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A CABLE TELEVISION SATELLITE EARTH STATION

by

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and
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SCIENTIFIC-ATLANTA, INC.

Introduction

Today the cable industry is searching for ways to obtain new subscribers and additional revenues from existing subscribers. Satellite communication is a technique available today by which every cable system can significantly increase programming in order to attract these new revenues. This additional programming can be obtained with relatively small capital outlay or additional operating cost. Satellite distribution eliminates the need of reaching all cable systems by terrestrial microwave and the expense of bicycling films or cassettes from system to system.

This paper describes a satellite receiving station designed specifically for CATV systems. This system fully demonstrates the availability and simplicity of interfacing satellite signals with a typical cable system.

Satellite Availability

Satellites in a synchronous or geostationary orbit simplify the mechanical requirements of the earth station since the satellite does not move with respect to earth. By placing the satellite in an orbit approximately 22,300 miles above the equator with an eastward speed of 7,000 miles per hour, the satellite will match the rotation of the earth and appear to be stationary. The earth station antenna needs only to be pointed at the satellite. There is no need for the antenna system to track the satellite since its total movement is less than 1 degree. The stationary satellite also reduces the operation and maintenance cost of the station since repointing will only be occasionally required.

In this system, signals from the Telesat Canada Anik satellites are used. Anik is the Eskimo word for brother. The satellite was designed by Hughes Aircraft Company and Anik I was launched in November 1972 from Cape Kennedy by NASA. Anik I is the first of three such satellites planned by Telesat. Each satellite will have the capability of relaying twelve full color TV signals. Presently the Anik is being used to distribute three TV signals to the remote stations in Canada.

The FCC has given permission for several U.S. common-carriers to lease satellite capacity from Telesat, Canada. Satellite service from at least one of these carriers will be available as early as July of this year, making CATV satellite systems a presen aday possibility.

Satellite Communications System Description

Although the satellite and associated launch operations are quite complex and expensive, the overall communications system is simple in principle (see Figure 1).

The TV baseband signal to be relayed is used to modulate the 6 GHz uplink signal from the transmit earth station. The communications satellite, in synchronous orbit 22,300 miles above the earth, receives the 6 GHz signal. In the satellite, the signal is translated to 4 GHz, amplified, and is beamed to one or multiple earth stations. Both the up and down link frequency bands of satellites to be launched in the near future are in the 4 and 6 GHz terrestrial microwave bands.

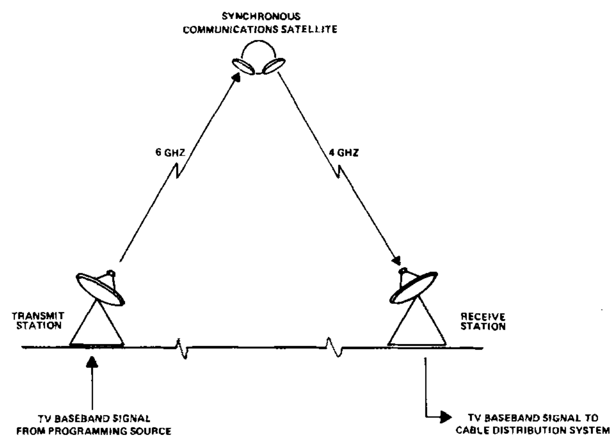


Figure 1–Overall Satellite Communications System

For CATV applications, up to 12 TV channels can be transmitted from the satellite within the 3.7 to 4.2 GHz band. As shown in Figure 2, each TV channel occupies a 40 MHz band (including guard bands). Wideband FM modulation is used to improve video signal-to-noise ratios and to reduce satellite power requirements.

It is the purpose of the earth station to receive the extremely weak 4 GHz signals and to restore them to a useful video and audio baseband form.

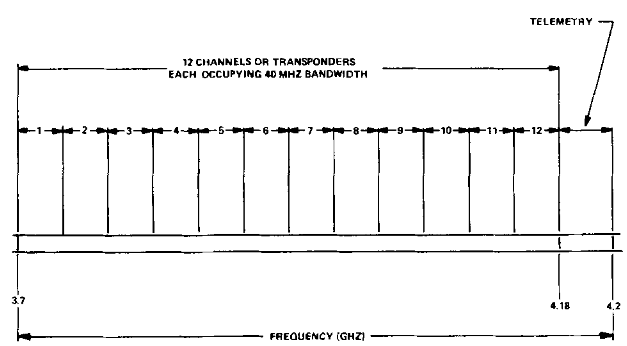


Figure 2–Satellite Signal Characteristics

CATV Earth Station Description

A transportable CATV satellite earth station is shown in Figure 3. The configuration for operational cable systems will be similar in appearance to this one, but will not require the trailer and cab assembly.

The system as equipped for two channels of TV reception consists of a 25-foot diameter microwave antenna, an extremely sensitive preamplifier called a low noise receiver (LNR) and two TV receivers, each capable of receiving any one of three desired channels. See Figure 4. Each receiver provides a video output and three audio outputs. In the Telesat satellite system, one program audio channel accompanies the video, and the two additional audio channels are provided to carry cue and radio broadcast signals.

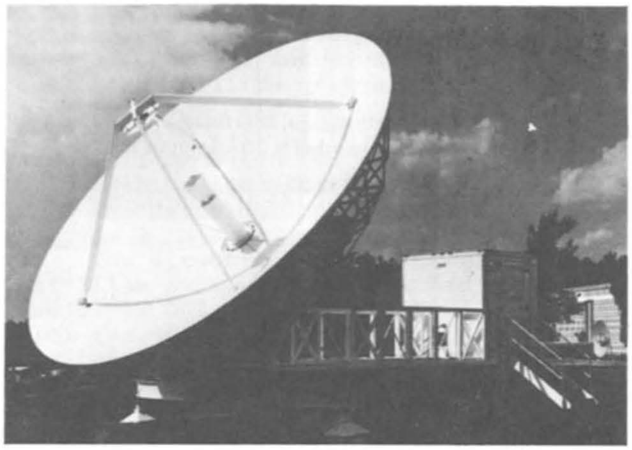


Figure 3–Transportable CATV Satellite Earth Station

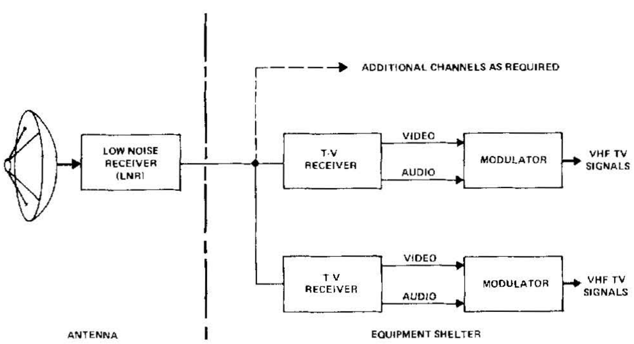


Figure 4–System Block Diagram

Antenna and Feed System

The antenna system used is a 25-foot diameter reflector with a Cassegrain configuration feed system. In this system (see Figure 5) energy received by the main reflector is reflected to the subreflector and then reflected again, where it is focused on the horn feed located at the center of the reflector.

The Cassegrain configuration is used because it is highly efficient, and it receives very little energy from surrounding terrestrial microwave stations. It also receives very little signal from the ground, which in sensitive satellite earth stations, can also be a source of interfering noise.

The feed horn may be manually rotated about its axis to provide optimum alignment in polarization. It is pressurized with dry air to keep moisture from accumulating on the interior.

Low Noise Receiver

The Low Noise Receiver (LNR) is a parametric amplifier to provide low-noise amplification of signals over the entire 3.7 to 4.2 GHz band. It is mounted directly to the back of the antenna feed horn to reduce losses

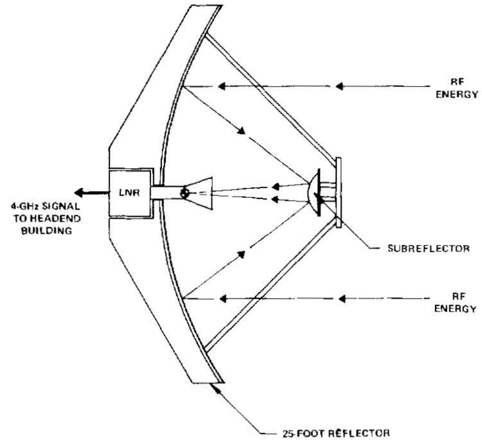


Figure 5–Antenna Geometery

to an absolute minimum. As mentioned before, this system is so sensitive that even energy radiated by the earth is a source of interference. For this reason, it is necessary to exercise extreme care in the antenna and LNR design.

The LNR offers about 50 dB of signal gain, so that the cabling losses between it and the TV receivers become relatively noncritical. The LNR is protected by the hub of the reflector and is additionally enclosed in a weatherproof enclosure. Figure 6 is a photograph of the LNR.

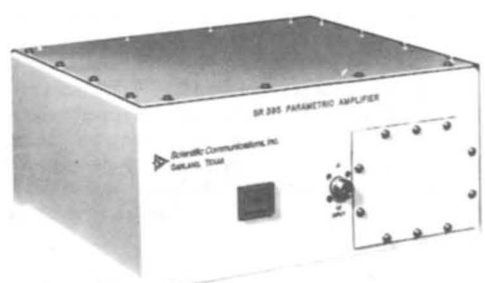


Figure 6–Low-Noise Receiver

TV Receivers

Two of the TV receivers are shown in Figure 7. One receiver is used for each TV channel. Additional channels may be added simply by adding TV receivers to the system. This receiver is very compact in nature and has been designed specifically for use in CATV headends. It differs drastically from other receivers previously used for satellite reception.

Each receiver is modular in construction and uses solid-state devices throughout. A front-panel switch allows the selection of one of three channels within the 3.7 to 4.2 GHz band. This may be readily expanded to obtain up to 12 switch selected channels.

Front-panel metering is provided for display of signal-to-noise levels as well as power supply, audio and video signal level checks. These functions can be monitored for remote alarms if desired.

It should be pointed out that this receiver is electronically tuned, which permits it to be remotely tuned at very little additional cost.

For rapid troubleshooting, the circuit modules are replaceable from the front panel without removing the receiver from the rack. A built-in module test slot is provided for maintenance procedures. The video output levels are standard 1V peak-to-peak, 75 ohms. Audio outputs are 0 dBm, 600 ohms.

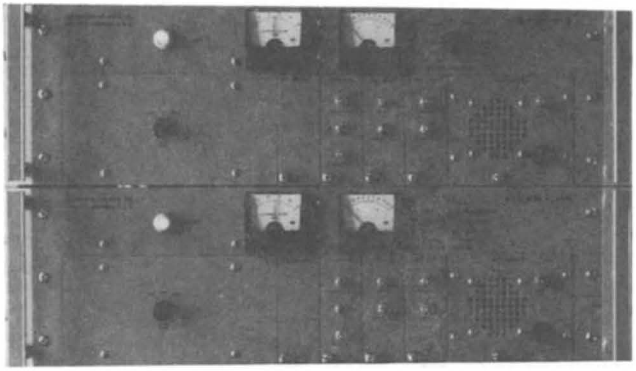


Figure 7–TV Receivers

Location of the CATV Satellite Earth Station

Siting for the typical CATV satellite earth station differs from a normal headend antenna installation or a terrestrial microwave system. In the case of the satellite earth station, it is desirable to locate the antenna in a low spot where natural terrain or surrounding buildings provide shielding from terrestrial interference. In many cases the satellite earth station will operate without degradation, where terrestrial line-of-sight systems might exhibit interference effects.

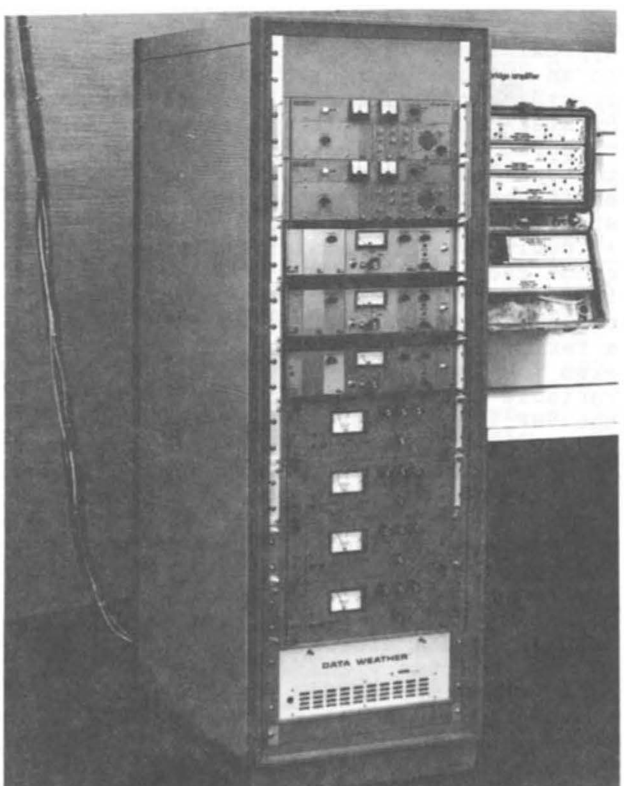


Figure 8–Typical Headend Rack with TV Receivers and Modulators Installed

In most locations, the 25-foot diameter Cassegrain antenna will provide 50 dB or better rejection of interfering terrestrial 4 GHz signals. Natural terrain or buildings can provide an additional 20-40 dB of shielding.

It should be pointed out that one of the important considerations of the design is that future satellites may be parked in orbit at a spacing of 5 degrees. The antenna system is capable of reducing those interfering signals to a negligible level.

CATV System Interconnect

It is felt that despite potential interference from terrestrial microwave stations, most CATV satellite stations can be located close to the headend system. In this case, the audio and video signals are processed by cable system modulators and enter the system as any conventional VHF TV signal.

Figure 8 is a photograph of a headend system including both satellites and off-the-air electronics. The headend electronics are complicated only by the addition of the TV receivers and modulators.

When terrestrial 4 GHz interference is severe, it may be necessary to remotely locate the satellite earth station. In this case, the remote signal may be relayed either by cable or by terrestrial microwave.

Overall Satellite Earth Station Performance

Television transmission requires special design considerations, because the equipment must be capable of passing broadband FM transmissions. In the overall system design, bandwidth, interference rejection, crosstalk, thermal noise and nonlinear effects have been very carefully considered in light of the application for CATV systems.

In color TV transmission work, nonlinearity effects are quite rapidly evaluated by differential phase and differential gain measurements. The receiver, which measured at less than 1 degree for differential phase and 0.5 dB for differential gain at 10-90% average picture levels, insures negligible degradation in picture quality. When compared to the off-the-air reception of UHF and VHF signals, satellite transmission realistically offers remarkable picture quality improvement as well as the programming potential previously mentioned.

A summary of the overall system performance specifications is given below:

Characteristic	Specification
Antenna Size	25-foot diameter
Operating Frequency	3.7 to 4.2 GHz
Antenna Gain (4.0 GHz)	48 dB
G/T (4.0 GHz)	27 dB
Video Signal-to-Noise (Clear Sky)	
Canadian Satellite	50 dB nominal at Anaheim
U.S. Satellite	54 dB minimum throughout U.S.
Video Response	10 Hz - 4.25 MHz (±0.5 dB)
Differential Gain	0.5 dB maximum, 10-90% APL
Differential Phase	1 degree maximum, 10-90% APL
Video Outputs	1 per receiver, 1V peak-to-peak, 75 ohms
Audio Outputs	1 program, 1 cue, 1 broadcast (Telsat) at 0 dBm, 600 ohms
Operating Temperatures	20 degrees F to 100 degrees F (indoors) -20 degrees F to 160 degrees F (outside)
Power	115V, 50/60 Hz, 12 amps

A HIGH POWER SINGLE CHANNEL AML MICROWAVE RELAY SYSTEM

I. Rabowsky C. Meyers P. Vaughn

Theta-Com Theta-Com Theta-Com

A microwave transmitter and receiver are described which utilize the successful Theta-Com of California Amplitude Modulated Link concept. This newly developed product consists of a high power transmitter, which provides a translation of the VHF spectrum of a T.V. channel to an assigned microwave frequency channel with up to 5 watts of peak microwave power output, and a microwave receiver which faithfully downconverts the received signal to the desired VHF, T.V. channel and provides a stable, constant output over a wide range of atmospheric conditions.

In the transmitter the VHF input signal is upconverted by a unique single sideband suppressed carrier parametric upconverter. The receiver, which has a wide dynamic range AGC, may be utilized to receive many channels simultaneously without introduction of undesired crossmodulation.

Today, I shall describe for you the unique microwave transmitter and receiver developed by Theta-Com of California which utilizes the successful Theta-Com of California AML concept. This particular system has the advantage of requiring the minimum microwave spectrum for each TV channel, that is 6 mhz per channel, and operates with input and output signals at the VHF frequencies of the TV channels rather than at video baseband. The microwave frequency band allocated for local distribution service for CATV application is 12.700 to 12.950 ghz, a 250 mhz wide band, thus the AML system is capable of transmitting 40 channels of TV information in contrast to 10 channels as transmitted by conventional FM relay equipment. Since the requirement for increased channel capability is growing at a rapid rate in the CATV industry, the ability to add channels is considered to be an important advantage of the AML system particularly in urban areas with growing frequency congestion.

Figure 1 shows how the CARS band frequencies are allocated to specific VHF channels.

Figure 2 is a view of the front panel of the high power Single Channel Transmitter model AML-STX-141. A panel meter and selector switch are mounted on the panel to provide the user with the ability to monitor the important functions of the unit.

Figure 3 is a block diagram of the single channel transmitter. A solid state source with an output frequency of approximately 12.646 ghz is phase locked to an integral harmonic of an ultra-stable crystal controlled oscillator. The crystal oscillator is in a thermal enclosure, which holds the temperature of the oscillator within a few degrees over a wide temperature range. The resultant stability of the oscillator is better than $\pm$ .0001% over the ambient temperature range from -30°C to +50°C. The output of the solid state source is fed as a "pump" signal into a parametric upconverter thru a ferrite isolator. The upconverter is also fed the VHF signal information. A variable attenuator is provided to adjust the VHF input level to the upconverter. The VHF and microwave signals are combined in the upconverter and the upper sideband signal is passed through a microwave output filter to the klystron amplifier. Another ferrite isolator is provided between the upconverter and the klystron amplifier to prevent undesirable feedback effects. A test coupler is used for monitoring the microwave signals out of the upconverter. The klystron amplifier is a high power active filter. In this circuit it is operated in the linear region of its operating characteristic, having a gain of approximately 42 dB and a frequency bandwidth of about 25 mhz. The output of the klystron amplifier is then fed through another ferrite isolator into a bandpass filter. This filter is a narrow band microwave filter designed to pass only the frequencies of the particular TV channel being transmitted. It is primarily utilized to provide the necessary isolation when multiplexing channels, and to remove unwanted spurious outputs of the klystron amplifier. The signal then passes through a harmonic filter which eliminates 2nd and 3rd order harmonics and through a coupler which has a crystal detector output for monitoring the signal level of the output. The output is then ready for multiplexing with other channels or attachment to the antenna system.

Figure 4 is a top view of the transmitter unit. The output power which can be obtained from the transmitter is largely a function of the linearity of the upconverter and klystron amplifier.

Figure 5 shows the test set which we have used to measure the spurious outputs of the transmitter versus the power output.

Figure 6 is a typical measurement of the spectrum of the transmitter with a three tone VHF input signal and with 1 watt of output power. The audio subcarrier is adjusted to 17 dB below the video carrier and the color subcarrier to 20 dB below the video carrier at the TV modulator. As you can see, the results are quite good. The beat between video, audio and color subcarriers is down 68 dB and the video-audio beat is down 66 dB. To obtain 1 watt power, output typically requires 40 dBmV VHF signal input. If the VHF signal level is increased, the microwave power output shows a corresponding increase.

Figure 7 shows the spectrum of the transmitter with 5 watts of output power. The beat between video, audio and the color subcarriers has increased to a level 59 dB below the video carrier, while the beat between the video and audio carriers has increased to a level 56 dB below the video carrier. The transmitter has been type accepted by the FCC up to an output level of 5 watts, thus the level at which the user will operate the equipment will depend on his particular system requirements.

Multiplexing of transmitters may be accomplished by conventional techniques utilizing ferrite circulators as combiners.

Figure 8 shows a typical multiplexing scheme. The output of channel 1 is circulated in circulator 2 to the output port of the number 2 transmitter. The band pass filter, in the unit previously discussed, reflects the channel 1 signal back to the circulator which then circulates the signals of channel 1 and 2 to the output port, and then on to circulator 3, where the process is repeated until the antenna port is reached.

The AML single channel receiver Model SRX 250 is capable of receiving and translating to VHF frequency any of the 40 channels operating in the 12 GHZ CARS band.

Figure 9 is a view of the front panel of the receiver. The front panel meter provides the user with the ability to monitor the important functions of the unit, including AGC voltage.

Figure 10 is a block diagram of the receiver.

The AML single channel receiver Model SRX 250 consists of 6 basic subsections. These are the preselector filter, mixer and pre-amplifier, microwave solid state source, crystal oscillators, AGC amplifier and ferrite attenuator, and the DC power supplies.

The received signal is passed through the bandpass filter which is designed to have minimal insertion loss in the passband, while providing in excess of 50 dB rejection of image frequencies. The microwave signal is then applied to a microwave mixer. The microwave mixer consists of a folded hybrid tee, utilizing two low noise, hot carrier mixer diodes. The diodes are arranged in a balanced configuration so as to minimize the effects of local oscillator noise. A solid state source phase locked to an integral harmonic of the crystal oscillator and identical to the one employed in the transmitter is utilized as a source of local oscillator power. The microwave received signal is thus down-converted to the VHF, TV channel which had been entered into the system at the input to the transmitter. The output of the mixer is fed into a low-noise VHF pre-amplifier. The pre-amplifier consists of a multistage, broadband hybrid amplifier design, featuring an exceptionally low noise figure, together with exceptionally low cross modulation characteristics. The amplifiers are operated in a push-pull configuration with a gain flatness of better than .2 dB per TV channel. A broadband frequency compensated briged-T attenuator is used to adjust the output power of the pre-amplifier, which is normally set at +24 dBmV. The noise figures of the receivers is usually on the order of 10 dB, as can be seen from figure 11.

The automatic gain control (AGC) system consists of an AGC threshold adjust, RF amplifier, RF detector, video amplifier, sync-pulse peak detector, DC amplifier and ferrite attenuator. AGC action is initiated when the received TV sync-pulse exceeds the AGC threshold setting of the receiver. This level may be adjusted from -50 dBm to -35 dBm by adjusting the AGC threshold control. The output of the AGC network is a DC voltage proportional to the peak sync-pulse. This voltage is applied to a solenoid coil encircling a ferrite slab and resistance card whose attenuation to a transverse electromagnetic field propagating through a waveguide is proportional to the strength of the magnetic field applied to the ferrite. Therefore, at any signal level exceeding the threshold setting of the AGC control, the received signal is held constant. As can be seen from figure 12, dynamic range of the AGC system is greater than 40 dB with a flatness of $\pm$ 1 dB and is capable of controlling signals greater than -5 dBm. A top view of the single channel receiver is shown in figure 13. Multiplexing of the receivers is accomplished in a fashion similar to that described for the transmitters, although usually a conventional AML broadband multi-channel receiver would be used in application requiring the reception of signals from a plurality of single channel transmitters.

Figure 14 is a graph of the signal to noise ratio of the VHF output signal as a function of path length for a transmitter power output of 1 watt. For a path length of 15 miles, the signal to noise ratio will be 78 dB if 10-foot antennas are used.

Figure 15 is a graph of the predicted hours per year the signal to noise ratio will be below 35 dB due to both multipath fading and rain attenuation in a dry area such as Albuquerque, New Mexico. For a ten foot antenna, the 1 watt equipment will have signal reception below a signal to noise ratio of 35 dB, over a 15 mile path, for less than 45 minutes a year.

Figure 16 is a similar graph for a wet area such as Mobile, Alabama. The time the received signal will be below a signal to noise ratio of 35 dB, for a 15 mile path, is less than 3.3 hours.

Figure 17 is a similar graph for a more typical area such as Washington D. C. for this location, the time the received signal will be below a signal to noise ratio of 35 dB, for a 15 mile path, is less than 2 hours.

The high power single-channel transmitters and receivers are utilized in a number of applications.

1. Where propagation and path considerations indicate marginal systems performance with lower power multi-channel and single channel equipment.

2. Where user requirements demand extrodinary fade margins to reduce propagation outage times to a minimal level.

3. Where user requirements exist for a few channels now, he can obtain single channel equipment at a comparative low price, and can add channels to the system as he needs them. If he is utilizing the broadband composite receiver, he can even add channels at the transmitter without the need for additional receivers.

4. As the uplink microwave system for a two-way CATV system.

5. For studio to transmitter links.

6. For industrial and governmental transmission of video information.

7. For repeater applications where it is desirable to tie a number of distant locations to a single video system.

Figure 19 shows a 10 channel system utilizing the high power single channel transmitters.

