For Public Broadcasting; Cultural, Public
2.) Issues, Drama, Music, Educational And Instructional Television Programming.

3. 24-Hour Weather Coverage By Professional Meteorologists For Entire U.S. Continuously Updated And Repeated.

4. Medical And Health Program For General Public And Continuing Education Courses For Doctors and Nurses.

5. Full-time Live Congressional Coverage Augmented With Video-tape Playback Of Congressional Proceedings.

6. Selected Network Replays, News, Public Discussion, White Papers, Minority Interest Drama and Music.

Figure 1

PROGRAMMING COSTS

Channels	Annual Cost (Millions)
1 -) CPB & NET To Provide) Programming; CATV Industry 2 -) To Provide The Interconnect	$ -0-
3 - Weather	0.3
4 - Medical & Health; HEW To Provide Programs; CATV To Provide Interconnect	-0-
5 - Congressional Coverage; Basic Headquarters Staff of 80 Persons	2.2
6 - Network Replays	0.5

Figure 2

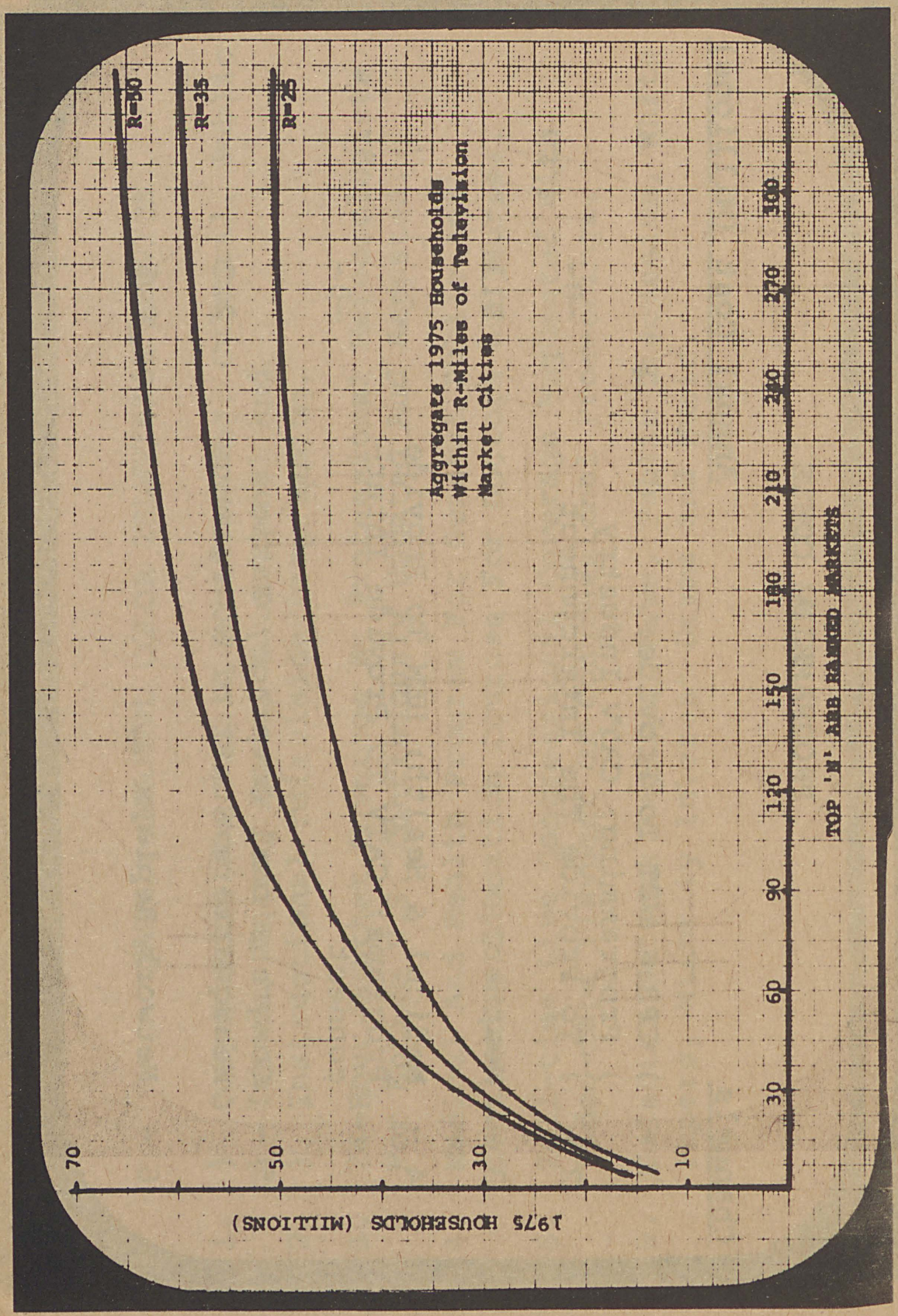

R=50
R=35
R=25
Aggregate 1975 Households
Within R-Miles of Television
Market Cities
1975 HOUSEHOLDS (MILLIONS)
70
50
30
10
30
60
90
120
150
180
210
240
270
300
TOP 'N' ARB RANKED MARKETS

Figure 3

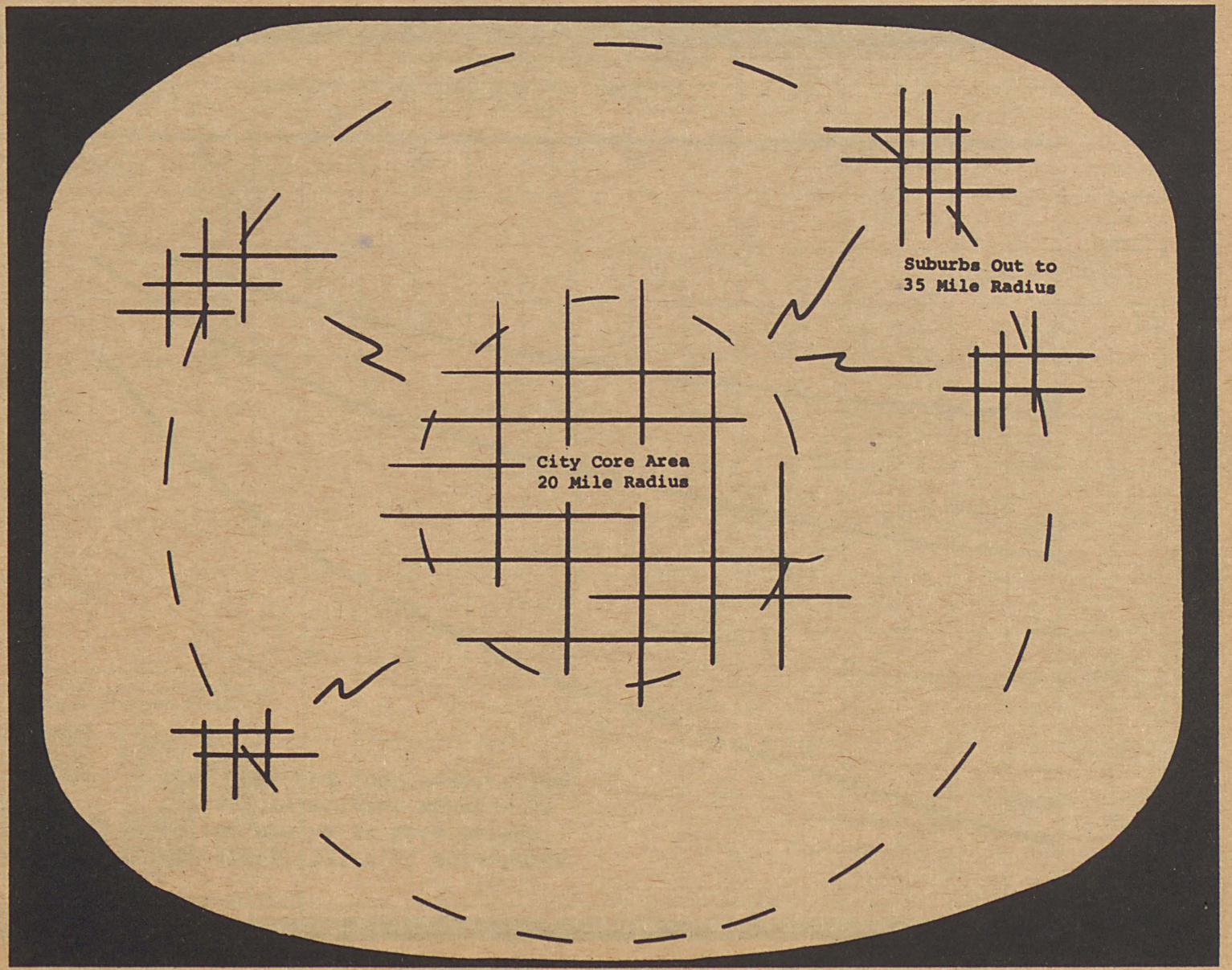


Figure 4

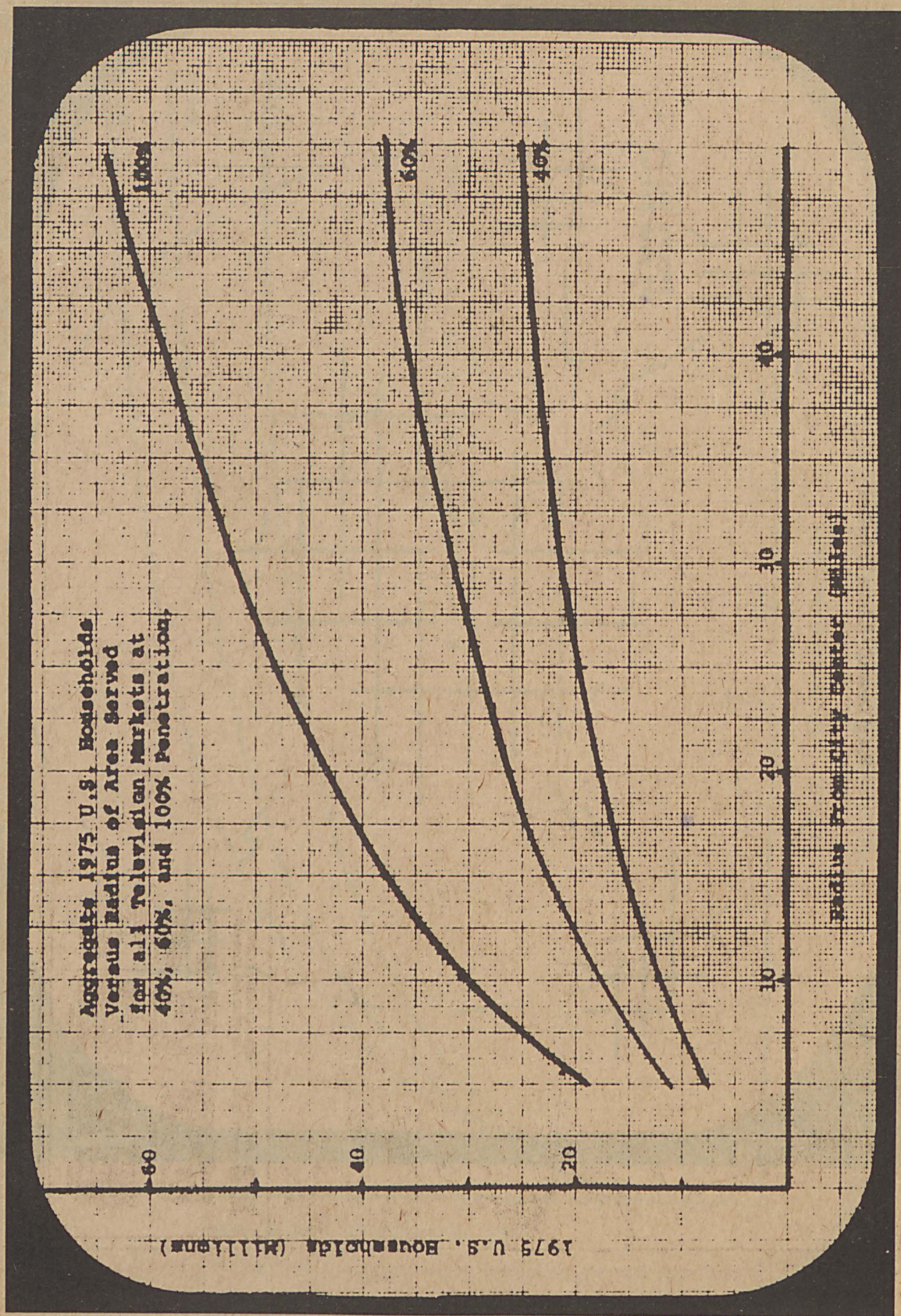

Aggregate 1975 U.S. Households
Versus Radius of Area Served
for all Television Markets at
40%, 60%, and 100% Penetration
100%
60%
40%
60
40
20
1979 U.S. Households (Millions)
10
20
40
Radius from City Center (Miles)

Figure 5

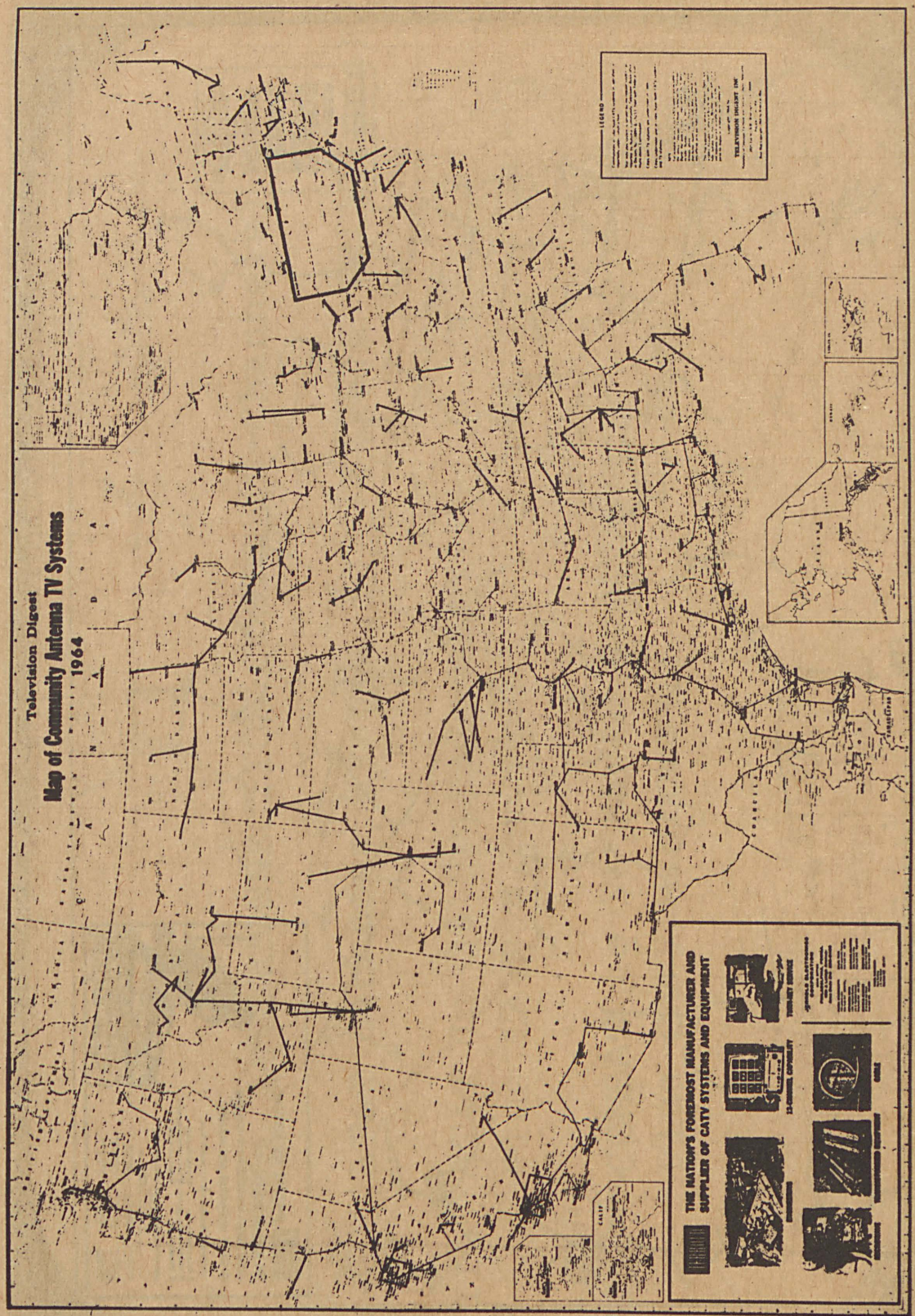

Television Digest
Map of Community Antenna TV Systems
1964
THE NATION'S FOREMOST MANUFACTURER AND SUPPLIER OF CATV SYSTEMS AND EQUIPMENT

Figure 6

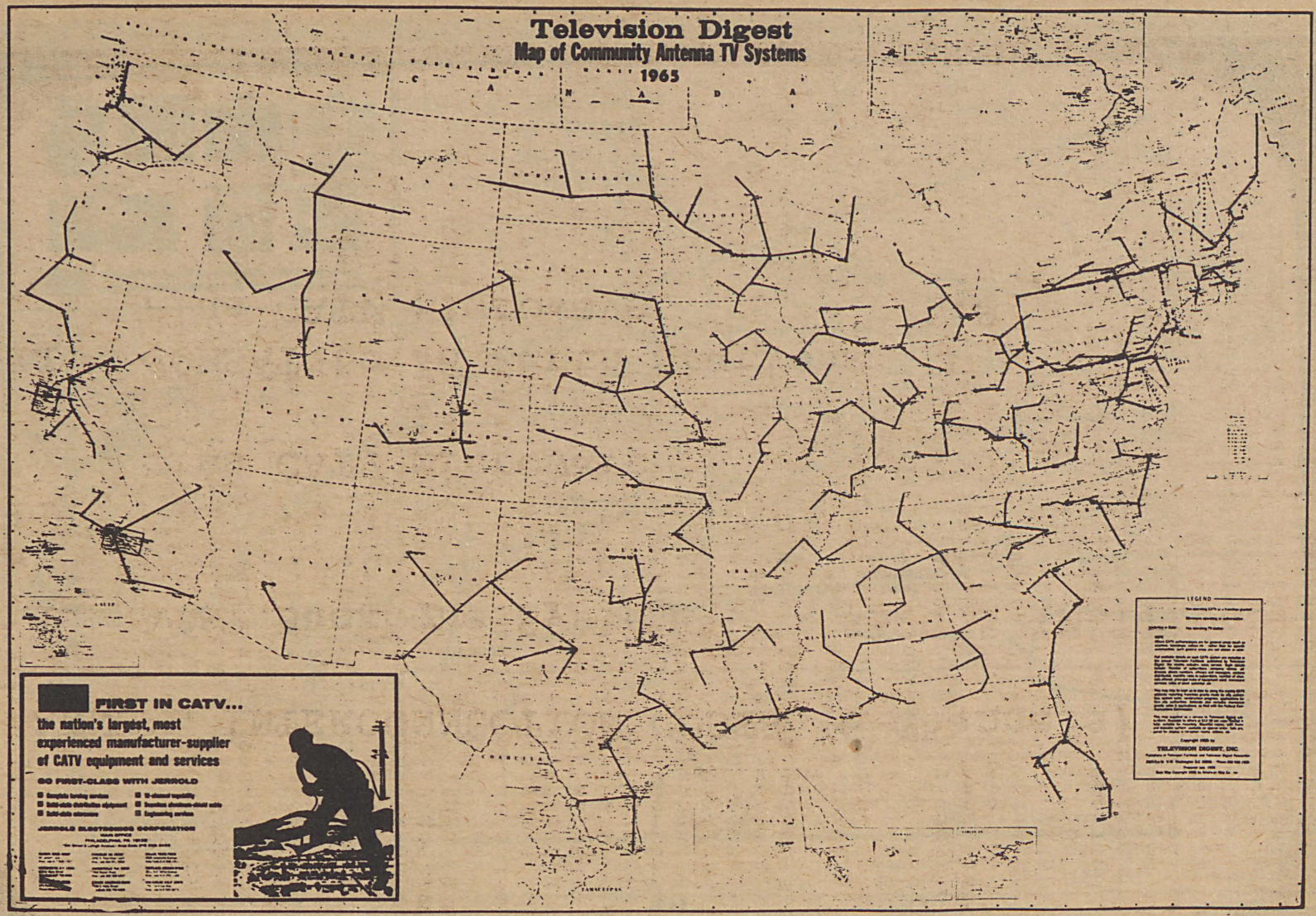

Television Digest
Map of Community Antenna TV Systems
1965
C A N A D A
LEGEND
TELEVISION DIGEST, INC.
FIRST IN CATV...
the nation's largest, most experienced manufacturer-supplier of CATV equipment and services
GO FIRST-CLASS WITH JERROLD
JERROLD ELECTRONICS CORPORATION

Figure 7

ANNUAL INTERCONNECTION COSTS (6-Channels)

I.	AT&T Backbone System	$126.5 (Millions)
II.	AT&T To 36 Service-centers; Plus CATV Microwave	63.3
III.	COMSAT to 36 Earth Stations; Plus CATV Microwave	25.8

Figure 8

COST PER SUBSCRIBER
(30 Million Homes)

	Annual	Monthly
Program Costs	$ 0.10	$ 0.0084
Interconnection	0.86	0.072
TOTAL COST FOR 6-CHANNEL SERVICE	0.96	0.08

Figure 9

LOUIS B. EARLY

We share in many ways a common bond, and that is part in the remarkable growth in communications.

In the last 20 years, your industry has experienced phenomenal growth. From a handful of subscribers receiving what was then called "Community Antenna" television you can now point to more than 2,000 cable systems serving more than 3 and one-half million households all across the country.

Let me take a few minutes to establish our credentials. We are proud of our contribution in the field of international communications. I am convinced that when you have reviewed the impact of communications satellites, you, too, will be as enthused as we are about the potential of satellites for our domestic communications needs.

CATV is only one group who stands to benefit, but your significance cannot be overlooked. You offer the American public a service which is needed, desired, and that cannot be provided in any other way.

We hope to be a party to this plan of yours. You have the potential of creating one of our largest demands for service. We in turn offer you a system for interconnection that cannot be equalled.

Although we started at a different point, and at a different time, we in the satellite business also have experienced substantial growth. Seven years ago, COMSAT didn't exist. We began as a corporation in 1963 in a rented Washington mansion with little staff, little money, but big expectations. Our task was unprecedented in communications history -- to establish a global system of satellite communications open to all nations without discrimination.

Just four years ago this month, after some successful testing and lots of watchful waiting, the first communications satellite went into commercial service. The satellite was Early Bird, weighing 85 pounds in synchronous orbit.

The precise date of commercial service linking North America and Europe was June 28, 1965. Our first major asset was 22,300 miles above the equator over the mid-Atlantic. Service started with 66 circuits and occasional television transmissions. That was the beginning.

Today, in marked contrast, advanced INTELSAT III Series satellites ring our world. When an Indian Ocean Satellite begins operations

next month, the original goal of a truly global system will become an operational reality. Each of these INTELSAT III Satellites weighs 332 pounds in orbit, has more than three times the design lifetime of Early Bird, and approximately five times the capacity.

The equivalent of more than 1,000 full-time circuits are now being leased; television usage of satellites for international programming has tripled each year since Early Bird, from 80 hours in 1966 to 220 hours in 1967, to 660 hours last year.

We believe that the day is soon at hand when the majority of the world's long-haul communications will be via the commercial satellite system.

The business of satellite communications is viewed by some as an exotic industry, a grand experiment to harvest the resources of space for the service of man, an event of the timeless future. But this ignores the record.

It should be emphasized that we are speaking of a commercially viable, operating system -- now. Satellites are not technological toys. They are a dependable means of communications with a versatility unmatched by present conventional communications systems.

For example, Early Bird, which had a design lifetime of 18 months, was in full-time commercial operation -- without a single major outage -- at the time we turned it off in January of this year.

It is still in orbit and still capable of functioning after 3 and one-half years. The reliability of the INTELSAT III Satellite which replaced it over the Atlantic has been 99.85 percent since it went into commercial use on Christmas Eve of last year.

Equally remarkable progress has been made in the development of the system on the ground. In 1965 five earth stations were in operation for communications via satellite. Four were in Europe: in England, France, Italy and West Germany; one in the United States was at Andover, Maine.

Today some 25 earth stations are in operation around the world. Let me just run through a few of them: Australia, Brazil, Canada, Chile, France, Germany, Italy, Japan, Mexico, Panama, the Philippines, Spain, Thailand, United Kingdom, United States. And this is by no means a complete list, as that is only but a few of the 25.

There are six stations now in commercial operation in the United States. We have one in Maine, West Virginia, Puerto Rico, Washington State, California, and Hawaii. We have been authorized

to construct a new station in Alaska, and we have pending before the Federal Communications Commission an application to build a permanent station on Guam.

Early next month five new antennas will begin service through the INTELSAT III Satellite stationed over the Indian Ocean. They include Bahrain, Japan, Kuwait, Indonesia, and a second antenna in England.

This ground network is expanding at an impressive rate. More than 40 stations are expected to be on the air by the end of this year. By the end of next year, close to 70 earth stations will be located around the world, on every continent, linking the major population centers of the world.

A satellite can receive and transmit all forms of high-quality communications -- voice, pictures, data, or television. An earth station is a doorway to this global system.

Unlike conventional point-to-point communications, any station in the satellite system can talk to any other, or to many other stations at the same time.

Thus, it is a long haul, multiple-point communications net of extreme versatility and high capacity. A country with an earth station has direct access to the mainstream of international commerce and news.

The superb scenes of the recent Apollo Moon Missions, for example, were seen "Live and in Color," as broadcasters say, via satellite in Chile, Brazil, Mexico, Puerto Rico, and more than 20 countries in Europe; at the same time they were witnessed by television viewers in the United States. They were sent simultaneously via satellites as well to viewers in Hawaii, Australia and Japan.

As a matter of interest, it took three satellites to do all that communication, with numerous substations.

Within the last few years, a telegram or telephone call between Rio De Janeiro and Santiago in Latin America often was routed through New York City. Today Brazil and Chile have earth stations and direct access through the Atlantic satellite to each other, or to the United States, or Europe, or anywhere in the Atlantic area where other stations are located.

Sumarizing, we have progressed from the INTELSAT I, or Early Bird Satellite, launched in 1965; through the INTELSAT Series Satellites launched in 1967 (one over the Atlantic and two over the Pacific); to a design lifetime in orbit now of five years for the INTELSAT III.

The capacity of the satellites has progressively increased from 240 circuits to approximately 1,200 circuits. The next generation of satellites, the giant INTELSAT Series, will have a design lifetime of seven years and a capacity of from 3,000 to 10,000 circuits, depending upon the antenna configuration.

These satellites are now being procured and are scheduled for launch in 1971.

Technological progress in this field has been awesomely rapid. However, it is sometimes more difficult to adjust to the social implications of such a technology that arrives as a brash intruder on the status quo.

But in our brief history, many social, economic and political adjustments have been made.

As most of you know, COMSAT is a unique, private American Corporation. I believe both of those words are important, "unique and private." Our basic charter is the Communications Satellite Act of 1962, passed by Congress after considerable debate and discussion and signed by President Kennedy. That Act established a corporation that really has a dual role.

Domestically, COMSAT is a private U.S. Corporation, created for profit, owned by stockholders, authorized by Congress as the U.S. Communications Satellite Carrier Company, and subject to regulation by the Federal Communications Commission. I am sure you all know what that means.

On the international front, COMSAT pioneered in the establishment of a worldwide joint venture, and I believe it was a unique venture in its whole concept. The organization that has evolved is called the International Telecommunications Satellite Consortium (INTELSAT), a working partnership that now embraces 68 nations of the world.

INTELSAT owns the satellites in the system, with each nation sharing in the cost and the revenues from the space portion of the system in proportion to ownership. COMSAT represents the United States in INTELSAT and acts as manager for the Consortium.

The words "Live Via Satellite" have become relatively commonplace to many homeviewers of television. But behind those three words is a dramatic economic story. As capacity in the satellite system has gone up, costs have come down significantly.

Since 1965 COMSAT has reduced its TV rates in the Atlantic three times and in the Pacific twice. There used to be extra charges

for color transmissions during so-called peak hours. These have been completely eliminated.

Let me give you just a couple examples. During "Early Bird," our rate for colored television between the United States and Europe, from an Earth Station to a satellite -- or half channel was $4,500 for ten minutes during the peak period.

Today that same broadcast in color at any hour is $650 for the first ten minutes, approximately one-seventh of the original rate.

In the Pacific, between the United States and Japan, for example, the COMSAT charge for a color TV program used to be $1,500 for the first ten minutes in 1967 when commercial satellites first began service in the Pacific. Today it is $725, less than one-half the rate of two years ago.

Other rates have also been reduced substantially, though not as dramatically as TV rates. For example, in 1965 a private line voice half circuit to Paris was $10,000 per month in the tariff of all international carriers.

COMSAT filed on June 27, 1965 a $4,200 rate for its portion of this service. As a result, in 1966 the carriers reduced their rates from $10,000 to $8,000. In 1967 COMSAT reduced its rates to $3,800, Again, the carriers reduced to $6,500 and in 1968 to $6,000.

These rate reductions must be attributed to the introduction of reliable and economical communications satellites. COMSAT's publicly filed rates represent charges that we make to appropriate U. S. International Communications carrier companies.

These companies, in turn, provide service directly to the broadcasters and other users. We have been told many times that we are living precariously in the Atomic Age, Space Age.

We emphatically are living in a time when the storehouses of information and knowledge are growing at an almost revolutionary pace.

It has been estimated that a new report on medicine, biology and electronics is published somewhere in the world every five minutes; a report on physics, every three minutes.

Less than four years ago, heart transplants were being discussed in medical journals as a curious possibility; today, more than 100 have been performed and wholesale transplants of human organs seems possible.

Less than eight years ago, no man had orbited the earth. Now, he has flown to the moon and back, and if all goes well next month, he expects to stand on the lunar surface.

This history-making space event may be seen in this country by millions on television, and relayed simultaneously abroad by INTELSAT Satellites to millions of more people around the world.

It is the job of communications to make available the means of exchanging this knowledge, of seeing and making possible an understanding of contemporary events. Satellite communications have a significant role in this process.

Through the inherent flexibility of the system, and wideband capacity for all types of information, it offers tremendous benefits on an attractive economic scale.

Already, television programs have flashed around the world; one broadcast was seen by an estimated thirty million people. Satellite TV offers great potential for closed-circuit medical diagnosis, or instructional programs for schools and institutions.

At the same time satellites can handle telephone calls, telegrams, facsimile, high-speed data and other high-quality commercial communications.

New Communications uses are emerging that were not considered possible or pratical before. In one actual test, computers in the United States were linked via satellite with computers in France.

They talked business at the rate of 50,000 words per minute. Information that would have normally taken eight hours to exchange by conventional means was transmitted via satellite in less than thirty minutes.

Computer storage and retrieval centers can now be linked by high capacity satellite channels, making the libraries of one country instantly available at the push of a button to scholars and scientists in other countries.

Satellites are not limited simply to communications. Soon they will be used for commercial aeronautical and maritime services. Their ability for certain broadcasting tasks and exploitation of the earth resources is assured.

And a sidelight here; recently the National Academy of Science has introduced a study* of the application of satellites for broadcasting. I highly recommend it to you for reading.

The spectacular capabilities of this new communications means is not limited merely to international services either. There is no technological uncertainty or barrier to using satellite communications for domestic or national communications needs.

We have been actively studying the matter of providing satellite services to meet domestic U. S. needs since 1965. We have submitted a detailed economic and technical plan to the Federal Communications Commission. Our request has been pending before the FCC for more than three years.

But it is only a matter of time until the unique capabilities and economic benefits of satellites will become available to the American public for their domestic needs. Mr. Briskman will describe a plan for this service to you.

I believe it sufficient to say that satellites will bring to the American public and CATV, as one potential significant user, a capability which will have a profound impact. It is an opportunity we cannot afford to miss. The potential for economic interconnection of CATV systems will open many new areas of service to you -- the American businessman.

* "Useful Application of Earth-Oriented Satellites," BROADCAST, Prepared by Panel 10 of the Summer Study on Space Applications.

ROBERT D. BRISKMAN

As you know, various proposals for domestic satellite systems have been advanced. Such a system would appear to have significance to CATV in the future, as mentioned by Mr. Ford and Mr. Penwell.

My presentation will be in three parts:

The first part will be a generalized description of the purposes, structure and history of domestic communication satellite systems; the second part will deal with specific proposals for a United States domestic satellite communications system and its applicability and use by CATV; and, the last part will present an illustrative example of CATV use of a domestic satellite system, identifying the more pertinent technical and economic aspects.

Communications satellites used for international purposes have been employed for many years. The use of such satellites for domestic communication is not new and, in fact, one domestic system is currently in operation. This is the USSR system called ORBITA, and it distributes telephone, television and facsimile throughout the USSR. Canada is also currently developing a domestic

satellite system which they would hope to deploy by 1972. Additionally, several other regions are considering such systems.

Essentially, satellites are another media of communications, the other pertinent ones being microwave radio relay and wide-band coaxial cable. Each of these media has its own advantages and disadvantages; consequently, the use of satellites will probably turn out to be complementary to microwave radio relay and coaxial cable. In other words, one will take the best media to do the particular job, considering the economic and technical advantages and disadvantages of both.

Well, what are the advantages of satellites? There are two unique ones. The first one is what I call relay capability (Figure 1). The satellite transmission goes directly from its origination point to its intended reception point passing through essentially a single microwave radio repeater (which happens to be in the satellite). Conversely, if you go terrestrially from New York to Los Angeles, you will go through over a hundred microwave radio repeaters. Also, of course, this satellite relay capability is particularly useful when you are confronted with terrain as difficult or inhospitible as in Alaska or in the Rocky Mountain states.

The other unique satellite advantage which is very important is called multi-point capability (Figure 2). This capability allows one to make available the same signal, such as the television picture, to all the users in the satellite coverage area simultaneously. Figure 2 is trying to depict graphically that the beam radiated from the satellite is covering the United States. The earth station near Los Angeles is transmitting the up-link television signal. The satellite retransmits it so that every one of those little stations all over the United States can pick up that same signal simultaneously. This is a unique capability of satellites.

I will now switch briefly to a slightly different subject. Figure 3 is a capsulated history of proposals to create such a domestic satellite system in the United States. In the course of these proceedings, various plans were filed with the Federal Communications Commission (FCC). I will be primarily describing only the Comsat Proposals, but all of this information is on public record and is available to any of you.

I would now like to go to part two of my presentation and talk about specific proposals by Comsat for a domestic satellite system.

There are two important technical principles underlying all of our proposals. One is our multi-service approach, and the second is meeting growth requirements by improved technology. As far as our multi-service approach is concerned, what I mean is providing through one satellite system, television, telephony computer data and a whole range of communication services.

Now why do we want to do this? There are three basic reasons. A significant one is avoiding duplication of facilities and duplication of things like R and D, launch costs, etc. Secondly, this allows all users to benefit by economies of scale. I think this concept is pretty well-known in the communications industry. Thirdly, this approach is favorable with regard to certain technical aspects of orbital and ground interference which I will touch upon a little bit later.

The second point was meeting growth in requirements by improved technology. We accomplish this by replacing earlier less capable satellites with satellites of greater capability. This ability to improve technology in the future will provide a decline of cost with time.

With any communications system, one has to start with requirements (Figure 4). This is an estimate of requirements that was generated a few years ago. Cross hatch bars are television channels and the darker ones are message channels. A very large growth is predicted between 1970 and 1980 in both television and message. The televison channels (in 1970 there were approximately 30 of them projected) are those whose requirements would be met by satellite facilities. CATV channels are included in these estimates as are channels for various other commercial and non-commercial uses of TV channels.

The basic system we are talking about is very simple. The first chart (Figure 5) shows how the system is used for telephony and record communications. The upper portion of the chart shows what is called trunk message where the communications go between two regional centers. These are centers in the United States where large volumes of communications are available for trunking via the satellite. The lower portion of the chart shows a multipoint arrangement for traffic which ties into the various nodes of the communication system. Figure 6 is more applicable, of course, to broadcast services and this shows television and radio distribution. Essentially it shows a lot of earth stations tied to users. The users are the square boxes with R's in them or O's in them. The R's meaning users who want to receive transmissions, and the O's being those who originate. The chart tries to show that any number of originators or receive users may be connected to one earth station. The linkage is from an originator user to an earth station then to a satellite, back from the satellite to all the other earth stations, and from them to the receiving users in R. This implies that the earth stations are connected to the users with some other form of communication, and I will discuss this, of course, later.

An important item is that both of these basic services (telephony and television) are provided for in the same satellites, in many cases to the same earth stations, and this helps the economy by

keeping down duplication. Secondly, each earth station serves several users and, therefore, the cost of the earth station to a single user is essentially prorated.

To meet the requirements that were projected, we postulated three categories of satellites (Figure 7) with time; the first one called the 1970 model, the second being the 1973 model, and the last being the 1978 model. The chart shows the progressive increases in satellite capability with time for both television and message. It shows an improvement in lifetime capability as well. The important thing is that we are inputting new technology, replacing the older satellites with improved ones which will give us a decline in the cost if the requirements for service grow as predicted. Later satellites make use of some new techniques which we are now experimenting with, higher frequencies and several other things that are being brought along.

I would like to mention that for the rest of my presentation--after the next illustration--I will talk only about the 1970 satellite. This is a satellite where the technology is here--here right now--today. And I will not talk about the 1973 or 1978 except to indicate they are in the cards if there is a viable growing program. Just to look into the wild blue yonder, Figure 8 shows the advanced 1978 satellite. It has capabilities for 24 television channels and about 60,000 telephony channels. It also has beams that are going directly to points of very high communications density. This will provide about 75,000 more telephony channels.

Earlier I mentioned a cost decline with time (Figure 9). This is shown hypothetically with time on the horizontal axis. What is shown is the relative projected decline in cost, using the 1970 model satellite system as a basis. As later satellites are implemented, you can see the progressive decline in costs with time. You see that, in a span of about ten years, you have annual costs per circuit going down to under one-half of what you started off with. You will see cost estimates of what one would start off with later in my speech.

I would like to concentrate now on this 1970 model satellite. We would like to show you what we would envision a satellite system would resemble in the mid'70s (Figure 10). We would actually be providing more television channels than are shown on this illustration and less message channels. However, these are completely interchangeable as I will mention later, and the division here is only illustrative. If solely used for TV, this complex could provide over 40 television channels. In fact, by 1975, the larger, more capable satellites would probably be employed if the initial program were started this year. This would increase the

capabilities beyond those shown and reduce the costs per channel.

The system shown has 158 small receiving stations, eight big sending and receiving stations, and twelve medium size ones. There is quite an earth station complex distributed throughout the country. One cannot build such a complex instantaneously. It would take a few years. Comsat has proposed to start with a first-phase implementation, or Pilot Program (Figure 11). The first-phase implementation concentrated on the western time zones and would involve about 30 small size earth stations in the Pacific and Mountain Time Zones and four large or medium size earth stations on the East and West coasts. There are three objectives of the Pilot Program. One is operational to show that the commercial objectives can be achieved. The second is to demonstrate new potential services and various uses, including operational alternatives. The third is to get experimental data from which you can improve your future system designs.

I would like to discuss some of the facilities very briefly. This is the building block approach mentioned earlier (Figure 12). The capability of this satellite is completely interchangeable between earth stations and the three types of services. In other words, you can have 12 television channels to small earth stations, or 7,400 multi-point message channels to the medium size stations, or 21,000 point-to-point message channels to the large earth stations. Since you can have various combinations of these, it is an extremely flexible system and can respond to the demands of the services. This is important, since one does not really know currently how these demands will come out quantitatively, and the point is that this system has the flexibility to respond to whatever the demands would turn out to be in the future.

The details of the satellite are given in Figure 13 - Note that it is kept in position in a stationary orbit with great precision which allows the use of very simple earth station antennas. Another point is that the satellite puts out tremendous amounts of power as compared to the present international satellites. Essentially, the satellite puts out a little less than 10,000 watts of radiated power. Figure 14 is an analogous illustration which shows the details of the earth stations. I will cover specific earth station details later on the CATV part of my presentation.

It is important to note that these are all small, simple stations and are not required to track the satellite like the present international earth stations. They have the ability to transmit with low-power transmitters. This makes it more feasible to operate without causing harmful interference to microwave radio relay.

I would like to concentrate the last part of my presentation on the possible use of such a multi-service domestic satellite system

by CATV. Please remember I am not in the CATV business so do not be too critical. The premise is, basically, that one or more television channels will be programmed by CATV for their use. These channels are assumed to originate from the East coast, West coast and in the central region.

We have performed an illustrative study which I will be discussing. The study is based on providing six television channels for CATV. We assumed the originating points are Los Angeles, Chicago and Washington, and we also assume the use of a mobile unit. A small change in these assumptions will not affect the conclusions of this study. The CATV distribution system is pictorally shown in Figure 15. It is worth following the distribution system in detail since this is, hopefully, the heart of your interest.

Essentially, there would be program pick-up points (remotes) which relay transmissions to the CATV television studio (which would also originate transmissions). The studio is connected by microwave radio relay to an earth station which will transmit these television channels up to the satellite. Now, as I've mentioned earlier, the satellite re-radiates these channels all over the United States and, we would expect, to over a hundred earth stations. However, there are at least 36 earth stations of more direct interest to you. These particular earth stations would each receive these particular channels and would provide them via microwave to CATV head ends. Of course, the CATV head ends would deliver these television channels to their subscribers using your normal techniques.

To be more specific, a very detailed analysis was performed on potential CATV requirements in 1975 and an illustrative system was derived. This analysis assumed that the CATV head ends to be served could be generally no further than about a hundred miles from an earth station. With this assumption, the use of relatively inexpensive microwave radio relay between the earth station and head end would be feasible without excessive degradation of the signal.

Figure 16 shows the results of the analysis of service requirements. The circles represent 36 service areas, with the small dots in them depicting some of the larger ARB television markets. Now the circles were arrived at by attempting to maximize the number of TV markets, in order of importance, to which CATV services could be potentially provided. The analysis was done for 1975. Now, to illustrate how well or badly we did, the 36 circles cover 96 of the top 100 ARB (American Research Bureau) markets; 180 of the total 256 ARB markets and 252 of the 334 towns and cities that are listed within those markets. We have the details here of how we arrived at this; however, the most significant point is the number of potential subscribers within these circles (Figure 17).

We have made an assumption in the analysis and in Figure 17 that a household is equivalent to a subscriber, so I am going to talk about households. Please interpret it as a subscriber. The potential for the 36 service areas is 61 million households which is 88% of the total households in the United States as projected for 1975. This means an average of 1.7 million households could be served by each earth station. To be more precise, there are 53 million households that are also within 35 miles of ARB markets. This numbers of households comprises 77 percent of the total U. S. households. We would like you to look at these numbers carefully, because when I mention costs at the end, which I think you are probably interested in, I will use these numbers as the total market which you would be attempting to penetrate.

Now I would like to go to some technical features. First, what are we going to provide? (Figure 18)

Essentially, we are taling about providing 99.99 percent of the time a 56 dB signal-to-noise video quality at the worst earth station in the whole system. This does not include terrestrial facility degradation. I would like to point out that such degradation is not usually correlated with degradations in satellite facilities.

Figure 19 indicates that we intend to provide a reliability equal or better than radio relay presently used for such communications in the United States.

Figure 20 describes the small earth stations which would provide (through connecting links) the service to the CATV head ends and so I think it would probably interest you to discuss these stations. They are simple and small and should work well. There's a 30-foot diameter antenna which is stationary. It's locked in place. There is essentially one six-foot electronics rack which can provide four television channels. Of course, we are talking about six channels, so we would have two six-foot racks. I would point out that the station complexity is equivalent to or less than most CATV head ends I have seen. There is dual radio equipment and no-break power. These stations could be provided for $200,000 apiece, assuming a bulk buy of many such units.

It is evident up to this point that I have ignored the question of how the signals get from the small earth stations to the CATV head ends. The difficulty in talking about this is that there are a number of ways to accomplish this from a technical point of view, and the choice probably would be different in each area -- each of the 36 service areas. Let me mention some possibilites. Coaxial cables could be used for head ends located very near to earth stations. Since there will be exit links needed from

earth stations for other types of users, at least at most of the earth stations, CATV signals could be routed over this exit facility, and tapped off at intermediate points or at the end of the route. A third possibility, of course, is connecting by either existing microwave radio relay or new microwave radio relay. We also could use any combination of these three possibilities. My point is that the choice would probably be whatever provides the most economical approach for a particular area.

I have two illustrations in this regard. Figure 21 shows a particular service area blown up, and essentially depicts the use of existing microwave radio relay to distribute the signals from the service area to other CATV head ends that are beyond its "boundaries." In actual fact, as you remember, there may be over 100 small earth stations. Consequently, there would normally be several earth stations in the area shown here, and this might not be the way one would connect them. However, this is an area where CATV is sparse compared with other markets. Figure 22 attempts to show the same markets in the service areas in the East coast and how the interconnections are relatively short.

Figure 23 shows the illustrative system in 1975. The annual costs I am talking about here are only the costs for the earth stations and satellites. They do not include the costs of programming nor the costs of interconnecting the head ends to the earth stations. Consequently, these are obviously not by any means the total costs.

I would like to mention a few things about these costs which are rough estimates, naturally. They assume the approval of a viable domestic satellite program along the lines that Comsat has proposed, and also a crystal ball projection of costs in 1975.

Essentially, the ordinate is the annual cost per household with the top number being one dollar and the bottom number being 20 cents. The abscissa is the percent of market penetration of the total households in the 36 service areas; 25 percent, 50 percent and 75 percent points being shown. For a given penetration, one can see the approximate annual cost per household of the satellite and earth stations for six interconnected television channels in the 36 service areas. I want to emphasize this percent penetration. A 50 percent penetration is 50 percent of the numbers shown on Figure 17. In other words, it assumes a total possible market of roughly 60 million households, and the percent is that which CATV might be able to penetrate.

The conclusion of my talk is short and hopefully evident. If interconnected, nation-wide CATV programming is to be provided, this interconnection can be economically done using a domestic satellite communications system.

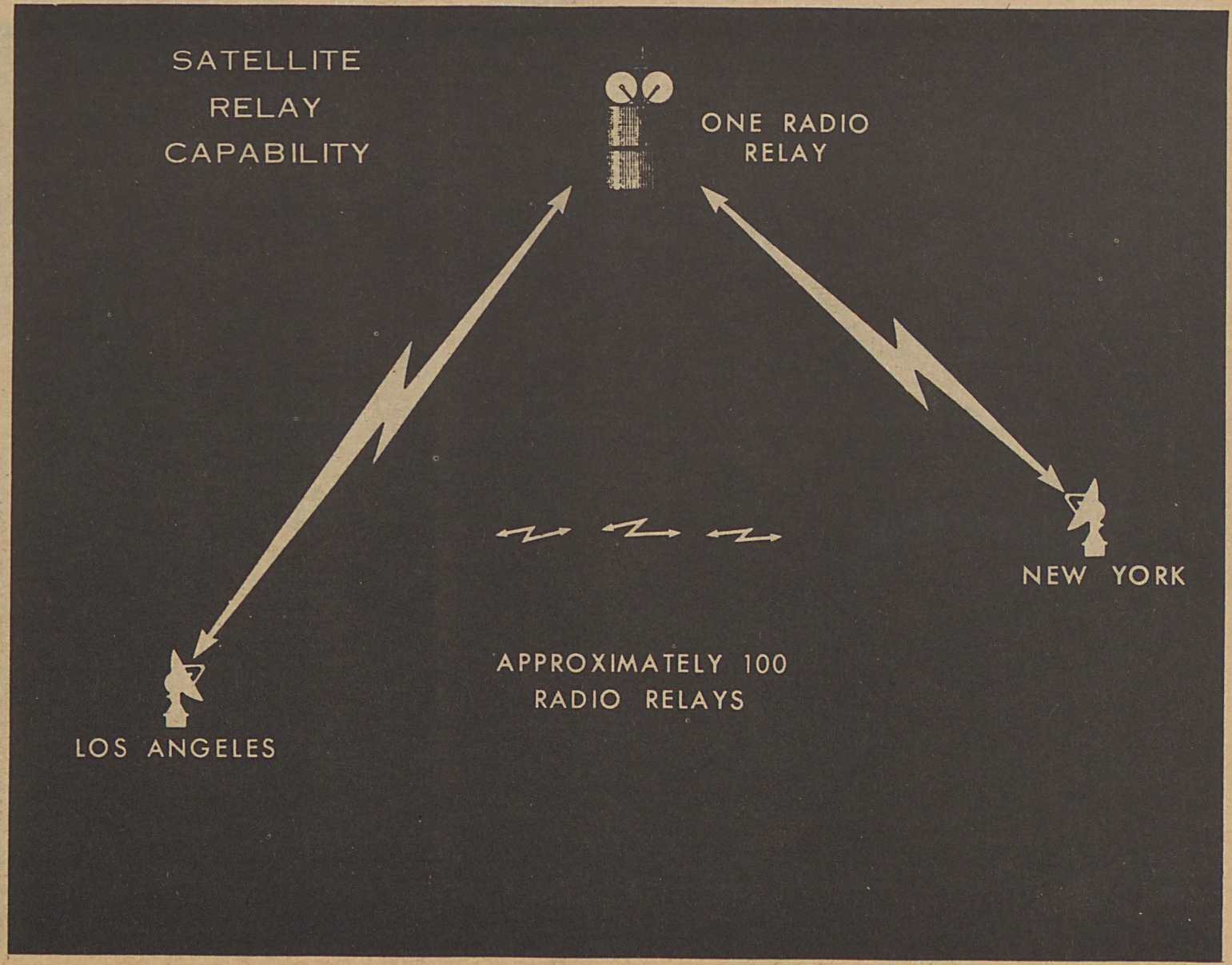

SATELLITE
RELAY
CAPABILITY
ONE RADIO
RELAY
NEW YORK
APPROXIMATELY 100
RADIO RELAYS
LOS ANGELES

Figure 1

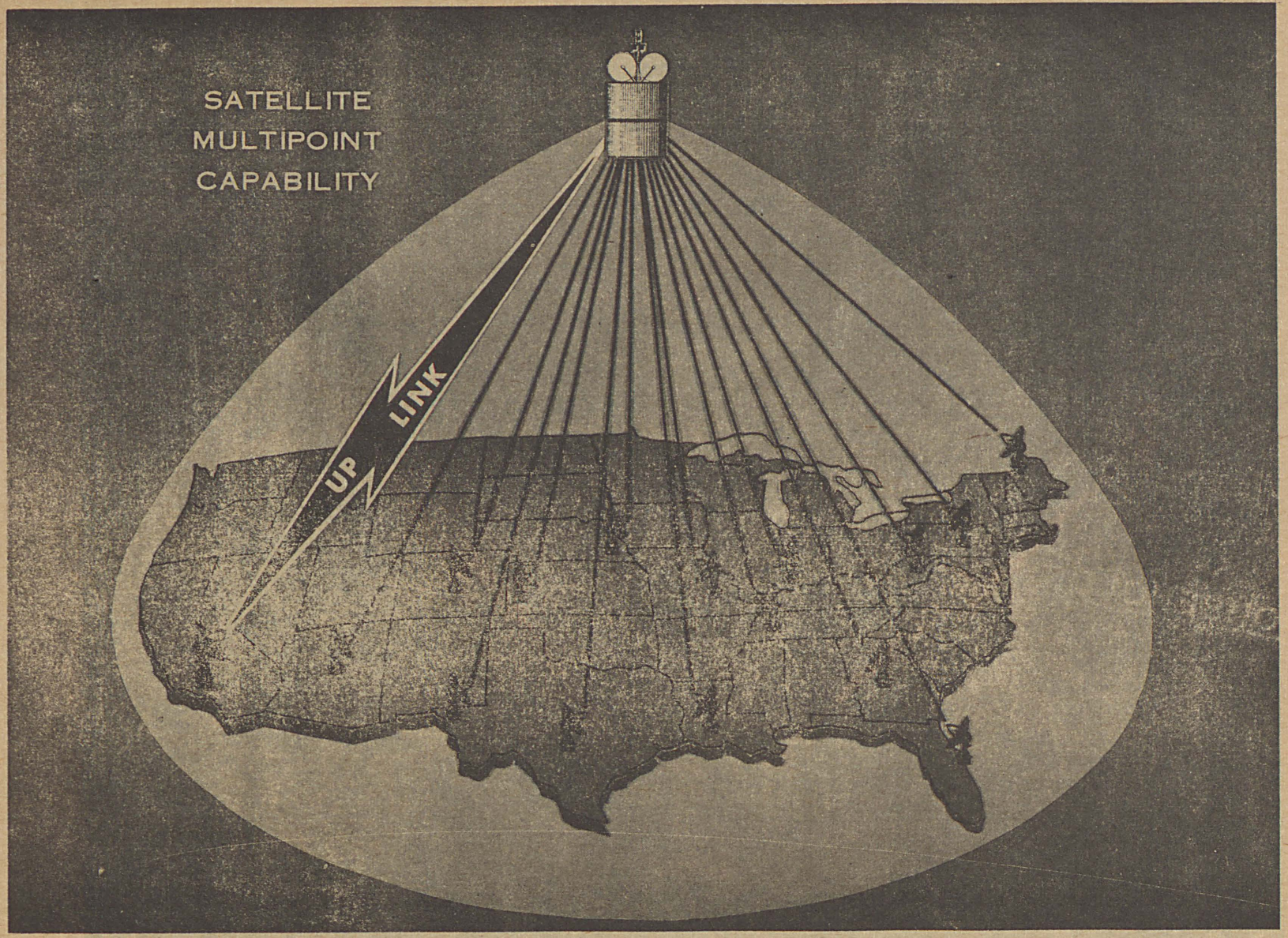


Figure 2

U.S. DOMESTIC SATELLITE PROPOSAL MILESTONES

MAR	1966	FCC INQUIRY
APR	1966	COMSAT TELEVISION SEMINAR
AUG	1966	INDUSTRY SUBMISSIONS
OCT	1966	FCC SUPPLEMENTARY NOTICE
DEC	1966	ADDITIONAL INDUSTRY SUBMISSIONS
APR	1967	ADDITIONAL INDUSTRY SUBMISSIONS
JULY	1967	COMSAT PILOT PROPOSAL
FEB	1968	INTELSAT IV-REQUEST FOR PROPOSALS
OCT	1968	INTELSAT IV AWARD

Figure 3

TOTAL ESTIMATED CHANNEL REQUIREMENTS

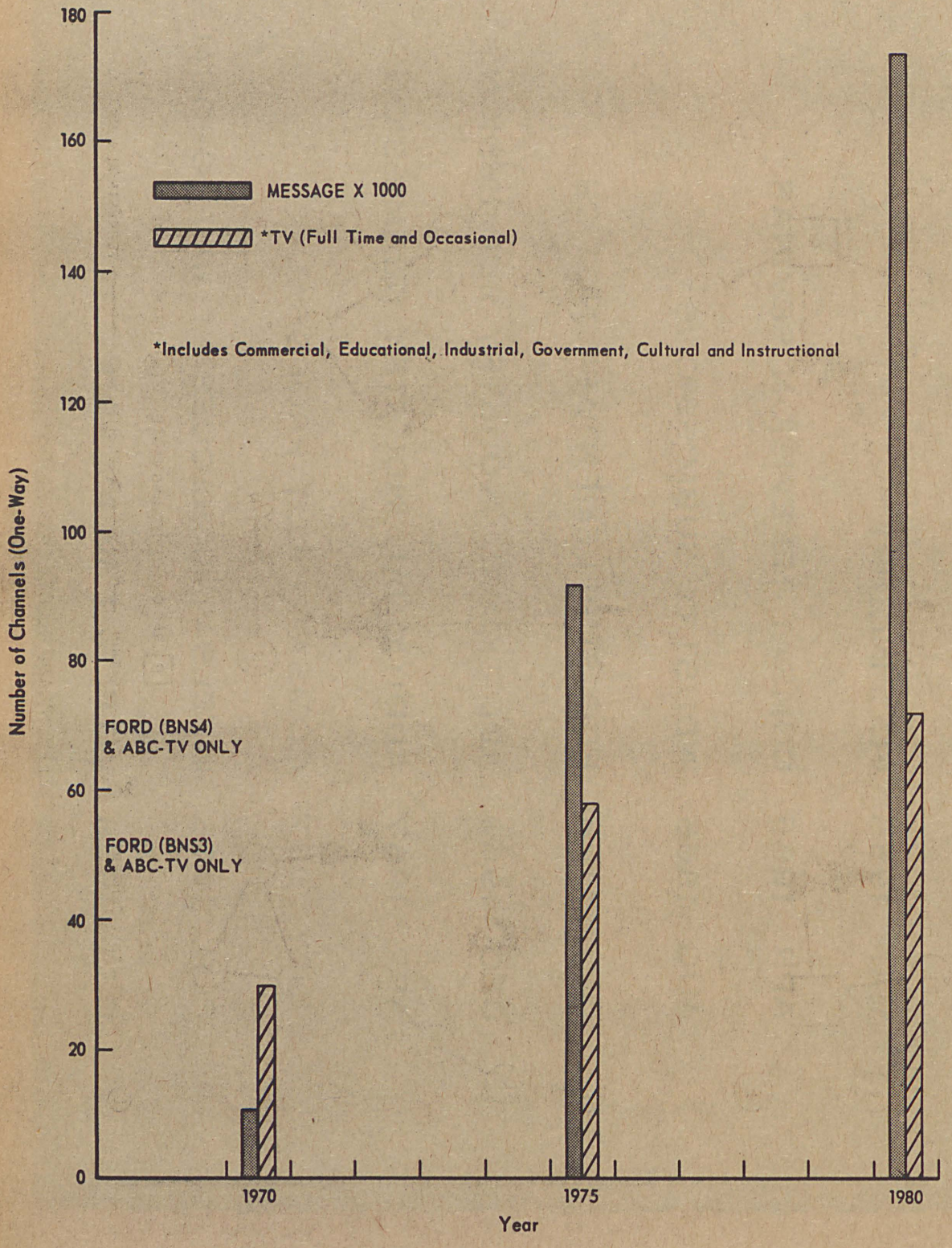


Figure 4

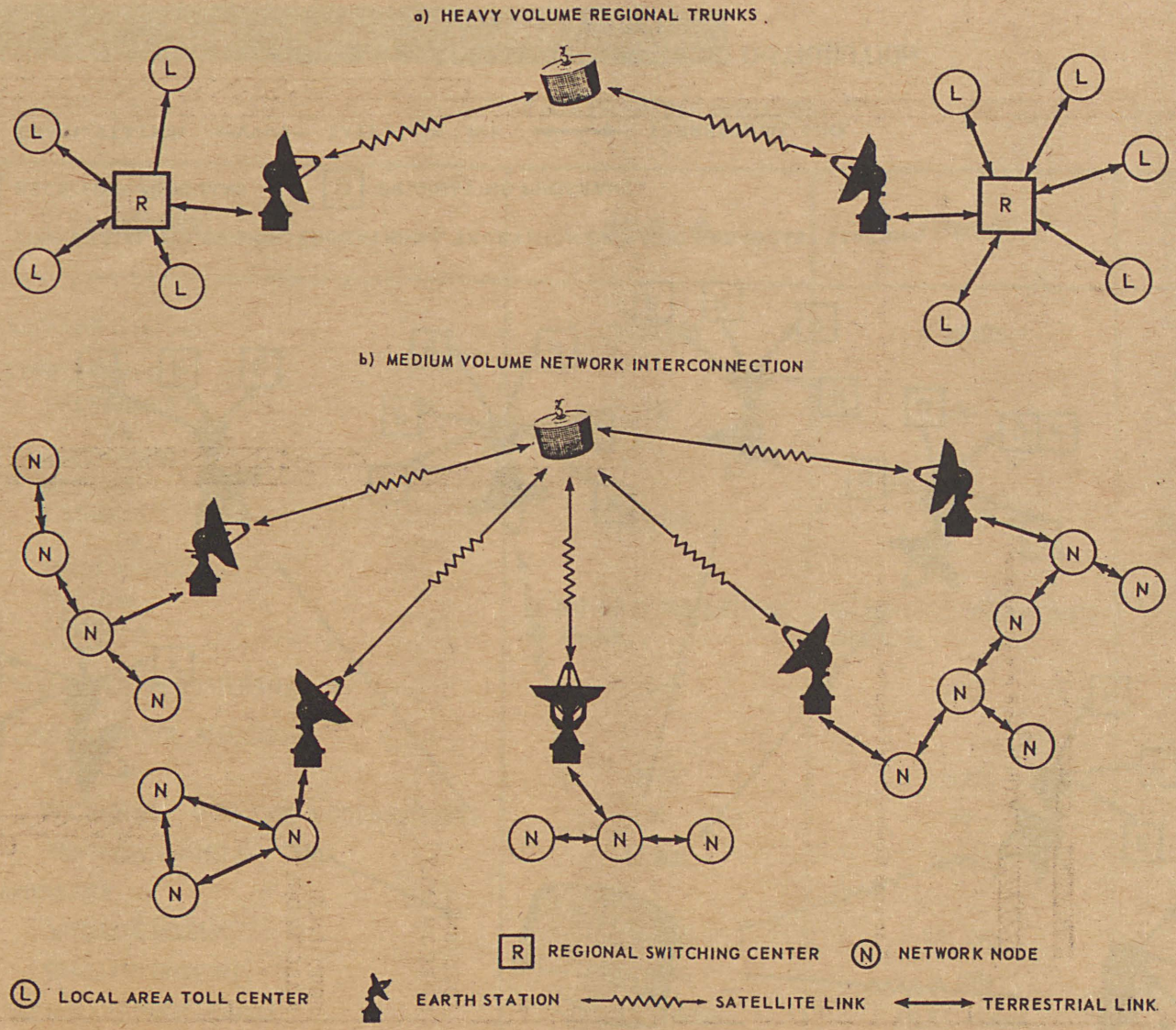


FIGURE 5 TELEPHONY AND RECORD CHANNEL DISTRIBUTION

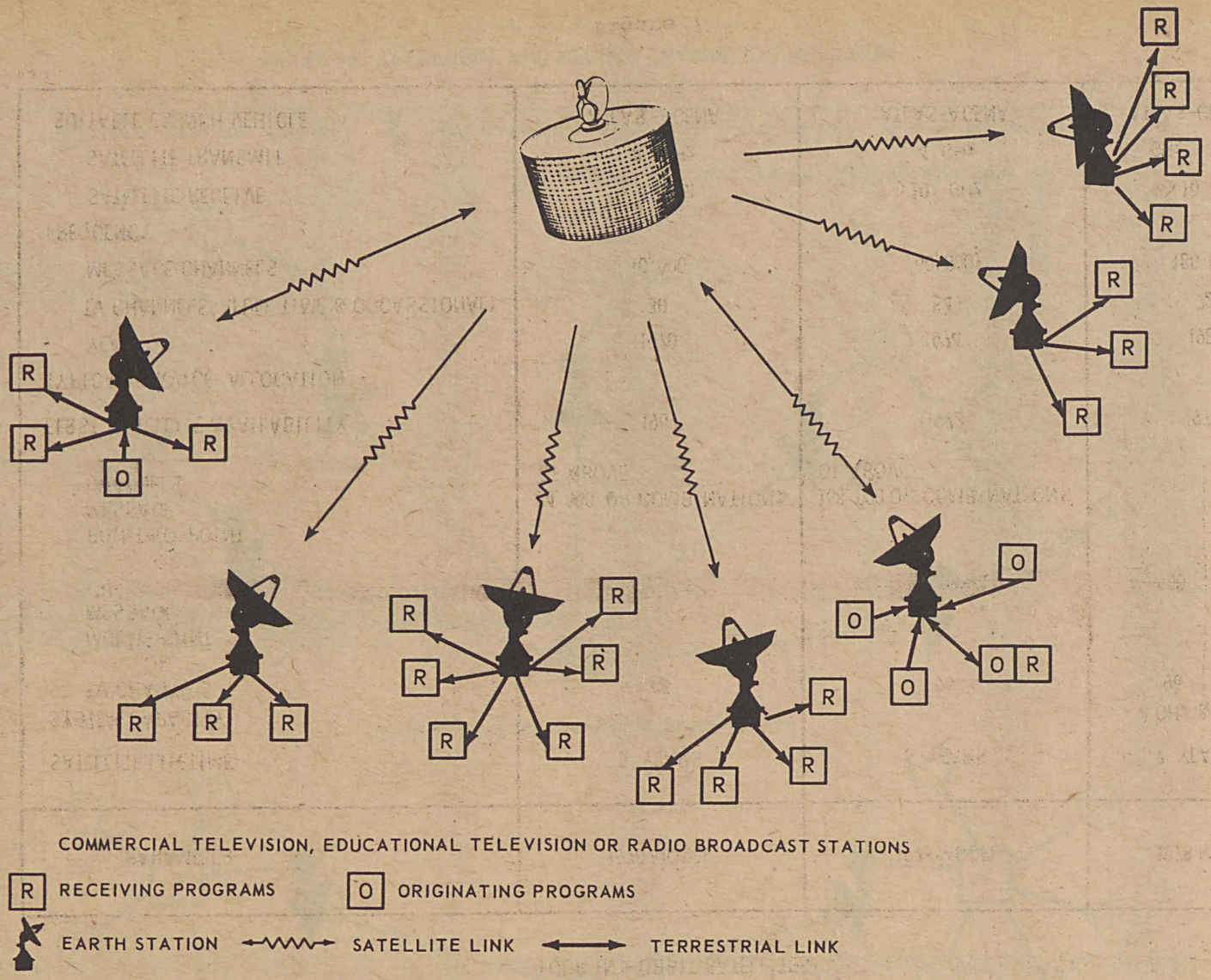


FIGURE 6 TELEVISION AND RADIO DISTRIBUTION

Multi - Service Model Summary

(FOUR IN - ORBIT SATELLITES)

PARAMETER	1970 MODEL	1973 MODEL	1978 MODEL
SATELLITE LIFETIME	5 YEARS	6 YEARS	7 YEARS
SYSTEM CAPACITY			4 GHz & 10 GHz
TV CHANNELS OR MULTI-POINT MESSAGE CHANNELS OR POINT-TO-POINT MESSAGE CHANNELS	48 / 38,400 / 84,000 OR COMBINATIONS OF ABOVE	96 / 76,800 / 168,000 OR COMBINATIONS OF ABOVE	96 / 76,800 / 160 TO 240 / 240,000 TO 360,000
FIRST SATELLITE AVAILABILITY	1969	1972	1976
TYPICAL SERVICE ALLOCATION			
YEAR	1970	1974	1980
TV CHANNELS (FULL TIME & OCCASSIONAL)	30	54	72
MESSAGE CHANNELS	10,000	60,000	180,000
FREQUENCY			
SATELLITE RECEIVE	6 GHz	>10 GHz	>10 GHz
SATELLITE TRANSMIT	4 GHz	4 GHz	4 GHz >10 GHz
SUITABLE LAUNCH VEHICLE	ATLAS-AGENA	ATLAS-AGENA	ATLAS-CENTAUR

G-334

Figure 7

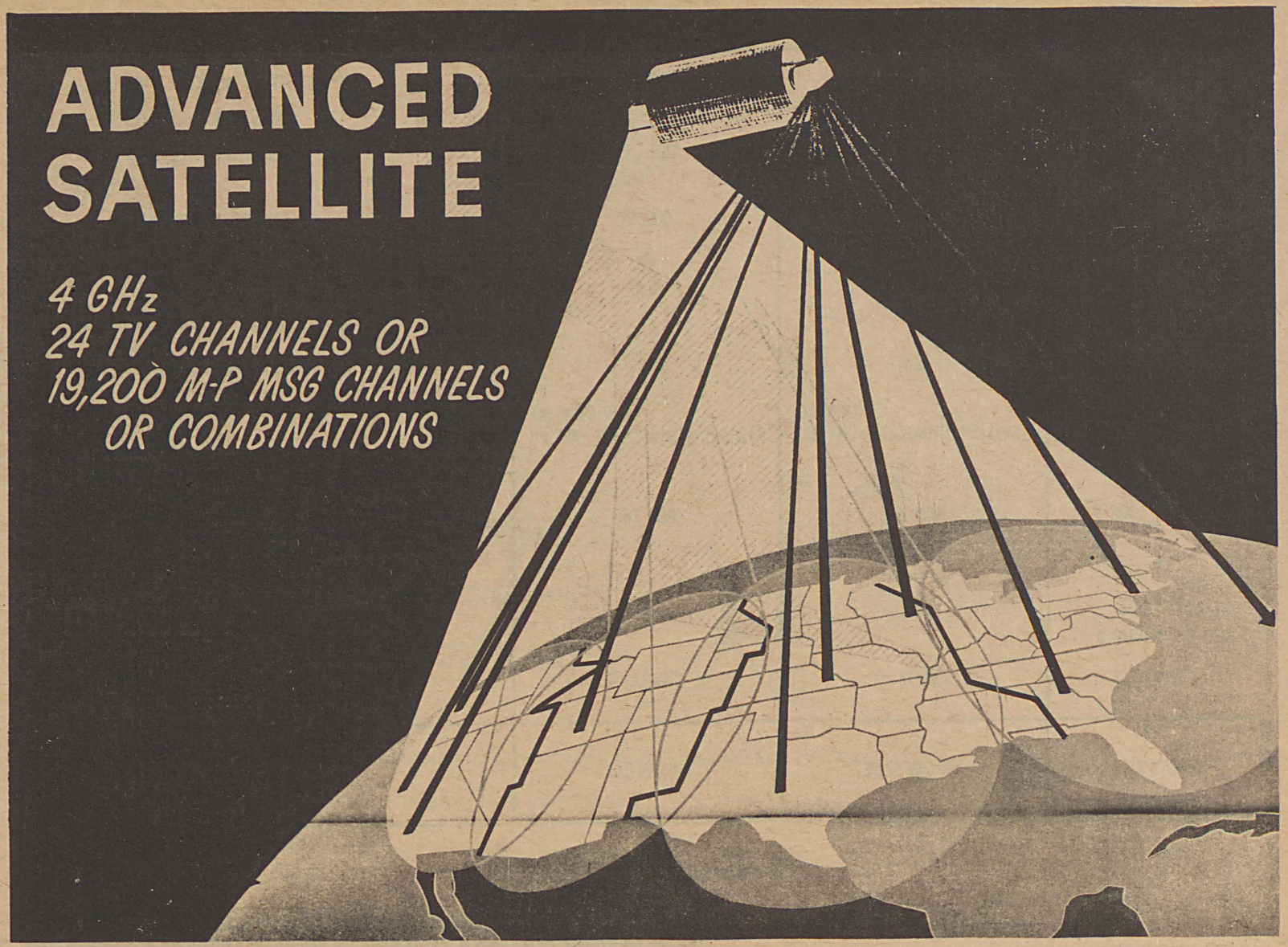

ADVANCED
SATELLITE
4 GHz
24 TV CHANNELS OR
19,200 M-P MSG CHANNELS
OR COMBINATIONS

Figure 8

COST DECLINE WITH TECHNOLOGY ADVANCEMENT
FOR MULTI-SERVICE SATELLITE

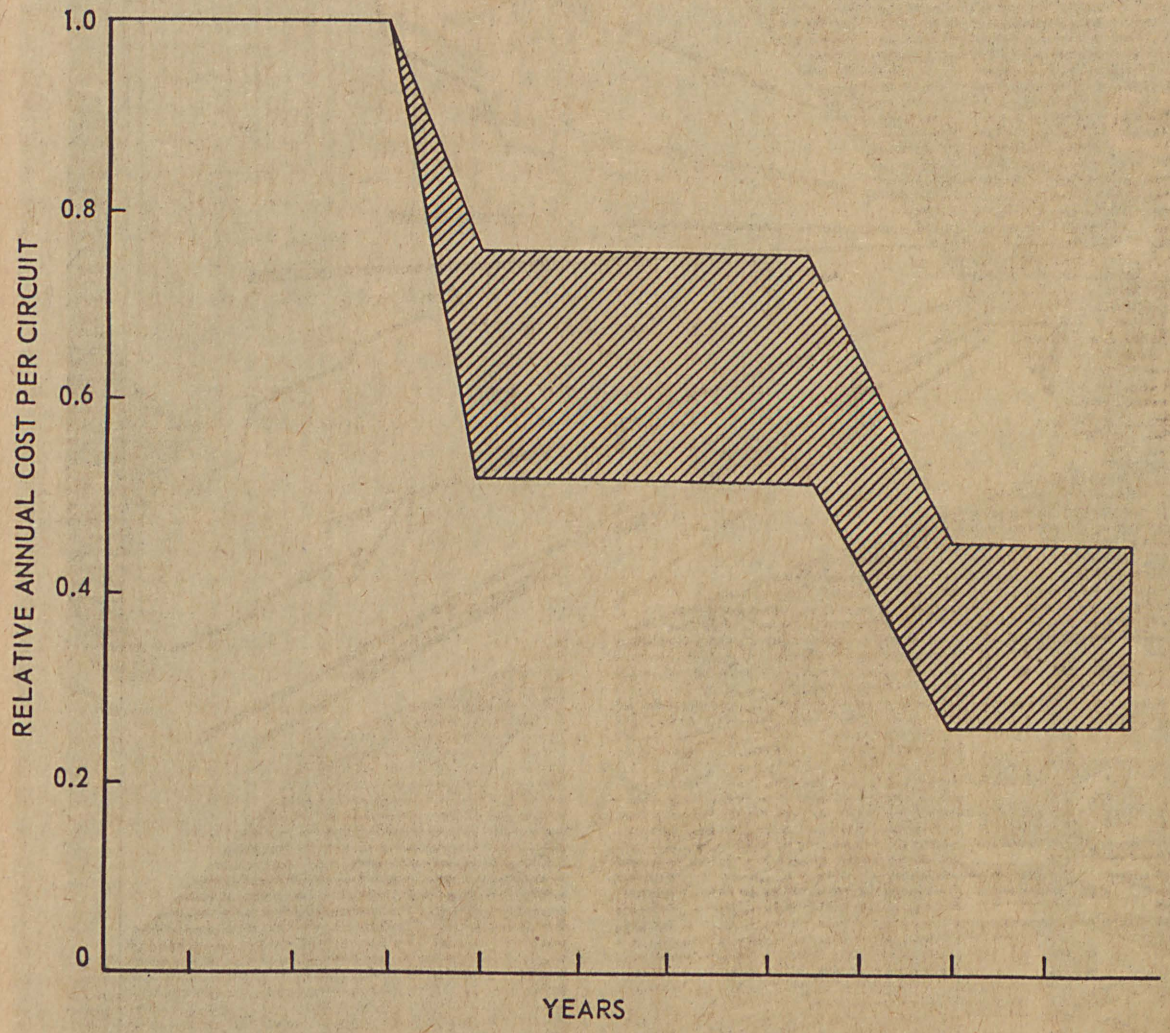


Figure 9

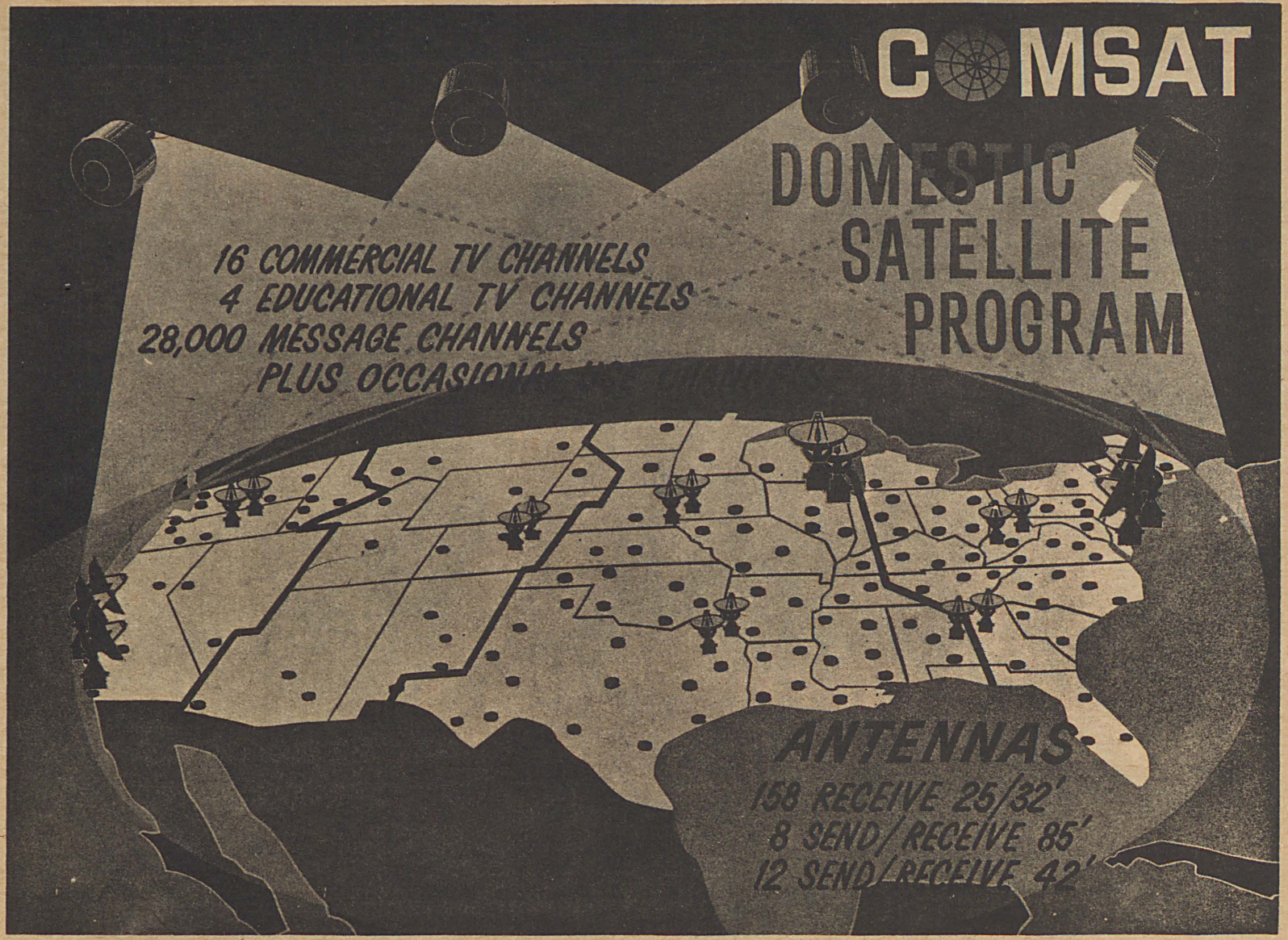

COMSAT
DOMESTIC
SATELLITE
PROGRAM
16 COMMERCIAL TV CHANNELS
4 EDUCATIONAL TV CHANNELS
28,000 MESSAGE CHANNELS
ANTENNAS
158 RECEIVE 25/32'
8 SEND/RECEIVE 85'
12 SEND/RECEIVE 42'

Figure 10

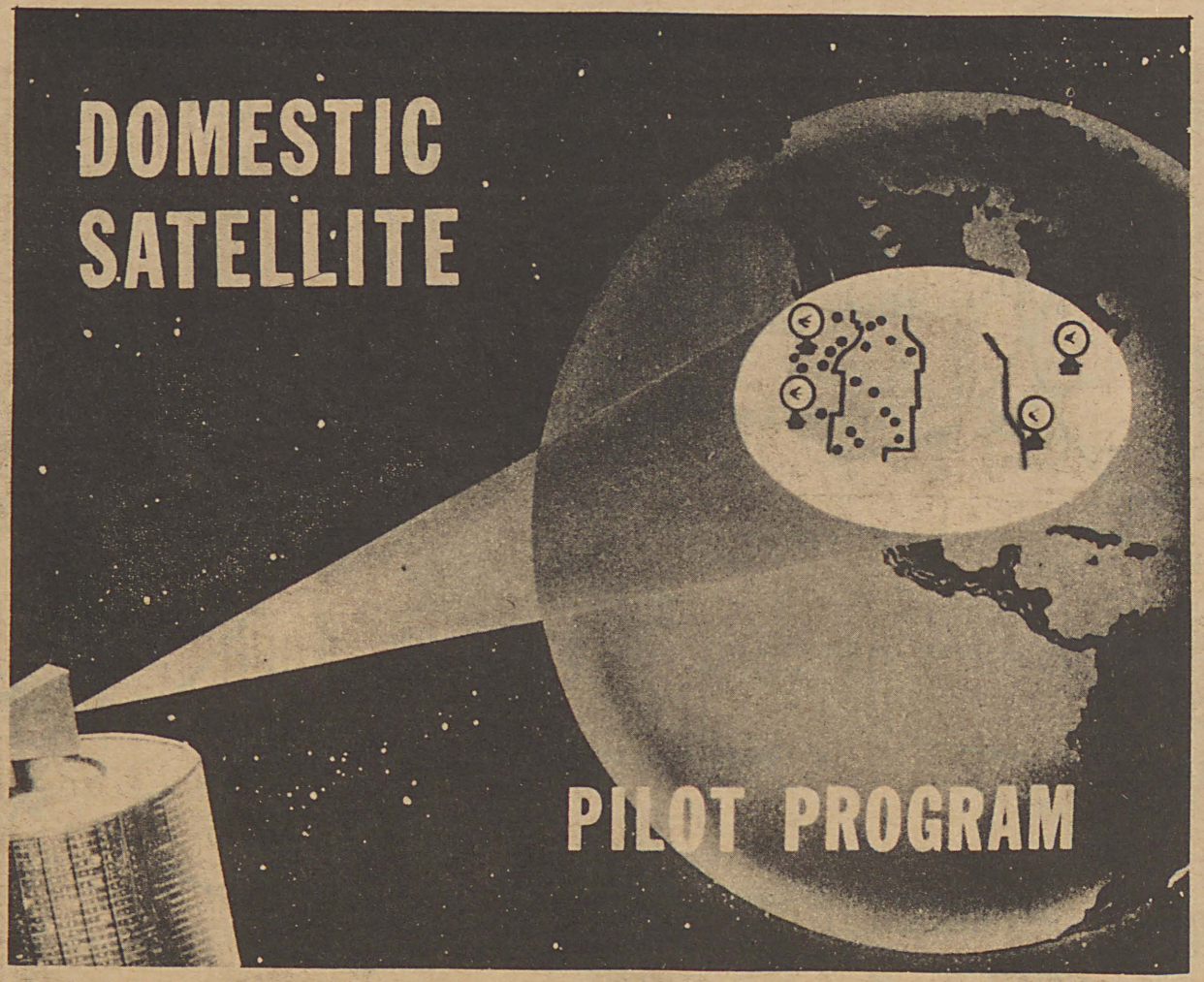


Figure 11

BASIC SATELLITE BUILDING BLOCK

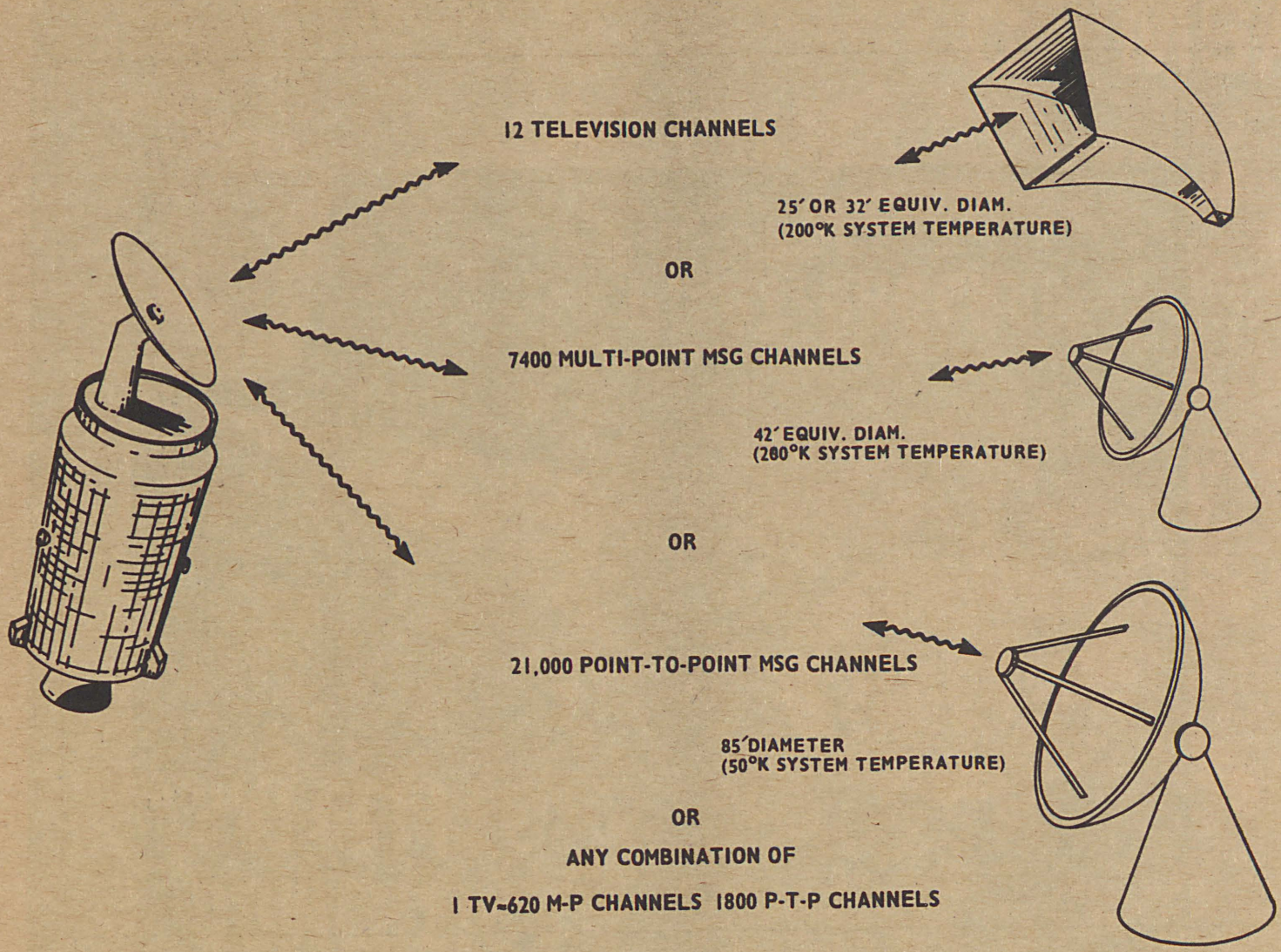


Figure 12

ITEM	DESCRIPTION
SATELLITE WEIGHT	APPROXIMATELY 2400 LBS. IN TRANSFER ORBIT WITH APOGEE AT SYNCHRONOUS EQUATORIAL ALTITUDE (TYPICALLY TITAN-AGENA)
SATELLITE POSITION	BETWEEN 70-120° W. LONGITUDE
ATTITUDE STABILIZATION	± 0.2°
STATION KEEPING	± 0.1°
ORBITAL INCLINATION	± 0.1°
POWER SOURCE	SOLAR ARRAY (STORAGE BATTERIES TO PERMIT OPERATION DURING ECLIPSE PERIODS.)
ANTENNA COVERAGE	SINGLE BEAM – CONTINENTAL UNITED STATES AND PORTIONS OF CANADA AND MEXICO.
POLARIZATION	LINEAR – BOTH VERTICAL AND HORIZONTAL USED.
NUMBER OF TRANSPONDERS	12 – 14
TRANSMIT FREQUENCY RANGE	3700-4200 MHz
RECEIVE FREQUENCY RANGE	5925-6425 MHz
e.i.r.p. PER TRANSPONDER	38 dBW – ON AXIS
USABLE RF BANDWIDTH	35-40 MHz PER TRANSPONDER
USEFUL LIFE	5-7 YEARS

FIGURE 13 SATELLITE CHARACTERISTICS

ITEM	EARTH STATION TYPE		
	97-FOOT	42-FOOT	25/32-FOOT
ANTENNA TRACKING	*AUTOMATIC FEED TRACKING	*NO TRACKING	*NO TRACKING
RECEIVE G/T	40.7 dB/°K	29.5 dB/°K	24.5/25.6 dB/°K
LOW NOISE RECEIVER	COOLED PARAMETRIC AMPLIFIER	UN-COOLED PARAMETRIC AMPLIFIER	UN-COOLED PARAMETRIC AMPLIFIER
RECEIVER BANDWIDTH	500 MHz	500 MHz	500 MHz
TRANSMIT e.i.r.p.			
TV	76 dBW	76 dBW	---
MESSAGE	87 dBW (1800 CHLS/CARRIER)	76 dBW**	---
TRANSMIT ANTENNA GAIN	62 dB	55 dB	---
TRANSMIT BANDWIDTH	500 MHz	500 MHz	---

*COARSE ANGULAR CHANGES ACCOMPLISHED BY PRE-SET POINTING POSITIONS.