FREQUENCY LOCATIONS OF TV CHANNELS

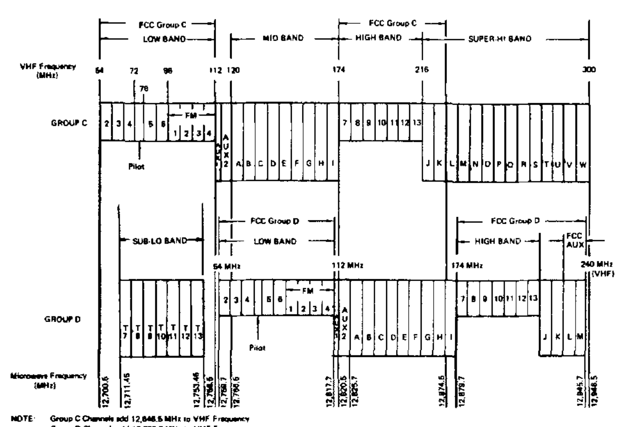


FIGURE 1

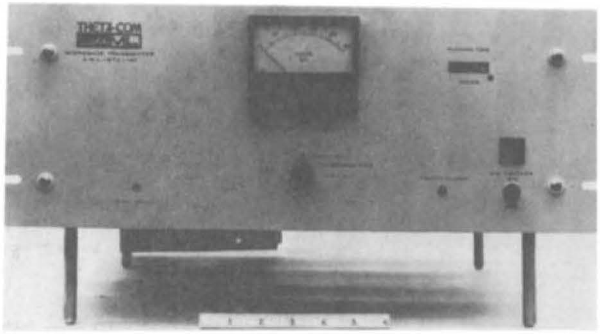


Figure 2. Front View AML-STX-141 Transmitter

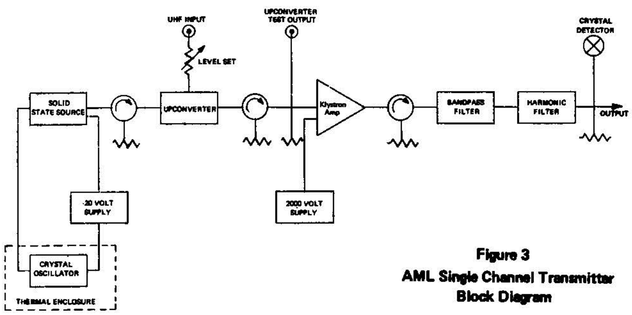


Figure 3
AML Single Channel Transmitter Block Diagram

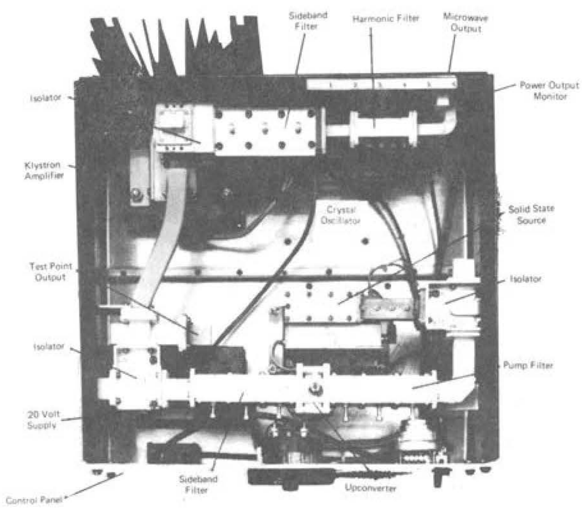


Figure 4 Top View AML-STX-141 Transmitter

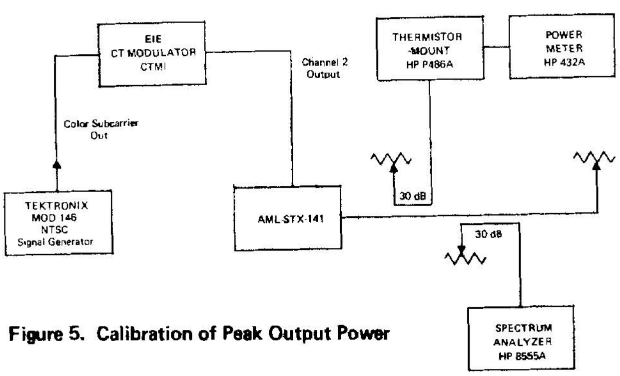
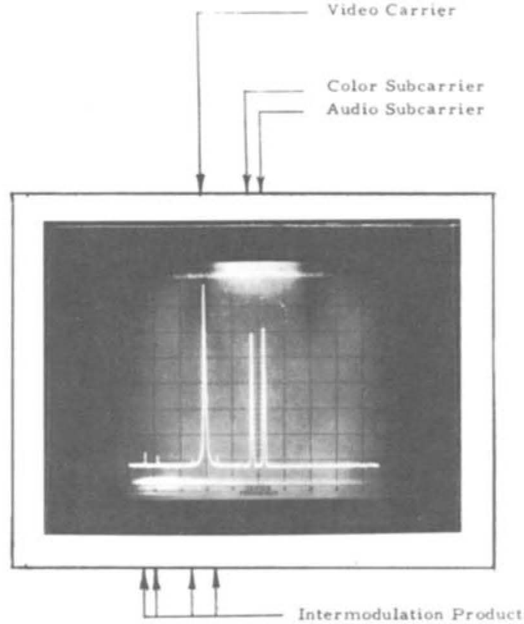
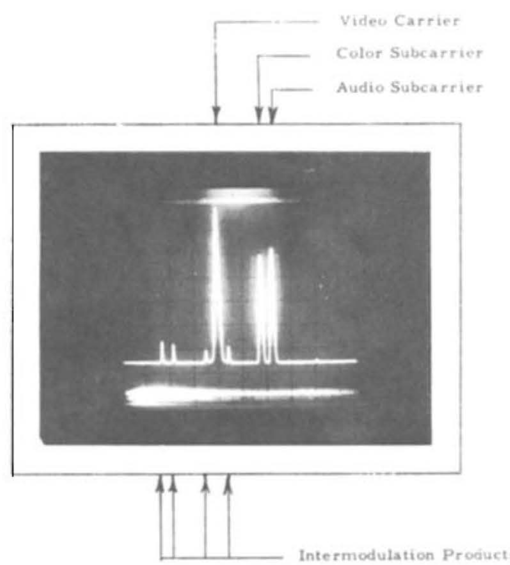


Figure 5. Calibration of Peak Output Power



Peak Power Output	1 Watt
Vertical Scale	10 dB/cm
Horizontal Scale	2 MHz/cm

Figure 6 Output Spectrum of AML-STX-141 Transmitter
1 Watt Output



Peak Power Output	5 Watts
Vertical Scale	10 dB/cm
Horizontal Scale	2 MHz/cm

Figure 7 Output Spectrum of AML-STX-141 Transmitter
5 Watts Output

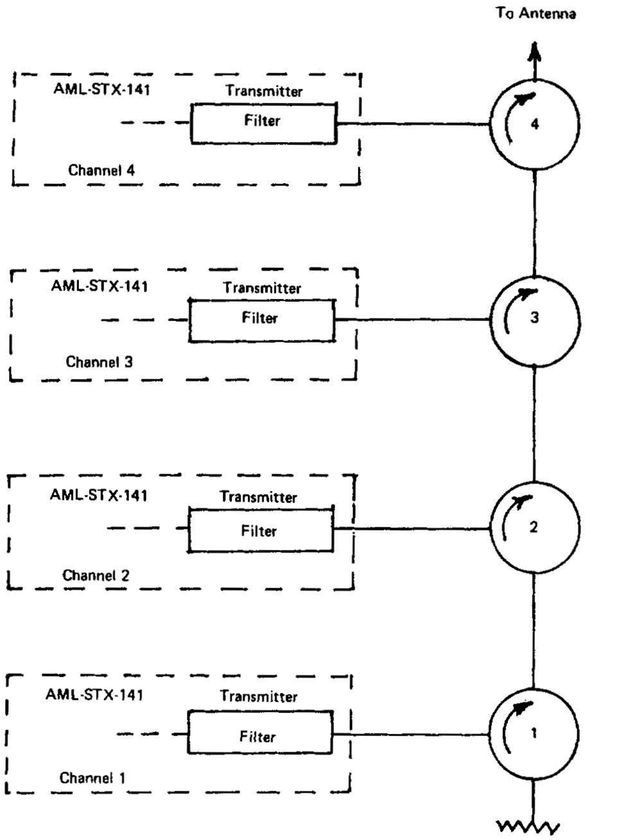


Figure 8 TRANSMITTER MULTIPLEXING

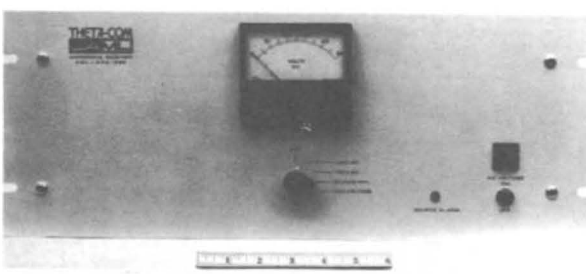


Figure 9. Front View AML-SRX-250 Receiver

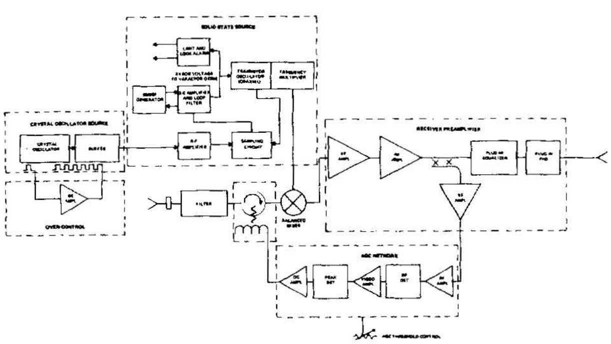


FIGURE 10 BLOCK DIAGRAM OF AML SRX-250 RECEIVER

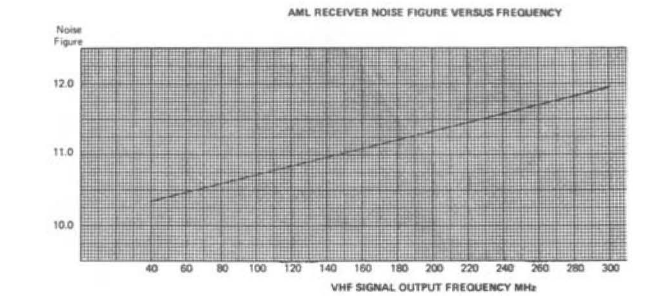


FIGURE 11

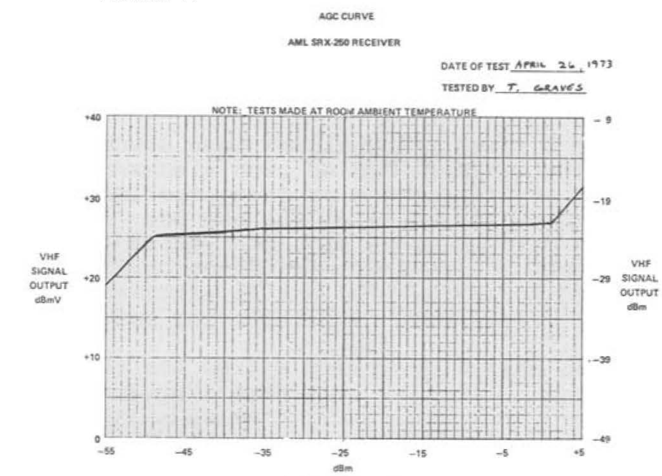


Figure 12

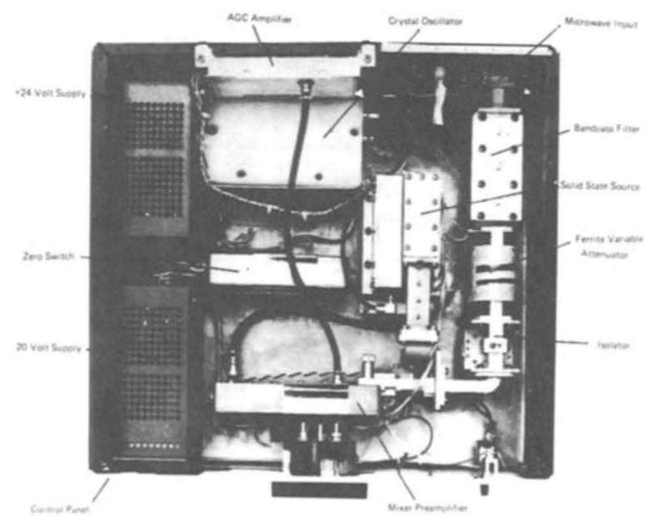
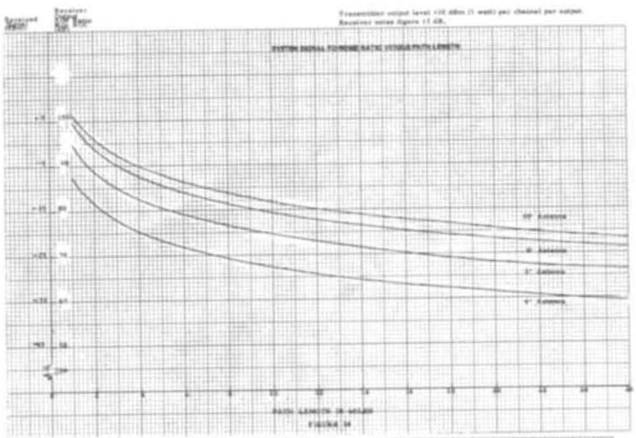
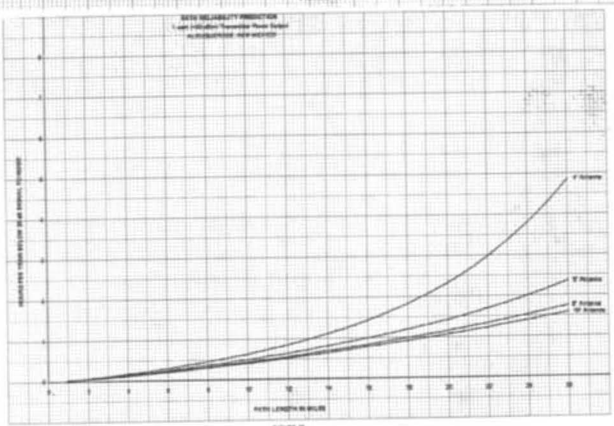
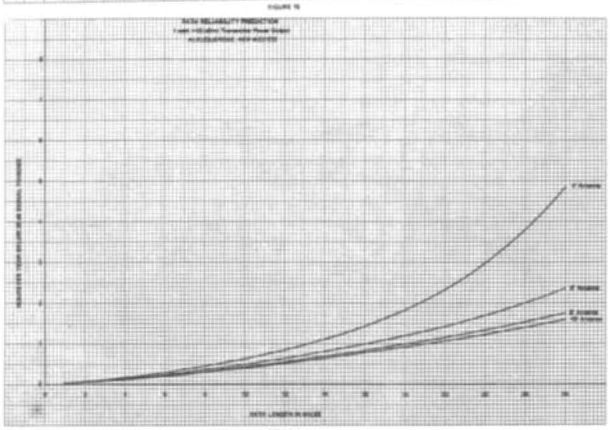
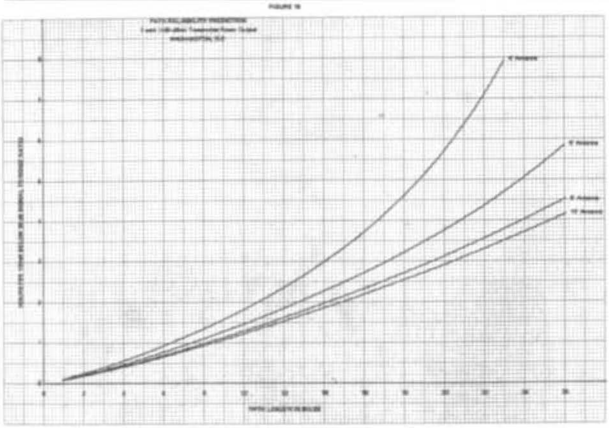


Figure 13 Top View AML SRX 250 Receiver









APPLICATIONS FOR HIGH POWER SINGLE CHANNEL AML SYSTEMS

1. Propagation and path considerations exclude lower power equipment.
2. Systems requiring higher than normal propagation reliability.
3. Systems requiring a few channels now, but flexibility to add channels later at minimal cost.
4. As the uplink microwave system for two-way CATV systems.
5. Studio to transmitter links.
6. Industrial and governmental systems.
7. Systems requiring repeaters.

Figure 18

SAN LUIS OBISPO 10 CHANNEL SYSTEM

A ONE-INCH VIDEO CARTRIDGE RECORDER DESIGNED FOR PROFESSIONAL CCTV AND CATV

Keith Y. Reynolds
International Video Corporation
Sunnyvale, California

The VCR-100 manufactured by International Video Corporation is designed for the professional CCTV and CATV market. Using tape one inch in width, it displays excellent timebase stability, signal-to-noise ratio and horizontal resolution. Because of these features, its color video output can be fed down a cable TV system and received by any of the wide variety of TV sets commonly found in the home with excellent results.

The numerous VCR formats in use today were designed primarily for playback on an adjacent fast-time constant monitor. The resulting picture is excellent, and the conclusion often reached is that these low cost VCR's are suitable as origination devices for cable television, educational dial access systems or even commercial broadcast television.

Further investigation quickly points out the inherent problems. Some of these are timebase instabilities, signal-to-noise ratio, color recording techniques and picture resolution.

The timebase instabilities result from transport design and playback tension errors. These errors do not usually show up on the Trinitron-type fast-time-constant monitors, since these monitors tend to follow the timebase errors.

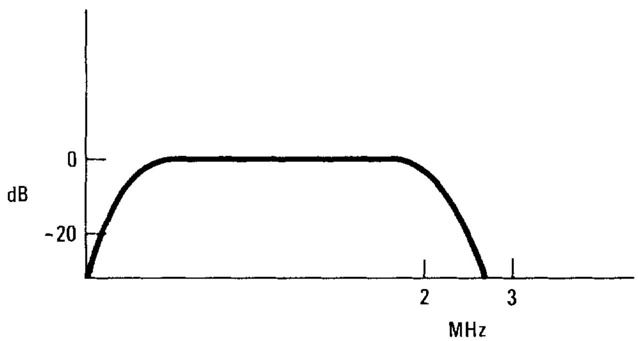
It is possible to mechanically and electronically compensate for these inherent errors, but the cost to do this can be 10 to 15 times the cost of the original VCR.

Signal-to-noise ratio limitations can be attributed to head-to-tape writing speed as well as the type of videotape used. The 1/2-inch EIA-J VCR's have a tape writing speed of 437 ips and are designed to use standard gamma ferric oxide videotapes. The 3/4-inch VCR's have a tape writing speed of only 404 ips and must use either chromium dioxide video tape or cobalt-doped gamma ferric oxide video tape, commonly called Hi Energy tape. The coercivities of these tapes range from 450 to 600 oersteds. As a result of the limited tape writing speed, signal-to-noise ratio can be a problem. Again, the selection of the monitor tends to minimize the noise; but when these VCR's are played back on most American-made receivers or monitors, the problem is evident.

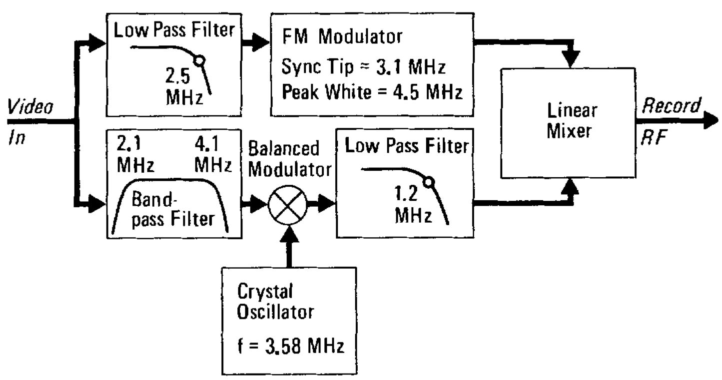
The frequency responses of the 1/2-inch and 3/4-inch VCR's extend to around 2.5 MHZ. This makes it difficult to record color, since the color burst frequency is 3.58 MHz. This difficulty is overcome by a technique commonly called "color under." In this scheme, the chroma information is down converted to around 600 kHz and is directly recorded onto the tape along with the monochrome FM video carrier. Upon playback, the chroma information is up-converted via heterodyne color techniques and recombined with the demodulated monochrome video. Again, this technique works well when the picture is played back on an adjacent Japanese color monitor, but it is extremely difficult to obtain timebase corrected direct color or realize good picture resolution. The maximum monochrome resolution is about 300 lines. Color horizontal resolution is about 240 lines.

So, although these imported VCR's produce excellent pictures when played back on their adjacent imported monitors, they are not entirely suitable for transmission purposes.

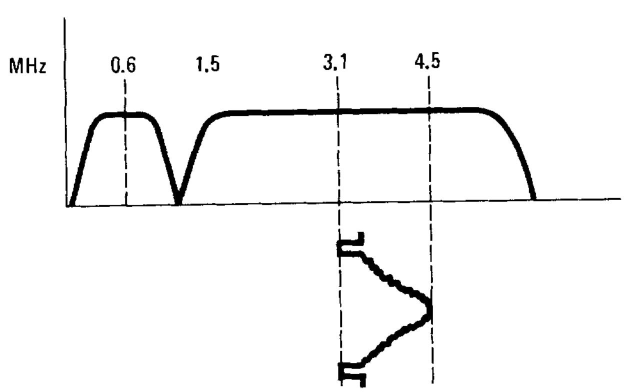
TYPICAL VIDEO FREQUENCY RESPONSE OF 1/2" AND 3/4" VCR'S



TYPICAL COLOR UNDER MODULATION TECHNIQUE



TYPICAL COLOR UNDER TECHNIQUE



What is required to make these pictures suitable for transmission purposes? Alternatives can be expensive; they extend all the way up to 2-inch quadruplex VTR's. Obviously, only a few CCTV and CATV operations can afford this luxury, and in most cases, it isn't necessary.

Engineers at International Video Corporation have come up with a reasonably priced alternative, designed especially for those applications where price is a consideration and where excellent technical performance is required, such as CATV, hotel entertainment systems or any application where it is not possible to control the receiver or monitor. These 1-inch, high-quality video cartridge recorders are called the VCR-100 Series.

The VCR-100 uses the widely-known IVC 1-inch helical-scan format. What does this format have that makes it better for these applications?

A look at the format reveals that a single head is used to record one field of video across the entire 1-inch width of tape. The video scan is relatively short for a single head helical scan machine, and this contributes to ease of tracking and lower tension errors. Since the entire width of the tape is used, coupled with an alpha wrap, the only missing information is "hidden" in the vertical interval. Therefore, no active video information whatsoever is missing. This is extremely important in CATV and broadcast applications.

Audio somehow has to be recorded onto the tape. Since we have used the entire width of the tape for video, how can this be done?

The answer lies with the azimuth difference between the longitudinal audio track and the helical-scan video track. The audio-1 track and the control track are located 100 mils from the top and bottom of the tape, respectively. These tracks, 39 mils wide, are recorded on the tape a second or so before the video is recorded. These two tracks are recorded at an angle of approximately 5° relative to the vertical dimension in the opposite plane. Hence, the angular difference between the two signals is about 30° and the interference or crosstalk between tracks is kept to a minimum.

The audio-2 track is recorded in a more conventional manner at the bottom edge of the tape. This track is 13 mils in width and is not recorded at an angle, but is centered 9.5 mils from the tape edge. The only portion of the video signal recorded here is the "back porch" portion of the vertical sync interval which occurs during retrace.

IVC VCR-100 Series

So, now we have video, audio and control track information on the tape with no interference between them. Wide video guard bands permit easy tracking adjustments, short straight video tracks permit stop action and the entire NTSC color information is recorded without any alteration during the record mode. The reason for this is the wide bandwidth.

All IVC format recorders have a bandwidth of 5 MHz, more than sufficient to record the full NTSC color signal. Since color correction, or stabilization, is required only during playback, all IVC recorders--even those without the playback color board--can record color. And since bandwidth is directly proportional to horizontal resolution, the 5 MHz bandwidth equates to 400 lines of resolution. Not only that, but the signal is capable of being timebase corrected to obtain direct NTSC color.

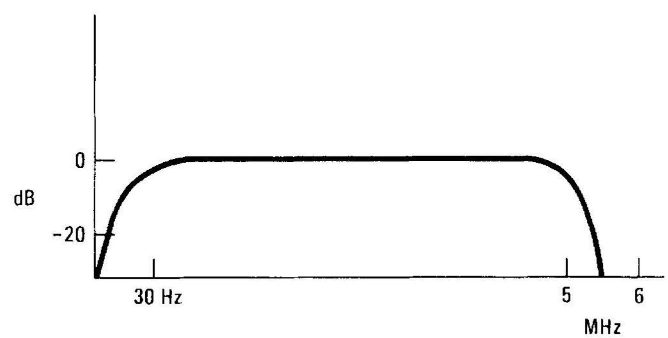
The writing speed of the VCR-100 is 723 ips, approximately 300 ips faster than other VCR's. This, coupled with ferrite heads and Hi Energy tape, results in a signal-to-noise ratio of 45 dB. However, regular gamma-ferrite oxide tape can be used and the resultant signal-to-noise ratio is a healthy 43 db.

The modulation technique used is a patented Pulse Interval Modulation, not Frequency modulation. PIM (as it is more commonly called) provides significant improvement in the signal-to-noise ratio and frequency response. Integrated circuits, which are particularly adaptable to the PIM technique, permit excellent carrier balance in the recorder's modulator and limiter circuitry, thus reducing moire' effects.

Videotape recorder timebase errors can be caused by capstan servo instability, capstan eccentricity, scanner instability and tape tension variations. These errors can be minimized by careful mechanical design as well as by electrical means.

The VCR-100 scanner is directly driven by a printed circuit dc motor. A printed circuit motor servomechanism offers much faster response time, has a lower mass, and provides generally better operating characteristics than a hysteresis synchronous motor. The scanner assembly is rigidly supported at both the top and the bottom. The combination of a fast-response printed circuit motor and a rigidly mounted scanner significantly reduces timebase errors.

VCR-100 VIDEO FREQUENCY RESPONSE



The VCR-100 utilizes a capstan servo, which further reduces timebase errors. The VCR-100 capstan uses a hysteresis synchronous motor, since motors of this type have smoother dynamic characteristics at the low speeds required for tape speed control.

The control of the supply and take-up reels is by means of another dc printed circuit motor. A dc printed circuit motor is ideal for this application as it has the extremely high-torgue capability required for rapid tape acceleration in the wind and rewind modes.

TTL logic circuits are used for all tape motion control circuits, and the control logic controls are all electrically operated. Remote control simply consists of a panel of momentary contact switches connected to a Jones-Cinch plug on the rear of the VCR. Control voltage is only 5 volts. This also means that the VCR can be used for numerous automation applications.

The VCR-100 also features a uniquely safe tape transport mode control. It is possible to go from fast forward or rewind directly into play without danger of tape breakage. Memory and timing circuits in the VCR ensure that it is impossible to damage the tape or VCR by switching between any two transport modes.

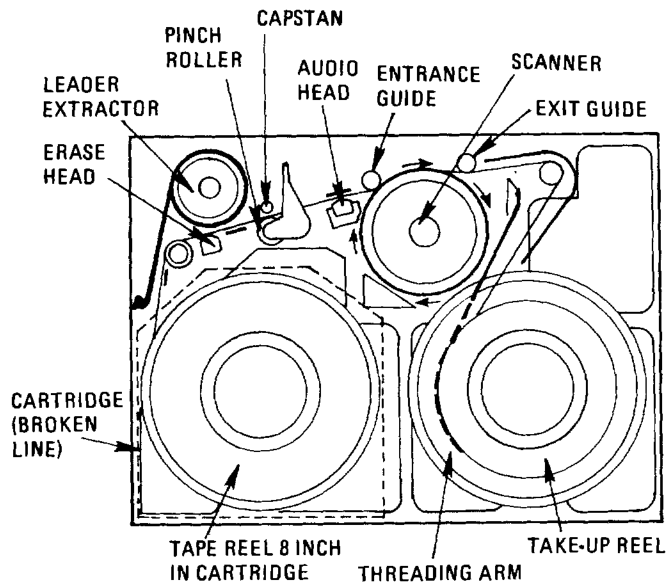
Since the VCR-100 utilizes the same IVC 1-inch format currently used on over 11,000 reel-to-reel VTR's already in the field, complete interchange between these VTR's and the VCR-100 is guaranteed.

The VCR-100 tape cartridge contains a standard reel of tape 8 inches in diameter. This tape can be recorded in the cartridge on the VCR-100, or recorded on an IVC reel-to-reel VTR and then placed in a cartridge for playback on the VCR-100.

If a recording is made on the VCR-100, the reel can be removed from the cartridge and played back on a standard IVC reel-to-reel VTR. This means that the IVC 1-inch format can be used for all VTR applications including the new, convenient, self-threading approach but without compromising picture quality.

The tape cartridge consists of a plastic enclosure which houses the standard 8-inch tape reel. To facilitate loading, a plastic adaptor ring is pressed into place on the NAB reel hub. A clear plastic leader is spliced onto each end of the tape. The head end leader has a small hole located about 4 inches from the front of the leader.

When the cartridge is loaded into the VCR-100 and the door is closed, the reel inside the cartridge rotates in a rewind direction, taking up any loose pack and rotating the leader. A motor driven arm with a hook on it is simultaneously moved into the cartridge. As soon as the hook engages the hole in the leader, the engagement is sensed and the direction of the arm is reversed, pulling the leader faster than the arm. The leader is then channeled past the audio heads and around the scanner. A shroud around it guides the leader in a circle. From the scanner it moves onto the take-up reel. As soon as the clear leader passes a photo cell and the opaque tape is sensed, the threading action stops and the VCR-100 goes into a standby mode.



IVC VCR-100 Tape Threading Path

Once this threading procedure is completed, the machine is ready to be controlled in any of the normal tape modes. Inhibit circuitry in the controller does not allow any tape mode to be engaged during the threading process. If, for any reason, the recorder has not achieved complete threading within 20 seconds, the video tape is rewound and the cartridge is ejected, thus notifying the operator that there is a fault in the system.

It is not possible to run the recorder all the way to the end of the take-up reel and completely off of the cartridge. This is because a piece of transparent leader is also spliced at the end of the tape. The same photoelectric sensor at the scanner exit, that notified the control logic that the tape was threaded, also acts to place the recorder in Rewind at the end of tape.

To protect the video head from possible damage by the leader during the thread mode, the scanner is run at half speed except during record or playback. The video head is spring loaded in such a way that it is always retracted whenever the scanner slows to half speed. Normal run speed extends the head to a preset position by centrifugal force. This feature extends the life of the video head, since it is never in contact with the tape during the fast wind modes and an unprecedented 2000-hour head life is guaranteed.

Although the 3/4-inch VCR's are designed to use only Hi Energy tapes and the 1/2-inch EIA-J VCR's are designed to use only gamma ferric oxide tapes, the VCR-100 is designed to use both. A lock-out plug on the cartridge automatically selects the proper record current for either type of tape. Another lock-out plug on the cartridge prevents accidental erasure of pre-recorded material.

The IVC VCR-100, with its convenient automatic threading, can easily be used in CCTV and CATV automation systems.

A cablecaster can tape his program on any IVC 1-inch recorder with the assurance that the reproduced picture will have the best resolution, signal-to-noise ratio and stability available. This tape can be played back on the VCR-100 with the assurance that it will look good on <u>any</u> home receiver. If the cablecaster is concerned with the cost of retaining a full-time technical staff, a bank of VCR-100's with automatic sequencing electronics can solve that problem. The prerecorded programs can be loaded into the VCR's throughout the origination day. This system could pay for itself within a few months after its installation.

A review of some of the pertinent specifications will show that this VCR can do a superb job in all CCTV and CATV applications, especially when the signal must be fed to a variety of different receivers or monitors.

The video bandwidth is 5 MHz. This equates to 400 lines of horizontal resolution. Video signal-to-noise ratio is 43 dB with standard gamma ferric oxide tape and 45 db with high-energy tape. Timebase stability is extremely low, about 10 to 15 microseconds with reference to horizontal sync. Other VCR's have a timebase stability of about 30 microseconds.

Add to this the convenience of automatic cartridge threading and interchangeability with other high-performance 1-inch VTR's, and it is evident that this VCR offers the industry a useful tool for CCTV and CATV.

A STUDY OF ALUMINUM CABLE-CONNECTOR INTERFACES AND THEIR EFFECT ON CATV SYSTEM RF INGRESS

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The cable-connector interface is dominant in considering long-term system shielding effectiveness. Mechanics of the interface indicate that radial cable stress can reduce contact pressure between cable and clamp; creep is a secondary phenomenon. Internal support sleeves help maintain required contact pressure. Laboratory and field tests show quantitative differences between connectors having internal support sleeves and those without.

The cable-connector interface resistance is explored as a factor in long-term shielding effectiveness; an increase in junction resistance with time is typical.

Field testing with simulated feeder lines is described in detail together with the concept of "effective shielding", the difference between the signal level at a dipole 10' away from the cable and the signal obtained in the cable system, expressed in dB.

A useful approach to the problem of maintaining satisfactory interfaces is presented. Arguments favoring aluminum cable connectors having integral internal sleeves are outlined.

System RF integrity has been a matter of growing concern throughout the CATV industry. The imperatives are self-evident; the need to meet FCC specifications, and the equally compelling requirement to guarantee RF integrity in any part of the spectrum where strong external signals may exist.

The potential routes of RF leakage are well-defined. They exist at the aluminum cable-to-connector and connector-to-housing interfaces, at housing and cover joints, at drop cables and associated fittings, and at the unused multitap connection. While each and every one of these may contribute to the overall problem, we are restricting this discussion primarily to the first of these factors - the cable-connector interface.

The direction of this paper is as follows:

1. To examine the mechanics and measurements of the cable-connector interface, with particular emphasis on finding logical explanations for the typical degradation occuring with time in field use.
2. To discuss the advantages and disadvantages of internal support sleeves.
3. To describe techniques for measuring RF leakage and junction DC resistance in the laboratory; to report on controlled RF shielding tests in the field showing system changes with time as affected by various connector combinations.
4. To present a useful approach to the problem of obtaining and maintaining satisfactory cable-connector interfaces.

1. MECHANICS OF THE CABLE-CONNECTOR INTERFACE

The typical aluminum cable connector contains a compressible ferrule which secures the cable and completes the outer conductor circuit by intimate contact with the outside of the sheath.

Once secured, in typical usage, the connection may be subject to alternate tension and compression, rotational, and both high and low frequency vibrational forces. Both diurnal and seasonal temperature variations contribute to further stresses and strains, while chemical attack from air pollutants, accelerated by varying humidity conditions, may contribute to the gradual deterioration of the vital sheath contact. The effective connector must provide permanent resistance against all these forces.

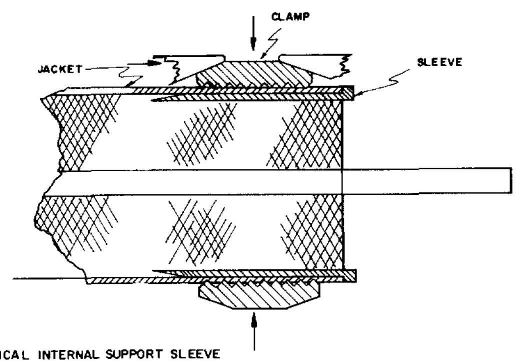
Some of the mechanical problems are readily overcome by good clamping methods. For example, 1/2" diameter polyethylene foam dielectric aluminum sheath cable will break at 400-450 lbs tensile load near or at the clamp; this is close to the tensile limit of the cable sheath. Such a gripping force will easily overcome normal rotational movements. However, experience has shown that mechanical joint strength alone does not necessarily guarantee satisfactory electrical performance.

The cable jacket is typically extruded 1060 alloy, a soft material having a yield point of 7-10,000 psi, depending on the amount of cold work applied.

Such materials, when stressed, are invariably subject to creep phenomena at normal ambient temperatures which result in strain relief or even in movement in stressed areas as a function of time. The squeezing action of the ferrule described above necessarily imparts compressive stress to the aluminum jacket; hence, a certain amount of creep must be anticipated. In addition there is creep of lesser magnitude in the aluminum alloy connector members, particularly in stressed threads.

2. USE OF INTERNAL SUPPORT SLEEVES

In recent years improvement in connector RF performance seemed evident when rigid support sleeves were placed underneath the cable jacket so that the cable was sandwiched between the compressing clamp as shown in Fig. 1. The obvious benefit from this arrangement is that contact pressure between the sheath and the ferrule is maintained and that jacket creep is limited.



TYPICAL INTERNAL SUPPORT SLEEVE

FIG. 1

The insertion of a close-fitting, thin wall sleeve is not without problems, however. Both out-of-round cable and ID burrs caused by cable preparation tend to make insertion difficult. If extreme compressive force is applied there is a tendency to reduce the wall thickness of the cable jacket, thus work-hardening and weakening it. The sleeve is a small, loose member, easily dropped, lost, or even discarded by an indifferent technician. Subsequent inspection after connector assembly is virtually impossible. Polyethylene foam dielectric is relatively tough, almost completely restricting the entry of the sleeve unless the dielectric is partially or completely cored out. The cable impedance is changed at the sleeve location. For 1/2" dia. cable, a typical thin-walled sleeve having an inside diameter of .400" inserted with no polystyrene dielectric removed would yield a characteristic impedance of 69.5 ohms. Coring is evidently always desirable and sometimes essential; the operation must be performed with care to avoid damage to the sheath and the center conductor.

3. LABORATORY R.F. LEAKAGE MEASUREMENTS

In order to obtain precise evaluations of the RF shielding capabilities of cables and connectors studied, a reliable and convenient test set-up was essential.

Fig. 2 shows schematically the apparatus used at the Jerrold Laboratory. System measurement capability is 145 dB. This technique compares a reference signal with the maximum picked up by a given tuned high-Q loop antenna, about 5" diameter. Five fixed frequencies, 5, 30, 54, 216 and 295 MHz were used, one antenna for each frequency. The high-level reference signal (about +80 dBmV) is introduced through solid-shield aluminum cable to the unit under test, then brought out of the screen room to a high power, impedance-matching attenuator to provide transition from 75 to 50 ohms and 60 dB attenuation, then back into the screen room at a conveniently lower level through 50 ohm flexible cable to provide a reference signal for comparison with that picked up by the antenna. All cable feed-through fittings are grounded to the screen room ceiling. Power line filters are installed so that there is no leakage through the AC power lines. Signal picked up from the device under test and the attenuated reference signal are fed into a co-axial switcher, thence to a low noise preamp, and to a mixer where the signals are mixed with the output from a fixed oscillator tuned 30 MHz above the test frequency, and fed into a G.R. 1216A 30 MHz IF strip and detector. The detected composite signal is displayed on an oscilloscope. Attenuation is varied until the same level is indicated for each position of the coaxial switch. The amount of leakage is characterized by the total attenuation inserted to match the level at the antenna terminals. This is an extremely reliable and sensitive test set-up. Repeatability of measurement is known to be within plus and minus two dB at the 140 dB shielding level. For any measurement the antenna is manipulated to yield maximum pick-up, usually obtained when its plane is parallel to the axis of connectors.

LABORATORY RF TESTING

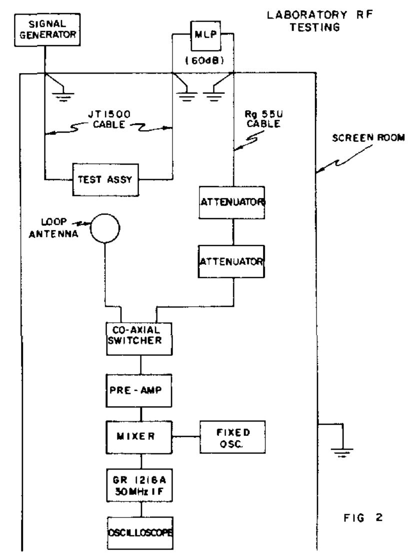


FIG 2

It is necessary to emphasize that the values obtained in this type of testing are relative to each other and are in no sense absolute. Maximum readings always occur close to points of actual leakage in the devices under test.

Using this equipment we have established a hierarchy of shielding numbers for various types of housings, connectors, and cables. Fig. 3 shows RF attenuation obtained with representative CATV hardware. Correlation with a commercial testing laboratory showed that a figure of 60 dB at 295 MHz in tap-connector combinations corresponded to current FCC RF radiation specification limit (15 microvolts/meter at 100 ft).

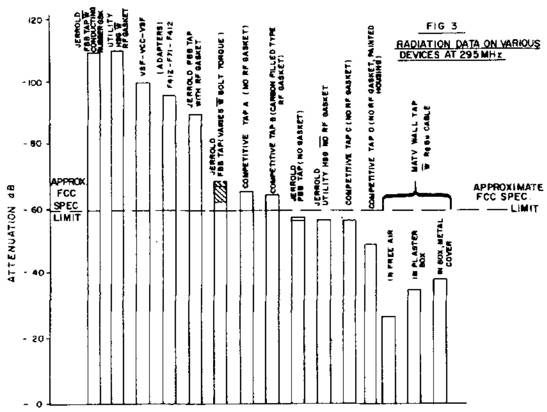


Fig. 4 shows the construction of an aluminum block used for testing cable-connector interfaces. This insures the integrity of the feed-thru device since there is no possible cover leakage. Cable center conductors are soldered together through the threaded port apertures. With the blocks described leakage measurements were initially made using various types of commercial connectors and styrene foam cable without any internal sleeves. As installed, many exceeded system capability - that is, attenuation beyond the 145 dB sensitivity limit. Those which did not invariably exhibited relatively loose cable contact due to insufficient ferrule grip, or due to a sizable gap in the ferrule slot.

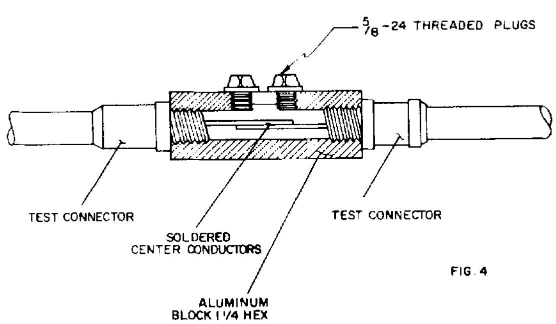


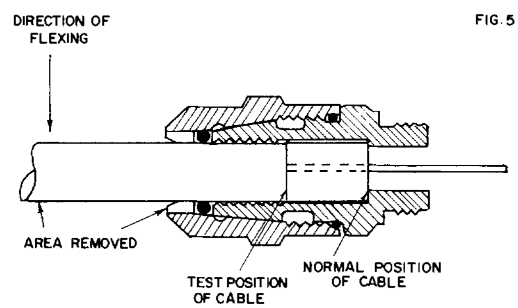
FIG. 4

TEST BLOCK FOR MEASURING LEAKAGE OF CABLE CONNECTOR INTERFACES

Fitting-cable-tap combinations when first installed generally have shielding effectiveness limited by the housing-cover RF gasket. One such combination, initially checked at -95 dB was heat-cycled between 20 and 60°C for two-hour periods twenty times while in the RF chamber; a 10 dB degradation was observed. This would indicate the degree to which creep may be a contributing cause of signal ingress. Similar combinations left at room temperature for periods in excess of 1000 hours showed little or no change. Evidently creep alone does not account for all the instability which has been reported from the field.

In the attempt to find a more likely source of cable-connector degradation sufficient to account for signal ingress of a magnitude reported from the field, we applied small alternating lateral forces to the cable in the connector block assemblies described above. We used Jerrold VSF-500-D connectors having no internal support sleeves, simulating occasional movements which might occur in aerial field use. Such motion arises from wind, from vibration induced in poles and cable by vehicular traffic, and other sources. In a few minutes the attenuation figure degraded from greater than the 145 dB sensitivity limit to the region of 90-125 dB intermittently. Where possible, tightening the connector nut restored the combination to an attenuation beyond the limit of measurement, following which the process could be repeated. This phenomenon is illustrated even more rapidly and dramatically by performing similar tests relying solely on the clamping mechanism, machining away all the areas of chance contact which normally exist in a connector, as shown in Fig. 5. Similar tests were made with many different connectors with the same results. Those with short clamping ferrules became intermittent rapidly; those with long ferrules took longer to fail.

FIG. 5



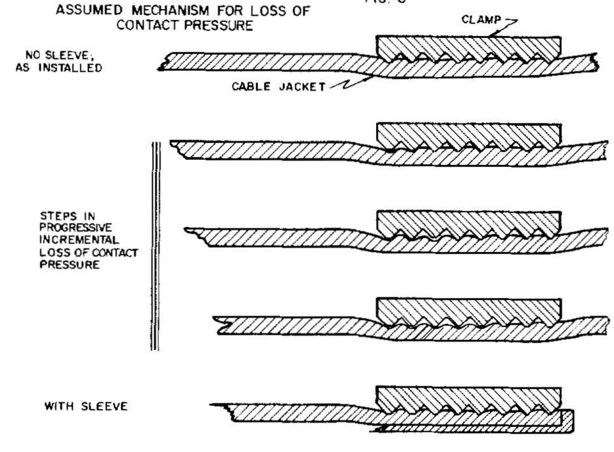
FLEXING TEST WITH MODIFIED VSF 500D CONNECTORS

These tests would seem to indicate that shielding degradation is largely due to mechanical phenomena which gradually diminish contact pressure and vital contact areas between clamp and cable OD. Creep may well contribute to further degradation of the interface but the drastic ingress noted at field locations where there is high ambient signal strength is more likely caused by the mechanism described.

Similar tests were run using the internal sleeve support. No measurable leakage was observed (i.e. no less than 145 dB shielding) when applying lateral forces to the cable, unless the clamp exerted insufficient pressure to force the cable sheath ID against the sleeve. This would seem to confirm that the primary cause for OD clamp loosening and consequent shielding deterioration is minute, incremental mechanical deformation, and that the internal sleeve helps to prevent it. Fig. 6 shows the assumed contact mechanism prevailing with and without internal support sleeves. Creep is considered to be a secondary effect.

FIG. 6

ASSUMED MECHANISM FOR LOSS OF CONTACT PRESSURE



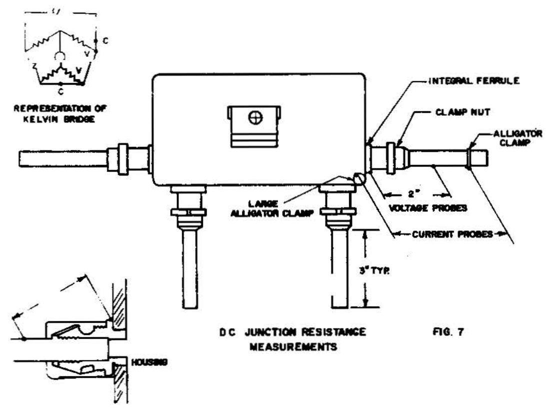
4. INTERFACE RESISTANCE MEASUREMENTS

The actual interface resistance is certain to bear some relationship to RF shielding capability. For example, connectors deliberately hard anodized .001" thick showed very poor shielding (70 dB), as would be expected. This is entirely understandable since large areas of the contact mechanism were virtually insulated. However, there is always some thickness of oxide film on aluminum surfaces. Ragnar Holm cited films 20A thick forming in a few seconds after scraping an aluminum surface.[1] Typical film thickness is given as 50-100A.[2] Contacts having films such as adherent oxides often show markedly erratic behavior, depending on the contact pressure and the applied voltage.[3] Oxide films on aluminum surfaces are omnipresent, tenacious and brittle. Low resistance contacts are made by rupturing the oxide film by shear and tensile forces.[4] We may infer with some certainty that between the extremes represented by the freshly scraped surface and the anodized film cited above, there is an oxide film thickness range which will materially affect contact resistance and shielding effectiveness.

Theoretically, the RF voltage measured across a single leaky interface is that which is developed by current flow across the impedance of that discontinuity. For example, assume that a very high intensity field causes a current of 0.1 amp to flow along the sheath. To limit the magnitude of the leakage signal within the cable to -40 dBmV, or .01 mV, the contact impedance of the joint would have to be less than 100 micro-ohms. Evidently we are looking for very low resistance contacts if we are to maintain low RF leakage paths.

In addition to the normal oxide films, the outside surface of the cable sheath is often stained, discolored and dirty. It is of interest to study the overall effect of all these films on the aluminum cable-connector joint. This was done by measuring D.C. contact resistance for various conditions of surface preparation.

Precise measurements were made using a Kelvin bridge with voltage probes 2" apart on a variety of 1/2" diameter cables with Jerrold VSF-500D and other connectors. Samples were aged outside, hanging from strand in dummy housings. Before each measurement, samples were brought inside and allowed to reach room temperature equilibrium for 24 hours. Typical test set-up is shown in Fig.7. Measurements include the contact resistance and that of 2" of cable plus connector.



DC JUNCTION RESISTANCE MEASUREMENTS FIG. 7

Fig. 8 shows the measured DC resistance of four 1/2" cable-VSF-500D connectors as a function of time. Note the average resistance as installed is about 50 micro-ohms. Resistance of three samples remained nearly constant after 3000 hours outdoor exposure while the fourth rose appreciably after 200 hours and reached 230 micro-ohms at 3000 hours.

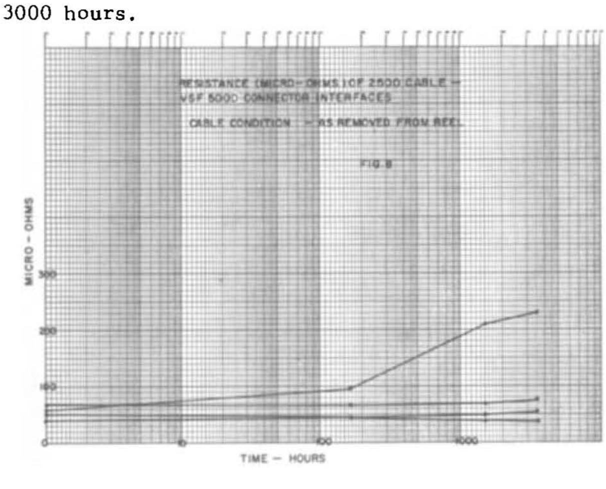


Fig. 9 shows resistances measured on five samples having the cable outer surface polished with steel wool prior to assembly. Initial readings varied from 40 to 130 micro-ohms (average 97). In four cases the resistance increased slightly, averaging 122 after 3500 hours. The fifth sample increased resistance from 55 to 130 in 500 hours and thereafter increased quite rapidly to 800 micro-ohms in 2000 hours. No obvious explanation was found for this erratic behavior. Disassembly of the connector showed the usual clamp indentations uniformly distributed around the circumference.

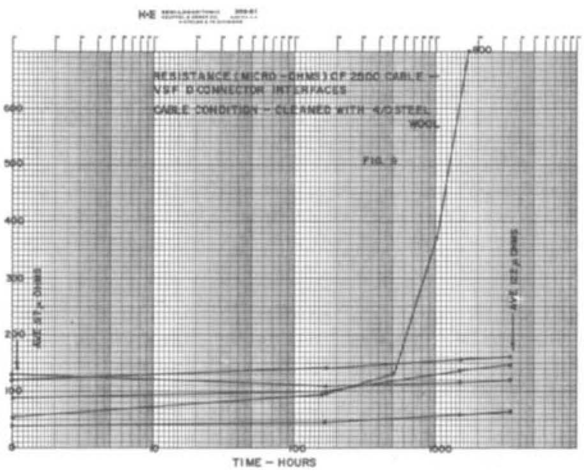


Fig. 10 shows the resistance of four samples having the cables polished as above, but also coated before assembly with a viscous silicone grease. Initial resistance averaged 105 micro-ohms, increasing to 174 after 3000 hours.

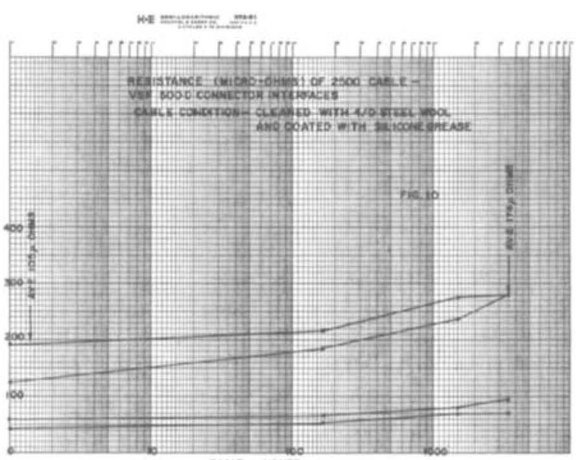
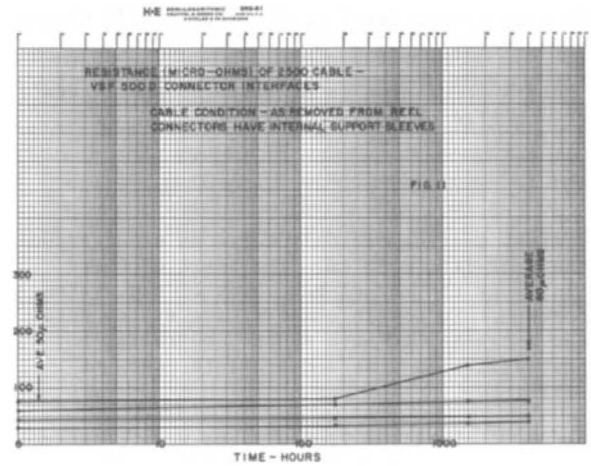


Fig. 11 shows the same test as in Fig. 8, but using internal sleeves. Average of four samples was 50 micro-ohms at the start, 80 after 3000 hours. Naybour and Farrell have demonstrated similar increases in resistance as a function of time when two smooth aluminum surfaces are compression loaded against each other.(5)



Similar tests were made using a connector with a heavy (yellow-green) chromate film; initial resistance was 200 micro-ohms, rising to 580 after 3000 hours. One connector was black anodized; initial reading showed a surprisingly low resistance of 600 micro-ohms. Microscopic examination showed fractured areas of the oxide film resulting from the clamping pressure, but the oxide particles had become embedded in the cable jacket.

One additional test was made following the procedure previously outlined showing how mechanical manipulation of the cable reduces shielding. As installed, with no internal sleeve, cable-connector resistance was measured at 89 micro-ohms. Periodic readings were taken at intervals during the flexing: 148, 144, 243, 299, 230, 121, 201 micro-ohms.

Visual examination of samples (other than the black anodized part) which exhibited definite increase in resistivity as a function of time showed no obvious oxide film formation or anything else significantly different from the more stable samples, within the limits of the optical inspection tools available. The data can be explained only by two mechanisms: (a) gradual reduction of contact pressure through creep reduces activated surface areas which constitute the available paths for current flow, (b) oxide films at contact areas are increasing in thickness thus increasing the contact resistance.

A comprehensive analysis of the chemical and physical phenomena underlying these experiments are beyond the scope of this paper. However, we may draw some tentative conclusions:

1) For 1/2" cable, the cable-connector interface D.C. resistance is typically less than 200 micro-ohms, as installed.

2) There is a tendency for the resistance to increase with time. For some assemblies the increase is abnormally great even though the initial resistance was no greater than in any other sample.

3) Cleaned and polished cable surfaces and protection by grease films do not necessarily prevent this increase.

4) Once a connection is minutely loosened, resistance may rise sharply.

5. SYSTEM TESTING OF CABLES-CONNECTORS-TAPS

Laboratory testing can only serve as a background to the real-life problem. The heart of these questions is the actual behaviour of the system components. To obtain quantitative system data it was necessary to have controlled radiation, an entire passive system, and accurate means of measurement.

Three 1200' simulated feeder lines were constructed on our laboratory property, as shown in Fig. 12, each having 18 Jerrold PBB-20 taps, VSF-500D connectors, and Times 2500 cable. All taps were equipped with RF gaskets, and had terminated tap ports. 8' ground rods were driven at each tap location, but no grounds were connected. One end of each line was terminated and the other introduced into the lab for monitoring purposes. The main test method was as follows: a three watt calibrated C.B. transmitter operating at 26.965 MHz, equipped with a tuned dipole antenna was mounted in a vehicle and moved parallel to the cable along its entire length at a 10' distance and at a velocity of approximately 400' per minute. Every time a pole location was passed, transmission was momentarily shut off. One of the three cables was connected to the input of a spectrum analyzer set at 10 kHz band width, and the output of the analyzer was fed into a strip chart recorder, thus obtaining a permanent record of all tests, including tap locations and measured signal ingress.

TAP LOCATIONS

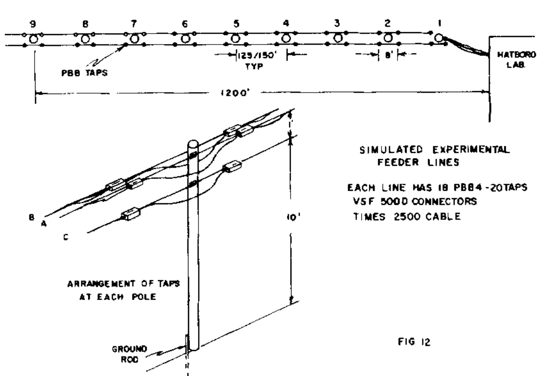
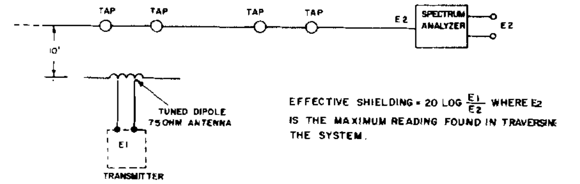


FIG 12

Before presenting data obtained in field system testing, it is necessary to define some measurement terminology which will be used in this discussion. Fig. 13 shows the system schematically. It is considered as a "two port" device, knowing with some certainty only the energy levels obtained at the terminals, and knowing little about radiation patterns or the radiating antenna field.