**BASED ON TDM (TIME DIVISION MULTIPLEX) WITH 4-PHASE PSK.

FIGURE 14 EARTH STATION CHARACTERISTICS

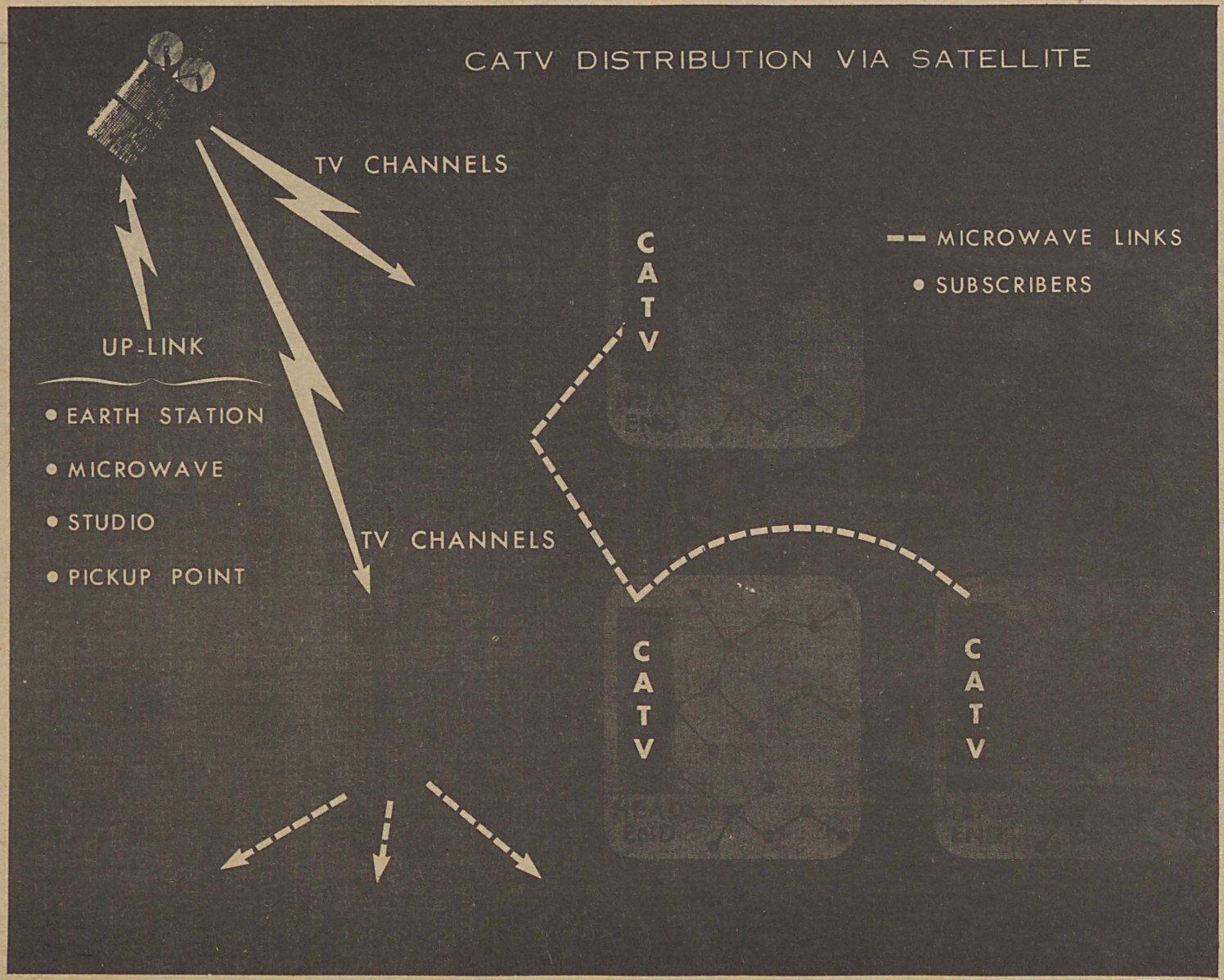

CATV DISTRIBUTION VIA SATELLITE
TV CHANNELS
UP-LINK
• EARTH STATION
• MICROWAVE
• STUDIO
• PICKUP POINT
TV CHANNELS
MICROWAVE LINKS
• SUBSCRIBERS
CATV
CATV
CATV

Figure 15

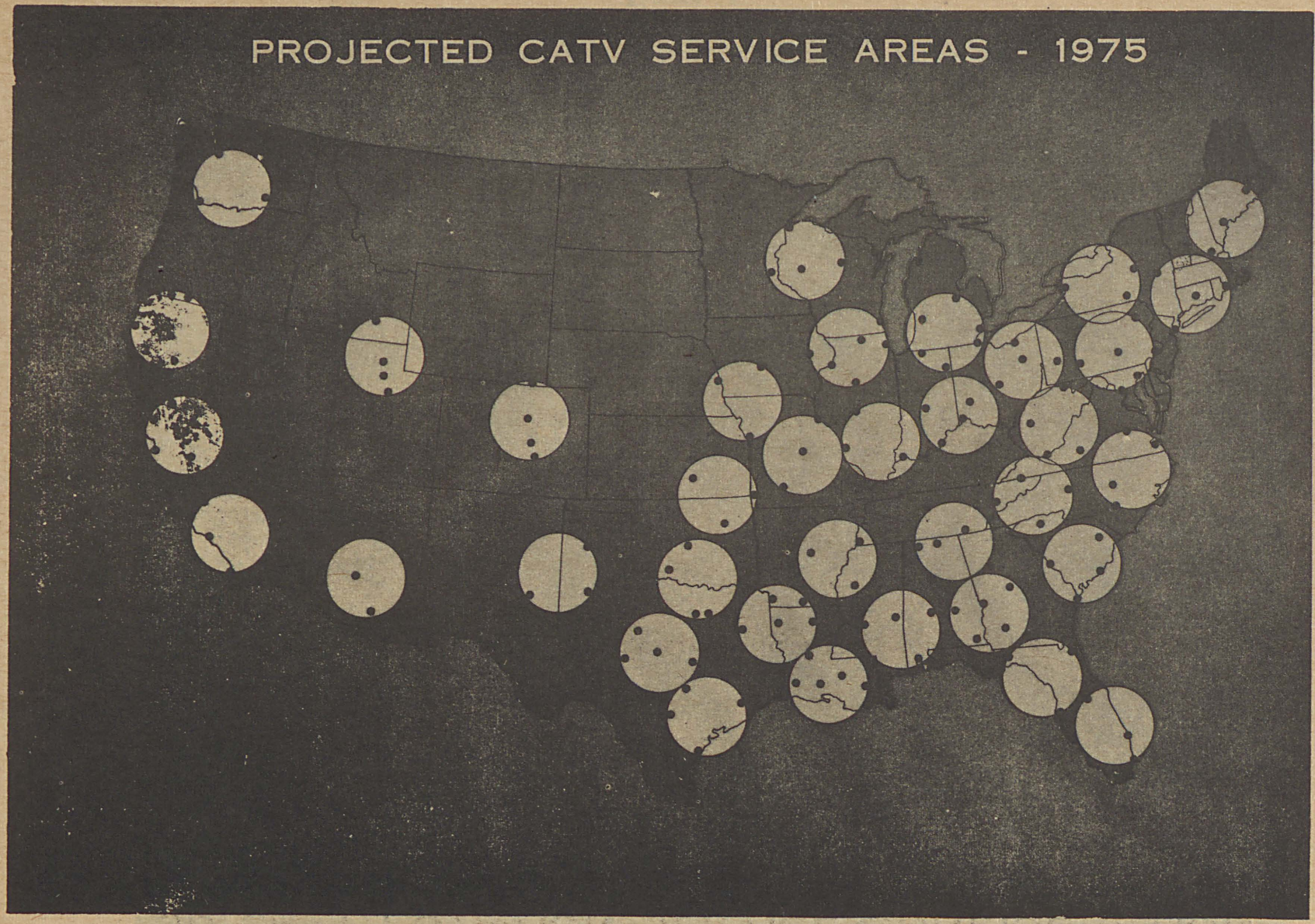


Figure 16

36 EARTH STATION SERVICE CONFIGURATION (1975)

61 MILLION HOUSEHOLDS* (88% OF TOTAL U.S.)

1.7 MILLION HOUSEHOLDS/EARTH STATION

53 MILLION HOUSEHOLDS (77% OF TOTAL U.S.)

WITHIN 35 MILES OF ARB MARKETS

1.5 MILLION HOUSEHOLDS/EARTH STATION

*INCLUDES SOME MARKETS OUTSIDE SERVICE AREAS.

Figure 17

VIDEO QUALITY

Signal-to-noise

98%: 58.2 dB peak-to-peak/rms weighted

99.99%: 56.0 dB

+ terrestrial degradation (mainly uncorrelated)

Uniform quality provision/Double-hop provision

Echo - Negligible

Differential Phase & Gain

Phase $\simeq 3^{\circ}$

Gain $\simeq$ 0.7 dB

No Signal Processing or Baseband Equalization

Figure 18

RELIABILITY

Continuity-of-Service: 99.99%

Satellite

Complete Redundancy/Conservative Design

Full-Time Service Reserve

Wear-out Mechanism Overlifing

Earth Stations

Redundancy/Protection

Modularity

Commonality

Figure 19

TYPICAL RECEIVE-ONLY EARTH STATIONS

30-foot Stationary Antenna

6-foot Rack Electronics (Equipment Shelter)

Includes Redundancy/All Solid State

Control & Monitor

3 Working + 1 Protection Channel

Dual Radio-Preamplifier

Power Rack

No Break Supply/Distribution

Cost $\simeq$ $200,000 (20 Units Minimum)

Unattended

Exit Link Not Included

Figure 20

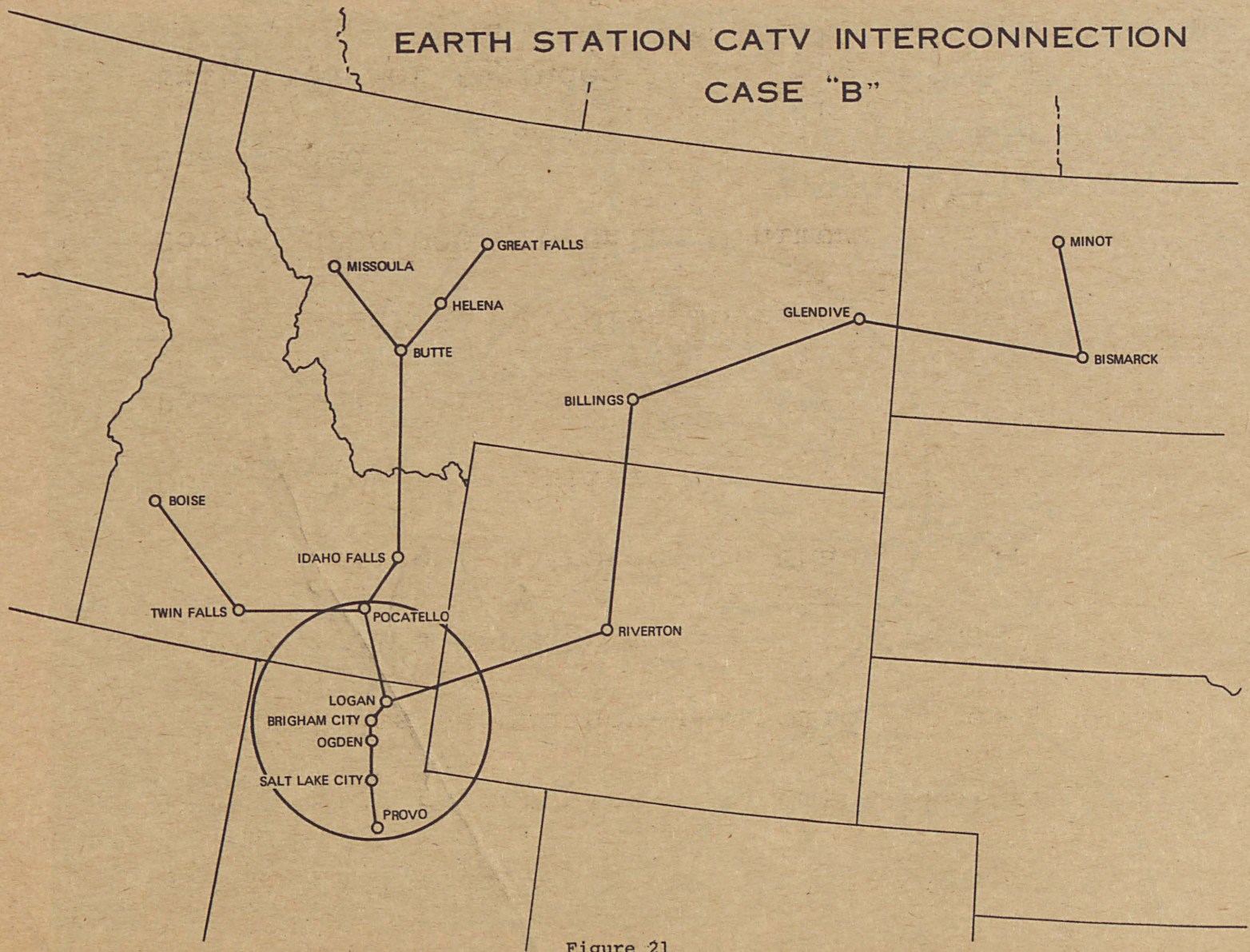
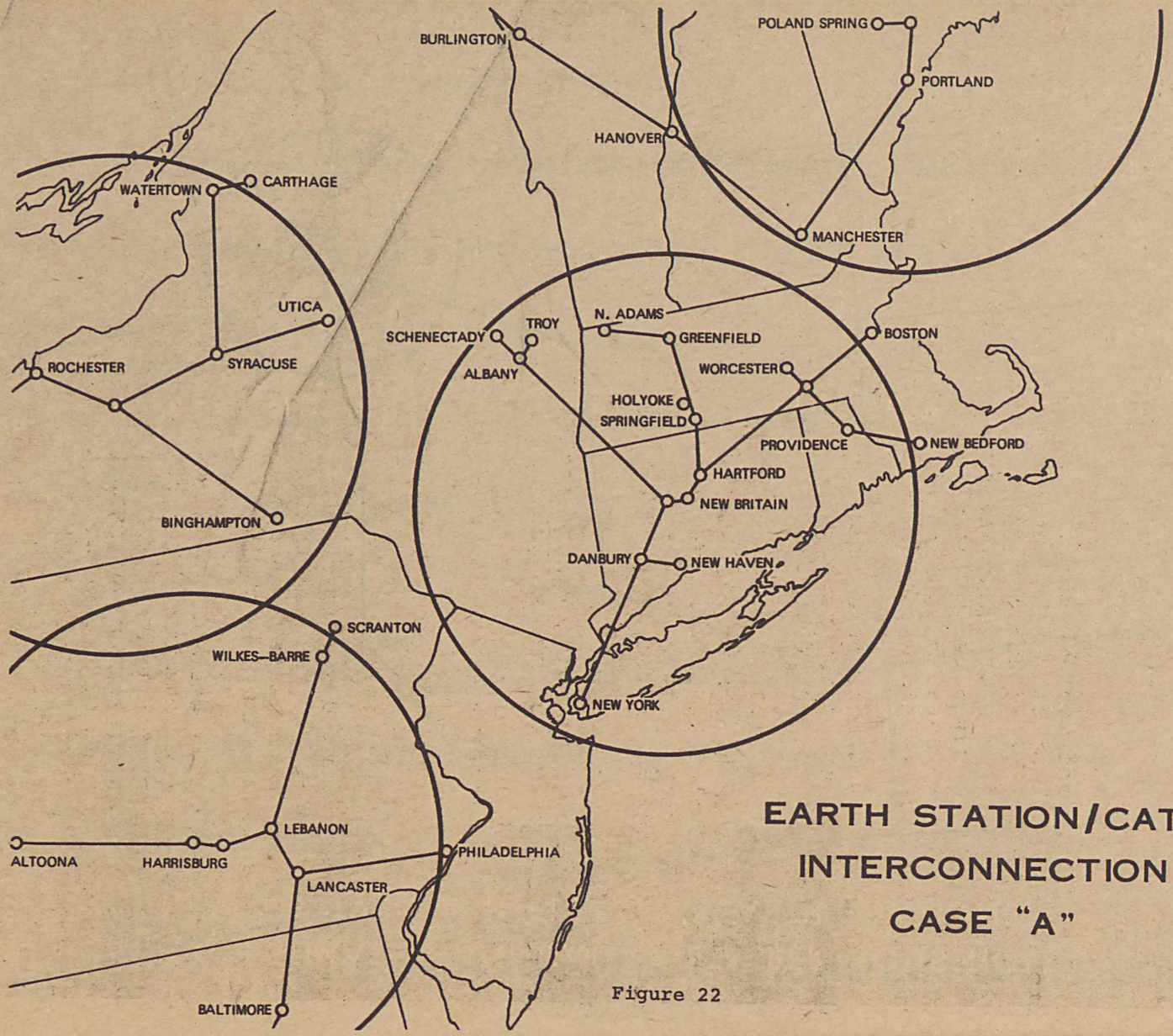

EARTH STATION CATV INTERCONNECTION
CASE "B"
MISSOULA
GREAT FALLS
HELENA
BUTTE
MINOT
GLENDIVE
BISMARCK
BILLINGS
BOISE
IDAHO FALLS
TWIN FALLS
POCATELLO
RIVERTON
LOGAN
BRIGHAM CITY
OGDEN
SALT LAKE CITY
PROVO

Figure 21



EARTH STATION/CATV INTERCONNECTION CASE "A"

Figure 22

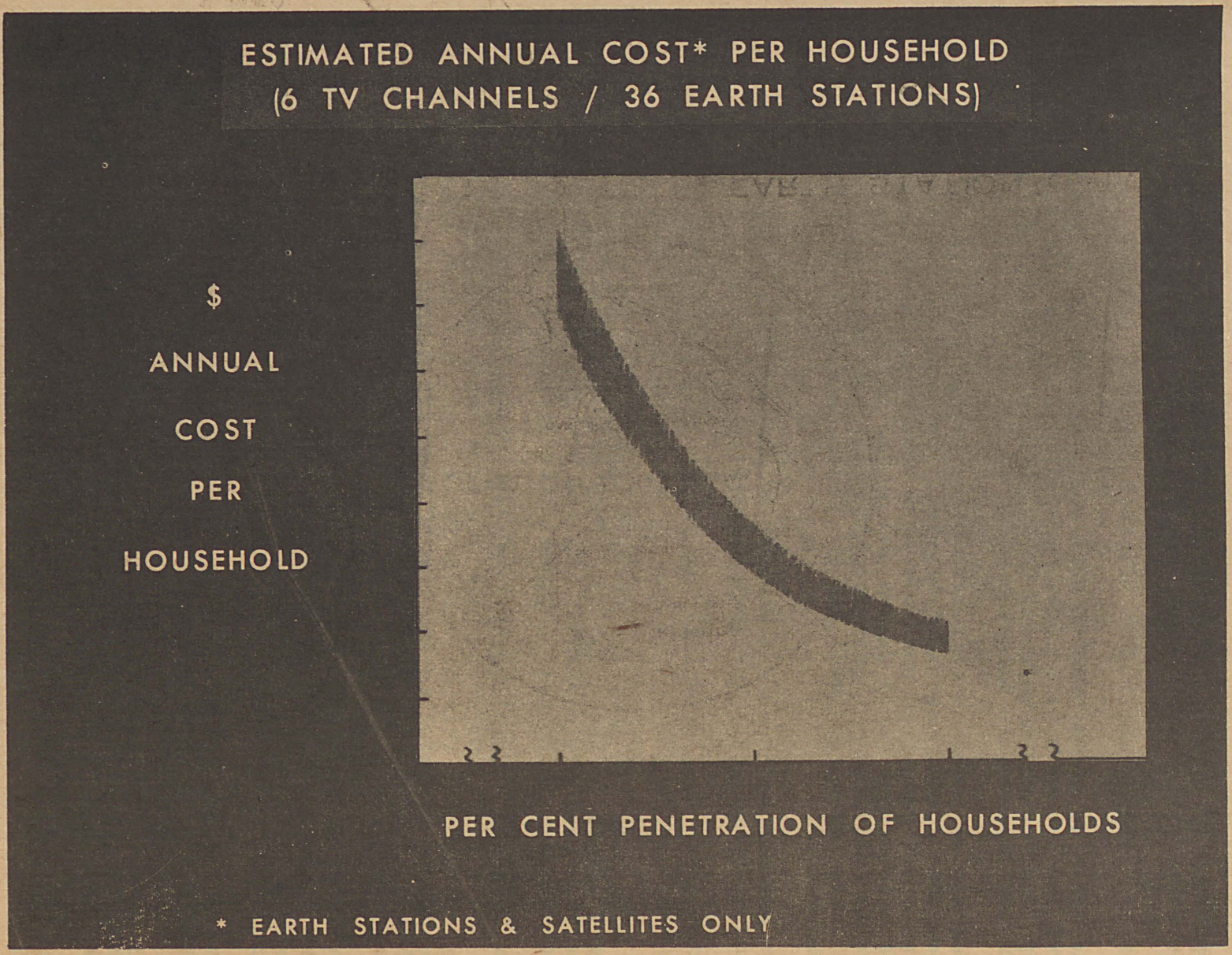

ESTIMATED ANNUAL COST* PER HOUSEHOLD
(6 TV CHANNELS / 36 EARTH STATIONS)
$
ANNUAL
COST
PER
HOUSEHOLD
PER CENT PENETRATION OF HOUSEHOLDS
* EARTH STATIONS & SATELLITES ONLY

Figure 23

IRVING B. KAHN

We have to climb down from those earth stations and get down here. First, I would like to start by saying any remarks that I would like to make here do not necessarily reflect the attitudes or opinions of the Hughes Aircraft Company.

As cable TV operators, we have grown accustomed to living in a very uncertain world. Every so often, it is a relief to look up from our regulatory and legislative and other problems and to contemplate the brighter world of tomorrow.

Perhaps we ought to be overawed and scared to death by the much heralded communications explosion. Instead, we, as an industry, are brash enough to consider it a challenge and an opportunity. We foresee our cable TV systems giving birth to a vast variety of new services -- electronic shopping and newspapers, meter reading, data retrieval and so forth. And we talk a great deal about them.

At our company's annual meeting of shareholders recently, a gentleman stood up and asked very bluntly:

"Are these real possibilities or are they perhaps just fancied ideas?"

I told him, "If they are fancied ideas, they are going to be a very expensive fancy for us. They are very real; we certainly believe they are possible. We are not talking of creating or solving new technical problems. The technology is already here."

We have had a very cogent reminder of some of that technology. I don't doubt but what there are some cable operators who, like my shareholder friend, wonder if it isn't all just fancy. But we can be grateful to the COMSAT team for making us realize that what we are talking about up there in the sky is not pie but something much more real and pratical.

It is plain that the important questions to be resolved are not the technical ones. We all know that satellite transmission works and that it offers vast possibilities for domestic communication transcending anything the present carriers can offer today.

The question, however, is who is going to be running this new show and under what ground rules -- or should I say "sky rules?"

By now, I think it is apparent that our CATV industry is more than just an interested bystander. We had better suit up and get into the game, because our own future is very much involved.

Our most obvious role is to provide the ultimate distribution process after the signals have made their 44,000 mile trip to

the hovering satellite and back to earth -- not just for six channels but for all of television services as we know them now and many more besides. I think we have a very strong case for cable TV as the most practical, economical and effective medium of distribution.

But once we accept that premise, we come to another question. Candidly, is not the distribution process just as important as the satellite relay -- and perhaps more important? Fantastic as it is to be able to hang those satellites up there in orbit, their function is meaningless without the final link -- cheap, efficient distribution of the signals -- along with relevant local programs -- to the American living room.

Therefore, I guess what I am asking is, do we need COMSAT as much as COMSAT needs us? I believe our industry should have -- is entitled to -- an important voice in the total domestic communications system. Not just the distribution function, but the operation of the satellite and the ground stations as well.

We learn from experience. Unfortunately, our experience with common carriers -- namely the telephone companies -- has not been, to put it mildly, ideal. And so we must ask ourselves what assurances we have that COMSAT, if it controls the domestic satellite program, will prove an any better custodian of the public interest than the telephone companies have been in operating their comparable monopolies in terrestrial communication.

We have learned from experience, too, how far we can trust the good will, fair-mindedness and just plain common sense of our friends, the broadcasters. About the length of a San Francisco miniskirt.

By the same token, we have learned that the FCC, being a captive of the status quo, has trouble conceiving that there is value in any new technological development that tends to depart from the well-worn rut of comfortable predictability. Our own company is still waiting a full go-ahead on its short-haul AML microwave system almost three years after we demonstrated its workability and its potential to bring more and better TV to millions in both rural and urban areas.

The cable TV industry must recognize the domestic satellite program for what it is, an entirely new chapter in communications, which can either bear us along on a tide of success or quickly make us obsolete. We will have to fight for the right to distribute satellite signals -- not to sit around hoping we will be favored over direct-to-the-home transmission or broadcast transmission or a system controlled by the telephone companies.

But more than that, we must be bold to stake our claim to a meaningful overall role -- not as a supplicant for crumbs from COMSAT's table, but as an equal participant.

I would remind you that COMSAT does not build the satellites or launch them. It's function is managerial, and my question is whether it really is essential.

There are three principal alternatives the FCC could follow to get a satellite program underway. The first is to consider this an extension of present common carrier service and merely turn the program over to AT&T and Western Union. I don't think there is any question how our industry would feel about that one. It would be tragic, and I don't believe it is going to happen that way.

The second would be to open up the field to others with a valid interest. Ideally, I'd like to see our industry put up its own satellite, and that is not such a pipe dream as you might believe. We have the growing stature, the future prospects, and even the resources to be able to undertake such a project. From the figures we have heard today, it is obvious that we could indeed open our own store and maintain it for less money, in the long run, than what it would cost to go the COMSAT route, and not restrict ourselves to six rather miscellaneous channels.

There is, of course, the third alternative, which, unfortunately, seems the most practical, politically speaking, for the present. That is the proposal that ultimate question of satellite proprietorship be deferred and COMSAT given the managerial role to get the program under way, which is the proposition to which current discussions have been slanted.

Now, if the second alternative, our own satellite, is not practical -- and mind you, I say <u>if</u> -- and we do wind up in a venture such as has been discussed here with COMSAT, we still have some hard questions to ask.

First, how do we achieve parity with other users and COMSAT itself in resolving issues that may affect our future?

Secondly, how can COMSAT rid itself of the taint (I can only call it that) of its 38 percent common carrier ownership? Because that may be the key to COMSAT's fitness to manage such a program. And finally, how do we carry our case to the FCC and the Congress to keep the door open for us to play a more complete role in time to come?

What I am most concerned about is that we do not just think of our future in terms of cable TV alone. We must not limit our

thinking in that way. The communications storehouse if full of new technology and new concepts. Cable TV and satellites are two of these -- but only two of many available to those with the vision and courage to use them.

Those two words -- vision and courage -- have been descriptive of our industry in the past. I hope they will continue to apply. For how these new developments are used, and by whom, will be immensely important to our own American society and to all of civilization, and certainly to all of you in the cable television industry.

FRANK W. NORWOOD

I want to begin by saying that I'm very pleased to be here, not only because the idea of combining the technologies of cable and satellite is a very exciting one, but even more so because your interests in the new opportunities which technology is opening up are very close to those of the Joint Council on Educational Telecommunications.

Let me take a minute to tell you a little about the JCET. We are a consortium of fourteen national non-profit educational organizations, including the National Education Association, the American Council on Education, and National Educational Television. Just as the JCET led the effort to reserve channels for ETV in 1950, our job is still that of alerting educational community to new developments in electronic communications and to the formulation of new public communications policy.

In December of last year, the JCET, with the help of the Charles F. Kettering Foundation, held a National Conference on Telecommunications Policy and Education at the University of Georgia. More than one hundred people from education and from communications were invited. Fred Ford and Wally Briscoe, Bill Carlisle of the NAB, Dan Karasik from Comsat, and others of you who are here today attended that meeting. Our central message was that American Education had best focus a weather eye on what is happening, and what is about to happen, in cable communications, in satellites,for domestic and for international use, and on the regulatory structure within which the new technologies will develop. Today's meeting bears out the fact that our predictions and our concerns were well placed. What seemed to be "futuristic" to some of the participants in our December meeting is already on the docket of today.

Our message to the educators gathered at our national conference was that the interests of educators and communications specialists are going to become increasingly intertwined. Educators, we said, have got to make themselves aware of what's going on in the field of communications. That's still my message to this national conference, today: The interests of educators and communications specialists are going to become increasingly intertwined. Communicators have got to make themselves aware of what's going on in the field of education.

Six months ago, in Georgis, we were talking about cable and about satellites. Today, here we are talking about the two in combination--two new means of communications, each independently capable of making significant changes in our communications system. Put them together, and the whole is even greater than the sum of the parts.

Satellite linkages clearly offer the possibility of new and different kinds of national programming for CATV--true program diversity. I suggest, though, that we not let these possibilities distract our attention to the opportunities and the challenges of locally-originated cablecasting. NCTA members have already demonstrated the CATV can bring a new kind of local television--the meeting of the town council, the campaign for state assembly, the Little League game in Inwood, school programs in Moab--to areas which have never had real local television before. That kind of local television is not only new to Loose Gravel, Wyoming--it's equally new to Beverly Hills and to Spanish Harlem.

I've been saying that education and communications have a lot of interests in common. Satellite communications is one of them. On June 13, the National Aeronautics and Space Administration invited a number of interested parties to discuss the possibility of new experimentation for NASA's Applications Technology Satellites. Comsat was at the meeting; so were the common carriers and the networks. So were some of us from education; the Corporation for Public Broadcasting, National Educational Television, the National Association of Educational Broadcasters, the JCET and the Ford Foundation. At an earlier meeting, we had agreed to ask John W. Macy, Jr., President of the Corporation for Public Broadcasting, and Fred Friendly, of the Ford Foundation, to speak for all of us. We put forth the outlines of an experimental proposal in which you may be interested. The experiment would do four things:

I. Transcontinental Interconnection for Public Television, linking some of ETV's key stations on the East and West Coasts using the ATS satellites and NASA's existing earth terminals in North Carolina and California.

II. A "Satellite Cities" Demonstration, in which some five or six cities would have their own, new, earth stations--some receive-only, some two-way--for public radio and television and for other educational communications.

III. Remote Production Capability-- One or more portable earth stations which would permit Public Television, and others, to originate programs from relatively remote areas on short notice.

IV. A Satellite-Based Radio Network--interconnection for noncommercial radio stations via the VHF narrowband transponders of ATS I and III.

In each of these configurations, other educational applications, in addition to noncommercial radio and television, would be explored. It's not too much to imagine that CATV might have a role to play. For example, how about exploring the potential audience for noncommercial radio in those many areas in which no educational radio station exists. For radio receive-only terminals, the costs are lower than for television by an order of magnitude. At $2,000 per system, one might deliver the national noncommercial radio service via a CATV system in Wyoming or Alabama.

I want to make clear that I'm talking about satellites which exist right now. ATS I and III, on which these proposals are based, are now over the Equator. ATS E will be launched this year, and F and G in the early 1970's. I suggest that you should be talking with our Task Force on Satellites, as well as with Comsat.

Your own plans, outlined at this meeting, also demonstrate to what degree we are interested in the same things. Of the six satellite channels proposed today, at least three, and I should argue four, of the six are to provide services in which the JCET and its members claim some experience and expertise.

The idea of turning over one channel to the Corporation for Public Broadcasting is very attractive, as is the assumption that CPB will fund the costs of filling the channel up with programs. I think you'll find John Macy and company interested in the idea, but they'll also call your attention to the fact that the thirty-five areas which the satellite and CATV will serve are areas in which there is already a Public Television station. Is CPB to fund a second program service which is competitive with the ETV stations in those areas for dollars as well as audience? If not, then the CATV systems can pick up CPB's programs off-air from the local ETV stations, just as they do now, and the satellite will be redundant.

A second channel, we've been saying, will be turned over to CPB or HEW or somebody, for instructional television programming. Indeed, you could run a full schedule of college courses, but we'd better move on to the question of who is going to pay for the program production...and who is going to sign the diploma. That project can only be undertaken with the full cooperation of America's colleges and universities.

The same thing is true with the channel for Health and Medical Education. Medical schools and medical associations are already engaged in using television, but doctors and nurses, like professors and school teachers, are an independent lot. It's certainly going to be necessary to talk at length with the people in the field of medical education before you can predict how that channel is going to be used.

Finally, I'd argue----and you may disagree--that full time coverage of Capitol Hill ought also to involve some of the JCET-types. You've budgeted figures for live, real-time, coverage of the Congress, but is that going to be the most effective way to do the job? Perhaps the afternoon debate on ABM may be more interesting than routine business which happens to be live in prime time. "Sitting in the gallery--via satellite" is going to be a lot like reading the Congressional Record from cover to cover. Sometimes tremendously exciting, but often deadly dull. If you tape and replay that afternoon ABM debate, which would be simple enough, you're into the area of interpretative reporting. That, in my view, is the area in which you ought to move. NET and the rest of public television has had considerable experience at that, and I suggest that you ought to tap that experience.

The educational community is exploring other areas which may also relate to "CATV via Satellite": wideband data transmission, retrieval and facsimile of library documents, and the like.

In summary, what I have been trying to prove is this: for both of us, new technologies are creating new opportunities. Just as the face of communications is changing, so is the face of education. For the details of that story, stay tuned for tomorrow's luncheon speaker, Dr. Gabriel Ofeish. (Incidentally, this is the third meeting in two weeks at which I have had the opportunity to hear Gabe. I caught his "out of town" tryouts in Vincennes, Indiana, and in Atlantic City, and I can tell you, you're in for a very exciting address.)

Our interests are rapidly converging--in fact, they have already converged. I don't think that we can really talk about "CATV and Satellites." I think there are three legs to the stool. We've got to talk about "CATV and Satellites and Education." Toward establishing that broader dialogue, let me close by offering you whatever help the Joint Council on Educational Telecommunications can provide.

NATHANIEL E. FELDMAN

My statement is made as an independent consultant. Any views expressed are my personal comments, and should in no way be interpreted as the opinions or conclusions of The Rand Corporation or any of its research sponsors.

Cable TV has been proposed as the means for providing greatly improved local programming in addition to a host of new services such as shopping via TV, polling, and facsimile services (electronic transmission of printed matter to the home).

I should like to discuss a scenario--one which extrapolates cable TV toward the limits of what is being proposed as its role--and then explores some implications of the resulting system.

If cable TV is to serve a community with local programming, then it seems desirable that the point at which programming is inserted into the system, i.e. the head end, be located in the community, and perhaps centrally located in the larger communities. It has been stated that the present design of wired distribution systems can cover an area of about 200 square miles from a single head end with good reception of up to 20 channels. On the basis of this figure, the 3 million square miles in the 48 states could be served by less than 15,000 head ends. But any such number, based purely on technological limitations, should be viewed solely as a lower bound. Other considerations should determine the number of head ends or input points to the cable distribution network. For example, if the basis were identifiable and distinct local political units, a more desirable number of head ends for emphasizing local programming would perhaps by about 35,000, since in January 1967 there were 18,048 municipalities and 17,105 towns and townships in the United States.

But another, perhaps more desirable, basis would be distinguishable groups or neighborhoods. Despite evidence that even in a major city a distinct neighborhood may consist of at most about 25,000 households, the planned number of households per head end in one major city is running over 100,000. If local programming is to realize its full potential, the number of head ends in the cities should relate directly to distinct neighborhoods rather than to an entity as large as the congressional district. Both local programming and picture quality are better served by a reduction in the length of cable between the head end and the farthest subscriber in the system. On the basis of the distinct neighborhood approach to determining the number of head ends, the optimum number of head ends might be as many as 50,000 rather than the 35,000 based on the number of municipalities, towns and townships.

Compare this number with the present number; there are at present about 2300 systems and perhaps about 2500 head ends. The increase

is about a factor of 20. If one were to reach this number of head ends some time in the 1980's when the number of U.S. households will have increased from the present 60,000,000 to about 100,000,000, the average number of households per head end would be about 2000--roughly the same as the average number of subscribers today per CATV system! This small average number of subscribers per head end must support the local programming.

Analyses of the cost of local programming for public service, neighborhood, and community use channels contain a major flaw. The usual practice is to use present programming costs, taken from data on existing commerical, educational, and instructional stations, as a basis for the future. One of the desirable characteristics of a future system is surplus channels to be used as needed, without the intense audience-attention competition and attendant high cost per minute. It is this pressure to maximize mass audience on relatively scarce channels that leads to intense professionalization of software. Monitoring the local school board or zoning board meeting, or airing the activities of the local junior high school, need not cost as much as commercial operations or well-planned televised pedagogy.

There is some data to indicate that local-interest and special audience programming can cost as little as $100 per hour. Industrial and business-generated programs for internal consumption, i.e., for select, highly motivated audiences, involve little more than the cost of the videotape, which is about $65 for one hour for recording an ongoing activity. Thus only the marginal costs of about $100 per hour may be legitimately attached to the videotape recording. Local event programming costs for cable TV do indeed approach this low value.

This example suggest that, to minimize the costs of programming, the CATV operator function as a rental agency, renting out videotape recorders and camera equipment and providing playback booths where the renter can monitor his videotape as well as run it for distribution over the CATV system. Students and other amateur groups interested in presenting their own programs can rent the video equipment. If costs for local event programming can be consistently maintained at $100 per hour or below, many new uses are likely to be found for cable TV.

A cable system can look to the viewing audience as well as to the local advertiser to cover costs. Thus the cable systems can propose low-cost programming to fill up excess channels.

If local programming is to thrive, everyone who is interested must be capable of generating programming and must be able to obtain access to the distribution network. For the fullest utilization of cable TV for local programming, therefore, channels must indeed be plentiful. At least one role of the CATV operator would have to be that of the common carrier--providing channels for a fee.

For the new services to succeed, note that is is necessary that distribution costs be negligible. This may not be sufficient, however, since special terminal equipment may pose problems and require appreciable investment.

Since 1968, systems are being built with 20-channel amplifier equipment. Although there are problems with picture quality in many existing systems and the problems become worse as the number of channels increase, improved solid-state amplifier and filter components are likely to solve these problems.

Next year, 25- to 30-channel equipment may be readily available, and 40-channel equipment will probably be available at litte extra cost in two or three years if there is such a demand. Solid-state amplifiers with flat bandwidths of 1000 MHz are available for use in sophisticated microwave equipment today, although they are exceedingly expensive. The use of such broad bandwidth amplifiers in a cable distribution system would permit sending more than 100 channels of television over a single cable.

To carry more channels, cable distribution amplifiers require not only more bandwidth but also more gain to offset the higher cable losses at the higher frequencies. Developments in the semiconductor industry ensure that the cost per amplifier stage measured in cents per unit of gain-bandwidth product will continue to drop drastically every year for some time to come. Perhaps only ten years from now the cost of solid-state amplifiers suitable for amplifying 100 channels of cable television may be only a little more than that of present amplifiers suitable for amplifying 20 channels of television.

The previous discussion suggest that some indefinite time on the order of 10 years must elapse to achieve about 100-channel capability and that this is some "end-of-the-road" limit. Neither of these is true. If four of the present ubiquitous 12-channels cable were installed in a single duct in one operation, along with four sets of 12-channel amplifiers, one could have a 48-channel TV distribution system tomorrow. Due to some economies of scale and some learning effects, the cost per mile of the operation is likely to be only 2 to 2.5 times as much as a single cable for the cheapest system, and much less than this factor for the most expensive systems. In 10 or 20 years, a four-cable system could provide 400 channels of television.

How might one use so many channels? How could one pay for the programming costs? One of the first uses for additional channels would be to repeat existing programming so that the viewer can see a given program when he wants to see it. Since some areas of the United States now receive 13 channels of television, mere repetition of this material on other days and at other hours could

consume 30 to 50 channels. TV watching like moviegoing, could become more discriminating; one could consult reviewers and friends about a program before committing time to it. Note that such extensive repetition of commercial TV would involve no additional costs for programming preparation.

The 100 most popular lecture classes on the university campuses each hours could be made available to a larger audience if a large number of channels were available; students who preferred could listen to the lectures at home, as some now do in dormitories. Lectures also could be repeated at several hours of the day to make them more readily avialable and to help those who want to hear the material a second or third time. Colleges and universities could become primarily places for small discussion groups, section meetings, and laboratory work. The money spent on large auditoriums and lecture halls could be made available for other needs. This approach might help alleviate the inexorable rise in costs per student for education, compounded by the increasing number of students applying for admission each year.

University education has functioned as a filter through which only the hardiest, most highly motiviated, and best equipped pass through. In an industrialized society where education is essential, such a filtering technique serves neither the individual nor society well. If cable TV can make it possible for the poorly prepared to hear each lecture as many times as necessary to fully assimilate it, and to take each course required for a university degree as many times as necessary, then it can indeed make a fundamental contribution to improving the quality of life for many.

Recent British discussions on the establishment of an open university by broadcasting lextures over BBC during prime time in order to reduce the cost of a university education, make it more readily available to all, and make it a more pervasive component of life at all ages, indicate an awareness of the potential value of plentiful TV channels.

The full benefit of instructional television in the home is likely to be realized only in a highly disciplined and motivated home environment. Thus, realizing the potential of cable TV will require much experimentation with programming and teaching techniques and aids to try to circumvent these fundamental obstacles. For some material, a higher payoff may result where the instruction can be integrated with on-the-job training. The work environment may be less distracting and may make the subject matter more relevant. In many cases, motivational reenforcement and rapid reward are more likely to be found on the job.

During evenings and on weekends, channels could be used for continuing education at home for a variety of professionals: doctors and paramedical personnel, dentists, lawyers, scientists, and engineers. The costs of these programs, i.e., for the continuing education of professionals, could perhaps be recovered on a pay-TV basis: a charge per course or lecture series in addition to the monthly cable charges. The number of hours offered for a particular specialty in this case need not be arbitrarily set. It can be determined by those who need and use the service. In fact, to maximize the quality, relevancy, suitability, and variety of programming material offered for continuing education, pay TV is perhaps both the simplest and the best solution.

Every automobile mechanic and home appliance repairman faces the same problem as the professional in trying to keep up with his field. If he is to be helped to maintain and refresh his competence, courses must be relevant, convenient, and timely.

Some of these channels could also be used for televised conferences. While pay TV has been suggested for supporting the programming costs of instruction for professionals, industrial support can be anticipated for channeling people into activities suffering from a shortage of personnel, and government support may be available for enriched and remedial education for school children.

Instructional television perhaps should be committed to the simple goal of effective self-improvement; such a nonelite principle best serves the objective of enlisting television in the service of diversity. Between formal and informal education, vocational training and continuing education for professionals, and avocations or hobbies, instructional television can make a contribution to everyone. To the extent that instructional TV can provide some professional, vocational, enrichment or remedial programming for everyone within the home or at work, or that local programming or specialized fare can at some time appeal to each viewer, it transforms TV into a rich menu of usages. The problem of audience capture for an evening by a single channel may be eliminated; in time, a more active and critical use of the medium by the general public should emerge.

Instructional programming aimed at the continuing education of professionals often must be timely (except for that part which constitutes basic instruction). Interest in a discovery, conference, or state-of-the-art survey tends to wane with age. The routing of film or magnetic tapes among thousands of cable systems on a sequential basis can thus be unsatisfactory, and on a parallel basis it is inordinately costly. Basic instruction tends to be on roughly the same schedule everywhere, and thus would also require a parallel operation. To store ten hours of programs for

100 channels at each of 50,000 cable head ends for simultaneous transmission at a cost of $65 per hour of videotape would result in a total cost of $325 million just for the tape for one day.

Can you imagine the problems of handling just 100 videotapes each hour--the personnel required to operate 100 video tape playback units! Instructional programming on the scale suggested could perhaps be best carried out by interconnection of cable head ends and an automated transmission system. The most likely alternatives for such interconnection are cables or satellites.

To be compatible with the present scenario, a communication satellite system would have to be capable of providing between 100 and 400 channels of TV to on the order of 50,000 cable head ends. One approach would be for all head ends in the same time zone to receive the same programming. If cable TV were to evolve in the directions suggested over the next few decades, then it would be desirable that any communication satellite system used for providing networking among the head ends, i.e., real-time interconnection, be capable of evolving in the same direction.

What about direct broadcast satellites? Any satellite system for direct broadcast which offers up to 10 channels is limited to networking for current commercial and educational needs. Ten channels can be a useful capability for isolated areas such as the seashore, the mountains, and the desert regions and for mobile users for whom no good TV signals are currently available. It does not appear to be economically feasible to supply these isolated and mobile users by other techniques.

For very large numbers of channels, there appear to be two advantages to satellite networking to cable TV head ends and subsequent distribution by cable rather than direct-to-the-home broadcast satellites. One is that the cost of the earth station can be spread over 500 to 25,000 subscribers rather than borne by each subscriber; another is that the frequency spectrum per satellite can be utilized more efficiently. A low-cost terminal receiving 100 high-quality TV signals from a single satellite must rely on significant signal-to-noise improvement by wideband deviation, i.e., by using large index modulation. The more expensive terminal at the head end of a cable distribution network can use a narrower bandwidth. Higher frequencies would be necessary for a system providing 100 channels of TV direct to the home which would tend to raise the costs of the terminal equipment. With wide-band modulation, e.g. 50 MHz per TV channel, 20,000 MHz would be required for 400 channels! With a narrow-band system, less than 4000 MHz might be required.

Perhaps over the next few decades some new exotic techniques, e.g. laser beams, may prove to be the best way to solve this networking

problem but at the moment it seems doubtful. The primary competitor to the satellite interconnection system for head ends is likely to be a cable interconnection system.

DISCUSSION

MODERATOR CONROY: We have a very limited amount of time for questioning. There are two additional people on the platform with the COMSAT Corporation here for the purpose of participating in a question-and-answer period. They are Mr. George V. Hart and Mr. Louis D. Hinton, director of rates and revenue requirements.

MR. OWEN EDDIGAN: If it will cost $230 for 30 receivers, if the present 2,300 systems require a receiver or even going to your 30,000, what would that drop the price down to so each individual system would have a procedure?

MR. ROBERT BRISKMAN: You will find the satellite is the prime controbutor to the cost; the annual cost with the design, depreciation in the year's satellite. You recall a seven-year design lifetime. And put up these large satellites that would be very precise and which also radiate amounts of power. It costs a considerable amount of money and essentially the space costs are dominant.

MR. IRVING B. KAHN: Am I to assume that you wouldn't have any objection to having the cable companies own their own ground station?

MR. BRISKMAN: I don't think we have a policy on that matter at the present time. As you recall, the real questions come about, what is the ultimate use? The CATV -- and I would think its people -- everyone has their own opinion on how the system will actually come about.

Now, I think you find very quickly who would send up these systems in the earth stations and then I think you could probably make an intelligent choice on who in the long term should own this. I know this is not a very satisfactory answer, but it's about the best you have.

MR. FELDMAN: The point I would like to make is the present round turn would be about $2 1/2 and $6 million apiece, and therefore there will be a big fight as to who is going to control that.

If you are going to get to dealing with all the headends, you get to 50,000 headends. The pressures might well be inducive to go to a system.

MR. LOUIS SERVAN: The gentleman from Rand Corporation talked about the point that every TV owner in the latest crisis -- satellite signal -- so that your TV set can receive it. What is going to stop a citizen from making a $250 unit -- and all this is in big brands, -- lend a helpless citizen and makes technological know-how to have a $150 unit.

Or is it the intent of our mistreatings to make it difficult while having the signals so quarterly that instead of using $150, you would have to pay $115. So I still do not grasp the significance of CATV combined with satellite or the satellites of the air.

MR. EARLY: A $250 set like you are referring to is not compatible with CATV. Considering the satellite will probably be available, perhaps by 1980, we have a tremendously expensive device. Maybe $15 million by the time we have launched one of those birds.

There are two different types of systems. They can be compatible but not competitive.

MEMBER: The last point the gentleman from Rand Corporation made, he alluded to the relationship between commercial network and the use of satellites in CATV. I wonder if you would recall the rephrase of the last remarks you made prior to the gentleman from Pennsylvania.

MR. FELDMAN: I don't think I talked specifically about this -- specifically to direct broadcast to the home to what extreme of present operations with communications satellites.

MEMBER: I guess I misunderstood about that.

MEMBER: I don't believe you answered this question from the gentleman from Maine completely. You asked, it seems to me, if the cost of the ground stations wouldn't put down after they were installed in more volume than the 39 that we indicated. Your answer was that the cost of the satellite would not change and I think we recognize that the satellite makes the whole system, regardless of whether it serves 39 stations or 3,900 stations.

The cost of the ground station was $230,000 on the basis of nine. Does it not seem reasonable there would be, perhaps, only $100,000 if we were on the basis of 2,000 or more, and would this cost largely be recouped by the costs of the terrestrial system which might have to carry the system over the 100 miles to the headend.

MR. BRISKMAN: My answer was correct. Yes, in very high volumes, production, very high numbers, that price would likely go down. I don't think I have speculated on $100,000. But commenting on production, you would expect a decrease in price.

With this decreasing price, it becomes more economical to put in more earth stations and increase your pensions on terrestrial stations, and this does then save the overall price.

ORATOR - EYE-OPENER SESSIONS

CABLECASTING WORKSHOP NO. 1:
Electronic Editing

Session Chairman:
Greg Liptak

Participant:
Matt Spinello
"Electronic Editing: The Ultimate Production Tool"

MATT SPINELLO

Electronic editing in the one-inch videotape format gives engineering technicians the professional capability of eliminating "dirty edits"; costly, time-consuming retakes; and the scraping of hour-long productions due to short segments of outdated material within previously taped productions.

Producer/directors employ the editing capability in the creation of multi-scene, involved productions. A single camera/recorder system employing electronic editing eliminates the need and expense for several cameras, operators, monitors, and control rooms normally required for a segment which might demand twenty various scenes spread throughout a taping location area.

Electronic editing, utilized in a present day CATV system gives the facility a full-fledged studio/control room/staff capability, at the expense of a single camera/recorder system, with a minimum staff of two: Producer/director/camera operator, and technician.

We have perhaps become so accustomed to the polished network productions we see today on commercial television and we have forgotten the many humorous incidents piped into our living rooms in the days prior to the availability of videotape, which first gave studios the ability to reshoot a segment, and eventually the editing capability to redo short portions or entire scenes within a production.

During one of the late President Eisenhower's whistle-stop campaign tours in New England, several television and radio studio crews were on hand to pass Ike's "live" comments to their audiences. As the story goes, five or six radio stations had strung cable from their remote vehicles to hand-held and mounted microphones; TV studios had placed similar equipment and TV cameras on the train station platform. Fifteen minutes prior to Ike's scheduled arrival word was received that the train would be arriving on track number six, instead of track number one, as originally scheduled.

Engineers, announcers, and TV cameramen scampered to add extensions, wire new cable connecting, and stretch their equipments across six pairs of railroad tracks.

Fifteen minutes later President Eisenhower's train arrived, on time, on track number one, as originally planned, severing all cables.

Thousands of viewers in the Midwest will recall a one-minute dairy products commercial aired in the mid-50's, written to spotlight the sponsor's ice cream and cottage cheese, with the last twenty seconds devoted to homogenized milk. The milk scene included the usual pour shot, with an extreme close-up of a drinking glass, the sponsor's carton of milk clearly identified,

and the announcer's hand. The female voice urged, encouraged, practically demanded that mom consider her children's health; that she buy the sponsor's product since it was as nourishing and delicious as it appeared on screen. The video side of the commercial at that point brought a drinking glass into viewers' homes, the size of their TV screens. As the talent poured, giant lumps of sour milk filled the glass.

Other viewers will recall a pitch by a sincere announcer who promised that the plastic automobile seat covers being shown were waterproof, fireproof, practically indestructible; they were, we assume, until he poured lighter fluid on the sample seat and lit it with a match, while viewers witnessed "live", the total flaming destruction of the seat and seat cover, in a matter of seconds.

The same announcer several months later left television to return to radio following his "live" demonstration on how a special exterior paint repelled water. A cement block was used as a demonstration sample; one side coated with regular (porous) paint, the other with the new repellent product. During the live demonstration, the announcer forgot to reverse the brick, and while expounding upon the quality of the product and its repellent characteristics, applied water to the surface of the brick. It was immediately absorbed deeply into the brick as though it were a sponge.

There have been other incidents, hundreds possibly thousands. The announcer who, on "live" camera, reached back toward several shelves to bring a beer stein to camera-front, failed to notice that one of his large, ornamental cuff links caught the thin wire shelf support. When he moved his hand forward, the shelving, supported by lightweight pegboard, moved with him enough to spill 150 ceramic beer steins to the floor in a thundering crash.

Possibly the most repeated incident relates to a pet show, another "live" segment, where on an extreme close-up, a spider monkey chose to put himself in the spotlight by grabbing a parakeet and biting its head off before the camera operator could pan away or the director could call for a shot change. The incident enabled the studio to determine what their viewing audience was at that particular hour of the day, since, as one spokesman relates, the switchboard received a maximum number of telephoned complaints from irate mothers and grandparents.

The aforementioned incidents when retold are very humorous to most listeners; they were not too funny when they actually happened, especially not to sponsors who canceled contracts because of them, and possibly generated lawsuits against the studios involved. They may be humorous sidelights in the career backgrounds of those who were involved in the individual productions; they were not funny at the time to those who may have been fired

because of their negligence in failing to preplan each segment ahead of time.

Videotape today gives the director, the engineer, the talent, another chance; in fact, as many chances as needed, time allowing. An editing capability lessens the pain even more by allowing replacement of the shortest or longest portion of a segment without sacrificing the entire production. The videotape recorder with editing enlarges the studio area by allowing segments to be taped individually, in sequential order. Most important to the system's budget, electronic editing provides the capability of scene-by-scene assembly for the most elaborate productions, with cost of equipment limited to a single camera/recorder/monitor system. It permits professional quality productions by less experienced personnel. This is an important consideration to CCTV or CATV videotape presentors.

The moment of truth in the matter lies with the end result achieved in the final videotaped presentation. At the Ampex Video Institute in Elk Grove, Illinois, west of Chicago, the instructors who deal with the production aspects of the institute's TV courses, intentionally overemphasize the importance of production preplanning; detailed preplanning. Reference is continually made to the "Monocular Eye", the non-dimensional TV tube, during the week-long courses on CCTV, and how it relates to the viewer.

Joseph Sheehan, Professor, Georgetown University, stated earlier this year in his opening remarks to the Northeast Conference on the Teaching of Foreign Languages, "A child has seen at least 4,000 hours of television by the time he enters kindergarten". That makes him an expert where the Monocular Eye is concerned, since he is consciously or subconsciously aware of a certain level of quality and content on any segment or portion thereof to which he is exposed via videotape, film, live or slide materials fed through a video monitor/receiver.

If a finalized presentation includes distractions such as out-of-focus scenes, jerky pans, tilts, zooms, or any one of the disastrous incidents mentioned earlier, the viewer, kindergarten newcomer or adult armchair veteran, may be taken more by what to him is considered humorous. The average viewing background of most audiences has been tabulated at from 15 to 20 years. This is a mass video educated audience that cannot be misled. A disinterested viewer, agitated by a dull, flat-lit telecast, with a variety of production flubs included, becomes a "channel-switcher". In the case of a captive audience that must remain in their seats, regardless of program content, they may be able to apply the technique used by various rebellious groups. The video and audio may be evident, but the disinterested can "tune it out", mentally.

A "running" segment, where a director must coordinate the efforts of several camera operators, a video switcher and talent on-stage, is a time-consuming venture involving detailed planning, rehearsal, and experienced personnel in every position. The final viewing audience of a production has no chance to see the overall studio arrangement, has no way of knowing that an ace camera operator, out with the flu, was substituted with a secretary who has perhaps never seen the backside of a TV camera; or that someone inadvertently walked through the studio area during the production and kicked the wall plug from two important lights, creating a near blackout during a critical point of the production. In fact, that audience to whom we are attempting to convey a message, to train, sell, basically to communicate with, couldn't care less about what our problems were. They can only judge our efforts by the final result as presented to them on the TV screen.

The network strikes of several years ago proved this point when executives were pressed into the positions of announcers and engineering technicians following walkouts by experts in those areas. Audiences were immediately alerted to the distractions of high, squeaky announcements, with occasional word-fluffs, in addition to audio from one source being aired with video from another. Audiences were humored by it all. If asked the next day whether they witnessed the mistakes of the evening before, most viewers would have been in a position to explain in detail what went wrong. However, it is doubtful they would have remembered what message the temporary announcer meant to convey.

Electronic editing, properly utilized, can serve the small, medium-sized, even the largest facility, as a form of magnetic insurance policy to produce effective, usable, salable video-tape productions. It can cut costs, professionalize final segments, and command viewers to accept the message.

A lengthy script, broken down into short segments can be more readily memorized by an inexperienced talent. Editing allows the individual to deliver short swatches of material, take time to collect thoughts for the next portion, tape it, view it for acceptance or retake, and repeat the process for each portion until finalized. An instructor who may have spent eight working hours finalizing an involved presentation, may find months later that portions of the statistical material within the segment have changed. The eight-hour session need not be repeated. New statistics may be edited into appropriate portions of the segment. Sequences may require remote location of the VTR system for various scenes, to be incorporated with film or slide sequences. The entire production may first be shot on remote location, with an audio track laid down in the areas on the tape where film or slides may be later edited in, back in the studio facility.

The Ampex Video Institute's "Road Show" crew has been involved on a number of occasions in accumulating as many as thirty hours of material for various organizations on remote location. The segments were then returned to Ampex, screened, and the best scenes chosen for editing into a master tape. On one occasion the production team recorded more than twenty hours of tape 11,000 feet up, in the mountains in Aspen, Colorado, for 8th Interski, a congress of professional ski instructors. The best scenes were chosen for a one-hour master in which one hundred-eighty edits were employed. The edits appeared as individual "takes" or cuts when viewed on the final master. Audio for the production was added after the edited master was produced.

When the background noise in a factory sequence prohibits the recording of the audio track, the video scenes may first be edited together, and the audio added later under studio conditions. Conversely, for special effects put to music. An audio track might first be recorded, the video portions later assembled in time with the music.

Time lapse sequences may also be compiled with an editing capability to study the deterioration of a product under adverse conditions, or, in the case of plant life, to study its growth pattern frame by frame. Animation may also be employed in a form of building blocks. A word may appear to be spelled out letter-by-letter by editing each scene as letters are added one at a time.

There is no denying that the suggestions made here demand a skill, a knowledge, and somewhat of a background to initiate. However, the demands center around two individuals: A producer/director and a technician. The 20-scene production need not employ twenty cameras and operators to be coordinated through a control room atmosphere, nor twenty monitors for the director to check each operator's position and composition. One inexperienced operator may be "talked into position" prior to rolling tape for the scene. The immediacy of videotape then permits monitoring the scene immediately. If the scene is acceptable, the director "talks" the camera operator into the next scene, repeating the process until the segment is finalized to satisfaction. Should a decision arise following the finalization of a one-hour production which argues that a 45-second portion of the tape is poorly framed, amateurishly performed by the talent, or statistically incorrect, an edit at the point replaces the flub, without retaping the entire one-hour production.

Videotape and electronic editing will never replace film. There is a definite place and need for both. As stated by Wm. Mutschmann, President, Mutschmann Films, Inc., before an American Petroleum Institute gathering in Chicago last month, "Most of us are aware, or have seen how motion pictures have been used to assist in corporate communications, training, telling and industrial story, etc. That motion pictures are not produced on

a wider scale lies simply in the fact of. . .cost. They provide dramatic impact and sweep of sight, they provide sound and action -- but they cost money.

"The principal advantage of videotape is that you can achieve these important factors -- at greatly reduced cost. At the same time, a videotape program or presentation does something no film can really do, . . .convey the immediacy of a talk or action -- as though, like television, it is happening right now while you are viewing the receiver. . . .

"Duplicate prints of a 15-minute film, professionally prepared at considerable cost, run about $75 a print. Duplicate copies of a 15-minute videotape, professionally prepared . . . run only about $36 a copy. . . . In the case of a film production, and here I speak as one who has produced many industrial films, you sometimes shoot 10 feet of film that never get used for every one foot that does . . . . Such a degree of perfection, however, is not required -- nor is it expected by an audience -- in video-taping . . . .

"Take the $75 film duplicates and the $36 videotape duplicates I just mentioned. Suppose, as is frequently the case, it becomes necessary to amend or to change what has been done. In the case of the film, each of your original $75 investments must be written off; you can recall the duplicates, but you must shoot and edit new film and process entirely new duplicates.

"In the case of videotape, you can recall the duplicates, erase the video and audio images, re-record and re-distribute. And what's more, you can do this ad infinitum".

In the case of the classroom teacher, videotape, its editing capability, and storage and retrieval characteristics, will enhance, supplement and aid their processes of instructions. As far as videotape eliminating instructors in a form of duplicable automation, the facts may best have been summed up by an anonymous professor who last year stated: "The teacher who is fearful that he will be replaced by videotape, should be!"

The fact remains that CCTV, CATV, or Commercial Broadcast Facilities currently incorporating electronic editing realize the immediate value in the added capability. To electronically splice scenes, from a number of sources, saves time, costs, and rumpled attitudes of talent, studio personnel and engineers.

Those who have been exposed to the editing capability within the one-inch videotape format are in general agreement that use of the electronic editor eliminates three-fourths of the battle toward the pursuit of high quality videotape productions!

NATIONAL CABLE TELEVISION CENTER AND MUSEUM
211 Mitchell Building
University Park, Pennsylvania 16802

TECHNICAL SESSION NO. 2:
Microwave for CATV

Session Chairman:
Milford Richey

Participants:
Ira Kamen
Dr. Joseph Vogelman
"Quasi-Laser Link Modulation Means for
Wide Spectrum Airlink CATV Services"

J. Walter Johnson
"Cars Band Microwave,
What It Is and What It Can Do For the CATV Operator"

Hubert J. Schlafly
"AML Report"

The Quasi-Laser Link System has been designed by Chromalloy American Corporation and conceived by Laser Link Corporation to meet the needs of the "superburgs" of the future. This system has vast implications to wide spectrum services in the home. The highlights of this system are:

1. Acceptable television reception when the signal-to-noise ratio is lower than: S/N=15 dB

2. 20-40 channels can be transmitted simultaneously on a single carrier

3. The modulation bandwidth can be as much as 25% of carrier frequency

4. 15 dB signal-to-noise means multiple uses of the same frequency in the same locality with suitable beam orientation siting, without co-channel interference. (See figures 1, 2 and 3)

5. Unaffected by normal rain, hail, snow, etc.

6. Economical to operate and maintain

The Quasi-Laser Link System has met the above requirements with a novel modulation technique on which multiple patents are pending. The modulation technique manifests itself as pulse modulation of the electromagnetic carrier in such a way as to vary both the pulse width and the spacing between pulses as a function of the information content. This system has a tremendous potential of airlinking all buildings in an area with 20-40 six megahertz channels, when required, from a single radiating source. The system functions independent of frequency and can work with carriers consisting of long wave, infra-red lasers, and other quasi-optical wavelengths including microwave.

The Quasi-Laser Link Communication System as described overcomes the high linearity problem inherent to microwave systems. The Quasi-Laser modulation techniques provide reliable short distance links through rain, fog and smog and also permits broadcasting in an uncluttered spectrum not susceptible to distortion from aircraft. The system will be operative under all atmospheric conditions and could even compensate for very rare periods of hurricane rain, of large particle size hail, and extremely dense fog. Overall the system will have a greater service reliability than a conventional CATV wired-system.

The reference articles show charts and measurements which validate performance under all weather conditions.

The role of the Quasi-Laser Link in the future of communications could be appreciable since data collected in experimentation

conducted under research licenses granted by the FCC to Chromalloy American Corporation, which is developing the system, indicate that it can operate on any assigned carrier frequency within the band of 10 to 10,000 GHz. The current state of the technology is such that maximum economies are associated with the lower frequencies closest to 10 GHz.

In instructional television, for example, a 20-channel instructional television broadcasting system operating under the Quasi-Laser Link principles could be made available at a cost approximately equivalent to that of a 4 channel service in the presently authorized 2,500 MHz ITFS band.

The Quasi-Laser Link channel capacity is so expansive and versatile, two or more electromagnetic carriers on the same frequency, each with a 20-channel capacity, can be utilized in contiguous areas and their beams diffused in different directions without interference as shown in Figure 1, 2 and 3. This versatility "removes the lid" on the number of services and applications possible in a locality, all beamed to roof-top, down-converters and thence, by intra-building cable into existing black and white or color television receivers.

This system which eliminates the need to make an unprofitable deal with the telephone companies opens new vistas for the CATV operator:

It provides a basis for the establishment of new types of low cost communication services at the purely local level.

It provides a supplementary arm for educational television that assures ultimate fulfillment of visual broadcasting as an important "teaching tool" at scholastic and collegiate levels and improves the image of the CATV franchise holder in providing this service.

It is an economic means of establishing Community Antenna Systems in urban areas by surmounting the obstacles of trenching through concrete, while "blending" its service into master antenna systems and coaxial cable installations.

It paves the way for expanded Community Antenna Systems in rural or suburban areas by joining contiguous small communities, jumping highways, crossing rivers, surmounting terrain barriers - and doing so economically in lieu of cable.

It makes possible channels for municipal and civic services; medical information for physicians and surgeons; community social service agencies; religious denominations - and more without affecting the basic entertainment function of CATV.

To understand how to install a Quasi-Laser System we will take you through the procedures of an actual planned installation.

The procedures required from initiation to operation can be grouped into the following general steps:

a. Location of origination point

   (1) Head End for off-the-air TV signals
   (2) Studio facilities for local generation

b. Location of market

   (1) Market survey
   (2) Economic evaluation of potential receiving sites
   (3) Comparative cost evaluation of various combinations of cable and Quasi-Laser Links

c. Mapping analysis to obtain optimum paths and site locations including a determination of required tower heights and relays to get line of sight paths

d. Field survey in accordance with the variables arrived at in item 'c' together with angular measurements from both terminals of all obstacles within the 20 dB points of the receiving beams

e. Optical survey to establish details of construction required, azimuth and elevation heading for all terminals

f. Radio survey to measure path losses over each transmission path at the required frequency

g. Elevation plotting of all paths to determine potential obstacles and placement of relays or reflectors

h. Systems engineering of layout of transmitter relays, reflectors, etc. for maximum cost effectiveness including computation of power requirements, amplification, antenna characteristics, reflector dimensions, etc. based on environmental and propagation analyses

i. Prepare specifications for power requirements, land acquisition and easements and shelters required

j. Provide detailed specifications for all transmitter and receiver components, channel amplifiers and local site cable distribution equipments

k. Install transmitting and receiving antennas for each site and make field strength measurements to confirm path losses and component criteria

l. Install transmitting equipment and relay transmitters and conduct propagation tests to determine signal-to-

noise margin under the required degree of reliability, greater than 98%

m. Tie in TV channels to Quasi-Laser Link modulation and transmitter and install receiving and demodulation equipment at each receiver site and measure and received signal level of each demodulated TV channel, i.e., TV Channel carrier levels

n. Adjust input levels of individual TV channels for equal output levels

o. Conduct system propagation and signal level tests while system is operating

Shown in figure 4 is the transmitter site of a Quasi-Laser Link in New York City. The site is in a location with a clear view of the Empire State Building which houses all the VHF TV station antennas. The site is so located that there are no sources of potential reflection within 30 degrees of line of sight to the Empire State Building and no sources of potential reflection behind the receiving antennas.

The three TV receiving antennas shown are used to pick up the TV channels for retransmission by the Quasi-Laser Link. The small building houses all the front-end channel amplifiers and the modulation and transmitter components.

The parabolic antenna is three feet in diameter and operates through the open door of the building and is set up well behind the door opening to protect it from the elements. In this configuration the building must be erected such that the face containing the door is perpendicular to the path of the beam.

The receiving site is located in the window of a building so situated that it is in the shadow of the Empire State Building amidst many other buildings of equal or greater height. The location is such that normal reception of TV signals shows the presence of many ghosts. The receiving site requires the Quasi-Laser Link receiving antenna to look between several buildings which fall well within one degree of the center link of the antenna pattern on either side and below it. The nature of this site is such that 20% of the beam's energy is intercepted by the buildings.

Since the location of this receiving site precludes the taking of good photographs, a photograph is included of a portable receiving terminal being tested in Carle Place, New York. This unit is shown in figure 5. The microwave portion of the receiver is mounted in a small box behind the 3 foot parabolic antennas and the final demodulator and amplifier is contained in the box at the side of the antenna mount. In this text configuration a small TV set is used to view the individual TV channels.

At the present time, a reflector is being fabricated for installation on one of the buildings which intercept part of the beam to reflect the transmitted signal at right angles to another receiving site. This reflector consists of a 4 ft. by 4 ft. polished aluminum sheet reinforced by aluminum angles.

Other Quasi-Laser Link systems currently being engineered include an 11 site configuration spread over three counties in very mountainous territory. In this situation towers of sufficient height to provide line of sight between origination point and receiving sites are prohibitive in size and cost. To obtain satisfactory results tower mounted relays are installed on the highest available ridges even though this requires irregular paths between sites. The relay is an 80 dB gain amplifier between receiving and transmitting antennas cross-polarized with respect to one another.

Another installation uses two antennas on an existing head end tower fed from a single Quasi-Laser Link transmitter to connect four small towns to an existing CATV operation now carrying eight channels. The receiving sites feed cable distribution systems connecting to the homes of the subscribers. The Quasi-Laser Link provides an economical means for reaching widely separated areas over water obstacles.

In North America the most important fact about this development is that it links every building in the urban area via air and costs far less than trying to cable people for even partial TV service. It does take some business away from the telephone companies, will fragmentize some of the broadcaster's audience and bring back viewers who have the tuning out habit. However the FCC in their final decisions have always supported their responsibility to the people of the United States to make maximum use of the airwaves, and many of the frequencies needed from 10 to 40 GHz are unassigned. The system proponents are seeking the progressives in government to overcome the reluctance of those who do not recognize the growth of new communication services. It is time to overcome the fear of the future and break through the barriers and positively exercise governmental power.

It is anticipated that the synergistics of the Quasi-Laser Link system will open new entertainment, education and communications vistas for urban dwellers and businessmen who have the wit and the means to benefit from these Wide Spectrum Services.

This Quasi-Laser Community Antenna Television System opens a wide spectrum of services for multiple dwelling residents who may be airlinked by a grid of dispersed beams. The new air link systems will offer CATV, commercial and business subscribers all available TV and FM entertainment channels along with additional services associated with education, shop by television, business and computer data, continuous news and weather and for a host of other entertainment, industrial and educational purposes.

The application of this principle to satellites in the laser band will offer these services to all areas of the world on a very economical basis.

The new worlds the Chromalloy-Laser Link people believe they will create seem to confirm the words of Marshall McLuhan, the prophet of the media, who wrote two years ago, "The medium, or process, of our time - electric technology - is reshaping and restructuring patterns of social interdependence and every aspect of our personal life. It is forcing us to reconsider and re-evaluate practically every thought, every action and every institution formerly taken for granted." The hope is that this total involvement technology will create new understandings, new attitudes and make possible a new will for peace.

CATV is a new urban medium at this time and all of the development work to use this medium for the purposes outlined above are in process by industry, entertainment and service leaders. Urban support is expected as city leaders realize that CATV can inform, educate and entertain the citizenry and that the plus services of CATV can advance a city's growth pattern, aid in protection of life, property and ease transportation problems. Most important is that the installation and usage of a total involvement system will enrich a city's social and cultural life as well as permitting all to participate in the political process.

We must possess courage and vision if the communications world we talk about is to come to fruition. Those of us who participate in this NCTA conference will face our greatest test and challenges in the next decade. We cannot afford to make a wrong evaluation of the present, or in our prediction that the future of communications will transform our world into a new electronic environment. We must exploit and keep pace with change but not fall victim to it.

Reference articles on the Quasi-Laser Link System are:

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"Cabling without Cable", Ira Kamen, BME Magazine, June 1969.

20-CHANNEL ITFS QUASI-LASER SYSTEMS IN LOCAL SCHOOL DISTRICTS TO SUPPLEMENT ONE-CHANNEL VHF OR UHF ETV STATION INSTRUCTIONAL PROGRAMS AND CONFORM WITH "BELL SCHEDULE" OF GRAMMAR, INTERMEDIATE AND HIGH SCHOOLS

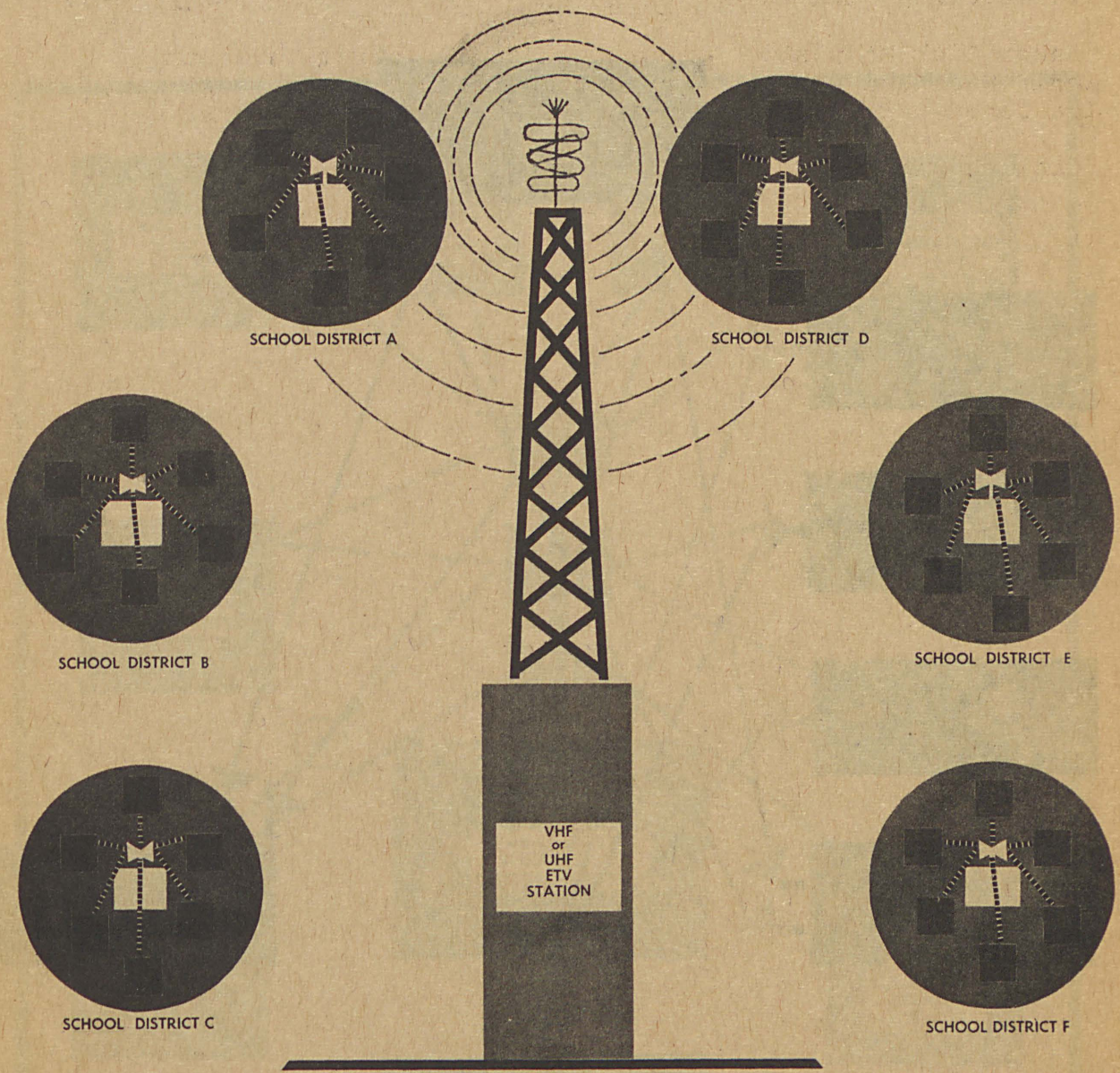


Figure 1

TYPICAL LAYOUT SHOWING USE
OF SAME FREQUENCY BY 3 DIFFERENT
BROAD BAND QUASI-LASER TRANSMITTING SITES
IN SAME LOCATION.

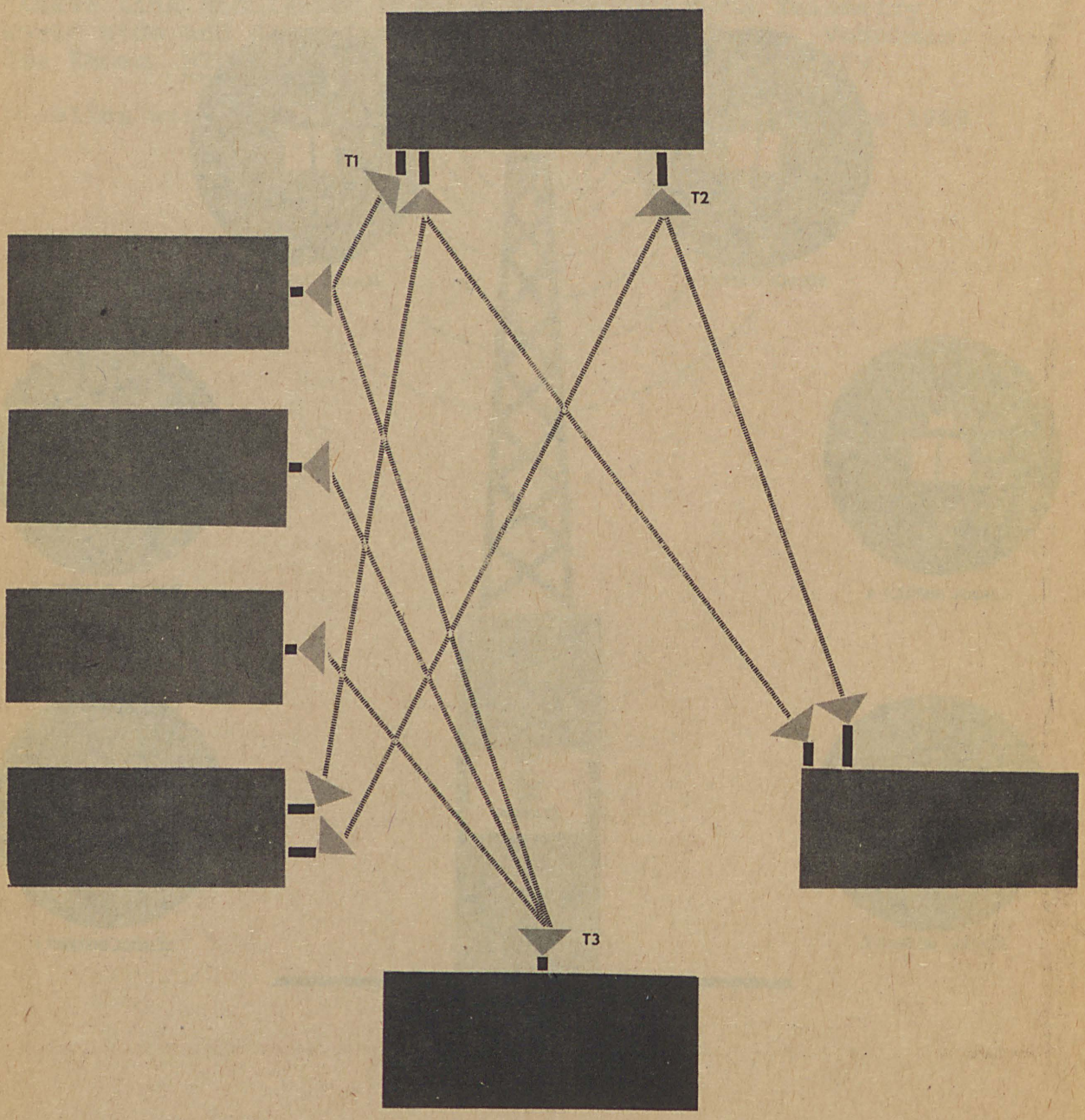


Figure 2

EDUCATIONAL, MUNICIPAL, CIVIC, RELIGIOUS AND INFORMATION SERVICES POSSIBLE ON MULTI-CHANNEL, QUASI-LASER LINK TV SYSTEM

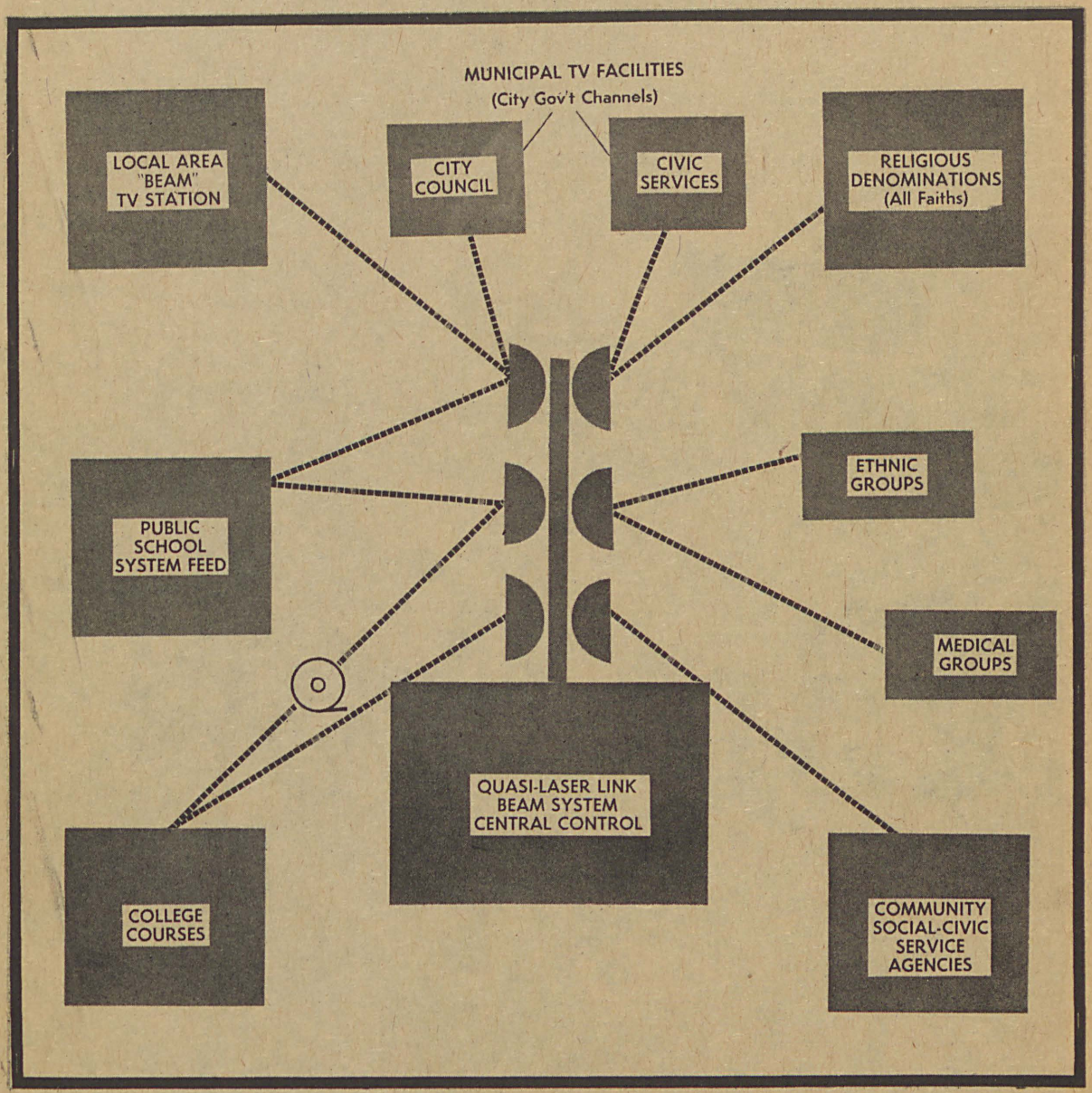


Figure 3

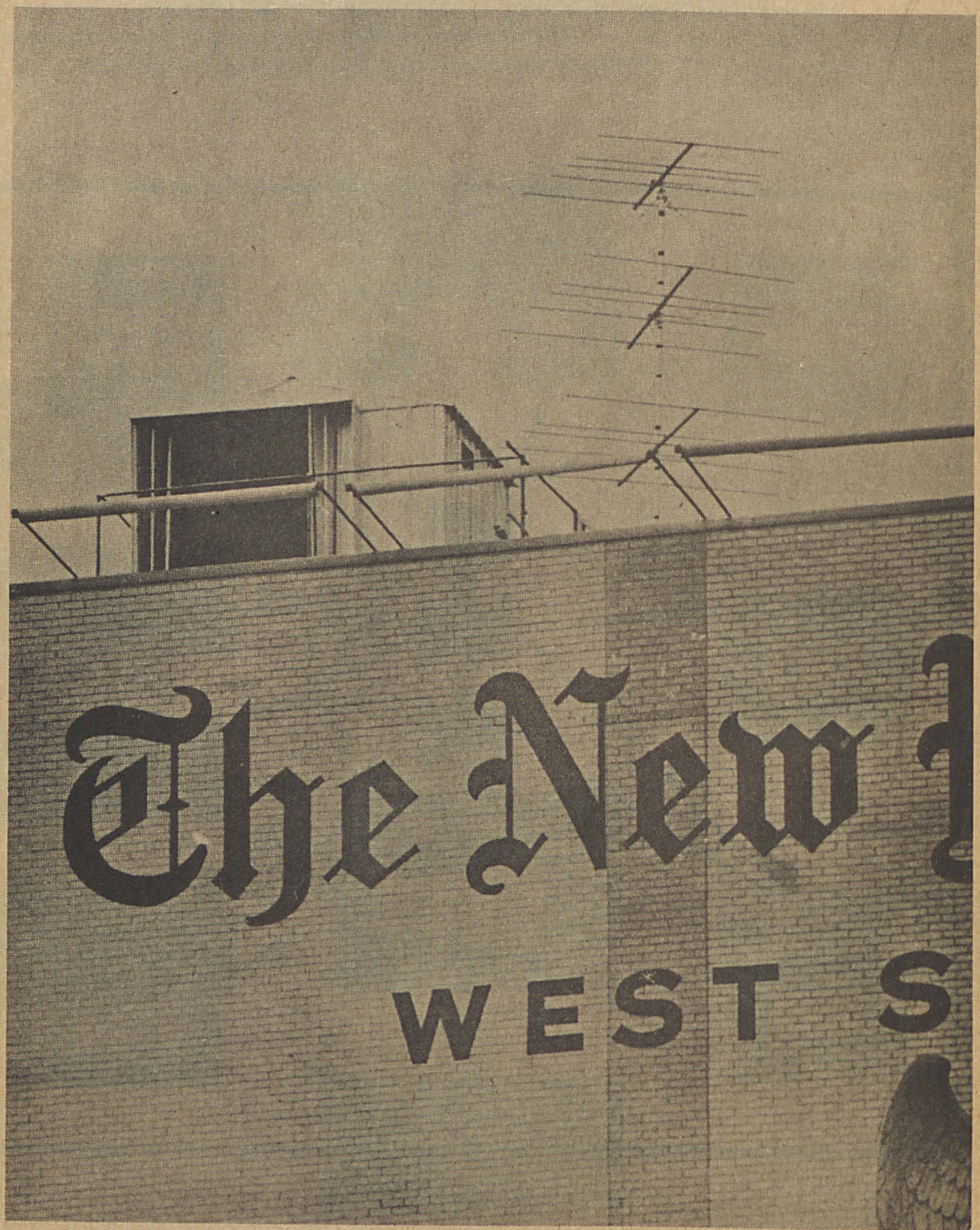


Figure 4

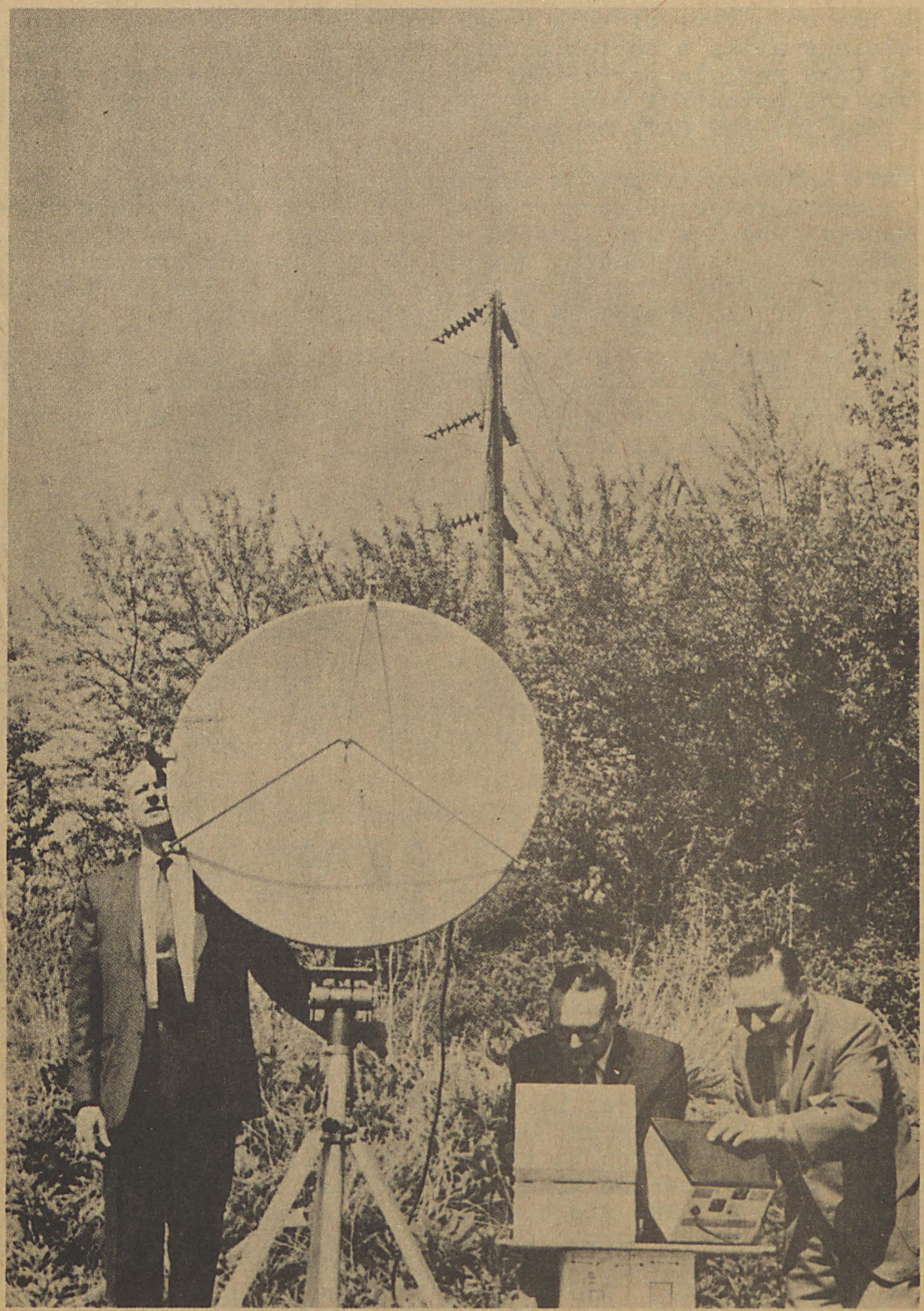


Figure 5

TECHNICAL SESSION NO. 1:
CATV Head-end Engineering

Session Chairman:
G. Norman Penwell

Participant:
Robert L. Pace
"R_x: Signal Processing"

ROBERT L. PACE

INTRODUCTION

The one place where a CATV Technician can still really be an individualist is inside his head-end. Some head-end installations get the floor scrubbed twice a week while others in the industry are virtually rats nests. Recently I called a Chief Technician's attention to the disorderly tangle of wires behind his head-end equipment racks. He said, "Oh, no man, I'm not going to do anything about that! That's my job security. They don't dare get rid of me because no one else could ever figure this mess out."