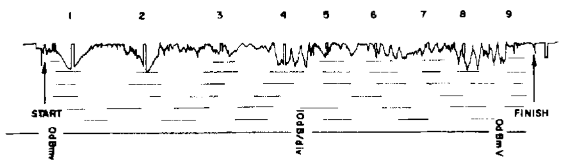


THE SYSTEM AS A "TWO PORT" DEVICE

FIG 13

We shall define "effective shielding" as the dB difference between the signal level at the dipole 10' from the cable, and the resulting signal level obtained in the cable system, for a given frequency of transmission. With the apparatus used the signal level at the dipole terminals was +82 dBmV as derived from 2.1 watts actually fed into a 75 ohm antenna. The effective shielding number is always recorded as the worst reading obtained on a system traverse. Therefore, it is numerically equal to 82 minus the maximum signal level found in the cable. We recognize the possible errors inherent in generalizing such an approach to signal ingress measurements; the presence of multiple cables, and proximate telco and power lines will undoubtedly influence the field intensity in a typical CATV cable system; terrain, moisture, and signal polarization may all affect readings. In these experiments the only variables were climatic conditions and time; the signal levels obtained certainly measure the R.F. integrity of the various arrangements tested.

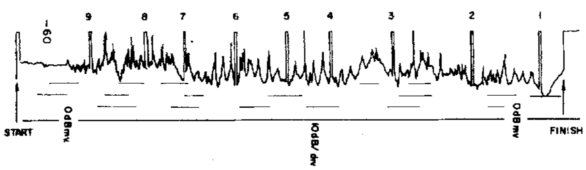
The first set of tests involved two cables. Cable A had internal support sleeves with connectors at locations 2, 4, 6, and 8 only, while cable C had no support sleeves at any location. We hoped to show differences in effective shielding that might occur where internal sleeves were used. Fig. 14 shows the record of ingress into cable A two weeks after installation. The worst reading on the spectrum analyzer was -50 dBmV at location 2, or an effective shielding (E.S.) of 132 dB. Fig. 15 shows the behavior of cable C similarly after two weeks. Note that the readings are definitely worse than in A. Fig. 16 shows the E.S. of both cables as a function of time, for the first seven weeks. Note the gradual deterioration, which is worse with cable C. Fig. 17 shows cable A after 4 weeks. Even though the E.S. has dropped 7 dB, it is not possible to tell any difference in shielding between taps having connectors with internal sleeves and those without, since standing waves completely confuse the issue.



CABLE A

TWO WEEKS AFTER INSTALLATION CONNECTORS HAVE INTERNAL SUPPORT SLEEVES AT LOCATIONS 2, 4, 6, 8

FIG. 14



CABLE C

TWO WEEKS AFTER INSTALLATION NO INTERNAL SLEEVES

FIG. 15

EFFECTIVE SHIELDING IN FEEDER LINES
18 P884 - 20 TAPS, 2500 CABLE, VSF 500D CONNECTORS

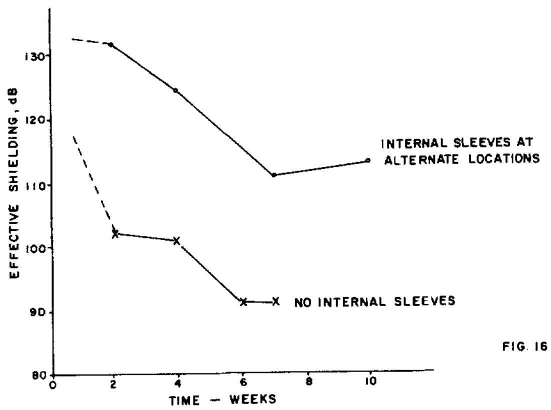
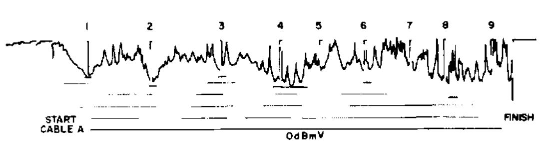


FIG. 16



CABLE A — FOUR WEEKS AFTER INSTALLATION CONNECTORS HAVE INTERNAL SUPPORT SLEEVES AT LOCATIONS 2,4,6,8. NOTE WORST READING AT LOCATION 4 STANDING WAVES OBSCURE "GOOD" AND "BAD" LOCATIONS.

FIG. 17

Fig. 18 shows a running record of cable C. After 8 weeks an experiment was conducted to see if the leakage was actually at the cable-connector interfaces. All 36 were tightly wrapped with steel wool. Note about 30 dB improvement. The following day the steel wool was removed, dropping the E.S. but only to 105 dB. Apparently the movement of the cable during the steel wool wrapping and unwrapping operation markedly improved some contacts in the relatively unstable connector-cable interfaces.

When the feeder lines were installed, no grounds had been connected at any tap location. Fig. 18 also shows the effect of attaching, then disconnecting grounds; no logical conclusion can be drawn since the instability of the connections is overriding.

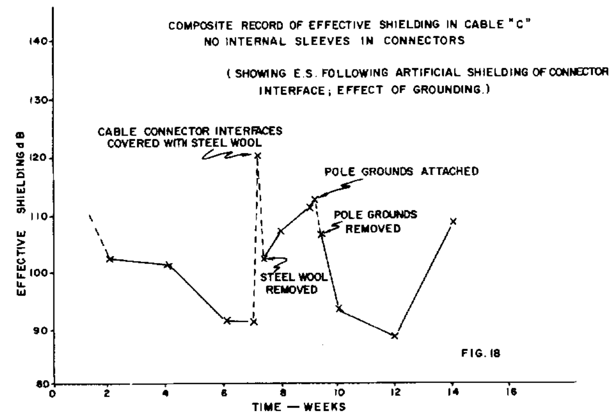


FIG. 18

Cable A was then modified to have all VSF connectors equipped with internal sleeves. Fig. 19 shows the E.S. value over a period of 18 weeks. Note the comparative stability although a degradation of 14 dB was observed. There is a strong inference that the internal sleeve, while providing significant improvement, may not eliminate the tendency for the vital cable-connector interface to deteriorate. Further long-term field testing is being conducted to ascertain the extent of this instability.

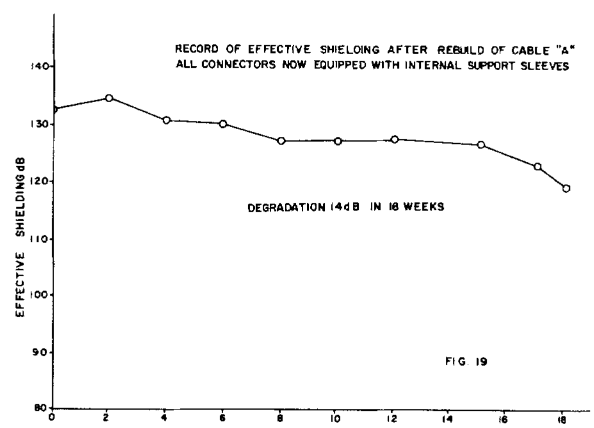


FIG. 19

We have referred to the systems here as "two port" devices. This says that the transmission loss between the cable terminal and the terminal of the test antenna is the same in either direction. Therefore, "effective shielding" is the same for signals radiating from the system or into it. This was easily verified by experiment using the antenna employed in our system measurements. Readings agreed to 2 dB at the 100 E.S. level. An additional test was made at 73.5 MHz introducing a +80 dBmV signal into the cable and using another tuned dipole 10' from the cable with a sensitive 5 kHz bandwidth receiver.

Receiving Antenna at Tap Location	Effective Shielding, dB	
1	128 at 26.965 MHz	129 at 73.5 MHz
2	128	125

The close correlation of results would indicate that the test method is not reflecting any special circumstances at the lower frequency.

6. AN IMPROVED CONCEPT OF CABLE-CONNECTOR INTERFACE

System tests have shown that the internal support sleeve minimizes but may not necessarily eliminate slow degradation of the cable-connector interface. Similarly, tests have indicated gradual increase of junction resistance with time, even with the use of internal sleeves, and that the condition of the cable sheath outside surface may be a factor in the joint resistivity.

These considerations led to the logical conclusion that the support sleeve should be integral with the connector, and that the sheath connection should be made to the inner rather than the outer surface. The advantages of an integral sleeve are manifold. The installer cannot omit it for any reason, since it is no longer a loose part. Current is carried on the inner surface of the sheath and transferred through intimate contact with the sleeve which is now electrically in series with the cable and the housing. The O.D. clamp serves only to secure the connection but not necessarily as a current carrying contact.

Fig. 20 shows the cross section of such a design. The steel sleeve is knurled at both ends. One end serves to make a splined fit with the I.D. of the connector barrel. the other end makes an intimate contact with the inner surface of the cable sheath when it is uniformly squeezed on the sleeve. The slotted fingers are embodied on a captive member which is counterbored at the back to accept an "O" ring for sealing the cable. It is essential to provide true radial squeezing of the cable sheath on the sleeve. Fig. 21 shows a typical portion of the inner surface of the cable jacket after installation. Note the serrations caused by contact with the sleeve knurl.

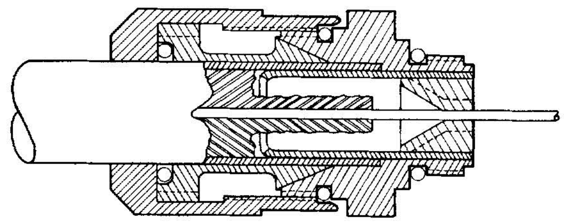


FIG. 20
CONNECTOR HAVING INTEGRAL INTERNAL SLEEVE

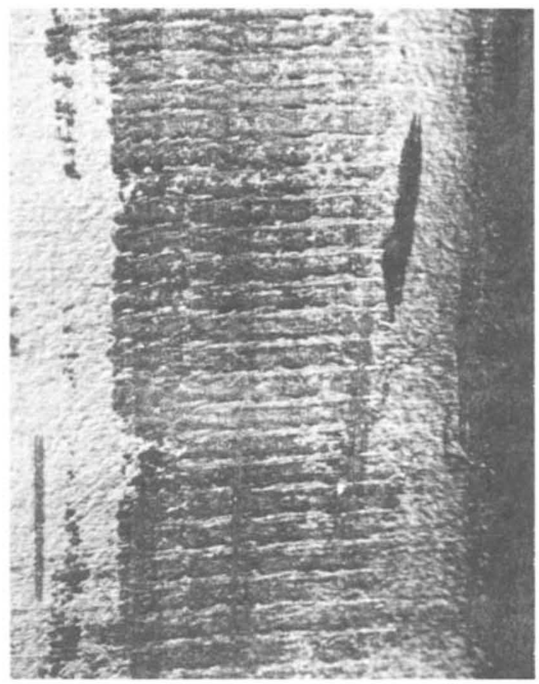
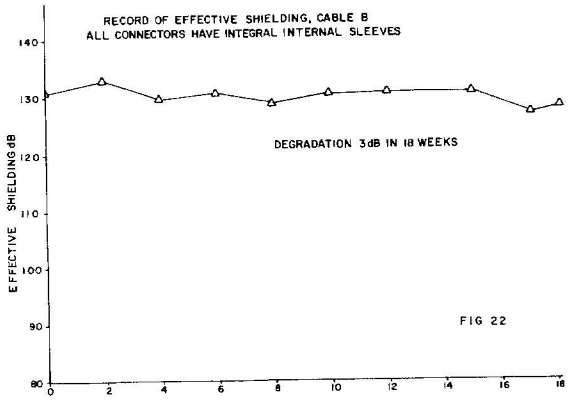
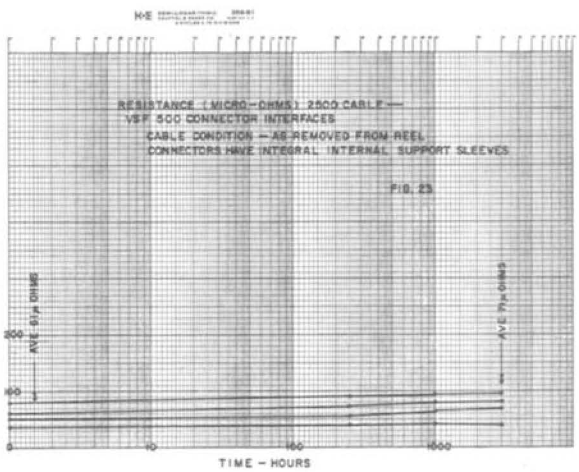


Fig. 21 Typical Contact Inside Cable Sheath After Squeezing on Integral Sleeve

This type of connector passed all R.F. laboratory tests with flying colors. An outside test was run with a feeder line equipped with connectors having integral sleeves in all 18 tap locations. Fig. 22 shows the variation of effective shielding over an 18 week period. Results indicate greater stability of the cable-connector interface; previous test results with connectors having separately installed sleeves are included for comparison. The variation of D.C. resistance with time is shown in Fig. 23. As installed the average resistance of four samples was 61 micro-ohms; after 3000 hours, average rose to 71. These samples show the least rise with time of any combinations tested.





In summary, the integral support sleeve makes and maintains contact with the inner surface of the sheath where all R.F. current flows. The benefits of this approach are revealed in the highest degree of connector-cable interface stability. The integral sleeve design would seem to have considerable merit as a step toward providing the CATV industry with connectors of superior reliability, with consequent minimizing of R.F. leakage problems.

7. CONCLUSION

The ideas presented here have been focussed almost exclusively on the critical cable-connector junction. Experimental evidence seems to show that this is, indeed, a most significant factor in system shielding. However, all of the interfaces as defined in our introduction must be carefully considered, since for maximum shielding capability no R.F. leakage path may be left to chance. Study of each part of the problem will inevitably lead to the most effective and least costly answers.

The author is indebted to Keneth Simons who devised the R.F. test methods, to Richard Kreeger and Donald Rogers for valuable assistance, and to Harry Reichert and Ronald Palmer for painstaking technical services.

REFERENCES

1. Holm, "Electric Contacts Handbook" 3rd ed.p114

2. Binger, Hollingsworth & Sprowls "Resistance to Corrosion and Stress", "Aluminum", Vol 1, p209 seq. Am. Soc. for Metals 1967.

3. Wagar, "The Making of a Good Contact", Bell Labs Record, July 1968.

4. Holm, op. cit. pp27-31 and pp158-159

5. Naybour & Farrell, "Connectors for Aluminum Cables: A Study of the Degradation Mechanisms and Design Criteria for Reliable Connectors", IEEE Transactions, March '73, Vol. PHP-9,No.1

APPENDIX A

The term "effective shielding" is defined in the text as the difference between the signal level, expressed in dB, at a transmitting dipole 10 feet from the cable and parallel to it, and the signal obtained at the output terminal of a cable system at a given frequency. Since theory indicates and tests show, within practical limits, that signal ingress and egress are caused by identical phenomena, we may extend the definition and calculate the equivalent effective shielding required to pass existing F.C.C. radiation specifications. These figures are shown for pertinent frequencies, assuming maximum signal level within the system is +48 dBmV. We postulate that the cable system is transmitting and that a dipole 10 feet from the cable is receiving.

Compare these figures with the shielding required under given conditions of signal ingress. For example: Assume signal ingress must be 50 dB below the typical minimum level in a trunk line (+10 dBmV). Further assume a 3 watt transmitter to be located 10' from the cable. Three watts into 75 ohms impedance, expressed as dBmV is +83.5. Offending signal must be -40 dBmV max. in the cable. The effective shielding required would be 83.5-(-40) or 123.5 dB.

APPENDIX A

FCC RADIATION LIMITS EXPRESSED AS "EFFECTIVE SHIELDING"

Present FCC specification:

0-54 MHz	15uv/m @100'
over 54-216	20uv/m @ 10'
over 216	15uv/m @100'

Signal received by a 75 ohm halfwave dipole in a field:

$$V = 48.3\ E/f^{(1)}$$

where V is microvolts

E is field intensity, microvolts per meter

f is freq. in MHz

Signal limits at 10' (assuming E is inversely proportional to distance)

Freq. MHz	Field uv/m	Level at Dipole output uv	dBmV	Effective Shielding Required* , dB
5	150	1450	+3.2	45
30	150	240	-12.4	60
54	20	18	-35	83
216	20	4.4	-47	95
300	150	24	-32.4	80

*Assuming max. signal in cable is +48dBmV.

These values are found by taking the difference between the dipole output level and the given maximum level inside the system. These numbers are the effective shielding required to comply with FCC requirements.

(1) Simons, "Technical Handbook for CATV Systems" 3rd Ed. p. 103.

A TELEVISION RECEIVER ESPECIALLY DESIGNED FOR CATV

G.W.Bricker, Director SelectVision
Consumer Electronics Div. RCA Corporation

G.C.Hermeling, Jr., Mgr. TV Tuner Engineering
Consumer Electronics Div. RCA Corporation

We welcome the opportunity to participate in a discussion of what we at RCA consider one of the key growth markets in our industry - a market in which we are deeply involved.

There is an accelerating expansion underway in operating cable television systems and we firmly believe there is a great potential in this market for color TV sets with built-in cable capability. This belief has been supported by our market studies and contacts with the MSO's. Your Companies have strongly encouraged the offering of this type of TV receiver.

Our Company, I am happy to say, is in step with the cable TV trend, and is responding to your requests, and the accompanying consumer demand for TV receivers specially designed to provide maximum enjoyment from Cable Television.

As you know the number of cable households in this country by the end of last year had risen to approximately seven million households - a very significant growth over the figure of just ten years ago.

In our efforts to intelligently examine the future of the cable TV market, we have participated in studies by the prestigious Stanford Research Institute and we expect to make continued use of their services to keep abreast of the anticipated growth rate of cable TV.

A Stanford Research Institute forecast indicates the number of cable TV households in the next five years will nearly double to approximately fourteen and a half million households - or about 21 percent of all TV households.

In other words, just five short years from now it is entirely possible that one in every five U.S. TV households will be linked to a cable system. And that will be the national average. In many areas, the percentage will probably be much higher.

It is pretty hard to ignore a market segment which may involve one-fifth of the total TV market in five years. My company has no intention of letting such a market go unsatisfied, but more about what steps we have taken in a moment.

There can be no denying that cable TV is growing fast. All of us here today know what has brought about that growth in the past - basically the desire on the part of the public for better TV reception.

In the future the motivating force will go beyond that to include the appeal of additional channels of entertainment and ultimately a broad range of consumer services.

The real key to the growth rate of cable TV in the months and years ahead will depend upon what happens in the top 100 markets. This is where the prime action is - involving by 1975 more than 85 percent of all the television households in the nation!

We are all well aware of the possible effects - I should say probable effects - of the FCC directive that any cable operator entering one of these key markets must provide a minimum of twenty channels for entertainment or other cable TV material and that all existing systems in these top 100 markets must comply similarly under the FCC timetable.

It seems natural that the cable system operator will move to use these extra channels. This will lead to further growth in the number of subscribers as the public realizes the added advantages of cable TV and the cable operator uses the extra programming as the incentive to increase his penetration.

With this growth new requirements will be placed on the TV set itself and will lead to new design considerations for TV receivers.

Now let me tell you a little about what my own firm has done in the area of cable television.

Two years ago, we introduced a 75-ohm connector which makes connection to a cable very easy in the home with no set adaptation required.

This was followed last year by the RCA Cable-Guard shielded Tuning system. Since May, 1972, all RCA 21-inch and 25-inch (diagonal) solid state XL-100 color TV sets have been equipped with this metal-encased VHF tuner, which was designed to help prevent local on-air broadcast signals from interferring with the cable TV picture. It also serves to block out interference caused by electrical appliances - both your own and your neighbor's.

This year we are introducing CableColor, a series of XL-100 solid state color TV receivers specially designed to take full advantage of cable TV's benefits. To help us determine the consumer attitude and interest in a special cable TV set, we conducted a market survey among subscribers and non-subscribers in New York City. Each respondent was given an explanation and demonstration of three sets, identical in appearance, with one set connected to the master antenna system, the second connected to cable through a converter, and the third set with built-in cable tuner, also, connected to the cable. Among the respondents who said they would buy a 23" screen size, or larger, set in the next 12 months, 71% or almost three quarters said they would pay a premium to get the new cable tuning feature, and 66% said they wanted both the built-in cable tuner and remote control. A strong indication that this is what the consumer wants - in lieu of a separate cable tuner. In planning for the growth of cable and its potential to provide new consumer services, we must ask ourselves will it be confusion coupled with inconvenience for the consumer? Or, will it be planned? Will the new requirements be incorporated and integrated into the present system for the consumer's convenience? We believe both the cable operator and the TV set manufacturer must approach the market with the consumer's viewpoint uppermost. And that CableColor is a major step in that direction.

We will cover the technical details of these advanced sets in the second portion of this presentation, but permit me to cover briefly the key features:

The new RCA ready-for-cable XL-100 color sets provide 24-channel VHF tuning directly through the set itself. There is no need for a black box or supplemental tuner on top the TV console.

There is complete antenna and cable compatibility. By means of a switch on the back of the set, the user can easily select the mode of reception, either cable or antenna. When set for "antenna mode" you can receive up to 12 VHF and 12 UHF channels with full parity. When the switch is changed to "cable mode" you can receive up to 24 cable channels. Think what this means! Now a family can buy a color set with the assurance that it's ready for the future. If their market has cable, they are ready immediately for single or dual cable use, and up to 24 channels. If their market does not have cable yet, they have a full featured RCA color set which is immediately ready when cable arrives. If they move - and one out of five American families do every year - their CableColor set is ready to adapt to their new locality, either cable or antenna.

If the cable channel frequency in your area should change, or you move to an area with different cable frequencies, you can, by a quick and simple adjustment of the controls located behind the door on the front of the set, change to the new frequencies.

Because all 24 channels are tuned through the TV set itself, there is no loss of the automatic fine tuning feature anywhere along the way. Every Channel can be fine tuned automatically.

By the same token all of the new RCA cable TV sets, except one manual version, are equipped with RCA's Signal Sensor remote control. With the wireless hand unit, you can electronically change all 24 channels, whether set for antenna or cable reception, adjust volume, and turn the set on or off. The increase in the number of channels available, will create more channel switching, and increase the consumer desire for remote control. We believe it will be a major subscriber benefit.

We have carried forward an active program with our distributors and through them with retailers to fully inform them of the cable television marketing opportunity. We have provided our distributors a complete program for their own use in preparing for the new market and spreading the word of cable TV.

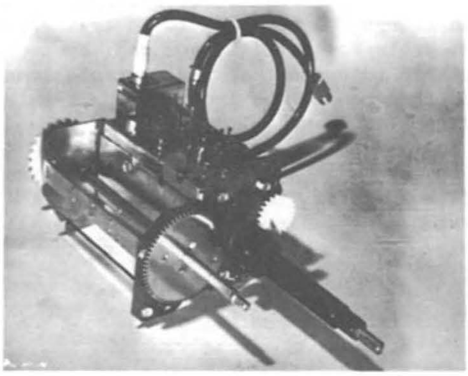
Most importantly from your viewpoint, we encourage them to meet and become involved with the management of cable systems in their area as soon and as extensively as possible. Training assistance is made available, including such things as a little fact book about cable television - and a handbook for the cable technician. (slides) We urge all cable TV system operators to seek out RCA's distributors in turn. The end result can be only to our mutual advantage.

Now, permit me to present the RCA series of cable television sets...five basic models in a variety of cabinet styles and finishes...all ready to maximize your enjoyment from cable television. The optional retail prices range from $675 to $795 and these sets will be available in RCA retail outlets starting in September.

RECEIVER DESCRIPTION

A 24 channel tuning system was chosen after weighing the following factors:

1. Results of market studies and MSO interviews.
2. Industrial design and circuit design considerations.
3. Wireless remote control capability.
4. Compatibility with broadcast and CATV systems.
5. Compatibility with single and dual cable systems.



KRK 211

FULLY SHIELDED VHF SWITCH TUNER (CHANNEL 2 THRU 13) WITH 24 POSITION DETENT MEANS

The three tuners incorporated are shown in the photographs. The KRK 211 is a completely shielded mechanically switched VHF tuner with means to convert from 13 to 24 detent positions. It is used in the broadcast and cable mode.

The KRK 194 is a UHF varactor tuner used in the broadcast mode.

The KRK 212 is a double conversion cable varactor tuner which tunes from channel 2 thru channel N. (54 to 246 MHz)

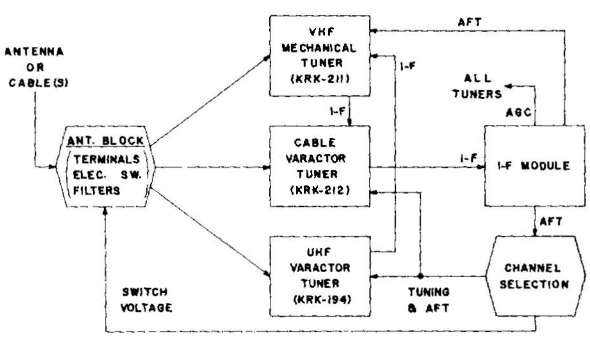
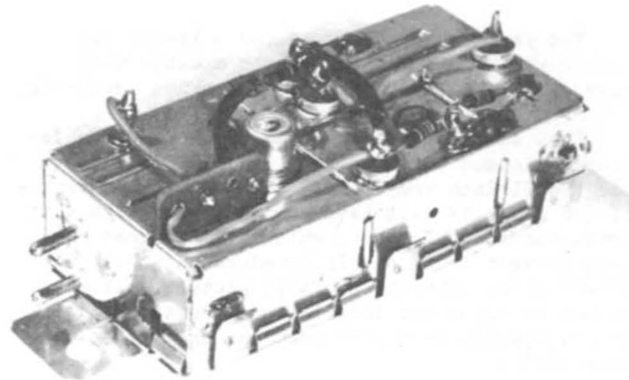
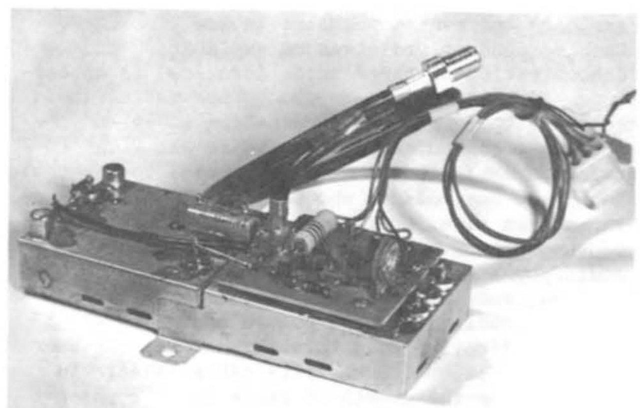


FIG. 1 ANTENNA & CABLE TV TUNING SYSTEM



KRK 194

UHF VARACTOR TUNER (CHANNEL 14 THRU 83)



KRK 212

CABLE VARACTOR TUNER (54 THRU 246 MHz)

Figure 1 is a functional block diagram of the overall tuning system consisting of the signal input circuitry which includes eletronic switching and filtering ahead of the two varactor tuners and one mechanical switch tuner. The KRK 211 tuner is similar in construction and circuitry to our 13 position shielded tuner used since 1972 in our XL100 21" and 25" models. The shielding effectively eliminates co-channel interference in areas such as Manhattan where conventional tuners are hopelessly overloaded by the strong ambient co-channel fields of the 7 local stations. A novel gearing means is used to make possible 24 position signal knob channel selection in the cable or antenna mode. As the detent shaft is rotated from 2 thru 13, these channels are selected in the conventional manner. Then as the shaft is turned past 2 or 13, the KRK 211 internal switches remain fixed and 12 adjustable voltages are selected in turn to supply tuning voltages to one of the 2 varactor tuners. The mode of operation, cable or antenna, is selected by means of a slide switch located on the terminal block at the back of the receiver.

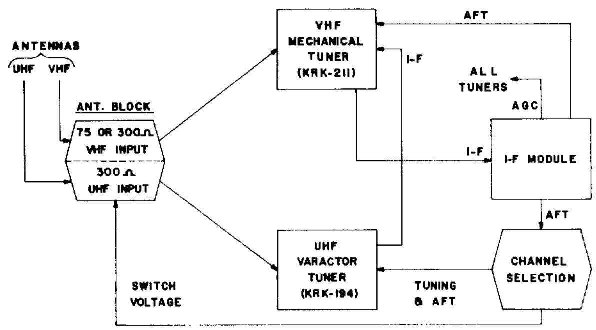


FIG. 2 ANTENNA MODE

Figure 2 is a functional block diagram of the tuning system in the antenna mode. Full parity between VHF and UHF is achieved for manual or remote control operation by the use of the KRK 194 varactor UHF tuner. Inserts are provided so that the correct channel number can be indicated.

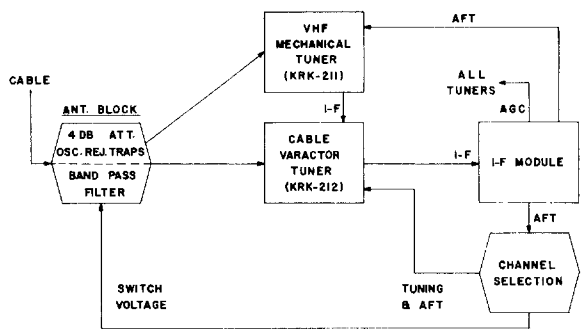


FIG. 3 SINGLE CABLE MODE

Figure 3 is a functional block diagram of the tuning system in the signal broadband cable mode. Circuitry in front of the tuners is used to protect the cable system from local oscillator leakage, assure adequate termination of the cable system and reduce intermodulation distortion products in the cable varactor tuner when tuned to the mid or super channels. The combination of this filtering with the circuitry and shielding designed into the KRK 211 tuner reduces the local oscillator leadage to a negligable level. The KRK 212 varactor tuner is energized in the same manner as the UHF varactor tuner in the previous example.

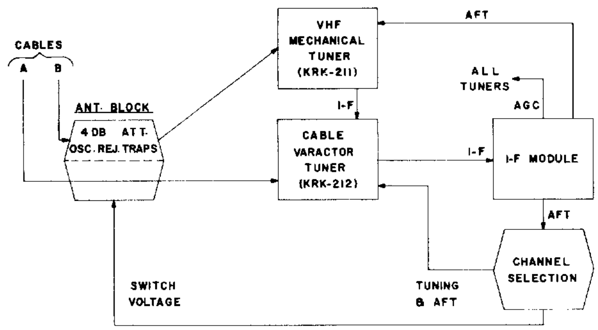


FIG. 4 DUAL CABLE MODE

Figure 4 is a functional block diagram of the tuning system in the dual cable (A/B) mode for systems where each cable supplies up to 12 channels on the FCC assigned broadcast frequencies. In the diagram cable B is fed through the built in attenuator to the mechanical VHF tuner. Cable A is fed directly to the cable varactor tuner which receives its tuning voltage from one of the 12 adjustable switched sources as in previous examples. In this mode no A/B switch is required and if the set is so equipped full remote control of all 24 channels is available.

PERFORMANCE CHARACTERISTICS

Since the broadcast performance of this special receiver is the same as other XL100 solid state color receivers in our line, we will address ourselves here to the characteristcs of concern to the cable operator and cable viewer. Of the TV receiver characteristics most often mentioned by cable interests, the following five are generally considered the most critical.

1. Immunity to direct pickup of off the air co-channel interference.
2. Local oscillator leakage into the cable system.
3. Image rejection.
4. Adjacent channel rejection.
5. Noise figure.

Sample No.	Equivalent Input* Channel 3	Equivalent Input* Channel 12
1	-40.9 DBMV	-40.9
2	-37.7	-33.2
3	-32.4	-38.4
4	-36.5	-32.8
5	-46.0	-40.4
6	-37.1	-38.1
7	-30.0	-46.0
8	-35.4	-37.1
9	-48.0	-35.4
10	-36.2	-37.1

* Equivalent Input Signal DBMV (75 ohm)

FIGURE 5

Figure 5 shows the equivalent input signal across 75 ohms expressed in DBMV induced by a 0.5 volt/meter field into 10 mass produced tuners as used in this receiver. The results of extensive field measurements by RCA and others show that it is extremely rare to find signal levels at receiving locations which equal or exceed 0.5 volts/meter. Also it has been demonstrated that with coherent signals a 40 DB desired to undesired ratio will not result in perceivable interference with normal picture content.

Our field tests show that with the order of immunity shown in Figure 5 there will be no complaints of co-channel interference where the leakage is not directly into the cable system itself.

LOCAL OSCILLATOR LEAKAGE

Channel	Channel Affected	Level In MicroVolts
2 (101MHz)	FM	Less than 10
3 (107MHz)	FM	" " "
4 (113MHz)	--	
5 (123MHz)	A	Less than 10
6 (129MHz)	B	" " "
7 (221MHz)	J	Less than 20
8 (227MHz)	K	" " "
9 (233MHz)	L	" " "
10 (239MHz)	M	" " "
11 (245MHz)	N	" " "
12 (251MHz)	O	" " "
13 (257MHz)	P	" " "

FIGURE 6

Figure 6 shows the local oscillator frequencies, the channel with which it could interfere and the typical level into a 75 ohm load. As can be seen, it is 14 DB below the maximum value of 100 uv usually suggested as a limit.

IMAGE RELATIONSHIPS AMONG CHANNELS

Channel	Freq. Band	Image Channel	Rej.
2	54 - 60 MHz	E	70-DB
3	60 - 66	F	82-DB
4	66 - 72	G	86-DB
5	76 - 82	I	87-DB
6	82 - 88	7	85
A	120 - 126	13	65-DB Min
B	126 - 132	J	"
C	132 - 138	K	"
D	138 - 144	L	"
E	144 - 150	M	"
F	150 - 156	N	"
G	156 - 162	O	"
H	162 - 168	P	"
I	168 - 174	Q	"

FIGURE 7

Figure 7 shows the image relationships among the channels and the desired signal to undesired signal ratio for equal input signals that are typical for this receiver.

The adjacent channel performance is a function of the IF selectivity except in the case of channels 5 and 6 where mixer beats are troublesome. The adjacent channel pix and sound carriers are greater than 60 DB down in the IF passband and improved mixer performance as related to mixer beats has been incorporated to reduce the most troublesome beat (channel 6 pix in channel 5) to an acceptable level. In a critical subjective test it was determined that with channels 7 and 9 10 DB above channel 8 no adjacent channel interference was perceivable on channel 8 even with the channel 8 pix carrier shifted ± 50 KHz.

NOISE FIGURE

ANTENNA MODE	NOISE FIGURE
CHANNEL 2 THRU 13	4 to 6 DB
CHANNEL 14 THRU 83	9 to 12 DB
CABLE MODE	
CHANNEL 2 THRU N (54 to 246 MHz)	9 to 14 DB

FIGURE 8

There may be a question as to why the noise figure in the antenna mode on channel 2 thru 13 is better than the same channels in the cable mode. Since the input VSWR becomes very high off channel when input selectivity ahead of the RF amplifier is used, we have found it necessary to switch in a pad ahead of the KRK 211 in the cable mode. The KRK 212 cable converter noise figure is typical of most dual conversion tuners with a balanced mixer.

To sum up, we are confident that this first introduction of a special cable/broadcast TV receiver will more than fill the requirements for reception on almost all of current and proposed CATV systems. We encourage you to look at one of these receivers on your systems when the receivers become available in the third quarter of 1973.

I would like to acknowledge the contributions of Messrs. D. J. Carlson, G. W. Carter, J. B. George, W. Howell and A. J. Schick, and others, who contributed to the design of this cable receiver.

ADDRESS
CLAY T. WHITEHEAD, DIRECTOR
OFFICE OF TELECOMMUNICATIONS POLICY

DR. CLAY T. WHITEHEAD: One of my favorite quotes came just a little over a year ago when one commentator stated that, "Cable television is going to be just the same thing as regular television, only worse. Real television," he stated, "dreary, hackneyed, boring and deathless as it is, is at least run by professionals. All the guys in the cable television companies are the guys who aren't good enough to make it in real television."

He went on to lament that the only things he had seen on his cable set were old British movies, which he had already seen a thousand times before.

This type of comment about cable is not unique. People have made such statements about every new technology or new service that has ever been introduced in the country. Let me read you some of the things that people were saying in the past about a few new-fangled ideas.

Most investors in the 1870's regarded Alexander Graham Bell's telephone invention as an interesting "toy for hobbyists," certainly not a serious long-term investment. One study reported as follows (see if it sounds familiar):

> Bell's proposal to place the telephone in every home and business is, of course, fantastic in view of the capital costs involved in installing endless number of wires.... Obviously, the public cannot be trusted to handle technical communications equipment. Bell expects that subscribers to his service will actually pay for each call made and they will agree to pay a monthly minimum if no calls are made. We feel it is unlikely that any substantial number of people will ever buy such a concept....

*   *   *

Obstacles of another sort were encountered by Lee De Forest, the inventor of the vacuum tube, which makes radio broadcasting possible. In 1913, De Forest was brought to trial on charges of using the U.S. mails fraudulently to sell stock to the public in his worthless enterprise. The District Attorney charged that De Forest made the absurd and deliberately misleading claim that it would soon be possible to transmit the human voice across the Atlantic. De Forest was acquitted, but advised by the judge to "get a common garden variety of job and stick to it."

Writing in the 1830's on the growth of the new railroad industry, one commentator argued that railroad growth should be curtailed. The reasons:

> Grave, plodding citizens will be flying about like comets. All local attachments will be at an end. It will encourage flightiness of the intellect. Veracious people will turn into the most immeasurable liars.... It will upset all the gravity of the nation.

*   *   *

The cable industry can expect to hear similar statements made against its development. In fact, the campaign to stop cable has already begun. Statements are being made in the press; arguments are being made to the Government; and the public is being told how cable will end the American way of life. Let's take a closer look at some of these claims and charges against cable.

One is that cable must be stopped because viewers should <u>under no circumstances</u> have to pay (or for that matter, be allowed to pay) for what they watch on a television screen. People can buy paperback books, magazines, and movies, but not television shows. Paying for television is inherently against the natural order of things, and maybe even down-right-un-American.

Never mind that there may be many viewers who would be willing to pay to get programming that advertisers don't find it profitable to support. Never mind that the aged, infirm, and the deaf may benefit immensely from having special-interest programming brought into their homes via cable. And that they would be willing to pay for these benefits.

We all know how closed-circuit movies are catching on in hotels and motels. These critics don't seem to realize that they are creating another immoral purpose for renting a hotel room, namely, to pay to a TV program they can't see in their homes.

Others claim that mass appeal national television programming promotes a shared national experience. It inculcates a unified national vision in our people. Cable's greatly expanded channel capacity would allow people to watch whatever they wanted, thereby fragmenting the audience and destroying this national vision. Cable might even bring low-cost channels devoted to single communities, or school districts, or even neighborhoods. This would turn communities inward, away from national goals, and it must be prevented.

Others charge that cable will violate the individual's right of privacy. A great deal of information on the subscriber's living habits would become available to industry, and government, resulting in "big-brotherism" in its worst form. Never mind the fact that in stopping cable's growth the Government would also be denying individual consumers the right to decide for themselves what they want to see and hear.

Concerns about privacy and security in cable communications are not only legitimate, they are extremely important; but these concerns are not reason enough for the Government to ban cable's development. Certainly it is as possible as it is necessary to achieve a balance in protecting the right of privacy while at the same time allowing customers to buy cable services.

Other complainers charge that cable's two-way educational, library, banking, shopping, and newspaper distribution services would put an end to human interaction. If people could handle their daily transactions via home cable hookup to stores, banks, and libraries, what would become of social contact? There would be an inhuman sense of alienation and individual anonymity (just as books brought about, I suppose).

Moreover, if people could see movies and sports in their homes, won't our theatres and expensive coliseums and sports arenas deteriorate with the rest of our inner cities? Without the bright lighting that is emitted from our arenas, movie and theatre marquees, our inner cities and even suburbs will become even more crime ridden.

Some of these charges are obviously far-fetched, and others are merely self-serving claims advanced by those who stand to lose business by cable's development. Embedded in some of these arguments, however, are elements of fact. We <u>should</u> be concerned over cable's ultimate impact on society.

But before we can determine what cable's impact on society will be, we must know how it is going to develop. And at this point it is too early to tell. We have to have some solid data and, to date, very little is available. It is possible, however, to make a few predictions.

First, cable television <u>is</u> going to come.

It will come with a multiplicity of channels; the majority of our American homes will be wired for cable; and we will have an electronic information distribution system in which cable and related technologies will play a major part.

Regulation at all levels of Government will have to be sorted out, but the biggest point here is that Government should not block cable's growth. No one has done more to that end than Chairman Dean Burch at the FCC. The Commission has done an exceptional job of getting cable moving again. The cable industry and television public owe a great debt to Chairman Burch for removing the regulatory logjam blocking cable's growth.

Many regulatory issues remain, of course, and some important policy issues regarding the regulatory environment for cable must be resolved. The Cabinet committee on cable television has been studying these problems and, hopefully, its recommendations will match the dynamic character and promise of the cable industry. But uncertainties about policy or regulation should not be an excuse for inaction.

Government can go only so far. Cable, like broadcast TV, is going to have to be a profitable private enterprise activity, so don't wait for Government to tell you what to do. The cable industry is going to have to make the next moves. The industry will have to decide whether to expand the range of programming and services presently available to the viewing public and ultimately take its place as full-fledged member of the communications industry. Or whether, instead, to accept the view of many of cable's detractors and remain simply an ancillary retransmission medium or merely as a purveyor of stale old films.

Let's face it. The viewing public can benefit from the full-scale development of cable systems throughout the country only if it means more and better programming with more choice for the viewer. The potential and capacity of cable to expand programming and the consumer's choice is great indeed. Granted, there will be problems and complications in cable's movement to industrial maturity. But they won't be any more difficult than those encountered by earlier entrepreneurs.

Some of the arguments lodged against the development of the railroads, telephone, and radio industries seem ludicrous to us today. But if you people gathered here measure up to those who went before in other industries, if your main concern is finding out what the public -- the consumer -- wants and needs, then I am sure that generations after us will be similarly amused at some of the exaggerated fears and short-sighted statements that were made against cable in <u>its</u> formative years.

ADVANTAGES OF DIGITAL TRANSMISSION IN CATV TRUNKS

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Seven advantages of using digital transmission in the CATV industry are given, and two of these advantages are discussed at length. A CATV system using digital signals can be significantly less expensive than a conventional system. The ratio of the cost of cables and amplifiers for a conventional system and a digital system is determined and bounded above and below. The economic advantage of the digital system increases as trunk lengths increase. This economic advantage can be further increased by using picture coding techniques to reduce the required bandwidth. The field of picture coding is reviewed and the most important results which have been obtained to date are referenced. The potential to transmit three digital, picture coded standard television signals in a conventional 6 MHz bandwidth is discussed.

Introduction

Digital transmission has long been considered a very useful modulation technique with several advantages over the more conventional analog transmission. Recent events and advancing technologies are making digital transmission feasible on very large scales. The major impetus to digital transmission has been the emergence of inexpensive and highly reliable integrated circuits, which means that sophisticated digital encoders and transmission schemes are now economically feasible. One result of this is that digital transmission figures strongly in the future of our two largest communication systems, the Bell system and the military communication system. In the 1980's, a large portion of the commercial telephone traffic between metropolitan areas will be by digital transmission with a data rate of hundreds of M bits/sec per channel, Bell Laboratories (1970). A major future transmission system for Bell System will be a buried millimeter waveguide carrying 230,000 voice channels of 64 K bits/sec each, A. T. &T. (1972). The military plans to use digital transmission for most of their communications by a 1980's time frame. There is presently a large scale effort underway to change existing military analog systems over to digital systems.

This paper lists some of the advantages of digital transmission as applied to CATV systems and discusses two of these advantages in some detail. The economic advantage of digital transmission for CATV trunks is illustrated, and the applications and advantages of picture coding for television pictures are discussed.

Advantages of Digital Transmission

Digital transmission has a number of advantages over the modulation scheme presently used for transmission of signals in CATV systems. The list of seven advantages given below is perhaps not exhaustive, but does include the most significant advantages. Some advantages are:

1. Digital transmission provides an efficient trade-off between bandwidth and signal-to-noise ratio. This translates into an economic advantage for long-distance trunks. A system for transmitting digital signals can be less expensive than a conventional system, as discussed in section 3 below.
2. Digital encoding of two-dimensional signals (picture coding) can greatly reduce data rate and bandwidth requirements. This is also discussed in greater detail below.
3. Digital signalling allows flexibility in multiplexing and multiple access, which should prove very important in two-way operations.
4. Information can be encoded for error control and/or security. These are two of the major reasons why the military has decided to change to digital transmission.
5. Digital modulation generally requires less dynamic range than a conventional TV signal for the same picture dynamic

range, and thus, less intermodulation type interference is generated in practical amplifiers. This is important since, in a CATV system, conservation of dynamic range is as important as conservation of bandwidth.

6. A digital system can reduce the effects of outside interfering signals in a CATV system.
7. Since digital modulation is a non-linear modulation, the degradation in picture quality due to reflections in the transmission system can be eliminated.

Naturally, the advantages of digital transmission are not obtained without some disadvantages. Some important disadvantages are:

1. The terminal equipment of a digital system is more complex than the terminal equipment of an analog system. However, because of the widespread use of large-scale integrated circuits, this need not result in extremely expensive or unreliable equipment. Kwan (1973) states that terminal equipment for digital radio has a "comparatively low cost". The cost of terminal equipment is not considered in this paper.
2. Digital techniques generally use more bandwidth than analog techniques. However, cable systems enjoy the option of being able to provide more bandwidth by simply paralleling cables. The Bell System presently plans to use 22 coaxial structures in one cable for their T4 coaxial cable digital system.
3. Digital techniques are not widely understood by practicing CATV engineers. It is hoped that this paper and others like it will help alleviate this disadvantage.

In the next section, an economic advantage of digital transmission for long-distance CATV trunks is discussed.

Cost Comparison of Transmission Systems

Until just recently, digital signalling and encoding equipment was prohibitively expensive so that digital transmission was used only where high performance was essential and cost was of secondary importance, as in the space program. As pointed out above, large scale integrated circuits have drastically lowered the cost of digital equipment. However, even with these lower costs, digital transmission will be more expensive than analog transmission for the next few years since the development costs for a digital system must be recovered. Development costs for analog systems have been largely recovered and market forces have lowered prices. Thus, it would be unrealistic to compare the total cost of a digital system with the cost of an analog system. A more realistic comparison is to consider the transmission costs of digital and analog systems.

Chang and Freeny (1968) have made a detailed study of digital transmission over a coaxial cable system with cascaded amplifiers. They concluded that "in many practical systems it is not only economical, but also optimum to use identical analog repeaters", rather than all digital repeaters when transmitting digital information over the system. This means that much of what is known today about cascaded systems is directly applicable for digital transmission.

It appears that the most reasonable comparison is to compare the costs of the transmission system for digital and analog signals carrying the same number of channels over the same distance and delivering the same output signal-to-noise ratio. Since the construction and right-of-way costs will be the same, it suffices to compare the cost of the cable and analog amplifiers for the system using digital signals with the similar cost of a conventional system. The main difference between the two systems is that the digital system generally will be a multi-cable system having parallel trunk cables, as discussed in Kirk and Paolini (1970). For the specific example here, there are three parallel trunk cables.

This comparison neglects the cost of digital terminal equipment since, as discussed above, development costs would be associated with the digital equipment and not with the analog equipment. Also, as trunk lengths increase, the terminal costs become less of a factor and can be neglected.

It is convenient to consider two different systems and to subscript variables with a 1 if they are for system one (conventional) and with a 2 if for system two (digital). Thus, let C_1 represent the total cable cost for system one and A_1 represent the total amplifier cost for system one. Define the transmission cost, T_1, as the sum of the cable cost and the amplifier cost, so that the ratio T_1 / T_2 is the transmission cost of system one divided by the same cost for system two and is referred to here as the cost factor. If T_1 / T_2 is greater than unity, the cost comparison is favorable to system two, while if the ratio is less than unity, the comparison favors system one. It is easily shown that

$$\frac{T_1}{T_2} = (k_1 + 1)\left(\frac{k_1}{R_c} + \frac{1}{R_A}\right)^{-1}$$

where $R_c = C_1/C_2$, $R_A = A_1/A_2$, and $k_1 = C_1/A_1$. Each of these three terms is briefly discussed below.

Assume that system one (the conventional system) has 25 cascaded amplifiers, each with 20 dB gain, and carries 40 channels. Then, assuming typical values for amplifier and cable cost, it can be shown that k_1 (cable cost over amplifier cost for system one) is given by

$$k_1 = 2.4\left(\frac{L}{10}\right)^3 ,$$

where L is the trunk length in miles. As L increases, the cable diameter must increase, so that attenuation will decrease to keep the same number of amplifiers. The larger diameter cable costs more and the amplifier cost stays the same, so the ratio of cable cost to amplifier cost must increase. However, it is surprising that it increases with the third power of the trunk length.

The ratio of cable costs, R_c, and the ratio of amplifier costs, R_A, can also be found and related to system parameters. The usual assumptions that the cost per unit length of the cable is proportional to the cross-sectional area of the cable and that there is no dielectric loss in the cable lead to

$$R_c = \frac{B_1}{B_2}\left(\frac{SNR_1}{SNR_2}\right)^2 ,$$

where B_1 is bandwidth per channel for system one and SNR_1 is the signal-to-noise ratio which system one must deliver to the receiver. For a conventional system, B_1 is 6 MHz and SNR_1 might be 40 dB. Since a digital system trades bandwidth for signal-to-noise ratio, B_2 can be several times larger than B_1, and SNR_2 will be much less than SNR_1. For the example which follows, B_2 is 20 MHz and SNR_2 is nearly 10 dB less than SNR_1, yet the second system delivers the same performance as the first system.

The ratio of amplifier costs, R_A, is found in a similar manner and has a form similar to R_c:

$$R_A = \frac{B_1}{B_2}\left(\frac{SNR_1}{SNR_2}\right)^{-1}\frac{U_1}{U_2} ,$$

where U_1 is the cost of an individual amplifier for system one and, since we have assumed 25 amplifiers for the conventional system, $A_1 = 25\,U_1$.

When the three terms, k_1, R_c, and R_A, are substituted into the cost ratio (or cost factor) equation and the resulting expression maximized with respect to the signal-to-noise ratio for the second system, the maximum value of T_1/T_2 is

$$\left(\frac{T_1}{T_2}\right)_{max} = \frac{3.95}{L}\,\frac{B_1}{B_2}\left[2.4\left(\frac{L}{10}\right)^3 + 1\right]\left(\frac{U_1}{U_2}\right)^{2/3} .$$

When T_1/T_2 is maximized, the optimum design value of signal-to-noise ratio for system two is obtained. Next, it is necessary to get some bounds on U_1/U_2; then a graph of the above equation can be presented.

To derive some upper and lower bounds on T_1/T_2, the cost of an individual amplifier must be considered in more detail. The cost of an individual amplifier for system one, U_1, is

$$U_1 = K_1 + E_1 ,$$

where K_1 is the cost of the case, power supply, and any regulating circuitry, while E_1 is the cost of the electronics and the equalizer. An upper bound is attained when the cost of the case is the dominating item; i.e., $K_1 \gg E_1$ and $K_2 \gg E_2$. A lower bound is attained when the cost of the electronics is the dominating item; i.e., $E_1 \gg K_1$ and $E_2 \gg K_2$.

An example of the upper and lower bounds on the cost factor is given in figure 1. The specific digital system in this example has three parallel trunk cables and uses an eight level amplitude shift keyed signal. The channel signal-to-noise ratio for the digital system is 9 dB below that of the conventional system, but as pointed out previously, the signal-to-noise ratio at the output of the receiver is the same for both systems and is 40 dB in this example. It is planned that the complete derivation and other examples with graphs similar to figure 1 will be given in a forthcoming report by the first author.

The major conclusion is that digital transmission has an increasing economic advantage as trunk length increases. This is shown for a specific digital scheme as compared with a conventional system, but the same conclusion holds for other digital systems. Also, the comparison here was between a digital system and a conventional single-cable trunk carrying 40 channels, but if a digital system is compared with a sub-band long distance trunking system carrying 40 channels the same conclusion holds; i.e., the digital system has an increasing economic advantage as trunk length increases.

The economic advantage alluded to above can be even greater if more sophisticated encoding is used. It is impractical to use encoding techniques for analog transmission, but source

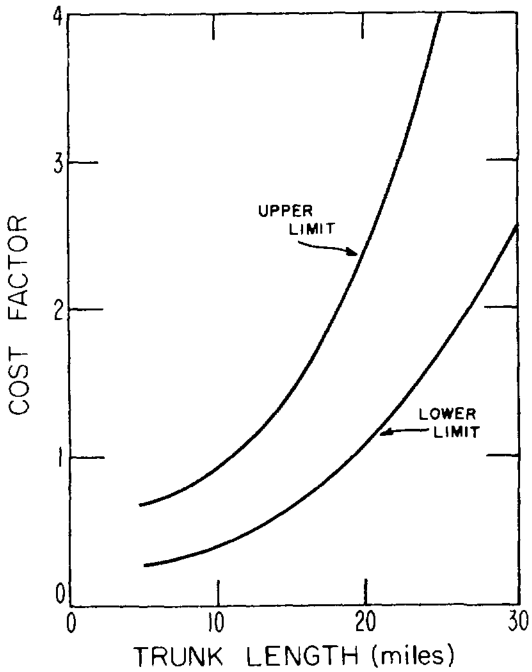

Figure 1. Cost factor vs. trunk length

encoding (picture coding) techniques can be easily realized when the picture is in digital form. The advantages of picture coding are discussed in the following section.

Picture Coding

U.S. broadcast quality television has 525 lines per frame, a four-to-three aspect ratio, and requires 30 frames per second for a conservative margin above the eye-sensitive flicker rate for studio light levels (Fink, 1957). Equivalent vertical resolution varies from 72 horizontal lines per inch for a 5 inch high display screen to 20 lines per inch for an 18 inch high monitor screen (Fink, 1957). The number of active lines per frame may vary from 483 to 499.

The picture can be visualized as a matrix of picture elements. The broadcast television picture has 2.7×10^5 picture elements per frame. For 30 frames per second, the rate becomes 8.1×10^6 picture elements per second.

For analog to digital encoding, eight bits per sample or picture element is considered sufficient for high quality television, with nine bits often specified for long distance relay. Television data rates would be greater than 64 M bits/sec. Each estimate excludes the housekeeping bits required for bit, word, line, and frame synchronization.

The broadcast television video bandwidth is about 4.2 MHz. Sampled at the Nyquist rate with PCM encoding of 8 bits/sample, the corresponding data rate is 67 M bits/sec, which includes all synchronization signals. None of these data rates include allowance for reduction possible through data compression techniques.

For comparison, the Bell System PicturePhone* video telephone station set (Cagle et al., 1971) is currently designed to have 267 lines per frame with transmission at 30 frames per second. The aspect ratio is 11 to 10 on the basis of a standard design viewing distance of 35 inches. Broadcast designs use a standard viewing distance of 63 inches. The PicturePhone* signal bandwidth is nominally 1.0 MHz. For digital transmission, a 6.312 M bits/sec data rate is used with differential pulse code modulation (DPCM) and sample-to-sample redundancy removal (Millard and Maunsell, 1971).

At this point it is appropriate to review some important aspects of digitally encoding television video signals. The first important concept is that the video signal or picture has three dimensions -- two refer to location in a two dimensional field and the third gives the brightness (varies from black to white) of the picture at that point. Color video adds a fourth dimension.