Every CATV Technician has his own special way of processing off air signals. I would like to pass on some of the methods which I have learned from helpful associates and many long nights spent in head-ends.

Nowhere in a cable system can money be more wisely spent than on well engineered and properly installed antennas. Antennas are an involved subject in themselves so I will not attempt to cover them in this paper.

Every piece of signal processing equipment should be checked for proper alignment prior to installation. This is especially important for equipment that is frequency selective. Although processing equipment may be carefully aligned at the factory it is often received in poor alignment after a few thousand miles of bouncing around in a freight truck.

1. PREAMPLIFIERS

Preamplifiers are designed to overcome downlead loss where weak signals are encountered. The benefits of using UHF and FM preamplifiers are often overlooked.

(a) BROADBAND PREAMPLIFIERS

Preamplifiers that pass all 12 channels are not recommended for CATV systems. However, preamps that cover either the low or the high band alone do have a limited place in a modern head-end. Broadband log periodic antennas are very popular now partly because several channels can be received from one antenna therefore saving valuable tower space. Broadband preamps are very handy to use with these broadband antennas. Cross modulation may occur however if all the channels received from a broadband antenna are not near the same level in signal strength. It has been my experience that input levels should be within at least 10 dB of each other to avoid visible cross modulation. Of course this problem is worse if the signal levels are high. It is possible to use only those stations received from the broadband antenna at near the same level and build a separate

(a) BROADBAND PREAMPLIFIERS Continued

high gain array for the weak stations with single channel preamplifiers. For example at one of our head-ends we receive channels 7, 9, and 11 at +3 to +8 dBmV and channel 13 at only -10 dBmv. All stations are transmitted from Mt. Wilson and received with the same high-band log periodic antenna. We have installed a broadband high-band preamp to overcome our downlead loss but only use channels 7, 9, and 11 from this antenna. We have built up a separate higher gain array for channel 13 with a single channel 13 preamplifier.

(b) SINGLE CHANNEL PREAMPLIFIERS

Preamplifiers are available with resonant cavity preselectors which are similar to a bandpass filter just ahead of the first stage. These preamplifiers can take more abuse from interference than broadband preamplifiers. In the presence of strong adjacent channel interference it may be necessary to cascade preselectors. Before cascading preselectors be sure the input and output impedance of the cavities are both 75 ohms. At times it may be necessary to supplement the preselectors with a narrow band trap to attenuate lower adjacent sound or upper adjacent picture carriers. Particular attention should be paid to the quality and temperature stability of traps for this purpose.

(c) UHF PREAMPLIFIERS

Do not overlook the possibility of improving UHF reception by using a good preamp ahead of converters. Many popular UHF converters have a 12 dB or higher noise figure. In weak signal areas it is common practice to mast mount UHF converters and follow them with a post amplifier to overcome downlead loss. It is a much healthier situation to place a UHF preamplifier with a low noise figure ahead of the converter and do away with the post amplifier.

(d) FM PREAMPLIFIERS

A good FM preamplifier can often mean the difference between providing a distant station or not. This is particularly true because FM stations are generally operated 15 to 20 dB below the level of the TV channels in CATV systems. Even though FM signals are inherently noise immune, noise builds up fast in a long system at these low levels.

2. UHF TO VHF CONVERTERS

(a) CRYSTAL CONTROL

UHF converters are one of the weakest links in CATV head-ends. UHF to VHF converters should have crystal controlled local oscillators to avoid being plagued by adjacent channel interference due to local oscillator drift.

(b) INPUT STAGE

For use in a low signal area another important feature to look at in UHF converters is the r-f input stage or absence of one. Many popular UHF converters have no r-f input stage. The input signal simply passes through a preselector filter and right into the mixer diode. The noise contribution of this type of converter is usually quite high. For weak signals either a UHF preamplifier or a converter with a built in low noise preamp is recommended. UHF converters that have post amplification built into them make external post amplifiers unnecessary.

(c) SPURIOUS OUTPUTS

UHF converters are notorious for unwanted spurious outputs that are difficult to filter out. Either a spectrum analyzer or a field strength meter should be used to check for spurious outputs that may cause beats in other channels. When using a field strength meter for this purpose it is wise to insert a trap tuned to the desired picture carrier between the converter and meter. Most meters will conjure up their own spurious image readings when hit with a strong carrier. If troublesome spurious outputs are traced to a converter check alignment and install necessary bandpass filters or traps on the output of the converter.

3. SIGNAL PROCESSORS

(a) STRIP AMPLIFIERS

The old 7 channel systems are quickly becoming a thing of the past. For the small systems that still don't have adjacent channels single channel strip AGC amplifiers are still a good economical choice. The main disadvantage of strip amplifiers is the difficulty of reducing the sound carrier level to protect an upper adjacent picture without also distorting the color information. This problem becomes more difficult in the high band as traps become more critical at higher frequencies. If deep fades are experienced the ALC range

(a) STRIP AMPLIFIERS Continued

of some strip amplifiers may also leave something to be desired. If you plan to run adjacent channels, but your budget is tight, by all means only operate strip amplifiers on channels that have no upper adjacent channel or have a guard band, such as 4, 6, or 13. You may get some trouble calls from color set owners complaining about sound modulating their color on these channels because they are used to tuning closer to sound on the other channels. All strip amplifiers that are operated adjacent to another channel should have an automatic noise silencer installed to render them inoperative when a channel leaves the air. If a strip amplifier is allowed to run wide open it will often noise up the adjacent channels and sometimes kill the color or sound of the lower adjacent channel.

(b) HETERODYNE SIGNAL PROCESSORS

Heterodyne processors are one of the most complicated and troublesome parts of a head-end. They represent a substantial portion of the head-end budget. However, they are very necessary for good color processing, especially in the high-band. I can not over-emphasize what was said during the introduction about checking frequency selective equipment for alignment upon receipt, especially when it comes to signal processors. The main advantage of processors is their ability to control the sound level and trap adjacent carriers with very little disturbance of picture and color information. This is possible because the incoming VHF channel is down converted to a lower i-f frequency (41-46 MHz) where control and trapping are done in less critical circuits before it is up converted to the desired output channel.

If your system receives frequency selective fading, evident by the picture and sound carriers fading independently of each other, consider processors with separate sound limiting and video AGC circuits.

When looking at processors check for access of controls such as substitution oscillator level control and substitution oscillator sensitivity control. The sensitivity control sets the minimum signal that will keep the substitution oscillator biased off. If the sensitivity of this circuit cannot be set a small amount of noise or co-channel interference can keep the substitution oscillator off and the processors gain will turn wide open and blast the system with noise.

(b) HETERODYNE SIGNAL PROCESSORS Continued

One of the nice advantages of heterodyne processors is being able to do switching at i-f frequencies. They are a real boon where systems must comply with non-duplication requirements or channels must be operated off-channel.

Processors can be used to switch more than 12 stations into a regular 12 channel system by utilizing the off-air time of part time stations. In our area we have a stock market station that only broadcasts in the mornings and a multi-lingo station that only broadcasts in the evenings. We inserted a miniature relay coil in series with the signal off light of the prime stations signal processor. When activated this relay operates an external solid-state coaxial switch. Just before the i-f enters the up converter we route it through the coaxial switch and back to the up converter input. On the other side of the switch we insert the video i-f output of another processor that contains all the necessary modules except the up-converter. When the prime station leaves the air the signal off light voltage activates the miniature relay which in turn controls the solid state switch. The secondary station will stay on until the prime station comes on the air again turning the signal off light out.

On another channel which carries a UHF station that broadcasts only a few hours a day, we switch in a message center channel. This is done with an i-f modulator in place of the secondary processor I mentioned earlier. Because we lose the stripping action of the i-f strip in the processor we found it necessary to install a custom i-f bandpass filter on the output of the modulator.

Most TV processors and strip amplifiers operate best with an input of +10 dBmV, gain of 40 to 44 dB and an output of +50 to +54 dBmV. Many technicians operate their processors and strip amplifiers at very low gain and output, especially in the low band. By doing this they often lose much of the AGC action and wonder why they have to set levels every day. By operating processors near their rated output you improve the desired to undesired spurious output ratio. If you operate your processors at +10 dBmV in and +50 dBmV out you will have a few dB's in reserve for inserting a bandpass filter or trap before mixing if necessary.

(c) FM PROCESSING

FM radio service is often neglected by CATV systems. If at least as much money is allocated for the FM band as you would spend for processing one TV station you

(c) FM PROCESSING Continued

will be well rewarded for your investment in the years ahead.

If you only receive a few FM radio stations in your area you probably can get by with a strip amplifier followed by a leveling trap. In a metropolitan area there are so many stations available it becomes nearly impossible to level out the strong stations without killing the weak adjacent stations. Why is it that the FM station everyone wants is always some weak sister right along side the strongest station on the dial? FM heterodyne processors have the selectivity and noise limiting to provide fade free reception under these conditions.

I am anxiously awaiting the production of the new solid state FM processors. If you are in an area without FM reception available don't neglect the possibilities of modulating your own music station or bringing FM stations in on your microwave system.

4. MIXERS

(a) ACTIVE SIGNAL COMBINERS

Reliability is a consideration when using active mixers. I don't know why, but if anything is likely to blow when you experience a power surge at the head-end it will be the electronic mixer, especially if you don't have a spare.

Electronic mixers should only be used where a high output level is required to traverse some inaccessible area out of the head-end. Active mixers are available with an output capability of about +57 dBmV. These could drive as much as 4800' of 3/4" cable, or 6700' of the new 3/4" dyna or ultra foam cable before the first amplifiers. With an overhead trunk line spanned this far the input to the first amplifier will swing several dB's with seasonal changes. This has the effect of seriously reducing the dynamic range of a system at the very start. It is a good practice to operate the head-end at the same output level as the amplifiers used in the trunk line. This will also facilitate sweeping the system from the head-end without the need for special setups.

(b) PASSIVE MIXERS

It takes at least 16 inputs to combine a typical 12 channel head-end. Passive mixers are usually comprised

(b) PASSIVE MIXERS Continued

of hybrid splitters, directional couplers or a combination of both.

(1) HYBRID SPLITTER

One of the oldest and most efficient mixers is made up from two 8 way hybrid splitter networks fed into a high-low splitter. This setup allows for 5 low-band channels, 2 FM inputs, a low-pilot, 7 high channels, and a high pilot. If good hybrid splitters are used and the trunk is well matched it is possible to develop as much as 30 dB of isolation between channels with only 11 dB of insertion loss. It will be necessary to install an appropriate pad on the low side of the high-low splitter to obtain proper tilt leaving the head-end.

(2) DIRECTIONAL COUPLERS

Directional couplers are very popular now for mixing. A series of directional couplers are installed backwards for each band and joined in a high-low splitter. With good directional couplers and a well matched trunk line you can expect 30 dB of isolation between channels and about 17 to 21 dB of insertion loss depending on the channels. The lowest channel of each band must be mixed in with a low value tap and the tap value raised on higher channels. Otherwise, you may experience too much tilt within a band because of through line insertion loss building up. Mixers made up from directional couplers allow additional channels to be installed later.

(3) FOUR WAY DIRECTIONAL TAPS

Many operators use a combination of the two methods mentioned above by using regular four way subscriber taps. Two taps for each band are installed like the directional couplers above. You have about the same insertion loss as directional couplers but lose some isolation because most four way directional taps have only 18 to 25 dB of isolation.

(4) EIGHT WAY DIRECTIONAL TAPS

Recently eight way directional taps with low insertion loss and 30 dB of isolation have become available. A 13 or 17 dB value tap can be mounted

(4) EIGHT WAY DIRECTIONAL TAPS Continued

on a blank panel for each band then joined in a high-low splitter.

(c) 20 CHANNEL MIXING

Many systems are contemplating using mid-band soon and make allowances for adding channels later. Three eight way directional taps can be connected in series and backwards to provide 24 inputs. Unused inputs should be terminated until needed. It will be necessary to install bandpass filters or traps on some channels to attenuate local oscillator and other spurious outputs before mixing. An appropriate custom low pass filter must be installed behind each preceding eight way tap.

(1) SEASONAL PAD

After all channels have been combined an inline variable attenuator with 1, 2, 3, and 6 dB steps is inserted in the out-going line. This pad can be used to compensate for changes in cable loss due to seasonal variations. On a cold night this pad can be used to eliminate a case of cross modulation a lot easier than climbing poles all over town. A log should be maintained of pad changes.

(2) SUMMATION SWEEP POINT

The output of the seasonal pad should be routed to a convenient place where a jumper can be removed to insert a sweep generator and pilot traps for summation sweep testing the system when needed. If the pad is front mounted a F 81 can be installed as a bulkhead adapter in the panel. A shelf for test equipment mounted on the front of the racks at this point is very handy.

(3) PILOT GENERATORS

A 17 dB four way directional tap is inserted backwards for mixing in low and high pilot generators. Two pilot generators for each frequency should be mounted in the racks. The spare generators should be set up and ready to operate at the throw of a switch. Some systems use two pilot generators which are continuously operated at the same frequency. They only experience a 3 dB change in system level when one pilot drops out. It is very important that the pilot generators be inserted after all channels have been combined and passed through the seasonal pad. The pilots are necessary to control the system gain when making

(3) PILOT GENERATORS Continued

summation sweeps of the system. If the pilots are inserted before the seasonal pad any attenuation changes would be corrected by the first AGC amplifier in the system so little benefit would result.

(4) TEST POINT

A 20 dB four way directional tap inserted just before the combined signals enter the trunk line is adequate for most head-ends to drive required monitors.

(5) LEVELING

Operate every channel so the mixer receives +50 dBmV picture carrier, +33 dBmV sound carrier and +30 dBmV for FM and other narrow band services after necessary traps and bandpass filters. With 3 dB of seasonal pad thrown in the insertion loss at channel 13 will be about 18 dB. This gives a block tilt output of 26 dBmV lowband, 29 dBmV midband, and 32 dBmV high-band. These levels are compatible with most CATV systems and will not restrict the dynamic range of the system as mentioned earlier.

(6) READY MADE MIXERS

This seems to be the year for mixers as several new models have been introduced by manufactures recently. Most of them employ either hybrid splitters or strip line directional couplers consolidated into chassis with 6 to 24 inputs. I recommend you either consider using one of these ready made mixers or neatly mount eight way taps behind blank panels for each band.

(7) DOWNLEADS AND JUMPERS

Semi-flexible aluminum sheathed cables are the best choice for downleads. In the last few years it has been popular to plumb the processing equipment also with aluminum sheathed cable. Many of the CATV Technicians that used aluminum cable for jumpers are sorry they did now and have gone back to flexible cable. They found the ridged jumpers too much of a hassle during everyday operation and breakdowns. As head-end gear becomes more trouble free semi-flexible jumpers will be more practical. Buy the best quality double shield,

(7) DOWNLEADS AND JUMPERS Continued

single jacket, solid dielectric 59/U or 6/U drop cable available for flexible jumpers. Check cable rolls that are planned for jumpers with a bridge before installation. Make all jumpers as short and neatly routed as possible. If ties are used around bundles of jumpers make them as loose as possible so jumpers can be traced and others added later.

CONCLUSION

Ask yourself the following questions:

Can your head-end picture quality use some improvement?

Are you providing your subscribers with all the services available?

Are you proud of your head-end when the manager brings in a guest?

Let's give our processing gear a little R_x and we may find it helps our job security.

CABLECASTING SESSION NO. 3:
Studio Lighting and Program Sources

Session Chairman:
Ed Drake

Participants:
Dr. J. Robert Burull
"Basic Television Lighting Techniques"

William C. Schweizer
"Free Film Availabilities"

Morton J. Fink
"Automated Program Sources"

DR. J. ROBERT BURULL

Television lighting usually poses daily challenges to the imagination and the professional skill of the experienced lighting technician and various producers and video engineers. However, most technicians and aesthetes work from a simple basic lighting formula--base, key, back, and fill. This is called the photographic principle with the key, back, and fill generally establishing base light level minimums. The basic technical lighting objectives are providing enough base light and limiting the contrast between high light and shadow so acceptable pictures can be produced. Nontechnically, lighting and production personnel continually attempt to enhance form and dimension and to create an illusion of reality or nonreality, as well as mood.

This paper is an attempt to provide general information for accomplishing the above objectives. It is directed towards the beginning professional, you who have had relatively little experience in television studio originations, and who do not have the time to study and practice at great lengths perfecting the art of television lighting. Many of my suggestions and much of the information-content are not original. My concepts are a composite gathered from contacts with many instructors, authors, and some experience.

I would recommend to all of you involved in television origination to haunt the professional publications for additional material. Four such publications, which have ample instruction and descriptive illustrations and which will provide you with most answers for your work in cable casting, or cable television origination, are Herbert Zettl's Television Production Handbook and his Workbook, second edition; Rudy Bretz's Technique of Television Production, second edition; and Robert Hilliard's Understanding Television. Don't forget the weekly and monthly journals, such as TV Communications, for ideas and illustrations, which might be helpful in your operation.

Lighting Philosophy

Since the television screen is only two dimensional (height and width), proper control of light and shadow is essential for revealing three dimensions or a three-dimensional concept. Objects must be given form by positioning in space and time and in relation to each other. Selective lighting helps to reveal the nature of an object, to give picture composition, or to give an illusion of reality. But as Zettl, professor of radio-television-film at San Francisco State College, states in his Television Production Handbook, "illogical lighting can effectively create the impression of nonreality," or, for you, cause subscriber dissatisfaction.

The specific purpose of this paper is to familiarize you with basic television production lighting principles, terminology, and equipment, so you can go back to your studios more equipped to develop your lighting plans and to provide reality and picture quality to your subscribers. For this purpose, I have assumed a studio for black and white (monochrome), vidicon camera television production.

Studio Layout

The lighting grid is the skeleton around which is laid the electronic nervous system and upon which are hung the arms and muscle extensions of studio lighting--the lighting instruments. Studio ceilings should be high enough to permit mounting a lighting grid, connector strips, and lighting fixtures so that lights are at least seven feet above the floor. A lighting grid normally consists of metal piping, usually one and a half to two inches in diameter, and ideally should be mounted from ten to eighteen feet above the studio floor.

If your budget cannot sustain a professional lighting grid, then ordinary galvanized water pipe will suffice. Jack Rickels in TV Communications states that the pipe grid normally costs about fifty cents a foot and can be self-installed. The grid pattern is usually set on six-foot centers or less and can normally be attached to walls with floor flanges. The cross-junctions of the pipe can be held together with double "C" clamps. The pipe itself normally has both ends threaded and couplings attached, so you can join as many pieces together as you wish. Again, because light intensity is influenced by ceiling height, an ideal height is approximately sixteen feet, but an operable minimum is possible at twelve feet and sometimes ten.

The studio itself should be air conditioned for comfort. Normally, basic adequate electric power requirements for small studios are either two or three wires of 40,000 to 50,000 watts. Ideally, installation for small studios should be four wire, three phase, 500 or 600 ampere service.

Generally, strip outlets, or connector strips, are installed over the grid. In some cases, however, you might need to have the power outlets installed above in the ceiling. Rickels in the May, 1969, TV Communications periodical describes in detail the rigging of a power source and outlet. His description, while general, can serve as a guideline for primary installation of electric conduit and wiring necessary for the lighting instruments.

He suggests that a contractor install conduit from the primary power box located near the floor to a breaker panel located at a convenient wall, preferably inside the studio. This breaker panel should be equipped with at least twenty 30-amp breakers, which can be used for switching on and off until a control board

is installed. Conduit and wire can be installed from the breaker box to three wire twist-lock outlets located above the lighting grid. Each outlet should be capable of handling at least 30 amperes, and there should be one for each light you intend to use. In addition, at least two 20-amp outlets should be installed on each wall near the floor to provide power for floor lamps, floor monitors, test equipment and the like. Of course, incandescent lighting should also be installed for normal lighting of the studio when the production lights are off.

Lighting Instruments

Television lighting employs two types of illumination--directional and diffused. Directional light illuminates a very small area with a light beam, e.g., a spot or spotlight localized on Sammy Davis, Jr., singing at the Hollywood Palace. It produces clearly defined light and shadow areas. Diffused light, unlike directional light, illuminates a relatively large area with an indistinct beam. It produces soft, undefined light and shadow area as compared to the hard, directional light. Both directional and diffused illumination are needed and obtained in a television studio through spotlights and floodlights--directed and diffused respectively--used as key, back, and fill lights.

Three types of light-producing elements are used for these two illuminations: the incandescent bulb, like the one used at home; the quartz-iodine bulb, which produces an extremely bright or high beam; and the fluorescent tube, which is seldom used now for monochrome or color lighting.

Light element choice. The choosing of lighting elements depends on several factors--the scene to be lighted, the lighting objectives, the background, and so forth. Quartz-iodine lights are now being extensively used for both directional and diffused lighting. However, if you have a limited budget and are not going to be immediately concerned with color production, perhaps you should rely on the incandescent bulb. Costs average about three to one with a "long-lifer" quartz-iodine tube costing from $20 to $25, as compared to the incandescent bulb costing around $5 to $7. The "long-lifer" has approximately the same life as an incandescent bulb.

Normally, a selection balance between the quartz-iodine and incandescent will provide enough alternatives to satisfy your lighting demands. Quartz lights illuminate at an extremely high efficiency. For example, a 1,000 watt quartz floodlight (scoop) provides the same illumination (in foot candles) as at least three 1,000 watt incandescent scoops. This light output does not decrease with age. Incandescent bulbs, however, gradually blacken with carbon and decrease their output with use. Also, the size and weight of quartz lights are less than those of equivalent incandescent instruments and require less bulky housing.

On the other hand, the quartz lights are less directional than the incandescent bulbs; they get extremely hot and radiate more heat than the incandescents; and they are destructive for attached parts, such as barn doors and lighting scrims. The most serious disadvantage of the quartz lights is the comparative difficulty in controlling the light beam. It cannot be shaped as precisely as the incandescent light beam; and when the spotlight is pinned to a narrow beam, quartz light has an annoying tendency to leave a dark spot in the middle of whatever is being lighted. For these reasons, a combination of both quartz and incandescent elements is recommended.

In any event, quartz lights demand extra caution. You should never touch the bulb with bare hands as the skin's chemical composition can cause bulb deterioration. Hot bulbs should be handled only with asbestos gloves. Just as with incandescent bulbs, quartz bulbs can explode and spread shattered glass. Installing a protective scrim or wire-mesh screen in front of quartz instruments will increase the safety factor without cutting down excessively on light output.

Spotlights. For the normal cable television studio use, I would recommend the Fresnel spotlight, which can be either incandescent or quartz lighted. It is light, flexible, has a high light output, and is easily spot focused. The spotlight can be spread to a wide flooded beam or can be pinned to a very sharply and clearly defined beam.

Another spot which is used is the ellipsoidal, which has an intense directional beam. It can be utilized as a projection spot or to play a shadow pattern on a backdrop or cyclorama. For example, if you wanted to create a certain mood for a production, perhaps using an ellipsoidal spotlight for background shadow pattern, or a grillework pattern, would suffice rather than using a much more expensive constructed background. In black and white television, in small studios, the ellipsoidal spotlight is very useful for simple effects.

Remember that the choice of lighting instrument is dependent upon such factors as camera used, camera tube sensitivity, the studio ceiling height, and the reflection of scenery and costumes.

Lighting intensity is affected by ceiling height--the higher the ceiling, the more light required; the lower the ceiling, the less light required, and thus a smaller instrument can be used with less heat radiation. Also, scenery which is highly reflectant requires less light. Even though identifying accurately your precise needs for studio lamps is difficult, I would recommend for most cable television studios from 750- to 1,000-watt spotlight lamps, in a combination of both quartz and incandescent.

One other light, which you will probably utilize, especially for remotes, is the "sun gun." This is a portable, 1,000-watt quartz light which can be handheld, or fastened to flats, door frames, or some other convenient object. These sun guns, a replacement for the older but still used internal-reflector spotlight, are used extensively at schools, community service projects, hospitals, and other remote locations.

Floodlights. So far we have only basically identified the source for directional light, the spotlight. The requirement for diffused light is fulfilled generally by floodlights, which play an important, yet really a secondary, role in monochrome or black and white television. They are very essential for color television.

Quartz lighting is recommended for floodlighting because of its size and efficiency. Five basic types of floodlights are the scoop, the pan or broad, the floodlight or flood-clip bank, the strip light or cyc lights, and the fluorescent bank. For the primary television work which you will be doing, I would recommend the scoop and the quartz broad with barn doors. The scoop has no lens; and the 12-inch scoop with a 500-watt quartz lamp will deliver almost as much light as the 1,500-watt incandescent scoop. If you are working with color, the 16-inch quartz scoop with 1,000 watts is the more popular floodlight.

The broad or pan is used most often for color production, but even for monochrome lighting, one or two broad scoops, whose reflector looks something like a baking pan, might be recommended. They come in various sizes from 400 to 1,000 watts. For a normal cable television operation utilizing vidicon cameras, and where the studio is approximately no larger than fifteen by fifteen feet, two or three flood quartz lamps of from 750 to 1,000 watts will produce a sufficiency of diffused light for most productions.

Lighting Control Equipment

Lighting control includes two basic maneuvers or steps, one visibly physical, the other electronic. Lighting control can be as simple as a panel box with off-on switches, or as complicated as a very expensive dimmer control board with transformer and electronic dimmers.

Controlling the lighting once the instruments are hot or turned on depends upon either movement of the instrument itself (directional control) or upon varying the light intensity (intensity control). Usually, in a small studio operation, where lighting equipment is minimal, greater flexibility of this equipment is needed. The lighting operation should be flexible enough to allow one man to change the studio lighting with a minimum of time and energy.

Directional controls for basic television lighting include basic mounting devices, basic hanging devices, mounting devices for floor lights and sometimes beam controls. The grid work is the basic structure upon which lights are mounted and moved. In some cases, the grid is so hung that it can be moved vertically up and down so the lights can be changed around without using ladders or other awkward contrivances for reaching the lighting devices. I recommend for the general, most inexpensive use, the stationary grid, which was described earlier in this discussion. Other modifications are available, but they are generally associated, because of cost and nature, with much larger studio operations than the typical cable television studio.

Basic Hanging Devices. For the needs of most studios, the "C" clamp is the cheapest and simplest light-mounting device, and I recommend it as standard hanging equipment. It can be attached to the overhead grid, which, in turn, can be clamped either directly to the light instrument, such as a scoop or Fresnal spot, or to a hanging device known as the pantograph.

The pantograph is a highly flexible hanging device as it is counterbalanced and adjustable quickly and easily from the studio floor within its more than 12-foot range. More than that, it eliminates the need for using bulky ladders. Some modern pantographs have a small pipe extension which permits mounting two separate lighting instruments on one pantograph. In most small studios with ceilings of 18 feet or less, the instrument attached to a pantograph can be pulled down quickly and easily to floor level to enable swift adjustments.

For your studio then, I would recommend for directional lighting control, lighting instruments attached to pantographs, connected by "C" clamps to the overhead grid. In addition, you will probably hang your diffused lighting instruments, such as the scoops, by "C" clamps. Floor lights are usually mounted on roller-caster stands with a three-wheel base, allowing quick repositioning.

Beam controls, such as the Fresnel spot-focusing device, the ellipsoidal shutter device, and the Fresnel spot barn doors, help control directional beam and spill light. Boom shadows, for example, can be eliminated by partially closing a barn door.

Intensity controls through dimmer and patch boards are now very common, even in small studio operations. However, for the neophyte cable television operator, dimmers are not essential. If your budget can accommodate dimmers, your entire lighting operation can be enhanced, especially in the area of special effects. Dimmers are usually used to balance over-all lighting, saving you time in changing lights of different wattage. For example, if you find one lighting instrument, such as a Fresnel spotlight, to be too intense or bright, you can dim it or turn down its voltage.

Many very successful studio productions for both live and taped programs are being done in all size studios, from the smallest closed-circuit educational studio to the larger professional on-the-air operation. For the CATV producer, better cameras and an increased sensitivity and aesthetic awareness by the audience compels technical sophistication. Dimmers and patch boards can enhance the cablecasting origination productions, but without a thorough understanding of the techniques of television lighting, the lighting director can use neither to his advantage. Television lighting techniques are the sine qua non of cable television origination.

Techniques of Television Lighting

The remaining portion of this discussion probably will mean the most to you on a day-by-day basis. That is, selecting lighting instruments and constructing grids are one-time efforts with lasting value for a considerable period of time. But, lighting the set and solving lighting problems are day-by-day challenges, which, at critical times, are harassing. As Zettl states, "a universal lighting recipe for every lighting problem is really not probable," but what is possible is an understanding of basic lighting principles. Again, I am speaking mostly to television producers working with black and white, but the basic principles apply to both monochrome and color. There are distinct variations here, especially in the area of operating light level, contrast between light and shadow, and the color of light itself, but these are factors unique mostly to lighting for color television.

Lighting terminology. For this discussion's purpose, the following terms and definitions will be used.

Base light: An extremely diffused, over-all illumination in the studio coming from no apparent source. A certain amount of base light is necessary for technical and aesthetic picture acceptability.

Key light: The apparent principle source of directional illumination falling upon a subject or area.

Back light: Directional illumination coming mostly from behind the subject.

Fill light: Generally diffused light to reduce shadow or contrast range. It can be directional.

Background light: A separate illumination of the background or set.

Side light: A directional light which illuminates the front side of a subject; usually opposite the key light.

Kicker light: Directional illumination from the back off to one side of the subject--usually low angle.

Camera light: Directional front illumination used for additional fill, eye sparkle.

In television lighting the base light level and the signal-to-noise ratio are corollary. Every television picture has a certain amount of "picture noise" generated by movements of electrons. Snow, which sometimes appears on our television screens, is the visible picture noise. However, if the station is carefully tuned in, the noise usually disappears; and the signal literally drowns out the video noise, while the picture appears very clear. This same problem occurs in television lighting if the studio light base level is not equal to the operating level of the camera tube. If the base light is too low, the noise will outweigh the picture signal, and the picture will appear unclear with degrees of snow. This is generally called a poor signal-to-noise ratio.

What is the proper base level of light for camera tubes? Generally, these following light levels have proven to be most satisfactory for ordinary television productions:

I-0 monochrome camera . . . .75 to 100 ft-c (foot candles)

Vidicon camera. . . . . .200 to 250 ft-c

Plumbicon camera. . . . . .75 to 100 ft-c

Color camera. . . . . .285 to 500 ft-c

As you can see, the vidicon camera, the kind being used by most of you and in most CATV studios, requires hotter lights, or more high lighting, than the black and white image orthicon cameras or plumbicon cameras. Color requires the most. The vidicon camera is subject to "lag," that is, the image retention of a subject when one pans away. Fairly high base light levels are needed to produce a high quality, lag-free picture.

Base light levels will vary considerably at times from these figures, but these are the standard optimum levels. Since lens, f-stop, and lighting contrasts have much influence on the base light level these must be considered, too. Base light, to repeat, is the overall diffused illumination in the studio, which comes from the principle lighting sources of key, back, fill, sometimes background, side and other directional or nondirectional lighting instruments.

Lens opening, as previously mentioned, is a significant factor in lighting. When the base light is low, the lens opening must be wider to allow enough light to strike the camera pickup tube.

Conversely, high base light levels call for small lens openings to keep excessive light from striking the camera tube. Remember, however, that depth of field decreases with wide lens opening; and if you need a great depth of field, you must operate with a small lens opening and a high base light level. You must also remember that the vidicon camera uses 16 mm film lens, and the f-stop-focal length relationship differs from that of the I-O 35 mm-lens system.

At this point, we should perhaps discuss such concepts and technical realities as contrast, contrast ratio, shadow, reference white and reference black, but they might have more meaning if we first constructed a typical lighting problem.

The basic television lighting setup for monochrome, as well as color production, utilizes three main light sources--key light, back light, and fill light--which will largely determine your picture quality. Other lights will be added later, but right now, let us concentrate on these three. They are directional and diffused, providing the base light, as well as the proper signal-to-noise-level ratio.

The key light is the principle source of illumination and is usually positioned first above and in front of the subject. If key light is moved slightly to one or the other side of the talent, then form is enhanced; and three sides of the talent become visible. Key light is the motivating source of light and must be directional. Most lighting professionals recommend a Fresnel spotlight with a medium spread.

The back light is next set directly behind the talent and above the set's back wall. Now talent's position is important because if he is too close to the background wall, the back light won't hit the top of him, and dimension will be lost. Generally, lighting angles of 45 degrees are considered ideal for normal lighting situations. In other words, by not placing the talent too close to the backdrop, and constructing the sets nearer the middle of the studio areas, more dimension will be gained, and you will have less trouble with shadows on walls and reflection annoyances. Again, a Fresnel spotlight is ideal for back lighting. Directional beam is needed, and the Fresnel furnishes the capacity.

The third light to position is the fill light, which will help illuminate, with key and back light turned on, a rather unnaturally dark and perhaps indistinguishable right side of the talent. Your challenge now is to lighten up this dark side by eliminating shadow altogether and thus curtailing what can be called the "modeling effect" of your key light. Placing a floodlight or a scoop to fill in some of the dark shadow just to the left and front of the talent opposite the key light will help you gain the effect you are looking for.

Fill light sometimes spills into too many other areas and erases too much shadow, so contrast is lost. If this happens, a Fresnel spotlight should be used instead of a scoop. In this case, adjust the spotlight for maximum spread beam by pushing the bulb-reflector unit towards the lens. This will soften the spotlight and perhaps eliminate the problem of washing out the shadow completely. Using controlled fill lights, such as spread spotlights, is very important for small studio operation.

Now we can look at the completed basic lighting structure with key, back, and fill in these positions. This is your principle lighting setup: key--a Fresnel spotlight just to the side and in front; next, back--a Fresnel spotlight, positioned at a 45 degree angle hitting on top of the talent; finally, fill light--either a scoop or spread spotlight, positioned left of the talent and opposite the key light to dampen shadow and illuminate the dark side.

Once your basic photographic principle requirements are satisfied, you can ascertain your base light. The most accurate way is to use a very inexpensive GE, or some other comparative-cost foot-candle meter to get your incident light reading--that is, the light striking the subject or, in this case, the talent. Remember, for vidicon cameras, approximately 250 f-candles base lighting is required. Color requires from 450 to 500 f-candles.

Light intensity ratios vary among the key, back, and fill lights, depending on shading of the talent, his clothes, the set, and so forth. Generally, a back light is equally or slightly more intense than the key light. A typical lighting setup employing the photographic principle of key, back, and fill for vidicon cameras could assume these ratios: 1 to 1-1/2 to 1/2. For example, a key light intensity of around 150 to 200 foot candles with a back light of about 1-1/2 times the key light intensity or about 250 foot candles, with the third light, fill, turned on at about 1/2 of the key light's intensity, or about 75-100 foot candles. The resulting base light illumination should be around the 200 to 250 foot candles desired for a vidicon camera high quality picture.

In addition, if more diffused light is needed, a side light can be added, as well as a background light. Background lights can accentuate drapery folds or perhaps make an otherwise unappealing cyclotron quite pleasing. A kicker light, such as a pin spot, can be added for special effect.

In summary, in all television lighting, the photographic principle of key, back, and fill light is used. For special effects and over-all lighting effect, additional sources, such as side and kicker lights, are used. Generally, a Fresnel spot with either an incandescent or quartz iodine bulb is used for key light. Back light is a Fresnel spot throwing off about 500 to 1,000 watts. Fill lights can be either scoops or Fresnel spots,

depending upon the studio make-up, the set, and the subject. For vidicon cameras, a base light of from 200 to 250 foot candles is desired with back light measuring about 1-1/2 times greater than key, and fill light about 1/2 as intense as key. When on remote telecasts, quartz scoops may be the best lighting sources. A general recommendation would be to integrate your general programming formats so that lights will be fairly stabilized at all times.

Lighting is as important a function of cable television origination as the audio and camera functions. One does not need years of experience in television production to light a set competently for cable television origination. All of the basic television lighting principles have been identified, and now you should be able to utilize them for your operation.

WILLIAM C. SCHWEIZER

Modern Talking Picture Service--that sounds like a very strange name. In order to explain it, I will have to give you a little bit of the history.

In 1927 the Western Electric Company set up a division to handle non-telephone products. In 1937 the FCC told them they should divest themselves of this line of business, at which time an employee purchased this division and called the company Modern Talking Picture Service. At that time they were distributing both films and equipment. A few years later they divested themselves of the equipment and stayed as a free loan film company. Now in its 32nd year, Modern has 30 non-theatrical offices across the country, six of which serve both TV stations and CATV stations.

I have mentioned the word "free-film." If it is free, where do these programs come from? Well, they come from companies both large and small. Therefore, we call the product "sponsored films." They are used in schools, clubs, theaters, TV stations, and recently in many CATV stations. You may be asking yourself how a free loan company can stay in business 32 years. They have to make money somewhere. This is true--and we do. The sponsors of our film pay us an "x" number of dollars to get their films distributed to the public. This allows us to send you the film on a free basis and to bill the sponsor for getting the film shown to your subscribers.

We have found that CATV stations are using the films in the same way television stations are. They can be used as filler material; for example, you may have purchased a show to run from 4:00 to 4:30 and you may have a local news show from 5:00 to 5:30, and rather than spend the money for another show you can use our films

to fill the 4:30 to 5:00 gap. We have series available in case you find your open slot is on a regular basis. Or you can use free films in your own series. An example would be if you had a series called "Travel, USA." There would be no reason why you could not use one of our films in a live show, where a guest has failed to appear, or in some cases actually program them into the live show.

The subject matter varies from sports to religion; with travel, general interest, and women's films all included. Most series are half-hour in length and run approximately 28:30 minutes, giving you time to put in spot announcements. We have even found some enterprising people contacting the local representative of the sponsoring company and selling them time around the film.

We do require two things of you: 1) is that you return the film promptly after it is played. By this we mean the next day; 2) that you fill out and return a telecast card indicating date and time the film played. This is the way we make our money, for we do not bill the sponsor until we get the card back from you saying the film was shown. We also have places on the card where you can indicate why you may not have shown the film, if this was the case. As the card is returned to the sponsor, any comments you wish to make will be seen by the sponsor.

Although Modern is the largest free film distributor, there are other places to get film. The U.S. government and its various agencies have many films which are available to you. This includes, of course, the Army, Navy and Air Force. There are also many companies who do their own distribution and we do have competitors. There is also a book out called "The Free Film Source Book" which lists firms by title, subject, and distributor which are available free to television stations. Consequently, most would be available to you. You can get a copy of this book by writing to "Free Film Source Book," 535 Fifth Avenue, New York, N. Y. 10017.

Modern also has available free video tapes. These are one-inch tapes, in both black and white and color on Ampex and sony tapes. There are not at this point a lot of films available on tape. However, in the future we hope to have more. Our requirements are the same for you people. They are free, but you must return them immediately and fill out the telecast card. For your information, the only library which handles the video is our New York office. However, your local office can give the address.

In summary, there are many free films available to you CATV operators.

They vary in both subject and length and are sponsored by many different companies. Although Modern is the largest distributor, there are other sources of free film. The "Free Film Source Book" lists most films which are cleared for television and when you can get them.

MORTON J. FINK

There's an old saw about a speech being like a woman's skirt -- long enough to cover the subject but short enough to hold the interest. My assigned subject -- sources of automatic programming -- could be covered, I think, by a speech no longer than the shortest micro-mini you have seen on the lovely, breezy hills of San Francisco this week. I am changing the subject -- slightly -- not because I didn't want to deliver a short speech but because like the recent seventh husband of one of America's famous beauties said on his wedding night -- I know what to do but I don't know how to make it interesting.

I also doubt that I can tell you gentlemen anything you don't already know about the different kinds of automatic programming available -- unless the selling arms of the companies which have been making these automatic systems are much shorter than I think they are.

I am, as you may know, President of Television Presentations Inc. which is a subsidiary of Sterling Communications Inc. Inside Sterling is another company called Sterling Movies and Sterling Communications is also the majority stockholder and manager of Manhattan Cable Television. I mention all this not to take advantage of free commercial time but it has a lot to do with my being invited here and with the validity of some points I'd like to make.

Sterling Movies is a leading supplier of free films to the cable TV industry. Television Presentations supplies both hardware and software via our alphamatic news and our converters which now makes possible reception of 26 clear channels. Manhattan Cable Television is a leader in origination and has taken on the ambitious program of cablecasting virtually all Madison Square Garden events previously not available to TV broadcast audiences. So many hockey and basketball fans in New York are unable to squeeze into the large garden that we are certain subscribers will stand in line to get the cable and until they do friends with our cable will have to keep their refrigerators stocked with beer. We know of one system near Detroit that has many subscribers primarily because blacked out Red Wings games are brought in from a distant station.

The point of all this is: all of us at Sterling Communications are deeply committed to the success of cable television. Virtually everything we do relies for its success on the success of cable television. When an FCC ruling or sub-ruling or sub-sub-ruling makes you hot under the collar you can bet our temperature matches yours.

Now that I have established, I hope, our credentials I think the time I have would be best spent by sharing our experiences with you concerning program origination particularly via automatic

means. Along with our experience I can call on two surveys we have made -- one of a system's subscribers and one (currently being conducted by a Ph.D. in market research) of system operators.

The name of the game, gentlemen, is "Add Subscribers and Reduce Overhead." How do you add subscribers? Our experiences and our surveys all tell us one thing -- give 'em something (almost anything) they can't get elsewhere. It seems that once the human being has invested in a television set he reacts to the soft grey of an unused channel the way a bull reacts to the matador's red cape. Every respondent commented on the extra channels the cable system gave them. The simplest vidicon weather scan is infinitely better than a dark channel in the subscriber's view. I think a picture of yesterday's local newspaper lying on the chief engineer's desk at the headend would be worth carrying at some cost over leaving the channel blank.

After reading the replies of subscribers to our questionnaire and adding the results of some telephone interviews I think a case could be made for your automatic programs (of any kind) reaching more people regularly on your system than network spectaculars. Not everyone likes song and dance programs, not everyone likes heavy drama -- but who doesn't check the weather or the news without waiting for the next scheduled report. Think of the telephone company; it has its own weather system which requires dialing seven digits. The company even advertises suggesting travelers dial long distance for weather. That's evidence of the strength of, perhaps, your simplest automatic channel.

On our alphamatic news we find that if, for any reason, a subscriber loses the signal, the loss of the New York Stock Exchange ticker draws a lot of vocal fire and that's true whether it is a small system or a large system.

The history of automatic cable television origination equipment is as well known to you as it is to me. In one way I think we may have reached some kind of ultimate in 24-hour all-electronic news and weather channels with equipment such as our alphamatic news systems which involves pushing a button to give subscribers the United Press International news report, the New York Stock Exchange ticker, and local message input capability. This is really a long way from the first scanning of a teletype printer. Suppliers of every kind of automatic equipment -- including TPI -- are here this week and are willing -- perhaps I could even say eager to sell you the equipment best suited for your situation.

But what about program origination? It seems certain that no matter how much backing and filling is done cable TV systems will be supplying a variety of programming from sheer entertainment to controversial public affairs. Our own Manhattan Cables now originates a substantial film entertainment package as well

as many hours of live origination -- all this in addition to the upcoming Madison Square Garden events.

We really think that one channel origination and more is a certainty in the future of cable television. We also know, as many of you do I'm sure, what a chore it is to fill up with a variety of programming just 12-hours on one channel. Simple arithmetic shows that 12-hours a day seven days a week requires 168 half hours of programming. Anyone who has been faced with the job of providing that much programming -- no matter how the package comes knows what a chore it can be -- riding gain on an old flick -- standing by in case a sprocket hole tears -- even video tapes has its needs -- and always there is the sheer work of coming up with 168 half hours of programming that your subscribers didn't see last week, or the week before....

I mentioned reaching something like an ultimate in one kind of automatic programming -- the all-electronic alphanumeric readouts that present 24-hours of news and weather seven days away with the push of a button. Well, ultimate is a tough word to live up to but I think we may have another near-ultimate in convenience programming.....Perhaps, some of you visited with us yesterday and saw a demonstration in which we were joined by CBS and Motorola. The demonstration showed the simplest and best method of presenting recorded television programming imaginable. A player, that works perhaps even easier than a phonograph, and gives pictures of greater resolution and clarity than even videotape. The film with a magnetic sound track is virtually foolproof and wear proof. Your secretary could replace the 50-minute cartridges which carry the film between paragraphs on the typewriter. A brief slide can be shown in the few seconds it takes to make the change. You can't be more automatic than that.

And what can be put on EVR film for this automatic origination? Anything that is on motion picture film, anything that is on videotape, anything that is presented live -- can be transferred to this relatively low cost easy-R system. Instead of shipping bulky films and videotapes and chancing the tearing of one or the wiping of another -- a small cartridge weighing a few ounces is shipped and reshipped. The film within the cartridge rides on air and resists damage and deterioration...

When it arrives at your headend, the nearest person slips it on its spindle -- as easy as playing an automatic phonograph -- and pushes a button when it is time to cablecast.

To get back to the name of the game -- "Add Subscribers and Reduce Overhead" -- we think CBS' EVR system is the perfect answer. It can bring you everything that the mind can imagine and it is push-button simple. We think so highly of this at Television Presentations -- this I admit is a short commercial but the possibilities are so dramatic that hope for your indulgence -- we think so highly of this at TPI that in order to become the first supplier of EVR

to the cable industry we have placed firm orders for large numbers of EVR players with Motorola -- the exclusive licensed manufacturer of the player? And we have committed ourselves to processing time with CBS' EVR Division -- needless to add the time demands on CBS are similar to the earliest days of the computer when corporations stood in line to get an hour on a computer even if it was at midnight. We think EVR is the future of cable television origination -- along with those local events you will do with your present equipment. None of your regular equipment incidentally has to be changed to use EVR. Its installation is just about as "automatic" as its use. We at TPI are so certain of EVR as the automatic origination of the future that we have formed TPI EVR Cablecast Service which will be complete program service created specifically to fill the technical and economic requirements of cable television systems.

With EVR as the latest addition to the cable television operators' automatic channel fillers there are no limits to the worlds which he can present to his subscribers economically. I believe that all of us here will see the day when cable TV systems are presenting 20 channels full time and perhaps offering an automatic shopping service via a two-way converter.

And now I would like to say thank you -- and that isn't automatic.

TEST PROCEDURE AND TEST EQUIPMENT

Session Chairman:
G. Norman Penwell

Participant:
Israel Switzer
"Test Procedure and Test Equipment"

ISRAEL SWITZER

The writer reviews CATV test procedures and equipment which has been developed in his company's engineering laboratory.

The company has made a substantial investment in laboratory grade test equipment for the following general purposes:

1. Independent evaluation of equipment proposed for systems use
2. Acceptance testing of equipment, cable and supplies
3. Commissioning of new systems
4. Trouble shooting in systems
5. System "proof of performance"

Equipment in regular use includes sweep test equipment, return loss bridges, time domain reflectometers, spectrum analyzers, field strength meters, frequency counters, automatic noise figure instrumentation, X-Y recorders, storage oscilloscopes, log detectors, signal generators, strip chart recorders, r-f voltage calibration standards, r-f impedance standards, r-f millivoltmeters, cross-modulation test set (to NCTA standard), phase lock microvoltmeter, sampling type millivoltmeter, TV waveform analyzer, RMS millivoltmeter, field strength meters, oscilloscope cameras, field portable X-ray equipment, temperature measuring equipment, WWV calibration receiver, high voltage insulation testing equipment, cable fault locators, etc.

Basic test setups are reviewed and some new and novel procedures are described.

Technical regulation of cable systems seems inevitable. Cable systems must equip themselves with the equipment and techniques required to assure themselves and others that they are meeting required performance specifications.

ISRAEL SWITZER - (Paper received after material sent to printer)

This part of the program is intended to go two or three hours, depending on how long my voice lasts and how long you people hold out. The topic is "Test Methods for Cable TV from an Operator's Point of View." I think it's a particularly timely one. It's been one of my main concerns over a great many years in the cable business, partly, if you will permit an immodesty, out of a foresight in perhaps anticipating the situation in which the cable TV industry finds itself today; that is facing the probable imposition of enforcible standards on the technical operation of the system; and partly my interest stems from purely selfish reasons.

Now before I get into testing, let me give you part of the background of our situation, that is, my personal situation in Canada, my company's situation and the industry as a whole in Canada and why, perhaps, the organizers of the program here perhaps saw fit to reach all the way into Canada to bring people here to talk about testing methods.

We have been in the business in Canada for quite a long time. The first systems there were built in 1952, and proportionately, the cable TV industry in Canada is even now substantially larger than that in the United States.

I will quote some statistics that were given by the chairman of the Canadian Regulatory Commission at a luncheon addressed to the Canadian Convention last month. Some 14 percent of the television sets in Canada today are connected to cable systems.

There are at least five systems in Canada which are larger than any system in the United States. Then I'll add some sort of personal statistics; that it is entirely likely within the next few months that two or three systems will pass the largest of any systems in the States so that probably by the fall, one might say that there will be at least eight separate independent systems in Canada which are larger than any of those in the States.

We have been under close federal regulations in Canada for a great many years. We have had licensing of cable systems in Canada today since at least 1955. Very recently the licensing of cable systems in Canada has been in effect tightened up and brought more closely and more clearly under exclusive federal jurisdiction so that we find ourselves today, in a regulatory sense, in exactly the same position as the broadcaster.

We come under the same Act. Many sections of that Act apply equally to all broadcasters. The Act has to do with what they call "broadcast undertakings," and there are sections of the

Act that deal uniformly with all broadcastings. The psychology now in the regulation which we face is that we are treated very much like broadcasters.

We are coming now to have many of the same kinds of regulations which have always been imposed on broadcasters now imposed on us We have been given, within the last few months, a draft of a new broadcast procedure called "Broadcast Procedure 23," which is for study and comment and criticism, but it is intended to be the procedure under which cable TV systems will be licensed from a technical point of view.

It will require such features as a very thorough-going, very complete technical brief to be signed by an approved consulting engineer or equivalent which will describe all the technical parameters of that system. This will be part of the license application. This is just part of the material in support of a comparative hearing for applicants to see who will get the license to provide cable TV receivers in a particular community.

The same document has a list of minimum performance standards for a cable system, because come license renewal time, we expect that the licensing authority will require probably a technical proof of performance; and just as the broadcaster does, many cable operators will find themselves at license renewal time, and possibly in-between, if a serious situation develops, in-between, where they will be before a Federal Government Commission defending the operation of their system.

And they may find themselves defending both parts of it, that is, the kind of business side of it and the production of programming side, and probably more of them will find themselves defending the technical side of their business.

Now it is possible, I gather from the discussion in meetings that I have attended here, that this kind of situation is coming in the States. In Canada we expect to face this kind of thing in -- you were just talking about it. The FCC is just talking about rulemaking here.

We are at least a year ahead of that. We will have a rule probably by the end of a year, certainly no more than a year from now, because the pressures have been building up under government regulation agencies in terms of what they consider their concern for the public welfare and in response to probably valid complaints from the public who are subscribers to cable TV systems of inadequate performance in the technical sense of cable TV systems.

Now when you come, then, to face this kind of situation, there is just no alternative but to go extensively into the equipment

and the know-how and the techniques for the thorough testing and evaluation and proof of cable TV systems.

There is another aspect to considering the importance of testing in cable TV systems. We can break it down into two basic categories. One is testing technique and equipment for the evaluation of equipment. There are a number of very large cable plants in Canada, that is, a 400-mile cable plant is not unusual.

In Toronto, for example, there are five major companies operating there, each of which has at least 400 miles of plant. Toronto, as a metropolitan area, has a population of 2 million people. And between us, we'll have all of Toronto under cable just as fast as it can be constructed.

There are about 100 miles of cable a month going up in Toronto; and it's going up at that rate until we have it all finished. So our company and other companies operating in Canada today have some very substantial investments in cable.

Now I think it was about two years ago that Bob Brown and Jerry Laufer reported to this convention the kind of reasoning and conclusions they had come to in facing the problem of selecting equipment and evaluating equipment and in trying to make some logical process out of the problem of buying and selecting equipment.

You will come to the convention and drink your supplier's liquor and eat his dinner and go to his party, and this might influence you in buying equipment. It might not. But, these people, Brown and Laufer, at that time pointed out that this was no way to buy equipment, nor could you believe specifications.

It's not that suppliers were created liars; it's just that many of them didn't know the techniques were not available. The standards were not available, and in any case, the evaluation of equipment was a mess. Now the work that they did then and the interest in that topic that they initiated and the personal opportunity that I had to work with them at that time on that problem got me interested further in the problem of evaluation of equipment.

There is certainly an excellent reason for the development of a well-equipped test department. Now because of what we consider the improvement in that behavior of manufacturers, which was really initiated by that program started in the State of Washington, we find that evaluation of equipment, while it is not unimportant to us, is not now our paramount testing program.

For this reason, when I come to describe and show you the lab that we have, we do not have an environmental test chamber. We would like to have one and perhaps sometime we will. But we

weighed this cost against cost of some other forms of test equipment that we had and gave it a slightly lower priority than some other pieces of test equipment; because the environmental chamber would, to us, be used more for the evaluation of equipment for purchase.

There are other environmental equipments which I will mention that we are interested in but don't have yet for the same reason that they have a slightly lower priority.

Now I am talking about a test facility in which our company has invested something over $150,000. So you can see we have spent a great deal of money, but there are still items that we don't have and we still have a priority list for items that we don't have and are interested in and hope we can get later.

Our emphasis on tests has been for operating purposes, that is, to help get our systems established, to maintain them in perfect order and to maintain a confidence in that system. I will come, in a while, to tell you why we need that confidence and how we use it.

I have discussed the aspect of impending government regulation. Now one way or another, you are all going to either have to have a test-and-proof facility of your own, or you are going to have to be able to hire it.

But either way, you will want to make yourself familiar with what the problems are so that you can do it on your own or so that you can use some judgment if you have to go outside to hire others to do it. Internally, we have some comparatively selfish purposes for having developed to the extent that we have our own engineers and test facilities.

From a company point of view, we figure it puts us probably in an advantageous position when it comes to what you would call in the States "franchise battles." We have a demonstratable, proven, well-established reputation in our technical department.

This, we hope, is going to be a factor when we come into comparative hearings where we are competing with others for, in our case, licenses. In the American case, it seems to be franchises.

Secondly, I have a rather more personal reason and it's just purely one of self-defense. The technical buck in our operations stops in my office. I am the chief technical officer for our company and I am held responsible for system performance.

You know, the sales problems and the administrative problems and the financing problems are comparatively minor. And I don't know how many other people share that view, but this is, from my desk, the way it looks. The only problems in the business are the technical ones, and my problems far outweigh those of anybody else in the office.

Now I may have facetiously overdone it a little bit there, but the technical problems of the cable TV business are substantial, particularly when you operate on any kind of scale at all, even on modest scales and in more modest sized communities than we do.

Our company, at the present time, has an investment of about $15 million in cable TV. This puts us, I expect, in what you would call here a medium-size MSO. I feel the whole weight of the $15 million right on my shoulders, because I am held responsible for it.

And I'm not going to be held responsible for the technical performance of umpteen million dollars worth of technical equipment scattered over ten systems, some of them two and three hundred miles away, with technicians, many of whom I have never even met personally unless I know what is happening. We have branch operations, as many of you do, with people that I don't even know in the company, you know, a company of that size.

Now we must have 150 to 200 people of all kinds in staff in our whole organization. And I am responsible for this through a chain of command with about two or three or four levels on it. There are systems that I don't get to but once a year.

Yet, to the general manager and the president of the company and then the chairman of the board of our parent corporation, I am the one that is held responsible for what, in my view, is the most important aspect of the whole business. Now I am not going to take that responsibility without everything going for me that I can get and that I know how to do.

The management of our company, I think, wisely has seen it my way, that they don't expect me to take that kind of responsibility without giving me some reasonable measure of help in carrying it. Now when you are dealing with a group of systems and a group of people, as I say, many of whom are at a technician level, I am sure those of you who have technical responsibility for groups know all of your chief techs in various systems, but I am sure there are technicians across the country who maybe were hired as recently as a year ago and you may not have met them yet.

Yet these people have your professional reputation, your job, so to speak, in their hands. Many of the systems that we have, particularly the one we have in Toronto, kind of stretches the state-of-the-art in terms of reliance and capability.

So I have my neck a way out on some of the basic technical decisions that I have made. You sleep a lot better when you know that you haye armored yourself with all kinds of technical facilities and know-how and procedures that you feel are necessary to properly run a technical business like this.

No one in this business -- and I must except, perhaps, the very smallest communities -- should be fooling around in this business. There is no place anymore, for amateurs in the cable TV business, either in the management or in the technical side of it.

In the exhibition area yesterday, I was talking to one of the suppliers about a piece of test equipment which is intended for use in the maintenance of head-ends, and we were looking at it. He was telling me how it might be used.

He said, "When you send a boy out to the head-end to," you know, "make some adjustment, this piece will help him." I said, "Just stop right there. I don't send any boys to the head-end." I said, "We have boys, I'll admit that. And we have men. The boys in my organization don't touch the head-end, not until they have grown up technically and professionally to the point where they are men."

At our bigger head-ends -- there are only two or three or four men, for example, in Toronto that have keys to it. These are the only people authorized to work on it. They have been specially trained for it. They are very competent, long experienced technicians.

They are the only ones we would have to put on a head-end, and they have access, for working on that head-end, to the very best equipment that is available. We separate, very consciously, the men from the boys in the technical side of the business.

We have an educational program, one of our own and one that we run in conjunction with the junior colleges, to build younger and less experienced people up to the point of more usefulness. But we just don't fool around. You can't afford to.

I will describe our Toronto situation, and you may appreciate why. Toronto is substantially the New York of Canada. I don't know how many of you have ever visited there, but downtown Toronto could be compared in a sense to downtown New York in terms of the density of high-rise buildings.

There just aren't as many square miles of it. But within that one square mile of downtown Toronto, the conditions are essentially similar to that in New York City. Then it tapers off as you get out toward the suburban areas, to where you have suburban conditions, typical North American suburban conditions on the outside of Toronto.

Our company doesn't happen to operate downtown, but there is a cable company that does, and very successfully so. The only reason they are able to do so is with a measure of technical control very similar to the controls that we impose on our system. We have no microwave feeds for Toronto.

Microwave is not allowed in Canada. There are three local stations.

The average person with the roof-top antenna in Toronto probably has a greater variety of television reception on his set, not in the number of stations but in true variety, better than almost anywhere.

He gets the three United States networks, he gets the Canadian networks, and he gets Canadian independent. So nobody really needs us and we are not allowed by microwave to bring in stations from any distance.

So I won't go into the commercial details of how we sell this and perhaps why it sells, but you can understand from that that we work in Toronto under -- what it comes down to, finally, is that we have to run a very tight technical ship in Toronto.

We have some rather difficult head-end problems. They don't have to do with distance. They have to do with man-made electrical interference. They have to do with ghosting. They have to do with the real estate problem that if you are going to buy a tower, you can't build a tower.

You can't buy any land. You can't afford any within ten miles of Toronto. So for various reasons, the trunklines are rather long.

So the prime requirement handed down to the technical department by management is that the system must run to a very high standard of picture quality. And we have other restraints. It must be very reliable, extremely reliable.

I won't dwell too much on the reliability problem today. It's really another topic in itself. Perhaps another year. Our problem is that in our service area, which is one of the wealthier residential areas of Toronto, we have -- are likely to have all of the head office people, that is, the national manager or the national sales manager of virtually every business organization in Canada.

And these are the types we get. They are fussy types, and Toronto being the commercial headquarters of Canada and the wealthiest city in Canada in terms of overall economics, they are fussy. Boy, they are sure not used to anybody fooling around. They just won't put up with it.

We feel from experience in our interpretation of our subscribers' needs, that they are fussier about the quality and the reliability of their cable TV service than they are about their telephone. If they don't have a teenager in the house, their telephone could be out of order for the whole evening and they not know it.

But boy, if their television so much as flickers, they are on the phone complaining. If I may put a couple of minutes on reliability, we put in a power standby unit at our head-end. It cost quite a bit of money, just about $2,000 for one kilowatt unit and its battery, and its change-over time is something like 20 milliseconds.

With the power capacity, there is not so much as a flicker when that head-end changes from utility power to standby. We could have put in a little gasoline generator for less than half that kind of money, but we would have worried, "Will it really start when we need it, and how about the 5 or 10 or 15 seconds that it takes to start up and pick up the load?"

And we couldn't stand the 5 or 10 or 15 second interruption. You know, you can usually say, "Well, it might come on in the middle of a commercial, and who cares?" But our subscribers care about the commercials because they are the vice-presidents of the advertising agencies that made that commercial.

I mean it, seriously. These are the subscribers we have. We have a significant number of subscribers who care about commercials. It may sound crazy, but we do. We can't afford to lose a flicker in service, and the problems become so severe to us that by the fall, we are expecting delivery momentarily of standby power units on the same basis, immediate, instantaneous change-over, high reliability inverter systems. If they prove satisfactory, we will probably, within a year, have put our complete systems onto automatic power standby.

That's the kind of community in which we operate. I'm going to show you some gear and quote you some dollars.

I want to build up the case for a spectrum analyzer which will cost us about $9,000. We figure we can't run a system without one.

Across the office from me is the comptroller, a CPA, pretty good type. We figure we must have good accounting. Now he doesn't run his department by saying, "There is a pile of money that's come in, checks and money, and that looks like about $1200 to me," by eyeball.

Yet there are systems which look at the technical side of that business and this is what they say. Our comptroller has got to account to the management, to the shareholders for the money that goes through his department. He can't just eyeball it and, as I say, look at a pile of money and say, "That pile of money looks about right, give or take a few thousand," and trundle it down to the bank and write up his books that way.

Yet many technical departments operate just that way. The general manager will call me in, or the president of the company will call me in for a report to the board of directors, and they say, "Well, how are things in North Bay?"

North Bay is 200 miles from us. "Well, I think the picture is okay." That's not good enough. Or even when I report on Toronto, we must have a day-to-day status report. We are doing our job in Toronto and not just eyeballing it from a TV set in my office.

We have to have numbers, the same way that the auditor or our internal auditor or external auditor has to account for the money side of our business. They count every penny. On my side of the business, we have to count every decibel. You don't count decibels reliably with two-bit equipment or with two-bit methods or with two-bit technicians.

Now let's get on, then, to discussing some of the hardware and the techniques. That's the kind of windup on how we got into this position of having that kind of test equipment and wishing we had just about double that. So I'll start by showing you some pictures of our engineering lab facilities and from that, we'll discuss individual instruments and go on to show you some of the results that we get.

Can we have slide 1 up there? That's our main engineering lab and really it doesn't look like much until you start to total up some of the dollar value involved. This is one side of it, and basically what we have here is a basic sweep setup, a sweep generator, and oscilloscope.

So, this is really the heart of our setup. I'll identify some of the other instruments for you. I hope the picture is big enough from the back of the room. We have two signal generators here. They are lab quality signal generators. Now just aside, I'm going to necessarily mention some equipment makes in manufacture.

It is not meant as an endorsement of that particular make, because, for example, the reason that happens to be a GR signal generator is because it is a very good signal generator, but I also happened to buy three of them brand new, war surplus, very cheaply. That one happens to be a HP-608. The intent here is that we use lab quality equipment and we try and buy the best ones we can at reasonable prices.

So any reference that I make to a particular brand of equipment is not necessarily meaning that we love that particular brand or is it meant as an endorsement. There may be other circumstances for why we have it there.

Here are a pair of lab signal generators. We generally keep two of them on the bench, and I'll discuss those in detail or justify what we feel,is a requirement for lab quality signal generators. There is a little multimeter tucked in back there.

This unit here is a Hewlett-Packard 141 storage scope. At the moment when this picture was taken, it had the TDR plug-in in it. We have spectrum analyzer plug-ins for it, and we have regular scope plug-ins for that unit.

There is a field strength meter in our lab. This is a funny thing for a lab, really, for a lab uses the 704 strength meter. It is almost an ideal meter. And this 727 is not really a good lab meter. None of our people that have 704's would let them go until I replace them with newer meters.

We had trouble getting deliveries on newer ones. So, at this time we had a 727 in the lab. There is a small frequency counter there. That's a pre-scaler 4. This is a 12-meg counter. This is a pre-scaler and this little unit here is a 100-meg pre-scaler and one we make a great deal of use of with frequency counting equipment.

I will give you later a sales speech for the frequency counter. There's a little power supply up there. That is a lab grade power supply we use for setups that require biasing.

And this, if you recognize it -- I don't suppose you can read the label. That is a Heathkit marker and you may wonder how a Heathkit got into this lab setup. We just don't find a better one, even at five or six times the price.

So it justifies its place in this setup. Other instruments in there are a side-band analyzer that we use for work on modulators. This is a special pulse generator that we had built for us several years ago, and we have done a fair amount of experimental work of our own on systems sweep techniques which don't interrupt the system, comparable to the system Mr. Levenson described yesterday.

As a comment on that, one of the other systems in Toronto has been using a sweep system like that for a while, and they found it to be a very useful accessory. Those of you who are interested in that technique should look into it.

Here is a Variac power board for setups for testing regulation of power supply and the like. There is a logarithmic amplifier, which we use for extending the range. For example, if we are using a field strength recorder setup, we can considerably expand the dynamic recording range of the recorder with an instrument like that.

That unit is a noise generator for checking noise figure of equipment. This is one of two units that we have. This is a manually operated model. That meter standing in the corner is a RMS, a true RMS millivolt meter that we use for baseband signal to noise checks.

So that's one side, then, of our main engineering lab. That is a close-up, then, of the service bench. This shows now what we consider a very essential piece of lab equipment. That is a scope camera. That one happens to be a Hewlett-Packard scope camera, because most of our better quality scope equipment, just by circumstance, happens to be Hewlett-Packard.

In this case, we have had to modify other kinds of scopes to take the same camera, because while we value a scope camera considerably, we don't feel we can afford several of them.

That's an amplifier under test on the bench. There is a little power supply for driving it. This is a fairly conventional sweep setup. Our preference has been to have sweep test equipment and sweep equipment like this in individual forms.

We don't necessarily feel that one test equipment manufacturer is all things to all people, and we have personally preferred to be able to pick and choose our pieces. When this picture was taken, there were slide switch attenuators on the bench. Our main test bench has some precision rotary type attenuators on it, plus another set of attenuators that permit us to go to 120 dB resolving power.

Now the scope camera we consider an essential part of any kind of test system where you are relying for results on others. There is a whole deck of Polaroids that burned up, ten packs of Polaroid film in one weekend, not just for acceptance testing of equipment but for checking in the system, and I bet we spend more money on Polaroid film alone in our engineering department than many systems spend on test equipment.

That's just a further close-up of the setup now. He has a sweep display on that screen and he is in the process of balancing it up. The technicians using this gear have that sweep setup very carefully balanced, probably to something like 50 dB. We have taken some pains for the impedance matching in the selection of the test jumpers and the like.

So, it's a fairly meticulously put together system. As I said, we prefer individual components because there is a greater flexibility in their selection and a greater flexibility in their arrangement. For example, we get some very oddball setups for special purposes. We'll describe some of them later on. Another close-up of an amplifier under a sweep test. That is a conventional setup.

I am sure these techniques are well known. There is the upper part of that test bench now, with a close-up on the counter. These units here are counters. A counter was one of the earlier pieces of equipment we bought. Perhaps this is a good occasion to discuss the counter.

I have kind of always wanted one, you know. Reasonable quality digital frequency counters had been available for possibly something like 10 or 15 years, and in cable TV I had felt that their application really was rather limited. You know, when you actually set forth what you were going to use a counter for in anticipation, the application seemed rather limited.

So when we had a budget for test equipment, I said, "Well, we should have a counter of some kind," so we went out and we bought just this little box here. Now that is a five-digit 12 MHz counter.

Then we found the 12 MHz wasn't enough. After we got the counter, we gradually developed more applications for it. Now we wonder how we ever did without one.

We gradually had to add units. The first one that became available was this, you see, and then we added this GR. Finally, we came out with this unit which then permitted us to count to 5 MHz with this adapter box on it, and when it finally came out, I had spent as much money as I would have spent on a 500 MHz counter in the first place and I got it in three separate boxes.

But we know now that we have a considerably better feel at present for counter application. I will discuss one in particular, because I really think that this particular application is so important that I'll bet that entirely all of you will have small counters just for this job within the next year or two.

That has to do with program origination. Any time you are using a modulator where you are generating your own sound, if you are going to meet any of the specs that are proposed you won't be able to check your operation without a counter. It is not the carrier frequency of the modulator; it is the intercarrier spacing which is critical.

Now the broadcast spec on that 4-1/2 MHz spacing between sound and picture carrier is ± 1 kHz. Now that is a very rough spec to meet on an FM unit. When you go into the detail of how these FM modulators are built, you will appreciate the problems that they have in generating a 4-1/2 MHz carrier or a sound carrier and holding it to that kind of a frequency spec.

When we got to discussing a firm proposal for a minimum standard for intercarrier accuracies in program origination modulators, we asked TV set manufacturers, "Now what is a practical spec, from your point of view? What are your sets built to handle?" They said, "Well, we could stand something like ± 5 kHz," which is a more realistic kind of thing for a medium priced program origination modulator to carry.

That's about the figure that we expect the government will finally come out with for program origination modulators for cable TV.

Well, when you come to the practicalities and how you do actually check it, personally, we find that the units, practical units, require checking. They do drift. They are no better than the AFC discriminators in them, which are, after all, just tuned circuits. These units we have found we have to monitor them once a week, and we find that we have to adjust them about every two months.

Now it turns out that it is reasonably easy to monitor the carrier of a program origination unit modulator without taking it off the air. If you have access to it on the bench, you can just count it directly with no modulation on it.

But when it is being programmed, of course the sound carrier is an FM carrier, and it would be blinking up and down. We find the most practical technique is, assuming that your lab test department has a system monitor line, is to take a demodulator -- in our case, we use a Jerrold demodulator, and we take the 4½ MHz intercarrier sound output and just count that.

You can just go around your dial and count that 4½ MHz carrier output. It's FM, and there is enough level from that output spigot to count reliably.

You generally need at least a tenth of a volt to drive them, but you get just one other minor problem in the gate time of the counter.

You see, these digital counters count each cycle. They count for a fixed period of time, and they count the number of cycles that come through that gate in a given amount of time. Depending upon the nature of your counter, we find that to take the account of variations we must be sure that we have averaged the frequency swings above and below the normal carrier position.

We set the carrier for a reasonable gate time and average these swings in our counter over a ten second period. We have found that this comes up with very reliable counts on the intercarrier spacing. On our own originated sources, we can check these once a week. They are recorded and they are filed. Any time that a modulator has strayed more than 5 kHz, then it's adjusted with the aid of a counter.

In the process of doing this since we are sitting in the lab and we are just flicking the dial around and just taking readings of the pre-counter, we, at the same time, check the carrier on all of our off-air stations.

Occasionally, we find one off and we let them know in a very polite and discrete way. We had one broadcaster who was 50 kHz off and drifting very badly. We had another one of the local flagship stations who was about 5 kHz off and steady.

It was tolerable, but it wasn't broadcast standard. Since we know them very well, we just called up and suggested they check their frequency monitor. We found this a very reliable system, if in your program origination for your own purposes, you want to hold it to 5 kHz.

We have seen in Toronto some modulators that we checked where the intercarrier was 4.8 and 4.9 MHz and the system was wondering why they had such distorted sound or none at all. Now that particular unit is a crystal base unit. This would have cost something like about $550 stateside, but it has some frills on it.

For example, we have what is called BCD output on the back, so we have drive printers and all kinds of accessory equipment. For our purposes, we wanted extras. But you can get a counter like this which is time-based from the power line for something like $350. For example, this unit is type approved for checking two-way radio frequencies, but for checking intercarrier, a low cost unit like a line frequency time-based unit, you can get it at about $350. They are available from several manufacturers here.

You people have an advantage when you talk $350 here. By the time I pay duty and taxes and exchange and the like, that's about a $500 unit to me. So I am sure you are all going to find a reason within the next year or two to get frequency counters.

Once you get one, those of you who perhaps look a year or so ahead -- I think once your technicians get one, you will wish you had got the whole unit for counting 5 megs or more.

Generally on the bench, we watch our markers. Right there, that cord going down is going around the back and to the variable marker on the sweep generator. When we sweep a trap, we don't use the usual crystal control marker. We don't think that's good enough for setting traps any more.

When we set our traps or check or verify a trap, for example, on a head-end unit that's come in, we check it with frequency counters. We likely wouldn't have gone out to buy a counter for that, but once you have one and you start checking, you will find that just gradually your technicians feel for themselves the utility of this kind of thing.

You will find them checking the width of traps and checking the center frequency of traps with a frequency counter. That is a close-up of the scope camera. There is a little article I did as a kind of tech note on this month's magazine as a kind of low-cost alternate to this, but one which is probably still acceptable.

The more you get to use some of this gear, the more you find a scope camera of some kind to be indispensable. In the lab we use a lab quality camera like this, and I think when I come to show

you the pictures, you will see that if you are using it a great deal, for a few hundred dollars more, a lab grade camera is nice to have, probably justified.

But you should have a scope camera of some kind. It doesn't do any more to have some guy tell you it was all right. You should have it documented. I am sure your washroom in your place might have a little sign up, you know, that says, "The Job Is Not Done Until The Paper Work Is Completed."

Documentation and paper work is an essential part of running a reasonably tight technical ship. That's our automatic noise figure meter. Now we have found generally that manufacturers have been pretty reliable on their noise figure specs, but we still keep verifying them all, and our amplifiers still get both in terms of expectance and in terms of routine maintenance whenever they are checked.

But with an automatic recorder, it's really so easy to do, once you are set up for it, that you've got to have noise figure instrumentation of some kind. Depending on the volume of work you do, you may want either a manual type unit, or an automatic is convenient if you have got the volume of work to justify it. That is the noise source. This one also has a variable i-f so that we can use it with a number of tuners in front of it or with a variety of tuners in front of it. This little box here is a logarithmic detector.

Really, I have never seen them in very common use and yet we find it a very useful piece of equipment on our bench and not very expensive. This particular unit is under $100. I will show you some samples of the places in which we use a logarithmic detector.

That is a familiar variable bridge. Now the unit we have here is a Jerrold BCC block. It's a splice block with VSF fittings, and we use it as a fairly high-quality transition to adapt that bridge to other fixtures that we may be testing.

Now in our view, and really, it's the view of Messrs. Lubars and Olszewsky in the general cable paper which they gave, released last December at the Cable Conference, and which they gave at this meeting, I think, yesterday -- I think the question in cable testing is whether a variable bridge is used or a fixed bridge, has been pretty thoroughly settled by them and there's no question for cable checking a variable bridge as a necessity.

Now once we have a variable bridge, we have some other lower cost fixed bridges which we use for what you might call gross testing, say, up to about a 20 dB return loss level, but when you start arguing with manufacturers over whether a cable actually meets its spec or not, you've got to get the best bridges available for that.

Also in our lab, we have a tentative 75 ohm standard. I guess it's kind of an unusual thing. Ours and Jerrold's lab are probably the only ones that made any attempt at all toward a standardization of impedance. We have 75 ohm line sections that Alfred made for us, and we are working now with the NCTA Standards Program in cooperation with NBS.

We hope eventually to have our section certified by NBS, but for the time being, we are using this as our internal impedance. That is one of several spectrum analyzers we have. This happens to be a Nelson Ross unit and we have had it for quite a while.

It was three or four years ago, I think, that we helped Nelson Ross develop this particular unit. We have two of these, one that stays in the lab and another that travels. We find spectrum analyzers extremely useful, and I will spend quite a bit of time on their use.

You should, in our view, get the best one that you can afford. I think when you come to look at the potential applications and the potential usefulness, you might surprise yourself on how good a one you can afford. I will show you some of the results we got with this particular unit and also some of the results we have with a considerably more expensive unit.

The main limitation on this one is the resolving power, but for many jobs around the lab, it is for general purposes comparatively low cost.

Now I call this a low cost spectrum analyzer. In the United States that plug-in alone is $1500. It is in a storage scope frame, which itself is worth about $1200. Really, for what you'd call any kind of serious spectrum analyzer work, you have got to have a variable persistence storage scope. It all gets to be expensive, but we figure it's well worth it. Once you have a unit, you know you find all kinds of jobs for it.

This is a set of plug-ins for the 140 scope system and a microwave power meter. There is a 191 precision television waveform monitor. There is a little 90 D scope. It does just one job. It's kind of a little toy scope, and in our cross-mod setup we are using this in, and when we get into cross-mod testing, we would tie up, for various purposes, just about every scope we had.

Then when we felt a need for this lock check technique, we just got a very low cost, very small scope. That's the case for the low cost scope camera.

This is what we call a Cadillac spectrum analyzer. It's one of Hewlett-Packard's new instruments and a very remarkable instrument. I will discuss it in detail later when I go to show you some of the results we got from it.

That particular one has a 110 meg head in it, resolving power down to 50 Hertz and it is just a fantastic instrument. Now it's priced, I think, in the U. S. probably around five or six thousand dollars. But if you ever get a chance to get one in your hands, use it on what you call some of the tough problems around the system. In our system we consider it worth every penny.

The ones we have are on an extended loan because they are in such short supply. We won't get delivery of permanent units until way late this fall.

This slide having come up, I think, is the occasion to discuss mechanical testing. This particular unit, just so you won't wonder what it is, is our X-ray machine. That's the power supply box. There is the technician holding the trigger cable there, and under his arm there he is holding the head.

There is a 25-foot cable there that connects that X-ray tube head to the power pack. We think normally in CATV testing only about the electrical and electronic aspects of testing, and while we are interested in environmental testing, we just weren't equipped for it.

There are some mechanical aspects of cable TV equipment that we did find it absolutely essential that we get involved in. One of these concerns took us into X-ray. The particular arrangement we have in Toronto and in a good part of Canada is that our cables are leased from the Bell.

We supply our own electronics, but the cable itself, the Bell has legal title to it, and they lease us the use of it. Now the scale of orders and construction which is going on in Toronto and in many of our systems is such that the Bell had to subcontract a great deal of the cable installation which we had ordered from them.

When the first part of Toronto was turned over to us by the Bell for testing, we found it to be impossible for testing. It just plain wouldn't work. It was in bad shape.

Now the line of command in our entire organization and the line of command within the Bell were such that it was extremely difficult to resolve this problem, to convince the head office people in Bell that we had to do something about it, to convince them that there was a problem, and to find out what to do with it, looked like it was going to take a year to straighten out.

So we thought the best way to convince them that there was a problem and to check on the quality work being done, was to go out and X-ray it. We went out and got a field portable X-ray outfit like that.

We trained ourselves to use it. Actually, the licensing didn't turn out to be a problem. Now I don't know if you can see it, but let me assure you that that man right over there is wearing a radiation badge and everyone concerned wears that unit.

The ones that work with it regularly wear it all the time anyway, but they get them into the habit. If you do get involved in X-ray, you want to keep in mind that it is radiation, and you want to conform with any safety regulations, health regulations that may be enforcible in the use of it.

We didn't have a severe licensing problem, but I personally have had to take the responsibility for the safety of our people using X-ray equipment. We laid down the rules and the way in which it is used. But those problems are by no means difficult, and it should legally not hinder you from the use of field X-ray equipment techniques, if you feel they have a place in your system.

That is what the equipment that we picked out looks like. The head is portable. It can go up on a pole. The cable length is variable. We had one head with a ten-foot length; we have one head with a 25-foot length.

This unit weighs about 60 pounds, and it requires about 1500 watts of field power, which all of our main trunks are well-equipped to supply. There is an example of the work we get out of it. That happens to be a good one, because I'll tell you, I have a regular wax museum of bad ones.

The first time we took this machine out for checking supplies, the very first day, we just picked splices at random. Two out of three of them were completely unacceptable. They were completely rejected, and you had no way of knowing by looking at it from outside. You learn very quickly with some experience in this.

Now this happens to be a good splice. But some of the things that can go wrong, for example, is that the technician won't crimp the splice properly. He will crimp it with the side cutters, and you can sure tell when he's crimped it with a side cutter instead of a crimp tool. Or else he will get it off-center, or some of the parts back here may be missing.

If he drops one of those little pieces, you can be sure he's not going to bother to climb down to get it again. You know he's not.

The sheath is coming in, and it comes right to there. There's the end of the sheath. There's the other edge of it. Now this is a good splice. In many of our splices, the sheath comes only in that far. It doesn't even get up to the ring that's going to crimp it and make the ground.

The reason is that the guy who made the splice made the center conductor too long, and he has just yanked them, and the sheath ended up way back there instead of where it is supposed to be. Then sometimes this unit up here buckles and becomes awfully close to the outside of that shell.

We have seen in the X-ray programs we have run, just about everything wrong that can possibly go wrong with splices and with connectors.

Now that outfit costs about $3,000 in the United States. It costs us about $4,000 with all the accessories, the film holders and image intensifiers and spare tubes and all that. But we consider it the best $4,000 we ever spent. We had no idea that the construction was that bad. Particularly, if you have got a contractor doing your job, many of these faults won't show up until six months later. That bad ground caused by the sheath only coming from there to there, might work from now until it gets a little wet or corroded inside, and the bad ground starts to show up and you get leakage out of that or you get an intermittent detector.

The thing just plain shorts and you have trouble. Many of these splices will pass an electrical test now and will fail in a comparatively short period of time. There's no better way to audit the work, the mechanical workmanship of the contractor who is doing your work, because the splicing end connector is one of the critical crafts.

You can see how well he is stringing the cable and lashing the wire properly and the proper number of clamps and if the anchoring is done right. You can inspect that. By the way, we take a Polaroid camera when we do all that visual inspection. We report the faults, for example, that we can see from the outside.

But there are just as many faults on the inside of that cable. Now an off-center connector like that would have been found probably by a return loss test in that cable. You might have looked a long time to find it. Then a TDR test might have found that the impedance distance continuity was right there. But the X-ray provides a very powerful tool.

In our system for several years we have used completely captive connectors. We don't allow a sliding fit of any kind in our cable systems.

I understand that the sliding fit into pull-ups is still quite prominent here. It's reasonably easy, then, to go around either 100 percent or on a spot check basis to X-ray a connector and see how far that center conductor is in. Is it a 16th of an inch away from the pull-up? You can tell. You can see the center conductor.

This is a very powerful inspection technique. We so thoroughly have scared our contractors and subcontractors that we just have to take it out once in a while and look like we are making an inspection. Boy, it sure had an effect on the Bell.

We sent in a package of X-ray pictures like that with a report that these were taken at such and such a place, and they were fixed on the next day. There was no questioning of whether it was right or whether it was wrong. You just didn't question the results at all.

That is a connector. This happens to be a 412 to F adapter. Our main concern is with connectors in the field, particularly with splices.

That's a pair of connectors. This happened to be an ABC type. This was part of our program for checking. We get cracks in that cable right there and there, and we just took these to show you why there is a crimp ring there. And for that particular type of cable, we got a connector made, once it became obvious why that was happening without that barb and without a crimp ring.

This has fixed our cracking problem with those cables. I think this is a convenient place to take a break now and allow a reasonable stretch.

If you are still with me in a few minutes, then we'll continue on from there.

(Whereupon the meeting recessed for 15 minutes.)

ISRAEL SWITZER: Now in attempting to make it interesting, I brought quite a few slides to show you some of the techniques and results that we get in testing these systems. Now this is the sweep response for this demonstration. We just happened to pick up a little FM tap. Now this is the FM notch in the TV side of it.

This is the response in the TV side of the FM tap. What it really is is a band notch. I will get my pointer up here. This is taken with conventional sweep equipment and by multiple exposure, which is a convenient technique with a scope camera and which you can do with a lab type scope camera because it's pretty firmly mounted.

We put multiple reference lines on it. Actually, this was taken with a good quality flicker switch. When you come to the photograph, it's more convenient to switch from one side to the other manually and to take your various references by multiple photography.

This is zero dB reference line. This is the reference line, this is 2 dB down and 10 dB down. There are 20 and 30 meg references, but they are way down here out of sight.

Now this is the same filter here, the same setup. The markers, by the way are markers at 81.08 megs. Now this is the same filter but not the same setup exactly. All we did was change detectors to a little logarithmic detector.

Now we can see the bottom of that trap here and reference lines here are 2, 20 and 30 dB, all in one shot, all in the one display. So that for work with filters, we find this 30 dB is about as low as we can go with this particular kind of comparatively low-cost log detector.

So for filters and traps in this range, it makes a very convenient way of checking them out a little more conveniently and makes you have a little better appreciation for what they are doing.

This is a demonstration of that little log detector. That is over a 1 to 300 meg range. Now we are looking forward eventually to the use of more than 12-channel operation, and all of our test equipment now is specified for such an eventuality.

We buy it now to be useful over a 300 meg range. Certainly our sweep generators are, and we are gradually upgrading the rest of the equipment to where we have the capability of a minimum of a 300 meg spectra.

This is that same notch and a logarithmic display over a wider spectrum range. Now I want to go on to show some bridge results. This is just to refresh your memory on a standard return loss bridge setup.

This particular diagram comes right out of Ken Simons' manual, so it's got to be right on return loss. Here is a sweep generator, flicker switch, reference arm, the bridge arm, the cable for other devices under test.

Here is a post amplifier detector scope. That is the return loss on that same FM tap that we had before. It's in the FM region, and the return loss references are 10 and 20 dB, again done by multiple scope photography.

This was part of a program of evaluating that particular FM tap unit. It turned out later that we decided we couldn't use any plain FM taps, but part of the consideration of making that decision was our experience with the evaluation of some of them.

This is the frequency range expanded, and there is a 10 MHz picket. These are 10 MHz intervals, the principal markers here, and eighty-eight one zero eight. Again, these are 10 and 20 dB return loss reference.

This is a high-gain trunk amplifier and its frequency response over a very wide range. This is a conventional setup except for the multiple exposure much as you are used to seeing it on a conventional setup.

This is an expansion of the upper edge. We are concerned with that, because that system runs a pilot up there. The markers are 220 and 235. The ripples that you see in there is a bit of a matching problem, a standing wave problem in what we call our delay line.

We have under the bench some rolls of aluminum cable which are patched together through coaxial switches, and we have them in a 1, 2, 4, 8, 16 dB configuration so that by flicking a coaxial switch, we can patch up a cable of any length we want.

And in the switching through those coaxial switches, we have just a little return loss problem which causes these ripples in the response. That's what a high-gain amplifier looks like without a cable in front of it, virtually impossible to look at.

It's just not practical to study the response of amplifiers, without either a piece of cable or an equivalent cable simulator in front of it. There is just so much slope there, it's really not a meaningful display for anything except the gain at that particular point.

That's about all you'd know about that amplifier from this display. Now this is a bridge check on a reel of cable. That's a reel of 412 cable. The reference line is at 28 dB, and we show a spike near 50 MHz. In this case we used the 30 dB gain post-amplifier. Again, this is conventional technique.

There is nothing really fancy about this, but it is done with a variable bridge. This is an expansion of that spike.

There is a spike, and you see it is not quite touching that reference line. But this is done at a line rep rate and really, we are sweeping that bridge setup too fast.

By narrowing the sweep, we get this effect. The true height of that spike is actually higher. This is the kind of detail you get involved in when you are actually arguing whether this is a 28 dB cable or whether it is actually a 26 dB cable up there, and that kind of thing, and whether that kind of display can make the difference in that kind of argument.

Now these are picket markers that just give us an idea where we are on there. That's 50 meg there, and these are 1 meg picket. Now this is the same return loss test that we had before, but now we have a 54 dB post-amplifier in and it's a far more sensitive setup now.

This particular amplifier just became available, really, on the day we were taking these pictures, so we thought we would show you the difference, and it makes a difference in the sensitivity of the test.

We picked another set of spikes. These are in the region of 100 to 120 megs. That's a 100 meg marker, 110 and 120 FM up there. That's a 33 dB reference line, and 43 dB. It's not a serious return loss spike, but with a reasonable quality sweep generator, it's awfully easy, and with a good quality marker facility, to touch the dial, and zero in on any portion that you want with reliable marker identification.

This is a test of bridge sensitivity, with a very good bridge and with a high gain post-amp. That line there is a 48 dB return loss reference, and the marker is a 240 MHz there.

You can see this particular termination shows performance. The return loss in this termination at high-frequencies is not as good, certainly, as at low.

This is merely a carbon resistor. If we want terminations of better quality right up to 300 megs, we are going to have to go to film and better quality terminations. Now you might ask how we decided this was a good quality termination and this is what we keep that piece of standard line for.

That termination is 75 ohms, which properly terminates a piece of 75 ohm transmission line. Our piece of 75 ohm transmission line is an 18 inch piece of airline, very carefully made for us, in this case, by the Alfred people.

This piece of cable is 75 ohms and that termination is 75 ohms which terminates that line with either minimum return loss in the frequency domain, or if we check it on a TDR, which gives us the minimum impedance discontinuity on a TDR test. So our stnadard is a piece of line.

Then we select terminations which are the best looking terminations for that piece of line. Then those calibrate our bridge and those become our working references in our system.

Now that return loss reference is now 45 dB for the same terminator, whereas formerly the return loss was about 48 dB. Now here we go to just a medium quality F-81 connector. We just changed a little F81 fixture to one of not quite as good quality.

Now the reference lines here are 31 and 41 dB. So for lab purposes, if you are really concerned with return loss, say, at 30 dB or better, you have got to be fairly careful about the bits of hardware pieces that you use.

This is another return loss test. This happened to be on a Jerrold BCC block. We call this a handy splicing block for joining our bridge or to a variety of other fixtures and terminations. This was just a reliability check on it.

So this gives you an idea of, if we have to use this block, what limitation does it put on our return loss measures. The original scope photograph on this was fairly good.

That is a scope display, spectrum analyzer display with a medium-priced analyzer, on our system.

This is on our test benches after an internal bridging amplifier and a distribution system. That is a similar display. I'll get through it to more meaningful spectrum analyzer displays.

Now we are looking closer up at a display, with a high resolving power, of the system as it appears on our test bench. There's Channel 2 there. The guard band and channel 5 picture sound. Channel 6, a bunch of FM channels. This stuff in here, this is a local signal. This analyzer didn't have the sensitivity here. Also, our second order distortion products are hidden down in there.

That is the high band, and you can see on close inspection, the sound carriers there. That is our low band. I am just gradually expanding the display by narrowing down the sweep. Now we can start to see more detail in our low band, 2, 3, 4, 5, 6, the associated sound carriers, the FM carriers.

We carry 20 FM carriers in there. Some of them are as close as 40 kHz. I should add that in Canada we are required by regulation to use FM processors. We can't just broad band FM. We can have as many FM stations as we like.

We have to designate them, and we have to be able to show the inspector that this unit here is handling this particular channel. So you can't just work on a 20-channel FM head-end with a field strength meter. You have got to have either a narrow band field strength meter, which is an expensive thing, or a spectrum analyzer, which is in effect the swept field strength meter.

This is a high band. 7, 8, 9, 10, 11, 12, 13, and there should be a pilot. There is the pilot there. That sound carrier there, for example, is way down. It is showing on here at about 20 dB down.

These are some of the FM carriers in the system, and we have spurs in the FM region. When you look at these, this is 10 dB per division vertically from there to about there. Those in there are all spurious.

See that spur there, about 15 dB below the level of that carrier. So the first time you start using spectrum analyzers with logarithmic displays, you kind of get alarmed, you know, wondering what is all this stuff in here you've never seen before.

But if you keep thinking that it's 10 dB per division, the marvel is that you can see it and you soon learn what's going to hurt you and what isn't. That's an individual carrier.

This is Channel 13 picture. This is color information, Channel 13 sound, and that happens to be a 220 meg pilot carrier in our system. We can start to see the sidebands being developed in there. We would see in here if we had any beats in that picture to give us trouble, because we can easily see 10, 20, 30 dB down.

There's a 40 dB level right there. There is still room in there to have beats even that wouldn't have given us trouble, that we could still see; because generally, as a rule of thumb, about 40 dB down is about the threshold of visibility for a beat.

So any problem on Channel 13 would have probably been seen unless it was right in close to the carrier here. This is a sound carrier now. We are getting the more reliable display of sound carrier. We are about 15 dB down sound to picture.

This is still a low-cost analyzer. Now we have expanded up here, and we could, if there had been bothersome beats in here, seen them, because we still have that 10, 20, 30 and 40 dB level right across there.

There is color subcarrier information there. You can start to see the sideband structure now. The modulation sideband structure is right there around the carrier. It is capable of a great deal of useful work in the checking out of beats and the like in a system.

On that particular medium low-cost instrument this is about as close in as we can see to the carrier. These are individual 15,750 modulation sidebands. We still couldn't see a co-channel beat or a beat close to the carrier.

This is 60 kHz per division, picture plus 60, picture plus 120, picture plus 180 about there. So that's an idea of the horizontal scale, 60 kHz per division.

Now we are into a different instrument. Now this is a Hewlett-Packard instrument. It is their newer spectrum analyzer. On this particular instrument, we have the 110 meg head, but the newer 12 meg head does a similar job.

Now we are in a position to see beats. Let me try and pick up some of the detail on the calibration for you. This is a Channel 6 picture carrier. We have 50 kHz per division horizontally and

the bandwidth of the instrument for this setting was 100 hertz.

Now we start to see the individual line components of the spectrum. That's Channel 6 carrier. Now we are looking right in close to the carrier. This must be 10 kHz. This is Channel 6 in the vicinity of the color subcarrier.

This is the color subcarrier. Now these are chroma sidebands, and this spectrum analyzer has a capability of showing the interleaving of color and luminance information, as you have seen in the textbook. This instrument is actually capable of showing it to you.

Now if there had been some fault in the color subcarrier frequency so that the interleaving was not perfect, these would have been apparent. But they are right there in the center where they should be. Their color signal, at least in that respect, was okay. This happens to be the Canadian Broadcasting Corporation flagship station.

We didn't really expect any problem with them, but we just did it to show you the capability of the instrument.

This shows the interleaving of color sideband component with luminance sideband components. There is their color subcarrier frequency. Now we have gone back to the Channel 6 picture carrier, 5 kHz per division, 10 dB per division vertically and a bandwidth of 50 hertz.

This is about the most the instrument can do. These are the first modulation sidebands on each side of the carrier. A co-channel, if we had one, would have fallen right in there or possibly there, if it were a 20 kHz sideband co-channel.

It could have gone on either side of it that way. But you can see that there is room. Now this is going down 10 dB per division, 10, 20, 30, 40, to 60 dB down. Now I have a co-channel demonstration coming up, but there is no trouble at all with an instrument of this kind in clearly seeing and identifying co-channel components way below the threshold of visibility.

We have any number of times in our system, particularly now that we have got into warmer weather, with the spectrum analyzer, been seeing co-channel components in the spectrum display that weren't yet visible on the screen.

We tried here to just push the instrument to the limit and try to look at the 30 and 60 hertz sidebands around the carrier, and with a 50 hertz resolving power, you just can't quite do it. Here we threw in an artificial beat out of a signal generator.

Here's where you get to enjoy a lab quality signal generator. You can move it in there and it will stay there, whereas the average $50 kit signal generator is just going to drift. You can't possibly do this kind of work with it.

We put that beat in there at the same level as the picture carrier, and it's about 7½ kHz off below the picture carrier. Now this picture was, of course, unwatchable. Now we have pulled the beat down, and I guess we have moved it to the upper side. There it is, there, 10, 20, about 26 dB down. There's no trouble seeing it.

That's closer in than a co-channel would have been. A co-channel would have been right there. It's still visible on the screen. Now we have pulled it down again right to there. This is not a 10 kHz. It's about a 7 kHz beat.

It's about -40 dB. It is now out of sight on the screen, but there is no problem in seeing it on the spectrum analyzer. Now that's fine in the laboratory, but we took it out to where we had a practical problem on a system.

This was taken at Midland, Ontario. The situation we have there is that we are trying to receive Channel 4, Buffalo, at a distance of about 140 miles when we have Channel 3 within 2 degrees of being right on course and only 30 miles away.

So you can imagine the relative signal strength, then, of those two channels. That's a real adjacent channel problem. We have put in all the trapping and filtering and the like that we could. When we looked, we found that we had the Channel 3 picture and sound carriers quite well-trapped out, quite adequately trapped out, but we were still getting a cross-modulation in our antenna pre-amp.

When we put the spectrum analyzer on, we could see what the problem was. We found, with the spectrum analyzer, that the offending carriers themselves were adequately trapped out, but there was enough sideband energy coming through, because there was something like a 60 dB disparity between the carriers.

Even when we trapped the first carriers, there was enough sideband energy, and particularly in the color region that it was cross-modulating and causing distortion in our antenna pre-amplifier. Once we understood that and had a look at the spectrum coming through out of that trapping and filtering, we decided that there was no amount of very narrow notching that would fix that problem; because you notch the carrier, but there is still the sideband.

We got a whole string of sidebands. Now what we learned from it is that really what we need is either an extremely efficient band reject filter for the unwanted carrier or a very efficient band pass filter for the wanted one.

We also, from the spectrum analyzer study, have a very firm handle on exactly what the characteristics of that filter had to be. We know that none of the current catalog filters are going to come close to our requirement.

We now are talking about the state-of-the-art aerospace filters in great big cabinets. We are going to end up with a cabinet the size of a piano, it looks like, for that job, but at least we know now and can talk confidently about filters like that (and the kind of money that this implies) with confidence that it's going to work because we know now exactly what our problem is.

Before, we were just fooling around, but we just can't afford to do that anymore. This particular picture is an actual co-channel case, a very severe case. We have two co-channels there, three of them there and there and there, two 10's and a 20. It was kind of a mess on the screen.

That one, we don't know what that is. But these were co-channel components. That's about 10 there, 20, 30. This one was visible. This one probably isn't, but it's there anyway. Now I want to get into video base band testing techniques.

That is the general spectrum characteristic of a channel. This is just a refresher. I'll go through these quickly. The vestigial sideband, the video signal, the position of the sound carrier. The normal spectrum -- this is the textbook illustration of what I was just showing you, actually taken off a spectrum analyzer.

It shows the interleaving down here. There is the color sub-carrier, and there is the interleaving. There are the color side-bands and here is a gradually reducing luminance sideband. Here are the interleaves, one with the other. This kind of thing you can only do on a textbook basis or with very tedious lab methods.

Here are the sync pulses. This one happens to show color information superimposed on what you call the luminance information. But this is the usual position of the color burst and the sync pulses. Again, here is the standard waveform to show you the timing involved, just to refresh you again on basic video; because we are now starting to test our system using video techniques.

Here you move the base line from being in the middle down to the bottom and you just use a portion of it. That is where a T pulse comes from, just derived from a sine wave that way. A 2T pulse is exactly the same when it's doubled in scale.

You start with a 2 meg sine wave and it has a .250 microsecond width at that point, but the shape is exactly the same. It is a portion, so to speak, of a sine wave. It is a cycle lifted out

of a sine wave. Now this is the effect of frequency of a T pulse.

As other people giving papers here on video have pointed out, this is the spectrum. It is virtually all down at 8 MHz and about half amplitude at about 4. Now this kind of T pulse just won't go through our head-ends and systems, so it's not really much use to us except that if the distortion we get on a T pulse is symmetrical, at least we know our base distortion wasn't too bad.

But a T pulse is going to be badly distorted in a transmitter so by the time we get it, it isn't much use. The most useful thing to us is a 2T pulse, which has the same kind of spectrum except it is now 4 MHz here. It's just double the width and a half the spectrum width here.

So a 2T pulse should pass through our systems in reasonably good shape, and it's the 2T pulse in effect that we end up using in our system for test purposes.

Now this is to show you from the textbook the 20T pulse. The 20T pulse itself is derived in the same way as the 2T pulse, except it is 20 times .125 there, and that's a 3.5 subcarrier. Now a 20T pulse like this going through a perfect system, this shows you in the textbook cases of what the pulse looks like with various distortions. This is a perfect 20T modulated pulse. The amplitude of color sub is okay, and the envelope delay of color sub is okay.

This is what it looks like where the delay is okay but the amplitude is not. Your amplitude is low here, and you get that scalloping up here. Here the amplitude is high on the color sub. Where you get this unsymmetrical S kind of shape here, you have a time delay.

You have a great delay problem when you get that kind of unsymmetrical thing. So that is a textbook case of what these things should look like.

Now we'll start into the problem of actually using something like that. By the way, this came from a Marconi book.

The 20T pulse has been in comparatively common use in Europe and is just beginning to be used now in North America. I think in many instances, particularly in broadcasting, Europeans have probably been further ahead of Americans in testing techniques for broadcast systems.

I think the reason is that most of the Europeans' broadcasting is by government-owned systems. Since they don't have too many commercials, an American broadcast network or station has a

constant commercial pressure on them. They have to sell soap flakes, and if the soap flakes don't look good in color, you have got to do something about that.

Now there isn't that commercial pressure in Europe toward running a first-class plant, so they have a great many engineers who feel that their main obligation, I guess, is to develop a number of test techniques.

There is no one really riding them for quality except their own good consciences. Since they don't have commercials to judge their quality, they have had to develop test techniques to judge their quality. So, many video testing techniques have really been brought over from Europe.

The sine square pulse and now the 20T pulse is also coming from Europe. Now this is taken with our waveform monitor. It's Toronto Channel 6, on which there is very commonly a ghost problem in our area. It is line 16.

Field One as displayed at our head-end on a waveform monitor, and we have expanded the scale vertically. That's the sync pulse from there to there. This is the sync pulse there. Now we have done it in order to look at line 16.

Now what we have here, (that disturbance) is a very small ghost. We have a ghost of the sync pulse showing there. Now we are able to time it from there to there, because we know the time base on the scope. We are able to take a relative amplitude measurement.

We can actually measure that amount of disturbance and relate it to what the peak-to-peak video would have been.

This is the sync pulse. Our video would have been way up there. But we know the standard height of this sync pulse, and we can then arrive at a numerical value for the size of that ghost that way. This ghost was not perceptible in the picture. It was below perceptible threshold.

In our file on it, we actually took a measurement on it, but it is not perceptible. There is a whole burst taken off air. Now it's not very good looking. There is 4.2 megs. It's a way down, and it is just plain really not a satisfactory multiburst.

Now at that time -- and this was taken more than a year ago -- we really didn't know and had no way of determining just what was at fault, whether it was the broadcaster or our head-end control unit or whether it was the demodulator; because we could equally have suspected all three of them.

It took quite a bit of work to start to get some standard instruments and to develop a reliability in their use. It's a problem that Frank Ragone went into when he discussed Jerrold's problem in evaluating their new modulators and demodulators.

All we know is that it's not right, but we don't really know which is at fault. Well, we did know this is a frequency response test and we could check our demodulator for frequency response. We did have it pinned down, but we didn't know now just where our faults started.

This is of the same channel, pulled out of the broadcaster's vertical interval. This is a T pulse, and there is a bar. Now it is not really very good looking, but this signal was generated in New York and has come to Buffalo over one of the very earliest networks in the States.

This was broadcast through a transmitter that we don't really know anything about, and this is what we get at our head-end right off the antenna. Well, we can go on down the system with it, and all we can do is to take a set of photographs and use our demodulator on the system and see if we can find any change which may be attributable to our system.

But it's such a lousy looking thing to start with that it becomes awfully hard to do any more with. So it's not entirely satisfactory to start with a broadcaster's VITS pulse and to try and do something with it. We tried to, but we are certainly not satisfied with it but is what we have to start with.

The T pulse really never got out of the broadcaster's transmitter. It never was intended to. It was intended for checking of broadband networks. That has 8 meg frequency components, so it never had a chance.

Now we start to look at equipment which we are getting involved in. I believe that ultimately our systems will have to be proven out on a baseband-to-baseband basis.

We are just one part of the television system, and I mean "system" in the broadest sense. The system starts with a camera in either movie studio or a television production studio, and it ends on our subscribers' TV set.

We are trying to make an honest living out of being somewhere in the middle of that. Now it starts at video and ends at video, and we are never going to have a satisfactory proof that will really satisfy anyone who is concerned until we are able to prove our system on that basis.

You can't prove your system without a modulator or demodulator which is ten times better than whatever you are checking. So we have been looking for some time for equipment to do this, and it

wasn't until this year that it looks like practical equipment is available for doing this, and at reasonably practical prices.

Some of it has been reported at papers earlier this week. We had the good fortune, or enough interest, to have a chance to actually field test some of the prototypes of equipment of this class some months ago.

Now this is a 20T pulse and bar shown on our waveform monitor. This is a modulator and demodulator set back-to-back, just connected through their attenuator. So this is the best that the system can do.

We start with a video test generator of good quality. We are displaying it on a very good quality oscilloscope, specially made for this purpose. We have what we consider a good quality modulator/demodulator. They are connected through an attenuator pad.

We are gradually going to separate that modulator and demodulator and work more and more of our system into that gap and see what happens to these ideal pulses when we do that. There is a 2T pulse standing right there, but it doesn't photograph too well.

We will show you that again. There is the 2T pulse. We have expanded it. There is a 20T pulse that we started with, expanded. It has a good level base line and no asymmetries. I have shown you in a textbook case what trouble looks like, and it's right up to the same height so far. Everything looks fine.

Now we have added these particular units we had at that time. We did not at that time have a tuner. We worked at i-f. The modulator worked at i-f and the demodulator worked at i-f. We had to supply the frond ends and back ends for the thing to make them work on svstem channels.

So, in this case we took a CCB up converter from a channel commander, and we took the tuner out of a Jerrold TV. These were the two tuners and up converters we were looking at here. We were interested in the difference, and how much distortion had we added? Just a little bit.

We considered it quite tolerable. Now we will go forward here to the response, then through a head-end control unit.

This is the additional distortion, then, in a 2T pulse going through one of the new type head-end control units. We have now worked it in, but this was still done on a bench basis. Now here is the signal arriving at our lab, 900 decibels down the system from the test insertion. This is a practical test on the system as a whole.

Now the head-end unit has some distortion and this is not as good a 2T pulse as we had with the mod and demod back-to-back. But we feel that we haven't aggravated it in going through the system, and this is what we expected anyway. The kind of distortions that will affect color and pulse response and the like are mainly in the head-end.

The system can contribute noise and it can contribute ghosts, but generally speaking, the broad band systems that we operate are not going to contribute phase distortion, at least significant ones.

Now in order to try and improve the adjacent channel selectivity, we processed it through adjacent channel traps in one of our Jerrold TD receivers, and we just made the problem worse, as we might have expected. When I say the TD receiver, it really isn't meant as a criticism of it. You must understand that that particular receiver was designed a great many years ago and probably even before color, and it just wasn't speced or built for the kind of testing and the like that we are putting it through in this particular demonstration.

This is what it does to a 2T pulse, and that's all you would expect out of an early model demodulator which was never intended to pass this kind of pulse or to be tested in any way. But I understand, from talking to other people who have tried demodulators in this way, that this was a remarkably good TD, but you can see what it has done to a 2T pulse compared to some of the other ones that I have showed you.

So the new type equipment which is being developed specifically for this kind of purpose, for absolute minimum phase distortions, either that you want to use for base band testing this way or you want to use for extremely critical color applications, is significantly better than the older type, particularly tube demodulators.

There is a frequency response of that TD. It's not bad. That is classically -- well, I guess it hasn't lined up right. The carrier is up there. It should have been down about there. But a fairly flat response is what we see.

There is the i-f response of a demodulator which has been designed for fairly good pulse type response. It's a haystack response without any sharp corners. Now this is one particular company's approach to that problem. Some of the other companies take other approaches to it.

In this case, the solution this particular company is making is that the demodulator was designed to get this haystack response instead of that kind of response. Now here is a 20T pulse. Now

what we had done was to take the 20T system out to the head-end and run it through our head-end processor. We found by using the calibrations provided on these 20T pulse generators, that we had about 100 nanosecond group delay on our color sub.

This we consider tolerable for head-end equipment. We then corrected it. We kind of tuned it out by pre-timed distortion, and then we passed this 20T on through to the office to see if there was any further degradation in the system.

We don't feel that there was, even trying to look through that hash from the adjacent channels. We feel that the base line there was symmetrical. We did not see any group delay in our transmission system beyond what we had at the head-end.

This again was in accordance with our expectation. We expect that this kind of testing is going to be used mostly on head-ends, but when you finally prove it, just to be sure, you are going to actually pass it through the whole system then and check the whole system out as a whole with probable test waveforms very similar to the ones that we have shown you here.

There is a 20T waveform with a bit of delay in it. This turned out to be about 100 nanoseconds delay.

This one was at the head-end, and we had that much distortion in the 20T pulse, which then, with the controls on the unit, we were able to establish at around 100 nanoseconds. We corrected it and sent it down the system, got this out at the office and we're confident that we had contributed no additional significant group delay.

This is a TDR display. Before I get on to complete the other topics, I have said that we expect baseband-to-baseband testing to end up as probably the approved and the most ideal way of testing and proving a cable system; because it tests where you live, so to speak.

The system is baseband-to-baseband, and we believe that it must be proven on a baseband-to-baseband basis. There are some problems, like subscribers' sets, and we get around that in effect by using a good quality demodulator with fairly ideal characteristics.

What we are using at the moment for this is the older tube type demodulators, which we are gradually retiring from other services. We are bringing it back into the lab to serve as what we would call standard receivers. When they are peaked up right, they have many of the characteristics of a first-class home receiver.

They are much easier to work with in that you can get in to check the alignment more easily. You can put manual bias on them if

you want. You have got an i-f test point. You have standard video output. They are very convenient to work with that way.

So this is what we are putting into our system. This is what we are using as a standard receiver, because we feel it approximates a home class receiver and it's much more convenient for us to work with. We also have, and will have a few more of them as we gradually retire more of them out of our system work and replace them with more cable units for systems purposes.

This is a TDR display. Let me see my notes here. Here is a standard line section. That whopping big display is our connector, which is our big problem in using our standard line.

This is the other signal on it. It turns out that this is 1 ohm high compared to our standard. And we read that cable, then, to be 76 ohms, which is okay. We don't spec that cable any closer than ± 2.

Now this one on the right side, is our standard line connector transition. There is a test piece we were looking at. In this case, here is a terminator. This turned out to be 76 ohms. This one happened to be a piece of cable we were checking. It turned out to be 77 ohms, which is the upper limit of our spec.

Any worse than that and we'd have been after the manufacturer. The aluminum cable we buy the spec at ± 2 ohms. Here we have a display which is not as obvious as it should be because of the connector problem. The connector puts excessive disturbances in it.

It's not too bad here, but on this display the connector disturbance is so bad that it just makes the rest of the display kind of hard to use. We are not really getting the kind of utility and accuracy out of our standard line references that we should be, because we just don't have connectors as good as they should be.

We can see through them, but it sure would be nicer if we had better quality. Those are all of the slides. Now there is a lot more gear, actually, that we use. There is a lot more we would like to have. One of the things I might mention briefly is field strength meter calibration, and I have referred to it a couple of times.

When you have as many field strength meters out in as fussy an operation as we have, and where it is really critical, if you are willing to take the time and trouble to control everything that can be controlled and has to be controlled, you can stretch a system considerably further than the operator who is not willing to.

If you actually work out the arithmetic of amplifier cascading in detail, where a manufacturer recommends a maximum cascade of 50, if you go through the arithmetic to his spec, you may find that the number of cascadable amplifiers is actually 100.

But in order to be conservative and to take into account all the things that can go wrong, the fact that all the amplifiers won't be at the same level and other things like how accurately can you actually set an output and check an input level, you get back into the field strength meter control.

Then if you are willing to control some of these things -- for example, in all of our main trunk system, out of 20 miles I don't think there has been but 1 mile of it aerial. At great expense and some maintenance problems, we put it underground because we have taken a great amount of temperature swing out of it.

We spent a great amount of time, money and effort watching the field strengths on our calibration. We were sent 12 field strength meters, and out of the 12, we selected 3 by hand. We picked 3 out of that 12 and sent the other 9 back, presumably for less fussy customers.

But we picked the field strength meters that are going to be flat across the band within our tolerance, which is about a dB. Some of them, it turns out, are better than others. Then they are checked every week, and if there is any suspicion at all, they are brought in and checked more frequently than that.

I want to thank you people for your patience. It's been a long morning.

I want to thank Norman and the NCTA for allowing me to take up this much of the time of the convention. I feel it a real privilege since I guess most of the other speakers at this convention probably had equally important things to say and unfortunately didn't get a fraction of this much time.

So I am grateful to all those concerned for the chance to come to talk to you and to have so much of your time.

DISCUSSION:

SESSION CHAIRMAN PENWELL: Any questions, gentlemen?

MEMBER: Mr. Switzer, could you give us just a little bit more detail as to the test equipment setup you are using for field strength meter calibration? You mentioned two different items. You mentioned the power meter as well as the transfer standard, which I was not familiar with, and I was wondering.

MR. SWITZER: Well, on the power meter we use a fairly conventional setup. We take a lab quality signal generator because it's good and stable with respect to both frequency and its level. It turns out, after we used it a while, that the calibration on the signal generator is pretty good.

When in a hurry, the technicians just use the signal generator, but otherwise, we take the signal generator and feed it into the splitter, which we have very carefully checked for balance. So we have a reliable splitter that we use for this purpose.

We take one load off it to the field strength meter and the other, then, to the power meter. On the power meter, since it's a 50 ohm instrument, we use a minimum loss pad to make the transition. We have gone through all of the calibrations on that MLP, and it's taken into account.

We use an MLP because the power meter head is not all that good a match to the line. If you don't have a good termination there, you are liable to have a standing wave effect between the splitter and the power meter head.

So the MLP has got enough insertion loss that it helps reduce the standing wave problem there. I think the technicians started using an extra 60 dB pad there just to be sure that we have no standing waves in this setup.

Then on the arm that goes to the field strength meter, calibrate with pad in position to clean up any possible standing waves in that line. Also watch the jumpers that you use.

So you have to take pains with the standing wave situation. Anytime you are making precision r-f voltage readings, you must understand the standing wave situation and do something about it. There is a potential for error there.

In the transfer standard, it is kind of hard to do without a black box, but what it is is a thermo couple and a very accurately calibrated precision r-f resistor in series. We started with DC and we put DC through it. In our case, we don't have a precision millivolt meter that is a digital type or a very good potentiometer.

We do have pretty good current measuring equipment, so we measured the DC current flow in this series string. We then measure the thermo couple output and we mark it accurately on the meter. Then we substitute r-f and when we have the same thermocouple output reading, we know that we have the same r-f current reading. In one case, we use 15 milliamps as a standard, so now we know we have 15 milliamps of r-f flowing and the r-f resistor has been very actively calibrated and certified by the NBS.

We multiply that current times that resistor reading, so we know we have so many millivolts across that r-f unit. Then that is

our r-f reference. This is a very low resistance value. We picked low resistors there because then when we load a 75 ohm field strength meter across that (the resistance values are around .5 ohms), so that the loading effect of even a 75 ohm resistor is negligible.

But you are working from an unmatched source, so that there again, you have to take care that your load is at least well-matched to take care of the standing wave. It is more trouble to use, but, you know, the microwave power meter, after all, is just another instrument.

Really, why should it be any more accurate or reliable than your field strength meters except that you know it's closer to home, and really, it is more reliable than our field strength meters. So if the question ever arises as to whether our power meter is accurate, we then take the meter to this transfer standard.

MEMBER: What do you figure is the overall accuracy of your total setup?

MR. SWITZER: Per calibration?

MEMBER: Yes.

MR. SWITZER: On the order of 1 dB absolute. That is, we believe that when we have finally calibrated a meter we are within 1 dB of absolute true voltage. The potentiometer is quoted at about 2½, 3 percent. You know, 1 dB sounds pretty close, but it's actually 10 percent.

MEMBER: I have a question related to the video band tests. I am curious about the Canadian broadcasting stations having two multibursts side by side of different appearance.

MR. SWITZER: What stations?

MEMBER: Particularly Channel 6 in Victoria.

MR. SWITZER: Yes.

MEMBER: There is some difference in appearance, and I don't know the significance of it.

MR. SWITZER: Channel 6 uses both CBC and CTV service, and it is a satellite of Channel 8 in Vancouver. I think your best approach is to discuss it -- is Ernie Rhodes still the chief engineer?

Ernie Rhodes is the chief engineer in Vancouver and very good and very cooperative. If you call him, I am sure he will be pleased to identify those for you.

MEMBER: Might that be on one line? It's a network multiburst, and on the other line it must be inserted at the station.

MR. SWITZER: It might be. I just have no way of knowing, Jerry. But Ernie would clear it up for any people that are interested.

MEMBER: I just wanted to make a comment. We are owned by the KING Broadcasting Company that operates a television station there. We put in our own VIT's at the studio. I think more and more broadcasters are doing this. We strip off the network VIT and put in our own.

Generally, it's sine-squared pulse and bar.

MR. SWITZER: 2-T?

MEMBER: 2-T. But we are happy to switch over to multiburst or other test signals. We are happy to make sure that the video gets through in the proper form.

MR. SWITZER: It's a constructive attitude on the part of the broadcaster. We have had a suggestion from some that they would rather not hear from us, you know, in terms of potential criticisms.

I am sure a responsible broadcaster will take the attitude that they will be pleased to help and include their part of the system in overall tests. We have had the stations in Toronto run special tests for us where we have started with a waveform monitor and camera, and we have followed right through from the test signal generator through the board, through the modulator, probe off the transmission line over our head-end.

We have a series of pictures right through the whole system with the cooperation of broadcasters. It is a kind of proof of the whole system. Very often, even if it's locally inserted, the sine-squared and the 2-T pulse will have some distortion due to the sideband filter.

We have found this, in our case anyway, in two instances. The 2-T pulse is also nice and neat from the broadcaster. The T pulse certainly is not. The 2-T has got half a chance of coming out all right.

MEMBER: You mentioned in your field strength meter calibration your padding and minimum loss of pads. Do you have a number for what type of standing wave ratio you run in your system here?

MR. SWITZER: I would say in that calibration setup, our return loss would be no worse than probably 24 dB, but it's one of the limitations in real accurate r-f voltage measurements and level measurements. We have taken some pains with this one. For example, we select the RG-59-B we use, and it's checked against our impedance standard.

We have checked the return loss on the minimum loss pads and the other pads that we use. With a little pain, you can select components to give you an overall system return loss situation of about 24 dB or so.

MEMBER: On your field strength meter calibrations, do you calibrate these meters in the lab or in an environment similar to where the meter is going to be used?

MR. SWITZER: We haven't considered the environment factor, Bob, and I suppose by next winter we will. They are done in the lab and generally, the chief technician does it or those fellows that we consider know enough to calibrate on their own. Otherwise, they are left in a rack for charging overnight anyway.

I think one night a week the chief technician comes in and goes through them all while they are sitting on the rack. We haven't considered the environment factor, but we certainly could. We could take the meter outside. I don't want to take the calibration gear outside.

MEMBER: I was wondering if you had a chamber.

MR. SWITZER: No, we don't.

MEMBER: Have you made any tests on what changes there would be through temperature change? If you set it up at one temperature, how much deviation is there with a temperature change?

MR. SWITZER: No, but come cold weather we will just put it out the window, the test cable, and I am sure we will be able to check that. Most of the carriers in our system, because we are underground, run fairly stable. Anytime they run into a level that they don't expect, then there are two choices, either the meter or the system is wrong, so as the occasion arises, depending on their feeling for it, they will then come in and check the meter.

If we have any trouble come cold weather again, we will check and see which it is, whether it's the meter or the system. I think that's all, Norman. Are there any closing remarks?

MR. PENWELL: If there are no further questions, I just want to thank you all, and particularly Mr. Switzer, for what I feel and hope for most of us has been a very informative morning.

TECHNICAL SESSIONS

THE CATV DEMODULATOR

Session Chairman:
Archer S. Taylor

Participants:
Carl T. Johnson
"A Comparison of Synchronous and Envelope Detection in Demodulators for CATV"

B. W. Osborne
"Demodulation and Modulation of Television Waveforms"

George Stoeppel
"A New Transistorized TV-Demodulator"

Frank J. Ragone
"Peformance Measurements of Modulators and Demodulators"

CARL T. JOHNSON

I. Abstract

First the general properties of the envelope and synchronous detectors are examined. Then, after a brief study is made of the modulation processes used in television, the responses of the two circuits to a video signal are compared. Finally, a practical synchronous detector system is briefly described.

II. Introduction

The process of envelope detection has been with us ever since the days of the cat whisker. In present AM broadcast receivers, the envelope detector is used almost without exception to extract the program from the signal.

With the advent of television, the simple and economical envelope detector was chosen for reproducting the video, and thus once again became an industry standard. In this role, it had done reasonably well until color TV came along. Then its performance became less acceptable, but still adequate in cost-trimmed home instruments. However, in precision test equipment and high fidelity demodulators, the deficiencies of the envelope detector prompted a search for something better.

One of several devices giving improved performance is the synchronous detector. The remainder of this paper is devoted to describing the shortcomings of the envelope detector and explaining how the synchronous detector overcomes these deficiencies.

III. Basic Concepts of Envelope and Synchronous Detectors

The envelope detector is, in principle, identical to a rectifier power supply for converting 60-Hz voltage to some dc voltage. Both circuits are comprised basically of a rectifying device and a filter which removes the half-wave (or full-wave) ripple component. Figure 1 illustrates the half-wave circuit.

If the 110-volt ac input to the power supply were to change, so would the dc output. The 60-Hz voltage would act as a carrier for the amplitude change or modulation. The envelope detector works in exactly the same way, only at a much higher frequency, - 45 million Hz, for example. Also, amplitude changes are much more rapid.

The rectifier does not have to be a diode; it could be a relay. But, for an envelope detector, the one-way conduction property of the rectifier is best obtained in the diode, either vacuum or solid-state. Note that the diode turns on for one polarity and off for the other. In fact, the best description for the diode is that it is a polarity controlled switch.

If the rectifier in Figure 1 were replaced by a switch or relay which could be opened and closed at a 60-Hz rate, then the circuit would become a synchronous rectifier power supply. Vibrator power supplies for the old tube car radios sometimes made use of the principle. Again, the synchronous detector operates in the same way except that at the very high carrier frequency an electronic switch must be used. Figure 2 illustrates the action of a synchronous circuit. When the switch is timed properly, it acts as a polarity controlled switch and hence as a rectifier.

Note that it is possible to adjust the switch so that the output is positive and negative for equal amounts of time. Under these conditions, the filtered output is zero. Obviously, this device is not a polarity controlled switch. Rather, it is a time controlled switch, which under certain conditions behaves as if it were polarity controlled.

But why is the synchronous switch more desirable than a polarity controlled switch for extracting video information from the RF carrier? In order to answer this question, it will be necessary to examine more closely the phenomenon of modulation.

IV. Pure AM Versus SSB

Consider again the low-frequency 60-Hz power supply. Let it be connected to 110 volts through a potentiometer as shown in Figure 3.

Now suppose the potentiometer setting is continuously changed in a regular and periodic fashion such that the rms voltage supplied to the rectifier reaches a maximum and falls to zero once every second. Assume that this variation is sinusoidal. The wave form applied at the input to the power supply will appear as shown in Figure 4a, and is called an envelope.

In Figure 4b, the variation in dc output, caused by the modulation of the input, is shown. This modulation is caused by the 1-Hz motion of the potentiometer. The output is made up of two components, a dc voltage and a sinusoidal voltage (Figure 5). The dc component is caused by the carrier and the sinusoid by the potentiometer.

As shown in Figure 6, the power supply input is now composed of three signals: the 60-Hz carrier and two sideband components, one at 59 Hz and the other at 61 Hz. The process just described can be called pure amplitude modulation (AM) and is the type of modulation used on the standard broadcast band.

In Figure 7, the phasor of length A rotates counterclockwise at a speed of 60 revolutions per second. Its projection on the vertical axis depicts a sinusoidal wave having a peak value of A volts and a frequency of 60 Hz. It is simpler to represent

the carrier and sidebands of Figure 6 by means of phasors. The diagram (Figure 8) is made up of three constant amplitude phasors, one rotating at 60 rps, one at 59 rps and one at 61 rps. Their sum is the resultant R, which varies in amplitude at a 1 Hz rate and rotates at 60 rps. Figure 9 shows the three components and the resultant R for various positions of the sidebands. It is important to recognize that the output of the power supply varies only in accordance with the resultant R. Likewise, the envelope detector responds only to R.

The diagrams of Figure 9 are for modulation by a single frequency. In a typical situation, such as an audio channel on the standard broadcast band, there would be coutless other frequency components, each of which would create a distinct pair of sideband components. If the highest audio frequency present were 10 kHz, then the sidebands would extend from 10 kHz below to 10 kHz above the carrier, requiring a channel width of 20 kHz.

For a television channel, the highest modulating frequency is 4.5 MHz. Therefore, if pure AM were used, the required channel width would be 9 MHz. In order to save spectrum space, most of the lower sideband is filtered out, resulting in the vestigial sideband AM signal, which is allotted 6 MHz of spectrum space.

For the purpose of analysis, the vestigial sideband signal will be treated as a single sideband signal with an unsuppressed carrier. Such a signal would have its carrier and all of one set of sideband components, but none of the other set. Also, for the sake of analysis, the single sideband will contain only one component. Suppose a very sharp filter were added to the circuit of figure 3 such that only the 59 Hz component were removed. Figure 10 shows the new circuit. The envelope now contains only a 60-Hz voltage and a 61-Hz voltage, and appears as shown in Figure 11. Figure 12 shows the output wave form produced by this single sideband input. Notice that the components are a dc level and a distorted 1-Hz sine-wave. As a matter of fact, the second harmonic distortion in the output is about 12 percent and the third harmonic distortion is about 3 percent. Higher order distortion also exists, but at a very low percentage. The cause of this distortion is the presence of a new quantity called quadrature component. This effect can best be visualized by the use of phasors.

In Figure 9, the sideband phasors S_1 and S_2 have the same length, and they have equal but opposite angles with respect to A. Consequently, R, the vector sum of S_1, S_2, and A, always points in the same direction as A. Now, observe in Figure 13 the phasor diagram of a single sideband signal. Let it be assumed that S_2 was eliminated from the signal of Figure 9 to obtain this SSB signal. The envelope detector still responds to the resultant Rq, which, however, no longer stays in line with A. This deviation of Rq about A causes the harmonic distortion illustrated in

Figure 12 and is the result of the presence of the quadrature component Q_1. Before S_2 was filtered out, Q_1 was exactly cancelled by Q_2.

The undistorted R is the sum of A, I_1, and I_2. An undistorted, although smaller R, would result if I_2 were taken away. Therefore, if a switching device could be designed which would be open for the Q_1 component in Figure 13 and closed just for the A and I_1 components, a nearly distortionless SSB detector would be realized. One such device is the synchronous detector.

Understanding the synchronous detector and how it can ignore quadrature components is facilitated by: (1) recalling that this device is a time-controlled switch, and (2) assuming that the switch is on for just a very small portion of a phasor revolution. In fact, assume that the on time of the switch is so short that the phasor does not move during the on time. At one instant during each revolution A will be at an angle such that the projection of Rq on the vertical axis is equal to A plus I_1. Figure 13 shows Rq in this position. If at this instant the synchronous switch is turned on, the output will be just equal to A plus I_1. If the switch were turned on 90 degrees later, it would pass Q_1 only and reject A plus I_1. At intermediate points, the switch would pass a mixture of both A plus I_1 and Q_1. The switch can be controlled by the carrier A, so that it always turns on at the proper time to ignore Q_1 and pass only A plus I_1.

The response of the synchronous detector to a pure AM signal is worth brief consideration. The prime characteristic of the pure AM signal is that R always coincides with A. Therefore, there is no quadrature component. If the on time of the synchronous switch does not coincide with A, then no new component will be sensed. Instead, the detector sensitivity to R is merely reduced.

V. The Television Video Signal

The range of frequencies of primary concern for demodulation is the i-f band, which typically is from 41.25 to 47 MHz. Signals in this frequency range are applied directly to the detector circuit.

For video frequencies up to 750 kHz, the modulation process, as far as the detector is concerned, is a mixture of pure AM and SSB. Beyond 750 kHz, the detector is responding to just SSB. Figure 14 depicts the relative amplitude of sideband components applied to the detector.

At approximately 3.58 MHz below the carrier is a subcarrier which transmits color information by a combination of phase and amplitude modulation. Figure 15 shows the carrier, A, and the color subcarrier, S. Phase modulation causes a change in a, which is the phase of S with respect to another 3.58-MHz carrier generated in the receiver. The receiver carrier, which is used to operate

the synchronous color demodulators, is phase locked to S by sampling this signal during the back-porch interval of the horizontal sync pulse. During that interval, S has a stable reference value. The receiver carrier changes phase only very slowly, so that it will not be affected by the long off time of the back-porch reference.

VI. Distortion Produced by the Envelope and Synchronous Detectors

1. AM-Phase Cross-Talk

The harmonic distortion inherent in the envelope detector has already been pointed out. Another type also caused by the quadrature component will occur when a second sideband component exists. It can be called AM-phase cross-talk, and is especially pertinent to color transmission. Figure 16a shows the familiar diagram involving only one sideband component, which here represents the color subcarrier. The phase of the detector output will be a function of a only. Normally a is changed only by the modulation of Sc. However, it is obvious that any phase modulation of A will also affect the value of a. Now, in Figure 16b, the presence of the second sideband component, Sv, has the effect of rotating A. Actually, Sv and A combine to form a new carrier, Rv, which is rotated from A by the angle a, as shown in Figure 16c. The component Sv also changes the amplitude of A, but only angle is of importance. The angle, γ, between A and Rv is affected only by the quadrature component of Sv. If Sv is the resultant of many components, then γ is still affected only by the quadrature portion of that resultant. This type of distortion is most noticeable during sharp luminance transients. The quadrature transient causes a phase transient which is manifested as color fringing.

The phase deviations accompanying this distortion can be measured readily. The test wave form shown in Figure 17 is an envelope made up of a 45.75-MHz carrier modulated by a combination ramp and 3.58-MHz subcarrier. The corresponding envelope detector output is shown in Figure 18a, and the synchronous detector output in Figure 18b. No significant difference between the two waveforms can be discerned. The corresponding phase displays are Figure 19a for the synchronous detector and Figure 19b for the envelope detector. The vertical distance between the two traces indicates the phase deviations of the 3.58-MHz subcarrier versus ramp amplitude. The difference between the two displays is caused by differential phase, which will be discussed presently.

Now, a third modulating signal, called the perturbation, is added. The envelope is shown in Figure 20. The resulting detector outputs are depicted in Figures 21a for the envelope detector and 21b for the synchronous detector. Once again no difference between the two waveforms is evident. Figures 22a and 22b show the phase displays. The rapid phase changes shown by the envelope detector display are the result of Am-phase cross-talk. Maximum phase deviation not including differential phase in Figure 22A is about 6 degrees.

2. Intermodulation

A third type of distortion caused by the quadrature component is called intermodulation. It occurs when two or more single sideband components are present in the envelope detector circuit. Consider two sideband components of frequencies f_1 and f_2. Then intermodulation distortion would appear principally as two new signals mixed with the originals and having frequencies $f_1 + f_2$ and $f_1 - f_2$, assuming f_1 to be the larger. This phenomenon is the result of the inability of the envelope detector to perfectly discern which is carrier and which is single sideband component. The only clue it has is amplitude. The larger a particular component, the more it assumes the role of carrier.

An example of intermodulation is the 920-kHz beat formed by the mixing of the 3.58-MHz color subcarrier and the 4.5-MHz sound subcarrier in the envelope detector. This mixing process does not occur in the synchronous detector because quadrature component is ignored. In effect, the true carrier has infinite amplitude, thus completely overriding the tendency of any sideband component to act as carrier. Indeed, the exalted carrier envelope detector is another method of ignoring quadrature component.

Figure 23 shows a test waveform consisting of a 45.75-MHz carrier modulated by a ramp and two subcarriers -- one at 3.58 MHz and the other at 4.5 MHz. The amplitude of both subcarriers was about the same. This signal was applied to both an envelope and a synchronous detector. The output of the detectors was passed through a sharp bandpass filter tuned to 920 kHz. Notice in Figure 24 the ringing in the filter output caused by the horizontal sync pulses. This is the synchronous detector output for either both subcarriers together or the 3.58-MHz subcarrier alone. Figure 25 shows the filtered envelope detector output with only the 3.58-MHz subcarrier present. As expected, this wave form is virtually the same as that of Figure 24. Upon adding the 4.5-MHz signal, the 920-kHz

beat becomes evident as shown in Figure 26. Notice that the amplitude of the 920-kHz beat depends on the amplitude of the carrier, which is minimum just before the horizontal sync pulse. At that time, the beat amplitude is maximum.

3. Differential Phase

Refer again to Figure 19b. The variation in the phase display of the envelope detector output indicates that the value of the phase angle a in Figure 15 is dependent on the magnitude of the carrier A. In order to have any meaning, differential phase must be defined as the change in a caused by changing A over a specified range -- usually from blanking level to 12.5 percent of sync peak. This is not the same as AM-phase cross-talk, since it is not caused by quadrature component. This type of distortion is important because of its effect on color reproduction, namely a change in hue with a change in luminance.

In the envelope detector an unwanted change in a is caused by a change in the average impedance of the diode with a change of rms voltage applied to it. This effect can be minimized by applying to the diode a large drive voltage from a low impedance source. The display of Figure 19b represents a phase change of about 3 degrees for the input waveform of Figure 17. The synchronous detector output for the same input waveform exhibited about 0.5 degrees of differential phase.

The reason for the difference between these two phase displays is that the envelope detector circuit impedance is a function of applied voltage, whereas the synchronous detector impedance is not. The envelope detector diode is switched by the modulated signal, but the synchronous detector is operated by an unmodulated signal that is much stronger than the modulated signal. Figure 27 illustrates the basic circuit used for this comparison.

4. Differential Gain

Differential gain is also the result of envelope detector impedance changes. It is manifested by loss of color brilliance or saturation in bright scenes. This can be understood by realizing that at the near-white level the RF voltage applied to the detector diode is close to minimum. The impedance of the diode circuit is higher than for larger voltages. Therefore, at low input levels the output level changes less rapidly than at high input levels. Figure 28 illustrates how subcarrier output can change with picture carrier level even though

the carrier input amplitude is constant. Just as for differential phase, a range of picture carrier amplitude over which differential gain occurs must be specified. It is usually from blanking level to 12.5 percent of sync peak. The differential gain is expressed as a percent change in gain or as a ratio of two gains either in percent or in dB.

VII. A Practical Synchronous Detector System

One form of basic synchronous switch was illustrated in Figure 27. The only problem in implementing this circuit is that of obtaining the phase-locked unmodulated drive voltage. The block diagram in Figure 29 depicts the working model used for distortion measurements. The location of the envelope detector used for comparison is also indicated. The source of voltage for the synchronous switch is a varactor-tuned oscillator. Voltage from the phase detector is amplified and then used to control the phase of the oscillator output. The slightest change in oscillator phase is automatically corrected by an error voltage from the phase detector. After being amplified more than ten thousand times, this error voltage is applied to the varactor, which changes the oscillator tuning so that the original phase deviation is virtually cancelled.

The amount of phase correction is determined by the total gain around the phase-lock loop, which is comprised of the phase detector, gating switch, servo amplifier, and voltage-controlled oscillator. Since phase detector sensitivity varies directly as average carrier amplitude, the total gain can change with picture content. This means that picture content could affect the amount of phase correction. In order to avoid this, the sync separator is used to drive a gate switch, so that the phase detector functions only during the horizontal sync pulse. The response time of the servo loop is slow, and it ignores this rapid interruption. This sampling operation is similar to that used for phase locking the synchronous color-demodulator driving voltage to the 3.58-MHz reference burst.

The most prominent aspect of obtaining the phase-locked detector drive voltage is getting the oscillator realiably to lock on the picture carrier. The system must know whether it is locking on a sideband component or not. Distinguishing between proper and improper signal component is accomplished by the search-control circuit, which will continually sweep the frequency of the oscillator until lock-up with the picture carrier occurs.

Phase lock is complete when the output of the phase detector is zero. The phase detector actually is another synchronous detector, virtually identical to the video detector. The phase detector output is zero only because the oscillator is forced to be 90 degrees out of phase with the picture carrier. This condition is obtained when the phase detector turns on at the time the carrier phasor is at right angles to the vertical axis. Indeed, while the video

detector responds only to in-phase component, the phase detector responds only to quadrature component. The phase shifter is required to bring the oscillator voltage into phase with the video detector input.

The video amplifier serves two purposes. It makes up for phase equalizer insertion loss and raises the detector output to a more usable level.

The phase equalizer compensates for the delay distortion introduced by the shape of the Nyquist and i-f amplifier bandpass.

VIII. Conclusion

The test results described in this paper show that the synchronous detector is preferred to the envelope detector for demodulating a vestigial sideband signal.

In applications such as a microwave link where repeated modulation and demodulation takes place, the synchronous detector should provide significant improvement.

The phase-locked synchronous detector system is practical, although more elaborate than an envelope detector circuit; but when higher fidelity is important, the synchronous video detector can be chosen as a reliable and effective technique.

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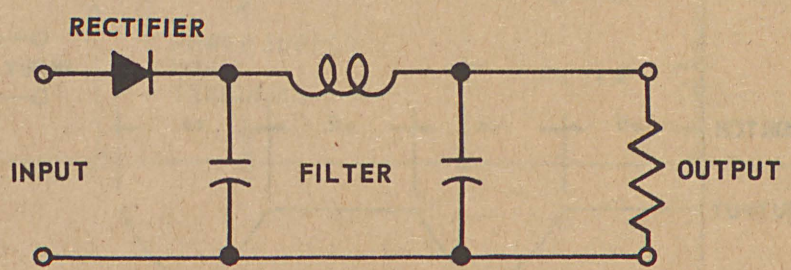
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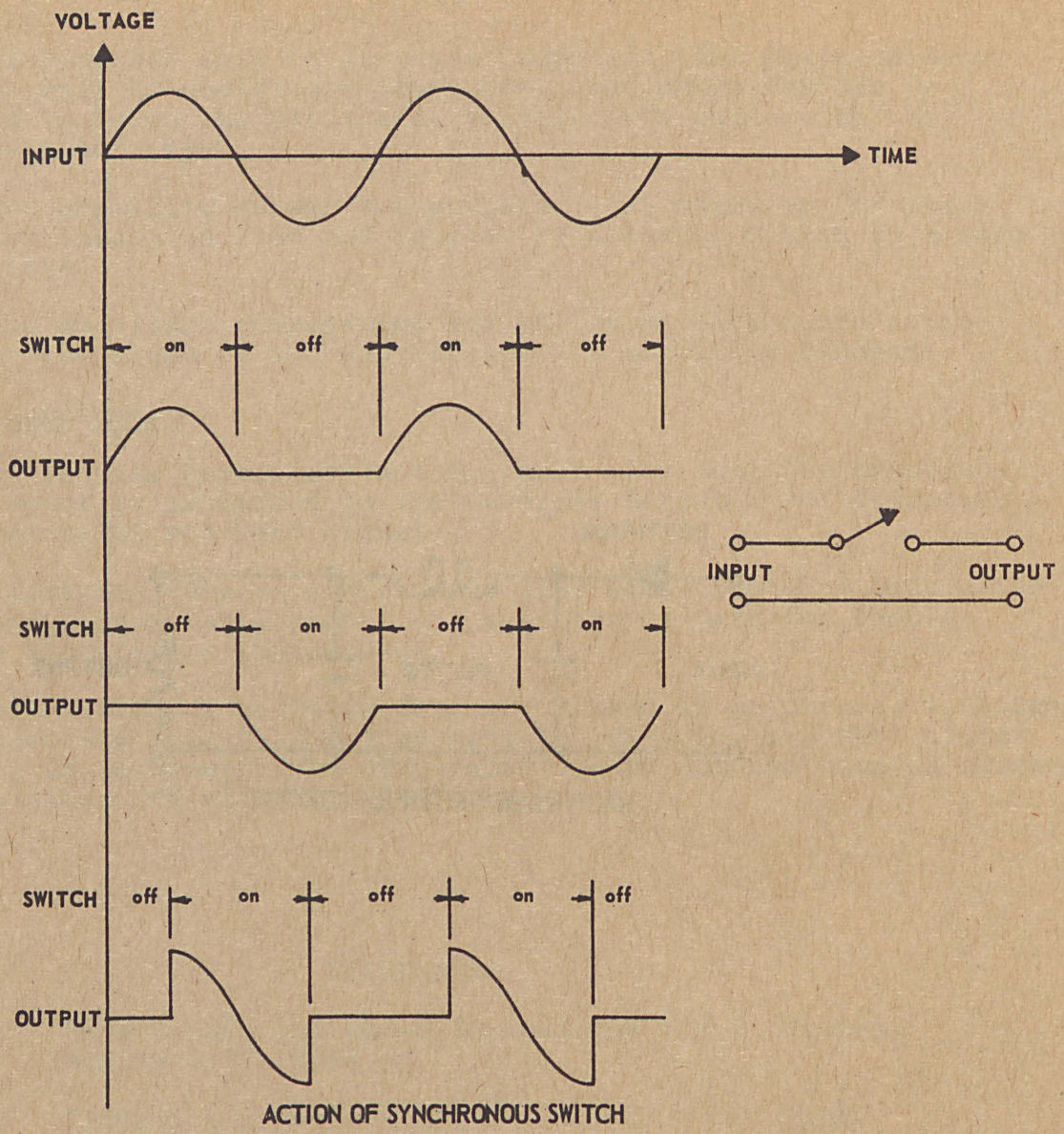
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HALF-WAVE RECTIFIER CIRCUIT

Figure 1.



ACTION OF SYNCHRONOUS SWITCH

Figure 2.

77539-13

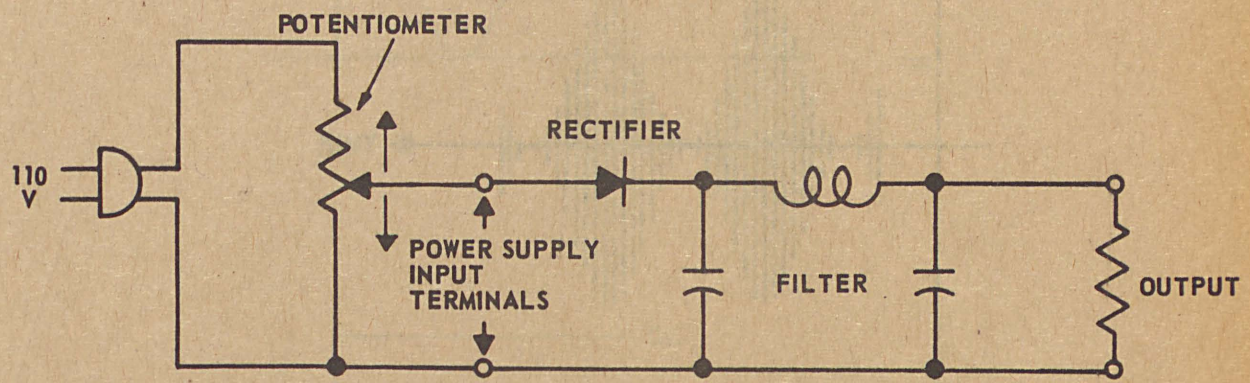

POTENTIOMETER
RECTIFIER
110
V
POWER SUPPLY
INPUT
TERMINALS
FILTER
OUTPUT

Figure 3.

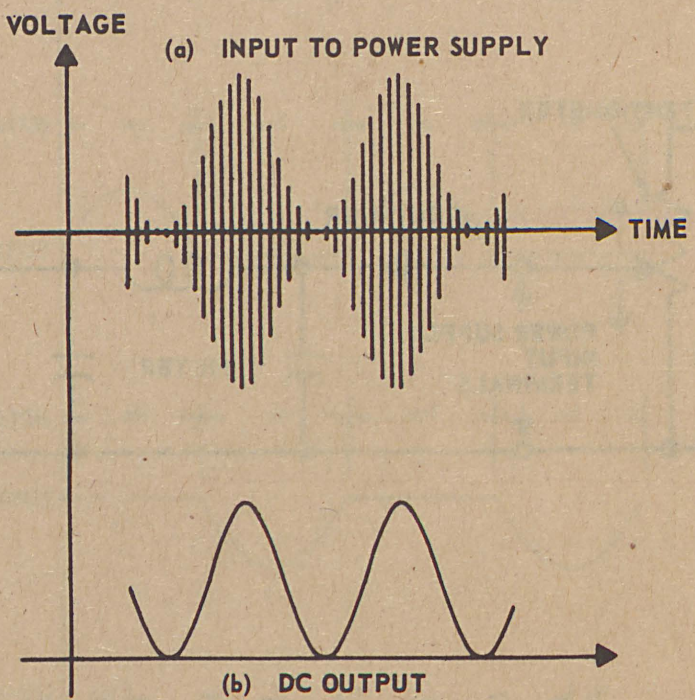


Figure 4.

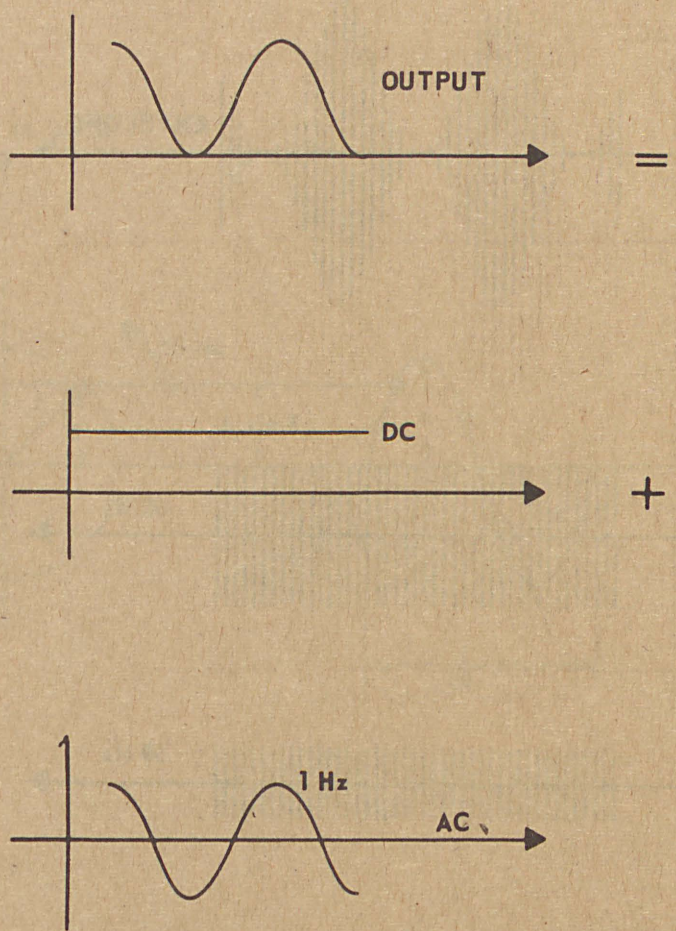


Figure 5.

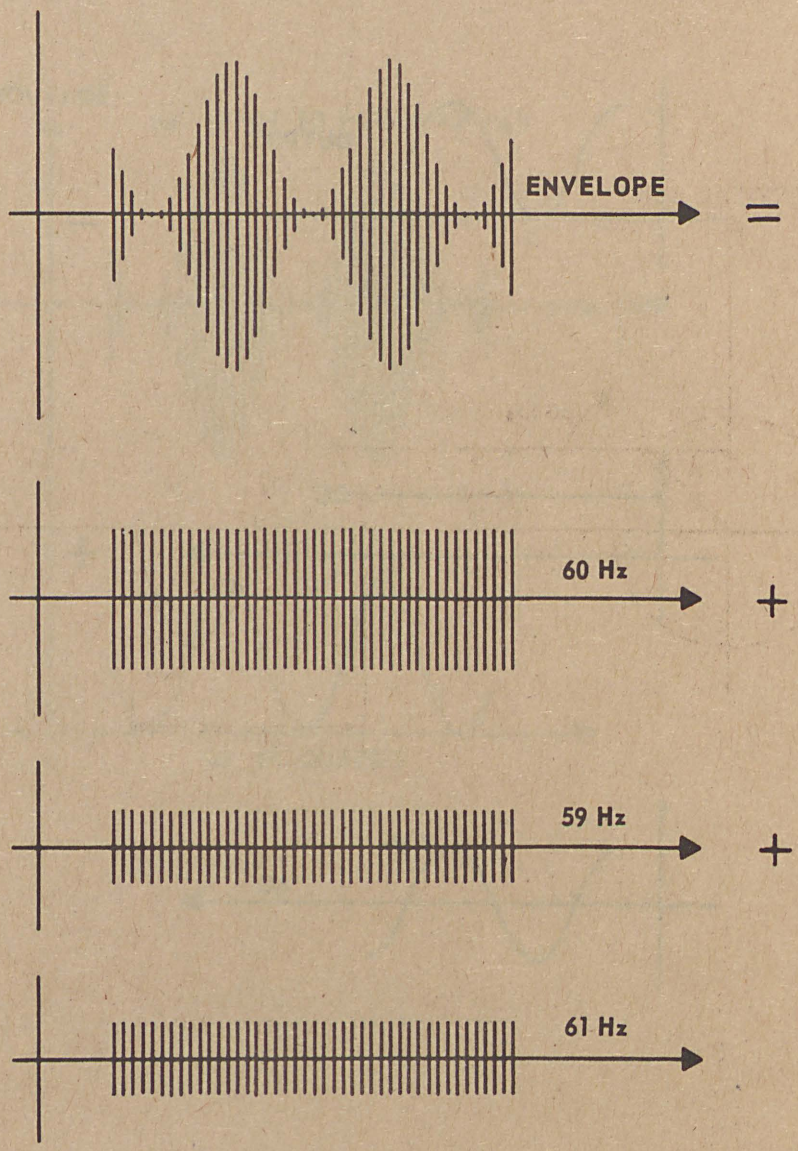


Figure 6.

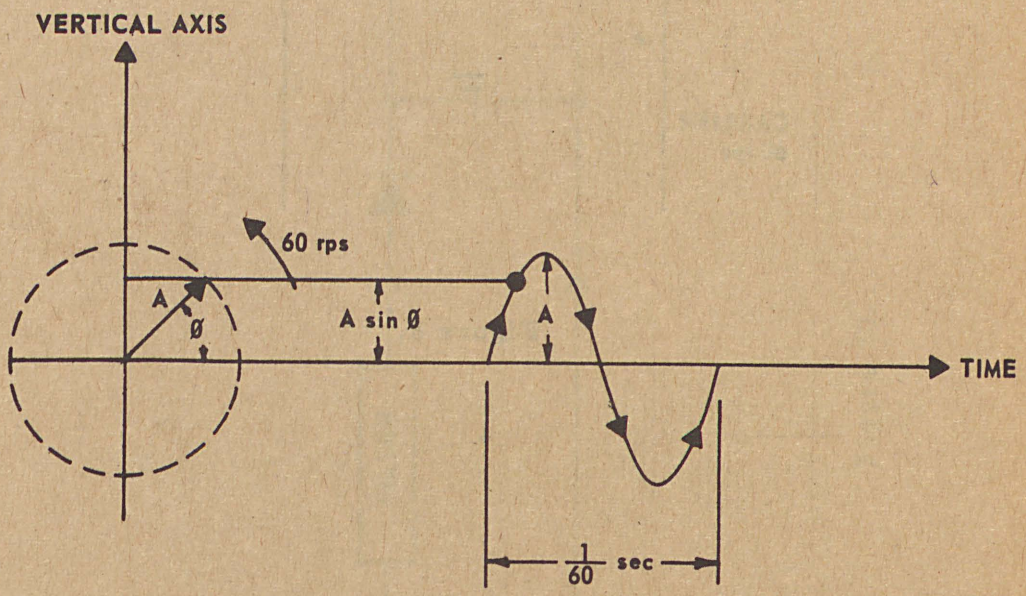


Figure 7.

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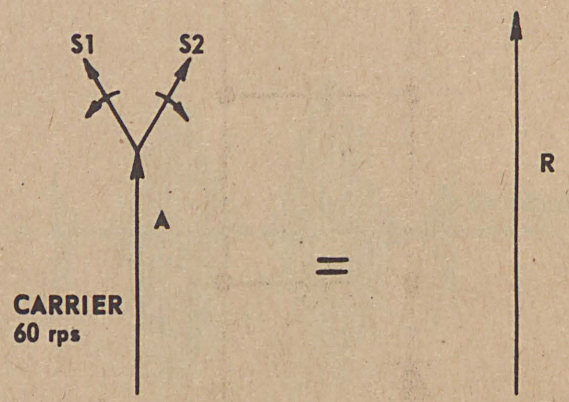


Figure 8.

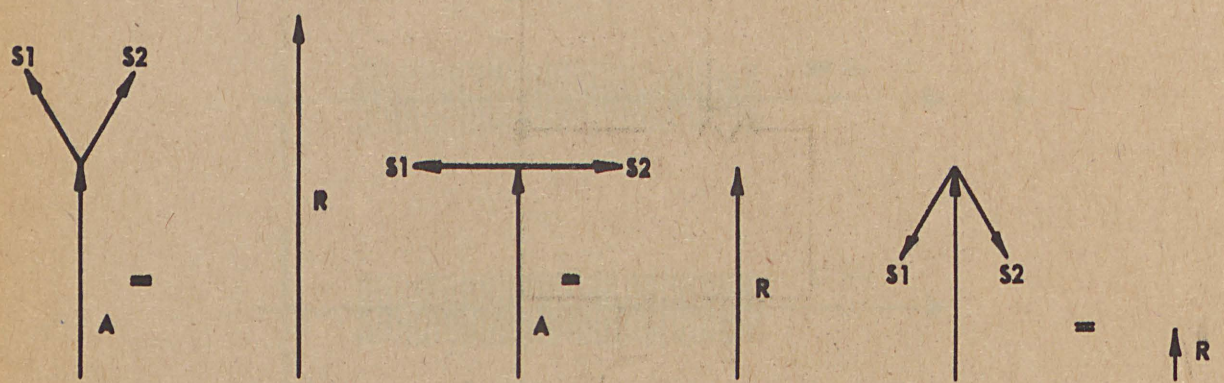


Figure 9.

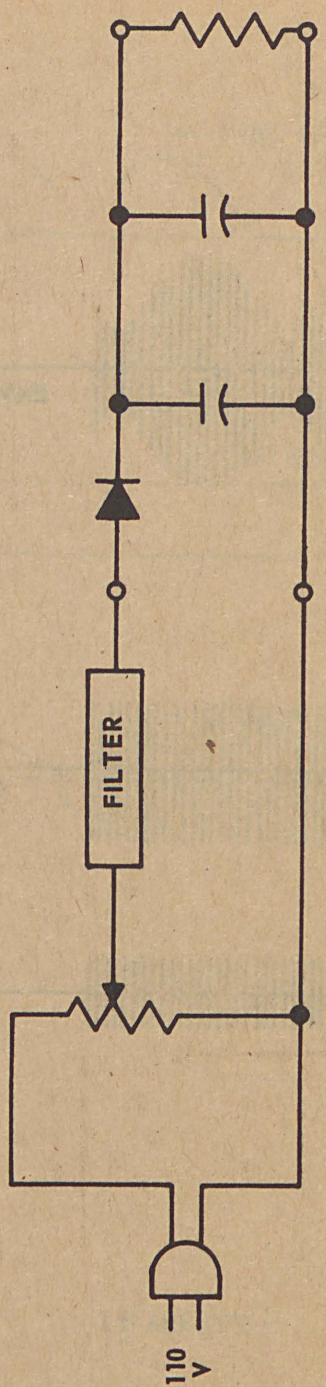


Figure 10.

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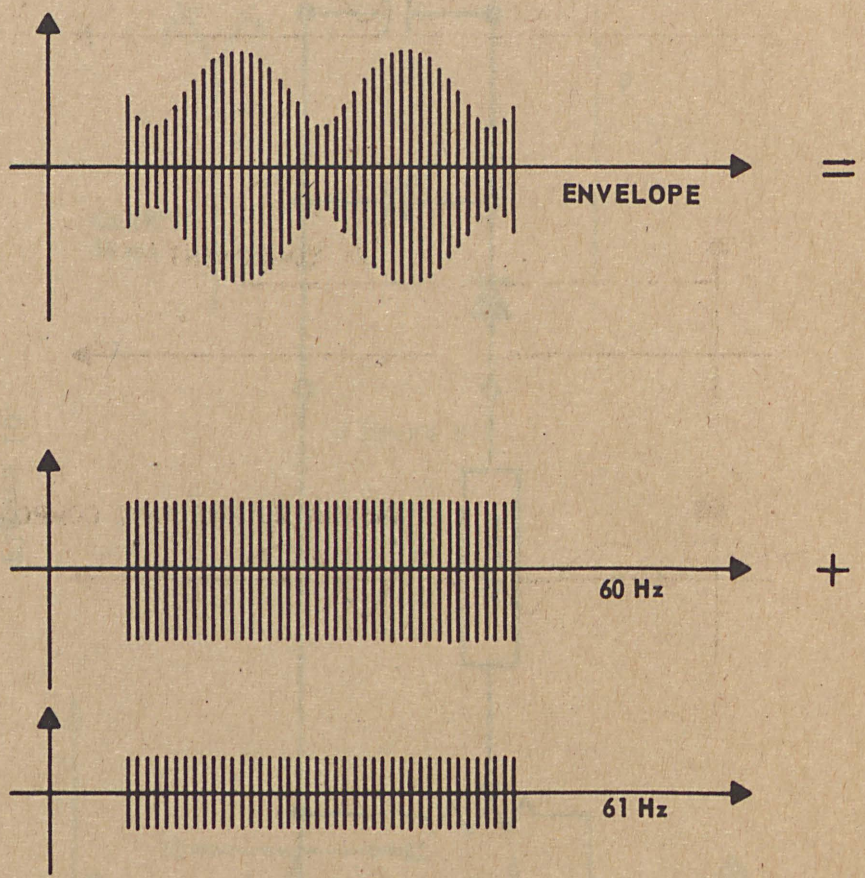


Figure 11.

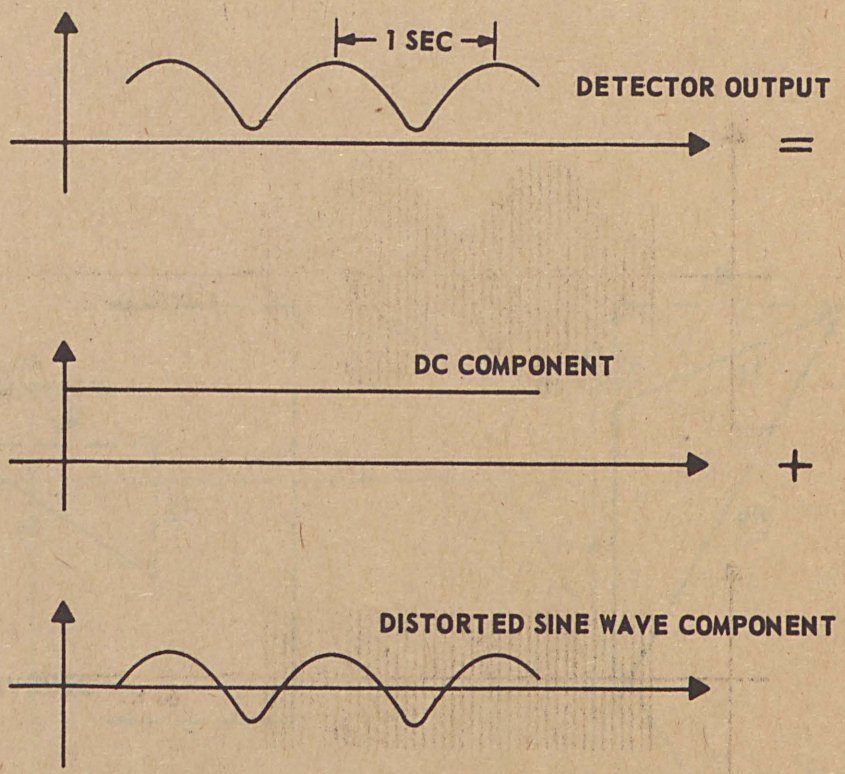

1 SEC
DETECTOR OUTPUT
=
DC COMPONENT
+
DISTORTED SINE WAVE COMPONENT

Figure 12.

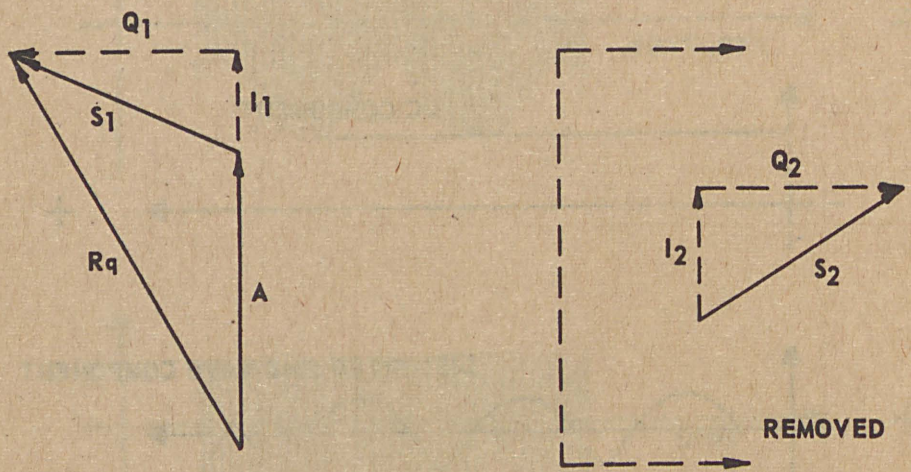


Figure 13.

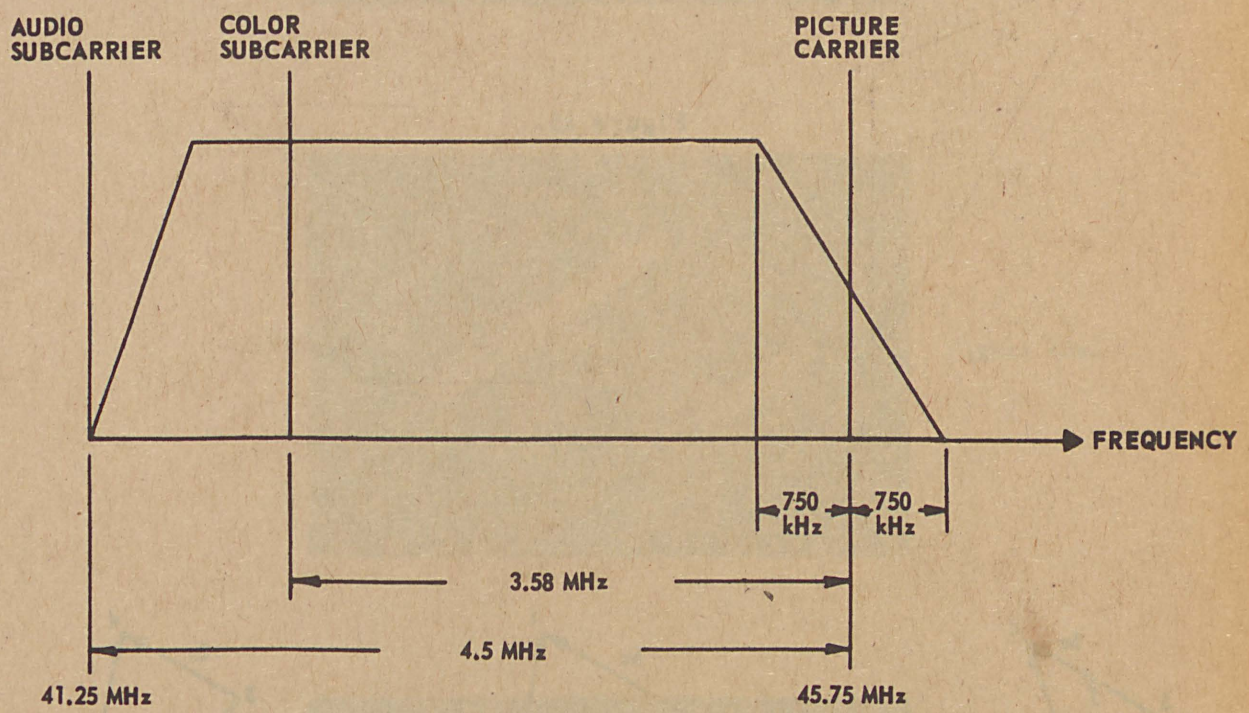


Figure 14.

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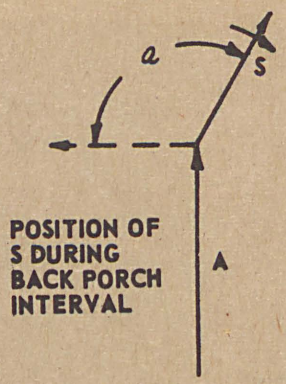


Figure 15.

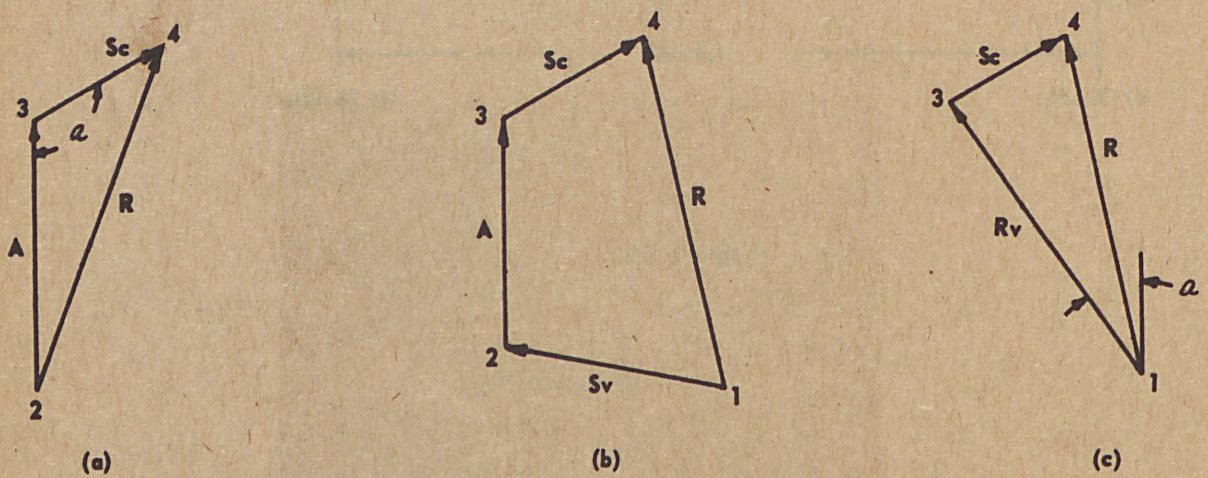


Figure 16.

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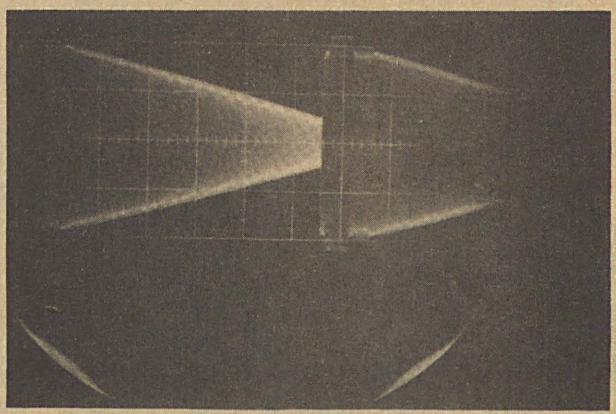


Figure 17.

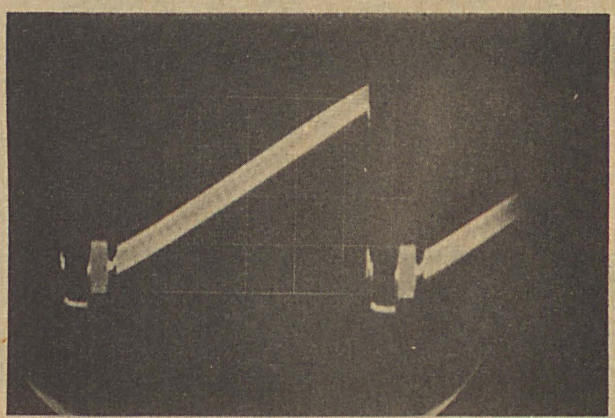


Figure 18a.

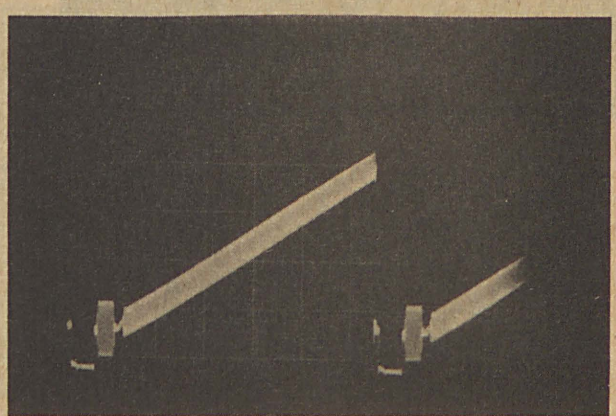


Figure 18b.

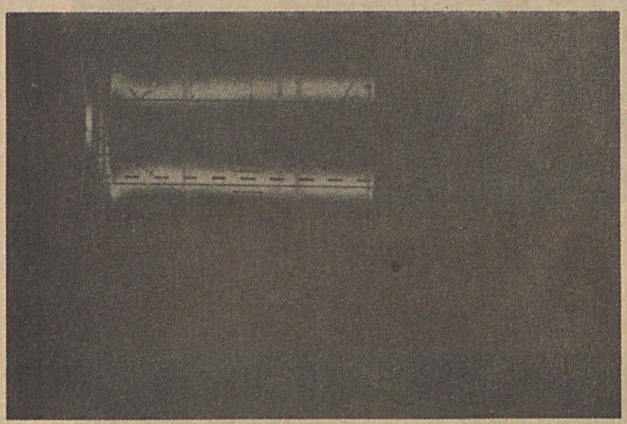


Figure 19a.

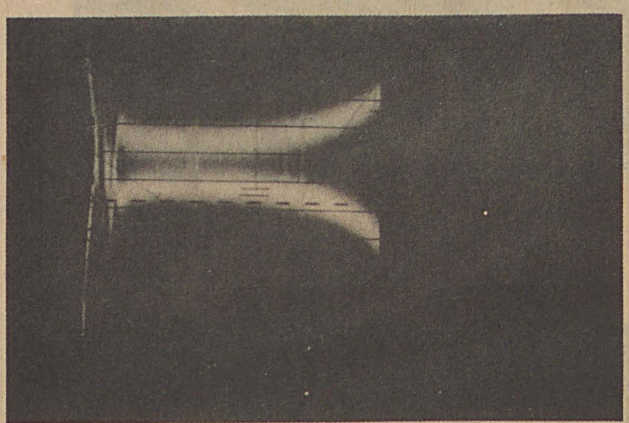


Figure 19b.

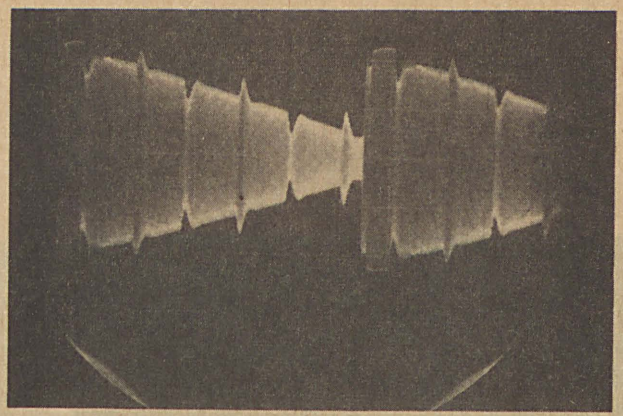


Figure 20.