The video signal power spectrum typically has an envelope that is relatively flat out to about twice the line rate or about 30 kHz for broadcast rates. Then the spectral envelope begins to drop at about 6 dB per octave. Hence, at 5 MHz (the nominal bandwidth), the spectral power is about 50 dB below the level at 10 kHz. The high frequencies are essential to maintain sharp edges. The low frequency power corresponds to large area brightness levels.

Conversion of the analog video signal to a digital signal and encoding for data compression to reduce the bit rate can be decomposed into two stages: irreversible encoding and reversible encoding. As an example, generation of a difference signal for encoding is a reversible process. With perfect transmission, the receiver can ideally reconstruct the picture exactly. In order to generate a digital signal from the analog video signal, quantization must take place. Quantization is an irreversible process because signals between decision levels are all assigned to the same representative level. The picture cannot be reconstructed exactly.

The simplest type of quantization to explain involves PCM encoding. The analog video signal

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is sampled at some rate equal to or greater than twice the highest frequency in the video signal power spectrum (Nyquist criterion). For discussion purposes, consider the highest frequency as 4.2 MHz. Then 8.4 M samples/sec are obtained as a sequence of PAM (pulse amplitude modulated) sampling pulses. This sequence drives the PCM encoder, which divides the black to white voltage range into 2^n discrete intervals. In uniform PCM encoding, all the intervals are equal. For each sample, an n-bit binary PCM word is generated to represent the quantized amplitude. The data or bit rate is then an $8.4n \times 10^6$ bits/sec PCM digital video sequence. For excellent broadcast quality pictures, n = 8 is generally agreed as sufficient except for long distance relay for which n = 9 may be required.

The PCM digital video sequence is the input signal to a reversible data compression encoder. For n = 8, the input data rate is 67.2 M bits/sec. If the encoder achieves a 10 to 1 compression, the transmitted signal bit rate (baseband signal) would be 6.72 M bits/sec. Conventionally, picture coding compression ratios are expressed in a different way, as explained later in the paper, although the concepts are similar. Further, in many techniques, the quantizing, encoding, and compression are performed simultaneously so that the signal processing explained in terms of PCM is not actually present. The digitally encoded and compressed data sequence has no resemblence to a picture structure unless the decompression-decoding algorithm is used.

Finally, it is noted that each method of quantizing an analog signal has a certain usable dynamic range for the input signal. Uniformly quantized PCM, for example, for n = 8 does not have sufficient dynamic range to digitize voice or video signals. Non-linear quantized PCM (referred to as companded PCM) is usually employed to obtain an adequate dynamic range to match the input signal dynamic range. Companding techniques have also been developed for delta modulation.

The state-of-the-art in reducing the data rate or bandwidth is reflected in Bell Laboratories publications (Mounts, 1970); special IEEE issues (IEEE Transactions on Communication Technology, Part I, December 1971, IEEE Proceedings, 1967 and 1972, IEEE Spectrum, 1972, and IEEE Transactions on Computers, 1972); and numerous survey papers such as Schwartz (1969), Huang et al. (1971), and Wilkins and Wintz (1971). A relatively up-to-date bibliography is available from the Image Processing Laboratory at the University of Southern California (Andrews, 1972). This bibliography contains approximately 1000 references on the subject of image processing, coding, and transmission. Some textbooks are also available (Rosenfeld, 1971; Lawrence, 1967; and Berger, 1971). The consensus at the present time indicates data rates of 1 M bits/sec for 30 frames per second can give good quality gray scale video transmission for Bell System PicturePhone* television signals. Recent developments presented at the 1973 Picture Coding Conference** indicate Bell System plans for a 1.544 M bits/sec PicturePhone* digital transmission data rate for network applications including T1 carrier. The single video channel encoder uses frame-to-frame redundancy encoding with Shannon-Fano variable code word lengths. A 345,000 bit frame memory and a 12,000 bit coder buffer are included.

The 525 line broadcast television picture, as noted previously, has 270,000 picture elements per frame. This is not 525 squared because of the 4:3 picture aspect ratio and other resolution factors. At a 30 frames per second rate, about 8.1×10^6 picture elements per second are obtained. Connor et al. (1972) summarize intra-frame coding techniques and the number of transmitted bits per picture elements as:

fixed length code with predicted algorithm	3-4 bits per picture element (24.3 - 32.4 M bits/sec)
Variable length code with predictive algorithm	2-3 bits per picture element (16.2 - 24.3 M bits/sec)
Adaptive techniques	1.2-2.2 bits per picture element (9.72 - 17.8 M bits/sec)
Transform techniques (2 dimensional, adaptive) Wintz (1972)	1-2 bits per picture element (8.1 - 16.2 M bits/sec

It is important to note that the statement 1-2 bits per picture element is the result of dividing the 8.1 - 16.2 M bits/sec data rate by 270,000 picture elements. It is an average and does not mean that each picture element requires 1-2 bits. Some picture elements need more and some less.

Inter-frame coding described by Haskell et al. (1972) simulated a 1 bit per picture element average rate with a 67,000 bit buffer required for overflow. Ignoring the forced updating of picture information due to buffer overflow, the long-term average data rate is about

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**Image Processing Laboratory, University of Southern California, Los Angeles, Calif. (see Andrews, 1972).

0.35 bits per picture element. Buffer size and delay make it difficult to achieve this rate with a single channel. If data from several (12-15) conditional-replenishment coders are combined prior to buffering and transmission, the required channel rate appears to be about 0.5 bits per picture element. This would involve a data rate of about 4.1 M bits/sec for each video picture signal using black and white rather than color techniques. For color transmission, the data rate would be around 10 M bits/sec. These rates actually apply only to the head-and-shoulders picture of the PicturePhone* application.

The CATV system will be assumed to use 5 MHz bandwidth for the television video signal. Also, a signal-to-noise ratio of 42 dB to 48 dB at a conventional television receiver is assumed as well as excellent phase stability because of color transmission. This type of communications channel can support an 8 level coherent PSK modulation (3 bits per signal element) for transmission on the cable or for interconnection. Assuming a required bit error rate of 1×10^{-6} (4 bit errors per second) for good picture quality, a signal-to-noise ratio of 19 to 20 dB is needed. The signal bandwidth for the 4.1 M bits/sec rate is needed. The signal bandwidth for the 4.1 M bits/sec rate would be between 1.4 MHz and 2.8 MHz (Hill, 1972). One could then ideally transmit two or three digital television black and white video channels for every analog television video signal as long as the PicturePhone* picture statistics are applied. For color, larger bandwidths would be needed. This would represent the current research and development state-of-the-art for digital PicturePhone* television. A key unanswered question in this area concerns the memory size for commercial television pictures because the rate of change of picture elements from frame to frame would be expected to be greater than in the PicturePhone* application. The numbers presented above are based only on a head-and-shoulders type picture. The savings in signal-to-noise ratio is substantial and represents an area for trade off with the required digital equipment and buffers for data compression.

Analog transmission is characterized by an accumulation of noise which gradually degrades the signal-to-noise ratio irreversibly. Operation of IF amplified microwave links with diversity and 80 dB signal-to-noise ratios does permit coast-to-coast video transmissions. Digital transmission accumulates errors during regeneration because of noise exhibited partly as clock jitter, but the degradation is reversible with error correction coding. Monitoring and fault location are easier with digital transmission, but degradation exhibits a threshold effect. If time division multiplex transmission is used, timing and synchronization requirements impose added costs and error sources.

From the point of view of CATV interconnection and to some extent within the larger CATV systems, digital transmission may be a feasible alternative in the future. An 80 video channel interconnection loop may be able to operate at less than a 400 bits/sec data rate in a bandwidth less than 200 MHz for black and white transmission. This bandwidth is within the capabilities of coaxial cable, microwave radio, and satellite relay. A digital loop network configuration would provide point-to-point CATV system interconnection with far less interconnecting links than other network configurations and also would give 24-hour full channel service without central office switching. It appears that investigation of the application of this technology to CATV systems would be desirable at the present time.

*Registered A.T.&T. Trademark

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AN ANALYSIS OF PROVEN PAY CATV SYSTEMS

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This paper deals with the practical aspects of integrating viable Pay-TV concepts into existing CATV systems.

The problems associated with order taking in one way systems are reviewed and several of the more practical solutions are discussed in detail.

The practical application of a currently available control system which is capable of selectively addressing over one million subscribers is described as it applies to the CATV operators' problems of computer billing and timely response to automated incoming orders.

The trade offs between on channel jamming, scrambling, pay channel converters and all channel converters are examined. Recommendations tailored to several varied but typical system situations are presented. Technical operation of the Tele/Theatre systems currently installed in over 63 hotels is reviewed.

The most significant questions which arise when planning a Pay-CATV system include:

1. Will good program material be continuously available?
2. How can individual orders be economically processed?
3. What will be the ultimate impact on operating costs?
4. How will customer billing be affected?
5. What will capital equipment cost?

The answer to each of these questions is a function of which marketing and technical concepts are selected. There are several from which to choose.

SUBSCRIPTION TV

To most, subscription TV means that some sort of secure channel(s) is programmed throughout the system and each subscriber that wishes may pay a flat rate and be equipped with a "box" which enables reception of that channel. The primary advantage of such a system is simplicity and minimum cost.

This concept has the primary disadvantage that each program producer will maintain that his share of the gross receipts should be greater because of the relative desirability of his product. Each time he is rebuffed, he will reduce the quality of program offered or withdraw his participation. Within a matter of months, the service will degenerate to nothing more than an old movie channel.

PAY PER PROGRAM

Motion picture producers are most comfortable with the "box office" concept where they can logically expect to receive a predetermined percentage of each "ticket" purchased by a customer who wishes to view their product. Therefore, the system which should ultimately prevail for distribution of truly premium programs will provide a convenient means for each subscriber to choose and purchase individual programs. The key word here is convenient.

- Impulse buying must be possible.
- The transaction must be effected from the home, otherwise one of your major selling points will be lost.
- The completion of the transaction must also be convenient for you as the system operator, otherwise your share of the revenue will be consumed in servicing the orders.
- The cost of all this convenience must be reasonable.

COMPUTER CONTROL

The obvious way to process large numbers of individual orders is with a small computer. BEWARE the XYZ Computer Company salesman who says his $7000 beauty will do it all. That's a fair cost for the processor alone but who's going to train 30,000 subscribers to operate the terminals, what will the software, interface and terminals cost, and how will they connect to the processor?

A two-way system would solve the connection problem and a two-way Pay-TV box, properly designed and supplemented with head-end control equipment, can bring the capital cost per subscriber to less than $250. The properly designed Pay-TV box will also require only minutes of customer training.

If you are reluctant to lay out over $250 per subscriber for your first venture into Pay-TV, I don't blame you. Not when a one-way system can be easily adapted to the same end with far less cost. Several systems have been developed for one-way networks but all can be categorized into three main classes.

1. Sell tickets in neighborhood retail outlets which the "box" reads and/or destroys.
2. Accept orders by mail.
3. Accept orders by telephone.

Categories 1 and 2 severely restrict impulse buying and entail a substantial amount of human support at significant cost. Tickets must be coded or controlled to prevent counterfeiting or multiple usage. Mail is slow and must be individually handled. Only the telephone seems to provide the ultimate solution for the one-way system.

SUBSCRIBER TERMINAL

Nearly every conceivable means for controlling the program has been tried experimentally and many have been reduced to hardware. A few are currently in production.

A review of the more popular schemes which are in production or scheduled for release this year is summarized as follows:

1. Transmit on a VHF Channel and filter or jam at each subscriber for the OFF mode.
2. Transmit on Sub or Mid Bands and convert at each subscriber for the ON mode.
3. Transmit a signal with suppressed sync and insert a separately transmitted or reconstructed sync for the ON mode.
4. Transmit 2 or more channels with the program time multiplexed between the channels and provide a means to follow the program through the channel switching sequence for the ON mode.
5. Frequency modulate the entire channel carrier set and provide a means for following this presumably elusive carrier and stabilizing the frequency for presentation to the TV receiver for the ON mode.

It is clear that security of some sort is desirable to reduce the instance of program theft. The primary factor is again economics. Any system can be cheated if enough money and effort is dedicated to that end. It would, therefore, seem foolish to spend an extra 50% per subscriber for a very complex security system to protect against the 1 or 2% who may be willing to spend an equal or greater amount to defeat it.

We must also consider that a significant percentage of those potential cheaters who might substitute their own box will also have the knowledge and bravado to open and modify the box you provide as soon as they find that you have so complex a system as to make it impractical to substitute their own box.

It seems there is no foolproof answer to this dilemma and there may never be. However, you must remember that your real purpose is to sell premium programs and do so in a fashion which will maximize your revenue with respect to your capital expenditures. Therefore, you must guard against the tendency to go beyond practical limits in an effort to eliminate moderate amounts of program theft.

Most protection methods employing filters or jammers used with VHF on channel transmissions eliminate the need for frequency conversion but fall short in other respects. Filters can be easily bypassed and in some cases counteracted with sensitive receivers and/or amplifiers. Jammers will usually tend to interfere with neighboring reception.

On the other extreme, the advocation of frequency modulation of the entire channel carrier set with a descrambler type demodulator circuit located in each subscriber's box seems to have found favor with some system engineers.

However, our studies have demonstrated that some television sets are so forgiving that they present a fairly acceptable picture even when the carrier set is frequency modulated to the maximum practical limit.

The final choice then seems to be between sync suppression or rapid band switching if scrambling is to be used. Transmission on the sub or mid-bands also appears to be essential regardless of the scrambling consideration. However, let us not fail to examine the possibilities of no scrambling at all.

Just operating on the sub or mid-bands will eliminate cheating by over 90% of your subscribers. A simple clause in your subscriber contract can provide for confiscation of bootleg converters connected to your network. This alone will deter a significant percentage of potential cheaters. The ability to add premium program channels for each available channel is possible when scrambling is not considered, simply because most scrambling techniques require band widths in excess of 6 MHz. If, for example, four channels were required to transmit two premium programs by using scrambling techniques, then those same four channels could supply four premium program channels if scrambling is not employed. The ability to add premium program channels on a one-for-one basis should add far more to revenues than the program thiefs would subtract. This coupled with the consideration that the unscrambled sub-band or mid-band converter will reduce your initial expenditure by nearly $25 per subscriber, should prompt some very serious thought before insisting that premium program material be thoroughly scrambled.

SUMMARY OF DESIRABLE SYSTEM FEATURES

1. To assure good program quality and availability - Sell your premium channels on a per-program basis and allow for impulse purchase.

2. To economically process individual orders - Let the customer use the telephone, an already familiar tool, to place his order. Don't provide a gadget to place the order over the phone. Put some of that money into a better and faster automatic answering device and order processor.

3. To minimize the impact on operating cost - Use automatic answering equipment rather than order-taking operators.

4. To minimize the impact on customer billing (Pay-per program coupled with automatic telephone ordering does impact billing) - Select a computer system which will preserve all orders on IBM compatible tape. Use a local computer service to prepare and mail your monthly invoices for a few cents each.

5. To minimize the cost of capital equipment - Select a subscriber terminal that is one way and non-scrambling.

A PROVEN SYSTEM

Since most telephone exchanges throughout the world still operate with dial pulses, a subscriber/computer interface which can count these pulses reliably would allow the use of the telephone for direct order entry. The K'SON Corporation Subscriber Order Concentrator (SOC) provides this feature as well as touch tone compatibility.

Studies have shown that with staggered program starts, as few as 15 incoming phone lines connected to the SOC will serve a 20,000 subscriber system with a 1% probability of a customer getting a busy signal during peak periods. The SOC will answer each line on a 15 line system the moment it rings and respond with a clear 800 Hz sine wave tone of 1.5 seconds duration. This signals the caller to proceed with the entry of his order. He then dials 4 or 5 digits which identify himself and 3 digits which indicate the channel ordered.

Three (3) digits are used to permit verification by complement checking that the order was dialed correctly. The SOC performs this verification automatically on each dialed order. When the order has been checked and validated, the SOC "hangs up" to clear the line for the next call. The order is formated and stored in register at the same instant. The register will be cleared and the order will be processed by the computer and the subscriber's converter will be commanded "ON" in less than 1 second. Provisions are incorporated to release the line if the caller does not enter his order properly in a reasonable time span.

With the advent of the Subscriber Order Concentrator, a Pay-TV system with proven profit potential in over 40 thousand hotel rooms has now been adapted to suit the needs of the cable operator. The concept applies directly to existing one-way systems. Allocation of one VHF channel, four midband, and one narrow band command channel provides the opportunity to sell four separate and concurrent premium programs to every CATV subscriber. The VHF channel carries promotional previews. This significantly increases pay program sales and also encourages non-participating subscribers to order the new service.

Each participating subscriber is equipped with a 24 channel Program Selector. Each Program Selector is capable of converting any one of 4 premium channels to a standard VHF channel (usually Channel 12). However, each premium channel in each unit may be separately enabled or disabled by a command word issued from a computer at the signal source. To view an enabled premium channel, the subscriber simply selects Channel 12 on his TV. To be enabled, he places a local phone call to the computer which answers with a "ready" tone. He then dials a few more digits which identifies him, indicates the desire channel, and assists the computer in checking the accuracy of his order. Within seconds his premium program is available. Mailed or voice-telephoned orders may also be executed via a keyboard terminal at any convenient location.

The operation at the studio or headend is completely automatic. A printed paper tape lists each order the instant the computer accepts the order. This record includes the subscriber number, channel ordered, date and time. A computer compatible magnetic tape records the same information in a format which permits inexpensive reduction to printed bills by any computer service.

The cost for accepting and processing orders in this fashion on a 20,000 subscriber system is less than 9¢ each including incoming telephone line rental, printed billing service, and full depreciation of all central office control equipment over 5 years.

AN ANALYSIS OF SYSTEM PLANNING

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The traditional approach to the building of a CATV system is to erect an antenna at a convenient location and distribute from the antenna location to all of the subscribers the received channels by means of an all-band cable system. As CATV penetrates the larger cities and as bi-directional transmission of signals becomes a reality, the trend is toward the segmentation of systems into areas served from separate hubs connected by various types of cable or microwave links. Within this new approach are contained so many alternatives for types of hubs, connecting links and combinations of forward and return systems that system planning has become a task of bewildering complexity involving the owner's objectives and the relative costs of various methods of implementation. This paper analyzes the general problem and describes a computer program developed as a tool to permit analysis of the system planning problem. The analysis permits a recommended solution to be found by the computer given the objectives, costs and general physical data of the geographical area or permits an analysis of preferred methods of system configuration. The analysis involves the use of a new family of mathematical operators developed by the author, called "COM" operators, which simplifies some of the mathematical problems involved.

1.0 Introduction

Today most prospective builders of new CATV systems have a fairly detailed concept of what they want their system to do. Due to FCC requirements, franchise requirements and market requirements they know what the channel capacity of the system must be for present and future needs and what system performance is required. Additionally, they are planning some special services that will use the bi-directional capability of their new system. However, the area of knowledge which has not yet been extended to a major portion of the industry is the details of assembling a complex system in a relatively large metropolitan area to meet the desired system operating and performance objectives.

2.0 Need for Analysis of System Planning

It is not uncommon for an owner to express surprise and dismay when informed it is not possible to build an all-band system extending from his headend location that will serve all of the subscribers with satisfactory signals. It is readily apparent that some kind of hub concept is necessary, but a more complex system rapidly produces more complex problems and rapidly increasing costs. To illustrate, a typical system configuration is shown in figure 1.

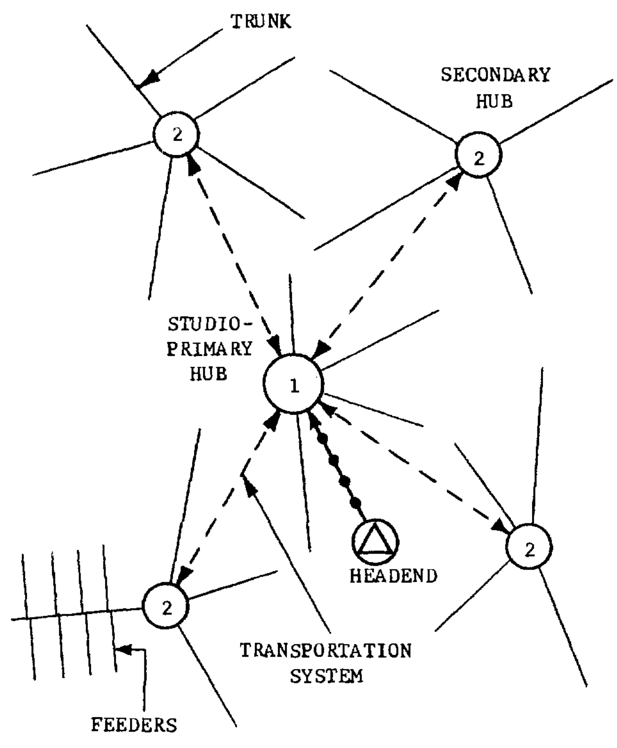

FIGURE 1
TYPICAL SYSTEM CONFIGURATION

2.1 Elements of a System

The center of interest of the system shown in the figure is the primary hub, centrally located in the area. The owner's studio is located in the primary hub along with the switching equipment to control the distribution of signals to the system. A transportation cable system carries signals into the primary hub from the headend, located remotely for convenience of off-air signal reception, and other transportation cable systems carry signals to and from the secondary hub sites. Emanating from the secondary hub sites are bi-directional trunk and feeder systems for distributing signals to and collecting signals from the subscribers. As may be practical microwave links can replace some cable transportation system links.

Of particular interest to us are those specific elements of the system that contribute to signal degradation. These elements are the processing equipment in the headend and hub locations, any conversion equipment used in connection with the transportation systems, the amplifiers in the cable systems and any microwave equipment used.

2.3 Conventional System Operation

The most conventional method of operating the system would be to receive all off-air channels at the headend and transmit them to the subscribers via the primary and secondary hubs. Any signals originated at subscriber locations would be carried to the primary hub and re-distributed to the subscribers along with the off-air channels. The problem with this arrangement is that all of the channels are carried from the primary hub on the hub-to-hub cable transportation links. Since the degradation in a cable system is proportional to the number of channels carried, the degradation in the transportation systems may make it costly or even impossible to design the trunk and feeder system to meet the overall system performance objectives.

2.4 Alternative System Operation

As an alternative only the distant channels may be received at the headend location with strong local signals received with less expensive antennas located at the secondary hubs. Additionally, not all signals originated at subscribers may be of interest to the entire area, and the signals of purely local interest could be intercepted and redistributed from the secondary hubs. The resultant reduction in the number of channels carried on the transportation systems and the corresponding improvement in performance permits a less costly basic design. However, the above alternatives introduce a new cost factor; i.e., a requirement for channel processing equipment at the secondary hubs.

Additionally, by dividing the system into a larger number of areas; i.e., more hubs, the amount of noise degradation collected at each hub in the return system is reduced, but more transportation systems are required to carry the signals from the collection points to the primary hub.

Another simple way of improving transportation system performance is to use a dual cable system. But how does the owner know which approach is the least costly? The amount of trial and error required to optimize the performance of any one approach is so formidable that it presents obstacles to producing a proposal within the time frame required by a customer. But when a change in system performance of a few dB may mean a change of several hundred dollars per mile in overall system cost, it is mandatory that the system builder carry out a system planning program that involves analyzing many different approaches to the implementation of his system objectives.

3.0 Solution to System Planning Problem

The purpose of this paper is to provide the mathematical analysis which makes possible the rapid evaluation of alternate types of systems. In particular, this analysis provides the basis for a tool for the system planner. Based upon this analysis a computer program has been written by the author which permits the system planner, sitting at a terminal of an ordinary commercial computer time sharing system, to selectively specify alternate system configurations to the computer, which determines optimum performance and automatically investigates some of the alternatives.

The analysis contained in this paper was specifically designed to provide the basis of a computer program concept that entailed the following steps:

(1) Apportion the strand mileage between the specified return hubs such that for any hub the performance of the combination of the return line extender, trunk and transportation amplifiers is maximized and is the same for all hubs. This process requires the finding of the best allocation of performance degradation between the several elements.

(2) Find the combination of forward transportation and trunk systems which has the worst performance. This process also requires the finding of the best allocation of performance degradation as above.

(3) Allocate performance degradation between the sub-systems of (1) and (2) for best performance.

(4) Find the trade-off of performance degradation between the sub-system of (3) above and the feeder system such that the system noise and cross-modulation performance specification is just met with the maximum possible levels in the feeder system.

(5) If there is no solution within the constraints imposed upon the system, the computer would increase the number of return system hubs until a solution is found. A maximum number of hubs may be imposed to avoid absurd answers. When the computer "creates" new hubs to increase the

total number, average values are used for the equipment densities and transportation system cascades in the added hubs.

4.0 Details of Analysis

4.1 Notation & Fundamentals of COM operators

To begin the analysis the reader should refer to Appendix 1, which gives an explanation of the notation used in this paper. Secondly, in Appendix 2 are shown the relationships for "COM" operators. These operators are used to express in simple notation the combining of noise or cross-modulation. For example, if amplifier A has a carrier-to-noise ratio of Na and amplifier B has a carrier-to-noise ratio of Nb, the carrier-to-noise ratio of the two amplifiers operating in cascade is by definition Na #p Nb; i.e., Na combined with Nb on a power basis. If we let

$$Na \ \#p \ Nb = Nt,$$

then by definition $Na = Nt \ p\backslash \ Nb$

Appendix 2 summarizes the above for cross-modulation as well as noise and lists other relationships that simplify derivations used herein. Derivation is accomplished in every case by straight forward substitution of the basic logarithmic/exponential expression into the stated relationship.

4.2 Maximum Performance

The first derivation that has a direct bearing on system performance is contained in Appendix 3. The expression obtained in this appendix calculates the difference in output level which produces the maximum performance for two units operating in cascade. Maximum performance is defined as the maximum value of X + 2N. The quantity X + 2N is independent of operating levels, assuming that relative level is constant, since (in an ideal system) an increase in all levels by 1 dB causes the carrier-to-cross modulation ratio to decrease by 2 dB and noise to improve by 1 dB. X + 2N is herein defined as the Performance Factor, PF.

4.3 Apportionment of Strand Miles Between Hub Systems.

With varying distances between the primary hub and the secondary hubs and with varying sizes of system fed from each secondary hub there can be a substantial difference in performance in the return system for each return collection and transportation sub-system. Rather than selecting the worst case and basing the calculations on this worst case the system planner can improve his overall system performance by allocating the strand mileage between the sub-systems served by each secondary hub so that each sub-system has the same performance. In other words, since the return performance of all segments is made the same (by adjusting their size) the "worst case" is improved to be the average return system performance. In Appendix 4 the performance factor

$$PFrt = Xrt + 2Nrt$$

is derived for the average return system performance as a function of the sub-system strand mileage, the equipment densities and the equipment performance parameters. With the expression obtained, a linear programming technique can be used that finds the strand mileage for each secondary hub system such that the sum of the strand mileages of the hub systems is equal to the total system strand mileage and the performance factor is the same for all hub systems.

4.4 Calculating Feeder Performance

Finally, in Appendix 5 a relationship is derived that permits the system levels to be found that just meet the system specifications. The expression involves the feeder cross-modulation, Xf, the system specifications, the performance factor of the feeder and the performance factor of the rest of the system.

Since a direct solution for Xf is not easily obtained, it was decided to use an iterative method for obtaining a solution. The method is illustrated in figure 2.

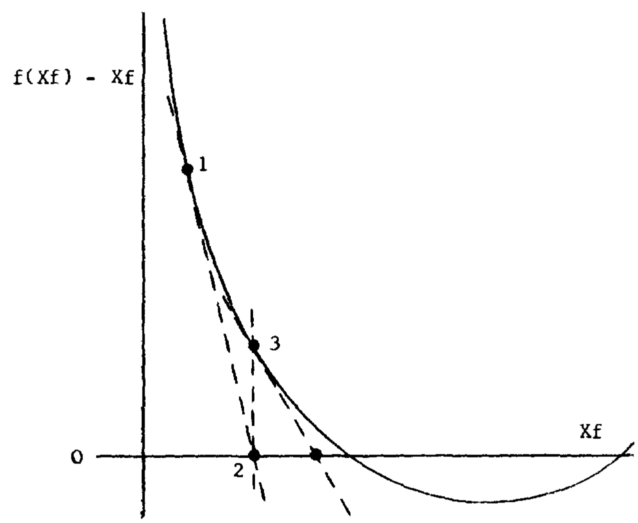

FIGURE 2
SOLVING FOR FEEDER CROSS-MODULATION, Xf

1. At point 1 the slope of the line tangent to the curve was found by incrementing Xf by a small amount.

2. The point at which the tangent line intercepted the "0" value of f(Xf)-Xf was calculated. (point 2).

3. Using the value of Xf so obtained a new point 3, was found on the curve.

4. The process was repeated until a value of f(Xf)-Xf less than an arbitrary value δ was found.

5. By always using negative increments in step 1 above, it is assured that a change in sign of the slope of the tangent line indicates that there is no solution.

After some experimentation with this method it was found that the largest number of iterations required to find a solution occur when the system specifications are near the maximum possible performance. It was found that with a value of $\delta = 0.01$ dB and the system specifications within 0.0001 dB of the maximum system performance, only 6 iterations were required to find a solution or determine that a solution was impossible. Typically a solution or non-solution was found in 2 tries with less severe constraints.

5.0 At the Computer Terminal

To use the computer program you would dial up the computer from your terminal and load the program. The computer types out on your terminal READY! Now you have a selection of things which you may type.

The program is interactive, i.e., it executes a command entered from the terminal and then prints READY! again and waits for the next command. The commands available are:

FILE causes the computer to read a computer data file which must be constructed before loading the program. The file contains for each hub the cascades, the equipment densities, the equipment noise figures output capabilities and gains for each sub-system, the number of return system hubs with the equipment densities, trunk cascades and transportation system cascades and proposed strand mileage.

PACK Loads a specified number into the same element in all hubs. For example, permits assigning a new value to the return transportation system amplifier output capability in all hubs.

DIF Establishes the difference in output level between bridger amplifiers and line extender amplifiers.

FIX Freezes the levels in the feeder at their current value.

MIN BR Establishes a minimum bridger amplifier output level.

MAX RH Sets the maximum number of return system hubs permitted.

NHUBS Sets the number of return system hubs.

RHUB Permits performance degradation for the return system hubs to be specified.

FHUB Permits performance degradation for the forward system hubs to be specified.

H END Permits performance degradation for the headend system to be specified.

MIC Permits specifying a fixed performance degradation for a transportation system.

SPECS Establishes the system noise and cross-modulation specification at desired values.

FWD HB Displays the number of the worst case forward hub system.

MAX Finds maximum possible performance of system as presently configured.

RUN Apportions strand mileage between return hub systems and calculates all system levels to meet the system noise and cross-modulation specifications. If no solution is possible within the limits imposed, a MAX command is automatically executed.

The first step is to issue the FILE command to load the basic data, then the other commands are typed on the terminal keyboard to establish the system parameters. The function of most of the commands is self explanatory. In each case the system planner types the command exactly as shown. The details of the specific item, i.e., the output capability, etc., and the relevant data, are input by the system planner after the computer prints out a message specifying that they are to be typed on the keyboard. No knowledge of computer operation is required by the user.

In particular it has been found that the strand mileage calculated by the computer for a particular return hub system may not be suitable due to the physical constraints of the geographical area. If a smaller number of strand miles must be used, the performance of that particular sub-system will be better than average, but that of the rest of the system will be poorer, since the strand mileage for the rest of the system will be increased. In this instance the strand mileage of the smaller than calculated hub system is subtracted from the total mileage, and the remainder of the system is re-processed as a separate system.

If a larger than calculated strand mileage must be used, the performance of this larger sub-system will be poorer than the remainder of the system and the performance of this sub-system becomes the worst case and is then processed as an independent system.

If the computer determines that a larger number of return system hubs is required than originally desired, the system planner may change the minimum feeder level limits, change the output capabilities of the amplifiers in the transportation systems (different number of channels) or enter specific information to include the added number of hubs.

To evaluate the cost of the various configurations it is necessary to have available cost per mile information on the types of transportation systems to be used, the cost of active hub sites, including buildings and equipment and the distribution system costs. Clearly, in the planning stage of a system close communication is required with the system owner to determine what locations are available practically. The distribution system cost can be based upon a sample design keyed to a fixed set of amplifier output levels.

The above analysis and associated computer program is providing us with a much deeper insight into the general area of system configuration to the point that questions have arisen that were not previously considered. Never-the-less in order to adequately analyze the alternatives possible in a large CATV system it is absolutely essential that tools be available that permit rapidly finding the best means to achieve the desired system performance objective. Undoubtedly to date we have merely an obscure view of the ultimate applications that the future will bring to the CATV industry, but it is intended that this analysis will provide the foundation necessary to meet the ever increasing challenge that we can expect from the inevitably more sophisticated systems to come.

* *

APPENDIX 1

Explanation of Notation

Operator Notation

Symbol	Explanation
A/B	A divided by B
A # B, A $\nwarrow$ B	COM operators, see Appendix 2

The following notation is used in the text and in the Appendices to represent the system and equipment parameters. Each parameter is represented by 1 or 2 capital letters followed by lower case letters that denote where the parameter is used in the system. The explanation of the letters is provided below the examples.

Example: Nrf = Carrier-to-Noise Ratio of the return feeder system amplifiers.

PFrt = Performance Factor for the total return system.

Capital Letters	Explanation
C	Amplifier cascade.
G	Amplifier gain.
KC	Amplifier cascade per $\sqrt{\text{strand mile}}$
KQ	Amplifier quantity per strand mile (amplifier density).
L	Signal level.
N	Carrier-to-noise ratio, abbreviated as "noise" in the text.
NF	Amplifier noise figure.
OC	Amplifier output capability, the output level of an amplifier at which the carrier-to-cross modulation ratio is 57.
PF	Performance factor = X + 2N
Q	Quantity, the number of amplifiers in a given area.
Sm	The number of strand miles.
X	Carrier-to-cross modulation ratio, abbreviated as "cross-modulation" in the text.
Z12	OC1 - OC2 + G1 - G2 + NF1 - NF2

Lower Case Letters	Explanation
a	Transportation system
f	Feeder system
i	Input
k	Trunk system
o	Output
r	Return system
s	Specification
t	Total
x	Trial value

* *

APPENDIX 2

Fundamental Relationships for COM Operators

Definitions

$$A \#p\ B = -10 \log \left[10^{-A/10} + 10^{-B/10}\right] \quad \text{(COMP)}$$

$$A\ p\nwarrow B = -10 \log \left[10^{-A/10} - 10^{-B/10}\right] \quad \text{(DCOMP)}$$

$$A \#v\ B = -20 \log \left[10^{-A/20} + 10^{-B/20}\right] \quad \text{(COMV)}$$

$$A\ v\nwarrow B = -20 \log \left[10^{-A/20} - 10^{-B/20}\right] \quad \text{(DCOMV)}$$

Algebraic Rule

If
$C = A \# B$, then $A = C \backslash B$

Distributive Rule

$(A+B) \# (A+C) = A + B \# C$

$(A+B) \backslash (A+C) = A + B \backslash C$

Derivative Rule

$$\frac{d(Y \#v\ C)}{dy} = 10^{-(Y - Y \#v\ C)/20}$$

(where C is a constant)

Associative Rule

$A \# (B \# C) = (A \# B) \# C = (A \# C) \# B$

Inter-Order Conversion

$(2A) \#v\ (2B) = 2(A \#p\ B)$

* *

APPENDIX 3

Maximum Performance

The following is a derivation of the difference in output level required between two systems to obtain the maximum performance.

If we have two sub-systems, 1 and 2, the criteria for setting the levels of system 1 (same criteria for system 2) is:

$$(1) \quad \frac{dXt}{dL1} = 2\,\frac{dNt}{dL1}$$

where $Xt = X1 \#v\ X2$

$Nt = N1 \#p\ N2$

The criteria is illustrated by the following example. Suppose that $Xt = 51$ and $Nt = 43$. Suppose also that $\frac{dXt}{dL1}$ is less than $2\,\frac{dNt}{dL1}$, i.e., suppose that increasing the operating level of system 1 by 2 dB results in an increase of Nt by 1 dB and a decrease of Xt by 1 dB. We now decrease all levels by 1 dB; the procedure is summarized in the following table:

	Noise	Cross-Modulation
Initial Performance	43 dB	51 dB
Increase System 1 Levels 2 dB	44	50
Reduce all Levels 1 dB	43	52

Thus, by changing the relationship between the levels of system 1 and system 2 the cross-modulation has been increased by 1 dB with the same noise performance. However, when the difference in operating level meets the maximum performance criteria, the improvement illustrated is not possible. Further reflection will reveal to the reader that the criteria is valid for more than two units operating together, but the two-unit case is sufficient for this paper.

Substituting for Xt and Nt in expression (1) and using the derivative rule for COM operators, we obtain:

$$10^{-(X1 - X1 \#v\ X2)/20} = 2 \times 10^{(N1 - N1 \#p\ N2)/10}$$

$$10^{-(X1 - Xt)/20} = 2 \times 10^{-(N1 - Nt)/10}$$

Taking the LOG of both sides of the equation

$$-(X1 - Xt)/20 = \text{LOG } 2 - (N1 - Nt)/10$$

$$Xt - X1 = 6 - 2(N1 - Nt)$$

by symmetry:

$$Xt - X2 = 6 - 2(N2 - Nt)$$

Solving the first equation for Xt and substituting into the second, we obtain:

$$X1 - 2N1 = X2 - 2N2$$

To find the difference in output level between the two systems we substitute the following expressions for X & N:

$$X = (OG - Lo) \times 2 + 57 - 20 \text{ LOG } C$$

$$N = Li + 59 - NF - 10 \text{ LOG } Q$$

the input level, Li, can be replaced by Lo - G.

Making the above substitutions and solving for L1o - L2o, we obtain:

$$L1o - L2o = (OC1 - OC2 + G1 - G2 + NF1 - NF2)/2 + 10 \text{ LOG } \sqrt{\frac{Q1\ C2}{C1\ Q2}}$$

It is interesting to note that the old idea of running all amplifiers midway between noise and cross-modulation is valid only when Q = C, i.e., for a single cascade of amplifiers.

* *

APPENDIX 4

Apportionment of Strand Miles Between Hub Systems

Cascade is proportional to $\sqrt{\text{strand miles}}$
Quantity is proportional to strand miles

$$\text{Cascade} = KC \times Sm^{\frac{1}{2}} = C$$

$$\text{Quantity} = KQ \times Sm = Q$$

$$Xrt = Xr - 20 \log C = Xr - 20 \log (KC \times Sm^{\frac{1}{2}})$$

$$= Xr - 20 \log KC - 20 \log Sm^{\frac{1}{2}}$$

$$= Xr - 20 \log KC - 10 \log Sm$$

$$Nrt = Nr - 10 \log Q = Nr - 10 \log (KQ \times Sm)$$

$$= Nr - 10 \log KQ - 10 \log Sm$$

The return system cross-modulation is equal to the combined cross-modulation of the return transportation, trunk and feeder systems.

$$Xrt = Xra \ \#v \ Xrk \ \#v \ Xrf$$

$$= \left[(OCra - Lrao) \times 2 + 57 - 20 \log Cra\right]$$

$$\#v \left[(OCrk - Lrko) \times 2 + 57 - 20 \log Crk\right]$$

$$\#v \left[(OCrf - Lrf) \times 2 + 57 - 20 \log Crf\right]$$

Substitute for Lrko and Lrfo using formula for maximum performance from Appendix 3, i.e.:

$$Lrko = Lrao + (OCrk - OCra + Grk - Gra + NFrk - NFra)/2 + 10 \log \sqrt{\frac{Qrk}{Crk}}$$

$$10 \log \sqrt{\frac{Qrk}{Crk}} = 10 \log \sqrt{\frac{KQrk \ Sm}{KCrk \ Sm^{\frac{1}{2}}}} = 10 \log \sqrt{\frac{KQrk}{KCrk}} + 10 \log \sqrt{Sm^{\frac{1}{2}}}$$

$$\text{Let } Zrka = OCrk - OCra + Grk - Gra + NFrk - NFra$$

$$Xrt = \left[2 \times OCra - 2 \times Lrao + 57 - 20 \log Cra\right]$$

$$\#v \left[2 \times OCrk - 2 \times Lrao - Zrka - 10 \log\left(\frac{KQrk}{KCrk}\right) - 10 \log Sm^{\frac{1}{2}} + 57 - 20 \log(KCrk \times Sm^{\frac{1}{2}})\right]$$

$$\#v \left[2 \times OCrf - 2 \times Lrao - Zrfa - 10 \log\left(\frac{KQrf}{Crf}\right) - 10 \log Sm + 57 - 20 \log Crf\right]$$

$$Xrt = \left[2 \times OCra - 2 \times Lrao + 57 - 20 \log Cra\right]$$

$$\#v \left[2 \times OCrk - 2 \times Lrao + 57 - 10 \log Sm^{3/2} - Zrka - 10 \log (KQrk \times KCrk)\right]$$

$$\#v \left[2 \times OCrf - 2 \times Lrao + 57 - 10 \log Sm - Zrfa - 10 \log (KQrf \times Crf)\right]$$

$$Xrt = 57 - 2 \times Lrao + \left[2 \times OCra - 20 \log Cra\right]$$

$$\#v \left[2 \times OCrk - 10 \log Sm^{3/2} - Zrka - 10 \log KQrk \times KCrk\right]$$

$$\#v \left[2 \times OCrf - 10 \log Sm - Zrfa - 10 \log KQrf \times Crf\right]$$

The return system noise is equal to the combined noise of the return transportation, trunk and feeder systems.

$$Nrt = Nra \ \#p \ Nrk \ \#p \ Nrf$$

$$= (Lrao - Gra + 59 - NFra - 10 \log Cra)$$

$$\#p \ (Lrko - Grk + 59 - NFrk - 10 \log Qrk)$$

$$\#p \ (Lrfo - Grf + 59 - NFrf - 10 \log Qrf)$$

Substituting for Lrko, Lrf, Qrk and Qrf

$$Nrt = (Lrao - Gra + 59 - NFra - 10 \log Cra)$$

$$\#p \ \left(Lrao + Zrka/2 + 10 \log \sqrt{\frac{KQrk}{KCrk}} + 10 \log \sqrt{Sm^{\frac{1}{2}}} - Grk + 59 - NFrk - 10 \log KQrk - 10 \log Sm\right)$$

$$\#p \ \left(Lrao + Zrfa/2 + 10 \log \sqrt{\frac{KQrf}{Crf}} + 10 \log \sqrt{Sm} - Grf + 59 - NFrf - 10 \log KQrf - 10 \log Sm\right)$$

$$Nrt = (Lrao - Gra + 59 - NFra - 10 \log Cra)$$

$$\#p \ \left(Lrao + Zrka/2 - 10 \log \sqrt{KCrk \times KQrk} - 10 \log \sqrt{Sm^{3/2}} - Grk + 59 - NFrk\right)$$

$$\#p \ \left(Lrao + Zrfa/2 - 10 \log \sqrt{Crf \times KQrf} - 10 \log \sqrt{Sm} - Grf + 59 - NFrf\right)$$

$$Nrt = Lrao + 59 + (-Gra - NFra - 10 \log Cra)$$

$$\#p \ \left(Zrka/2 - 10 \log \sqrt{KCrk \times KQrk} - 10 \log \sqrt{Sm^{3/2}} - Grk - NFrk\right)$$

$$\#p \ \left(Zrfa/2 - 10 \log \sqrt{Crf \times KQrf} - 10 \log \sqrt{Sm} - Grf - NFrf\right)$$

The return system performance factor,
$PFrt = Xrt + 2Nrt$

$$= 57 + 2 \times 59 + \left[2 \times OCra - 20 \log Cra\right]$$

$$\#v \left[2 \times OCrk - 10 \log Sm^{3/2} - Zrka - 10 \log (KQrk \times KCrk)\right]$$

$$\#v \left[2 \times OCrf - 10 \log Sm - Zrfa - 10 \log (KQrf \times Crf)\right]$$

$$+ \left[-2Gra - 2NFra - 20 \log Cra\right]$$

$$\#p \left[-2Grk - 2NFrk - 10 \log Sm^{3/2} + Zrka - 10 \log (KCrk \times KQrk)\right]$$

$$\#p \left[-2Grf - 2NFrf - 10 \log Sm + Zrfa - 10 \log (Crf \times KQrf)\right]$$

*

APPENDIX 5

Meeting Performance with Maximum Feeder Levels

Let Nt and Xt be the combined noise and the combined cross-modulation of the elements of the system other than the amplifiers in the forward feeder. Let Ntx and Xtx be trial values of the above that are calculated at some arbitrary operating level of the system. The utility of these latter values will be seen below.

Since the noise of a system increases 1 dB for each 1 dB increase of operating level and the cross-modulation decreases 2 dB for each 1 dB increase in operating level, it follows that:

$$\mathrm{Nt} = \mathrm{Ntx} + \Delta \mathrm{L}$$

$$\mathrm{Xt} = \mathrm{Xtx} - 2\,\Delta \mathrm{L}$$

where ΔL is the change in operating level.

If we multiply the first expression by 2 and add to the second expression we obtain:

$$\text{(1)} \qquad \mathrm{Xt} + 2\,\mathrm{Nt} = \mathrm{Xtx} + 2\mathrm{Ntx}$$

The quantity X + 2N is independent of level for any system and is herein defined as the Performance Factor, PF.

If we let Ns and Xs be the system noise and cross-modulation specifications and let Nf and Xf be the feeder noise and cross-modulation that we are attempting to calculate, it is true that:

$$\mathrm{Nt}\ \#p\ \mathrm{Nf} = \mathrm{Ns}$$

$$\mathrm{Xt}\ \#v\ \mathrm{Xf} = \mathrm{Xs}$$

by definition:

$$\mathrm{Nt} = \mathrm{Ns}\ p\backslash\ \mathrm{Nf}$$

$$\mathrm{Xt} = \mathrm{Xs}\ v\backslash\ \mathrm{Xf}$$

substituting into expression (1):

$$\mathrm{Xs}\ v\backslash\ \mathrm{Xf} + 2(\mathrm{Ns}\ p\backslash\ \mathrm{Nf}) = \mathrm{Xtx} + 2\mathrm{Ntx}$$

$$\mathrm{Xs}\ v\backslash\ \mathrm{Xf} = \mathrm{Xtx} + 2\ \mathrm{Ntx} - 2(\mathrm{Ns}\ p\backslash\ \mathrm{Nf})$$

$$\mathrm{Xs} = \left[\mathrm{Xtx} + 2\mathrm{Ntx} - 2(\mathrm{Ns}\ p\backslash\ \mathrm{Nf})\right]\ \#v\ \mathrm{Xf}$$

$$\text{(2)} \quad \mathrm{Xf} = \mathrm{Xs}\ v\backslash \left[\mathrm{Xtx} + 2\mathrm{Ntx} - 2(\mathrm{Ns}\ p\backslash\ \mathrm{Nf})\right]$$

Xtx + 2Ntx is the performance factor, PFtx, of the non-feeder system and can be calculated.

Nf can be found using expression (1)

$$\mathrm{Nf} = (\mathrm{Xfx} + 2\mathrm{Nfx} - \mathrm{Xf})/2$$

substituting for Nf in expression (2):

$$\mathrm{Xf} = \mathrm{Xs}\ v\backslash \left[\mathrm{PFt} - 2(\mathrm{Ns}\ p\backslash \left[\mathrm{Xfx} + 2\mathrm{Nfx} - \mathrm{Xf}\right]/2)\right]$$

Applying the COM operator rule for inter-order conversion to the last terms and substituting for Xtx + 2Ntx:

$$\mathrm{Xf} = \mathrm{Xs}\ v\backslash \left[\mathrm{PFt} - (2\mathrm{Ns}\ v\backslash \left[\mathrm{PFf} - \mathrm{Xf}\right]/2)\right]$$

APPLICATION OF PHASE LOCKED MODULATORS AND PROCESSORS

By James O. Farmer

Scientific-Atlanta, Inc.

Recently much has been said about the advantages phase locking techniques offer the CATV operator. This paper is intended to further acquaint the reader with the phaselock technique, so he can better utilize the available phase locked equipment.

Phaselock is not new to the electronics industry. The first practical applications were coherent detectors in homodyne radio receivers built in the 1930's. However, the circuit complexity of a phase locked loop is so great that until recently the technique was restricted to a few specialized applications. Now, thanks to progress in components and circuit techniques, phaselock is becoming economical for a wide range of applications.

CATV application of phaselock includes precision demodulation, minimizing the subjective effects of strong local TV signals, and various phase locked headend schemes. This paper is concerned with only one of these applications of phaselock: minimizing the subjective effects of a strong local signal leaking into a subscriber's television set. This leakage problem has required the cable system to distribute strong signals on channels which are not locally used for TV broadcast. This off-channel conversion for cable distribution eliminates the leakage problem at the expense of available cable channels. New FCC rules and increasing program availability to cable systems have created pressure to use these fallow channels for some type of locally originated program. If the cable channel carrier is not exactly at the frequency of the interfering carrier, a co-channel beat will be seen on the subscriber's set.

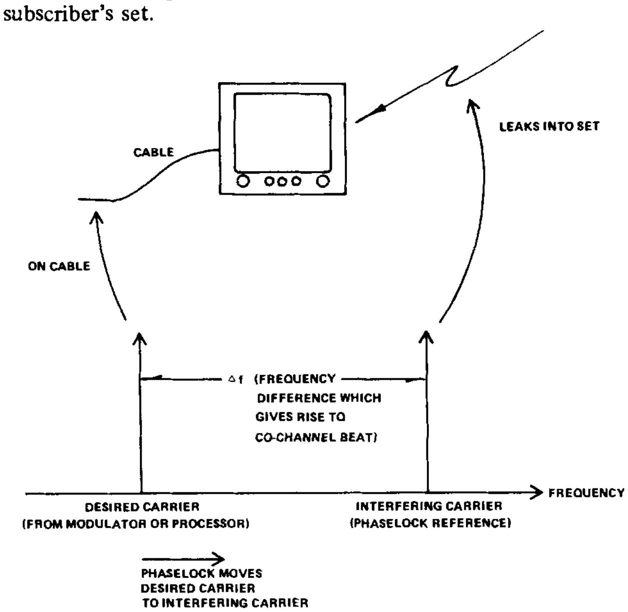

FIGURE 1. INTERFERENCE SITUATION

Figure 1 illustrates the situation where two video carriers close together in frequency are present simultaneously. The signal on the left is the desired carrier, perhaps carrying a weatherscan picture. To the right is an interfering carrier which has leaked into the subscriber's TV set. When the two signals are detected, their frequency difference will create a component Δf in the video. This shows up as black and white co-channel lines in the picture. The severity of the co-channel beat is dependent upon the relative levels of the two signals, and upon their frequency separation, Δf. Phaselock can be used here to force the desired carrier to the frequency of the interfering carrier, reducing Δf to zero and eliminating the co-channel beat.

How do we accomplish this? Figure 2 is a simplified block diagram of a phase locked modulator. A sample of the interfering signal is picked off the air and applied to a fairly narrow bandpass filter. This filter removes all energy except the picture carrier and some of the luminance sidebands. The remaining signal is the reference, which is applied to a phase detector. The output of a voltage controlled oscillator is also applied to the phase detector. The output of the phase detector is a d.c. potential proportional to the cosine (in this case) of the phase difference between the reference signal and the voltage controlled oscillator (VCO) output. This phase error is applied to a loop amplifier (normally configured as an integrator for low frequencies), whose output is the VCO control voltage. Since the amplifier has very high gain at low frequencies, it will act on the VCO in whatever manner is necessary to reduce the phase error to nearly zero. Thus, the VCO output is required to maintain a strict phase relationship to the reference signal, and hence must operate at the same frequency. The VCO output is then applied to the modulator, and the remaining modulator operation is identical to that of a non phaselocked unit. In the case of Scientific-Atlanta's Model 6300 PL Modulator, the modulation is performed at the 45.75 MHz intermediate frequency, which is then upconverted to the desired channel. A common local oscillator is used for up conversion and for down conversion of the reference. This assures phase coherency. For stability the VCO used is a voltage controlled crystal oscillator (VCXO).

Use of the reference signal directly instead of locking another oscillator to its frequency is not practical. This is because a bandpass filter cannot be realized that will adequately strip all modulation sidebands off the reference, maintaining this characteristic over all combinations of reference drift, time, and temperature. In this respect, the phase locked loop operates as a tracking filter, since its output is at the frequency of the input, and all sidebands can be suppressed to an arbitrary degree. Even so, the output can track the input carrier over a greater range than the effective filter bandwidth.

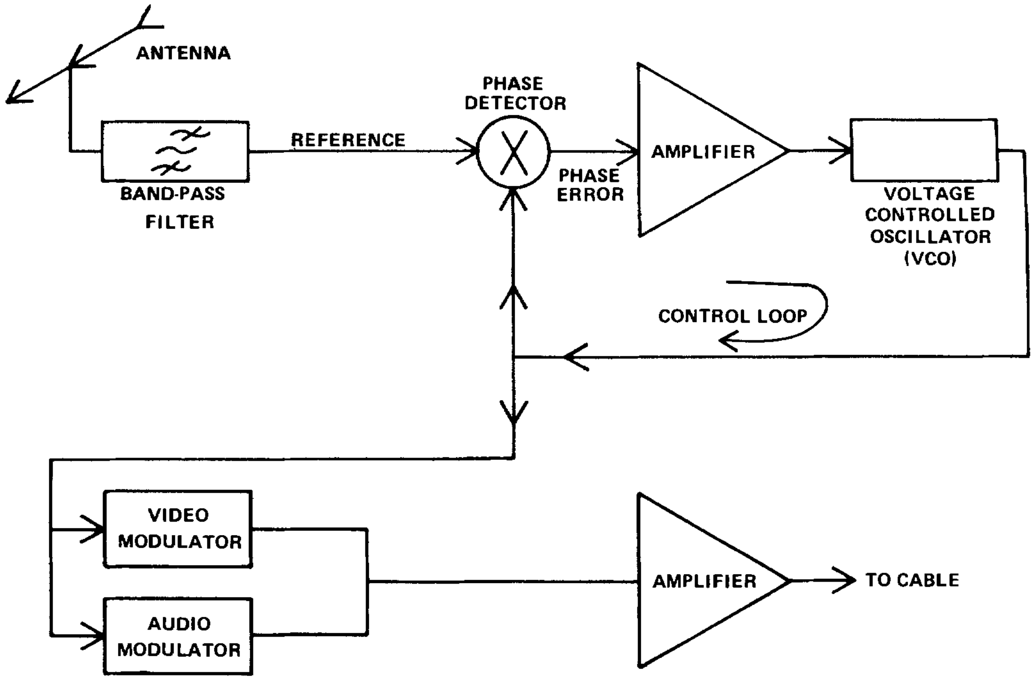

FIGURE 2. SIMPLIFIED BLOCK DIAGRAM, PHASE LOCKED MODULATOR

Before a phase locked situation can exist, the VCXO must be made to run at the same frequency as the reference. Figure 3 defines some terms that are appropriate to the acquisition of phase lock. This figure is a spectrogram centered on the free running frequency of the VCXO; as this frequency changes, it will appear to stay fixed, but other features of the spectrogram will move. The free running frequency is the frequency at which the VCXO would run if no control voltage is applied from the loop amplifier. When power is first applied, or when the reference carrier first becomes available, the loop must somehow move the VCXO frequency to the reference frequency before phase lock can be achieved. Also shown in Figure 3 is the frequency of the reference, which might appear anywhere in the spectrogram.