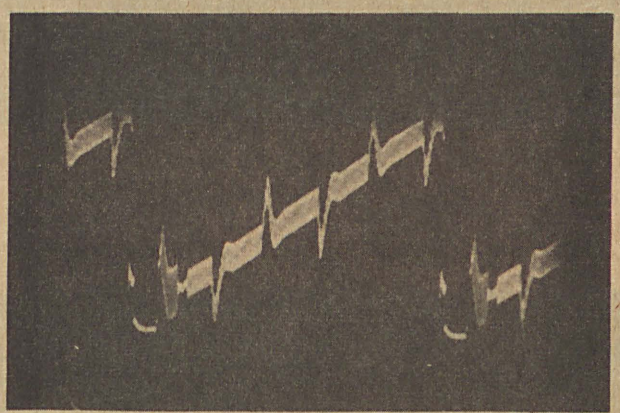


Figure 21a.

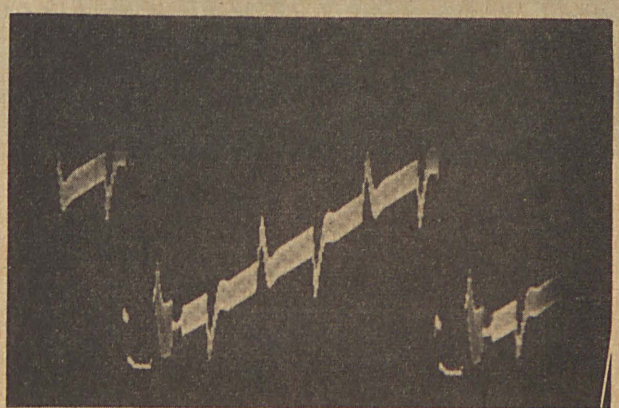


Figure 21b.

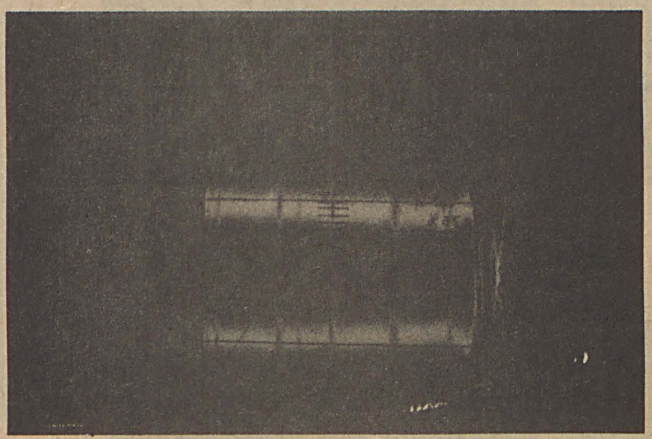


Figure 22a.

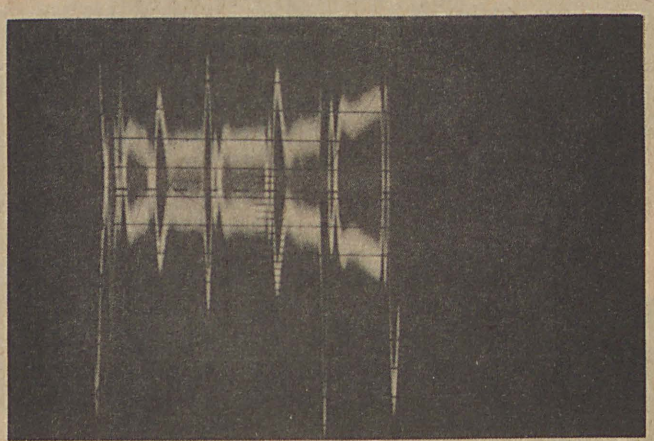


Figure 22b.

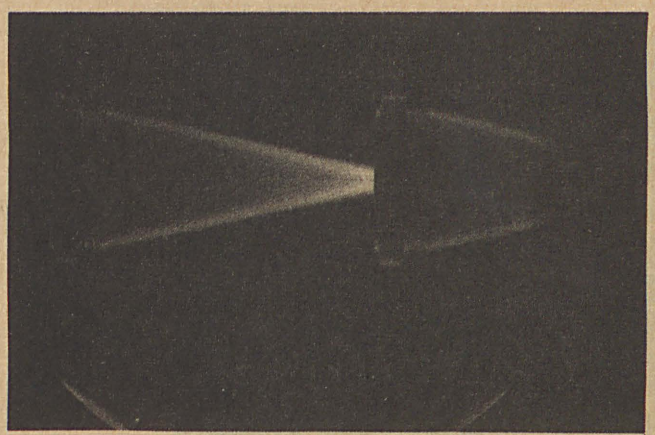


Figure 23.

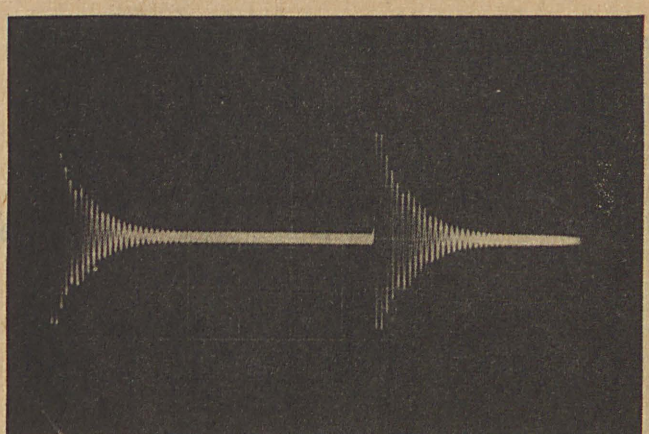


Figure 24.

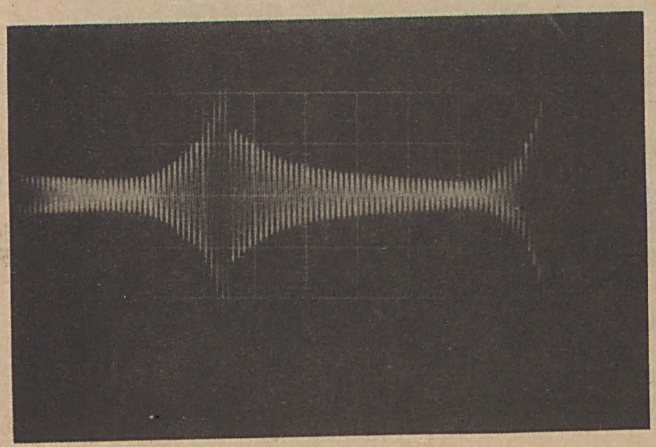


Figure 25.

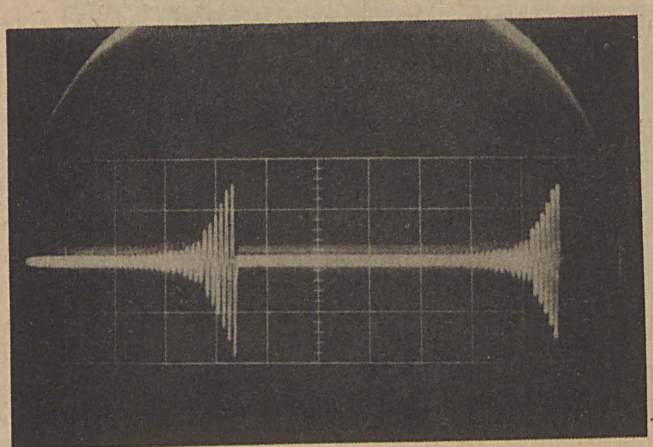


Figure 26.

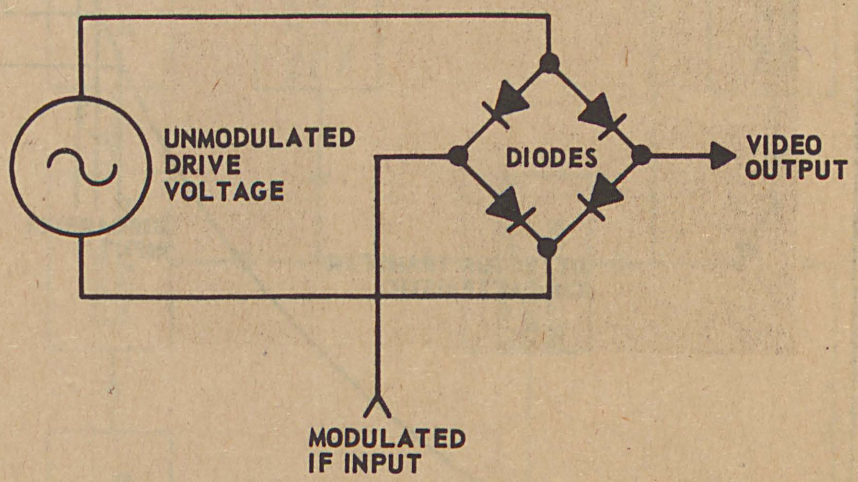

UNMODULATED
DRIVE
VOLTAGE
DIODES
VIDEO
OUTPUT
MODULATED
IF INPUT

Figure 27.

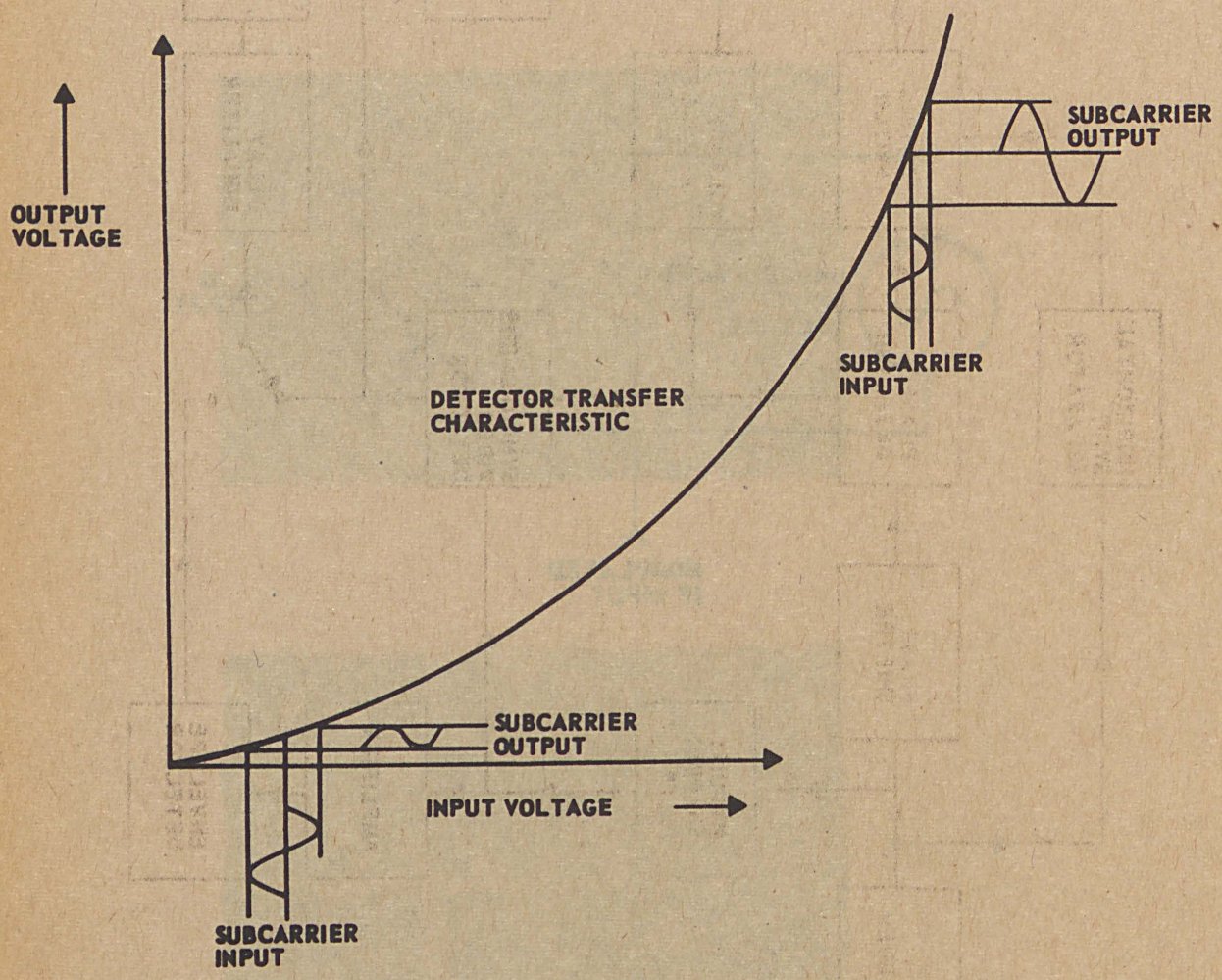


Figure 28.

77539-33

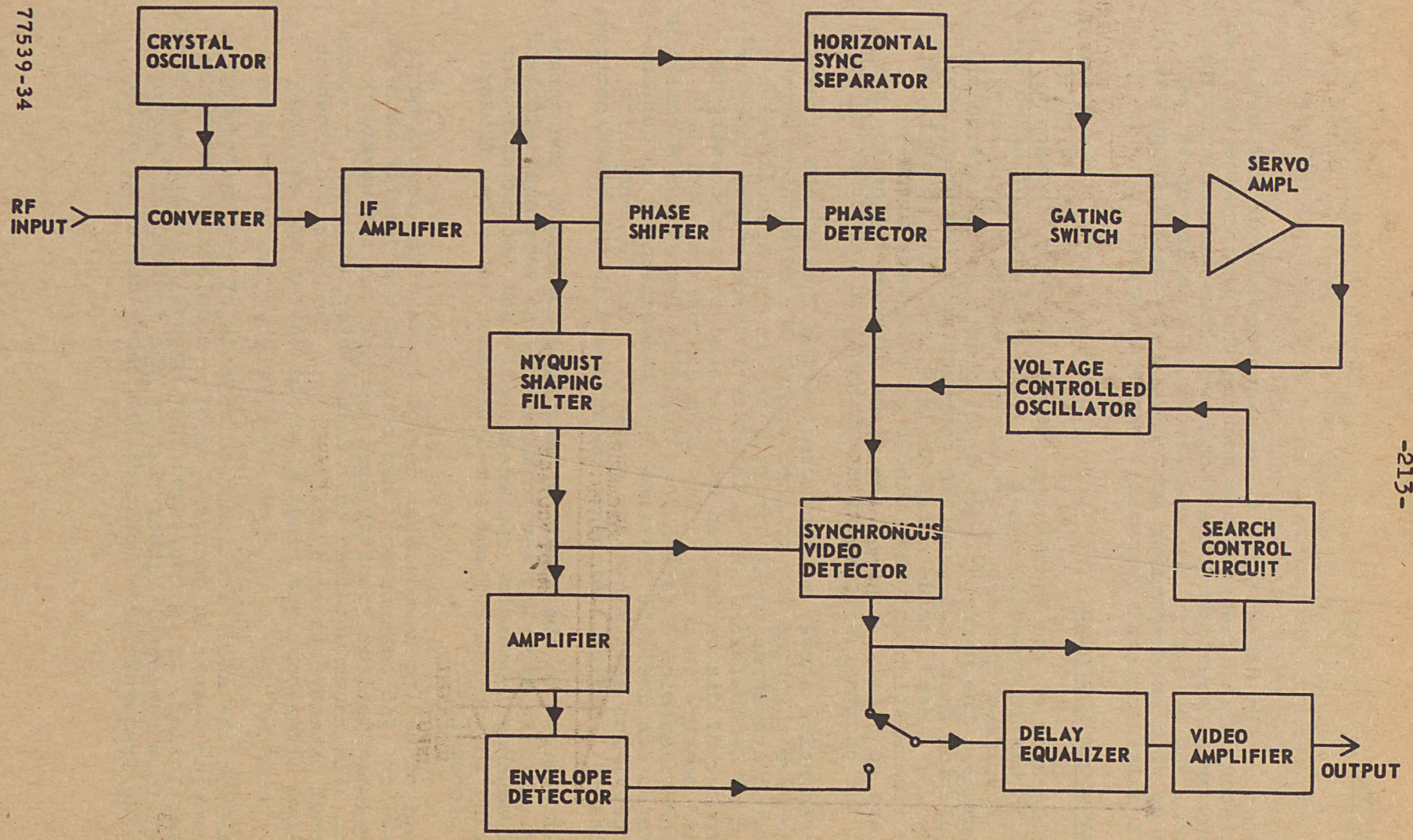

CRYSTAL OSCILLATOR
HORIZONTAL SYNC SEPARATOR
SERVO AMPL
RF INPUT
CONVERTER
IF AMPLIFIER
PHASE SHIFTER
PHASE DETECTOR
GATING SWITCH
NYQUIST SHAPING FILTER
VOLTAGE CONTROLLED OSCILLATOR
SYNCHRONOUS VIDEO DETECTOR
SEARCH CONTROL CIRCUIT
AMPLIFIER
DELAY EQUALIZER
VIDEO AMPLIFIER
OUTPUT
ENVELOPE DETECTOR

Figure 29.

B. W. OSBORNE

SUMMARY

A discussion of the design of a television demodulator and ancillary modulator, with illustrations showing the performance obtained using transversal equalization at baseband after detection in the demodulator, and at i-f in the modulator. A K rating of 2% can be obtained, with corresponding performance on the 20T composite color test pulse and in differential phase and gain.

1. The waveform approach

In his 1952 paper on the sine-squared pulse network, Thomson[1] commented in his introduction that ' ...the designing of networks to have a specified frequency response has reached a high level of development. The needs of such developments as television and pulse modulation have made waveform response more important than previously....' Macdiarmid[2] noted in 1959 that 'The concepts of sine-wave transmission and the methods of sine-wave circuit analysis are so firmly fixed in the minds of some engineers that they find the greatest difficulty in thinking in any other terms'.

In a comprehensive survey of waveform testing Theile[3] has stressed that 'sine-wave thinking is not good enough for television work'. In television transmission in general, and in the specification and design of demodulators and modulators in particular, where only a small amount of distortion can be tolerated it is necessary to specify and measure in terms of waveform distortion. For this purpose the television K rating, developed by Lewis[4] and Macdiarmid[2], has now found its dominant position in the measurement of performance of television equipments and networks. The 20T composite color pulse[5,6,7] filled a hitherto empty space in the test spectrum.

Some modifications to the K rating had been proposed by the author to be desirable in applying waveform methods to vestigial-sideband carrier frequency television applications[8,9] and the extension of the K rating to include 20T pulse measurements and other factors has been proposed.[11]

The concept of basing demodulator design on waveform requirements is not new; in 1965 Johannesen[13] had compared the results obtained in a television monitor receiver designed for minimum waveform distortion with those obtained on a demodulator designed to a more conventional 'steady-state' specification. The negative preshoot and positive aftershoot and ringing on the latter are all too familiar.

In considering the specification requirements of the performance of a television system in general, or of a modulator/demodulator loop in particular, it is contended that emphasis should be placed on the waveform response, rather than on the individual 'steady-state' delay/frequency and amplitude/frequency characteristics.

Whilst the amplitude/frequency characteristic may be sufficient in itself to control the levels in the various channels of a wide-band stacked-carrier CATV system, within any one television channel we must be concerned with the overall visual impairment to the picture.

It is not practicable (or indeed possible) to quote tolerances on envelope delay that are directly related to equivalent limits on picture quality impairment. Nor can tolerances on the amplitude/frequency response be directly related to picture quality.[2]

If the waveform response (as exemplified by 2T and 20T rating) meets specified limits, then both the steady state characteristics are also adequate. But to quote tolerances on the steady state amplitude characteristic does not necessarily ensure specified or desirable waveform distortion, a point well illustrated by Johannesen[12]. It may sometimes be wrong to specify arbitrary amplitude-frequence response limits where it is intended to control the response to television waveforms.

The waveform approach to television specification and measurement utilizes the sine-squared pulse and window test waveform, in conjunction with the 20T composite color test pulse and with suitable linearity test waveforms. This applies to the overall measurement of performance of a v.s.b. television modulator/demodulator link or CATV head-end equipment, as well as to the assessment of a video baseband link.

A precision modulator and demodulator should (together or separately) meet the following simultaneous requirements:

a) An overall K rating of 2%

b) Overall linearity such that differential gain is not worse than 1/2 dB and differential phase not worse than about 3^{o} (1^{o} would be better but may not yet be possible).

c) A chrominance-luminance relative delay difference of 25 ns maximum.

d) A chrominance-luminance relative amplitude difference of 1/2 dB maximum.

e) Adequate rejection of unwanted signals including sound, adjacent sound, sound-chrominance beat, and adjacent vision (i.e. (a) to (d) must be met with all necessary traps in circuit).

f) The above requirements must be met over the quoted dynamic range of input level (which should not be less than 40 dB).

g) The overall waveform distortion seen through the v.s.b. demodulator should not change whether d.s.b. or v.s.b. modulator outputs are used; i.e. any waveform distortion due to v.s.b. shaping in the modulator must also be corrected in the modulator.

2. Correction of waveform distortion in the v.s.b. modulator

In a double sideband modulator, where the carrier frequency is high compared with the highest modulation frequency, there is little difficulty in obtaining good waveform response. Either of the circuit configurations shown in Figure 1 can be used, and the modulation performance can be assessed by direct measurement of the modulated K rating on a wideband oscilloscope (Figure 2). Any waveform defects, including any relative chrominance/luminance delay or amplitude errors, can be seen immediately; and the superimposition of the video input and modulated output waveforms is also useful as a preliminary linearity check. Exact linearity measurements of a modulator alone are not easy, as the use of the Kelly set test waveforms (Figure 3) for differential (level-dependent) gain and phase measurements does require that a demodulator is measured at the same time; and it may happen that non-linearity in the demodulator is controlling. Equipment comparison can be made by substitution.

In vestigial sideband television the energy spectrum of the modulated signal has to be restricted (in accordance with the prescribed limits) so as to prevent overlapping of the radiated spectra on adjacent channels. As it is convenient to modulate to i-f before converting to v.h.f. the necessary band shaping can also be done at i-f, the upper i-f sideband being restricted above 46.5 MHz so as to obtain the necessary 20 dB level reduction at 47.25 MHz. The design problem of the v.s.b. modulator is thus to ensure that the required amplitude characteristic is obtained without introducing waveform distortion.

Broadcasting authorities have required the introduction of specified pre-distortion of envelope delay,[16] so as to correct for the assumed characteristic of the television receiver. This requirement can be criticized on the grounds that this pre-distortion is inevitably based on receivers of an obsolete type, that some receiver designers prefer to work to a "flat" delay characteristic in the transmitter, and that pre-correction is an artificial restriction which tends to inhibit future designs of distortion-free demodulator and receivers. If the pre-correction is introduced at baseband before modulation, this leads to increased phase distortion of the vestigial sideband [9, 12]. In 1959, the CCIR at Los Angeles had proposed eliminating or halving the pre-correction.[17]

For CATV test purposes and for the demodulation and re-modulation of broadcast signals, it is wrong to include pre-correction in the modulator. A modulator/demodulator loop should be free of pre-distortion. The user always has the option of introducing distortion externally.

In separating the waveform distortion due to the modulator from that due to the demodulator, measurements on the i-f. modulated carrier can be made on both d.s.b. and v.s.b. envelopes, using a wide-band oscilloscope. For example, if the v.s.b. modulated envelope shows the modulated 2T pulse to be symmetric (and therefore free of delay distortion) and the modulated 20T pulse composite color pulse has a symmetrical envelope shape at its base, then any 2T preshoot or 20T chrominance delay error observed at the demodulator output must be due to the demodulator and not to the modulator. If a demodulator is available having an ideal Nyquist slope (i.e. -6dB at carrier at the input to the stage driving the detector[13] and well down at 46.5 MHz), it can be used to compare the overall waveform distortion through a d.s.b. modulator with that through a v.s.b. circuit following the modulator; and this helps in the correction of waveform distortion in the v.s.b. filter. (Provided that the demodulator "cuts off" over that part of the vestigial flank where the modulator is "flat", the demodulator can equally well be fed with either v.s.b. or d.s.b. information).

The necessary v.s.b. waveform correction in the modulator can be done in one of several alternative ways:

a) By pre-distortion of the incoming video waveform before modulation, either by use of a transversal equalizer or by bridge -T delay sections. This approach does however prevent the simultaneous provision of d.s.b. and v.s.b. outputs from the same modulator, a feature of some practical use in checking the origin of any waveform distortion in the modulator/demodulator loop; and it can lead to difficulties with modulation depth.[14]

b) By use of delay-correcting circuits at i-f in the v.s.b. channel, using bridge-T delay sections; or

c) By use of a transversal equalizer to correct the waveform distortion at i-f, as viewed directly on the modulated envelope. This method is a rapid and accurate way to ensure good waveform results. (The application of a transversal equalizer to a modulated v.s.b. television waveform had previously been shown by the author[9,15] to be feasible in waveform correction on h.f. CATV networks). The modulator of Figure 4 uses this carrier frequency transversal equalizer technique.

3. A waveform approach to demodulator design

It had been customary to attempt to get a demodulator amplitude/frequency characteristic as flat as possible up to the highest sideband frequency, with the vision carrier at the -6 dB point on the Nyquist flank.

Because this is not a sufficient and necessary design requirement for the best K rating, most receiver designs have used a gradual i-f roll-off at frequencies near the color sub-carrier in order to get lower phase distortion.

In transmitter monitoring, Gluyas and Behrend[18] refer to the need to maintain a flat amplitude characteristic in the demodulator in the measurement of the transmitted color subcarrier burst amplitude and of the depth of modulation of color signals; and contrast this with the approach taken in television receivers, where, for best picture quality, rapid changes in the i-f amplitude/frequency characteristic are avoided.

The problem is related to that of the optimum design of a video base-band low-pass filter having high attenuation at the inter-carrier frequency[19], where it is more important to ensure a constant envelope delay for all frequencies within the pass-band than to obtain a perfectly flat-topped amplitude response.

Loughlin[20] and Newell[21] have referred to the de-saturation of colored areas caused by the conversion of sub-carrier energy to luminance shift in the envelope detection of a negative-modulated v.s.b. signal. Correction of relative chrominance/luminance levels after detection reduces this desaturation, though a luminance level error remains.

A demodulator for use in waveform testing and picture quality control must have a good K rating on both the 2T and 20T signals. To allow degradation of the 2T luminance channel K rating in order to bring up the color level is not acceptable (a good 2T K rating being as necessary for the color picture as for monochrome).

Experience has shown that a good 2T K rating can be obtained using a "haystack" style of amplitude characteristic (as that of Figure 5).

In the v.s.b. demodulator the alternative design techniques available can be summarized as follows:

a) The shaping of the amplitude characteristic for v.s.b. reception in the i-f amplifier before detection, the detector and video output circuits having a flat amplitude response. This design has been found to be different to achieve, because of the phase distortion at frequencies approaching those of the sound and adjacent sound traps.

b) Correction at base-band after detection, the i-f amplifier having a flat amplitude characteristic over the pass-band, and the video circuit having 6 dB more gain at the highest video frequencies than at the lower, with the necessary envelope delay correction. But again, 2T pulse symmetry is difficult to achieve.

c) Restoration of the missing sideband of the v.s.b. signal before detection[22], so as to avoid the quadrature and phase distortion problems of the envelope detection of the v.s.b. signal. But with the necessary sound traps in circuit the problems of obtaining low waveform distortion on both 2T and 20T test waveforms are not entirely avoided.

d) The exalted carrier technique[20] in which the i-f is shaped so as to boost the vision carrier level prior to detection, and using an extra detector to cancel the narrow-band enhancement at baseband.

e) The use of synchronous detection to avoid the effects of quadrature distortion in the second detector. But these quadrature distortion defects are generally not so serious as those related to 2T and 20T waveform distortion in the presence of the sound traps; and the generation of the phase-locked vision carrier in the receiver, though not difficult, does increase the complexity and cost to an extent that may not be justified in a general-purpose demodulator.

   Figure 6 shows two superimposed 2T pulses, one being undistorted and the other that obtained at the output of a v.s.b. demodulator of 2% K rating employing envelope detection. The visible pulse narrowing is due to the quadrature distortion introduced by the envelope detector, but this is probably not significant in terms of picture quality impairment, provided that the differential gain performance of the demodulator is good. That used for Figure 6 was measured at 0.4 dB through the complete modulator/demodulator loop.

f) The approach selected for the Telemet 4500-A1 demodulator is a compromise between (a) and (b) above, in that the i-f amplitude characteristic selected for best 2T pulse shape symmetry is the rounded curve in Figure 5. The partial loss of information at 4.2 MHz is restored by use of a transversal equalizer at base band after envelope detection, the echo channels of this video processing module being selected in time so as to provide maximum boost at 4.2 MHz, and in amplitude so as to provide a 20T pulse with minimum errors of relative chrominance/luminance delay and amplitude.

4. A new demodulator

The design of the Telemet 4500-A1 demodulator of Figure 7 was based on the waveform approach (f) described above.

The main i-f amplifier is a stagger-tuned triple, so that the main amplitude response shaping can be set up by tuning the separate circuits at specified frequencies. This i-f amplifier uses field effect transistors in order to obtain low distortion at the high signal levels necessary to drive the detector, and with good isolation between the tuned circuits. Circuit elements are selected for good long-term mechanical and electrical stability.

The detector circuit uses hot-carrier diodes in a balanced envelope detector, the detected video signal being developed across a load of about 800 ohms. With sufficient amplitude of the signal applied to the diodes and with optimum diode dc bias, this was found to give linear detection, the differential-gain measured with the Kelly test waveform on modulated carrier meeting the desired 1/2 dB limit through modulator and demodulator.

The i-f triple-staggered unit is preceded by a wide band silicon integrated pre-amplifier, a diode a.g.c. circuit, and an input circuit comprising a bandpass filter (to reject adjacent vision, not otherwise adequately attenuated) and the traps for rejection of the 39.75, 41.25 and 47.25 unwanted frequencies. The block schematic of the demodulator is shown in Figure 8.

The overall i-f amplitude frequency characteristic is shown in Figure 5. Note that, following van Weel, this is measured at the input to the stage feeding the second detector.

Inspection of this curve shows that the chrominance/luminance amplitude ratio at the detector is about 4 dB low because of the gradual fall-off towards the sound carrier frequency; but this is corrected by the signal processing circuit following the detector.

This processing circuit is essentially a transversal equalizer, with time delays selected for use with negative-going echoes so as to increase the amplitude at 4.2 MHz; and, to a slightly lesser extent, at 3.58 MHz. This corrects the color subcarrier amplitude without delay distortion, and replaces most of the missing upper color sideband information prior to external color demodulation. I-Q crosstalk should therefore be acceptable.

A fine adjustment of the relative amplitudes of this echo pair was made available to compensate for chrominance/luminance delay error.

The slight excess of mid-band signal amplitude was reduced by the use of an additional echo correction channel having maximum effect at about 2 MHz, the echo being located so as also to reduce residual preshoot.

The input to the i-f demodulator is linked at the back of the unit. In normal use this i-f link is closed so that the i-f unit is fed from a plug-in v.h.f. down-converter, crystal-controlled for the particular channel in use.

This v.h.f. plug-in unit employs two stages of v.h.f. selectivity before the mixer, and uses dual gate FETS so as to get a wide dynamic a.g.c. range without introducing waveform distortion.

The output waveform from the demodulator detector (and before video processing) is shown in the lower trace of Figure 9, compared to the video input to the modulator (upper trace). Note the 20T symmetry, showing the relative chrominance/luminance delay error to be low. The color subcarrier level and the 2T preshoot are corrected in the video processing circuits of the demodulator.

The 2T preshoot is more clearly visible on a faster time base in Figure 10, where the associated pulse shape K factor at this point is seen to be 3%.

In Figure 11 the demodulator output is shown in the lower trace, the upper trace being the modulator input. The corresponding waveform response at field rate is shown in Figure 12, with the demodulator AGC circuit operational.

The T pulse response is shown in Figure 13. Note the symmetrical preshoot and aftershoot, indicating low phase distortion. Good T and 2T pulse shape symmetry is necessary for low differential gain and phase distortion.

5. Acknowledgements

Thanks are due to Mr. I. Switzer of Maclean-Hunter Cable TV, Toronto, Canada for the opportunity to field test experimental equipment; to Mr. Archer S. Taylor of Malarkey Taylor Associates, Washington, D.C. for helpful discussion of demodulator applications in CATV; to Mr. Jost Ladwig of Telemet for his capable assistance; and to the Telemet division of Geotel for permission to present this paper.

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Captions to figures

Fig. 1 (a) and (b)
Alternative modulator diode ring circuits. Using hot-carrier diodes each of these was found to give low waveform distortion.

Fig. 2 The 20T and 2T test waveforms seen at i-f on v.s.b. carrier.

Fig. 3 The Kelly test waveform for measurement of level-dependent distortion at color subcarrier, seen at baseband and on modulated carrier.

Fig. 4 The Telemet 4400-Al modulator.

Captions to figures (cont'd)

Fig. 5 The i-f amplitude/frequency characteristic of the Telemet 4500-A1 demodulator, measured on carrier at the input to the detector.

Fig. 6 Quadrature distortion narrows the 2T pulse. (The wider pulse is that at the modulator input).

Fig. 7 The Telemet 4500-A1 demodulator.

Fig. 8 Block schematic of the demodulator.

Fig. 9 Demodulator detector output before video processing (below) compared with input to modulator (above).

Fig. 10 Preshoot of 3% K on the 2T pulse (before correction).

Fig. 11 Demodulator output (below) compared with modulator input (above).

Fig. 12 As Figure 11 but at field rate.

Fig. 13 T pulse response.

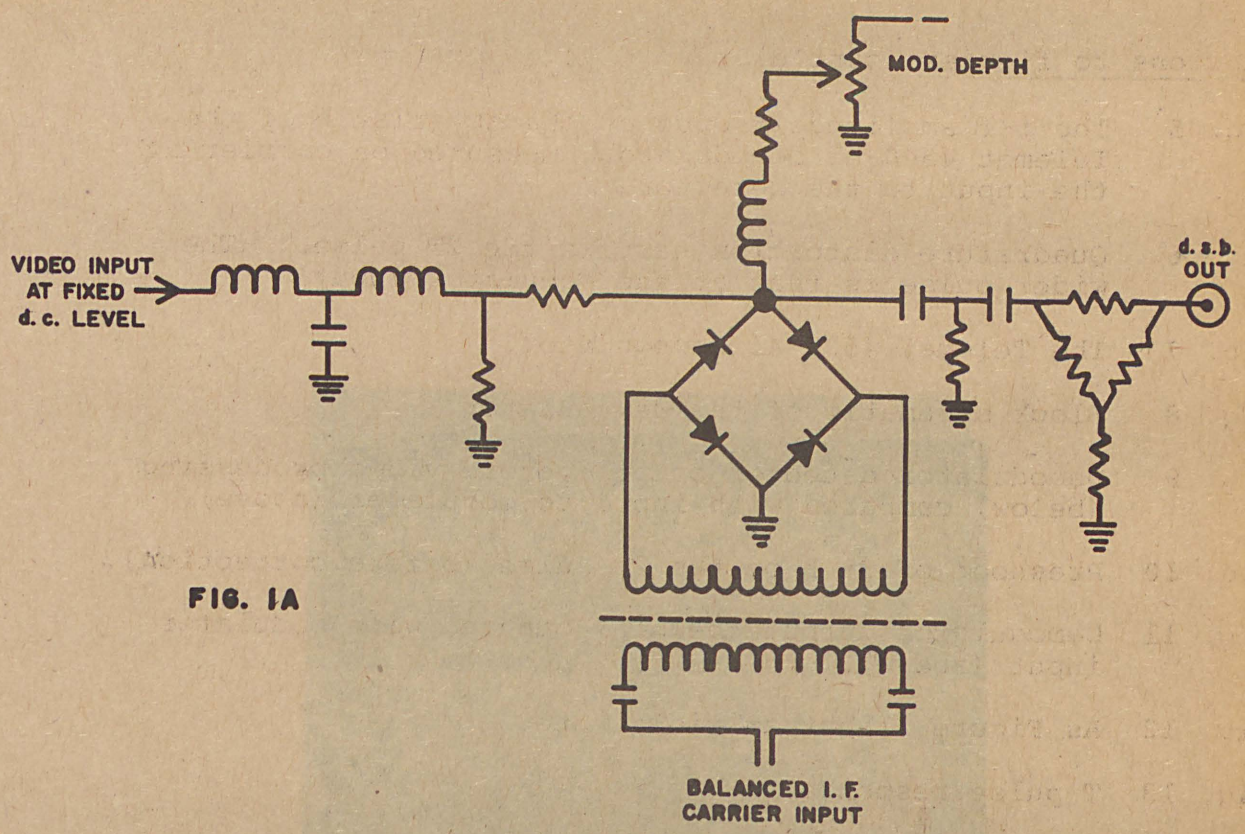

MOD. DEPTH
VIDEO INPUT
AT FIXED
d. c. LEVEL
d. s. b.
OUT
BALANCED I. F.
CARRIER INPUT

FIG. 1A

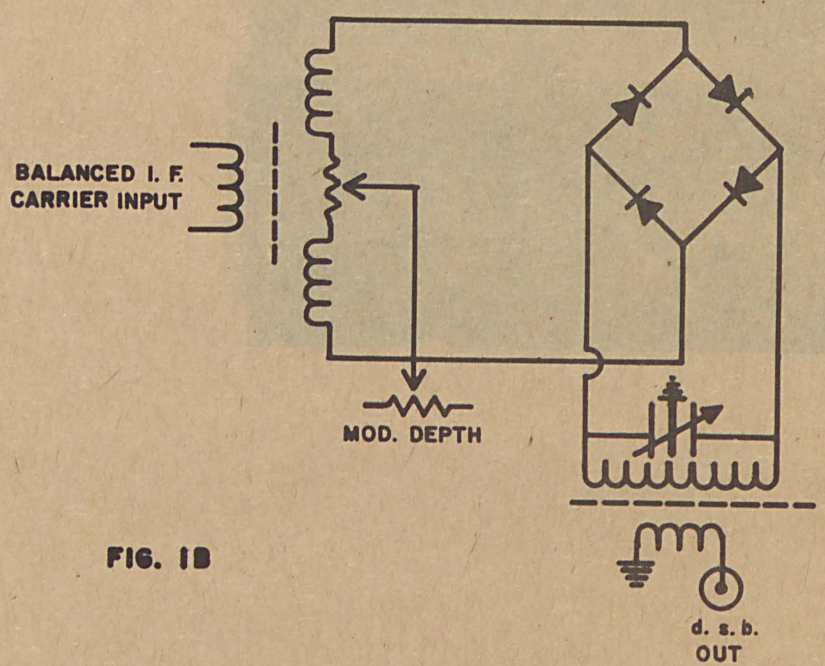

BALANCED I. F.
CARRIER INPUT
MOD. DEPTH
d. s. b.
OUT

FIG. 1B

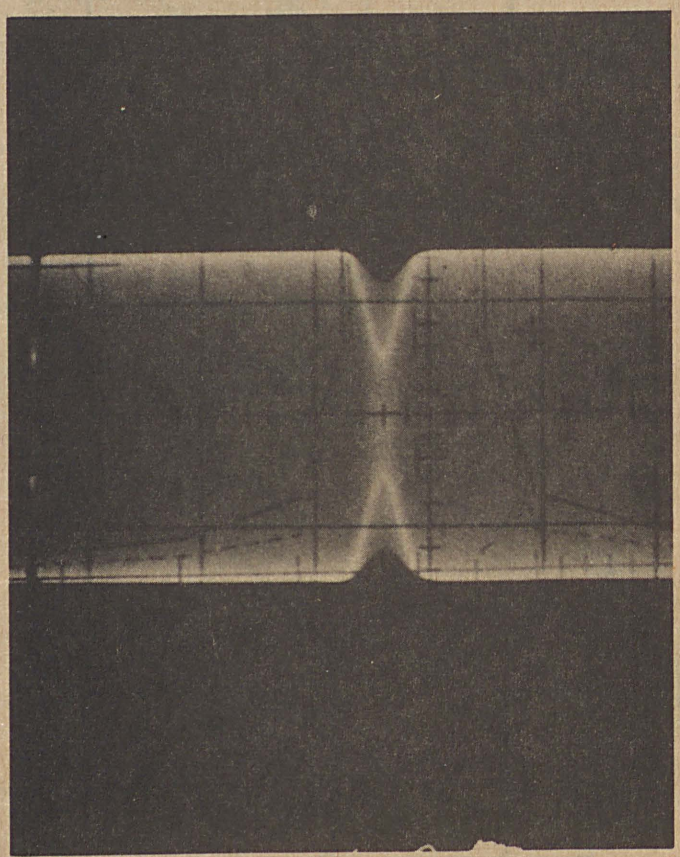


FIG. 2

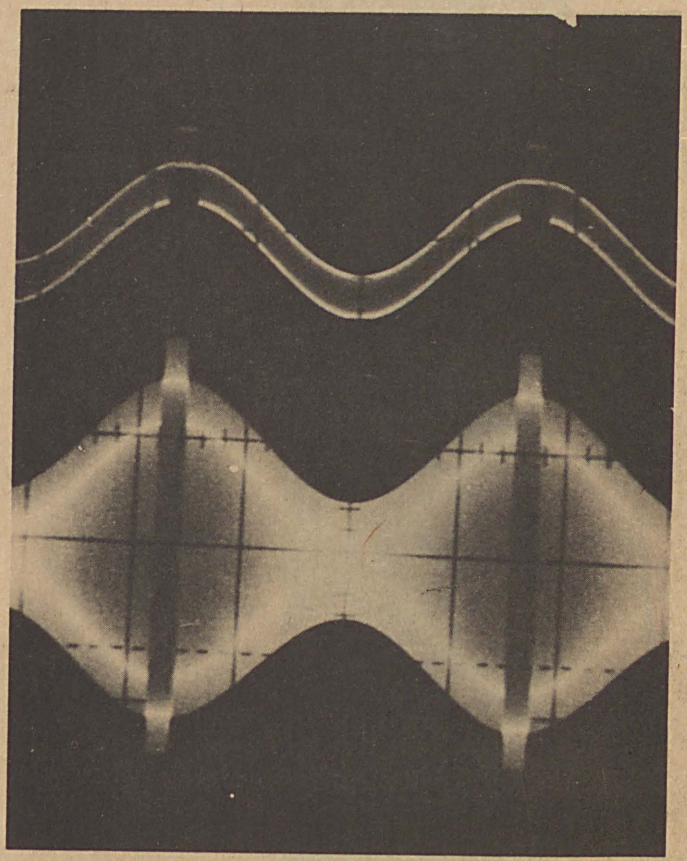


FIG. 3

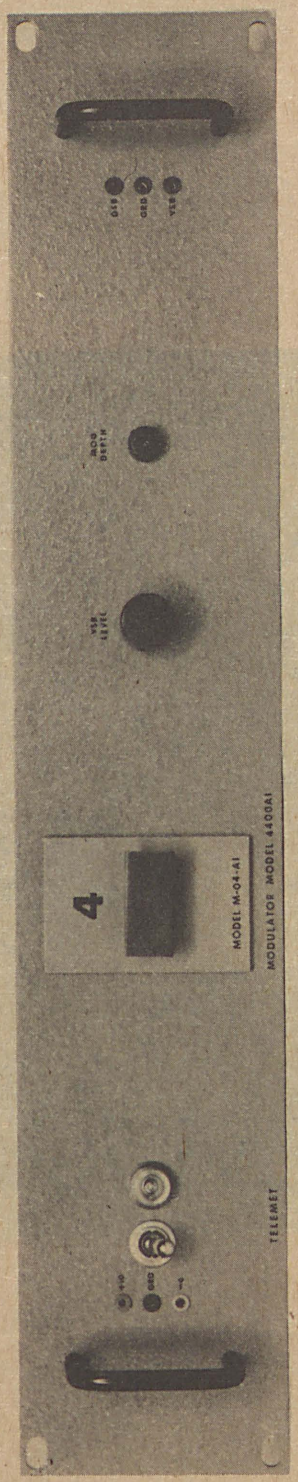

MOD DEPTH
VSK LEVEL
4
MODEL M-04-A1
MODULATOR MODEL 4400A1
TELEMET

FIG. 4

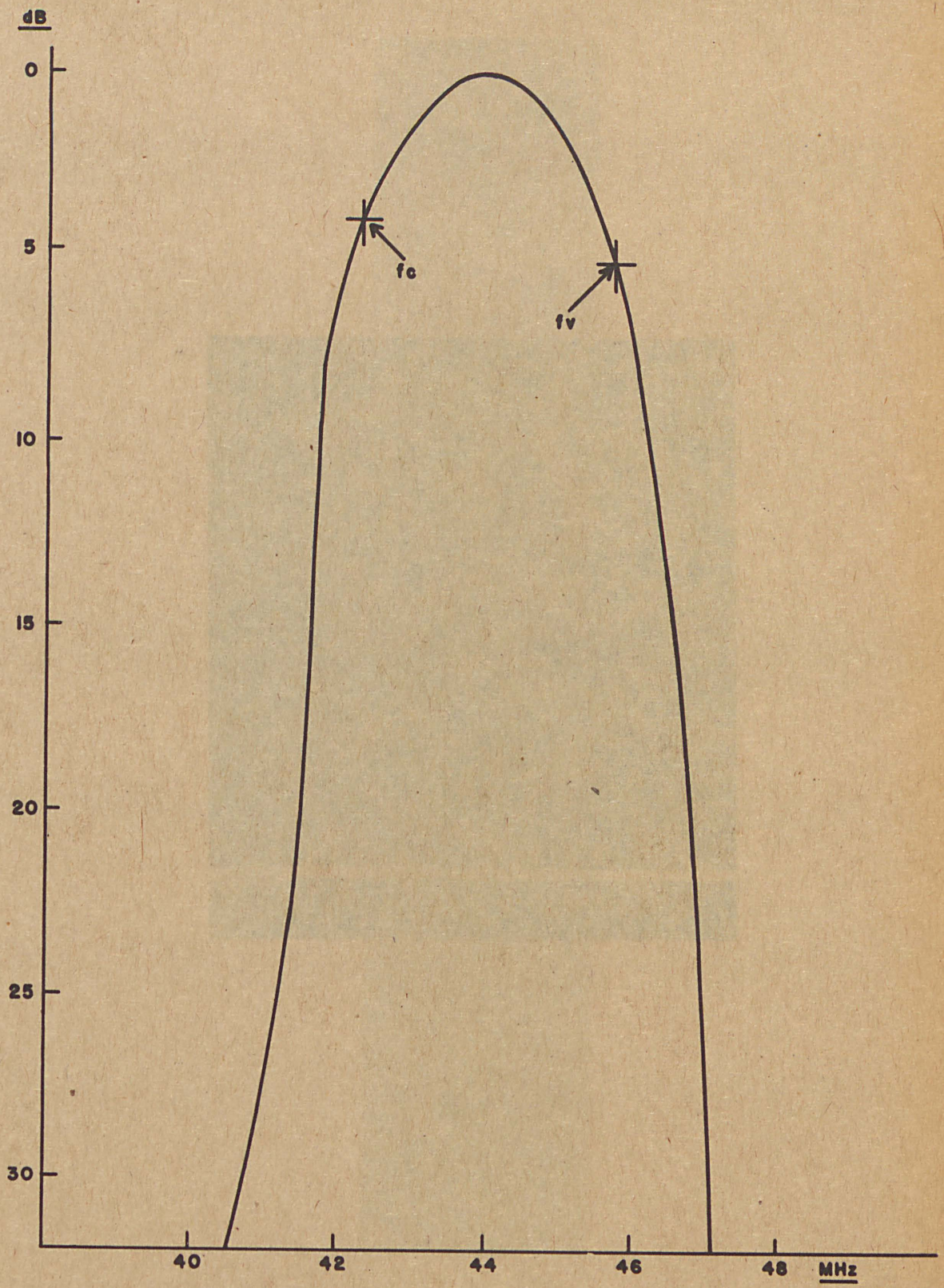


FIG. 5

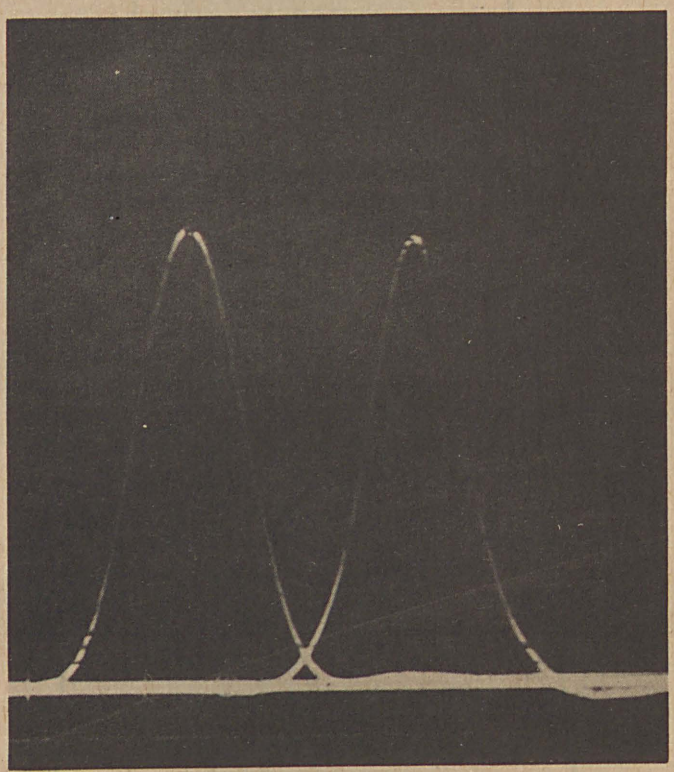


FIG. 6

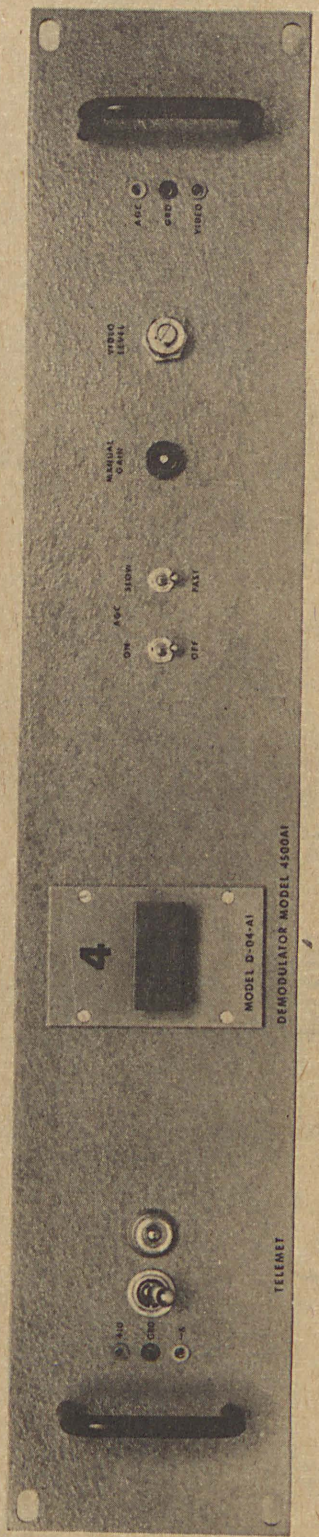

AGC
GRD
VIDEO
VIDEO LEVEL
MANUAL GAIN
AGC SLOW
FAST
ON
OFF
4
MODEL D-04-A1
DEMODULATOR MODEL 4500A1
TELEMET

FIG. 7

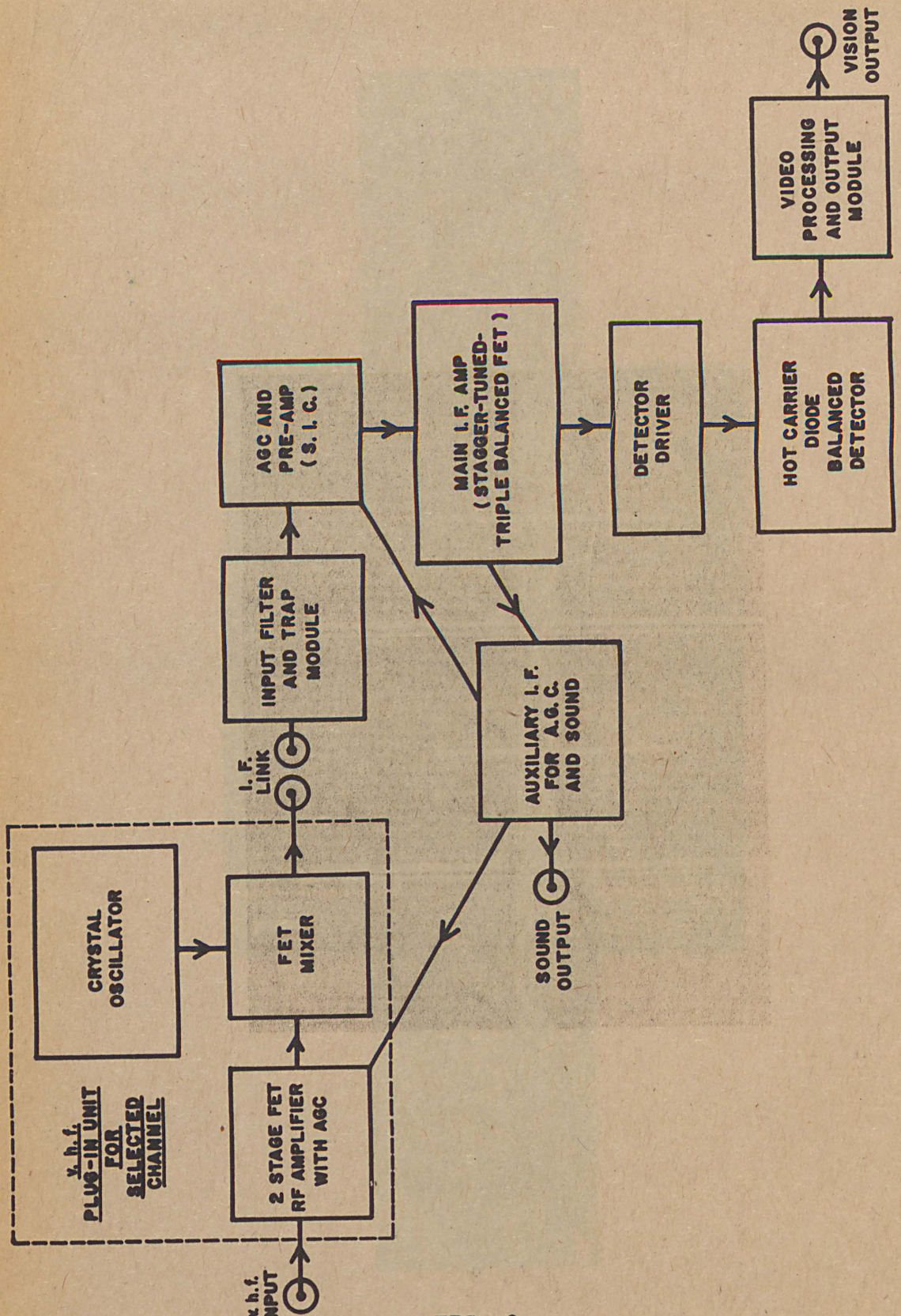

v.h.f. INPUT
v.h.f. PLUG-IN UNIT FOR SELECTED CHANNEL
2 STAGE FET RF AMPLIFIER WITH AGC
CRYSTAL OSCILLATOR
FET MIXER
I.F. LINK
INPUT FILTER AND TRAP MODULE
AGC AND PRE-AMP (S.I.C.)
MAIN I.F. AMP (STAGGER-TUNED-TRIPLE BALANCED FET)
AUXILIARY I.F. FOR A.G.C. AND SOUND
SOUND OUTPUT
DETECTOR DRIVER
HOT CARRIER DIODE BALANCED DETECTOR
VIDEO PROCESSING AND OUTPUT MODULE
VISION OUTPUT

FIG. 8

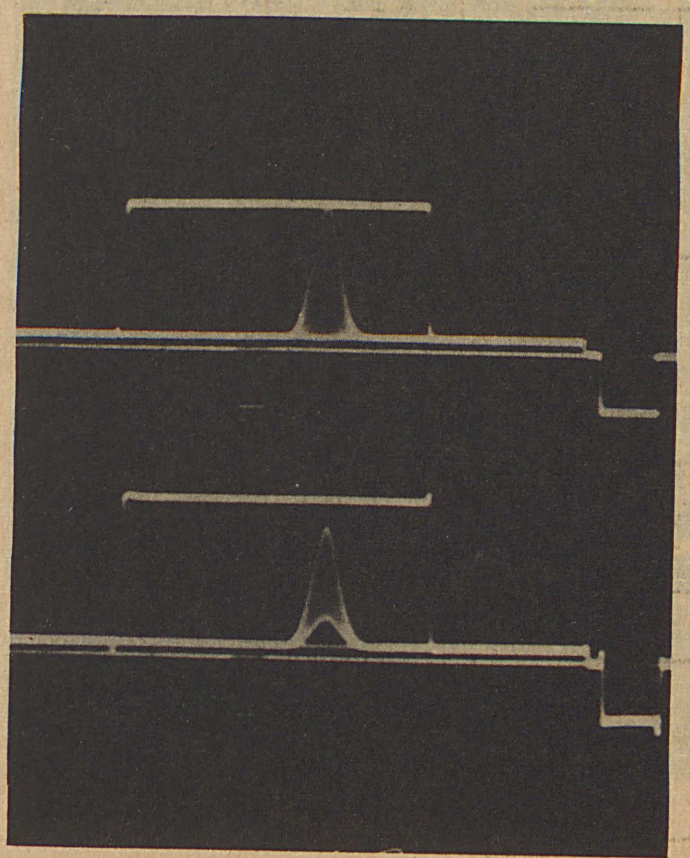


FIG. 9

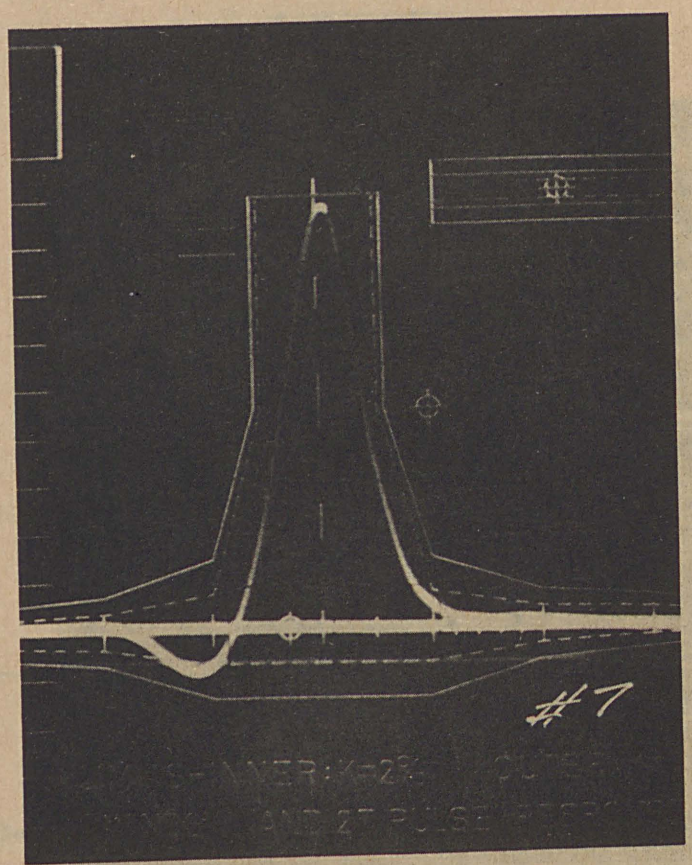


FIG. 10

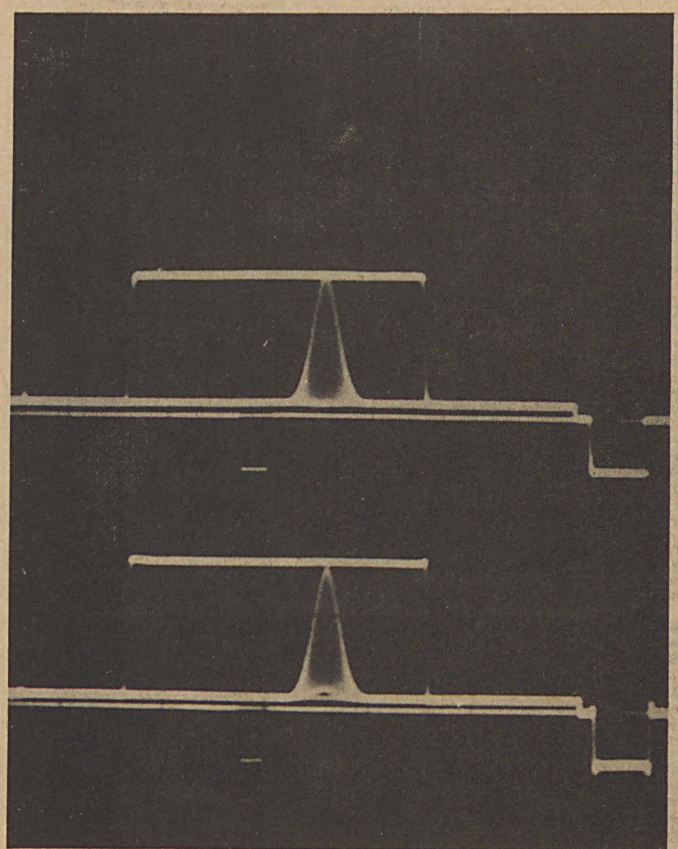


FIG. 11

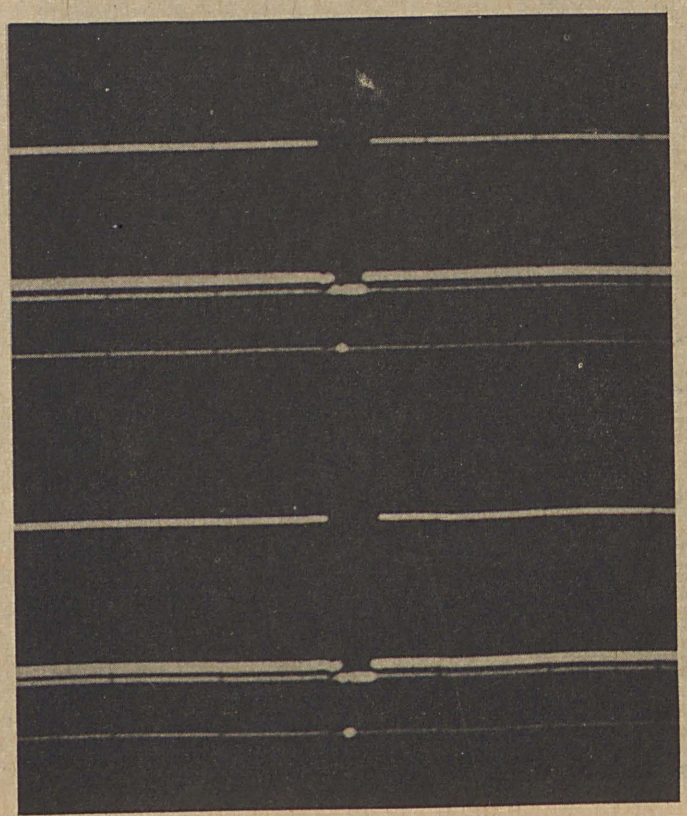


FIG. 12

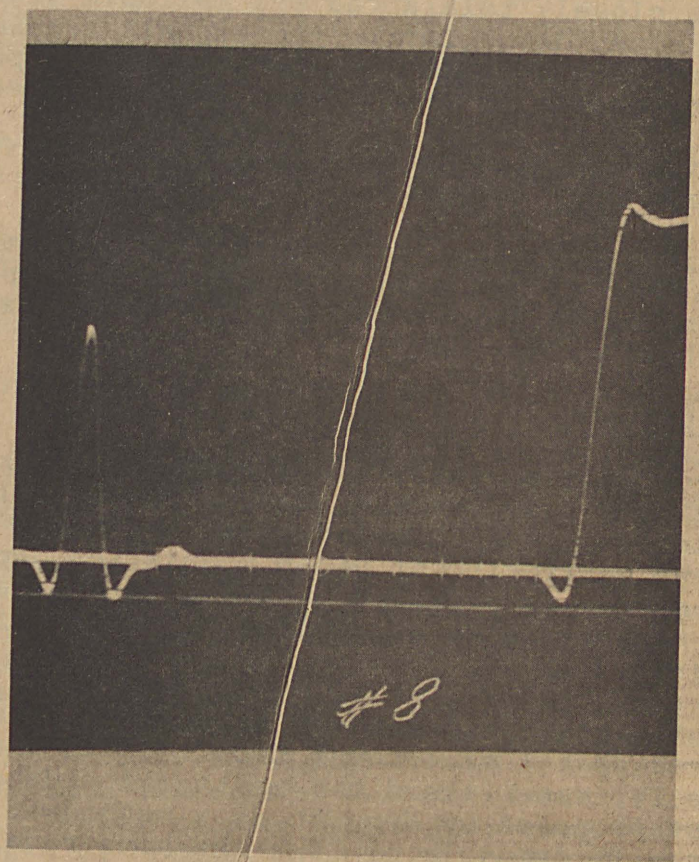


FIG. 13

GEORGE STOEPPEL

1. General Considerations

1.1 Purpose of the Instrument

TV demodulators find application in TV transmitter installations for monitoring the picture and sound quality and measuring the transmitter characteristics during interruptions in transmission. The instrument therefore plays a dual role. During broadcasting, it performs as a closely toleranced and reliable standard for the receiver in the home, demodulating the signals transmitted so that the video and sound can be evaluated using respectively an oscilloscope and monitor or amplifier and loudspeaker.

The TV demodulator can also monitor the video modulation depth and the sound frequency deviation.

Both the linearity and phase response of the instrument must be in keeping with that of the home receiver so that optimum picture quality can be attained when setting the pre-equalization of amplitude and phase distortion.

1.2 Basic Concept

For the TV demodulator to fulfill all the above tasks satisfactorily, the selectivity provided must have a Nyquist slope and considerable carrier suppression relative to the video modulation. To facilitate the monitoring of video modulation depth an optional zero reference marker is provided. This generates a white level in the form of a short pulse every line, corresponding to a carrier level of 0%. (Fig. 1)

FM sound demodulation is carried out by an intercarrier demodulator which derives an i-f of 4.5 MHz from the video and sound carriers. Because TV transmitters use vestigial sideband methods, which were first proposed by Nyquist as a method of economizing on bandwidth, the TV demodulator like the home receiver must have a particular frequency response. (Fig. 2) and (Fig. 3).

For modulation frequencies up to 0.75 MHz, the transmitter radiates the carrier and both sidebands. Above 1.25 MHz, the lower sideband is suppressed and only the carrier with the upper sideband is emitted. The Nyquist slope of the receiver ensures that, for modulation frequencies up to approx. 1.25 MHz, the smaller lower sideband and the larger upper one add up to 100%. Beyond 1.25 MHz, the upper sideband with 100% amplitude is demodulated, the lower being less than 1%. When the transmitter and the receiver are taken together the overall video response is a straight line. (Fig. 4)

If the transmission signal is demodulated with a double sideband demodulator, an ideal response as in Fig. 5 is obtained. (Fig. 5)

In practice, the filter is not as angular as shown in Fig. 2, and Fig. 5 but exhibits a smooth transition from 100% to 50% relative amplitude.

When testing the video transmitter during pauses in transmission (or a standby transmitter), it is advantageous to be able to switch out the sound trap. With the sound carrier inoperative, the broadband demodulator can then be used for measuring and checking the video transmitter up to the upper frequency limit. With the introduction of color television, interest in the upper video frequencies was increased and they must be demodulated with fixed amplitude and linear phase when the sound trap is switched off. The Nyquist slope is effective in both types of operation. (Fig. 6)

In order to satisfy the above conditions in all the television channels, it is essential to convert the channel frequency to a standard i-f. Conversion is most commonly carried out using a frequency-multiplied crystal oscillator signal. If it is possible to readjust the oscillator and multiplier, after a crystal change, without using external test equipment, the TV demodulator can be used for all the channels in a TV band.

Because i-f modulated transmitters are being used more and more, a demodulator using an i-f technique has the added advantage that its secondary i-f input can be used for a step-by-step testing.

2. Distortion

An important requirement of any test demodulator is that it should exhibit no distortion on a monitor screen, other than that due to the normal system conditions. It must also be suitable for the measurement of distortion in a transmitter and both these factors necessitate extremely low, linear and non-linear distortion. System distortion, in the case of envelope demodulation, results from the heavily modulated single-sideband signals. This so-called quadrature distortion does not arise if demodulation is performed with carrier reinsertion. This method artificially reduces the depth of modulation, prior to detection, by reinserting a suitable picture carrier. Because this involves relatively elaborate circuitry and high expense, it is not used in home receivers. It would therefore be impractical to use this technique in a demodulator for transmitter monitoring because the instrument would lose its character as a standard home receiver. When measuring a transmitter during transmission breaks or by using the test line facility, it is in any case customary to transmit signals at low modulation depths which themselves show up quadrature distortions.

2.1 Non-linear Distortion

2.1.1 Linearity departures, chiefly caused by quadratic characteristics of the mixer, amplifier and above all the demodulator stages, must remain small to prevent errors in the brilliance or color saturation.

2.1.2 Differential phase alterations, i.e., phase changes in the color carrier between high and low modulation levels due to complex gain variations, should be low to avoid chromaticity faults between light and dark pictures.

2.1.3 Intermodulation distortion, arising from cubic curving of the characteristic, leads to mutual degrading of brilliance, chromaticity and color saturation.

Linearity departures and differential phase alterations are relatively easy to take care of. As intermodulation distortion is almost always a problem with the sound carrier (SC) it is useful to consider this more closely.

An assessment of intermodulation effects shows that a maximum amount of carrier suppression before detection is required and this has consequences for the selectivity and group delay requirements at high video frequencies.

To take a simplified view of the likely interference, consider a signal, consisting of picture, sound and color carriers (PC, SC and CC) with the color carrier behaving as information that modulates the picture carrier from black to white. The following spectrum is then generated: PC, SC, CC. (Fig. 7)

Interference components falling within the video band are then

SC - PC = 4.5 MHz

SC - CC = 0.9 MHz

Picture 7 does not show spurious signals which result from interaction between luminance components around 0.9 MHz and the sound carrier, which would fall in the color range at about 3.6 MHz. All these spurious signals are due to interaction with the sound carrier which must be suppressed at the earliest possible point in the i-f amplifier.

Spectrum at the detection diode with a sound carrier suppression of 50dB. (Fig. 8)

If one assumes that no spurious components arise in the stage before the sound trap, it can be seen from the above diagram that intercarrier signals will be attenuated 40 dB relative to the wanted frequency. Moreover, the wanted sideband takes over the role of the sound carrier at the demodulator so that the now permanent 0.9 MHz spurious signal is also of this order.

Except for the intercarrier interference at 4.5 MHz, which can be further suppressed by a trap, these components are fixed and cannot be eliminated subsequently. The magnitudes are permissible for home receivers as they are below the level of perceptibility. For measurement quality demodulators, however, these form the absolute upper limit.

From these arguments, it follows that sound carrier suppression of more than 50 dB is required before demodulation, and that the stages which amplify both sound and video signals must be extremely linear.

There are two more methods of reducing interference, namely:

a) Reduction of the color carrier signal before demodulation by several dB, and restoration in the video section. This has the added advantage (with envelope demodulation) that less quadrature distoriton of the color signal is produced.

b) Lowering the sound carrier power by 3 dB, i.e., a picture-sound ratio of 10:1. This has been used in several countries for 1-1/2 years without any disadvantages appearing.

3. Linear Distortion

When considering linear distortion effects, one must differentiate between the linear demodulator without sound trap and the measuring receiver mode with home receiver characteristics. With the sound trap switched out, the receiver must exhibit constant amplitude and group delay time up to the highest video frequencies, i.e., the group delay time of the Nyquist filter must be compensated for.

With the sound trap switched in, the TV demodulator should function as a standard for the home receiver. It should at least contain traps for the sound, neighboring picture and neighboring sound signals. (Fig. 9)

4. Design of the Sound Trap

In principle, three possibilities exist for the construction of a sound trap. (Fig. 10)

A) Using one trap, which is made sufficiently high Q by loss compensation.

B) By two or more traps arranged symmetrically about the sound carrier frequency.

C) With a filter whose return characteristic remains below a certain value.

Assuming that the traps have a fall-off of less than 3 dB at the end of the pass band (4.18 MHz) and that the attenuation is 50 dB, the following bandwidths at 140 dB are obtained.

Type A	Type B	Type C
approx. 15 kHz	approx. 160 kHz	approx. 200 kHz

The group delay curves are correspondingly different.

	A	B	C
0.1 MHz	0	0	0
3.6 MHz	+ 75 nsec	+ 130	+ 170
3.9 MHz	+ 160 nsec	+ 300	+ 400
4.18 MHz	+ 430 nsec	+ 600	+ 700

When using an FM sound carrier with ±30 kHz deviation yielding main spectral components extending up to ±45 kHz from the carrier, trap A provides insufficient picture interference rejection. This is because the sidebands of the sound signal fall on the slopes of the filter response and are converted into AM which is demodulated as interference at the video detector. This trap is also unsuitable for home receivers because of the instability of the local oscillator.

Two sufficiently broad traps, as in Fig. 10 B, give much better results regarding interference but exhibit a much sharper increase in the group delay at the passband extremity. An example can show this more clearly. If a trap, with a response as on the left, is used to suppress the sound carrier by 58 dB, the following picture interference rejection values result from the sound signal alone (minus noise and hum). (Fig. 11)

Power ratio Picture: Sound = 5 : 1

Unmodulated sound carrier = 54 dB

Sound carrier modulated with 1 kHz:

Deviation ±30 kHz 53 dB

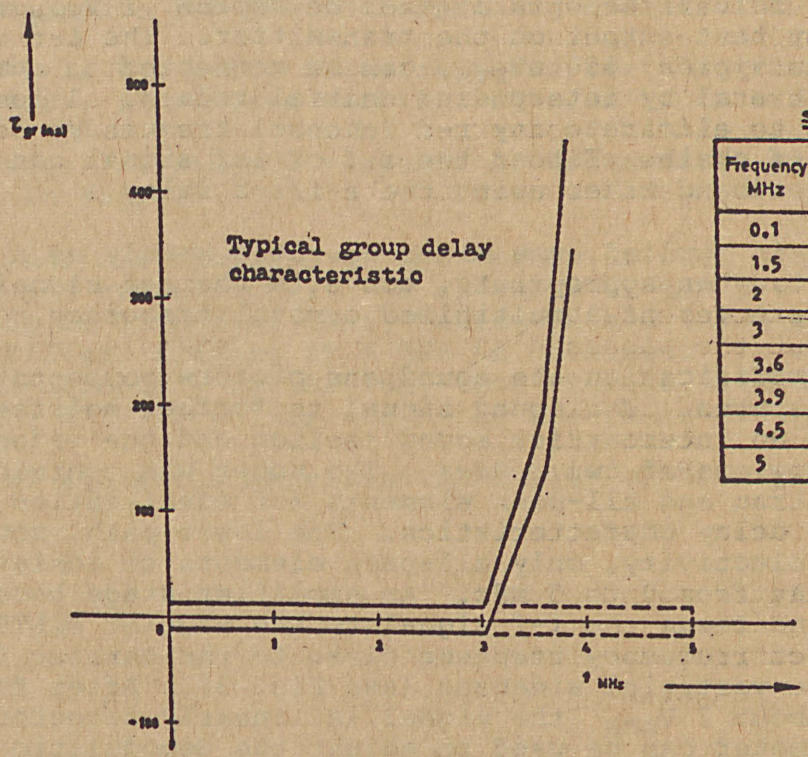
±50 kHz 44 dB

The spurious signal rejection values are referred to the sync level. The waveforms are roughly sinusoidal so that the figures are valid for both peak or rms measurements.

In practice the intermodulation and sound interference on the picture tube are of more interest than the numerical amount of sound suppression. For this reason the intermodulation product (SC-CC) and video spurious signal level are often quoted in preference to the frequency response of the sound trap, when sound modulation is applied.

To conclude, it is clear that to keep intermodulation distortion low, the sound carrier suppression, before video detection, must be sufficient (150 dB). Moreover, the sound trap must have a minimum bandwidth to reduce sound-on-picture and achieve adequate stability. Neighboring channel suppression must also be adequate in home receivers.

The selectivity specifications, for a system with minimum phase correction, e.g., home receivers where costs must be kept low, require a sharp increase in the group delay at the upper end of the video band and a gradual fall-off amplitude beyond the color carrier frequency.



Frequency MHz	with sound trap group delay nsec	without sound trap group delay nsec
0.1	0 ±15	0 ±15
1.5	0 ±15	0 ±15
2	0 ±15	0 ±15
3	0 ±15	0 ±15
3.6	170 ±25	0 ±15
3.9	400 ±50	0 ±15
4.5	—	0 ±15
5	—	0 ±15

The Figure and Table on page 236 show the more important tolerances, required of a demodulation standard. The ones that are dotted apply when the sound trap is switched out. If the transmitter pre-equalization is set to give a constant group delay time for the transmitter and receiving standard together, one can expect optimum quality for the range of contrast and color on the home receiver.

Nowadays, transmitter pre-equalization is often applied after the modulator in the i-f stages. This avoids the evident disadvantages of equalization at video frequencies.

5. Short Description of a TV Demodulator

An instrument with the characteristics already discussed is shown in the functional diagram 12.

The RF input (50 Ω ± 1.5%) accepts a level of approx. 1 V_{rms} from the diplexer or any test output on the transmitter. The i-f channel, which requires approx. 150 mV_{rms}, can be connected to one test point or to several by interposing coaxial relays. A low-pass filter is included to eliminate any r-f (channel frequency) signals appearing in the i-f chain. Either the r-f or i-f signal can be switched to the broadband mixer using the r-f/i-f relay.

When an i-f signal is applied, the mixer operates merely as a damping circuit but, when appropriate, converts the r-f signals to the i-f range by means of a multiplied crystal frequency.

After common i-f amplification the sound and picture components are split into two paths. The sound signal is further modified and demodulated in an intercarrier sound section and the video component can follow one of two routes. The upper one contains the sound carrier trap and all-pass elements for equalization of the receiver group delay characteristics. The lower path, sound trap out, has no selectivity, only all-pass elements to achieve a constant group delay from 0 to 5 MHz. An amplifier stage boosts the signal level and feeds the i-f signal to the NYQUIST FILTER which has the correct frequency response close to the carrier for the addition of the vestigial sideband (see Fig. 3). After further amplification to about 7 V_{rms}, the signal is linearly detected and a peak responding meter can be used to adjust the demodulation level to optimum. The source impedance is then corrected and four video outputs are fed with the standardized video signal via two decoupled video amplifiers. A zero reference circuit derives short pulses from the video signal, which block the i-f amplifier so that the voltage corresponding to zero signal level appears at the video output for the pulse duration (see Fig. 1).

All the filter and amplifier inputs and outputs have a fixed impedance of 50Ω. The filters and all-pass networks are entirely passive and constructed from ceramic inductors to obtain maximum frequency stability.

6. Measurements on a TV Demodulator

Figs. 13 to 16 show the frequency response of amplitude and group delay for a measuring demodulator with and without the sound trap. They were obtained using a double-sideband modulator.

In Fig. 13 one can see the sharp amplitude rise above the sound carrier frequency. Better neighboring channel rejection is desirable. Fig. 15 shows the sharp increase of the group delay above 3 MHz.

Fig. 17 represents the sideband characteristic of a TV signal generator in Band V and Fig. 18 shows the group delay equalization. For this test the TV demodulator was operated with the sound trap switched out.

Up to 3 MHz, the transmitter delay response is linear and falls to compensate for the corresponding increase at the receiver.

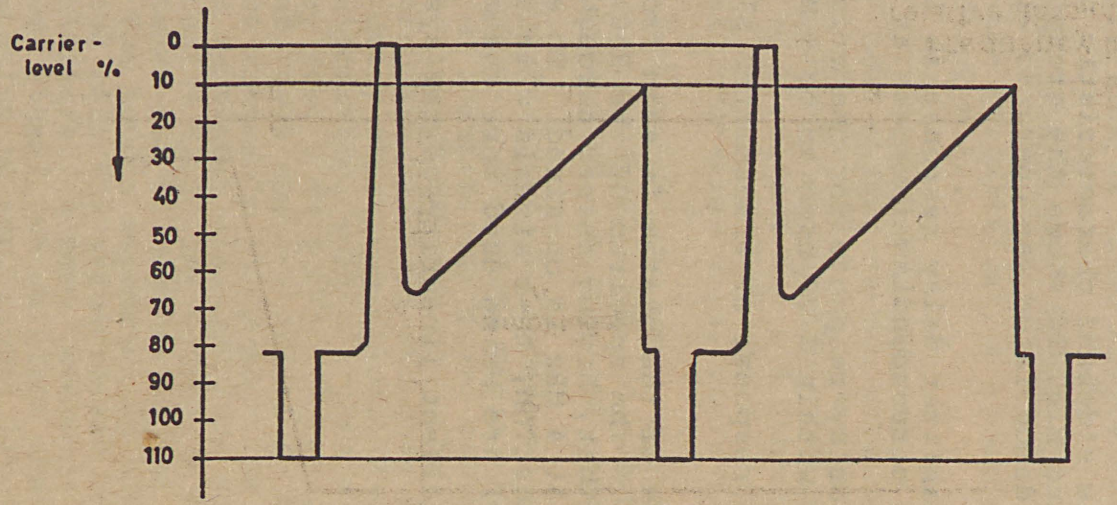
Fig. 19 is the group delay response for the transmitter plus receiver. It remains within $\pm$ 20 nsec up to 4 MHz.

The overall frequency response of transmitter plus receiver is given in Fig. 20.

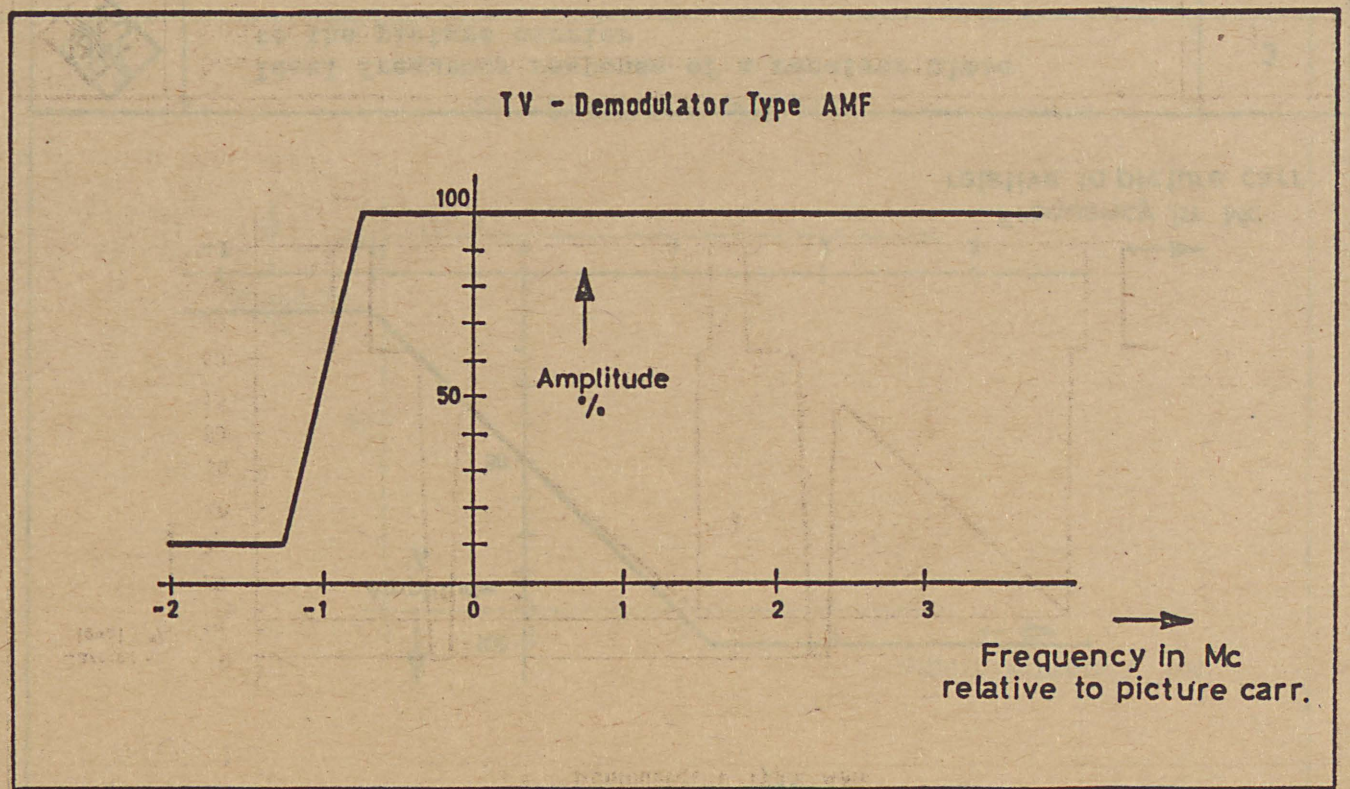
The transient response of the system is seen from Fig. 21 to be clean and symmetrical. The spectrum of the 250 kHz squarewave extends to 10 MHz so that, having passed through the 4 MHz low-pass filter, ringing at 4 MHz is obtained. To exclude the system-dependent distortion, test signals with spectra reduced to $<$4 MHz (2T/20T pulse) are being used more and more.

Fig. 22 shows the excellent linearity of the system.

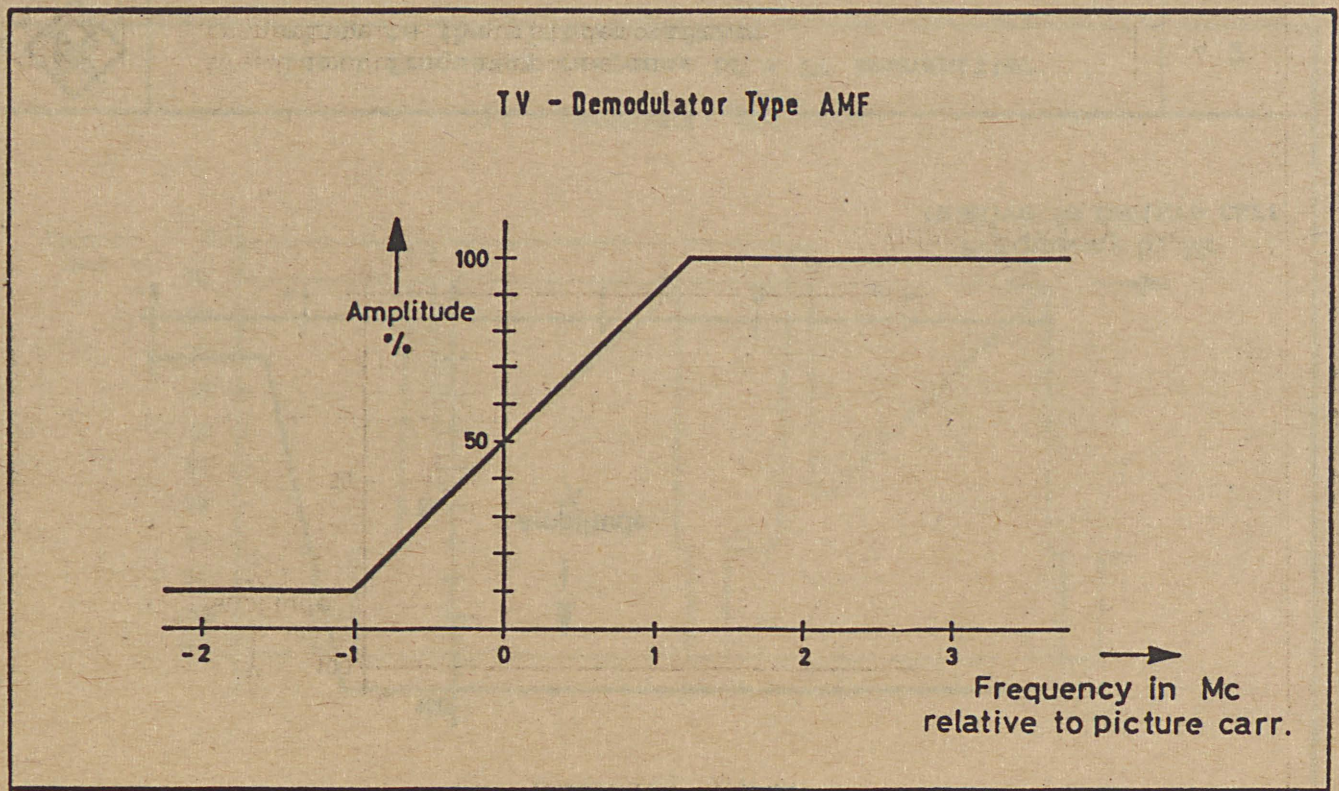
TV - Demodulator Type AMF



	Sawtooth signal and reference marker for 10 % residual carrier	1



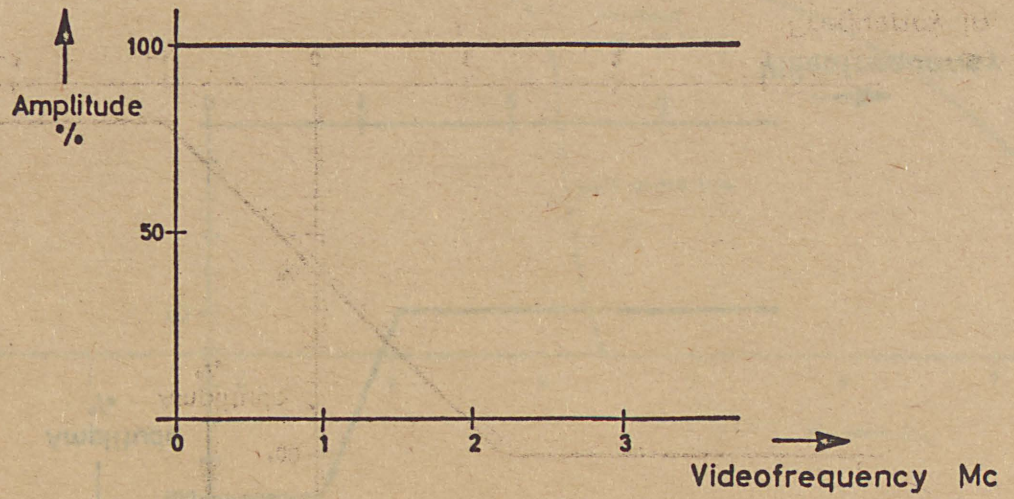
	Ideal frequency response of a TV transmitter close to the picture carrier	2



Ideal frequency response of a receiver close to the picture carrier

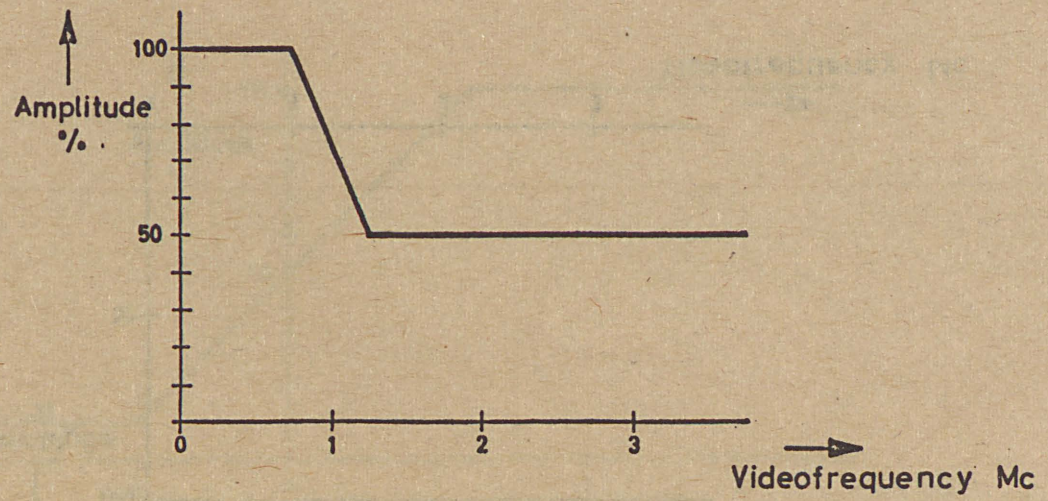
3

TV - Demodulator Type AMF

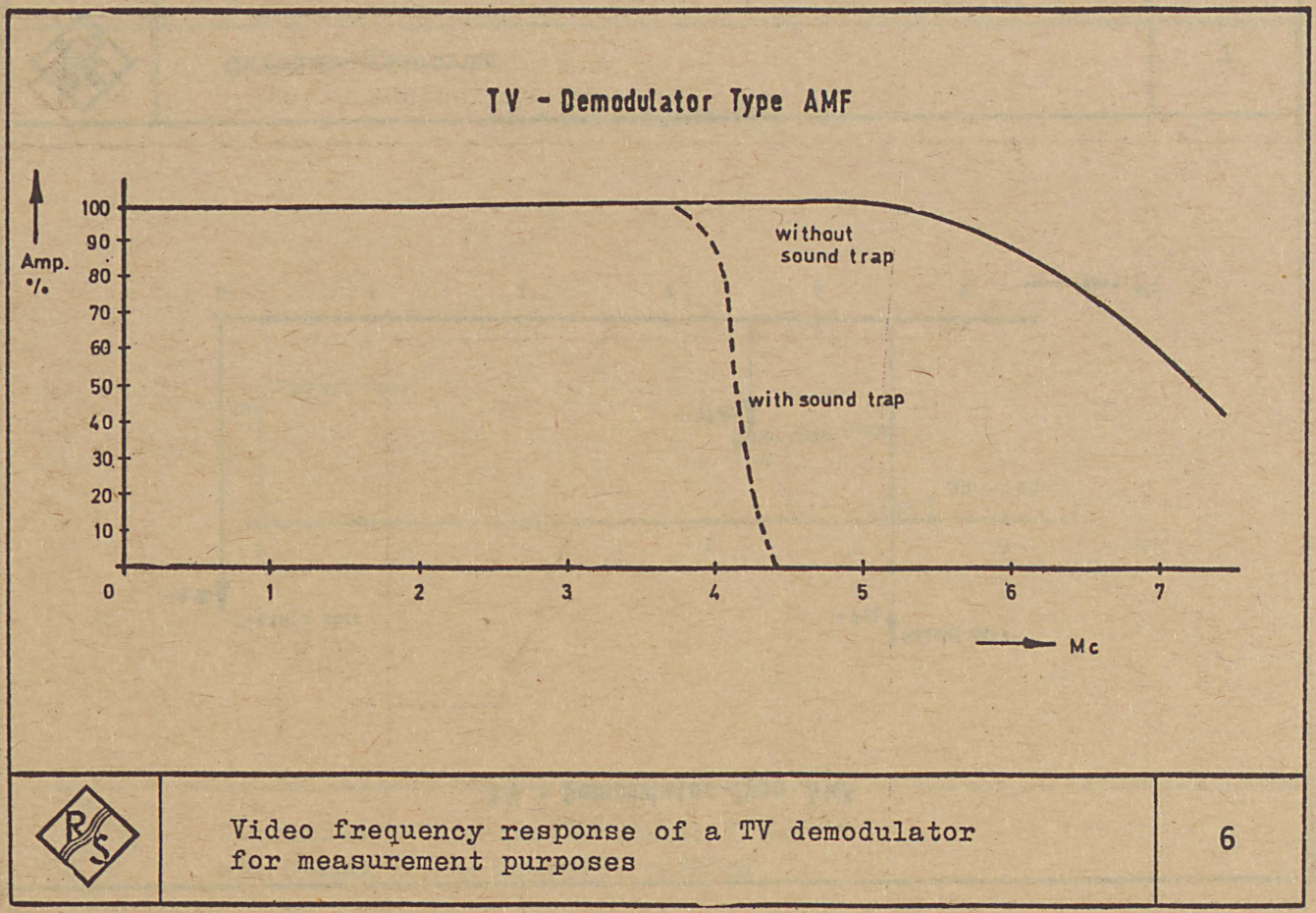


	Ideal frequency response of a TV transmitter + Nyquist demodulator	4

TV - Demodulator Type AMF



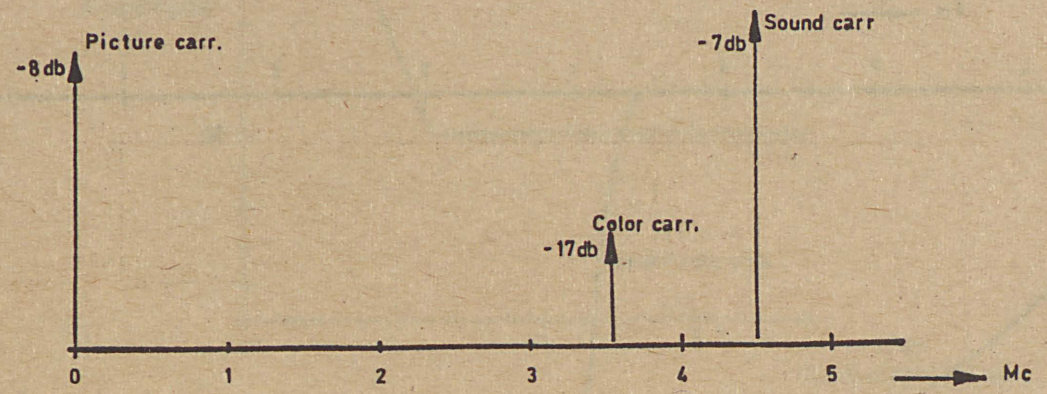
	Ideal frequency response of a TV transmitter + double-sideband demodulator	5



Video frequency response of a TV demodulator for measurement purposes

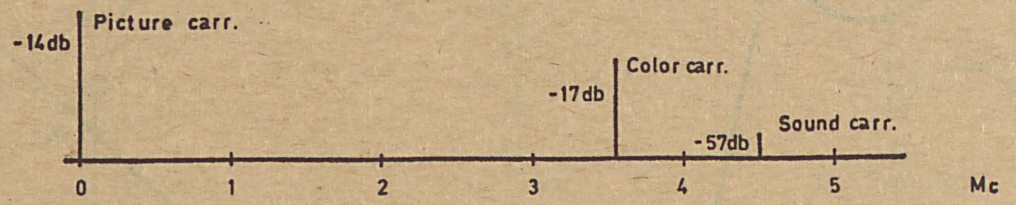
6

TV - Demodulator Type AMF



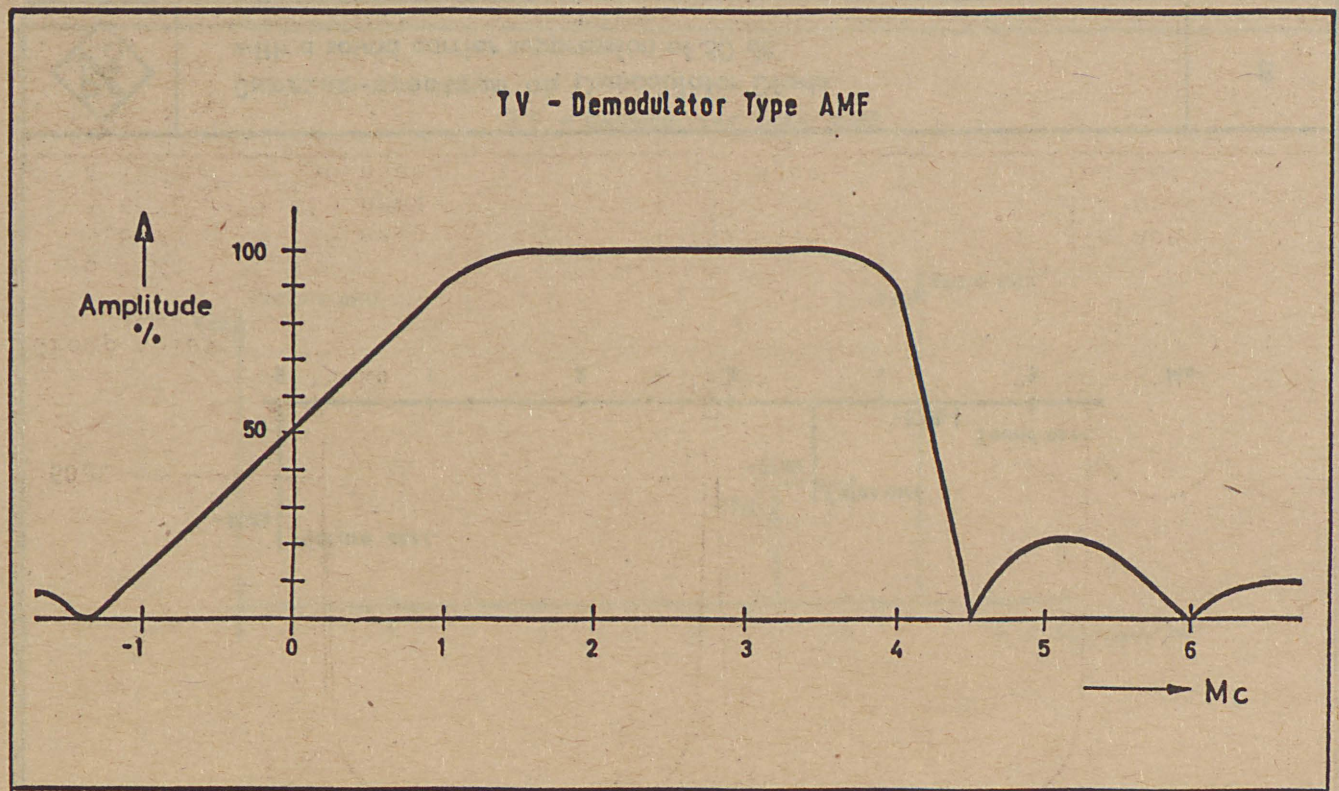
	Carrier-spectrum	7

TV - Demodulator Type AMF

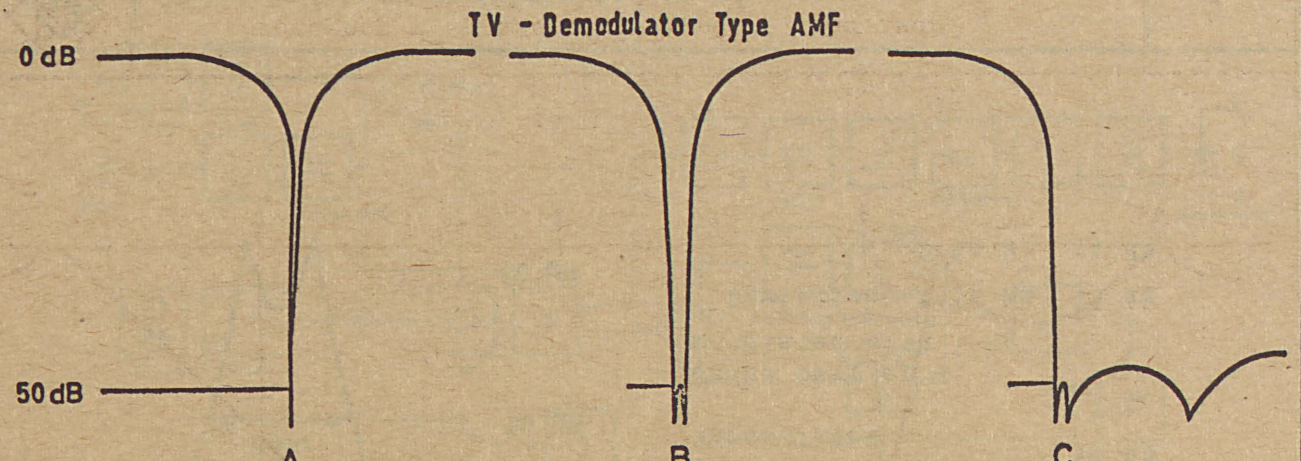


Carrier-spectrum on Demodulator Diode
with a sound carrier suppression of 50 dB

8



	Frequency response of a home receiver	9

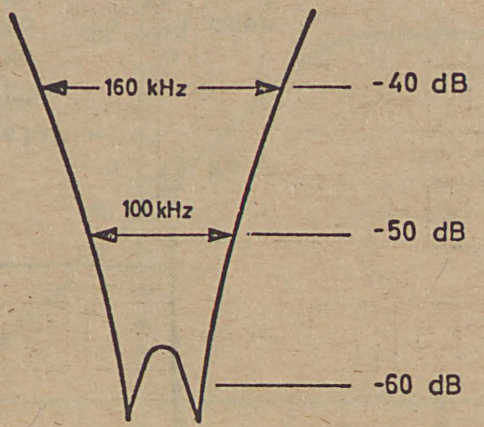


Group delay - curve	A	B	C
0,1 Mc	0	0	0
3,6 Mc	+ 75 nsec	+ 130 nsec	+ 170 nsec
3,9 Mc	+ 160 nsec	+ 300 nsec	+ 400 nsec
4,18Mc	+ 430 nsec	+ 600 nsec	+ 700 nsec

Three different sound traps

10

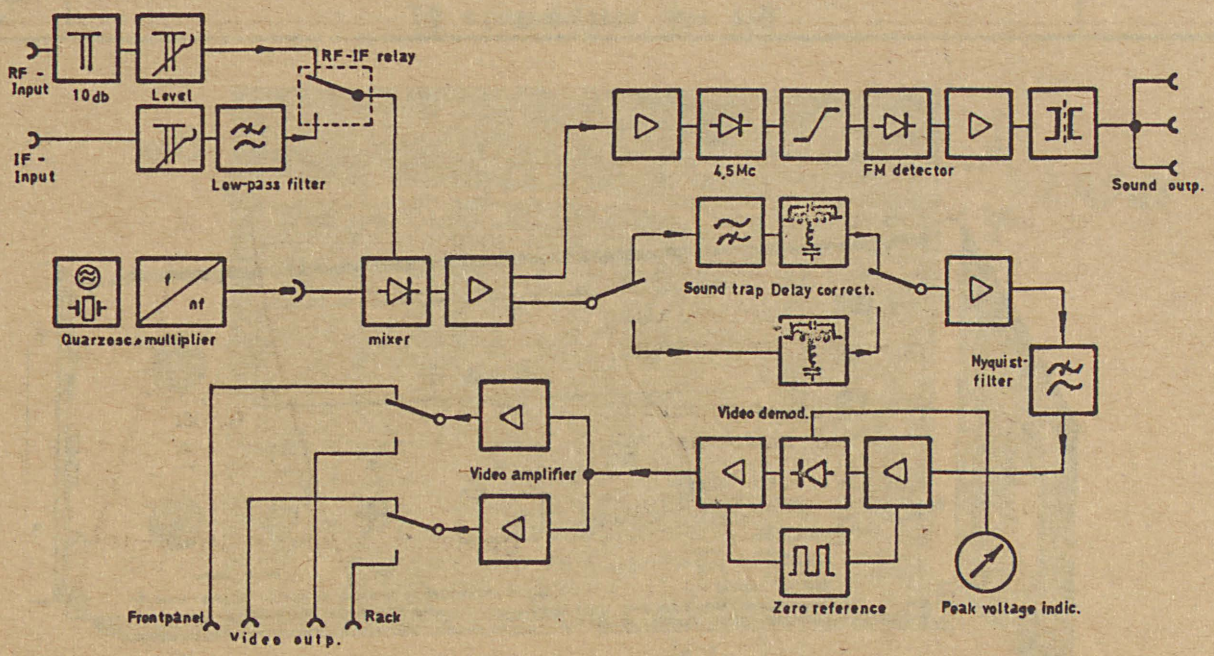
TV - Demodulator Type AMF



Sound level		2o %
Sound carrier - unmodulated		54 db
Sound carrier - modulated with 1 kc		
Deviation	± 3o kc	53 db
	± 5o kc	44 db

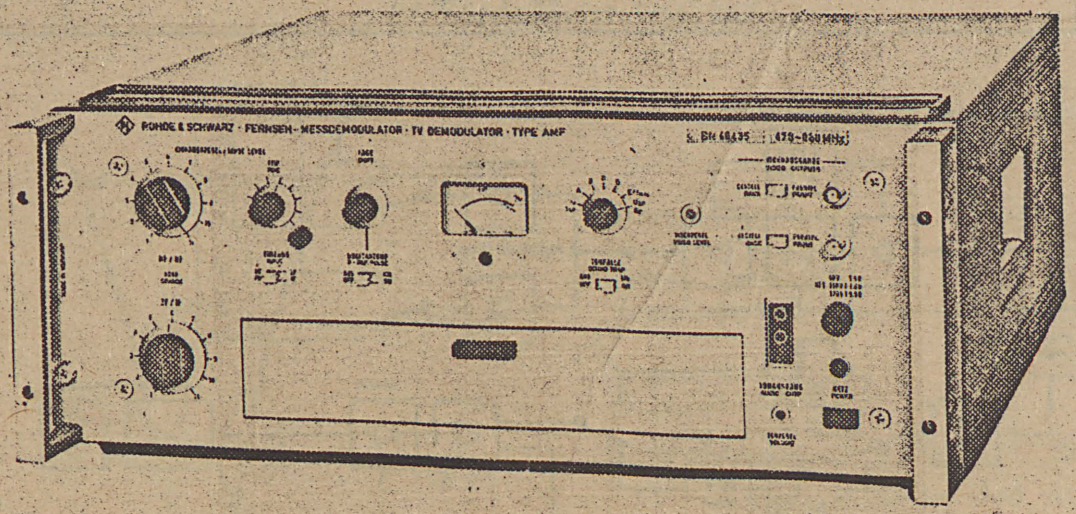
Whiteband carrier filter for sound

11



Block Diagram for
TV - Demodulator Type AMF

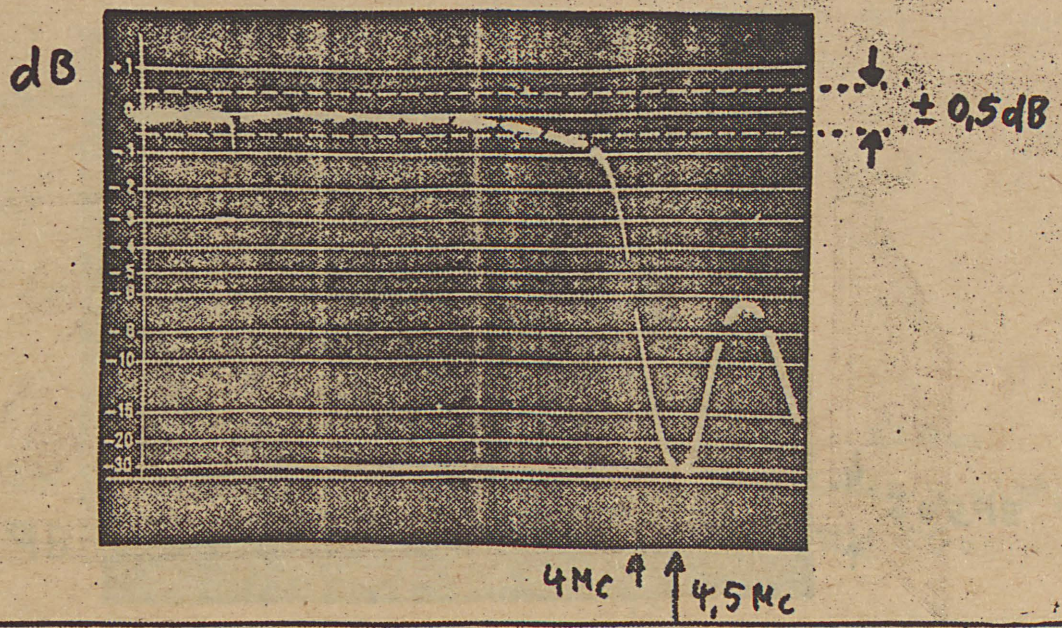
12



TV-DEMODULATOR Type AMF

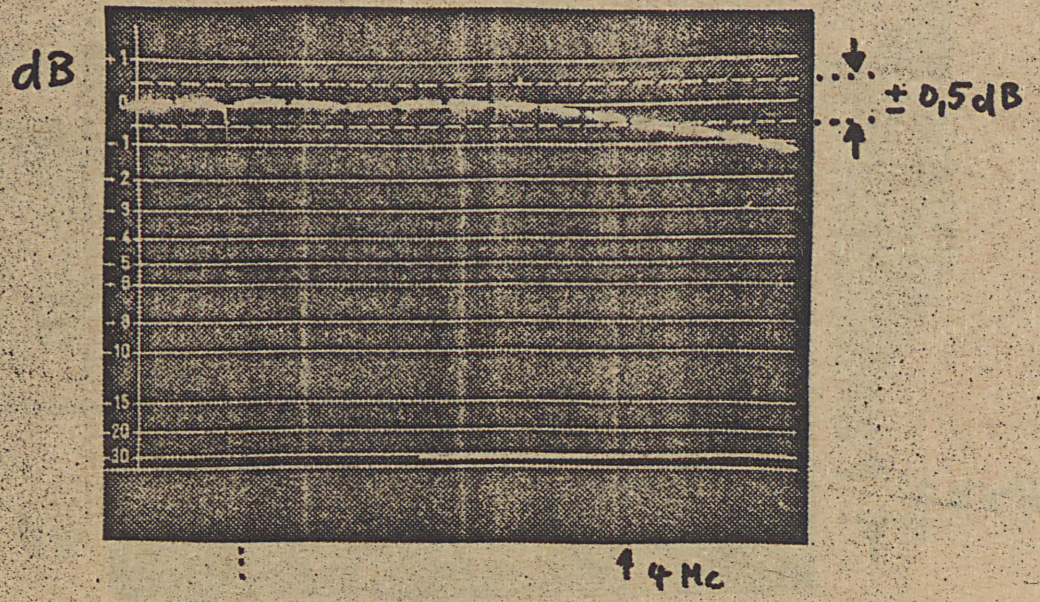
12 a

TV - Demodulator Type AMF



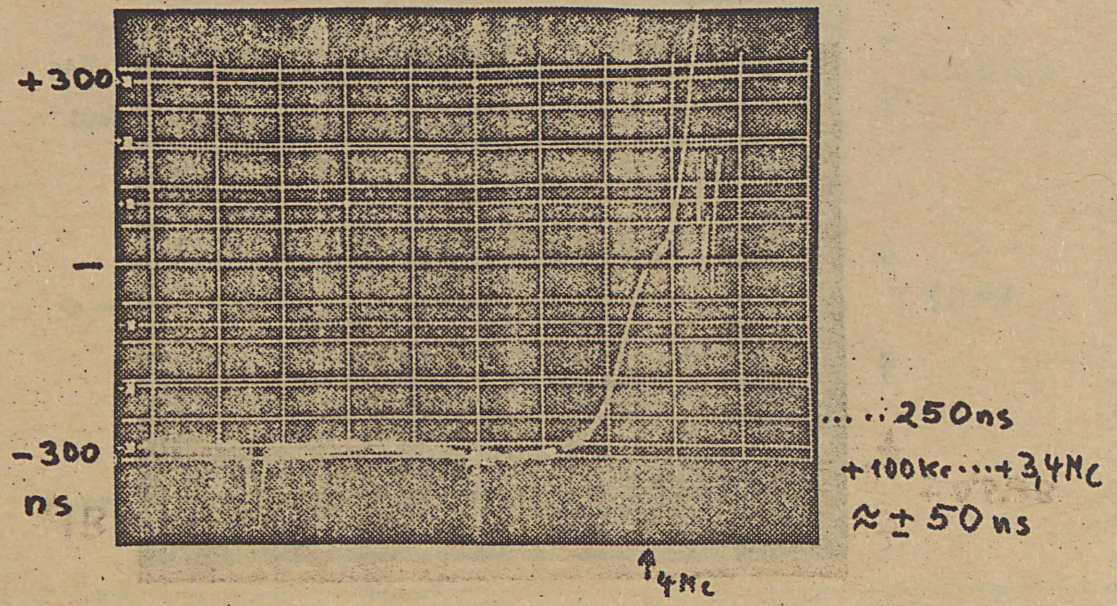
	Video frequency response with sound trap, measured with a video sweep generator and RF modulator; frequency markers 0.5 MHz.	13

TV - Demodulator Type AMF



R/S	Video frequency response without sound trap, measured with a video sweep generator and RF modulator; frequency markers 0.5 MHz.	14

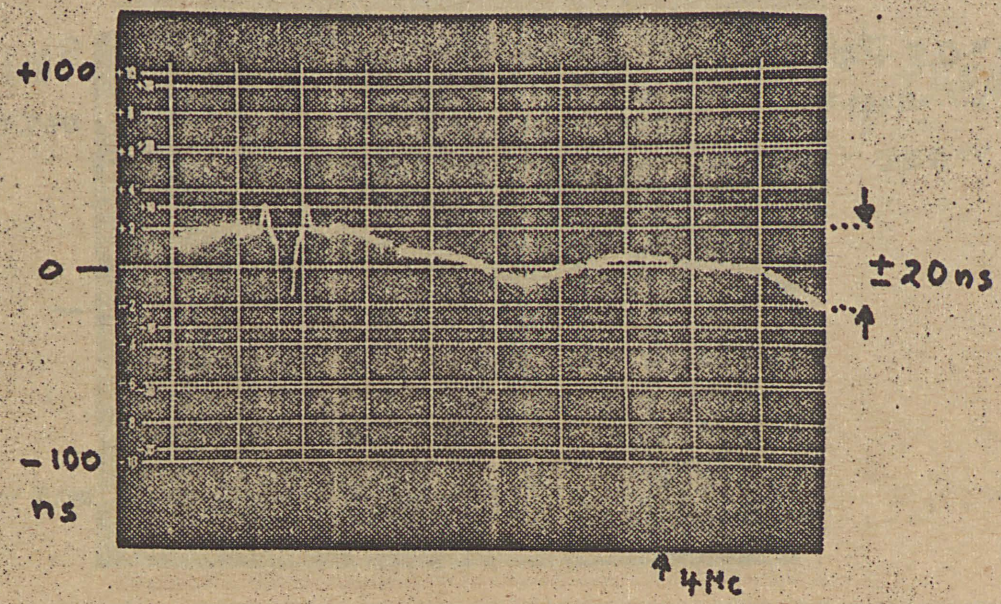
TV - Demodulator Type AMF



Group delay behaviour with sound trap, measured with the LFM Group Delay Test Assembly; marker spacing 1 MHz.

15

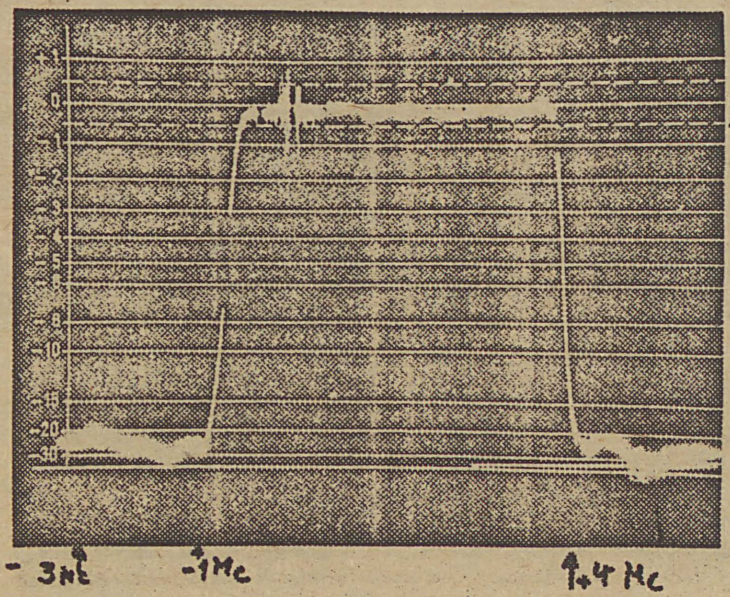
TV - Demodulator Type AMF



Group delay behaviour without sound trap, measured with the LFM Group Delay Test Assembly; marker spacing 1 MHz.

16

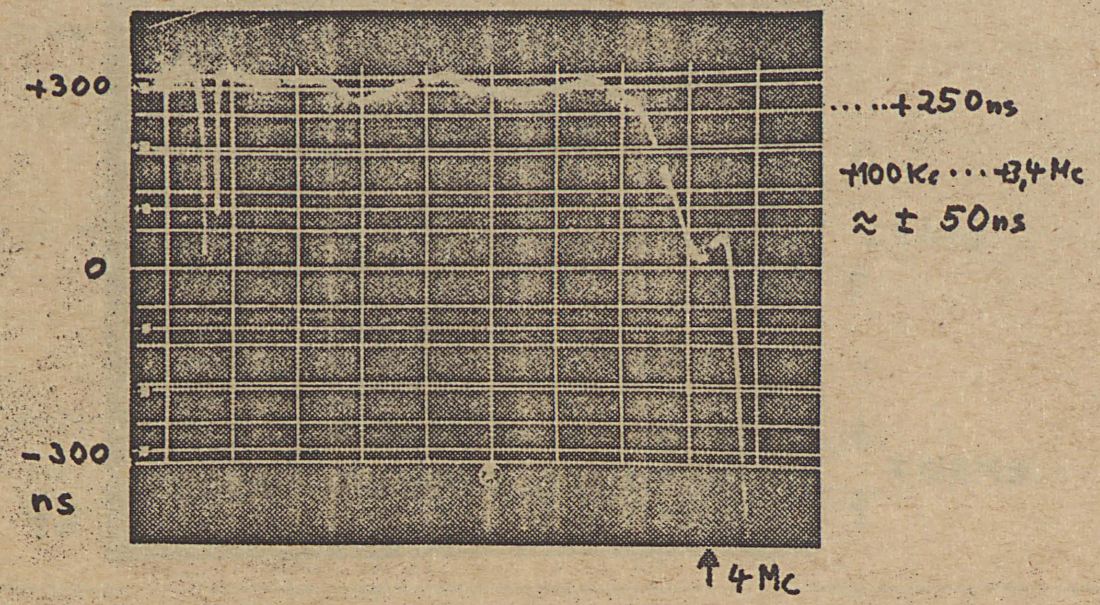
TV - Demodulator Type AMF



TV transmitter response curve, measured with a video sweep generator and sideband adapter; marker spacing 0.5 MHz.

17

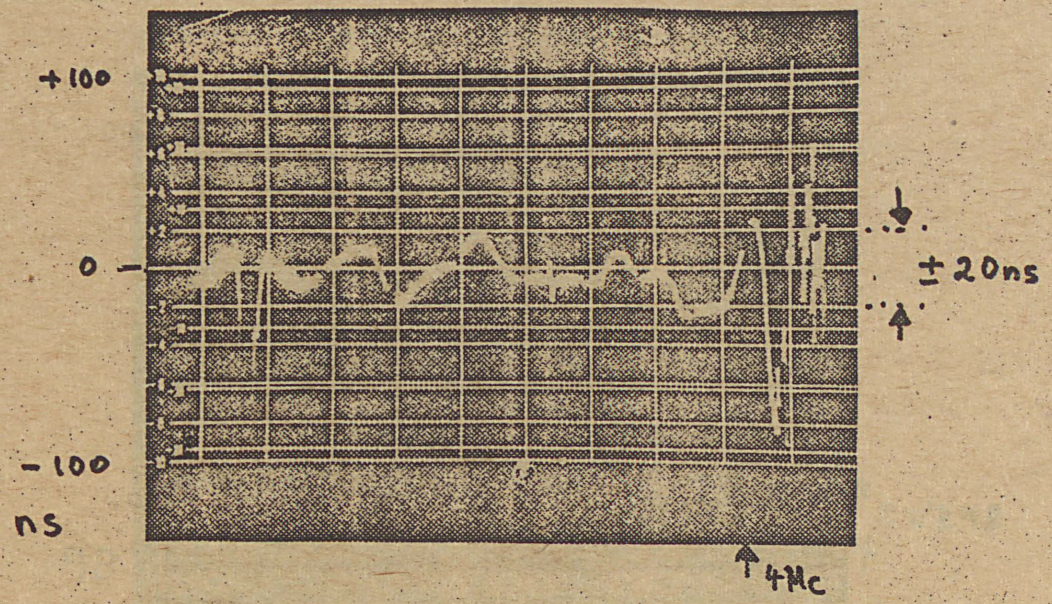
TV - Demodulator Type AMF



TV transmitter group delay behaviour, measured with a TV demodulator without sound trap; marker spacing 0.5 MHz.

18

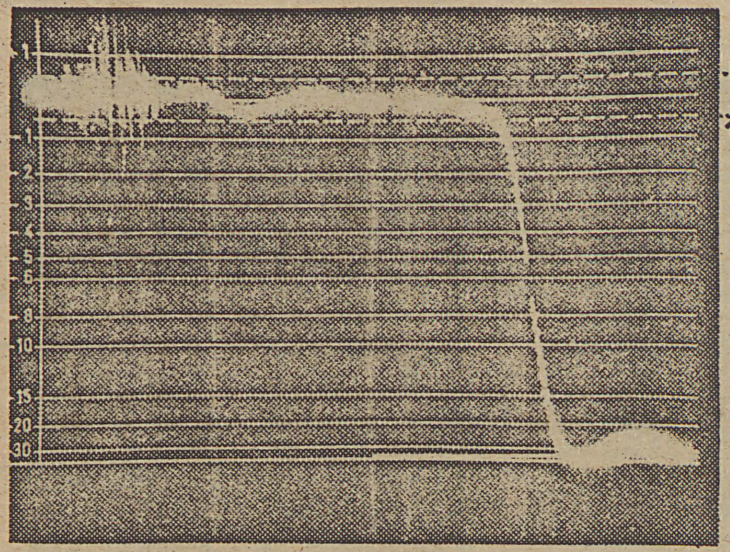
TV - Demodulator Type AMF



TV transmitter group delay behaviour, measured with a TV demodulator with sound trap; marker spacing 0.5 MHz.

19

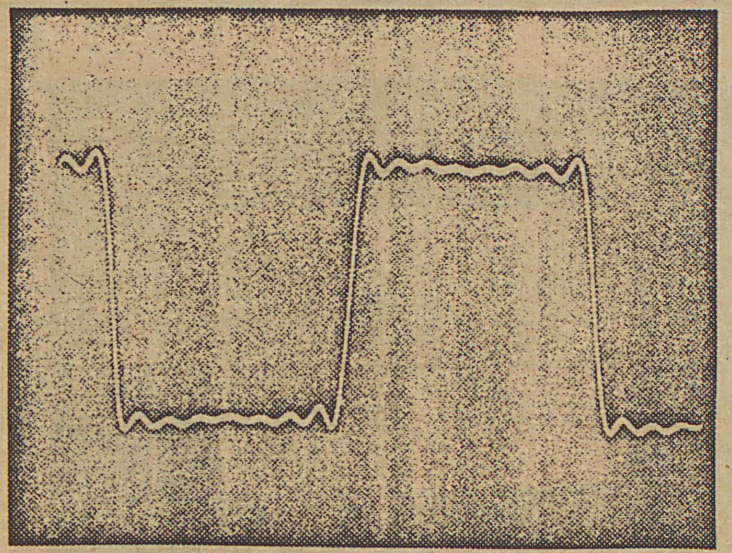
TV - Demodulator Type AMF



Video frequency response of a TV transmitter and AMF, measured with a video sweep generator; marker spacing 0.5 MHz.

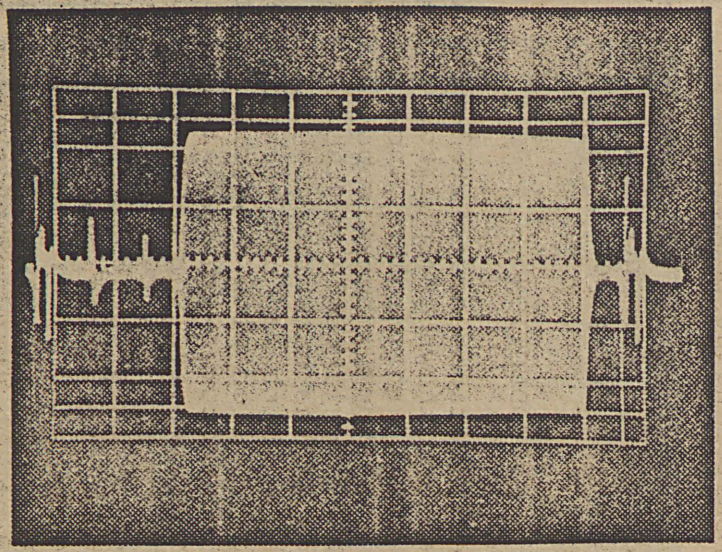
20

TV - Demodulator Type AMF



Transient response of a 250 kHz squarewave (50%/70%), rise time 90 nsec. TV transmitter measured with a TV demodulator. 21

TV - Demodulator Type AMF



Linearity (differential gain) of a sawtooth superimposed with a 3 MHz signal between 10% and 70%. TV transmitter measured with a TV demodulator.

22

FRANK J. RAGONE

Summary - The specifications required to guarantee proper performance of a VHF television modulator or VHF demodulator are relatively well defined. Measurements associated with the specifications are somewhat complex and require techniques and equipment not normally available to Community Antenna Television system engineers.

The traditional video-to-video measurement technique is employed on modulator-demodulator units assigned to terminal applications such as microwave links and head-end processing units. Special measurement techniques are required on units assigned to non-terminal applications such as modulators for local origination and demodulators for monitoring purposes.

The more significant specifications, the performance measurements and the correlation between performance measurements and picture quality will be discussed in the paper.

INTRODUCTION

There are numerous specifications associated with a modulator or a demodulator. An ideal or known demodulator is required to test a modulator, or, conversely, an ideal or known modulator is required to test a demodulator. Although there is no universally accepted starting point, the modulator appeals to the user as the most practical. A major portion of the measurements can be conducted on a video-to-r-f basis; those which can not be conducted on that basis can be conducted in conjunction with a special "ideal" wideband linear detector. The modulator, with "ideal" or "known" specifications, can then become a device for testing a demodulator.

Two unique design concepts incorporated in the Channel Commander Modulator and Demodulator facilitate these measurements and provide for more accurate results. One: the basic modulation or demodulation process, including the required filter passband characteristic, is performed at the standard television intermediate frequency. For the modulator, a selected crystal-controlled i-f to r-f converter provides the desired outgoing channel. For the demodulator, a selected crystal-controlled r-f to i-f converter accepts the desired incoming channel. Two: the units are fabricated on a plug-in module basis employing standard coaxial terminals.

The subjects to be discussed are differential gain, differential phase, envelope delay, amplitude versus frequency, low frequency performance and other performance measurements.

DIFFERENTIAL GAIN AND DIFFERENTIAL PHASE

In color television transmission, differential gain is the change in gain of the 3.58 MHz color subcarrier as the level of the luminance signal on which it rides is varied from blanking to white.

Differential phase is the change in phase of the 3.58 MHz color subcarrier as the level of the luminance signal on which it rides is varied from blanking to white.

Differential gain, expressed in per cent or decibels, causes variations in the purity of reproduced colors. Differential gain data may be expressed as: (1) a function of one of the stated low-frequency levels with the other level arbitrarily fixed, (2) the extreme values of differential gain with respect to that portion of the differential gain function judged to be most nearly constant (plus implies expansion, minus implies compression), or (3) the maximum range of differential gain (difference of extreme values). Figure 1 illustrates examples of differential gain data. It appears to us that the difference of extreme values of differential gain (method 3) is the most practical way of expressing differential gain data.

Differential phase, expressed in degrees, causes variations in portrayal of the hues of reproduced colors. Differential phase data may be expressed as: (1) a function of one of the stated low-frequencey levels with the other stated level at blanking, (2) the extreme values of differential phase with respect to the value at blanking level (plus implies leading phase, minus implies lagging phase), or (3) the maximum range of differential phase (difference of extreme values). It appears to us that the difference of extreme values of differential phase (method 3) is the most practical way of expressing differential phase data.

Differential gain and differential phase are commonly caused by video amplifier circuitry, the basic modulator stage or the basic detector stage.

The basic video signal used to test for differential gain and differential phase consists of a large low-frequency component, such as a 15 kHz sinewave or staircase, on which is superimposed a small high-frequency component, usually a 3.58 MHz sinewave. It is usually desirable to use a test signal containing synchronizing pulses to establish peak output voltage. Typical waveforms are illustrated in Figure 2.

Figure 3 is a simplified block diagram illustrating the measurement of the differential gain of a modulator. In this method, the output signal from the modulator is applied to two tuned r-f voltmeters (FSM 704B). #1 meter is tuned to the video carrier and basically serves to indicate depth of modulation. #2 meter is tuned to the video carrier plus 3.58 MHz and basically serves to indicate differential gain. This measurement correlates with video-to-video measurements conducted with the "ideal" detector. Differential phase measurement of a modulator is made with the "ideal" detector.

With an "ideal" or "known" modulator, the tests can be conducted on a demodulator. For such a video-to-video test, the Western Electric Transmission Test Set 47A (commonly called the Kelly Set) or the Telechrome Test Signal Generator and Receiver is used as illustrated in Figure 4. The set-up is utilized to evaluate differential gain and differential phase versus depth of modulation, operational carrier levels, detector level and video output level.

Commander Modulators are guaranteed to yield a maximum differential gain of 1 dB and a maximum differential phase of 2 degrees. Commander Demodulators are also guaranteed to yield a maximum differential gain of 1 dB and a maximum differential phase of 2 degrees. Units tested in combination yield a differential gain within 1 dB and a differential phase within 2 degrees.

ENVELOPE DELAY

Envelope delay refers to the time of travel of the modulation envelope. Envelope delay does not in itself cause distortion in the video signal. Video distortion results only when envelope delay varies significantly across the passband. A transmission system which introduces envelope delay distortion may alter the time coincidence between the chrominance and luminance portions of the signal or between the luminance carrier and side band components. The former distortion will result in misregistration between the color and luminance components of the reproduced picture and is commonly described as the "funny-paper" effect. The latter distortion will result in "overshoot", "undershoot" or ringing of the video signal. The distortion is commonly caused by rapid or severe changes in the passband characteristic of a system.

Envelope delay measurements can be performed with a Rhode and Schwarz Group Delay meter which consists of the following: a Model BN 17950 Modulator/Demodulator and Indicator, and a Model BN 17951 r-f Modulator. The measurements can be performed on a video-to-r-f basis, an r-f-to-video basis or a video-to-video basis.

The envelope delay characteristic of a typical commercial TV receiver has been established as a starting point.

When a modulator is used for local origination in a CATV system, it has the same function in overall picture transmission as has the TV transmitter in a broadcast system. The FCC has established requirements on the envelope delay characteristics of a TV transmitter based on predistortion to compensate for the envelope delay distortion of the "receiver". Figure 5 illustrates the required envelope delay predistortion and tolerances. The center line represents the reciprocal of the envelope delay characteristic of the receiver and the upper and lower lines represent the tolerable limits.

The FCC requires that the envelope delay, relative to the average envelope delay between 0.05 and 0.20 MHz, shall be zero nanoseconds up to a frequency of 3.0 MHz and then linearly decrease to 4.18 MHz so as to be equal to -170 nanoseconds at 3.58 MHz. The FCC requires that the tolerance on the envelope delay shall be ± 50 nanoseconds at 3.58 MHz. The tolerance shall increase linearly to ±100 nanoseconds down to 2.1 MHz, and remain at ± 100 nanoseconds down to 0.2 MHz (tolerances for the interval of 0.0 to 0.2 MHz are not specified at the present time). The tolerance shall also increase linearly to ± 100 nanoseconds at 4.18 MHz.

In practice, the modulator provides both the standard predistortion as well as the corrective predistortion for delay errors generated in the unit.

Figure 6 illustrates the envelope delay versus frequency characteristic of a Commander Modulator. The measured characteristic is within ± 20 nanoseconds of the required characteristic. Figure 7 illustrates the envelope delay versus frequency characteristic of a Commander Demodulator. The measured characteristic is within ± 70 nanoseconds to 4.1 MHz, approaching + 100 nanoseconds at 4.18 MHz.

AMPLITUDE VERSUS FREQUENCY

The present television vestigial sideband system is based on a specific transmitter-receiver relationship. Figure 8 illustrates the idealized lower sideband response of a modulator and demodulator. At the modulator, the frequencies ± 0.75 MHz about the video carrier basically represent a double-sideband transmission system and the frequencies at + 0.75 MHz and above basically represent a single-sideband transmission system. The demodulator shall exhibit a vestigial slope characteristic ± 0.75 MHz about the video carrier and uniform response at 0.75 MHz to 4.18 MHz. The vestigial slope characteristic is required to provide uniform response of upper and lower sideband pairs at the output of the video detector.

Constant gain of the overall system is required to guarantee proper reproduction of signal waveforms. Low frequency gain changes can cause streaking and high frequency gain changes can cause loss of detail, spiking or ringing. In a color system, it is necessary to maintain constant gain to 3.58 MHz to ensure proper color saturation. In fact, it is necessary to maintain flat response to 4.18 MHz to maintain symmetrical amplitudes of upper and lower sidebands of the color subcarrier.

Experiments have shown that a smooth 6 dB tilt variation in a TV channel is not detrimental, but discrete variations within a narrow pass band can contribute to picture degradation. A modulator or a demodulator should exhibit a constant gain characteristic consistent with other characteristics such as low frequency response (overlapping region of modulator and demodulator attenuation characteristic) and high frequency cut-off (spiking and ringing).

Figure 9 illustrates the assumed ideal detected output of a vestigial sideband modulator. The FCC has defined the overall attenuation characteristic of a transmitter as follows: with respect to a signal produced by the amplitude of a sine wave of 200 kHz, the amplitude of a 0.5 MHz signal shall not be greater than 2 dB below the ideal curve, the amplitude of a 1.25 MHz signal shall not be greater than 2 dB below and the amplitude of a 2.0 MHz signal shall not be greater than 3 dB below. The amplitude of a 3.58 MHz signal shall be down 6 dB ± 2 dB. In addition, between the modulating frequencies of 2.1 and 4.1 MHz, the amplitude of the signal shall not vary more than ± 2 dB from its value at 3.58 MHz. At the modulating frequency of 4.18 MHz, the amplitude of the signal shall not be down more than 4 dB below its value at 3.58 MHz.

The amplitude versus frequency characteristics of the modulator can be obtained by standard sweep frequency displays of the individual modules which comprise the unit: (1) a delay equalizer and pre-distortor module, (2) a double sideband i-f modulator unit, (3) a vestigial sideband filter assembly, and (4) an i-f to VHF channel converter module. For a final overall performance evaluation, the attenuation characteristic of the modulator may be measured by applying a constant-amplitude variable-frequency signal, including synchronizing pulses, at the video input terminal and measuring the signal voltage produced at the output of a wideband linear detector. A spectrum analyzer can be used at the output terminal in place of the wideband linear detector, assuming voltage addition of both sideband pairs in the vestigial portion of the channel.

The amplitude versus frequency characteristic of the demodulator can be obtained by standard sweep frequency displays of the individual modules which comprise the unit: (1) a VHF to i-f channel converter module, (2) an i-f filter assembly, (3) an i-f amplifier module, and (4) an i-f demodulator module. The i-f portion of the demodulator module, including the low frequency (60 Hz) response of the detector and video amplifier, is measured with a sweep frequency display. The detector-video portion is measured by using a known or measured modulator as a source.

Thus, with a modulator as a starting point, the demodulator can be evaluated. The user then can rely on a final video-to-video test measurement, including the multi-burst signal, and other standard test signals.

PASSBAND CONSIDERATION

Figure 10 illustrates the overall passband characteristic of a commercial transmitter as defined by the FCC. With reference to the amplitude of a 200 kHz modulating frequency, the amplitude of a lower sideband modulating frequency of 1.25 MHz or greater shall not be greater than -20 dB and, for color, the amplitude of a

lower sideband modulating frequency of 3.58 MHz shall not be greater than -42 dB. The amplitude of an upper sideband modulating frequency of 4.75 MHz shall not be greater than -20 dB.

The curve plotted on Figure 10 shows the response of our modulator. You can see that this response falls above FCC limits at -1.25 and +4.75 MHz with respect to the video carrier.

This deviation represents a design compromise which should be explained. Since the filters in a small modulator like this handle very little power, they are very inexpensive compared to the units required for a broadcast transmitter. It would be quite easy and not expensive to increase the selectivity of the filter so that it would meet FCC requirements for a transmitter. Because of the increased selectivity, the envelope delay response would be seriously degraded. The situation could be improved by using very elaborate phase equalizers similar to those used in a broadcast transmitter, but the cost of these circuits would be, in our opinion, excessive for a unit selling into our market.

By allowing the more gradual slope illustrated here, we can get a very acceptable group delay performance. Extensive subjective tests have convinced us that in a system where these modulators are operated on adjacent channels, no visible interference results from this compromise.

LOW FREQUENCY PERFORMANCE

Sweep frequency displays do not guarantee the low frequency performance of a transmission system. Streaking, caused by transmission distortions in the frequency region up to about 200 kHz, appears as a luminance error extending horizontally toward the right edge of the picture from that point in the picture marked by a sharp transition in luminance. Smearing, a distortion similar to streaking, appears as a blurring of the vertical edges of objects in the scene.

To guarantee proper low frequency performance, a 60 Hz square wave is applied to the input terminal of a modulator and observed at the output terminal of a demodulator. The amplitude variations of the square wave, in the form of tilt or sag, are limited to 1% maximum as illustrated in Figure 11.

OTHER PERFORMANCE MEASUREMENTS

There are, of course, other measurements which can be conducted on modulators and demodulators to guarantee performance. The tests, such as multiburst signal, window signal, sine-squared pulse and RETMA test pattern, are commonly associated with units in combination or with a total system performance.

Sine-squared pulse testing is perhaps the most commonly used of several wave-form type performance checks. The sine-squared pulse can be considered to represent a picture element whose amplitude represents a transition from black to white level. If the half-amplitude width of a sine-squared pulse is equal to the reciprocal of the high frequency limit (i.e. a 1/4 microsecond width for a 4 MHz system; designated as a "2T-pulse"), then any amplitude or delay distortion within that bandwidth will distort the pulse since its entire frequency spectrum is contained within the system bandwidth.

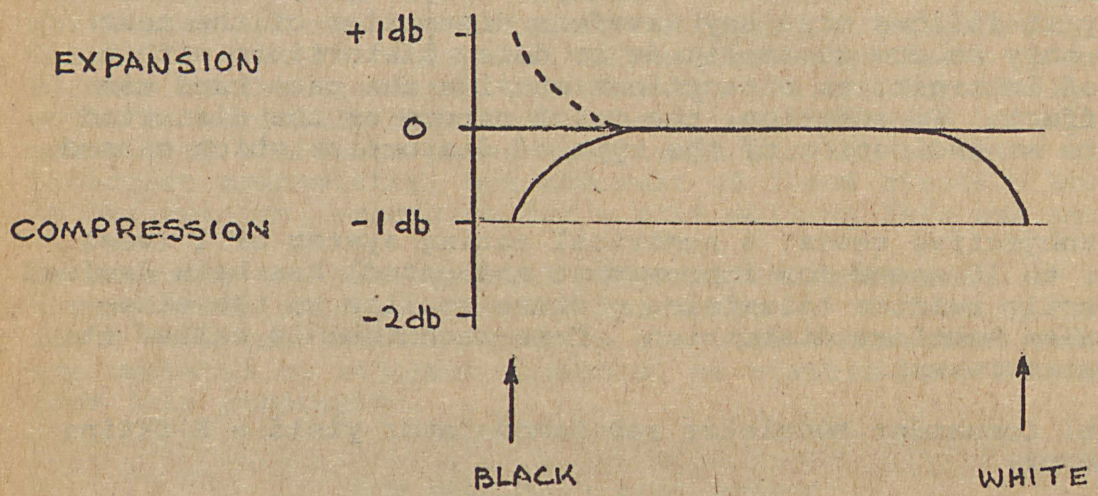
Conversely it follows that any waveform distortion of the test pulse can only be due to amplitude or delay distortions within the band of interest, as distortions outside the pass band can have no effect. In addition, the exact nature of the distorted waveform is an indication of the type of distortion which caused it.

Based on subjective tests, a numerical rating system of 1 (most desirable) to 10 (need for improvement indicated) has been devised which directly relates television picture quality to the sine-squared pulse waveform distortion. This technique is called the K rating measurement.

The Channel Commander Modulator and Demodulator yield a K rating of 3 or lower.

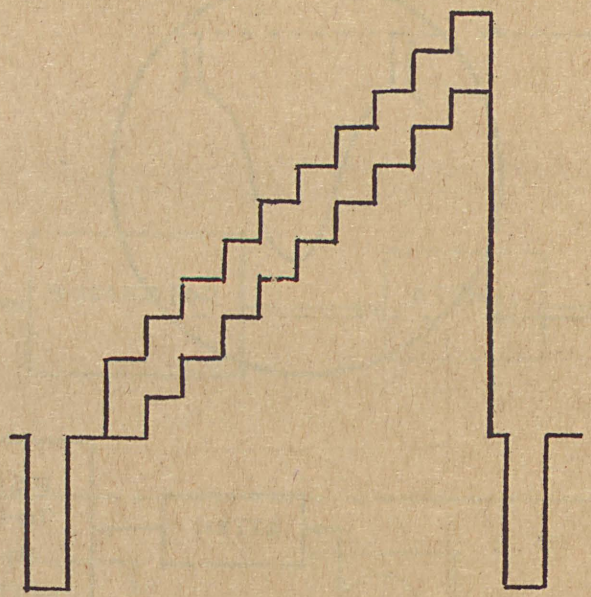
CONCLUSION

To accept composite television video signal and provide a standard vestigial sideband signal or, to accept a standard vestigial sideband signal and provide composite television signal requires the ultimate in performance. Many specifications are required to guarantee this performance, of which the most significant are differential gain, differential phase, envelope delay, 60 Hz square-wave tilt or sag and amplitude versus frequency.

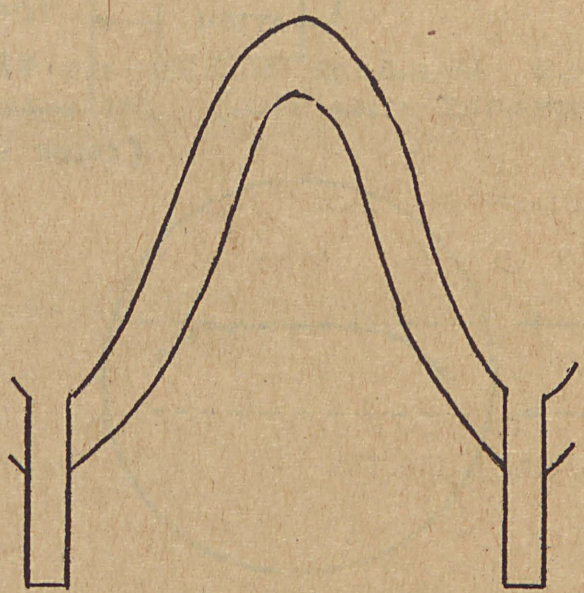


1. 0 dB BLACK LEVEL WITH RESPECT TO WHITE LEVEL
2. -1.0 dB WITH RESPECT TO MOST LINEAR PORTION
3. 1.0 dB MAXIMUM

FIG. 1 - EXAMPLES OF DIFFERENTIAL GAIN DATA



a. STAIRCASE SIGNAL - 3.58 MHz SUPERIMPOSED



b. SINUSOIDAL SIGNAL - 3.58 MHz SUPERIMPOSED

FIG. 2 - EXAMPLES OF TEST SIGNALS

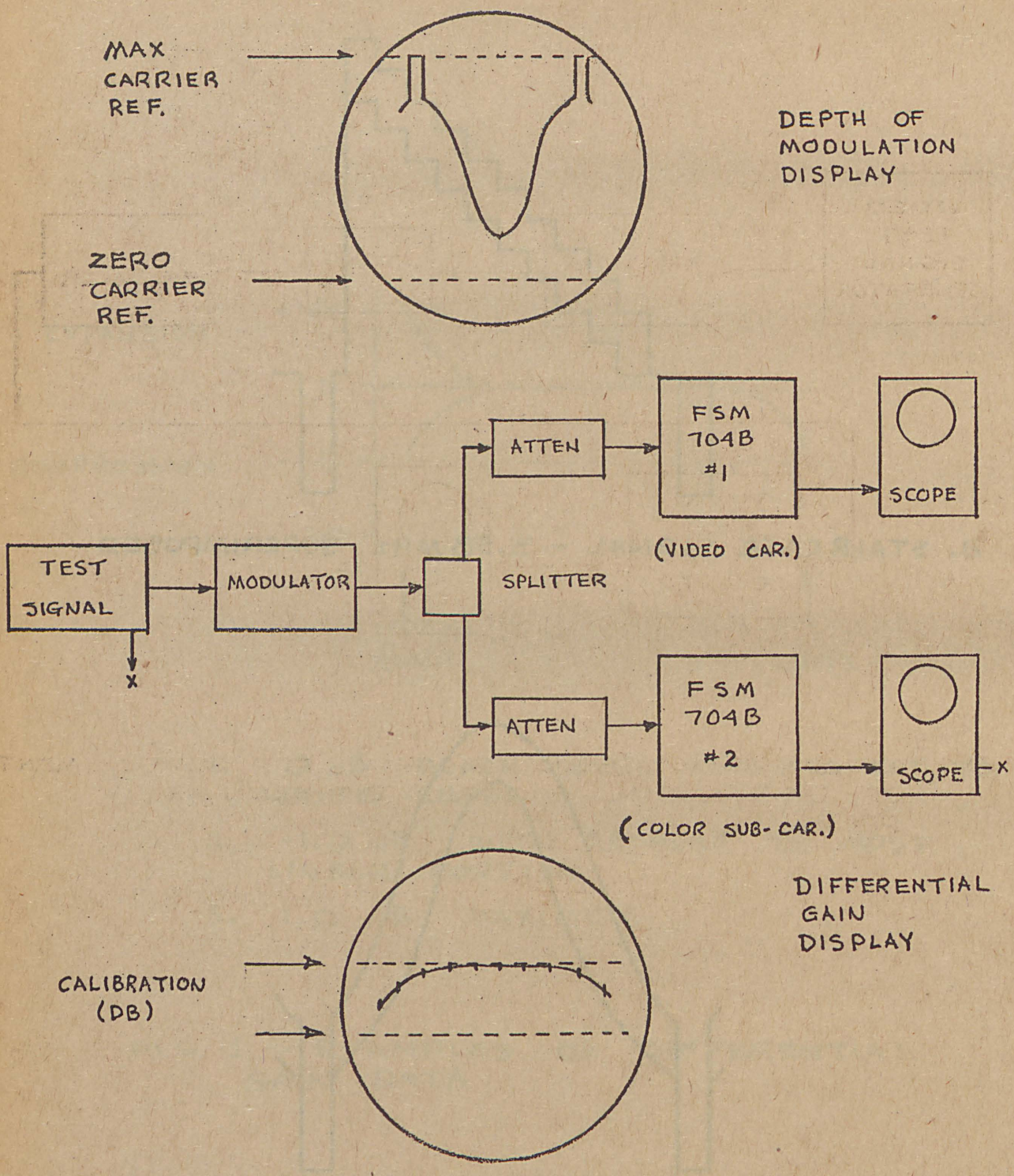


FIG. 3 - MEASUREMENT OF DIFFERENTIAL GAIN OF MODULATOR

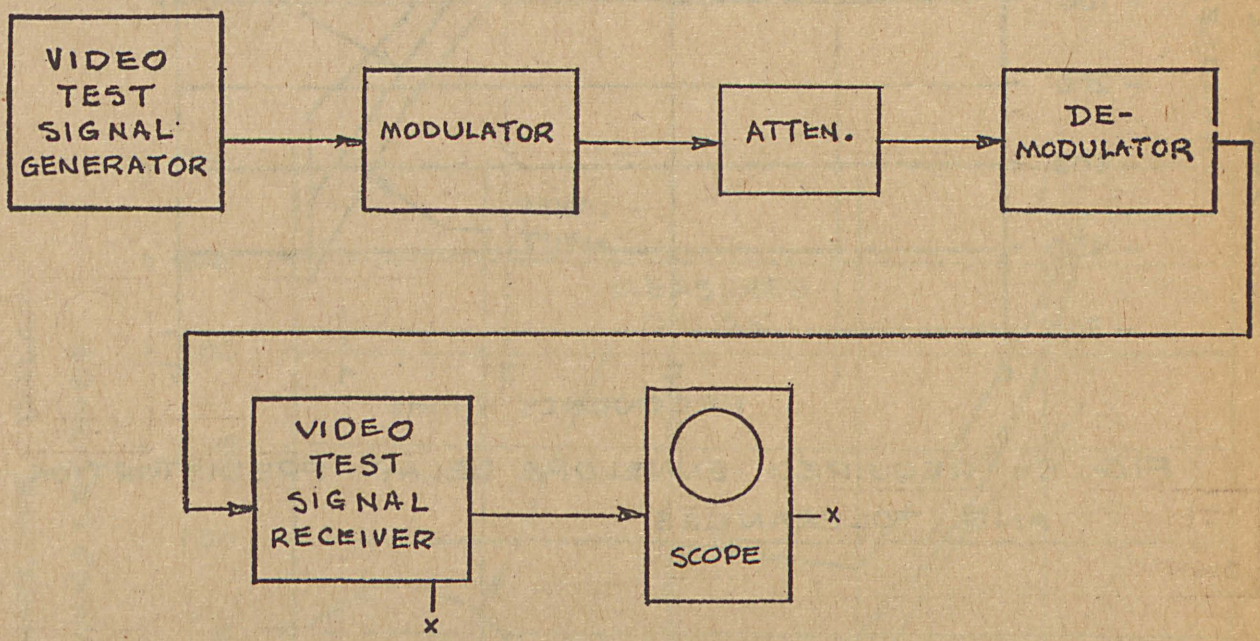


FIG. 4 - SIMPLIFIED BLOCK DIAGRAM FOR MEASUREMENT OF DIFFERENTIAL GAIN AND DIFFERENTIAL PHASE

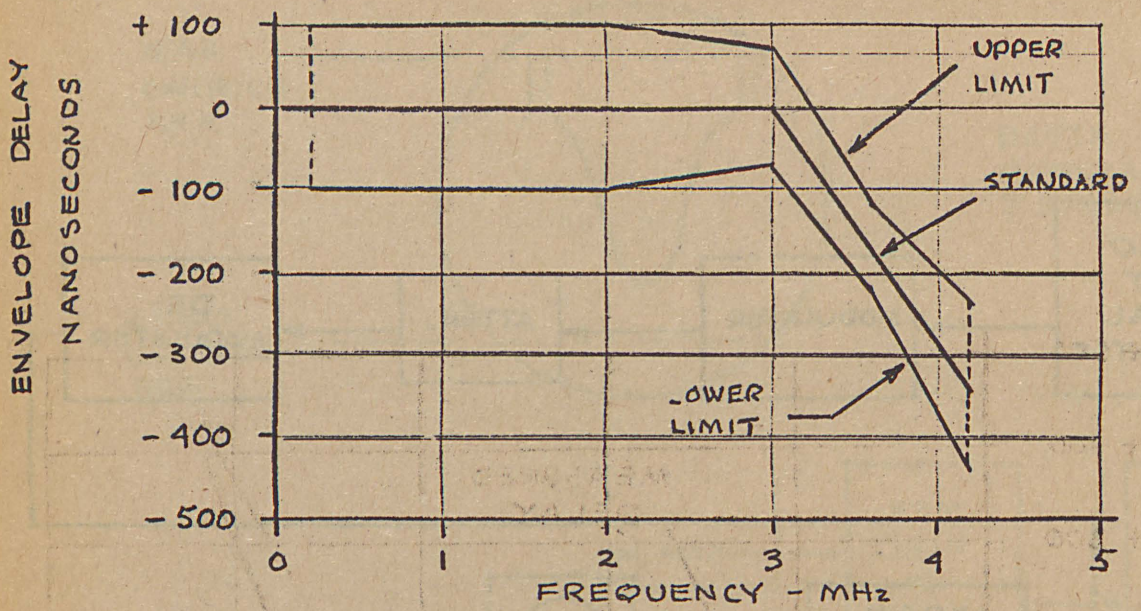


FIG. 5- REQUIRED ENVELOPE DELAY PREDISTORTION AND TOLERANCES

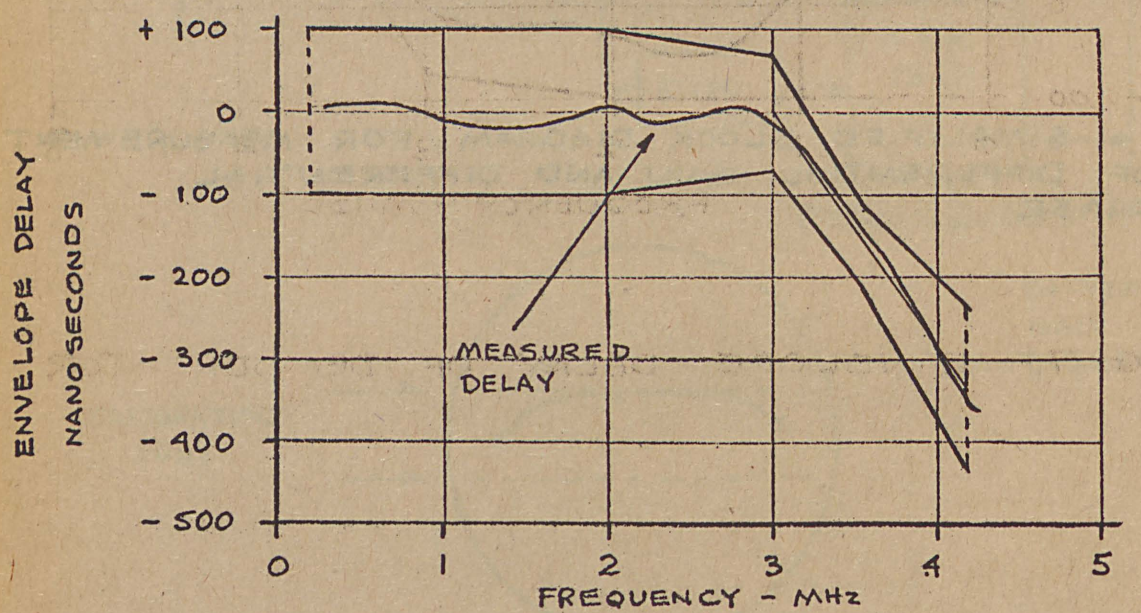


FIG 6- ENVELOPE DELAY OF MODULATOR

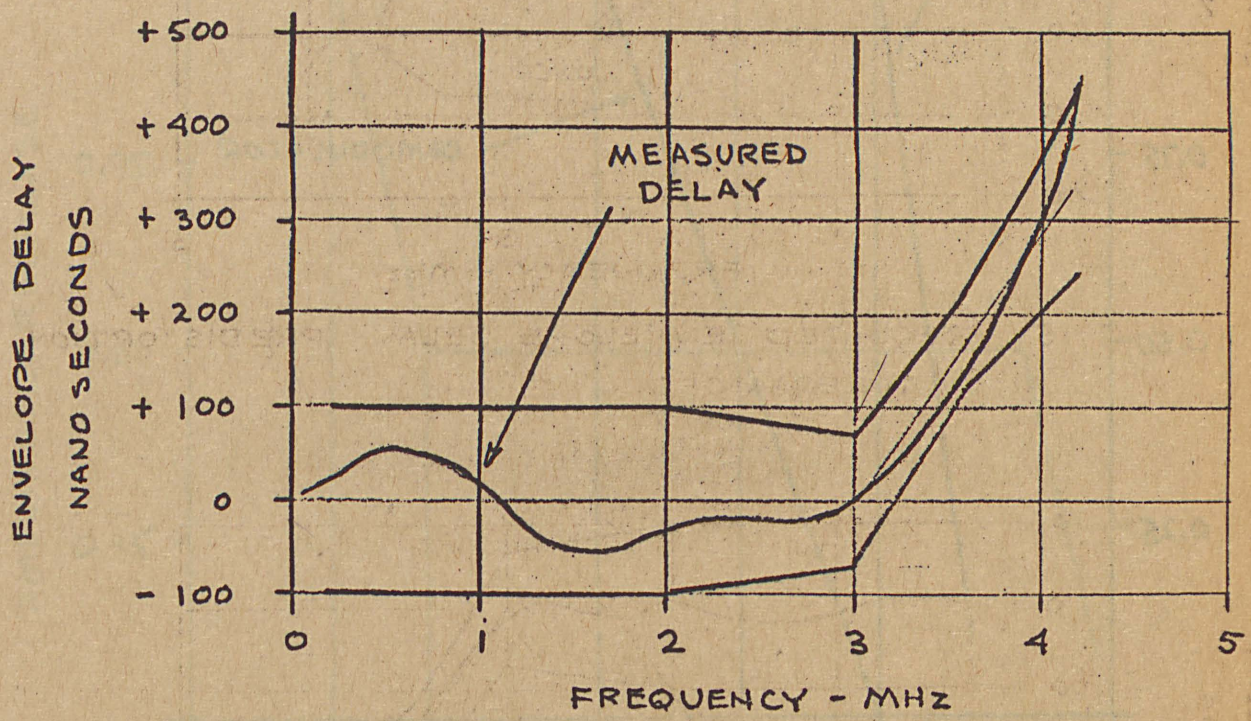


FIG. 7 - ENVELOPE DELAY OF DEMODULATOR

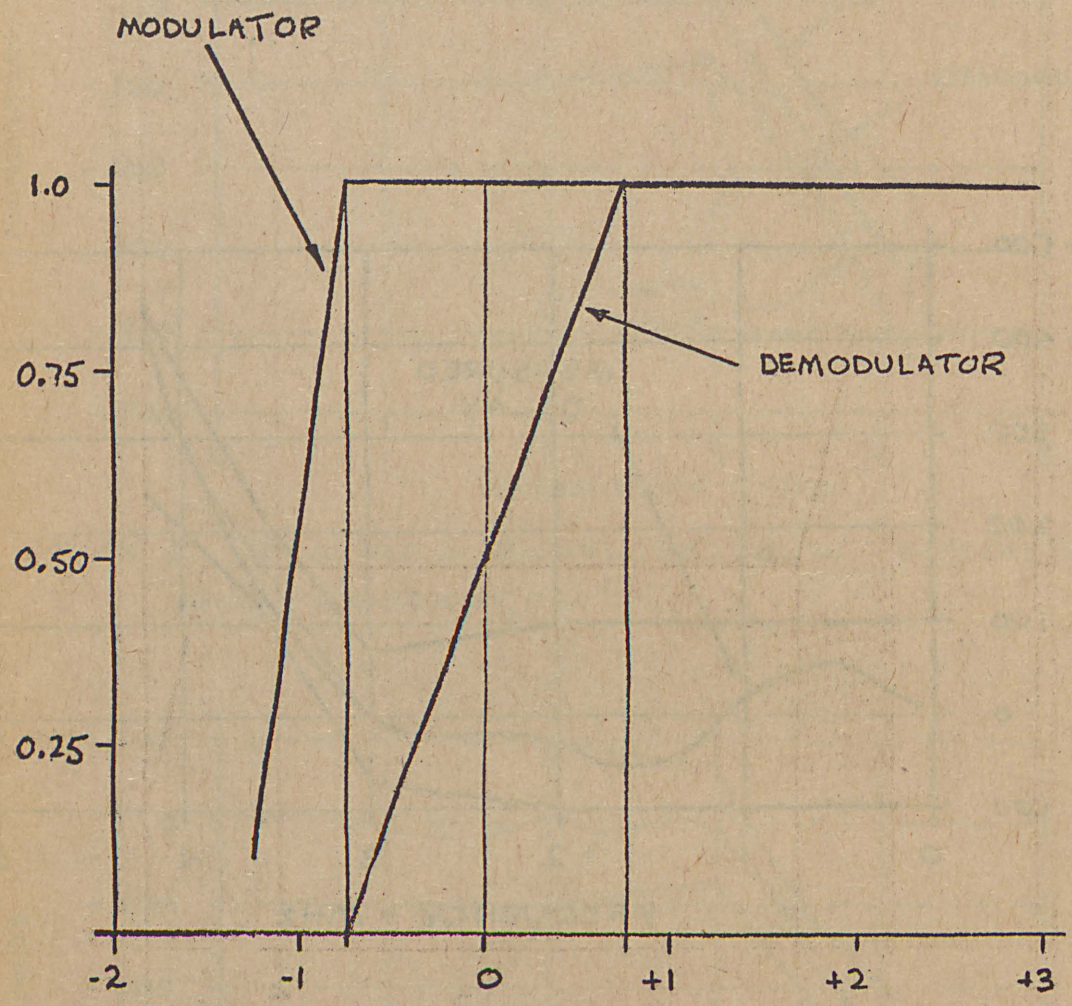


FIG. 8 - IDEALIZED LOWER SIDEBAND RESPONSE OF MODULATOR AND OF DEMODULATOR

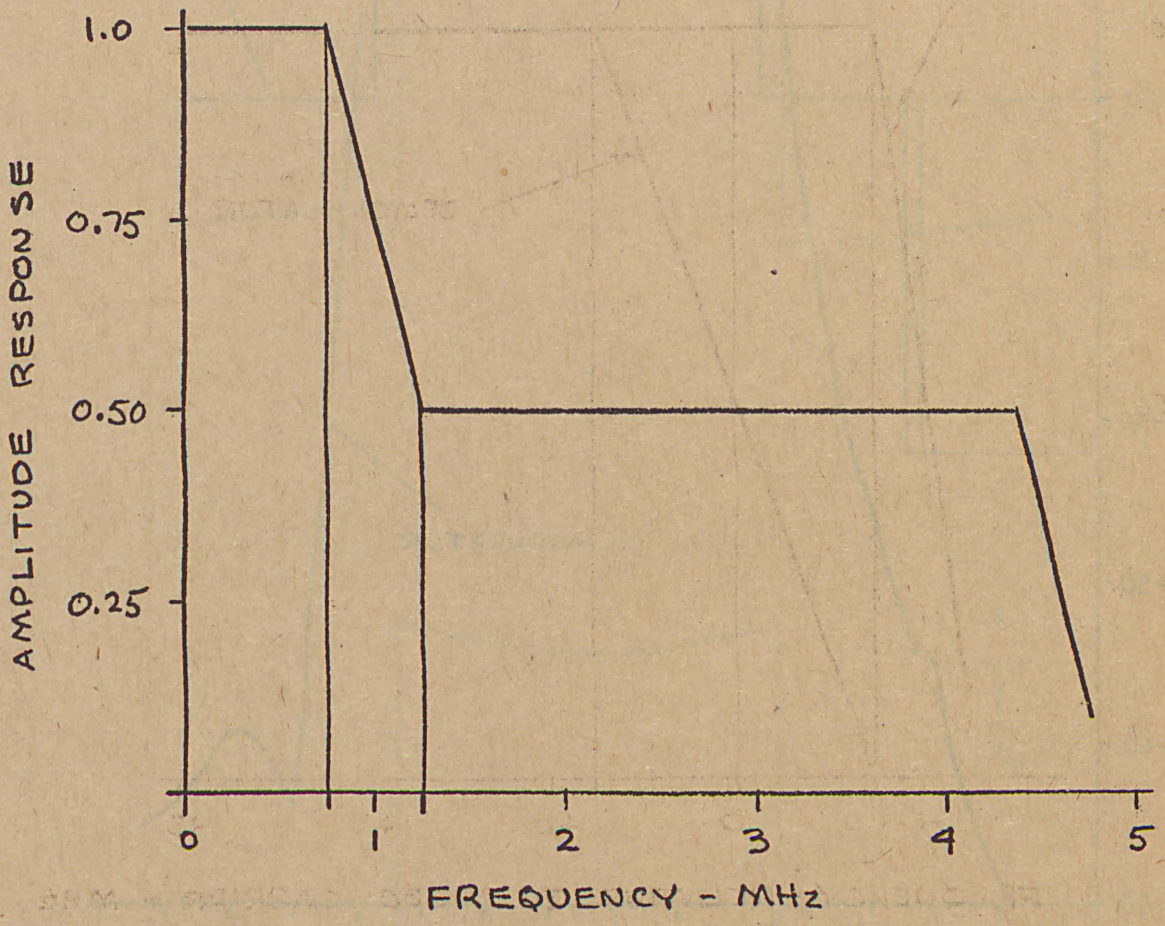


FIG. 9 - DETECTOR OUTPUT OF VESTIGIAL SIDEBAND MODULATOR

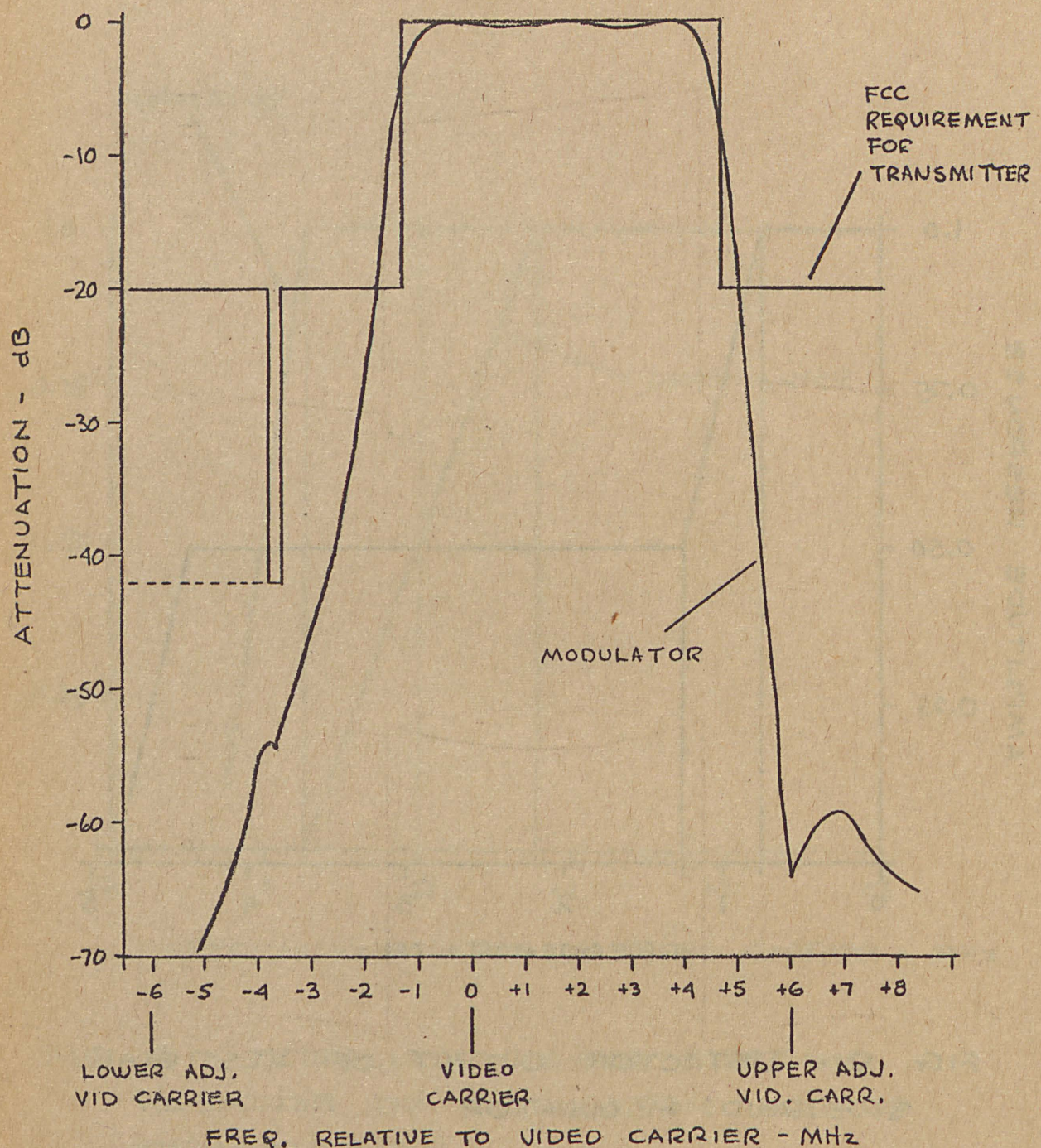


FIG. 10 - SIDEBAND RESPONSE OF MODULATOR

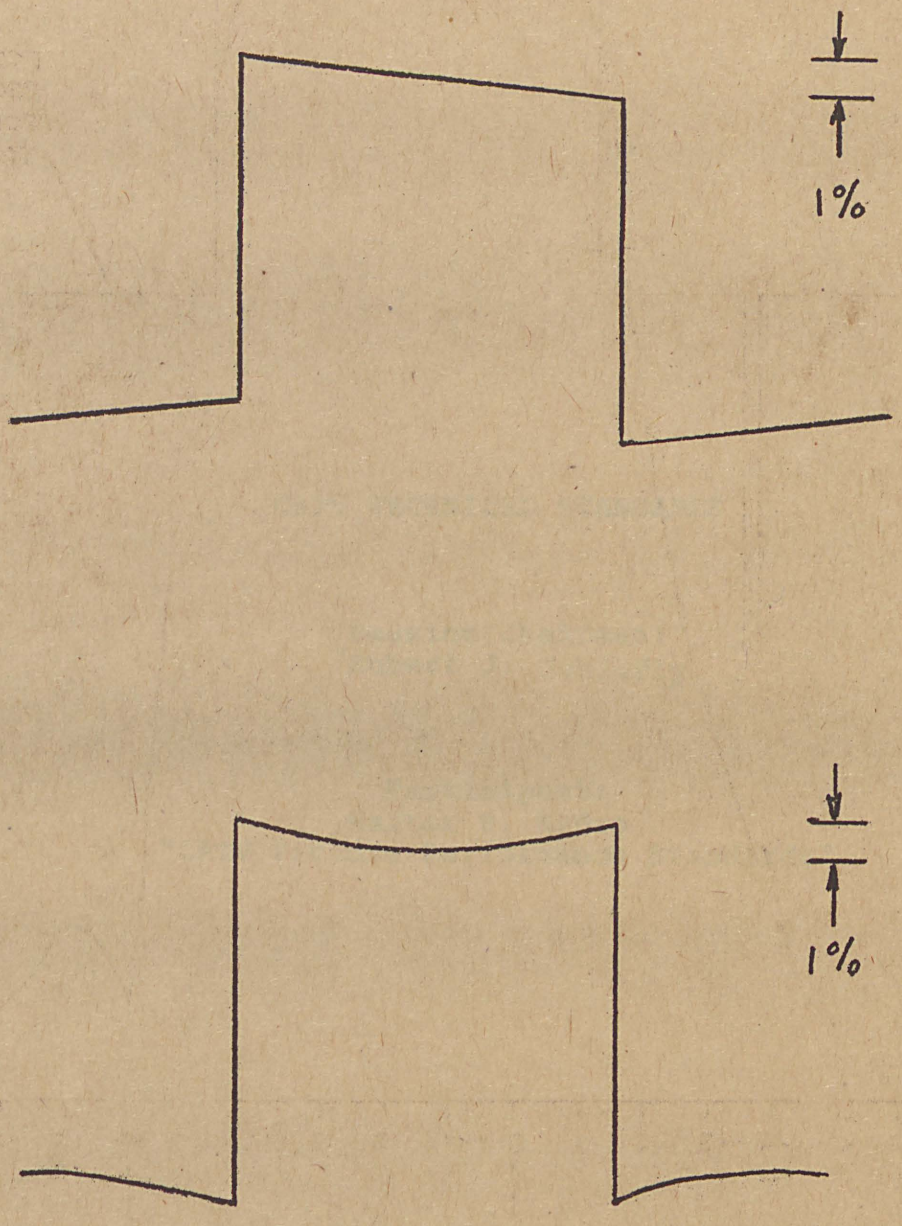


FIG. 11 - EFFECT OF TRANSMISSION SYSTEM ON A 60 Hz SQUAREWAVE TEST SIGNAL

THE COAXIAL CABLE

Session Chairman:
James W. Stilwell

Participants:
H. Lubars and J. A. Olszewski
"Analysis of Structural Return Loss in CATV Coaxial Cables"

Jack Arbuthnott, Jr.
"Dynafoam Coaxial Cable"

Ronald D. Lowe
"TDR - Theory and Cable Fault Locating"

Bert Arnold
"Surge Protection in CATV Amplifiers"

H. LUBARS AND J. A. OLSZEWSKI

I. INTRODUCTION

Coaxial cables in CATV systems transmit the video and audio information from one location to another. Ideally the cable should not affect these signals in any way. However, in reality this is not physically realizable because the signals are affected by the propagation characteristics of the cable. If in addition, the cable is non-uniform along its length, the irregularities cause reflections which in turn further alter the transmitted signals.

The effects on the signal due to propagation characteristics of a given CATV cable are known and can be easily corrected by auxiliary equipment. However, signal changes due to structural irregularities are unpredictable and cannot be easily compensated in the system. Low levels of this type of distortion are essential for proper operation of a CATV system.

The structural changes along the cable length can take the form of:

1. A localized change or changes causing echo phenomena.

2. Randomly distributed changes of random size persisting throughout the cable length causing reflections which do not add in phase.

3. Periodic changes of minute magnitude uniformly distributed along the cable length, the magnitude of changes being essentially equal from period to period due to the nature of the manufacturing process, causing reflections which will add in phase at certain frequencies. The signal strength relationship of the reflected wave to the incident wave is commonly referred to as structural return loss (SRL).

The first two types of structural irregularities were discussed at length in references 1 through 7.

The purpose of this paper is to present a study of the SRL phenomenon pertaining to coaxial cables in the CATV frequency spectrum. Basic equations are developed and used to determine the relationships of signal frequency and length of non-uniformity to magnitude of reflection of the fundamental frequency and integral multiples thereof (harmonics). Consideration of the practical aspects are given by analyzing the effect of periodic changes in the physical structure of the cable components. Also discussed are measuring principles and techniques presently in use by the industry; fixed versus variable terminations; narrow versus wide band testing; and the accuracy of the measurement that can be expected.

II. PHENOMENON OF SRL

In the Appendix of this paper, equations are derived which are used to study the SRL phenomenon. These equations are based on the following assumptions:

(a) the line discontinuities or irregularities are discrete (abrupt),

(b) the two sections (ℓ_1 and ℓ_2) forming a period are repeated throughout the cable length,

(c) the effects of higher order reflections are negligible.

In (a) above, it is assumed that the irregularities are abrupt, even though this may not always be the case. In general, minute changes tend to be sinusoidal as can be seen in Figure 1, while more pronounced changes are often abrupt, as can be seen in Figure 2. It is recognized that a Fourier analysis would be more appropriate for sinusoidal changes[2], however, for relatively simple period forms, assumption (a) should hold very closely because in the model (see appendix) the maximum and minimum impedances characterize the mean changes of the cable irregularities.

Assumption (b) stems in part from practical experience. Cyclic contributions of some components of manufacturing equipment tend to cause longitudinal non-uniformities that are relatively uniform both in magnitude and period.

With regard to assumption (c), data are presented in the Appendix which show that reflections can be neglected without affecting the engineering accuracy of the results. For a reflection coefficient of 0.05, such as a periodic mismatch of 68 ohms to 75 ohms, which would be large from an SRL standpoint, the error cannot be greater than ± 0.45dB.

The general equation for the total reflected voltage for a single periodicity is:

$$V_e = \frac{X R' \sin \omega\phi \,[1 - K^2 \cos \omega\zeta][1 - K^{2(n+1)} \cos (n+1)\,\omega\zeta] + K^{2(n+2)} \sin \omega\zeta \sin (n+1)\,\omega\zeta}{1 - 2K^2 \cos \omega\zeta + K^4}$$

$$- \frac{X R' \cos \omega\phi \, K^2 \sin\omega\zeta [1 - K^{2(n+1)} \cos (n+1)\,\omega\zeta] - [1 - K^2 \cos \omega\zeta]\, K^{2(n+1)} \sin (n+1)\,\omega\zeta}{1 - 2K^2 \cos \omega\zeta + K^4}$$

$$+ X R' \cos \omega\phi$$

This equation, however, can not be examined with ease because of the time functions. Therefore, by considering resonant points, i.e. SRL spikes, the equation for the magnitude of the total reflected voltage is:

$$|V_e| = X R' \frac{(1 - K^{2n})}{(1 - K^2)}$$

The symbol X in the above equation represents the magnitude of the incident voltage, R´ the magnitude of the resultant reflected voltage vector due to one period, K the change in incident voltage magnitude caused by one period, and n the number of periods in the line under study. As shown in the Appendix, resonances occur when the period length is equal to half wavelength ($\lambda/2$) and integral multiples of half wavelength.

The above relationship shows that the magnitude of the reflected voltage is a function of:

1. The magnitude of the incident voltage,
2. The magnitude of irregularities or reflection coefficient ρ,
3. The line attenuation α,
4. The length of line or the number of periods n,
5. The length of irregularity or asymmetry of the period.

The effect of the first four variables is self-evident. The mechanism of the fifth is more complex and will be described in greater detail. It determines the magnitude of the resultant reflected voltage at resonant frequency and the magnitudes of the harmonic frequencies.

It is shown in the Appendix that, under resonance conditions, the reflections from each of the two discontinuities in a period, and consequently from all the discontinuities in the line, arrive at the input and add exactly in phase only when the period is symmetrical, i.e. $l_1 = l_2$ or $\omega t_1 = \omega t_2$. This represents the condition for maximum SRL spike.

Symmetrical periods are recognizable by the absence of SRL spikes of even multiples of the fundamental resonant frequency and the presence of odd multiples or odd harmonics as shown in Figure 3.

The deviation from period symmetry causes the voltages to arrive at the cable input out of phase. As the l_1/l_2 ratio is decreased or increased from the condition of unity, as shown graphically in Figure 3, the resultant voltage decreases in magnitude and becomes practically insignificant when the extent of discontinuity (l_2) becomes either very small or very large.

The magnitude of the reflections of the harmonic frequencies are affected by the change in symmetry of the period. For example, when the asymmetry of the period is 25/75 or 75/25, a pronounced reflection of second harmonic frequency results. The reflections of the fundamental and third harmonic are of lesser magnitudes, and there is no reflection of fourth harmonic. Thus, the length and type of period gives the location of the SRL spikes in the frequency spectrum. Also, depending upon the asymmetry of the

irregularity period, the SRL spike due to the fundamental frequency can be of a lesser amplitude than the spikes caused by the harmonics. For this reason, these frequencies are sometimes misinterpreted as sub-harmonics.

It is also apparent that if the input end of the line is uniform and the irregularities exist further down the line, the difference between the magnitude of the fundamental frequency and of the harmonics will increase with length of undistorted input end. If the difference is greater at one end than it is at the other, then the end exhibiting the greater difference is relatively free from discontinuities.

The magnitude of the reflected voltage varies sinusoidally if the line contains only one period. Maximum values will occur at the fundamental resonant frequency and its multiples. In reality, however, the line contains more than one period and the variation in reflected voltage is no longer sinusoidal. The magnitude at resonances will be higher by the factor

$$\frac{1 - K^{2n}}{1 - K^{2}} .$$

At other frequencies, reflections from successive periods have a constant phase shift and the resultant amplitude is significantly reduced. Thus, the longer the line, the narrower are the affected frequency bands or the SRL spikes.

The SRL expressed in decibels is defined as:

$$SRL = 29 \log_{10} \frac{V \text{ (reflected)}}{V \text{ (incident)}} .$$

However, the SRL measurement generally performed throughout the CATV industry (described in Section IV) assumes that the incident voltage is constant and is equal to a portion of the voltage applied to the r-f bridge. Therefore, the SRL as measured by the industry is:

$$SRL = 20 \log_{10} \frac{V \text{ (reflected)}}{V \text{ (reference)}}$$

Small errors result when the cable under test deviates from 75 ohms nominal average impedance. The equation for SRL for small expected values of ρ at resonance is:

$$|SRL| = 20 \log_{10} R' \frac{1 - K^{2n}}{1 - K^{2}} .$$

This equation was used to determine length relationships versus change in SRL for the various cable types used in CATV systems and are shown in Figures 4-7. The family of curves in each figure shows the relationship for frequencies up to 300 MHz. In theory,

length relationships are a function of the irregularity p. However, since actual values are of a very low order of magnitude (approximately 0.0002), the family of length relationship curves can be considered as independent of this parameter. These curves can be interpolated for intermediate frequencies.

It is apparent from the curves that cable types having lower attenuation characteristics enable longer lengths of cable to be effectively measured. It follows therefore, since cable attenuation is a function of frequency, that longer cable lengths can be seen at lower frequencies. The curves serve to illustrate the effects of length on SRL; however, it should be kept in mind that they are theoretical and based on the assumption that the cables are identical in all respects except for length. Table 1 presents calculated and measured values of SRL versus length.

Figure 8 is a plot of SRL versus frequency for infinite lengths of cable types used in CATV systems with frequency considered as resonant. The values of p were chosen so that in the frequency spectrum up to 300 MHz an SRL of - 26 dB was not exceeded. The difference in these values show that for cables with lower attenuation, it is necessary to maintain lower magnitudes of irregularities. It is clear from Figure 8 that the recent extension of requirements from 216 MHz to 300 MHz placed in effect an additional 1.3 dB SRL burden on cable manufacturers.

When more than one periodicity is present the SRL interpretations become more complex. These periods will tend to add or subtract depending on their relative displacements or phase relationships. Periods of different lengths should be considered as independent entities which may interact. Each can produce independent spikes at fundamental resonant frequencies and associated harmonics. The analysis of more complex period forms has not been attempted because of the innumerable variations which may exist.

III. PHYSICAL CHANGES AFFECTING SRL

It is of practical interest to study the effect of physical changes in the coaxial cable on its impedance and SRL. In the CATV frequency spectrum, the impedance is given by:

$$Z = \frac{138.06 \log_{10} D/d}{\sqrt{\epsilon}}$$

The above shows that the cable impedance is affected by changes in the geometric factor D/d and the dielectric constant ϵ. For a given impedance change (irregularity), the changes in the diameters of the conductors are related by: $\Delta d \sim \Delta D \times D/d$

For 75 ohm cables, this can be rewritten as
$\Delta d \sim 4.7\ \Delta D$ for foam polyethylene insulated cables,
$\Delta d \sim 3.7\ \Delta D$ for disc insulated cables,
and $\Delta d \sim 6.3\ \Delta D$ for solid polyethylene cables.

For foam polyethylene insulated cables this means that a 1-mil change in the inner conductor diameter is equivalent to a 4.7-mil change in the inside diameter of the outer conductor. However, in the case of aluminum sheathed cables the above is only approximately true. The aluminum outer conductor is applied tightly over the foam polyethylene insulated core in a swaging operation. Any compression of the dielectric resulting from the swaging operation can affect its dielectric constant. This effect is not pronounced when there is a reasonably small degree of squeeze since the outer layer of the insulation absorbs all of the radial pressure. If the aluminum tube is reduced in diameter significantly, the radial forces are transferred all the way to the center conductor reducing the air cells. This results in an increase in the dielectric constant and decrease in the impedance. Therefore, in the case of a high degree of squeeze, if the cable core is periodically dimensionally non-uniform, SRL may be accentuated.

In the solid polyethylene and disc insulated cables, the dielectric constant parameter ϵ is for all practical purposes constant. Consequently, changes in the impedance of these cables are affected only by the variations in the dimensions of the conductors.

It is shown in Section II (and Figure 8) that for -26 dB SRL foam polyethylene insulated cables the following values of reflection coefficient should not be exceeded:

ρ

Cable Type	10 MHz	50 MHz	100 MHz	150 MHz	200 MHz	250 MHz	300 MHz
.412" CATV coax	.000696	.000329	.000236	.000198	.000175	.000159	.000147
½" " "	.000549	.000260	.000186	.000156	.000138	.000126	.000116
¾" " "	.000402	.000190	.000136	.000115	.000101	.000092	.000085

These values imply the following maximum changes in the impedence:

ΔZ, ohms

Cable Type	10 MHz	50 MHz	100 MHz	150 MHz	200 MHz	250 MHz	300 MHz
.412" CATV coax	.1044	.0494	.0354	.0297	.0263	.0239	.0221
½" " "	.0824	.0390	.0279	.0234	.0207	.0189	.0174
¾" " "	.0603	.0285	.0204	.0173	.0152	.0138	.0128

Since at CATV frequencies the cable impedance can be expressed as

$$Z = \sqrt{L/C},$$

the maximum allowable periodic changes in capacitance for resonances are:

ΔC %

Cable Type	10 MHz	50 MHz	100 MHz	150 MHz	200 MHz	250 MHz	300 MHz
.412" CATV coax	.278	.132	.094	.080	.070	.062	.058
½" " "	.220	.104	.074	.062	.056	.050	.046
¾" " "	.160	.076	.054	.046	.040	.036	.034

Similarly, the maximum allowable periodic changes in the inner conductor diameter are:

	Δd, mils						
Cable Type	10 MHz	50 MHz	100 MHz	150 MHz	200 MHz	250 MHz	300 MHz
.412", ½", ¾" CATV Coaxials	.163	.077	.055	.046	.041	.037	.034

The maximum allowable periodic changes in the inside diameter of the outer conductor is 4.7 times the values given above for the inner conductor.

If the SRL requirements are upgraded, the tolerances given above, which are based on -26 dB, will have to be correspondingly tightened.

Possible discrepancies between measured SRL and calculated SRL based on observed deviations may be due to the lack of uniformity of the periods and/or slight shifts from period to period or other complexities.

It will be noted that in foam polyethylene insulated cables, both periodic dimensional and dielectric constant changes can occur simultaneously. This can also lead to discrepancies between measured and calculated SRL.

IV. DETERMINATION OF SRL BY MEASUREMENT

Reference 8 clearly shows by illustration that the determination of structural irregularities by the transmission loss measurement or impedance testing is not practical because these measurements are too insensitive to discern small magnitudes of change. In the return loss method, the voltage due to average cable impedance is balanced out with the aid of the variable arm of the r-f bridge and only the deviations are fed into the detector. These changes are suitably amplified and a high degree of resolution and sensitivity is obtained.

The method of SRL measurement as shown in reference 8 is based on a comparison of two levels. This method is essential in order to overcome the non-linearity that may exist in the generator and detector systems.

As stated in Section II, SRL is accepted as the ratio of reflected voltage to reference voltage. This reference voltage is derived as follows:

The calibrated variable arm of the r-f bridge is preset to 75 ohms. The cable terminals of the bridge are shorted and therefore the voltage across the detector is a portion of the voltage applied to the bridge. For a measurement system having a constant voltage, the output of the reference (standard) branch is adjusted to equal the detector voltage.

When the cable impedance is not 75 ohms, the cable input voltage is no longer equal to the preset voltage of the reference branch. Also when the cable has periodicity which causes large reflections at resonances the cable input voltage further deviates from the reference voltage. It is shown in Table II that the reflected voltage subtracts from the voltage applied to the cable. The effect is small when the reflected voltage is small. However this test is valid even for large reflected voltages, since it provides comparative figures of merit.

The recommended measuring technique for determining cable SRL consists of employing a variable bridge and variable termination and adjusting their R and C dials. The dials are adjusted for minimum reflection and the pattern displayed on the scope screen as well as a minimum indication on the r.m.s. voltmeter are used to determine this minimum. The R setting on the bridge represents the average characteristic impedance of the cable since the termination is adjusted to match the cable.

The test is also being performed with fixed 75 ohm bridge and termination. Arguments in favor of this method are:

1. No adjustments are required and therefore the test is more objective,

2. It is faster to perform,

3. In the CATV system, components are not adjusted to match the cable.

However, there is an important point to consider in the use of a fixed 75 ohm bridge. If the bridge does not match the average impedance of the cable, then the measured SRL is dependent upon the point of connection to the cable under test. Specifically this means that measured values of SRL can be affected by cutting short lengths (fractions of a wave length) from the input end. This was verified experimentally and results are shown in Figures 9a and 9b. This phenomenon does not occur if the bridge is balanced to the average impedance of the cable because under this condition the detector sees only the magnitude of the reflected signals. When a fixed 75 ohm bridge is used to test a cable in which the average impedance is somewhat different from 75 ohms, the reflected signals would add or subtract vectorially depending upon the phase of unbalance and reflected voltages. Therefore it is possible that when SRL measurements are made under poor balance conditions, results can change if short lengths are cut from the reel under test.

Limited frequency response of the detector assembly determines the general accuracy of the test. The fast rise time spikes are reduced in amplitude and stretched in time and thus can be undetected. The SRL errors introduced by the frequency response characteristics of the detector can be minimized by the reduction

of the sweep rate. This is accomplished by either sweep width or sweep speed so that the individual spikes are swept more slowly and more easily displayed on the broad level detector.

The bridge is the most important component of the measuring assembly. Its balance affects directly the accuracy of measured cable SRL. Any bridge used for measurements should have the highest possible balance over the frequency range 0 to 300 MHz. Tables III and IV show the effect of bridge balance on the accuracy of the measurement. For -26 dB SRL cables, a bridge balance of -50 dB provides reasonable accuracy. The balance can easily be checked with the aid of a standard resistor whose value should preferably be 75 ohms and its balance or VSWR about -70 dB.

If the worst bridge balance is considered to be -50 dB, the uncertainty of SRL measurement is shown in Table III. The errors due to bridge balance cannot be corrected because of the loss of direction through rectification in the detector. In the range of practical interest (SRL up to -36 dB) the error is not greater than 1.9 dB. It can also be seen that the errors decrease with lower values of measured SRL.

V. CONCLUSION

This analysis of structural return loss in CATV coaxial cables leads to the following conclusions:

1. SRL spikes (resonances) occur when the period length is equal to a half wavelength and integral multiples of half wavelengths.

2. Maximum SRL spikes occur when the period is symmetrical.

3. The SRL spike due to the fundamental frequency can be of a lesser amplitude than spikes caused by the harmonic frequencies depending upon the asymmetry of the irregularity period.

4. The length of cable that can be effectively measured varies inversely with cable attenuation. It follows, therefore, that periodic impedance changes are more critical in low attenuation cables.

5. For a specific SRL value, the recent extension of requirements from 216 MHz to 300 MHz adds to the difficulty of meeting the requirement.

6. The recommended procedure for testing SRL is to match the cable average impedance by employing a variable bridge and termination. When a fixed 75 ohm bridge is used to measure cable whose impedance differs from 75 ohms, the voltage due to the mismatch may vectorially add to or subtract from the reflected voltage. By cutting a small length from the cable, the phase relationship of the unbalance voltage and reflected voltage may subtract to provide a better SRL reading.

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LIST OF SYMBOLS

l_1 = length of one section of irregularity period
l_2 = length of second section of irregularity period
a = average attenuation of cable per unit length (nepers)
Z = average characteristic impedance of cable (ohms)
Z_1 = characteristic impedance of section l_1 (ohms)
Z_2 = characteristic impedance of section l_2 (ohms)
T = arbitrary time (microseconds).
t_1 = time for signal to traverse section l_1 (microseconds)
t_2 = time for signal to traverse section l_2 (microseconds)
p_{12} = reflection coefficient of $l_1 - l_2$ junction
p_{21} = reflection coefficient of $l_2 - l_1$ junction

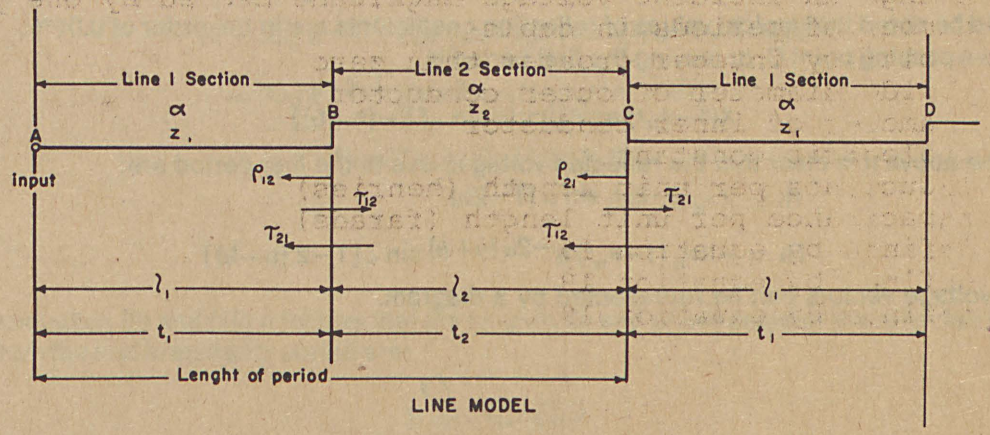
LIST OF SYMBOLS (contd)

T_{12} = transmission coefficient of $\ell_1 - \ell_2$ junction
T_{21} = transmission coefficient of $\ell_2 - \ell_1$ junction
ω = angular velocity ($=2\pi f$)
f = frequency (H_z)
X = magnitude of the incident voltage (=V incident)
R′ = magnitude of the resultant reflected voltage from one irregularity period
R = XR′
θ = phase angle of R
K = change in incident voltage magnitude caused by one period
n = number of periods in cable
n′ = arbitrary integer greater than zero
D = inside diameter of outer conductor
d = diameter of inner conductor
ϵ = dielectric constant
L = inductance per unit length (henries)
C = capacitance per unit length (farads)
ψ = defined by equation 16
ϕ = defined by equation 19
ζ = defined by equation 19

Appendix

Mathematical treatment of randomly distributed reflections has appeared in other publications. The analysis herein is devoted to reflections from irregularities which are systematically distributed along a cable length. While it is recognized that other classical methods can be used to develop useable equations, the mathematical approach presented in this paper was selected to illustrate the SRL phenomenon and behavior.

Let the line irregularities, transmission and reflection coefficients of each junction, attenuation, characteristic impedances, lengths of irregular line sections, and time to transverse each section be as follows:



LINE MODEL

It is assumed that:

a. the line irregularities are abrupt,

b. the l_1 and l_2 period is repeated throughout the line length.

$$\rho_{12} = \frac{Z_1 - Z_2}{Z_1 + Z_2} \tag{1}$$

and

$$\rho_{21} = \frac{Z_2 - Z_1}{Z_1 + Z_2} = -\rho_{12} \tag{2}$$

Also by definition

$$\tau_{12} = 1 + \rho_{12} \tag{3}$$

and

$$\tau_{21} = 1 + \rho_{21} = 1 - \rho_{12} \tag{4}$$

Let the incident wave leaving point A be

$$X \sin \omega T \tag{5}$$

Therefore, the wave reflected from point B is $X\rho_{12} e^{-\alpha l_1} \sin \omega (T - t_1)$ and at the input or point A

$$X\rho_{12} e^{-2\alpha l_1} \sin \omega (T - 2t_1) \tag{6}$$

Similarly, the wave that goes across junction B is $X (1+\rho_{12}) e^{-\alpha l_1} \sin \omega (T - t_1)$ and that reflected from point C is $-X\rho_{12}(1+\rho_{12}) e^{-\alpha (l_1 + l_2)} \sin \omega (T - t_1 - t_2)$, and at input

$$-X\rho_{12} (1 - \rho_{12}^2) e^{-2\alpha (l_1 + l_2)} \sin \omega [T - 2(t_1 + t_2)] \tag{7}$$

The terms shown in equations (6) and (7) neglect re-reflections. The magnitude of the re-reflections is a function of the reflection coefficient. Since expected reflection coefficients are small, the resulting errors will be negligible. For example:

$\rho_{12} = 1\%$, the error cannot be greater than $\pm 1\%$
$\rho_{12} = 2\%$, the error cannot be greater than $\pm 2\%$
$\rho_{12} = 5\%$, the error cannot be greater than $\pm 5\%$

The above expressed in decibels are as follows:

$\rho_{12} = 1\%$, the error cannot be greater than ± 0.1dB
$\rho_{12} = 2\%$, the error cannot be greater than ± 0.2dB
$\rho_{12} = 5\%$, the error cannot be greater than ± 0.45dB

It should be noted that typical values of reflection coefficients are in the order of 0.01%. The wave passing point C, or leaving the first period is

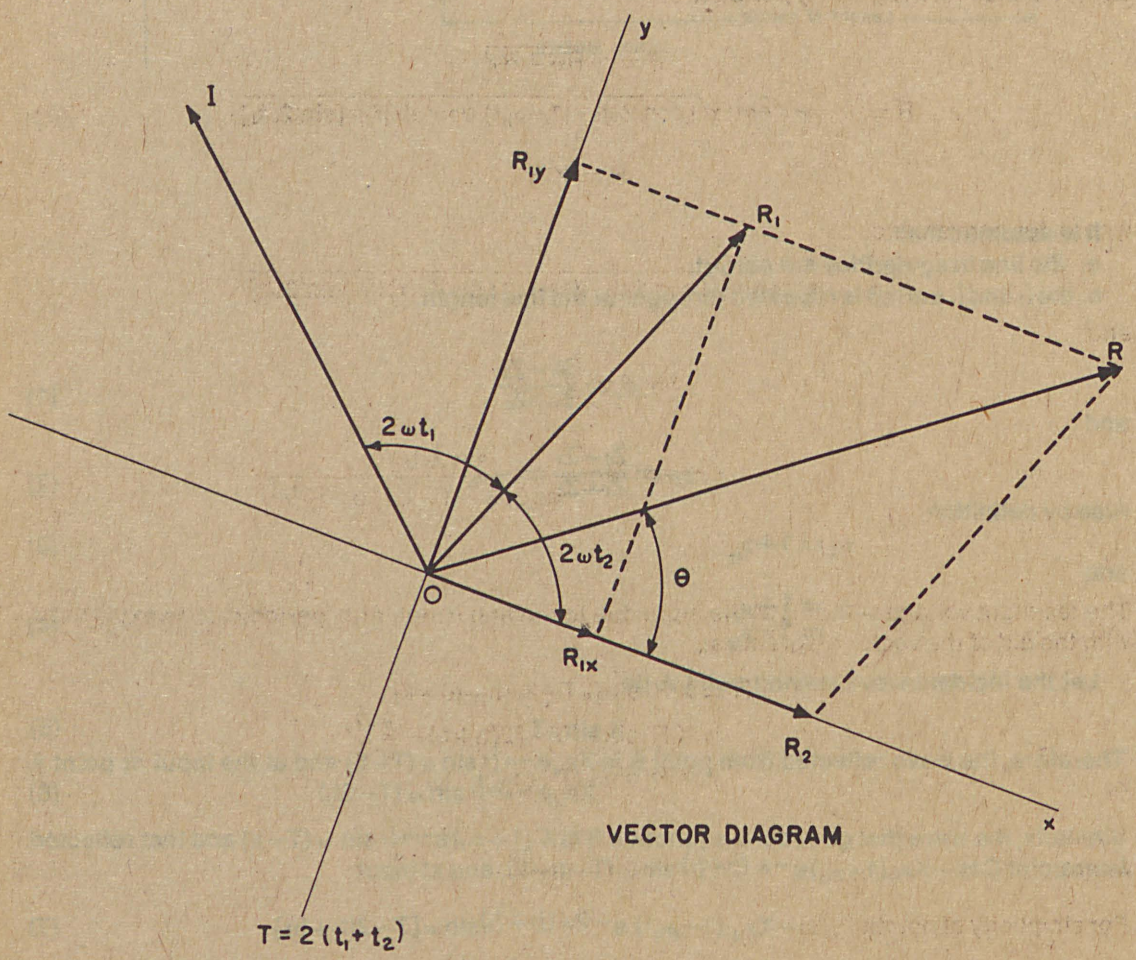
$$X(1-\rho_{12}^2)\, e^{-\alpha(l_1+l_2)} \sin \omega[T-(t_1+t_2)] \qquad (8)$$

From the above it is clear that the reflected voltages due to the first period are:

$$R_1 = X\rho_{12}\, e^{-2\alpha l_1} \sin \omega (T-2t_1)$$

$$R_2 = -X\rho_{12}(1-\rho_{12}^2)\, e^{-2\alpha(l_1+l_2)} \sin \omega[T-2(t_1+t_2)]$$

These voltage vectors can be represented by a diagram.



VECTOR DIAGRAM

In the above diagram, R is the resultant reflected voltage at the input due to the first irregularity period in the transmission line. Its angle is θ.

To calculate this resultant vector and its angle θ, x and y components of R_1 and R_2 are determined.

$$R_{1x} = X\rho_{12}\, e^{-2\alpha l_1} \cos 2\omega t_2$$
$$R_{1y} = X\rho_{12}\, e^{-2\alpha l_1} \sin 2\omega t_2$$

$$R_{2x} = -X\rho_{12}\,(1-\rho_{12}^2)\, e^{-2\alpha\,(l_1+l_2)}$$
$$R_{2y} = O$$

The sums of the x and y components of both vectors are:

$$R_x = X\rho_{12}\, e^{-2\alpha l_1} \cos 2\omega t_2 - X\rho_{12}(1-\rho_{12}^2)\, e^{-2\alpha\ (l_1+l_2)}$$

$$= X\rho_{12}\, e^{-2\alpha l_1}[\cos 2\omega t_2 - (1-\rho_{12}^2)\, e^{-2\alpha l_2}] \qquad (9)$$

$$R_y = X\rho_{12}\, e^{-2\alpha\, l_1} \sin 2\omega t^2 \qquad (10)$$

From equation (9) and (10) it follows that the magnitude and phase angle of the reflected voltage from the first irregularity period are:

$$R = \sqrt{R_x^2 + R_y^2}$$

$$R = X\rho_{12}\, e^{-2\alpha l_1}\sqrt{[\cos 2\omega t_2 - (1-\rho_{12}^2)\, e^{-2\alpha l_2}]^2 + [\sin 2\omega t_2]^2} \qquad (11)$$

$$R = X\,R' \qquad (12)$$

where, for convenience:

$$R' = \rho_{12}\, e^{-2\alpha l_1}\sqrt{[\cos 2\omega t_2 - (1-\rho_{12}^2)\, e^{-2\alpha l_2}]^2 + [\sin 2\omega t_2]^2} \qquad (13)$$

and

$$\tan\theta = \frac{R_y}{R_x}$$

$$\theta = \text{arc tan}\frac{\sin 2\omega t_2}{\cos 2\omega t_2 - (1-\rho_{12}^2)\, e^{-2\alpha l_2}} \qquad (14)$$

The resultant voltage vector R at the input due to the first irregularity period can be expressed with the aid of the vector diagram as:

$$R = X\,R' \sin[\omega T - 2\omega(t_1+t_2) + \theta]$$
$$= X\,R' \sin\omega\left\{T - [2(t_1+t_2) - \frac{\theta}{\omega}]\right\}$$
$$= X\,R' \sin\omega(T-\psi) \qquad (15)$$

where
$$\psi = 2(t_1+t_2) - \frac{\theta}{\omega} \qquad (16)$$

For simplicity of notation, let

$$K = (1-\rho_{12}^2)\, e^{-\alpha(l_1+l_2)} \qquad (17)$$

From equation (5) for incident voltage leaving point A and equation (8) for the voltage exiting the first period, that is, leaving point C, the voltages entering consecutive periods can be expressed in terms of K. Similarly, their corresponding reflected voltages arriving at the input can also be written. These are:

Irregularity period	Incident voltage at entrance to the following period	Reflected voltage at line input due to specified period
0 (Generator)	$X \sin \omega T$	
1	$X K \sin \omega[T-(t_1+t_2)]$	$X R' \sin \omega(T-\psi)$
2	$X K^2 \sin \omega[T-2(t_1+t_2)]$	$X K^2 R' \sin \omega[T-2(t_1+t_2)-\psi]$
3	$X K^3 \sin \omega[T-3(t_1+t_2)]$	$X K^4 R' \sin \omega[T-4(t_1+t_2)-\psi]$
4	$X K^4 \sin \omega[T-4(t_1+t_2)]$	$X K^6 R' \sin \omega[T-6(t_1+t_2)-\psi]$
5	$X K^5 \sin \omega[T-5(t_1+t_2)]$	$X K^8 R' \sin \omega[T-8(t_1+t_2)-\psi]$
etc.	etc.	etc.

From the above, the total reflected voltage at the line input is the sum of individual terms. Therefore, the total reflected voltage can be written as:

$$V_e = X R'\{\sin \omega(T-\psi)+K^2 \sin \omega[T-2(t_1+t_2)-\psi]+K^4 \sin \omega[T-4(t_1+t_2)-\psi]$$
$$+K^6 \sin \omega[T-6(t_1+t_2)-\psi]+K^8 \sin \omega[T-8(t_1+t_2)-\psi]+ \ldots\ldots \text{n terms}\} \quad (18)$$

Substituting in the above for convenience

$$\left.\begin{aligned}\phi &= T-\psi \\ \zeta &= 2(t_1+t_2)\end{aligned}\right\} \quad (19)$$

the series becomes

$$V_e = X R'[\sin \omega\phi+K^2 \sin \omega(\phi-\zeta)+K^4 \sin \omega(\phi-2\zeta)+K^6 \sin \omega(\phi-3\zeta)$$
$$+K^8 \sin \omega(\phi-4\zeta) \ldots\ldots \text{n terms}]$$

and can be rewritten as:

$$V_e = X R' \sin \omega\phi[1+K^2 \cos \omega\zeta+K^4 \cos 2\omega\zeta+K^6 \cos 3\omega\zeta+K^8 \cos 4\omega\zeta+ \ldots\ldots \text{n terms}]$$
$$-X R' \cos \omega\phi[1+K^2 \sin \omega\zeta+K^4 \sin 2\omega\zeta+K^6 \sin 3\omega\zeta+K^8 \sin 4\omega\zeta+ \ldots\ldots \text{n terms}]+X R' \cos \omega\phi$$

The above series is summed up using reference 9

$$V_e = X R' \sin \omega\phi \frac{[1-K^2 \cos \omega\zeta][1-K^{2(n+1)} \cos (n+1)\omega\zeta]+K^{2(n+2)} \sin \omega\zeta \sin (n+1)\omega\zeta}{1-2K^2 \cos \omega\zeta+K^4}$$
$$-X R' \cos \omega\phi \frac{K^2 \sin \omega\zeta [1-K^{2(n+1)} \cos (n+1)\omega\zeta]-[1-K^2 \cos \omega\zeta] K^{2(n+1)} \sin (n+1)\omega\zeta}{1-2K^2 \cos \omega\zeta+K^4}$$
$$+X R' \cos \omega\phi \quad (20)$$

The above is a general equation for total reflected voltage for a uniformly irregular line. It can be seen from equation (18) that each reflection term differs from the preceding term by a factor

$$2\omega(t_1+t_2)$$

Therefore, in order to maintain the time function of each term at a maximum

$$2\omega(t_1+t_2)=n' 2\pi \quad (21)$$

Equation (21) shows that multiple resonant frequencies exist and the SRL spikes occur when

$$\text{period}=n'\pi=\omega(t_1+t_2) \quad (22)$$

Equation (22) shows that resonances occur or SRL spikes are produced when the frequency corresponds to a period of $\lambda/2$ or multiples of $\lambda/2$ i.e. all the higher harmonic frequencies.

Referring back to equation (18) it can be seen that ψ appears as a constant shift in every term. Analysis of ψ reveals that two vector voltages which are produced by the two junctions of a period add directly to produce a maximum under certain conditions.

In order to maintain the time function of each term at a maximum value of unity or $\sin \omega T=1$ then

$$\omega\psi=n'2\pi \tag{23}$$

Substituting in equation (16) for ψ

$$\theta=2\omega(t_1+t_2)-n'2\pi \tag{24}$$

Combining the above with equation (14), the following transcendental equation is obtained

$$2\omega(t_1+t_2)-n'2\pi=\text{arc tan}\frac{\sin 2\omega t_2}{\cos 2\omega t_2-(1-\rho_{12}^2)e^{-2\alpha l_2}}$$

which simplifies to

$$\tan 2\omega(t_1+t_2)=\frac{\sin 2\omega t_2}{\cos 2\omega t_2-(1-\rho_{12}^2)e^{-2\alpha l_2}} \tag{25}$$

Solving the above by substitutions, the condition for maximum SRL spike is:

$$\omega t_1=\omega t_2=\frac{\pi}{2} \tag{26}$$

which is a symmetrical period.

Since it has been shown by equation (21) that, at resonances, all reflected voltage terms add in phase, equation (18) can be rewritten as:

$$V_{(\text{reflected})}=X\,R'(1+K^2+K^4+K^6+K^8+\ldots\ldots n \text{ terms})\sin\omega(T-\psi)$$

However, only the magnitude of the reflected voltage and not its phase is of practical interest, therefore,

$$\begin{aligned}|\,V_{(\text{reflected})}\,| &= X\,R'(1+K^2+K^4+K^6+K^8+\ldots\ldots n \text{ terms})\\ &=X\,R'\left(\frac{1-K^{2n}}{1-K^2}\right)\end{aligned} \tag{27}$$

By taking the definition of SRL as

$$|\text{SRL}|=20\log_{10}\frac{|V_{(\text{reflected})}|}{|V_{(\text{incident})}|}\text{ decibles} \tag{28}$$

then from (27) the SRL becomes

$$|\text{SRL}|=20\log_{10}R'\left(\frac{1-K^{2n}}{1-K^2}\right)\text{decibles}$$

Table I

EXPERIMENTAL STUDY OF SRL CHANGE WITH CABLE LENGTH

(101 MHz and 150 MHz spikes in .412" CATV coaxial cable)

Cable Lengths Under Test (ft.)	Measured* magnitudes of SRL Spikes, dB		Measured cable average input impedance (ohms)	Calculated magnitudes of SRL Spikes, dB			
				Δ			
	101 MHz	150 MHz		101 MHz	150 MHz	101 MHz	150 MHz
175	—37.6	—33.9	75.0	—8.0	—7.1	- 38.1	- 35.5
250	—35.5	—32.2	75.0	—5.7	—4.8	- 35.8	- 33.2
325	—33.8	—30.9	75.0	—4.1	—3.4	- 34.2	- 31.8
400	—32.8	—30.2	75.0	—3.1	—2.5	- 33.2	- 30.9
475	—32.5	—29.6	75.0	—2.2	—1.7	- 32.3	- 30.1
550	—32.2	—29.2	75.0	—1.5	—1.2	- 31.6	- 29.6
625	—31.5	—28.9	75.0	—1.0	—0.8	- 31.1	- 29.2
700	—30.8	—28.6	75.0	—0.6	—0.4	- 30.7	- 28.8
775	—30.2	—28.5	75.0	—0.3	—0.2	- 30.4	- 28.6
850	—30.1	—28.4	75.0	0.0	0.0	- 30.1	- 28.4

**Narrow band measurements with variable r.f. bridge.*
NOTE: Lack of agreement between calculations and measurements is due to deviations and shift from period to period.

Table II

MEASUREMENTS ON HIGHLY PERIODICALLY IRREGULAR EXPERIMENTAL LINE

(Line consisting of 145 ft. .412" cable input end, symetrical 75/50 ohm ($\rho \approx 0.2$) irregularity periods, 1065 ft. long .412" cable output end. Irregularity period: 15 ft. of RG-8A/U and 18.4 ft. of .412" CATV coaxial.)

Number of periods Inserted n	Measured line attenuation suck-out		Measured SRL	
	dB	drop in transmitted voltage volts/volts	dB	mv/volt
0	0.0	0.000	>—33.0	<22.39
1	0.4	0.045	—10.0	316.2
2	2.2	0.224	— 4.8	575.4
3	4.8	0.425	— 2.9	716.2
4	7.9	0.597	— 2.0	794.3
5	11.5	0.734	— 1.3	871.0
6	14.5	0.812	— 1.0	891.3

NOTE: 1) The above figures are for 10.6 MHz fundamental resonant frequency.
2) SRL and attenuation/suck-out magnitudes are practically independent of point of connection. Studies conducted with variable bridge. Cable input end shortened in one eighth wavelength steps.

Table III

ACCURACY OF SRL MEASUREMENT VERSUS BRIDGE BALANCE OF —50 dB

Measured SRL dB	Maximum Possible Spread in Reading		Maximum Possible Error dB
	mv/Volt	dB	
—18.0	129.06 . . . 122.74	—17.8 . . . —18.2	—0.2 . . . +0.2
—20.0	103.16 . . . 96.84	—19.7 . . . —20.3	—0.3 . . . +0.3
—22.0	82.59 . . . 76.27	—21.7 . . . —22.3	—0.3 . . . +0.3
—24.0	66.26 . . . 59.94	—23.6 . . . —24.4	—0.4 . . . +0.4
—26.0	53.28 . . . 46.96	—25.5 . . . —26.5	—0.5 . . . +0.5
—28.0	42.97 . . . 36.65	—27.3 . . . —28.7	—0.7 . . . +0.7
—30.0	34.78 . . . 28.46	—29.2 . . . —30.9	—0.8 . . . +0.9
—32.0	28.28 . . . 21.96	—31.0 . . . —33.2	—1.0 . . . +1.2
—34.0	23.11 . . . 16.79	—32.7 . . . —35.5	—1.3 . . . +1.5
—36.0	19.01 . . . 12.69	—34.4 . . . —37.9	—1.6 . . . +1.9
—38.0	15.75 . . . 9.43	—36.1 . . . —40.5	—1.9 . . . +2.5

NOTE: —50 dB bridge balance ≡ 3.16 mv/Volt unbalance voltage.

Table IV

ACCURACY OF SRL MEASUREMENT VERSUS BRIDGE BALANCE OF —40 dB

Measured SRL dB	Maximum Possible Spread in Reading		Maximum Possible Error dB
	mv/Volt	dB	
—18.0	135.90 . . . 115.90	—17.3 . . . —18.7	—0.7 . . . + 0.7
—20.0	110.00 . . . 90.00	—19.2 . . . —20.9	—0.8 . . . + 0.9
—22.0	89.43 . . . 69.43	—21.0 . . . —23.2	—1.0 . . . + 1.2
—24.0	73.10 . . . 53.10	—22.7 . . . —25.5	—1.3 . . . + 1.5
—26.0	60.12 . . . 40.12	—24.4 . . . —27.9	—1.6 . . . + 1.9
—28.0	49.81 . . . 29.81	—26.1 . . . —30.5	—1.9 . . . + 2.5
—30.0	41.62 . . . 21.62	—27.6 . . . —33.3	—2.4 . . . + 3.3
—32.0	35.12 . . . 15.12	—29.1 . . . —36.4	—2.9 . . . + 4.4
—34.0	29.95 . . . 9.95	—30.5 . . . —40.0	—3.5 . . . + 6.0
—36.0	25.85 . . . 5.85	—31.8 . . . —44.7	—4.2 . . . + 8.7
—38.0	22.59 . . . 2.59	—32.9 . . . —51.7	—5.1 . . . +13.7

NOTE: —40 dB bridge balance ≡ 10.00 mv/Volt unbalance voltage.

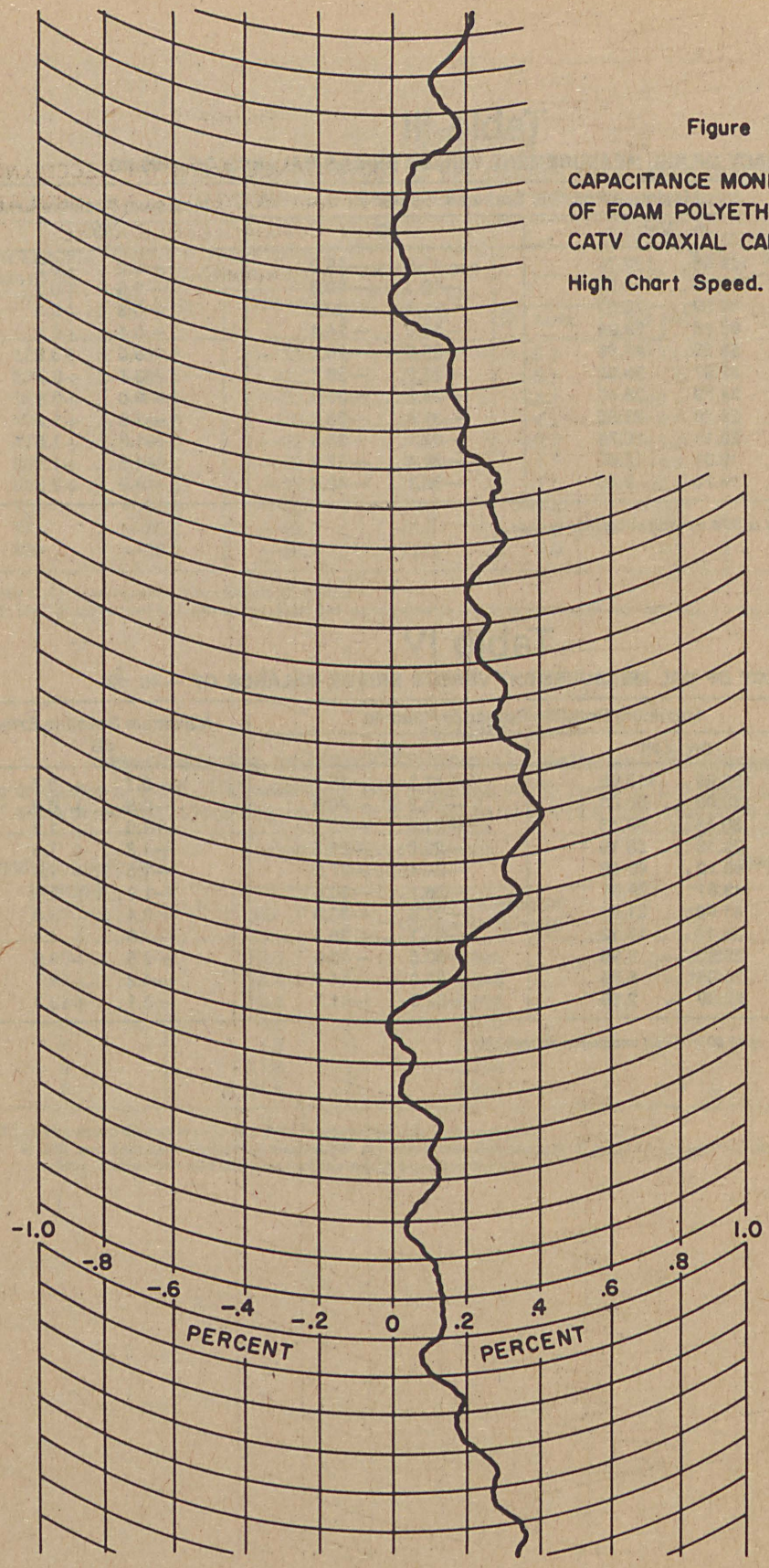


Figure 1

CAPACITANCE MONITOR RECORDING OF FOAM POLYETHYLENE INSULATED CATV COAXIAL CABLE CORE.

High Chart Speed.

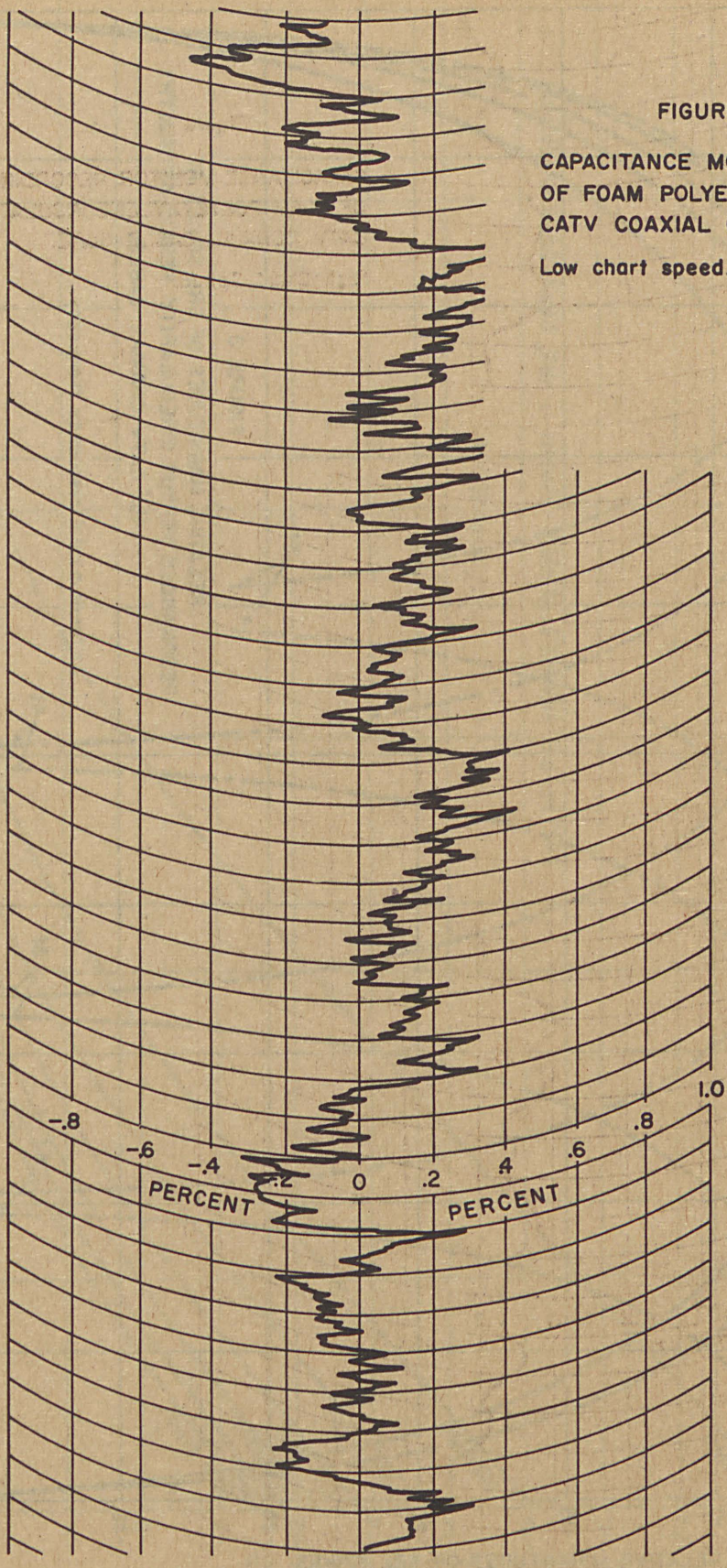


FIGURE 2

CAPACITANCE MONITOR RECORDING OF FOAM POLYETHYLENE INSULATED CATV COAXIAL CABLE CORE.

Low chart speed.

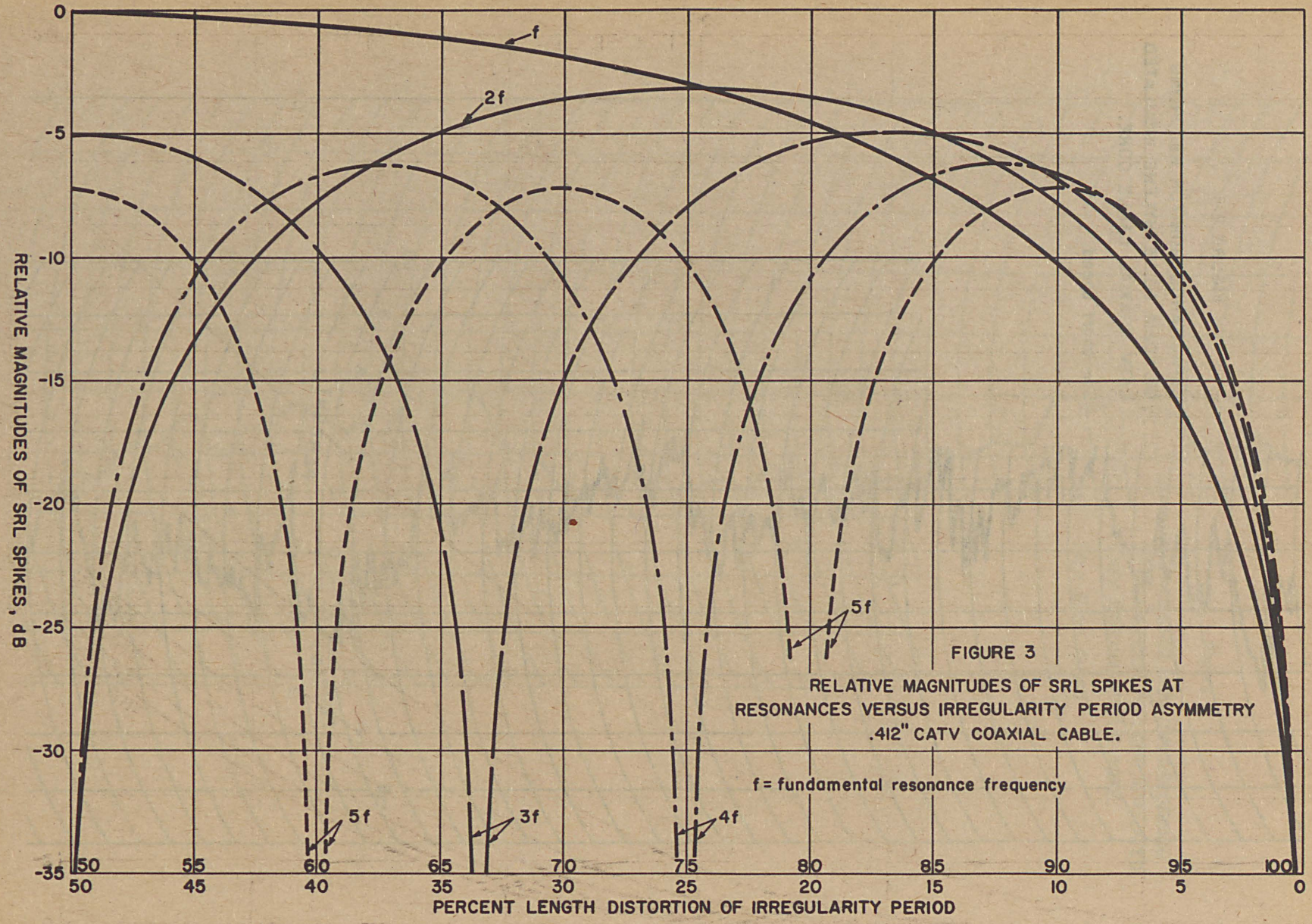


FIGURE 3

RELATIVE MAGNITUDES OF SRL SPIKES AT RESONANCES VERSUS IRREGULARITY PERIOD ASYMMETRY .412" CATV COAXIAL CABLE.

f = fundamental resonance frequency

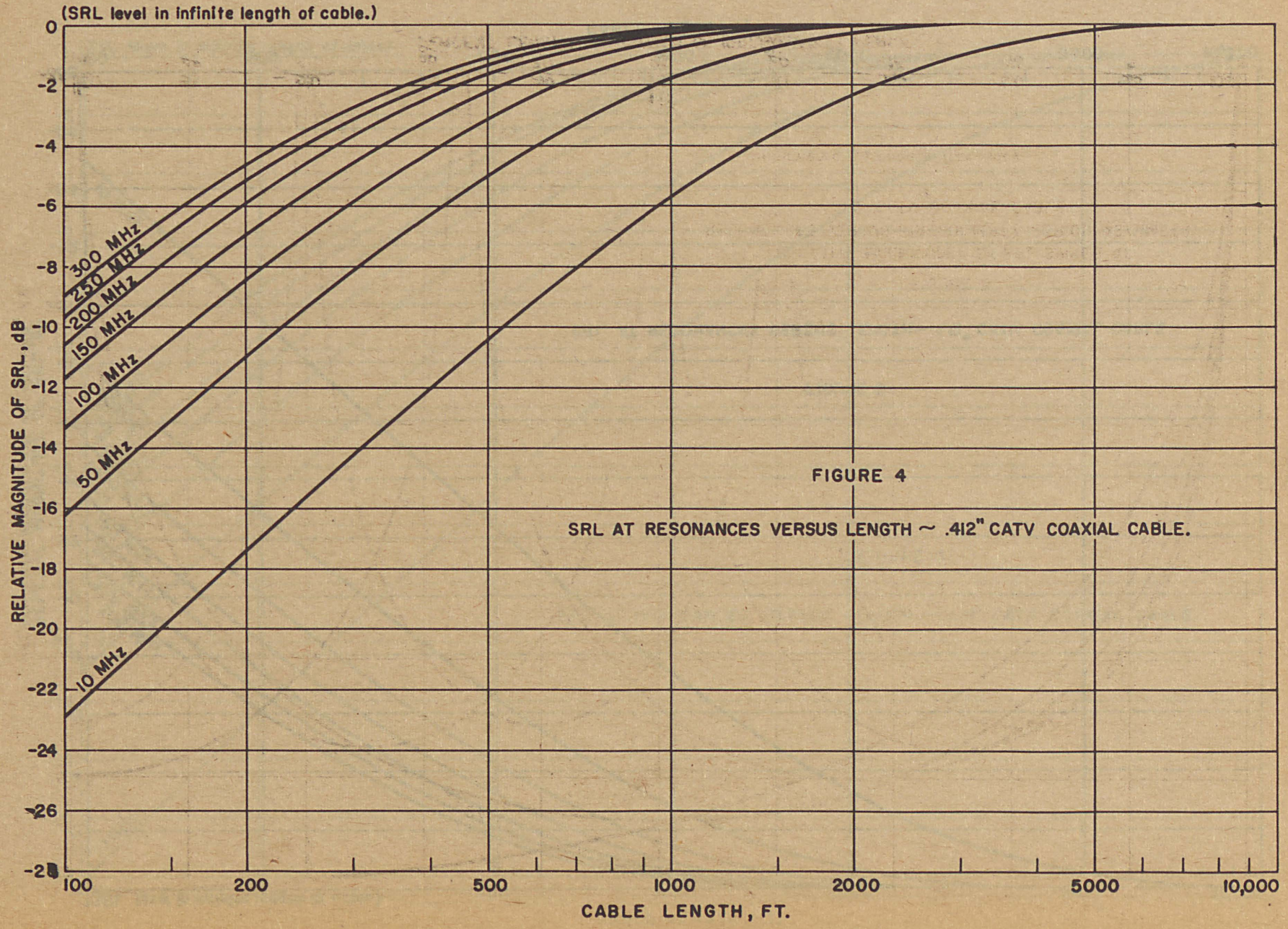


FIGURE 4

SRL AT RESONANCES VERSUS LENGTH ~ .412" CATV COAXIAL CABLE.

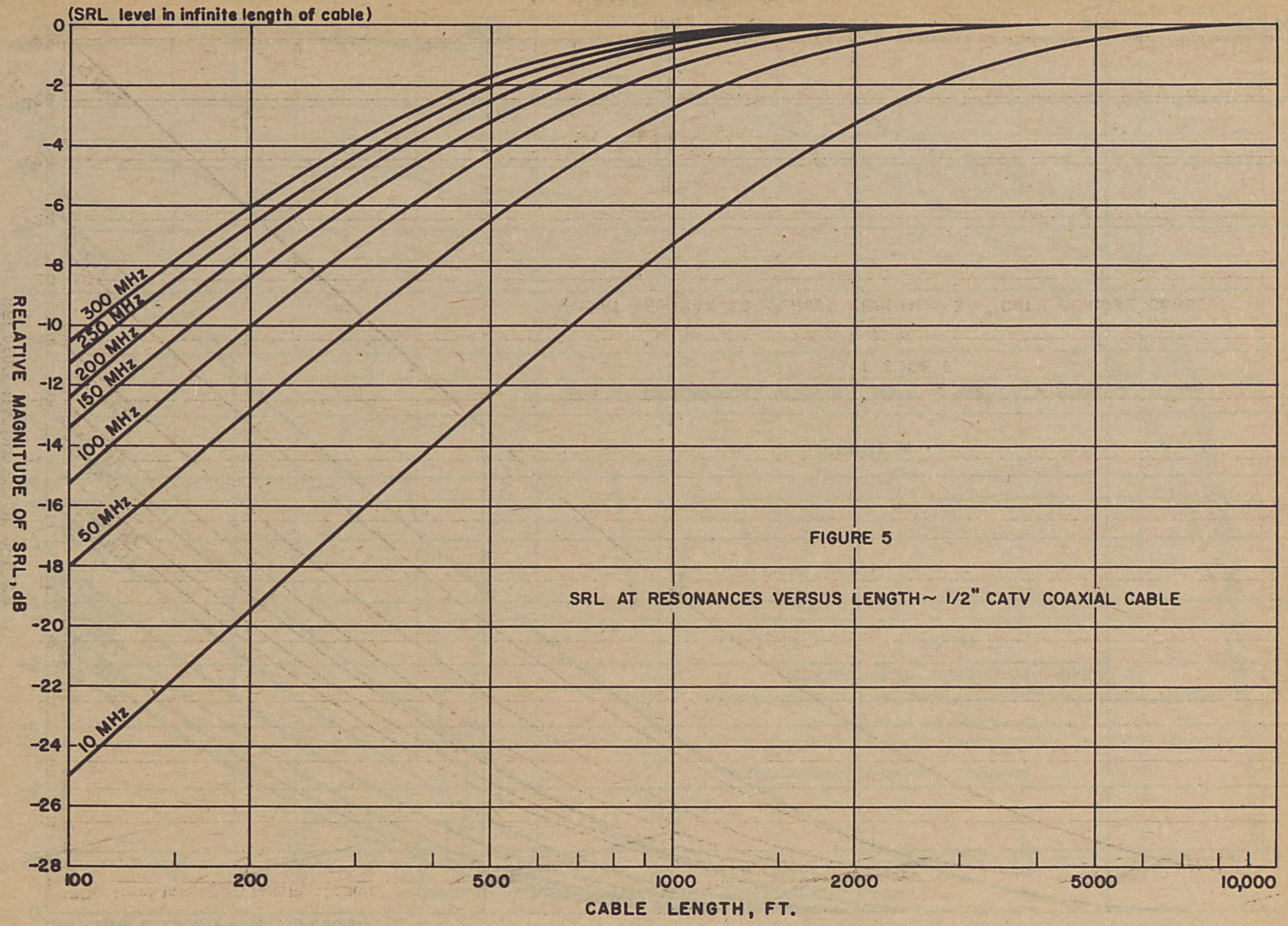


FIGURE 5

SRL AT RESONANCES VERSUS LENGTH~ 1/2" CATV COAXIAL CABLE

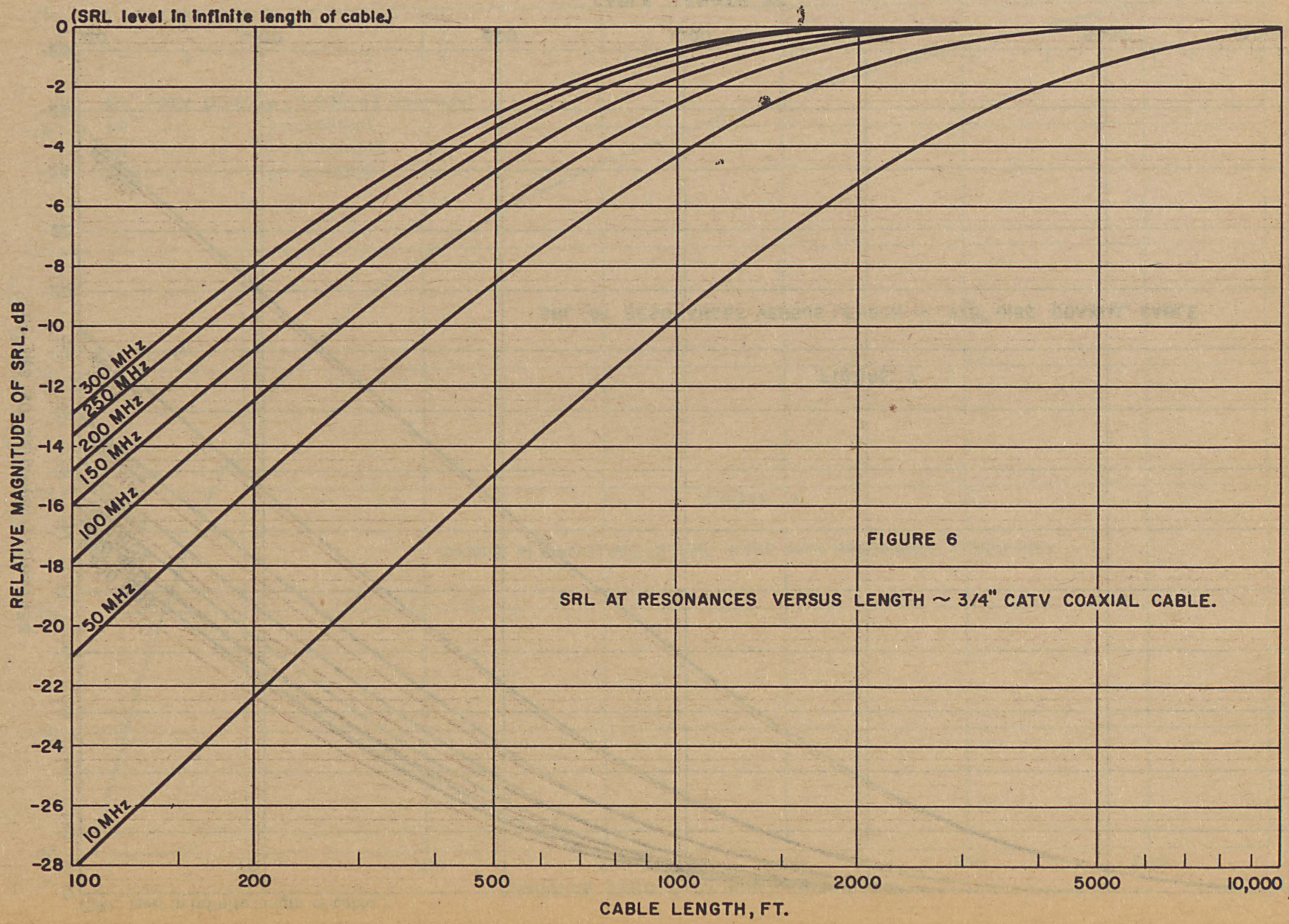


FIGURE 6

SRL AT RESONANCES VERSUS LENGTH ~ 3/4" CATV COAXIAL CABLE.

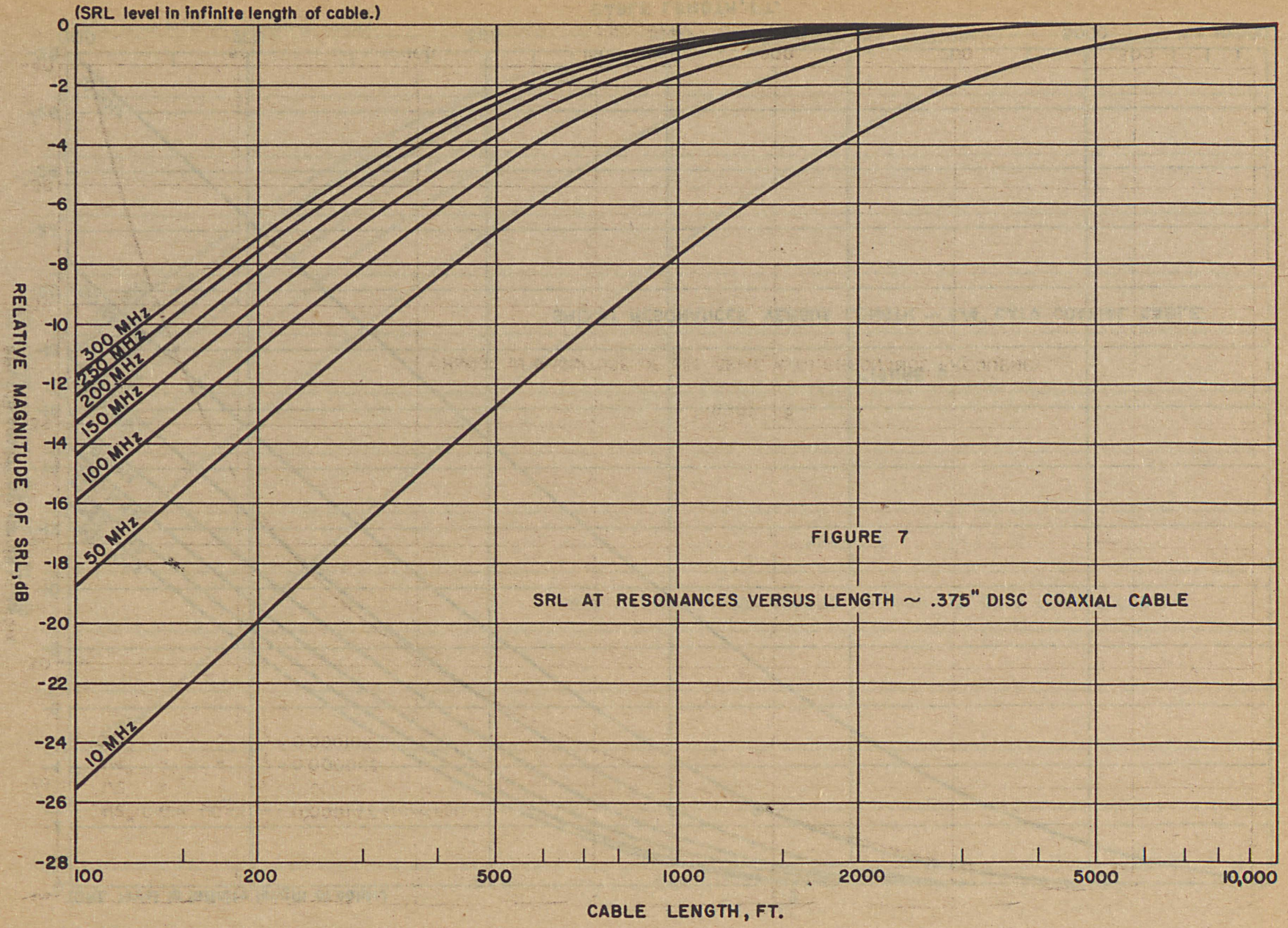


FIGURE 7

SRL AT RESONANCES VERSUS LENGTH ~ .375" DISC COAXIAL CABLE

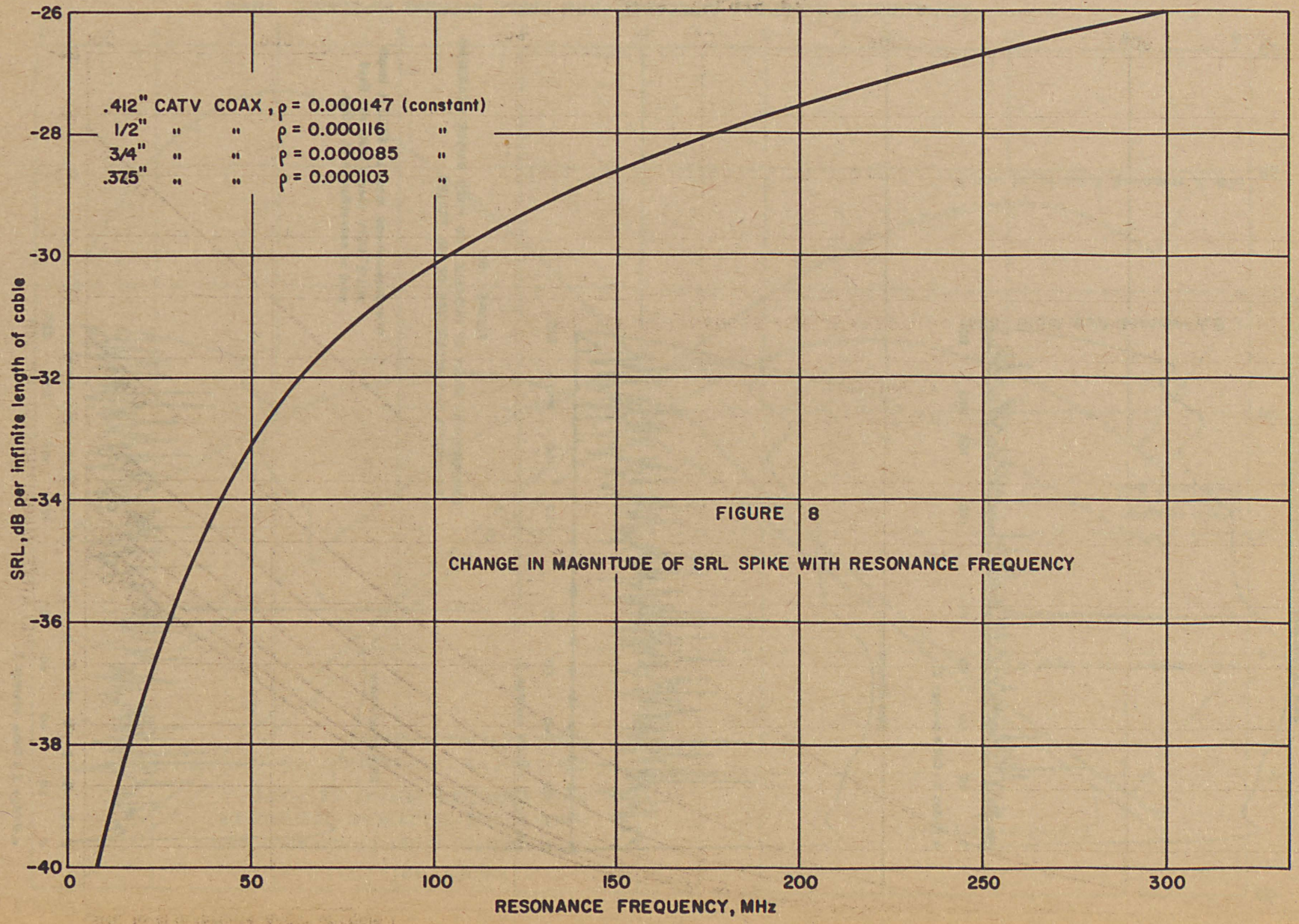
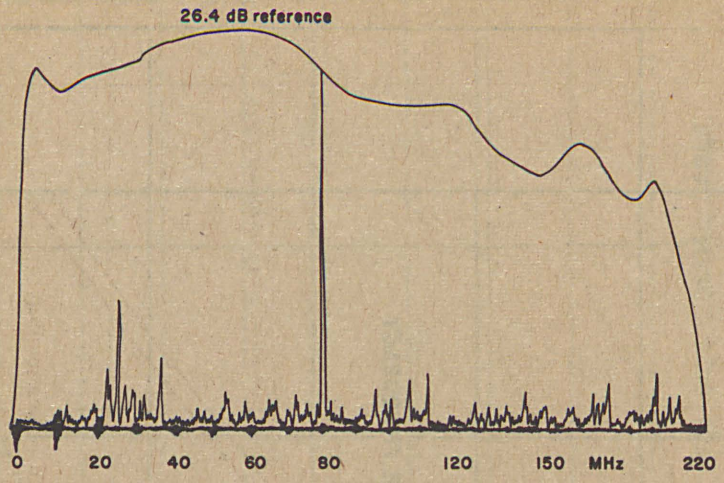
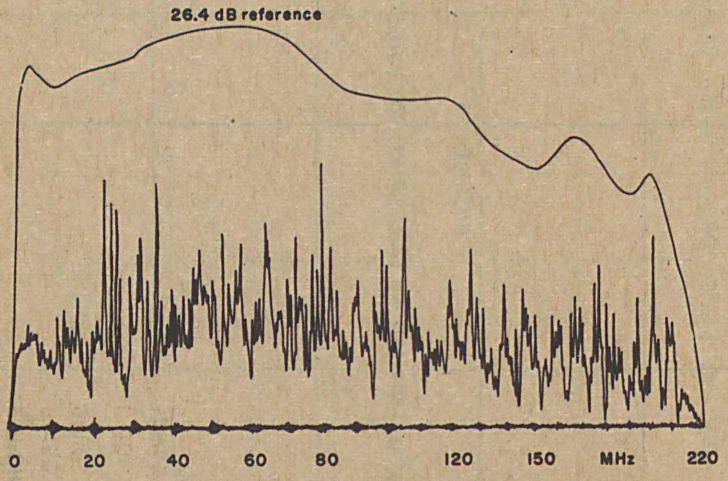


FIGURE 8

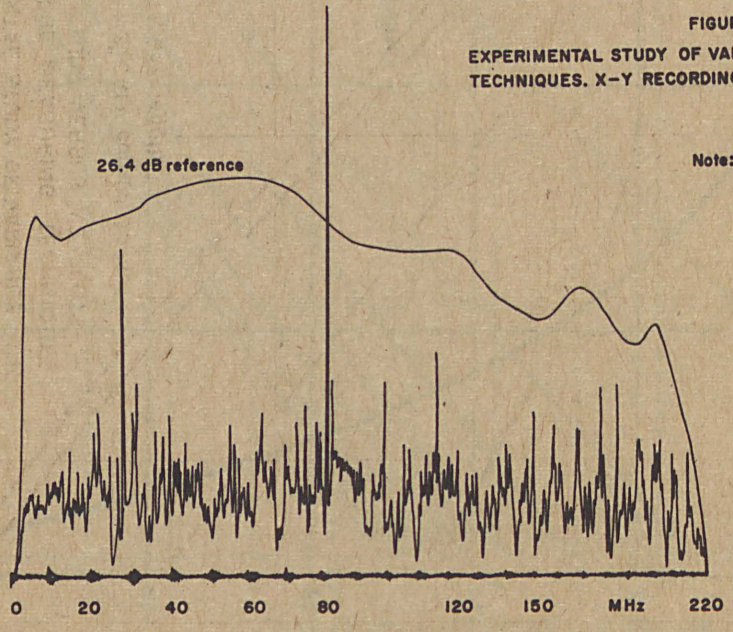
CHANGE IN MAGNITUDE OF SRL SPIKE WITH RESONANCE FREQUENCY



a. Bridge Z = Cable average Z.



b. Bridge Z > Cable average Z.



c. Bridge Z < Cable average Z.

FIGURE 9A

EXPERIMENTAL STUDY OF VARIABLE AND FIXED BRIDGE MEASURING TECHNIQUES. X-Y RECORDINGS OF SRL TRACES.

Note: Measurements made on 2500 ft. length of 1/2" CATV coaxial cable with fixed point of connection to r.f. bridge.

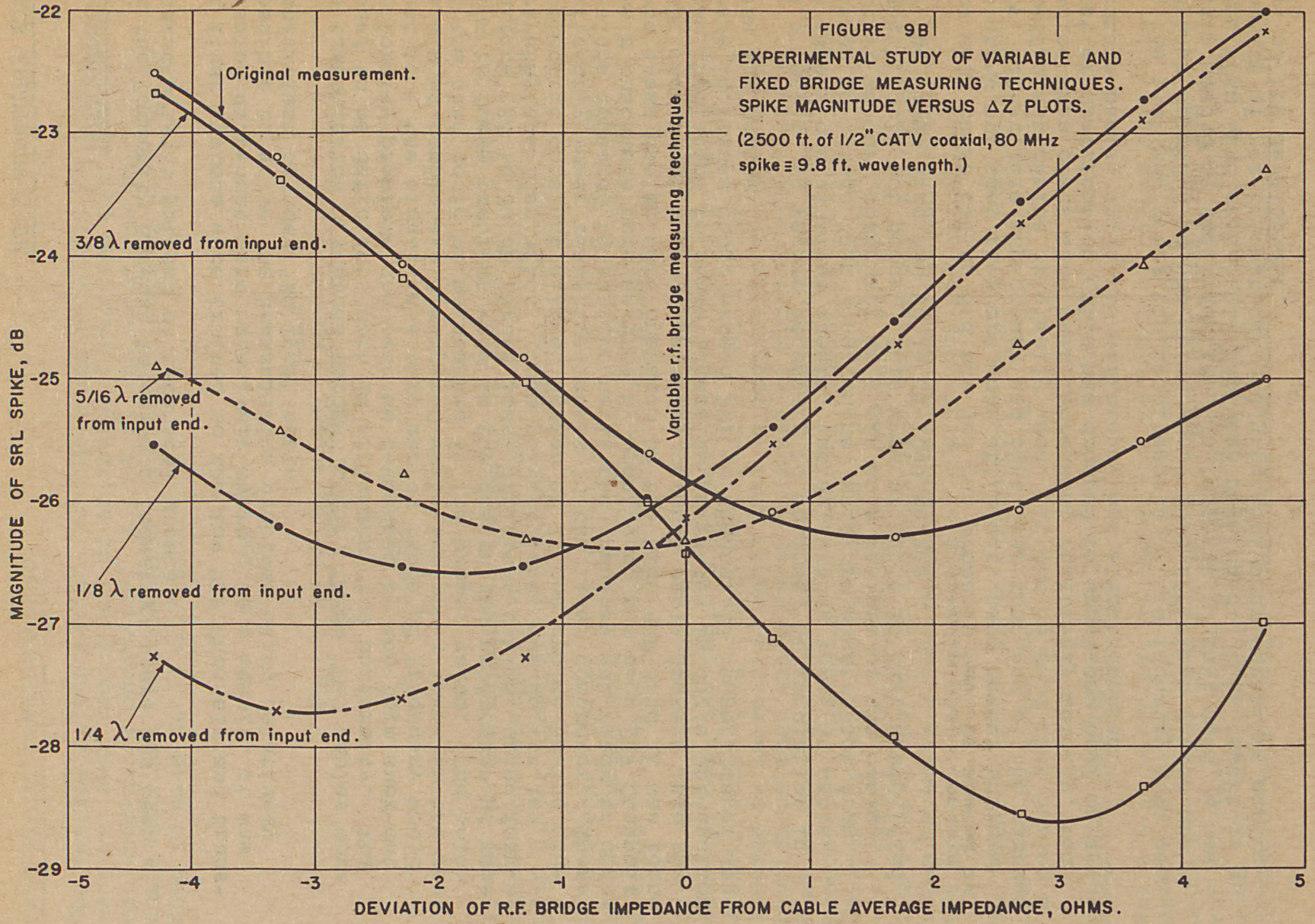


FIGURE 9B

EXPERIMENTAL STUDY OF VARIABLE AND FIXED BRIDGE MEASURING TECHNIQUES. SPIKE MAGNITUDE VERSUS ΔZ PLOTS.

(2500 ft. of 1/2" CATV coaxial, 80 MHz spike ≡ 9.8 ft. wavelength.)

JACK ARBUTHNOTT, JR.

INTRODUCTION

In the Community Antenna Television Industry, there has been a characteristic pattern of technical growth.

At first systems were limited to the low VHF Channels and transmission distances were relatively short. As a result, it was possible to solve the transmission problems using relatively inefficient braided "RG Type" cable.

As transmission distances became longer, these "RG" cables were found to be deficient, both in efficiency and uniformity. The uniformity problems can best be described by the term suck-out, that is - the signal in a very narrow range of frequency would be almost completely dissipated while the power level in the rest of the band could be maintained at its proper value. The solution to these problems were in the design and production of more uniform (26 to 30 dB return loss) efficient cables, using foam polyethylene insulation. Foam polyethylene, due to its low dielectric constant allowed design of 75 ohm cables having significantly lower resistive losses in the inner conductor. These designs appeared to suffice until the industry was ready to offer their customers more service by opening up the high VHF Channels. When these cables were operated on the high VHF Band it was found that enough water could permeate through cable jackets into the foam insulation to cause excessive increases in cable attenuation. These increases could exceed 20% at Channel 13 in periods of less than six months.

As a result, it became necessary to enclose the insulation in an impervious aluminum sheath, taking further steps in cable design to insure that longitudinal moisture penetration from either an open connector or a pin hole failure of the cable sheath could not occur. This type of cable is best exemplified by the Times Wire and Cable JT-1000 series.

How well these cables did the job can probably best be stated by pointing out that they are more efficient, have better uniformity, better life expectancy and cost less than any of the various inefficient cables originally used. It can be said that during a period when costs have been increasing relatively quickly, the cost of distribution cable has dropped to about one half on a footage basis, while its efficiency has almost doubled.

In the past few years the requirements of the industry have been further upgraded to the point where more efficient cables are again needed by the industry. In response to that need, a new type foam insulated cable has been developed. This report is a summary of the theoretical and practical considerations pertinent to its development.

THEORETICAL CONSIDERATIONS

The overriding theoretical consideration pertinent to development was that regardless of anything, lower loss per unit length was absolutely necessary. A look at the equations describing the electrical relationships involved illustrates what can be done to make cable more efficient.

$$Zo = 0.6 \quad D/d \quad Vg$$

$$\alpha_m = \frac{1.045}{Zo} \left(\frac{.414}{d} + \frac{.525}{D} \right) \sqrt{Fmc}$$

$$\alpha_d = \frac{278 \; T \; an\delta \; Fmc}{Vg}$$

If Zo, the characteristic impedance of the cable, is kept constant, an increase in Vg, the velocity of propagation, requires that d, the diameter of the inner conductor, be made larger.

If d becomes larger, the metal loss of the cable, α m, becomes lower. Furthermore, the third equation predicts that α d, the dielectric loss, will decrease as Vg increases.

It can also be shown that the same percentage increase in D, the diameter over the cable core, as in d will decrease metal loss without varying Vg - this merely says that attenuation can be lowered by increasing cable size (a poor solution, when it is considered that cable costs increase at about 2 to 4 times as fast as they increase in size). On the other hand the first proposition, increasing Velocity of Propagation, allows us to decrease attenuation at a modest increase in the cost of conductor, partly counterbalanced by a decrease in the cost of insulation. As a result, it was decided to manufacture a more efficient cable by using a less dense insulating material and maintaining the present basic diameters of the JT-1000 series cables.

The type of cable can be manufactured using a Foam Styrene insulation having a density of approximately 9# per cubic foot.

PRACTICAL CONSIDERATIONS

While high velocity, so called Air Dielectric, cables have been manufactured before, they have had two important drawbacks. Most important, they have for the most part been unsealed from end to end allowing moisture penetration throughout their entire length when, for any reason, the seals at the cable ends or in the outer conductor were broken. This moisture naturally results in lowered

cable efficiency and, in particularly unfortunate cases, to voltage breakdown. This problem can be prevented using pressurization but, requires additional capital expense and higher operating costs.

An additional disadvantage of Air Dielectric cable is that the value of labor put into its manufacture is quite high. The slower manufacturing processes required to insulate the conductor of necessity make this type of cable more expensive than cable: insulated by normal extrusion techniques.

Upon consideration of these facts, it was noted that present foam insulated cables do not exhibit either one of these drawbacks. First of all, the foam is placed on the cable rapidly at a relatively low cost. Secondly, because it is unicellular, the foam will not allow passage of gas longitudinally, provided that it is properly extruded and provided that it is sufficiently compressed to seal against the outer conductor. This point is vitally important when it is considered that reports from the field indicate that moisture penetration into improperly sealed cables can allow attenuation increases of more than 15 per cent in three months' time. On checking a failure of this type, we found that a 5 foot length leaked gas at an approximate rate of 163^{in3}/hr. at 5 psi pressure differential. This particular cable leaked at the inner conductor, because of the manufacturer's extrusion techniques. Calculations indicate that cables tested this way should exhibit leak rates of less than 1^{in3}/hr., if they are to have reasonable life expectancy. Most of our cables we have tested show leak rates in the order of 0.03^{in3}/hr. or better. We have not received any indication of failure in the field so can not assign any factor of confidence in the 1^{in3}/hr. figure.

It may be possible to get another figure for reference in the near future. Measurements on longitudinal tape shielded constructions indicate leak rates in the order of 50^{in3}/hr. Where these cables have been buried underground, one would expect reports of failure due to moisture penetration within a reasonable length of time.

ECONOMIC CONSIDERATIONS

Analysis of the different design approaches can best be summarized as follows. Taking a given size cable using a copper braid outer conductor and protected with a good Polyethylene jacket as standard and assigning a cost factor of 1, an aluminum sheathed foam polyethylene cable having equivalent attenuation will cost about 61 per cent, and an aluminum sheathed foam styrene cable having equivalent attenuation will cost about 54 per cent.

These rather startling results are almost entirely due to reduction in weight of material used and in reduced cost per pound of material.

DESCRIPTION

The new cable designed consists of a copper clad or copper center conductor, a layer of unicellular polystyrene foam insulation and a seamless aluminum alloy tube outer conductor. The foam styrene is kept under compression by the aluminum tube to insure moisture tightness and good conductor adhesion., The following table shows the sizes currently available.

	Inner Conductor	Outer Conductor	
		ID	OD
JT-2340	0.075	0.300	0.340
JT-2412	0.092	0.362	0.412
JT-2500	0.114	0.450	0.500
JT-2750	0.172	0.680	0.750

BASIC ELECTRICAL PROPERTIES

Predictions of the basic electrical properties of the cable were made using the fundamental formulae and are tabulated below.

Type	Vg %	Ω0 ohms	Attenuation at 216 MHz
JT-2340	91.5	75	1.65 dB/100'
JT-2412	91.5	75	1.30 dB/100'
JT-2500	91.5	75	1.07 dB/1000'
JT-2750	91.5	75	0.72 dB/100'

Figure #1 shows the attenuation curve from 50 MHz to 300 MHz.

These values indicate that size for size we have achieved an approximate 20% improvement in characteristics over our JT-1000 series cable.

MECHANICAL PROPERTIES

As stated before several practical considerations were thought essential to the good performance of any new cable. These were as follows:

Leak Resistance - Leak tests were performed on these cables and on normal polyethylene foam cable as illustrated in Figure #2. The amount of air collected at one end of the cable with 5 psi pressure at the other end was measured and recorded in terms of cu/inch/hr/ft of cable. The values shown were typical results noted on pieces actually tested in this manner.

Conductor and Cable Adhesion - Adhesion of the inner conductor to the cable insulation and adhesion of the outer conductor to the cable core were measured using a setup similar to that shown in Figure #3. Comparative tests between polystyrene and polyethylene foam insulated cables were made and values recorded in terms of pounds/foot and are shown below:

Type	Insulation to Conductor	Core to Shield
JT-2412	70 pounds	>50 pounds
JT-2500	> 80 pounds	>60 pounds
JT-2750	>100 pounds	80 - 100 pounds

Inner Conductor Migration - It was felt that it could be possible for the inner conductor of the cable to wander at cable bends. X-ray tests of bent cable samples were made to check.

Figure #4, shows X-rays of typical cables as manufactured, after 3 bend cycles.

CONCLUSION

In summary, the foam polystyrene insulated cable represents the most forward step in improved CATV Cables since the introduction of semiflex cables. The dramatic improvement in attenuation characteristics coupled with the basic economy of design could mean that we now have a new standard for system layout and construction.

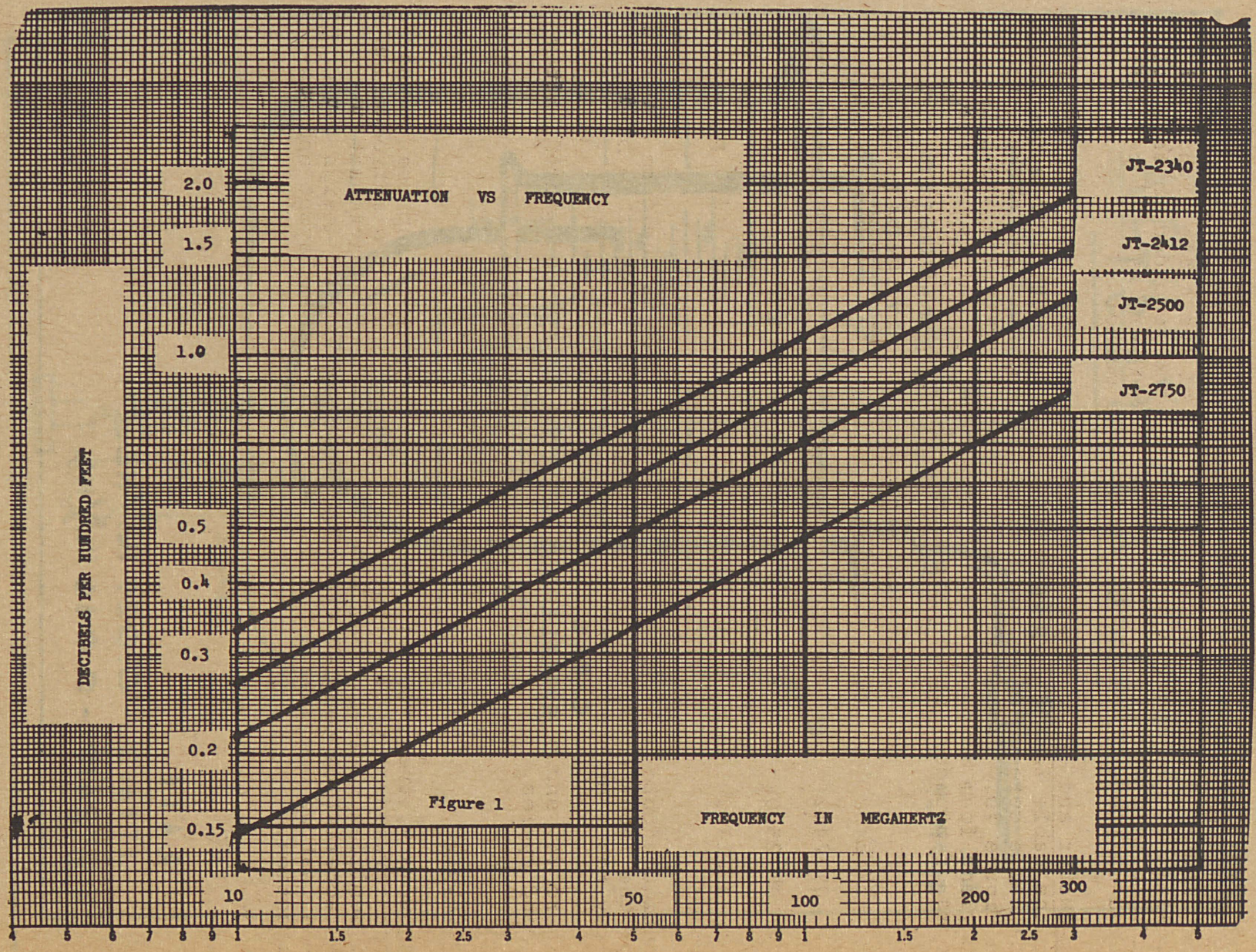
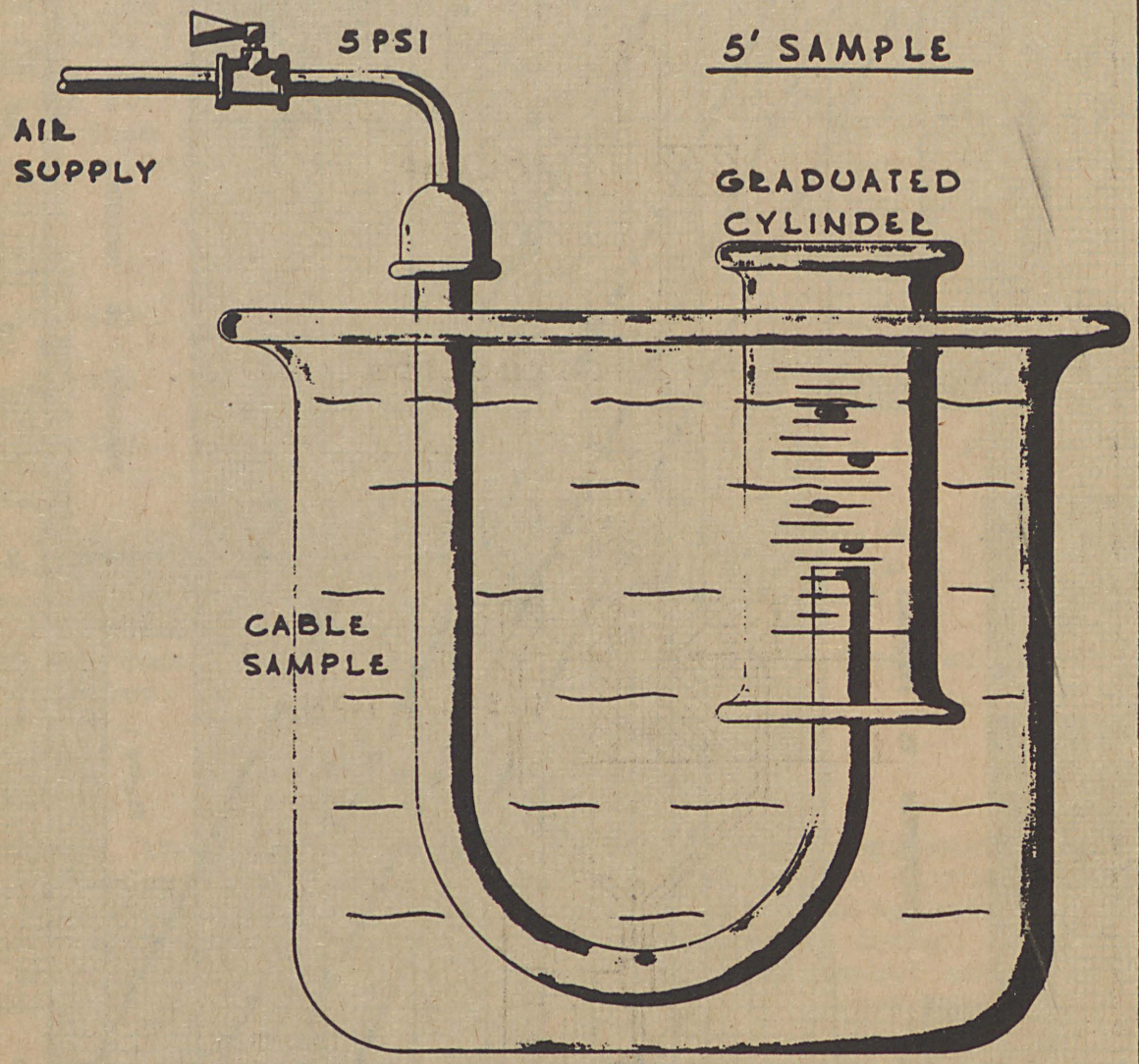

ATTENUATION VS FREQUENCY
JT-2340
JT-2412
JT-2500
JT-2750
DECIBELS PER HUNDRED FEET
2.0
1.5
1.0
0.5
0.4
0.3
0.2
0.15
FREQUENCY IN MEGAHERTZ
10
50
100
200
300
4 5 6 7 8 9 1 1.5 2 2.5 3 4 5 6 7 8 9 1 1.5 2 2.5 3 4 5

Figure 1

LEAK TEST



RATE

JT1412 - 0.027 $IN.^3/HR.$

JT2412 - 0.046 $IN.^3/HR.$

FIG*2

ADHESION TEST

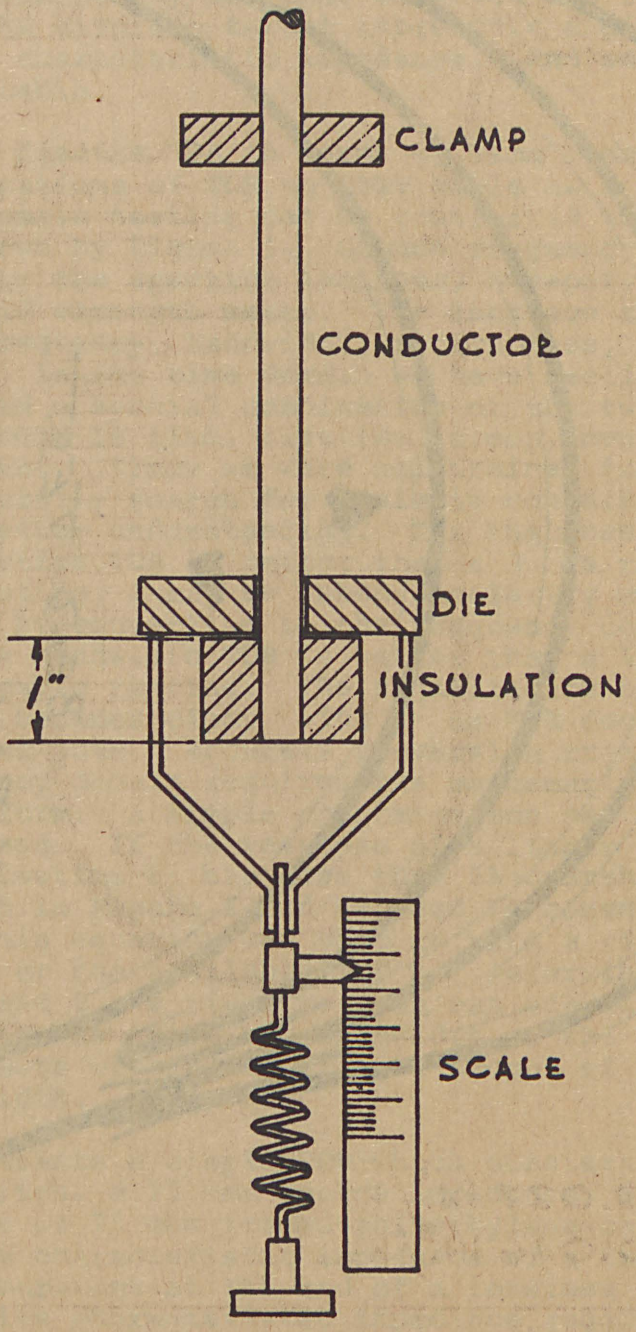
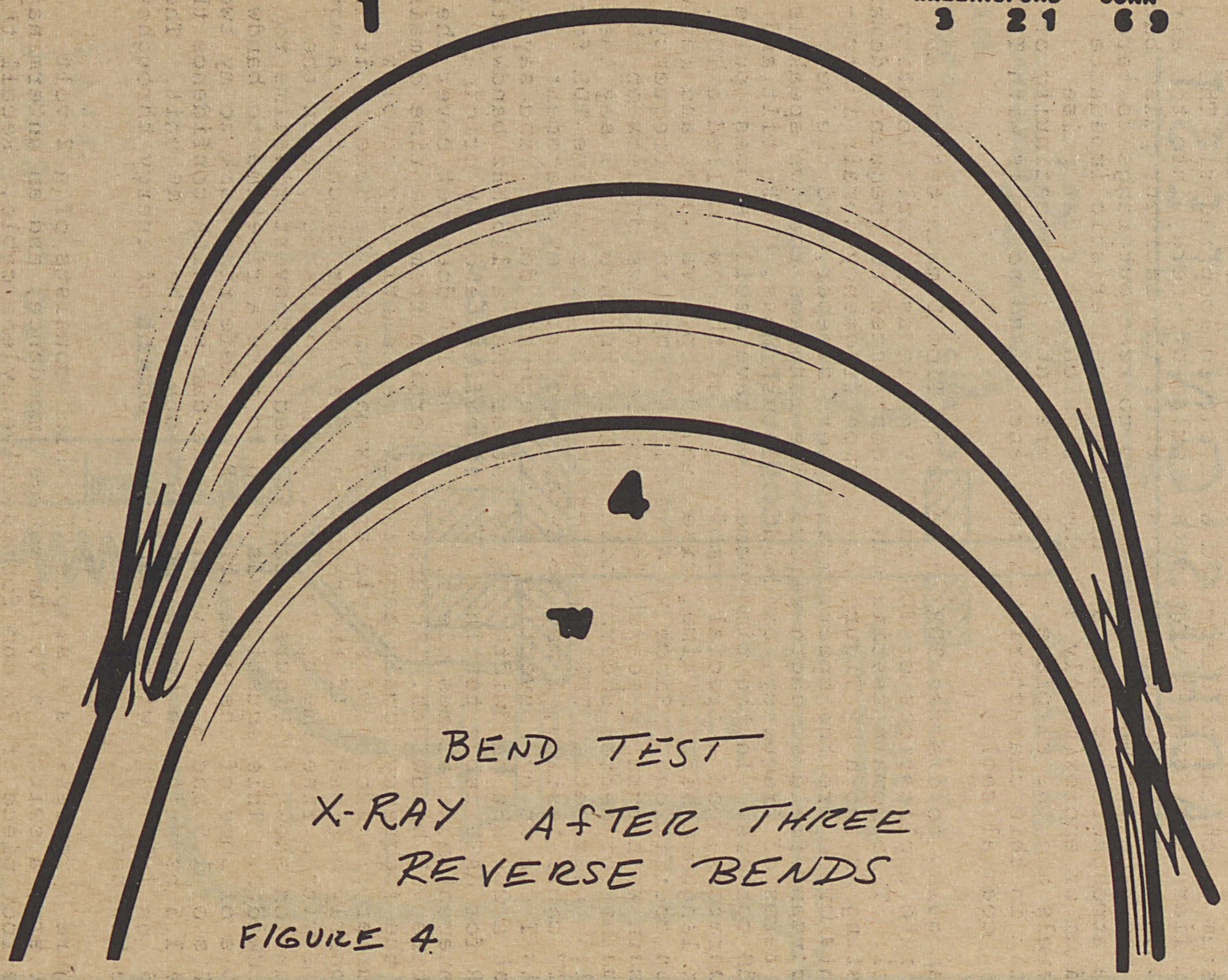


FIG. #3

INDUSTRIAL TEST LAB
WALLINGFORD CONN
3 21 69



BEND TEST
X-RAY AFTER THREE
REVERSE BENDS

FIGURE 4.

RONALD D. LOWE

Time Domain Reflectometry (TDR) is a measurement made in a system which can be described as a closed loop radar. The familiar radar system transmits a pulse of energy into the air. A target, an airplane, reflects part of the incident pulse back to the receiver which is calibrated to read out range to target. The atmosphere represents a uniform characteristic impedance medium of approximately 300 ohms in which the radar pulse travels and the airplane target represents a discontinuity or a fault in this characteristic impedance. And so it is with TDR on a coaxial cable.

I am going to discuss TDR in terms of Time Domain testing and go into applications of TDR on CATV cable as a fault locating tool. Time Domain testing can be contrasted to frequency domain testing as shown by Figure 1. Common frequency domain instruments in use are the spectrum analyzer, sweeper, and the very important field strength meter. The language that we speak is in terms of frequency, bandwidth, return loss, VSWR, tilt and 3 dB corners. In the time domain we have oscilloscopes, pulse generators, and a special combination of the two called a TDR. Our language here is time, risetime, droop, overshoot and reflection coefficient. Since we were all trained in the frequency domain we naturally search for a simple conversion between the domains for better understanding. For instance; if I say that a 1.5 ns risetime TDR is better than a 3 ns risetime TDR for CATV cable testing, I may be asked to clarify my statement. This I can do by converting to the frequency domain and saying that a 230 MHz bandwidth TDR is better than a 115 MHz bandwidth TDR for CATV cable testing. The significance of my original statement now becomes clear. The 3 ns TDR does not cover the entire VHF bandwidth. Accurate conversion from the time domain to the frequency domain requires the mathematically complex Fourier Transform. A simple approximation can be made if it is properly defined. If the response of a linear circuit to a square wave with a risetime t_r has less than 5% overshoot, then the equation shown in Figure 2 can be used to convert risetime to bandwidth. This equation was used to make a risetime to bandwidth table of some of the available TDR's. Referring back to my two TDR's of 1.5 and 3 ns risetime, one can say with confidence that the 1.5 ns unit has twice the bandwidth of the 3 ns unit. The 1.5 ns TDR tests with a significant amount of energy throughout the VHF bandwidth.

Figure 3 represents a simple TDR which consists of a 2 volt battery, a switch, a 75 ohm source impedance, and an unterminated one-foot piece of 75 ohm foamed-polyethylene cable. Recall the concept of the characteristic impedance of a transmission line. Impedance measurement at the end of a lossless terminated coax cable yields its characteristic impedance regardless of the length of line. We shall plot the voltage versus time at point A at the time the switch is closed. At time t = 0 + the voltage at A rises

to 1 volt showing the voltage divider action of the source resistor and the 75 ohm cable. The voltage wavefront has propagated down the line, banged into the open circuit, and has been reflected with a 100% reflection. The wavefront at time t arrives at point A raising the voltage to 2 volts. The relative velocity of propagation in foam coax is 0.81 which gives us an actual velocity of 800 X 10^6 ft/sec. Time t can be calculated to be t = 2L/V = 2 ft./800 X 10^6 ft/sec = 2.50 n sec. If you want to measure a foot of cable you need a system that will resolve 1 to 2 nsec or approximately 300 MHz bandwidth. Figure 4 will allow me to clarify this concept of % reflection that I used in the previous statement. ρ = % reflection divided by 100, can be completely defined around 3 examples of our TDR. We will define a ρ of 0 if the cable is properly terminated, a +1 if the cable is open and a -1 if the cable is shorted. The equation derived from these conditions is

$$\rho = \frac{z_1 - z_o}{z_1 + z_o}.$$

The standard TDR step display is really a unique impedance meter in disguise. Rewriting the equation to get

$$z_1 = z_o \times \frac{(1 + \rho)}{(1 - \rho)}$$

you can determine the impedance magnitude at the source and at every point on the cable to the load.

The next characteristic of TDR I will discuss is that of resolution. There are two types of resolution that we must deal with for fault location, display resolution and fault resolution. The display resolution of a TDR can be determined from the front panel controls and the CRT graticle. Figure 5 is an example of how to determine it. With the distance switch set to 500 ft/div the expand switch to X10 and 5 graticle lines per division we have a display resolution of 500/(5 x 10) = 10 ft. On the 5 ft/div range the display resolution would be 5/(5 X 10) = 0.1 ft. This specification tells you nothing about the instrument's capability of displaying these short lengths of cable, as that information is all tied up in fault resolution. Fault resolution does not have an acceptable definition at this time. One definition offered is that of echo separation. Given two faults on a coax cable, how close together can they be before they merge into one apparent fault on the TDR? $S = vt_r/4$. For example, to evaluate an in-line tap installed on foam cable, you would want to be able to distinguish the input and output connectors. If the tap is 6 inches long, what system risetime do you need?

$$t_r = \frac{4s}{v} = \frac{4 \times 0.5}{800 \times 10^6} = 2.5 \text{ ns.}$$

A TDR with lower bandwidth will display a blob instead of two blips. You do not need to go very far down in bandwidth before even the blob disappears completely. It is clear that in order to display reactive faults and impedance variations in the VHF frequency range, the TDR must have a system risetime on the order of 1 to 2 ns.

You can create problems if your TDR has too much fault resolution. A 200 ps risetime TDR will test your cable over a 1.75 GHz bandwidth. The problems created are those of interpretation of the display. Every connector, tap, and even the cable itself will appear faulty and it probably is at 1.75 GHz. The attenuation of the cable at these frequencies is so great that the CRT presentation changes drastically as one proceeds out along the cable's displayed length.

There are two types of display for TDR instruments, the step and the impulse. Each has its own merits, neither by itself is a panacea. The impulse display or pulse echo test has been used for years by the power utilities industry. Disconnect line amplifiers when using one of these instruments. Some instruments have output pulses as high as 600 volts and can cause damage to the system. The silicon transistor used in the input circuit of your line amplifiers will break down at 5 volts reverse base-emitter so pulse amplitude output should be a guideline on your choice of a TDR. The impulse usually is specified by the pulse width rather than risetime. Since we are interested in reflected energy in the VHF bandwidth, the risetime of the impulse is also important and should be specified. If the impulse has a constant width for all distance ranges, it will give you an indication of cable loss in the bandwidth. The impulse suffers the same attenuation that your TV signal does. Cable loss due to water is evident with this test. The impulse will allow you to evaluate the match of capacitively coupled line terminations and you can TDR through transformer coupled taps without the ringing that is seen on the step display. The impulse does not give impedance information. Referring to Figure 6 we see the ambiguity present in impulse testing. Two test setups are given. The first using a length of 75 ohm cable joined to a length of 50 ohm cable with a good connector. The second set is two lengths of 75 ohm cable joined by a faulty connector. The impulse display looks the same in both setups. The step display is needed here to determine the true fault. The step allows one to TDR over very wide bandwidth without overloading the circuits under test. It is the classic precision display for impedance measurement in the time domain. Attenuation of high frequencies in the step mode causes rounding of the corners and loss of fault resolution. The reason that you cannot TDR through some of the transformer coupled taps with a step is because of the low frequency resonance of the coupling capacitor with the transformer primary of the tap. Figure 7 illustrates this.

It is possible to get a wrong answer on a TDR if you TDR a cable that is longer than the maximum range of the TDR. The TDR timing system is designed to send out a pulse, display a reflection, if any, and then to repeat the process. If the instrument generates a second pulse before the reflection returns, the TDR can show a reflection in the wrong place on the display.

One might assume that if he had a 10,000 ft cable and a 5,000 ft TDR capability, he could accurately check the cable at each end. If the cable is good and is properly terminated the TDR will indicate correctly. Figure 8 shows an example where the TDR yields a different answer for each end of the cable.

We haven't said much about what constitutes a fault in terms of magnitude or % reflection. Scanning data sheets for the return loss, typical taps and amplifier inputs and outputs, it looks like the present equipment has approximately 20 dB return loss. This transforms into a % reflection of 10 on a worst case basis. Reflection from good taps, amplifiers, and hardware should be smaller than that number. Wideband TDR's, all sampling oscilloscopes, have tremendous dynamic range. The vertical axis can be expanded 20 to 100 times without overloading the scope.

Figure 9 represents a typical section of good cable. There are a few operating procedures that I would like to suggest in order to get the most performance out of your instrument.

A TDR is used to test a de-energized cable. Turn off the amplifier power supply. Break only one water seal at point A leaving amplifier at B connected. Set up your TDR with a test cable. You are faced with the problem of connecting to a piece of .412 or .5 inch cable so why not do it with a known length of drop wire. This allows you to check your TDR for calibration. Before connecting, short the cable to remove any static charge that may be present.

Let's look at this piece of cable with our TDR doing both a step and an impulse test. Referring to Figure 10 see the step display showing the four inline taps and the end of the cable which looks like an open circuit due to the coupling capacitor. The upward tilt in the display is due to series dc resistance of the cable. The rounding of blips is due to the attenuation of high frequencies. Looking at the impulse display of the same line we can now evaluate the amplifier as a 75 ohm cable termination. If #1 tap is defective it would appear as a larger blip. Locating of the tap is no problem so distance calibration is not used in this case. Your procedure should be to repair the tap and then retest the line. When using TDR on a line that has several faults the first fault dominates. Only after it is repaired can you make a decision on the next fault. The reason is that a fixed bundle of energy is put on the line in the form of a pulse and a fault is evaluated on the amount of pulse that is reflected. The pulse that passes the first fault is reduced in energy. The

second fault has less energy to work with and will appear smaller than it really is.

Suppose a fault was indicated between tap #2 and #3. Your accuracy in locating the defective point on the cable is greater if you range from tap #2 using instrument magnification than from the connector of the instrument. In most cases you can locate the trouble within a foot of length by this method. There are errors in distance measurement on TDR that we as instrument manufacturers cannot control. Taps can introduce delay to the TDR pulse which you may mistake for instrument calibration error. The dielectric constant of cable has a nominal tolerance of ± 3% which means that you may be off 1.7 feet in 100 feet with a perfect instrument. In a buried installation you have a potential error due to cable feet versus ground feet. Every time the cable comes up to a tap there are one or two feet of cable in the vertical direction that you must account for when you measure out to your digging point. Where precision is necessary you can TDR from both ends of the cable and average the readings.

This paper has been an attempt to help you to better understand TDR measurements and to convince you that it can be a useful fault-locating tool. In conclusion I would like to refer you to Figure 11 which is a summary of the instrument specifications that we are suggesting as necessary and useful. This paper is a result of studies of present TDR instruments used by CATV companies and tests in the Delcon CATV Test Cable Laboratory. Delcon is a division of Hewlett-Packard Company in Mountain View, California.

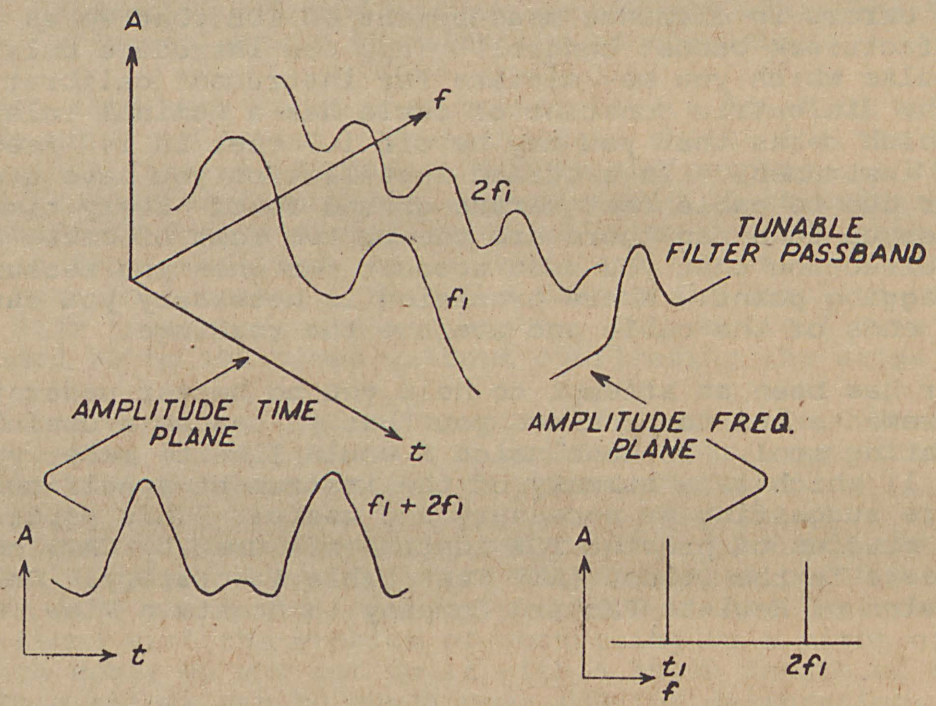

A
f
2f1
f1
TUNABLE
FILTER PASSBAND
AMPLITUDE TIME
PLANE
t
AMPLITUDE FREQ.
PLANE
f1 + 2f1
A
t
A
t1
f
2f1

FIG. 1

$$BW = \frac{0.35}{t_r}$$

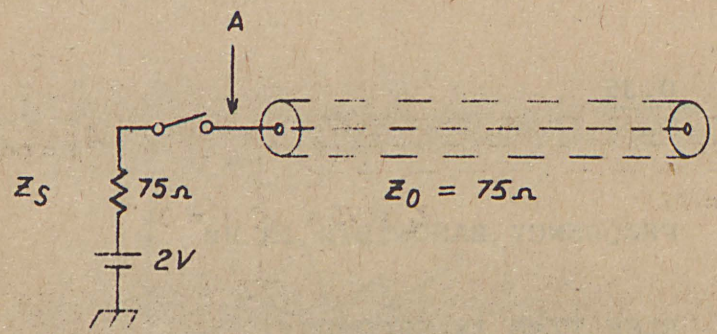
BW = FREQUENCY BANDWIDTH IN Hz

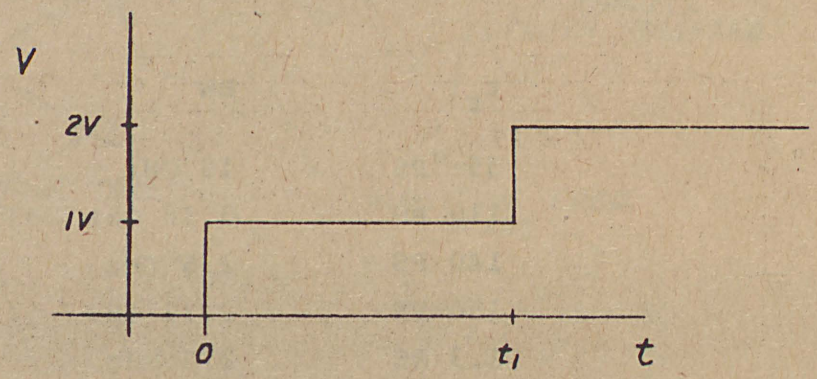
t_r = RISE TIME IN SECONDS

t_r	BW
35 PS	10 GHz
110 PS	3.18 GHz
140 PS	2.5 GHz
150 PS	2.32 GHz
1.3 NS	270 MHz
5 NS	70 MHz

SOME PRESENTLY AVAILABLE TDR RISE TIMES AND THEIR APPROXIMATE BANDWIDTHS

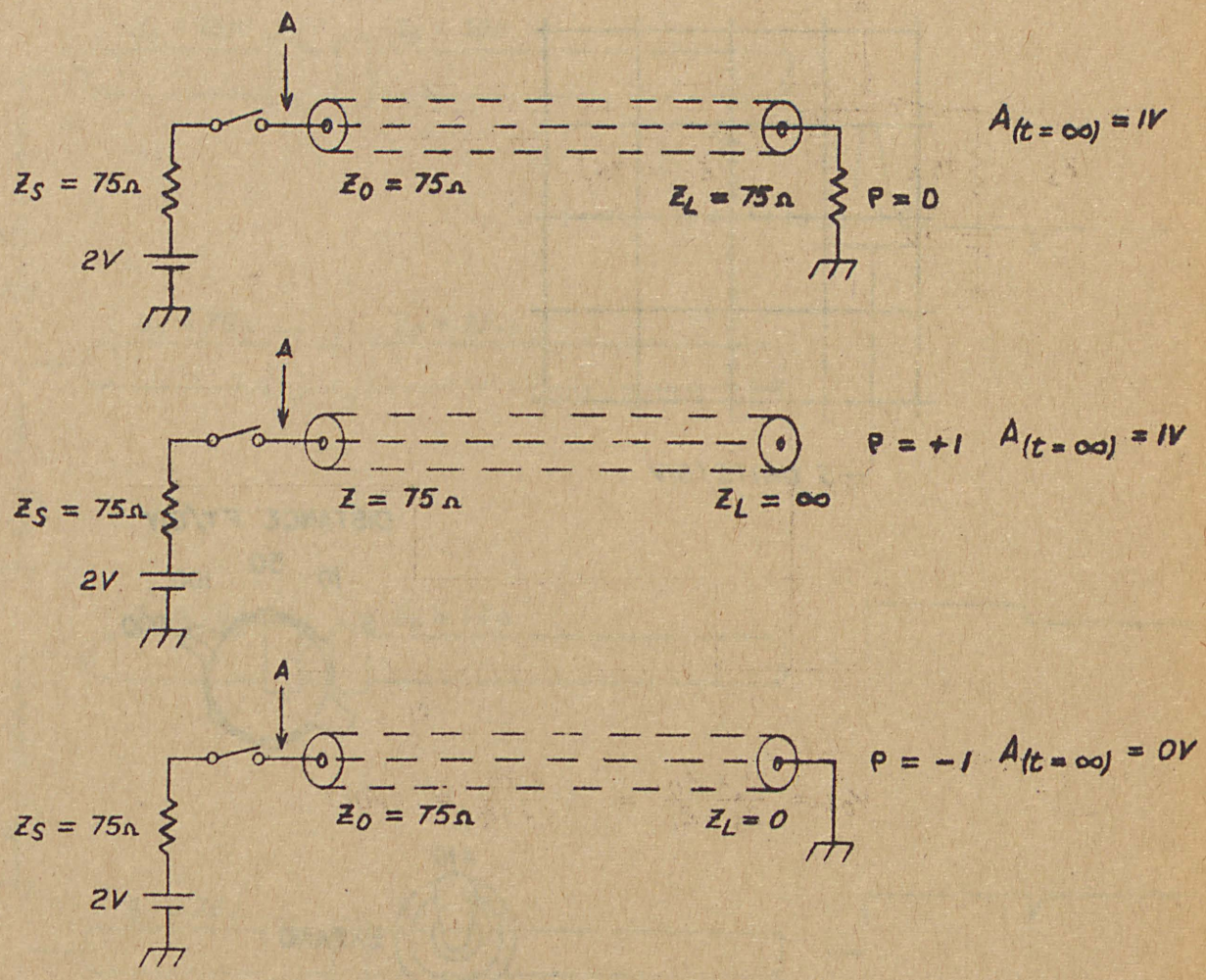
FIG. 2





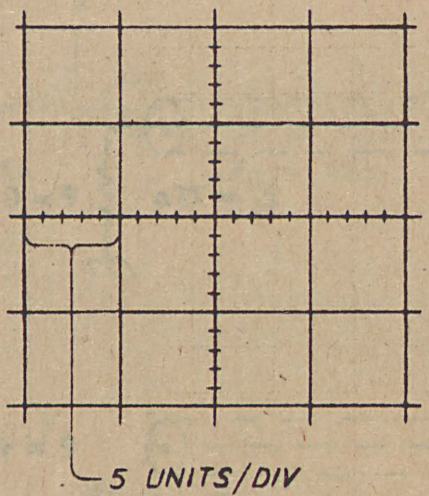
$$V_{0+} = \frac{2 \times Z_0}{Z_S + Z_0} = \frac{2 \times 75}{75 + 75} = 1 \text{ VOLT}$$

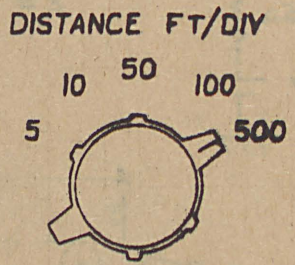
FIG. 3

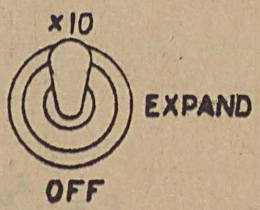


$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad 100\,\rho = \%\ \text{REFLECTION}$$

FIG. 4







$$\text{DISPLAY RESOLUTION} = \frac{500}{5 \times 10} = 10\ \text{ft}$$

FIG. 5

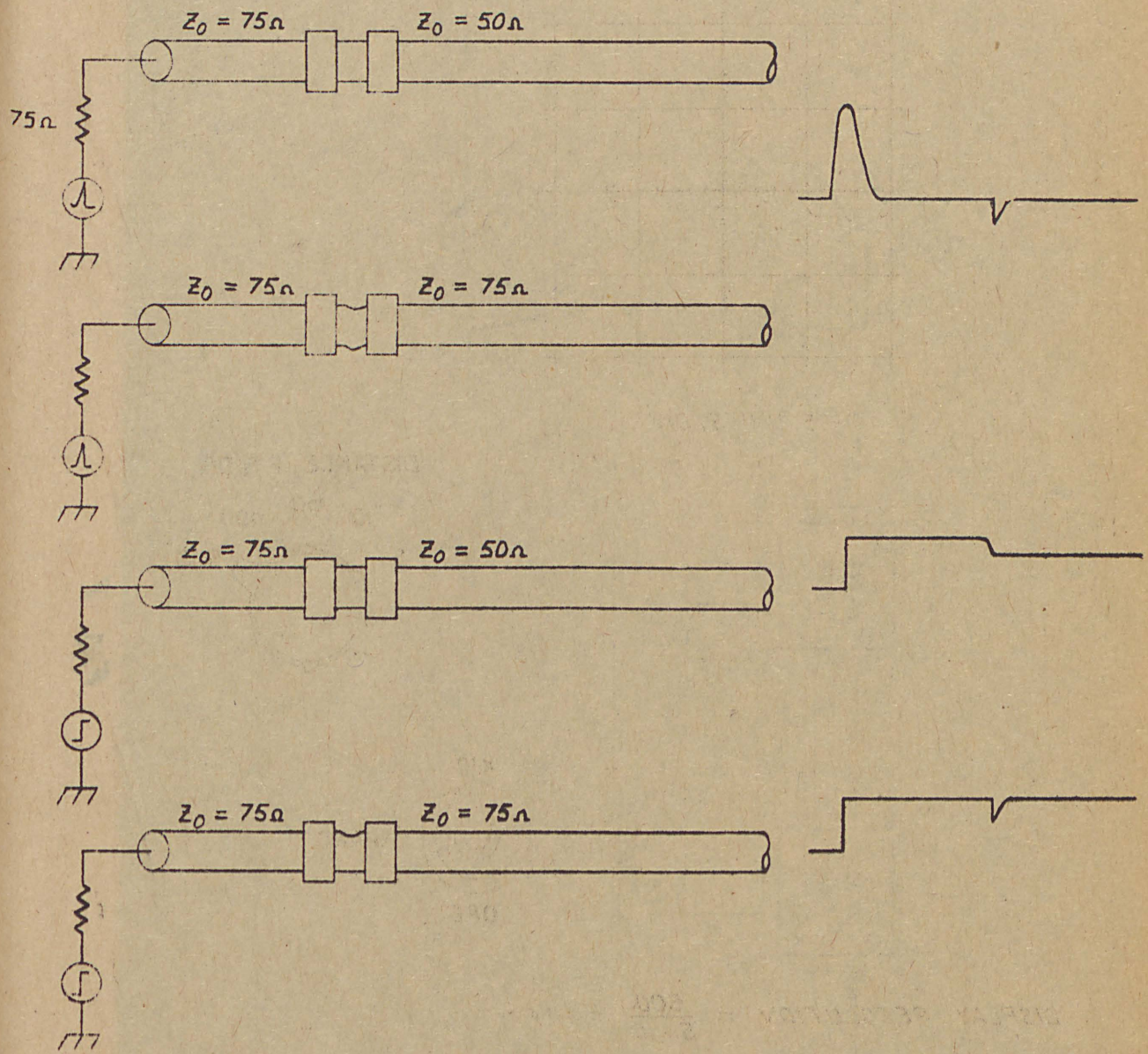

$Z_0 = 75\Omega$
$Z_0 = 50\Omega$
75Ω
$Z_0 = 75\Omega$
$Z_0 = 75\Omega$
$Z_0 = 75\Omega$
$Z_0 = 50\Omega$
$Z_0 = 75\Omega$
$Z_0 = 75\Omega$

FIG. 6

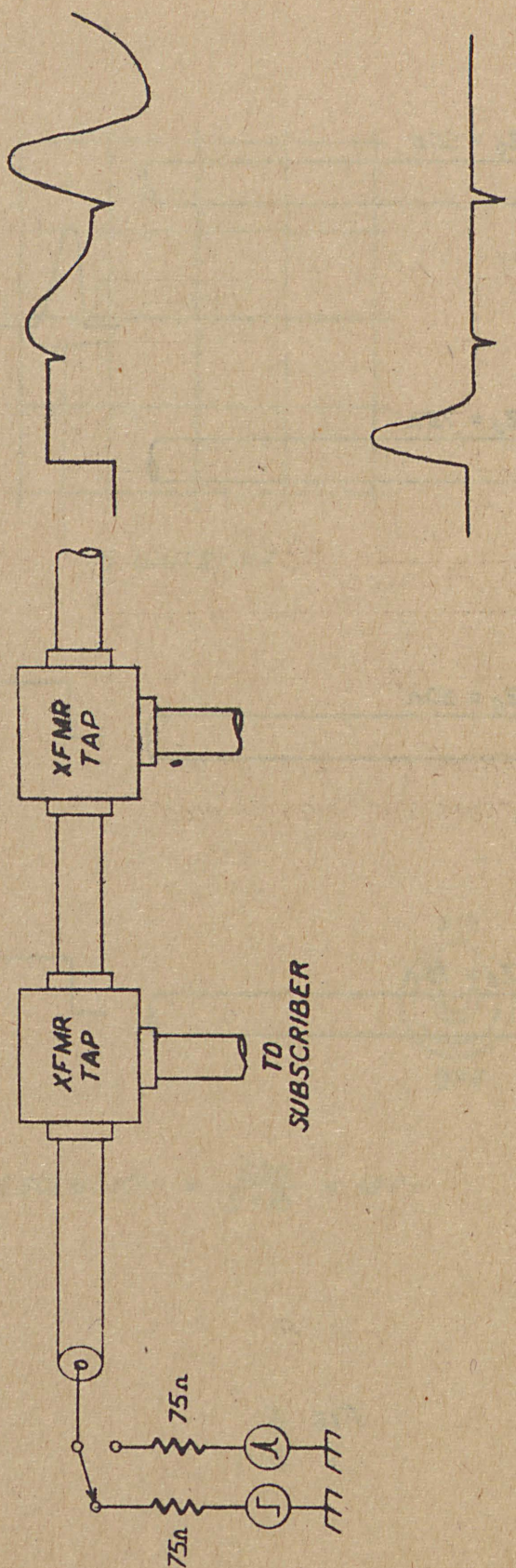
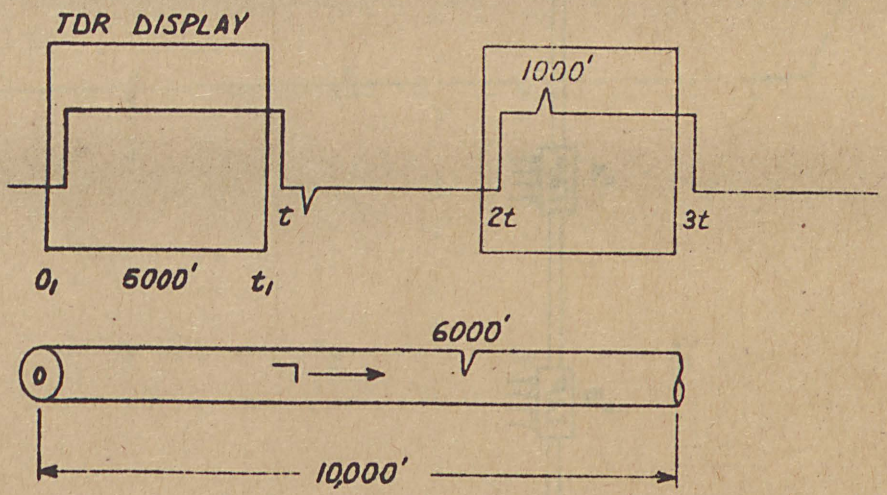


FIG. 7



TDR FROM THE LEFT = 1000'

TDR FROM THE RIGHT = 4000'

FIG. 8

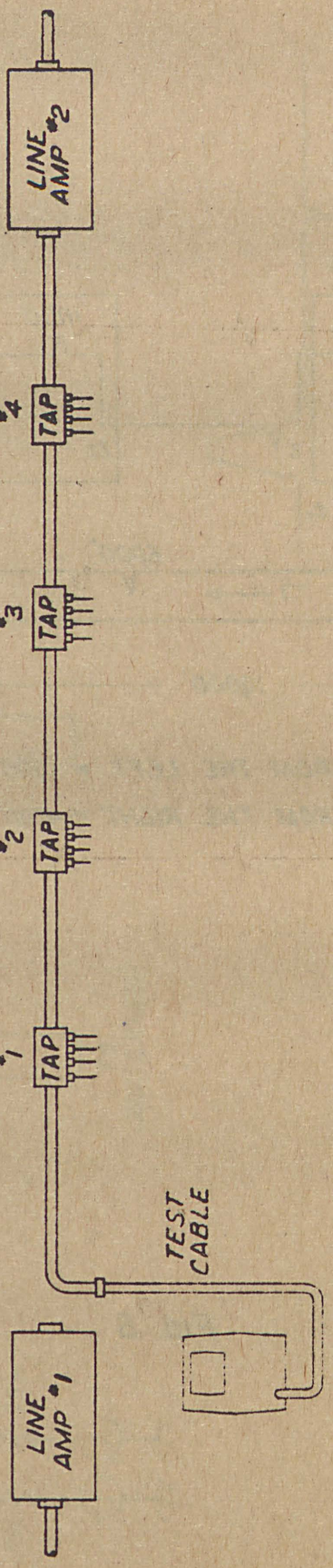


FIG. 9

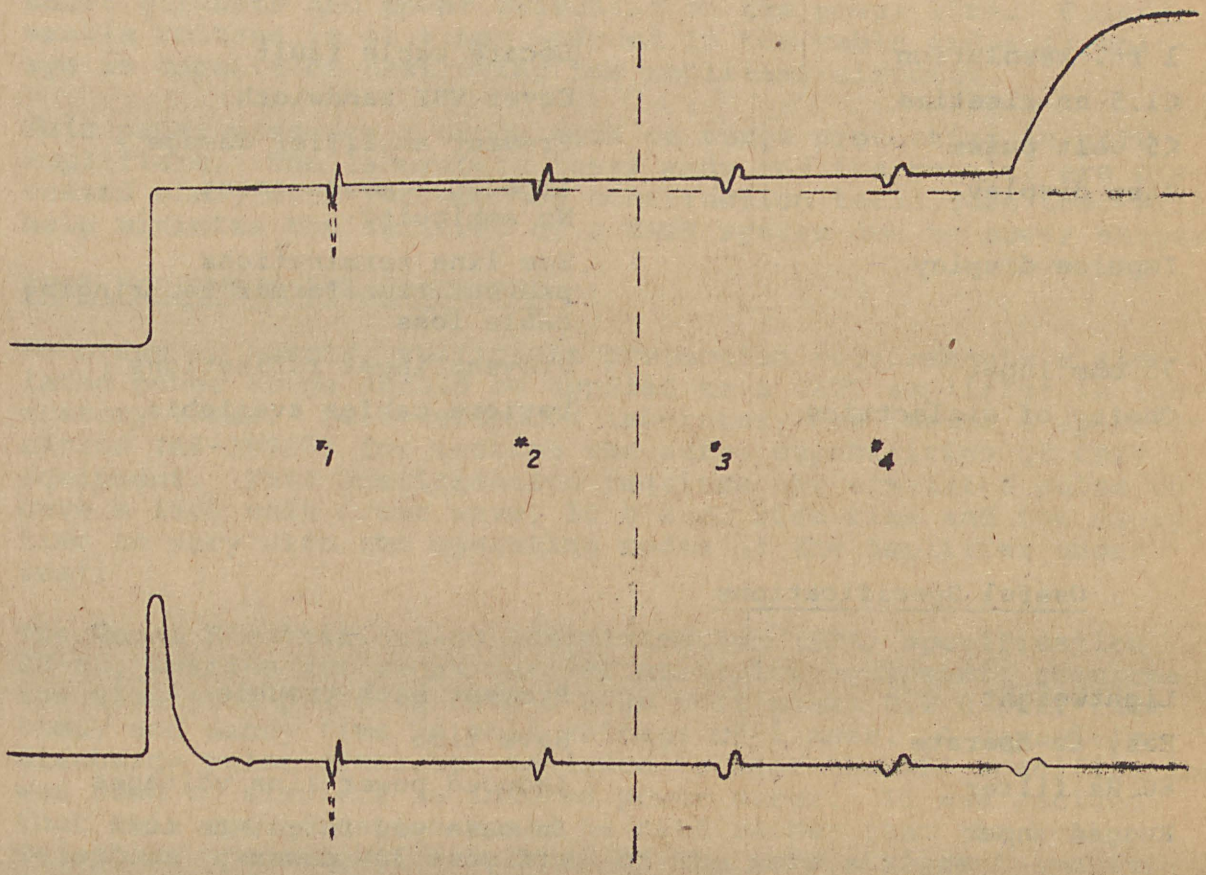


FIG. 10

Necessary Specifications	Reason
1. 1 ft. resolution	Locate cable fault
2. <1.5 ns risetime	Cover VHF bandwidth
3. <5 volt pulse	Prevent amplifier damage
4. Step display	Impedance measurement No ambiguity
5. Impulse display	See line terminations prevent transformer tap ringing cable loss
6. 75 ohm input	Prevent input reflections
7. Choice of dielectrics	Various cables available

Useful Specifications	
1. Lightweight	Prevent back trouble
2. Easy to operate	Save time
3. 60 Hz filter	Induced power line voltages
4. Rugged input	In case you forget to turn off your 30V power

Fig. 11

BERT ARNOLD

CATV distribution systems are subject to transients due to electrical fields in the atmosphere initiated by lightning, short circuits and power switching on the power line. Considerable voltage is at times induced in the cable and this voltage is capable of destroying the amplifier circuits.

This paper presents a study made on surge protection in CATV amplifiers. The laboratory tests made and the results are discussed along with recommended construction techniques that will help minimize the failures of a CATV system due to power surges.

TEST EQUIPMENT AND PROCEDURE

In order to specify sufficient protection requirements a simulated power surge should be applied to a CATV amplifier in laboratory tests. Bell Telephone laboratory has issued a specification (KS-19925) for testing the surge capabilities of CATV equipment. This specification requires the simulated pulse to have a 1500 volt crest wave, 10 u sec. rise time and the decay time to vary with the operating modes of the amplifier under test.

The Rural Electrification Administration (REA) specification PE-60, written for trunk carrier multiplex equipment, requires the simulated pulse to have a 2000 volt peak, 0.2 u sec. rise time, and decay time to half voltage of 1 msec. A capacitive discharge pulse generator designed to meet the REA specification was used to simulate an induced power surge. It was decided that this specification would be used rather than the Bell Telephone specification because of the more stringent requirements. The faster rise time of the REA specification causes the energy induced to be greater. The energy of the pulse content of a surge is dependent on its peak voltage and wave shape (i.e., rise time and decay time). A short rise time will provide a more severe test of inductive circuit elements, and for a given decay time the shorter the rise, the higher will be the total energy of the surge. For a discussion on the derivation of energy as a function of time, refer to the Bell System Technical Journal, March 1961, pages 547-569.

A 36 volt RMS power supply was used for AC powering of the amplifiers in order to simulate as close as possible the actual conditions of an operating system. However, no r-f signal was fed into the amplifier due to the possibility of damage to our head end equipment. The tests were made with powering on the input and on the output.

RESULTS

The first step was to determine what components were breaking down due to power surges and then what was necessary to protect

these components. The pulse generator was connected to the test amplifier and a pulse was applied. The amplitude of the pulse was increased in approximately 50 volt increments until breakdown occurred. The regulating transistor in the DC supply shorted with a 250 volt pulse along with the reference diode. Increasing the pulse, in the 50 volt steps, to 400 volts shorted the two rectifier diodes which became reverse biased due to the positive pulse. The 400 volt pulse also shorted all r-f transistors in the amplifier. It was noted that the pulse broke down the r-f transistors through the DC supply circuit and not through the r-f circuit due to a DC blocking capacitor in the r-f circuit which was undamaged by the high-voltage pulse.

To protect the internal power supply of the amplifier and the associated r-f circuits, a voltage limiter would have to be placed at each powering terminal. A power surge can be either negative or positive and, therefore, the voltage limiter or surge arrester would have to be capable of operating under these conditions. Various surge arresters were evaluated which resulted in the selection of the gas tube type surge arrester.

The gas tube surge arresters consist of a discharge gap sealed in a rare gas atmosphere. When an overvoltage is applied to the arrester, the gas is ionized and an electrical short circuit is produced across the discharge gap of the arrester. The arrester has a high current carrying capacity and normally returns to the non-conducting state following each overvoltage. A 90 volt surge arrester was chosen to limit the voltage as low as possible without interfering with the AC powering.

Two problems were encountered while testing the amplifier with the surge arresters installed on each powering terminal. The turn on time of the surge arrester was marginal compared to the rise time of the pulse, and the voltage limit varied between arresters. Since the relative turn-on time of the arrester was too long, the internal power supply could still be damaged by an induced voltage with a fast rise-time.

With a voltage induced in the input of the amplifier, the tolerance of the voltage limit could allow the output arrester to fire before the input arrester. This would result in very large currents being drawn on the through powering line of the amplifier until the input arrester fired. The possibility of the through powering line being damaged would be a problem.

A time delay was therefore incorporated into the powering circuit to allow the surge arrester sufficient time to respond to the pulse. An r-f choke was already in each powering circuit and it was used as the inductance in the delay network. The r-f bypass capacitor following each choke was increased in value to give the desired time delay (Figure 1). For complete protection of the amplifier circuits all input and output terminals to which the AC power may be applied should have separate surge protection.

Another area of concern is current protection. If the internal power supply of the amplifier is not current limited, a sustained overvoltage could cause the power supply to draw excessive current sufficient to damage components. A simple method of limiting these current surges is to place a small value resistor in series with the rectifier bridge (Figure 1).

SYSTEM CONSTRUCTION

Even with the above protection incorporated in each amplifier, it is possible for an amplifier in an actual system to be damaged by power surges if the system is not properly constructed.

Each amplifier in a cascade should be grounded with its own grounding rod to insure that the amplifier remains at ground potential. Should it be necessary to connect to the power company's ground rod, the possibility exists that the amplifier may be damaged from lightning or switching surges on the power line. If large transients are induced in the power lines, large currents can flow through the ground rod to ground. These large currents will cause a potential to be developed along the grounding rod which will result in floating the amplifier above ground. Therefore, if a voltage surge is induced in the amplifier at this time the surge arrester will not fire due to the ground potential of the amplifier being as large as the surge. This would permit large voltage surges to be passed through the amplifier to the next amplifiers in the cascade until the differential voltage across the arrester was large enough to cause it to fire. Once the arrester fired, very large currents could be drawn through the preceding amplifiers causing damage in the "through powering" lead.

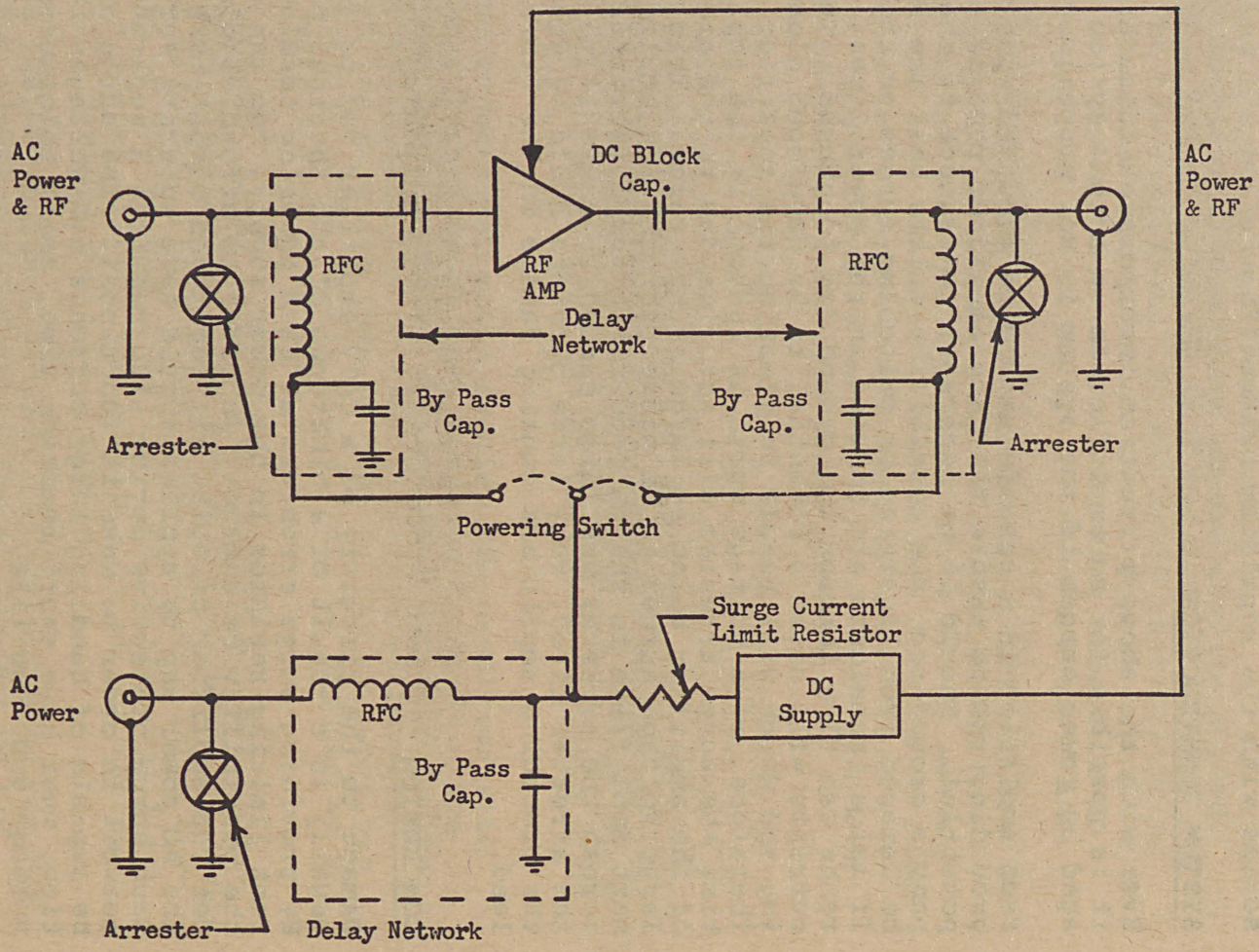
CONCLUSION

Damage to the circuitry of a CATV amplifier due to voltage surges usually is a result of a breakdown of the internal power supply. By providing surge arresters at each powering terminal and a current limiting resistor in the power supply, one can greatly reduce the possibility of damage. In order to afford complete protection for the amplifier circuits all input and output terminals to which the AC power may be applied should have separate surge protection. Each surge protective device also requires a separate LC delay network in order to make it functional. The surge arresters must be capable of handling large currents and voltages in either direction, must have short reaction time, small tolerances of firing voltage and long life.

A CATV system should be constructed with good grounding at each amplifier in the cascade. If possible, the ground used by the telephone company or the power company should not be used by the CATV system.

Figure 1

Surge Protection



GEORGE P. DIXON

INTRODUCTION

The aim of this paper is to review the basic concepts of heat generation and transfer from the standpoint of the technical man with CATV operational responsibility.

The paper will also present some information, which it is hoped will be found useful in solving specific practical problems imposed by the fact that the CATV system must operate over a wide ambient temperature range.

It might be argued that the thermal design problems belong to the equipment designer and to a certain degree this is true. However, it should be pointed out that the final equipment operating temperatures can be strongly influenced by installation techniques and location. The operating engineer or technician is very often much closer to this problem than the designer.

This paper is not suggesting that the operating engineer should plunge into realm of mathematics of heat transfer but rather to point out that the investment of a little time to understanding the principles plus a modest investment in some temperature measuring equipment can pay off in improved reliability and performance.

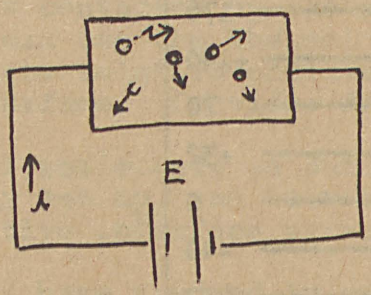
I have in mind some specific situation where unreliability was "installed in". To illustrate, I know of an installation in a boiler room where a few changes in the housing could have avoided a lot of grief. I suspect also that most pedestal installations are unnecessarily over heated and could be vastly improved by making a few basic changes. I am sure there are many situations where AC input voltage on amplifiers are greater than required, a procedure that usually does nothing more than increase operating temperature.

THE NATURE OF HEAT AND HEAT TRANSFER

Heat is a form of energy, thermal energy. The heat of a body is the total kinetic energy of the random motions of the molecules of the body. In understanding the behavior of heat, it is wise to keep, firmly in mind, this concept of molecules moving at increasing velocity as heat is applied.

Heat is generated by conversion of other forms of energy, such as electrical energy into thermal energy. Hence, if electrical energy is pumped into something like a resistor at a constant rate (constant power input) without providing a means of removing it, the thermal energy of the body (resistor) will increase until something drastic happens to the molecular bonds. As you know, it is the matter of removing the thermal energy from the resistor which presents the practical engineering problems

(the study of heat transfer). I have attempted to show schematically the pertinent relations for heat generation and transfer in Figure 1.



Q = TOTAL HEAT

P = ELECTRICAL POWER = HEAT INPUT PER UNIT TIME

Q = CONSTANT + P x ΔT - LOSS TO AIR

Q = $\sum \frac{1}{2} mv^2$ = SUM OF KINETIC ENERGIES

BASIC RELATIONS HEAT GENERATION

FIGURE 1

Fortunately, it is not necessary to have a precise understanding of the physics involved in order to deal with heat. Like many other engineering problems, we handle this by devising ways to measure the thermal state of the bodies and mathematical laws which will predict the behavior of heat and various substances at varying thermal states.

It turns out that one can also draw thermal circuit diagrams in a similar fashion to electrical circuitry. This allows us to conveniently analyze the flow process by familiar electrical methods like Ohm's law. An illustration of these approaches will be covered later in this paper, utilizing a typical pedestal mounted amplifier installation as an example. A summary of important data for use in thermal calculations is included at the end of this paper.

BASIC LAWS AND DEFINITIONS

TEMPERATURE

Temperature is the yardstick which is used to measure the thermal state of a body. It is a measure of the thermal state on some arbitrary numerical scale. The three commonly used scales are compared in Figure 2 at approximate temperatures which concern us in CATV work.

RELATIONSHIP OF VARIOUS TEMPERATURE SCALES

ABSOLUTE	CENTIGRADE	FAHRENHEIT
+374	+100	212
353	+80	176
333	+60	+140
294	+21	70
+273	0	+32
+256	-17	0
+233	-40	-40
0	-273	-459

FIGURE 2

It should be noted that on the absolute scale the temperature changes which concern us represent a fairly small percentage of the absolute temperature. This is significant, since it turns out that radiation of heat and intrinsic electrical noise are strongly dependent on absolute temperature.

HEAT FLOW

Heat flows from one body or substance to another by three basic processes: conduction, convection or radiation.

CONDUCTION

Conduction is the transmission of heat within the body by means of molecular collision. It involves intimate contact of the materials conducting heat. The thermal energy is propagated by direct collision of the molecules of the material.

The relations for calculating temperature drop are illustrated in Figure 3.

From this it can be seen that the thermal resistance of the body (R) is proportional to the length and inversely proportional to area and conductivity of the material. It can be seen that on the basis of this equation, one can draw a circuit diagram comparable to an electrical circuit representing heat flow rate (i.e., watts or BTU per hour) as a constant current and at temperature difference as potential drop.

CONVECTION

Convection is a similar process to conduction except that a fluid (like air) is involved which must flow over the surface.

In this process heat is transferred by conduction to the fluid, which then carries it away as it moves. The movement of the air may be due alone to the fact that the air is heated or it may be due to some force acting on it. This process tends to get quite complicated since the efficiency of the heat transfer depends on shape of the body, as well as the surface area of which is contacted by the moving air. For practical purposes one can use the thermal resistance concept to visualize and calculate relative efficiencies of a convective heat transfer surface. Consider Figure 4.

The thermal resistance as defined for this body, as well as any similar set up, can be used to analyze and or evaluate any convective interface under varying heat flow.

Specialists have studied in great detail the optimum convection surface and considerable data is available in literature. The main points to remember are that the resistance will decrease with increased surface area; but that the surface area to be effective must not restrict flow. It has also been clearly shown that a "short height" area will transfer heat substantially better than a tall one. This is because the air in rising absorbs heat near the bottom and hence, has less heat absorption ability at the top of the area.

Forced air cooling will in general greatly increase the efficiency of heat transfer and is widely used to obtain efficient heat transfer in electronic equipment. For obvious reasons, its use in CATV is limited to headend equipment or in special situations.

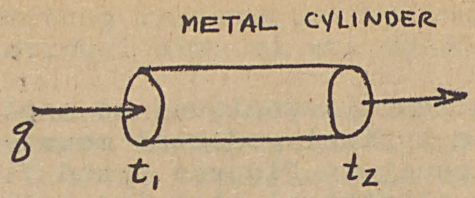
RADIATION

When a body radiates, it transmits energy without the necessity of a medium in the same manner as radio waves. Thermal radiations are emitted by all matter unless at absolute temperature. This energy is absorbed by other matter and reconverted into heat. When the rate of absorption exceeds the rate the receiver emits, then it is a net transfer of radiant energy and unless the heat is removed by some means, the temperature of the receiver will rise.

In CATV environment solar radiation and the absorption of it is a very important consideration. This radiation level has been measured at approximately 250 BTU/hours per square foot at noon on a typical clear and sunny summer day. Where poor thermal conductivity or convection conditions limit cooling by other means, radiation may be a vital part of the heat transfer mechanism from electronic equipment to the atmosphere.

Radiation from a black body follows the low $q = uT^4$. Where T is absolute temperature of the body, u is a constant. The black body is the most efficient radiator and absorber. For

surfaces other than black, only a fraction of the maximum energy will be radiated or absorbed. A fractional coefficient, the emissivity, is used to account for the relative efficiency of the material. Values of this coefficient have been measured for many materials and are recorded in literature.



q HEAT FLOW RATE
K THERMAL CONDUCTIVITY
A CROSS SECTION AREA
R THERMAL RESISTANCE OF CYLINDER

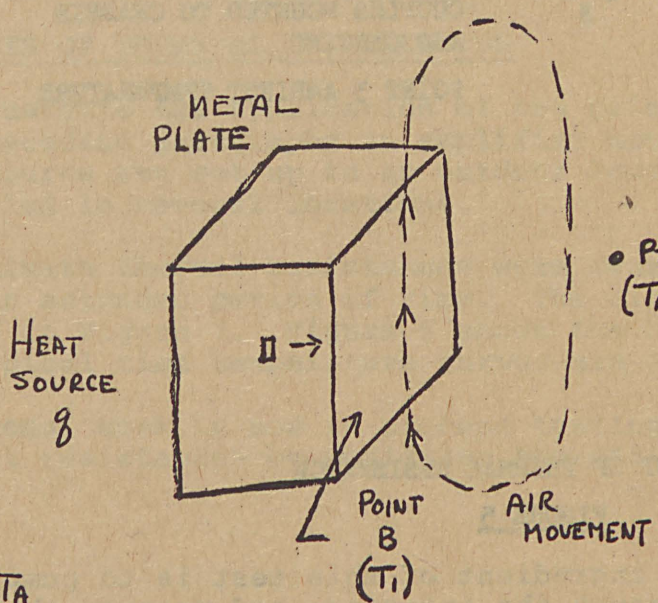
$$q = k\frac{A}{L}(t_1 - t_2)$$

$$q = \frac{t_1 - t_2}{R} \qquad R = \frac{L}{kA}$$

$$I = \frac{E_1 - E_2}{R}$$ (ANALAGOUS ELECT. CIRCUIT)

HEAT FLOW BY CONDUCTION

FIGURE 3



POINT A IS A POINT AT AMBIENT AIR TEMPERATURE

R IS THE THERMAL RESISTANCE BETWEEN THE METAL BLOCK AND AMBIENT AIR

$$R = \frac{T_1 - T_A}{q}$$

$$T_1 - T_A = R \times q$$

HEAT TRANSFER BY CONVECTION

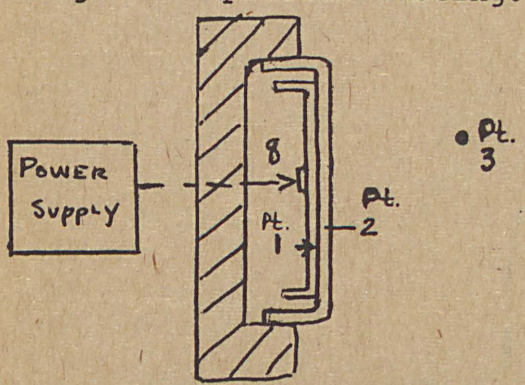
FIGURE 4

ANALYSIS OF THERMAL CIRCUIT

To illustrate the use of equivalent circuit technique, as applied to thermal circuits, I have sketched a typical pedestal mounted amplifier along with an equivalent circuit in Figures 6 and 7. It can be seen from this that like an electrical circuit, a thermal circuit can get quite complicated. However, as in electrical circuit analysis, one can simplify the circuit by neglecting those items which are not likely to cause serious errors. In order to do this one needs to be able to estimate the magnitude of the thermal resistance at the interface in question. This can be done most easily by making temperature rise measurements, however, in many cases involving conduction one can calculate the resistances from the resistivity (conductivity) information in the literature.

A discussion of how to measure thermal resistance can be helpful in understanding this concept.

Figure 5 shows a technicque for measuring the thermal resistance through an amplifier casting.



q CONTROLLED HEAT SOURCE

POINTS 1 & 2 ARE THERMO-COUPLES MOUNTED TO CHASSIS AND CASTING

POINT 3 AMBIENT TEMPERATURE

$$R(1-2) = \frac{t_1 - t_2}{q}$$

$$R(1-3) = \frac{t_1 - t_3}{q}$$

MEASUREMENT OF THERMAL RESISTANCE

FIGURE 5

Note that the necessary ingredient of this test is to pump a known amount of heat through the interface and measure the temperature rise across it. It is not necessary to understand mechanism of actual heat transfer since the thermal resistance gives a coupling coefficient, which relates to the total heat transfer however it occurs. Of course, it is also possible (and in many cases more practical) to measure temperature drops under actual conditions and estimate the limiting thermal resistance. The next step involves attempting to reduce these

limiting resistances by some means such as increasing the cross sectional area of the metal contact to bridge an air gap.

It should be realized that the discussion up to this point has assumed "steady state" condition. By this it is meant that sufficient time has been allowed for the thermal losses to balance out. All materials require a finite quantity of heat (watts for a definite time•period) to raise their temperature a fixed number of degrees. This property is analogous to capacity in an electrical circuit and depends on the mass of the material, as well as the intrinsic properties of the material. The term "specific heat" is used to describe the thermal capacity of the material and the relationship which can be used to calculate time lag is shown below. A constant heat flow is assumed.

$$\text{TIME} = \frac{(\text{SPECIFIC HEAT})(\text{MASS})\Delta T}{\text{WATTS}}$$

The analogous relation for an electrical circuit is

$$\text{TIME} = \frac{Ce}{i} \qquad \frac{(\text{CAPAC})\ \text{VOLTAGE}}{\text{CURRENT}}$$

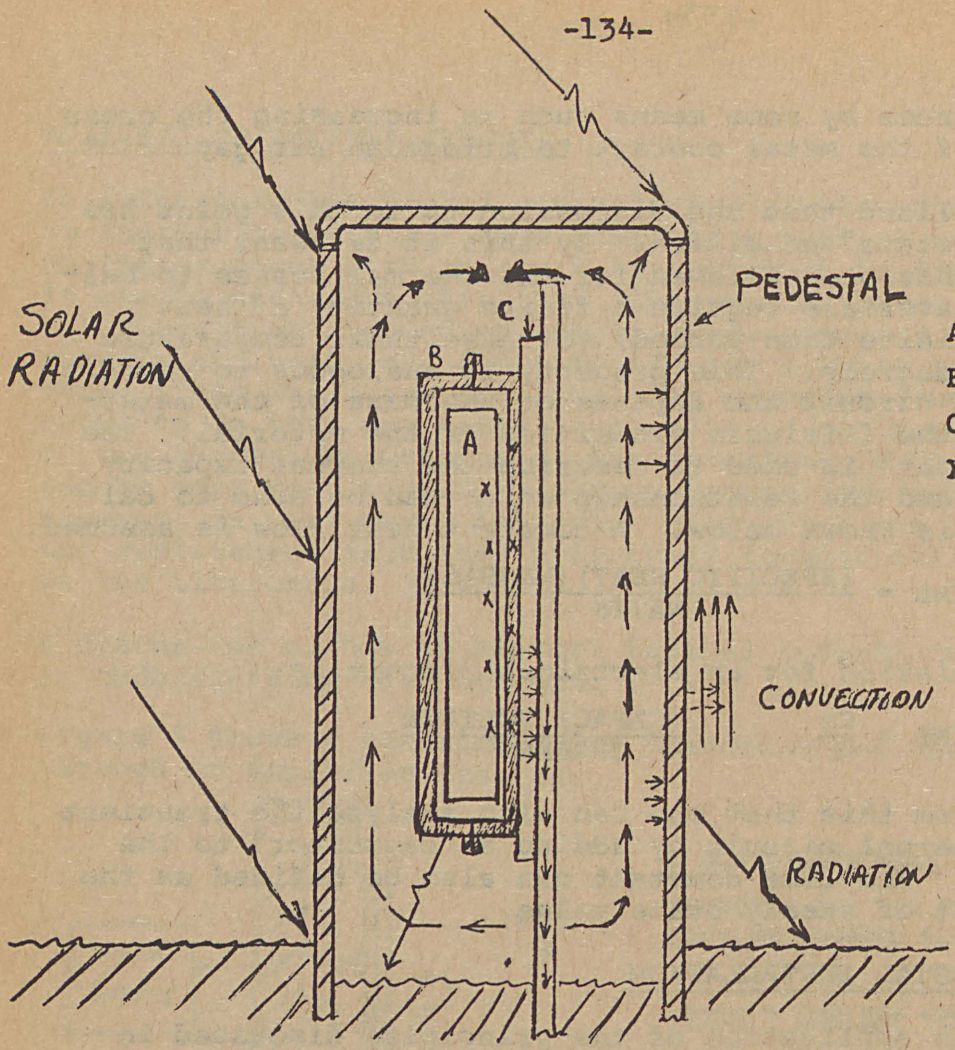
It is obvious from this that one can also analyze the transient behavior of a thermal circuit by adding a "capacitor" to the circuit diagram. The time constant can also be defined as the time to reach 70% of steady state value.

ANALYSIS OF PEDESTAL INSTALLATION

To illustrate the application of the principles discussed in the preceding paragraphs an amplifier housing with an internal heat source was set up in an outdoor location with thermocouples installed in several locations.

Approximate thermal resistances were measured and tests were run over an extended period of time. The circuit diagram is presented in Figure 7. Figure 6 shows the heat transfer interfaces and typical time temperature curves are shown in Figure 8.

Additional work is now in process testing methods of reducing thermal resistances by modifying the pedestal.



NOTES:

1. PEDESTAL IS SEALED EXCEPT FOR SEAMS AT TOP AND SIDES. AIR MOVEMENT INSIDE IS SEVERELY LIMITED.
2. PEDESTAL DIMENSION ABOVE GROUND 10.5" x 10.5" x 32"

   TOP AREA APPROXIMATELY .77 SQUARE FEET

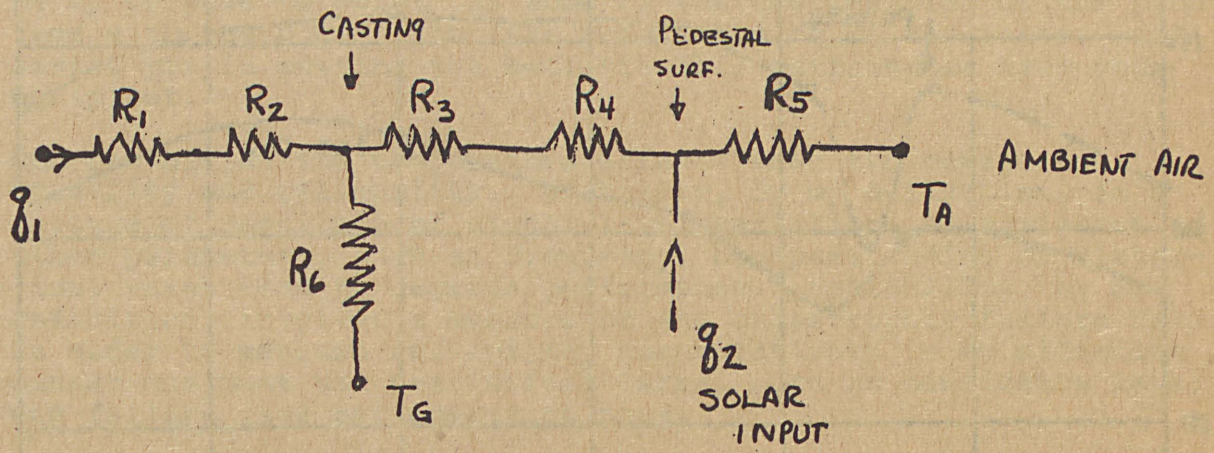
   SIDE AREAS APPROXIMATELY 2.3 SQUARE FEET
3. PEDESTAL MATERIAL:

   STEEL DARK GREEN PAINT, 3/32 THICK, ABSORPTIVITY APPROXIMATELY .73
4. ALUMINUM CASTING:

   APPROXIMATELY 7.5" x 16" x 4", APPROXIMATE AREA 2.7 SQUARE FEET

HEAT TRANSFER IN PEDESTAL

FIGURE 6



R_1 HEAT SOURCE TO INTERNAL MODULE

R_2 MODULE TO CASTING

R_3 CASTING TO INTERNAL AIR

R_4 INTERNAL AIR TO PEDESTAL

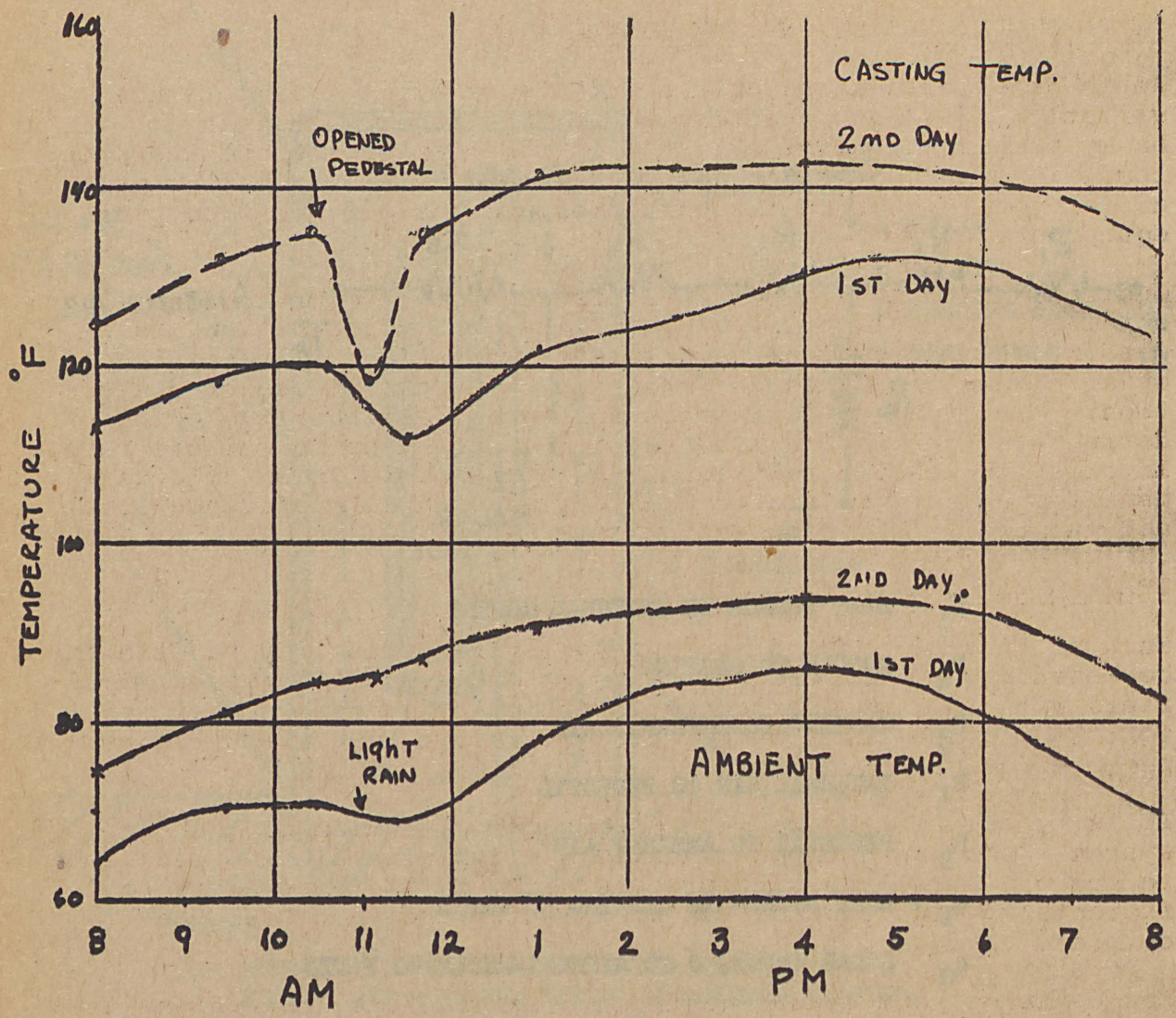
R_5 PEDESTAL TO AMBIENT AIR

q_1 = HEAT SOURCE IN CASTING 58 WATTS

q_2 SOLAR INPUT, 0 TO APPROXIMATELY 40 WATTS

EQUIVALENT THERMAL CIRCUIT
PEDESTAL INSTALLATION

FIGURE 7



TEMPERATURE TESTS ON PEDESTAL INSTALLATION

FIGURE 8

TEMPERATURE EFFECTS ON CATV SYSTEM

An in-depth discussion of the effects of ambient temperature variation will not be attempted in this paper. Instead it will be my purpose to point out some of the complexities of the problems with the conviction that understanding of the basics will assist you in getting the best possible performance from your equipment.

One can divide the temperature effects into two categories: stability and reliability. Stability, by my definition, is a measure of magnitude of signal level variations or variation of other parameters, such as frequency, bandpass, noise or distortion, which tend to degrade performance. Reliability, by my definition, involves a measure of the catastrophic failure rate. In order to measure reliability quantitatively in an effective manner one must use statistical terms, such as confidence level and failure rate per operating hour.

TEMPERATURE STABILITY

Much of the technical discussion on system stability to date has centered around the effectiveness of ALC systems in trunk amplifiers with the implication that "cable loss versus temperature" follows precise rules over wide temperature ranges and the complete frequency spectrum.

It is my belief that we must direct our attention to the complete system - headend equipment, cable and amplifiers. We need also to concern ourselves with precise behavior of temperature coefficients at high and low temperature extremes and over the complete bandpass.

For instance, our measurements on coaxial cable loss versus temperature indicate rather peculiar behavior at temperatures below 30° F. Certainly more actual test data must be made available on this important system component. It would not be unusual to find that temperature coefficient of cable is frequency selective or varies non-linearly with operating temperature. An investigation of other components, such as resistors, capacitors, transistors and other electronic components, shows that temperature coefficients very often vary in an unexpected manner. Consider the following examples taken from manufacturers' literature.

1. Carbon resistors increase in value with both increasing and decreasing temperature about a 25° C nominal temperature.

2. Ceramic capacitors may have a temperature coefficient which varies by a factor of 2;1 over the temperature range of zero to +40 C. There is also substantial variation for different types of dielectrics.

3. Electrolytic capacitors typically show negligible change in impedance for temperatures 25° C to 85° C, while in the range +25° C to -20° C the impedance will increase by 50% (50% decrease in capacitance).

With regard to headend equipment, it is of course true that this equipment need not withstand wide temperature variations. On the other hand, it is also true that this equipment is often not as carefully designed as the distribution amplifier and tends to be more sensitive to temperature because of the narrow band characteristics of the circuitry. I am afraid that the stability problem with this equipment is often accentuated by poor installation techniques in the rack mounting. A little air circulation and more careful distribution of heat sources will often help.

RELIABILITY VERSUS TEMPERATURE

Any one who has been involved in CATV for any length of time has had some direct experience with the adverse effect of high temperatures on the reliability of CATV equipment. The average CATV system includes tens of thousands of electronic components and each of these is subject to a predicted failure rate, which is directly dependent on operating electrical parameters and its ambient temperature. A quick review of some published data derived from component testing will illustrate this point.

CARBON RESISTORS	MIL R-11 quotes a failure rate at 50% of rated wattage, .018% per 1000 hours at 20° C and .03% per 1000 hours at 70° C at confidence level of 60%.
FILM TYPE RESISTORS	MIL R-10509 quotes .04% per 1000 hours at 20° C and .08% per 1000 hours at 70° C at confidence level of 60%.
SEMI-CONDUCTORS	Typical data taken from manufacturers' published information predicts an increase in failure rate by 2.5 times, if junction temperature is increased from 80° to 100° C.
ELECTROLYTIC CAPACITORS	Typical data shows the predicted failure rate is reduced by 50% when the temperature is reduced from 85° C to 75° C.

I have purposely omitted absolute failure rate numbers from the discussion in order not to imply that the data is directly applicable to CATV equipment. In practice the designer has the ability to derate most components to reduce failure rates to

very small value. Another problem, which is difficult to cope with is the fact that the "failure" as defined for the test data may have little relation to the CATV application. Nevertheless, any such tests which could be devised from CATV equipment would show a correlation between temperature and failure rates.

In our quest for the best possible reliability, it is important that temperature extremes be minimized with good design and installation. The large numbers of components involved in a CATV system mean that highly reliable components are a must.

Temperature fluctuations with the inherent mechanical and electrical stresses tend to "shake down" new equipment by showing up manufacturing defects or defective components which tend to fail within the first 100 hours of operation. Hence, a moderate number of failures in the early life of equipment may not represent a true picture of the typical expected long term failure rate of the system.

CONCLUSION

I have reviewed the basic concepts of heat transfer with the hope that this will lead to further study on your part. In addition I have attempted to point out the advantages of the use of a thermal circuit diagram in studying and analyzing heat transfer.

The discussion on the effects of temperature was included to point out the many areas which are affected by temperature and the caution that temperature coefficients are variable with operating temperature.

It is my contention that your inquisitive minds, coupled with temperature measuring instruments and ingenuity, will result in a measure of increased CATV performance.

In closing I would like to point out one additional fact. CATV equipment has a decided advantage over aerospace equipment in that extreme miniaturization is not an overriding consideration. With miniaturization invariably comes increased component density and along with it increased thermal density and very special heat transfer problems to maintain reliability. Equipment users will do well to keep this in mind.

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