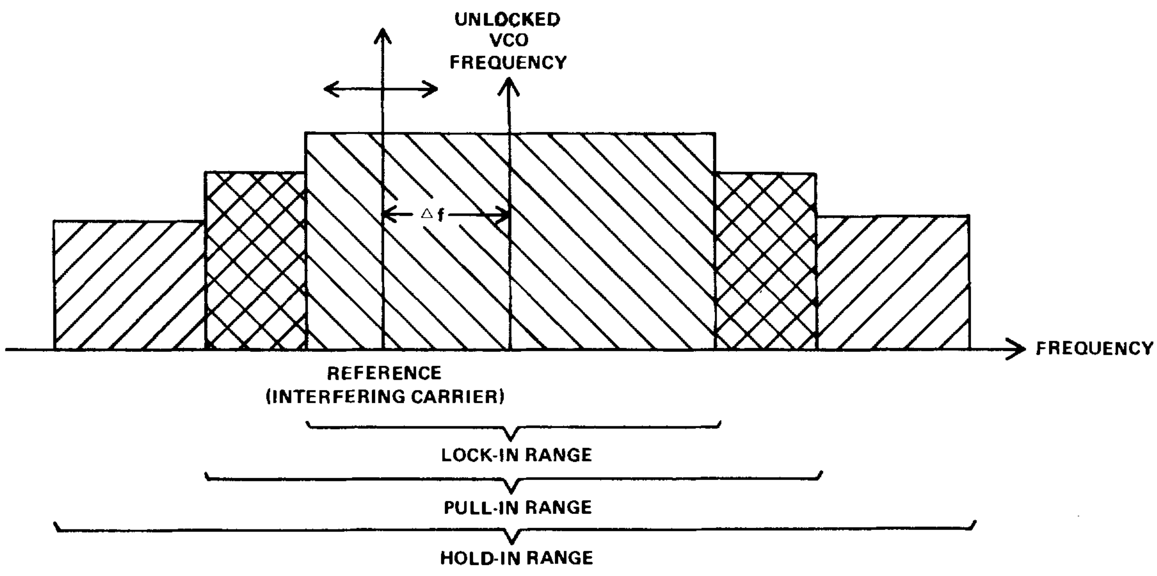

FIGURE 3. DEFINITION OF TERMS

The detailed process of bringing the VCXO into lock is quite complex and beyond the scope of this paper. However, a brief discussion of the process involved is in order. The difference between the reference and free running VCXO frequencies is defined as Δf. If the frequency difference is sufficiently small, the control loop is able to rapidly bring the VCXO into lock. The range over which this can be accomplished is called the lock-in range. For all practical purposes, the lock-in range is roughly equal to the loop bandwidth, which should be small in order to improve rejection of the reference sidebands. If the initial frequency difference is within the lock-in range, the loop will rapidly acquire. If the initial frequency difference is out of the lock-in range but within the pull-in range, the loop can theoretically lock if given enough time. However, in this range practical considerations of amplifier offset and noise are such that lock generally cannot be achieved without additional circuitry. Outside of the pull-in range, lock cannot even theoretically be achieved without additional acquisition circuitry. However, once lock is achieved, the loop is able to hold lock over a much wider range, known as the hold-in range. This is the frequency difference over which, after lock is achieved, Δf may drift and still permit the loop to remain locked. For the most useful type loop, the hold-in range is not a function of loop dynamics, but rather is a function of saturation levels of loop amplifiers or other components in the loop. Within certain practical bounds, the hold-in range may be made arbitrarily large.

Proper acquisition circuitry may be used to aid the loop in locking up at any frequency in the hold-in range. An adequate acquisition (and hold-in) range is one which permits acquisition under the worst possible initial frequency error, Δf, due to all causes. This acquisition must be without operator intervention. In order to determine the required acquisition range, we will develop a worst case error budget, taking into account all known sources of frequency error. Table 1 lists the major contributors to the error budget. The first source of error is the 1 kHz frequency tolerance imposed upon the broadcast station. Although not a frequency error, we will add in the 10 kHz broadcast carrier offset. If the acquisition range is insufficient to handle the carrier offset, then the offset must be specified when ordering the phase lock equipment or when transferring it to a different location. To the above tolerances must be added the drift of the VCXO, which might reach 5 kHz at the higher channels. This may be drift reduced to 0.2 kHz with a highly stable VCXO enclosed entirely in an oven. However, an oven is undesirable because the higher temperature will accelerate component failure, and will also increase power consumption. In addition, an oven stabilized oscillator must be allowed to warm up after turn-on or a power failure.

Another error which must be taken into account to insure that the operator does not have to "treak" the phase lock after installation, is the initial frequency setting of the VCXO. A reasonable allowance for this is 0.5 kHz.

1. BROADCAST CARRIER TOLERANCE	1 kHz
2. BROADCAST CARRIER OFFSET	10
3. VCXO DRIFT (Ch. 13, non oven controlled)	5
4. VCXO INITIAL SETTING	.5
5. CRYSTAL AGING	?
6. COMPONENT AGING	?
7. VARIATION WITH POWER SUPPLY	?
ERROR BUDGET	16.5 kHz

(For heterodyne processors, add down-conversion error)

TABLE 1. ERROR BUDGET FOR DETERMINATION OF REQUIRED ACQUISITION RANGE

So far the error budget is ±16.5 kHz and there are still several other sources of error to consider. These errors are more difficult to quantitize. They include crystal aging, frequency fluctuation with power variations, etc. In the case of a phase locked heterodyne processor, we must also add the tolerances pertaining to the station whose signal we are processing. A safe acquisition range to consider is plus or minus 25 kHz. This allows for known sources of error, plus some margin for the undefined errors.

Implicit in the discussion of safe acquisition range has been the requirement that the loop must also exhibit an adequate hold-in range. Considerations with respect to adequate hold-in range include the use of servo compensation that develops a very high gain at low frequencies, so that a significant phase error does not develop at the phase detector output. Also, the VCO must be capable of being controlled over an adequate range. For good stability, the VCO should be crystal controlled, but special design techniques are required to pull a VCXO over the frequency range required.

Several types of acquisition circuitry have been developed over the years. Probably the most common technique in communications applications is use of a triangular ramp which drives the VCO back and forth over the entire hold-in range, searching for a signal to lock to. When the VCO is driven to within lock-in range, the loop locks and the ramp is disabled. The technique works, but is relatively slow, because acquisition dynamics limit the maximum search rate. Also, if significant sidebands exist within the search range, the loop may attempt to lock to them rather than to the carrier.

Recently several types of digital phase detectors have become popular for frequency synthesis work. The most elegant is a sequential circuit, available in I.C. form, that matches the negative-going transitions of the two waveforms. This detector has the property that if one input is higher in frequency than the other, the phase detector output is maximum in the direction that drives the VCXO into lock. Thus, if this detector is used, acquisition circuitry is unnecessary. For noise free applications such as frequency synthesis, this detector is often an excellent choice. However, it tends to be overly sensitive to noise or modulation sidebands, because of its characteristic of responding only to a waveform transition. In addition, its maximum operating frequency is only about 10 MHz, so it is not useful for our present application. Another acquisition scheme involves use of a frequency discriminator, which must be accurately zero'd with the VCXO free running frequency.

Scientific-Atlanta has used an acquisition technique in our 6300 PL phase locked modulator and 6150 PL processor which to our knowledge is unique. Before the loop pulls into lock, a beat note exists at the phase detector output. The characteristics of the beat note are analyzed to determine the direction in which the VCXO must be driven in order to acquire lock. This technique permits lock to be achieved in a few milliseconds, with an initial frequency difference of fifty kilohertz. Circuit logic makes the technique insensitive to false lock on the reference sidebands as long as their amplitude is less than that of the carrier.

The visual effect of non phaselock is primarily the familiar co-channel beats, the subjective effect being dependent upon the frequency difference. When the two signals are phaselocked, a ghost of the interfering signal will still be seen on the screen. No satisfactory method exists for eliminating this ghost except to eliminate the signal leakage. However, several things may be done in order to minimize the subjective effect of the ghosting. The subjective effect depends upon the relative magnitude of the interference, upon picture content, upon the relative phase of the two carriers, and upon the relative frame rates of the two pictures.

Some reduction of the effect of ghosting may be obtained, in the case of display of text only, by utilizing white lettering on a black background. This is possible because black will then occupy the larger area, and a ghost is less noticeable with black picture content than with white. Black level is less affected by the ghost because of its higher carrier amplitude. Also a subjective effect is apparently at work here.

Phase angle between the two carriers is important because the effects of modulation of the interfering carrier on the overall instantaneous carrier amplitude may be shown to be dependent upon the manner in which the two carriers add vectorially. Unfortunately, this characteristic cannot be put to use in minimizing interference, because the relative phase of the two carriers at the home receiver cannot be maintained over time.

The relative frame rates of the two pictures is important because sync information is transmitted at a blacker-than-black level, and if the ghost sync bars are moving through the desired picture, a more distracting situation is seen than would be seen if the sync bars were stationary. For this reason, the operator should be careful to operate at the same frame rate as that of the interfering signal, if maximum picture quality is to be maintained. This should not be a problem if both the desired cable picture and the interfering picture are synchronized to broadcast quality color sync generators: the frequency stability demanded ensures that the two frame rates will be so nearly identical that the sync bar will move slowly if at all. Such may not be the case if the local origination picture is in black and white. This is because a 60 Hz field rate is traditionally used for black and white, while the field rate for color transmission is slightly retarded. This can give rise to sync bars moving rapidly in the picture. This problem may be eliminated if the local origination signal is genlocked to the interfering picture. This normally required, in addition to a camera, a sync generator capable of being genlocked to external video. To provide this video source for genlocking purposes, Scientific-Atlanta has provided a utility demodulator on its phaselocked modulator. This demodulated video output is available on the rear panel of the modulator.

Phaselock techniques have several applications in CATV systems, but phaselock should not be looked upon as a "cure for what ails you." Intelligently applied, it can be useful in several applications, including elimination of co-channel beats. As with any other tool, it must be reasonably well understood before it can be used to good advantage. For this reason, the CATV engineer considering phaselock should be sure he understands the advantages and limitations of phaselock, in order to maximize his return on investment and avoid unnecessary disappointment.

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COMMERCIAL DATA COMMUNICATIONS OVER A CABLE TELEVISION SYSTEM

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Sterling Manhattan Cable Television is franchised to operate in New York City south of 79th Street on the West side and 86th Street on the East side. This area includes some 350,000 dwelling units and encompasses the entire midtown Manhattan business district and the concentrated Wall Street financial community. This represents one of the world's highest concentrations of business and financial offices. In seeking sources of revenue outside of domestic television service, carriage of commercial data became a prime candidate. A good deal of effort has been expended by Sterling Manhattan and other interested parties in surveying this market potential. The conclusions have been very encouraging to the point of initiating technical studies, tests, system design and equipment development. An overview of this data system with emphasis on the technical aspects and the particular concerns of the cable operator will be presented.

DATA REQUIREMENTS

The data transmission environment in New York City, as one might expect, is almost totally interconnected by telephone circuits. With the enormous growth of electronic data processing over the past few years the telephone network is having difficulty keeping pace with the mounting requirements. One group of typical data users is the banks. One bank may have as many as 30 branch offices in the franchise area which must communicate extensively with a central computer and with each other. These are generally polled systems where the central computer interrogates the terminal at each branch office stimulating a responsive transmission of data back to the central computer. The central computer also transmits data to each branch office. These systems currently utilize synchronous and asynchronous data transmissions with rates to 50 kilobits per second. Many of these signals are carried in multiplexed form where several lower rate channels are combined into a single high rate data stream. The same type of service is often required by businesses for control of finances, inventories, shipments, and the like. The financial community employs extensive data communications between branch offices and central computers. In addition, hundreds of low speed circuits are employed with teletype-like terminals used in financial information services and buy and sell communications to brokerage firms.

Facsimile is another area of broadening interest. With the advent of high speed facsimile machines, letter size documents may be transmitted in just a few seconds; however, transmission bandwidths as high as 50 kbs are required. Many firms have found that duplicate orders, etc., transmitted by facsimile are more useful than ordinary data transmission between offices due to the convenience of complete standard forms rather than hard to handle lists of received data. Use of facsimile frees the computer while utilizing only the fax transmitter on one end and the receiver on the other end of the link.

In the future some long haul data services may need local trunking and distribution. These circuits might utilize data rates to 250,000 kbs.

The results of the market surveys indicate the following technical bounds for profitable involvement in commercial data transmission.

1. Full duplex capability
2. Synchronous transmissions only
3. Serial data rates from 1.2 to 50 kbs. Below 1.2 kbs does not appear profitable. Above 50 kbs should be available when the market demands it. Low speed circuits can be accommodated if premultiplexed.
4. Perhaps 2000 terminals within five years.

CABLE OPERATOR'S PERSPECTIVE

With the background of possible markets for a CATV data service, let us assume the perspective of the cable operator. In this case Sterling Manhattan Cable Television has viewed the potential market with its existing CATV system clearly in focus.

SMCTV is not only unique in the fact that its residential service surrounds an enormous commercial community, but it is also one of the few cable systems which have been built totally underground. SMCTV's 54 miles of trunk serving approximately 60,000 subscribers, is routed through a maze of underground ducts running beneath city streets. For the most part the trunk is accessible only by manholes. Amplifiers are often housed in these underground facilities or, at best, in sidewalk boxes accessible by lifting heavy steel plates which cover them. Much of the distribution system also runs in these ducts before being routed into the basements of hundreds of buildings all over the city. This may seem to be academic information at this point, however, it becomes a serious consideration if the implementation of the data system requires placing of sensitive equipment at best in someone's cellar and at worst in what is very nearly a sewer.

Also to be considered is the depth of the operator's involvement in the sophisticated realm of electronic data processing. Reviewing the systems previously described it can be seen that many phases of data communications are involved. Such terms as Time Division Multiplex, Store and Forward, ARC, CRC, etc., are encountered and we find that the modes of transmission used are far from uniform. In this regard it was the desire of SMCTV that direct involvement in the details of user's data transmission systems, data formats, etc., be avoided to the greatest degree possible.

A switched type of data service could be provided. However, this is very expensive and sophisticated. A headend computer would be required and bring with it the headaches of software and foreign equipment maintenance.

With these negatives in bold relief SMCTV has avoided such involvement wherever possible. The basic philosophy of SMCTV's data system can be summarized as follows. The desired system should:

1. Provide point-to-point service
2. Be sold and utilized strictly on a bandwidth requirement basis without knowledge or manipulation of the customer's data formats
3. Require investment and equipment modification more or less in proportion to the number of customers avoiding large initial equipment expenses
4. Be easy to operate, dependable, and easily maintainable by CATV technicians.

With these goals in mind an investigation of present systems and methods was initiated.

The normal methods of data transmission applicable to the New York City situation are largely those developed and used by the Bell Telephone Company. Starting at the customer's terminal they provide a direct dial line or a leased line with the proper frequency response characteristics. Where transmission of several channels is required they are normally combined by frequency division multiplexing into banks of 12 voice channels, called groups, which may be further combined into super groups, master groups, etc. One transmission carrier for microwave or coaxial cable may contain in the order of a thousand voice channels or equivalent. This type of arrangement requires modulation (multiplexing) and remodulation at every point of group compounding.

Applying this technique to the CATV environment we can picture combining, let us say in every block of the financial district, recombining sets of blocks and perhaps combining a third time before entering the trunk. This immediately requires the installation of expensive multiplexing equipment some of which must be located in the undesirable locations mentioned before. Thinking this system through also shows the need for "uncombining" in the same manner for the down stream signals. For the projected data loading of the system this approach could be extremely complex. To make a long story short this may be fine for "Ma Bell" but it is not the answer for the CATV operator.

The use of Time Division Multiplexing has been explored and suggested by some. This would mean that a basic timing system must be set up in the data channel of interest (this would have to be in some RF channel or for the sake of discussion some Television channel). Each terminal in the system would then be assigned a specific time slot and could transmit or receive its data, bit by bit, each time the assigned time slot occurred. There are two major disadvantages of this approach. First the timing of a "tree" type system, such as a CATV system, becomes quite complex. Secondly, the TDM "modem" becomes a rather sophisticated device especially when the timing system must include operation at RF frequencies. It is estimated that a terminal will cost in the order of $2000 in reasonable quantities after development. The TDM approach was seriously considered but was not accepted due to these limitations.

SMCTV SYSTEM CONCEPTS

After all the above the following rather simple system was formulated and steps taken to achieve its implementation. The system concept involves single level frequency division multiplexing. That is, each customer is assigned a certain frequency slot in the data portion of the RF spectrum on both upstream and downstream systems. This slot will be of a bandwidth sufficient to carry the maximum data speed. Many such channels will be required so that the frequency band allocated to data will contain many discrete carriers. Since repeated modulation of one signal onto another generates unwanted mixing products, it was decided to generate each customer's carrier frequency at his location and passively couple each of these signals into the cable system. In this way no spurious products will be produced.

The basic mode of operation is to transmit upstream all signals originated by terminals, passively combining in the distribution system before entering the trunk. All signals will be assigned frequencies within a block, probably within the assignment of one unused TV channel. This block will then be up-converted with a standard CATV translator to some unused downstream TV channel, probably near the high end of the spectrum. All transmitted signals will be on the downstream system and receivable at all locations. Point-to-point communication will then exist upon assignment of compatible transmitter and receiver frequencies at each end of the link. Full duplex operation may be utilized and multiple reception of any transmission can be provided. The data terminal can be given any serial binary signal and modulate its RF carrier accordingly without concern for any of the parameters of data, coding, formating, and the like except for the maximum baud rate which determines the required bandwidth. This then does not require the cable operator to get any deeper into the data transmission schemes than providing the channel and modulator/demodulator functions.

The first reaction to this concept was "Surely, this is a simple system requiring no complex computer control, equipment in manholes or expensive overhead and monitoring paraphernalia. The hardware should be simple and straightforward and certainly is manufactured by someone." To find this someone was a "horse of a different color." It seems that everyone makes "modems" but modems, in today's form, are built for operation over the telephone lines and are completely unusable in this situation. Unfortunately nobody makes this type of simple FDM equipment for the frequency range involved. Consequently the decision was made to develop the equipment needed. Estimates for equipment development and production of the data interface in relatively small quantities fell under $1000 per unit.

DATA INTERFACE DESIGN

The major factors in the design of the Data Interface modules are:

1. Frequency selection and stability
2. Modulation method and bandwidths
3. Automatic and unattended operation
4. Self-testing and maintainability.

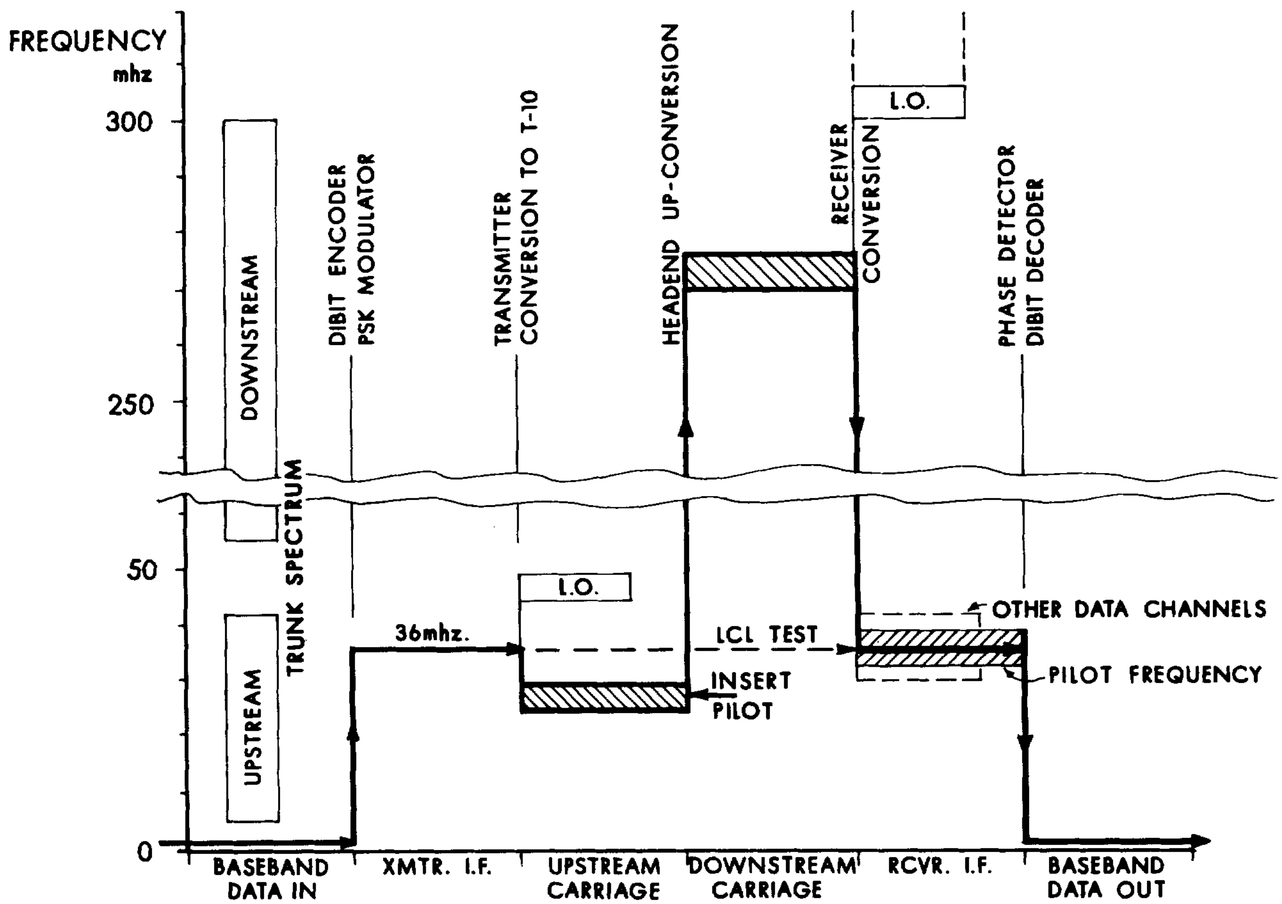
Assuming proper system environment, which will be discussed later, the above factors dictate the design strategy. Since all origination signals will proceed upstream on the cable system at a low frequency stability of the transmitted signal can be easily achieved. In the SMCTV system the sublow T-10 channel was chosen for initial data utilization. This channel was chosen because the group delay in this frequency range on a 5-32 MHz reverse carriage system precludes its use for video. Any of the other sublow channels can be used.

In this range crystal controlled oscillators having overall frequency tolerances of ±.0005 percent are readily obtainable. Carriers may then be easily located and stabilized to within ±500 Hz (including local oscillator tolerances). Now the entire data spectrum can be up-converted as a block from channel T-10 to a higher channel (in this case channel R at 264 to 270 MHz was chosen). Before up-conversion a pilot carrier of high stability is inserted for final frequency control. Since the pilot is accurately maintained relative to the data carriers, high frequency stability in up-conversion is not required. The pilot carrier will be used to locate the correct data channel amidst all of the others when receiving the block of signals in channel R. In the receiving section of the data interface a frequency conversion of the block is made to allow reception and demodulation of the proper data carrier.

Let us take a closer look at the details of the system operation and the requirements of the transmitting and receiving sections of the data interface. Referring to Figure 1 the various steps of modulation, frequency conversion, and demodulation can be followed. The baseband binary data, as it is received from the computer or data terminal, modulates a 36 MHz carrier. This carrier is then translated to the T-10 channel (23.75 to 29.75 MHz). The local oscillator frequencies for this conversion lie in the CATV system "crossover frequencies" between 32 and 54 MHz. Should any of these leak into the system (which they should not), they would be harmless. The data signal then is introduced into the upstream CATV system and transmitted to the headend. At the headend the highly stable pilot carrier is introduced. Standard CATV equipment is used to translate the block and pilot preserving the amplitude and frequency relationships. The data block is then transmitted downstream like a television signal.

The receiver portion or the data interface is tuned to the assigned receiving channel. Due to the close spacing of the data channels it is very difficult to distinguish one channel from the next, therefore frequency selection is accomplished by use of the pilot carrier. The receiver signal IF frequency is exactly 36 MHz. The pilot carrier is greater in amplitude than the data carriers (the specifics of this will be discussed later). Knowing the frequency of the data channel desired and the frequency of the pilot carrier a crystal is selected to establish oscillations at a frequency equal to the frequency of the data channel minus the frequency of the pilot carrier plus 36.0000 MHz. A local oscillator frequency is established in the band of 300 to 306 MHz. This local oscillator when compared to the frequency of the data channel must produce a 36 MHz output. To achieve this the 300 MHz local oscillator beats with the pilot carrier and the difference is compared to the frequency of the crystal previously selected. The output of this comparison is used to correct and finally phase-lock the 300 MHz local oscillator and bring the proper data channel carrier into the 36 MHz IF. Examination of the diagram and the crystal selection equation will help clarify this operation.

With the desired data channel at exactly 36 MHz it is further amplified and limited in a narrowband IF. The bandwidth is assigned depending on the customer's maximum data rate. Beyond that a phase detector and digital circuits restore the original data stream which was introduced at the transmitting end of the circuit.



Data System Frequency Chart

fig. 1

In passing it is well to note that the transmitter and the receiver have common IF frequencies allowing "local loop" operation for test purposes. In this mode it is possible to check operation of most of the interface circuitry. In normal operation the transmitter and receiver sections operate independently in a full duplex mode.

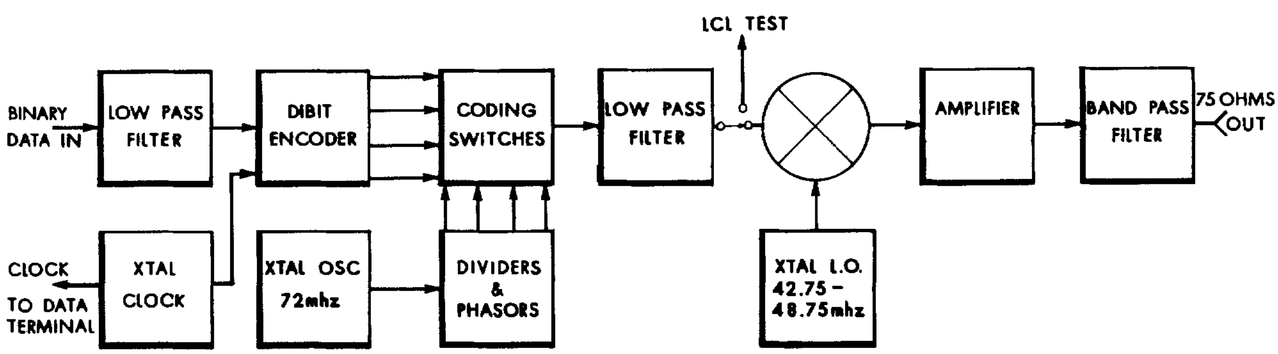
With these general principals of operation in mind let us look at the block diagrams of the transmitter and receiver portions of the data interface as shown in Figures 2 and 3. So far we have not mentioned the type of modulation on the bandwidth required for transmission of data. As previously explained synchronous data at rates from 1.2 to 50 kbs will be handled. An FM or Phase modulation system would be in order due to superior noise immunity. The minimum possible bandwidth for any such system is equal to the baud rate of the system. (The baud rate is the number of bits per second and the maximum modulation frequency is one half that figure.) Add to this the requirement of guard bands between channels and we find that our maximum data speed is in the order of one half of the bandwidth occupied. It is desirable to make this somewhat more spectrum efficient. Therefore, a system of bandwidth compressions is employed using four phase PSK modulation. This will allow modulation bandwidths of one half the baud rate to occupy spectrum at the rate of one bit per second per Hertz of bandwidth allowing for 100 percent guard bands (100 percent guard bands are quite generous).

With this modulation system the data interface will accept data to be transmitted in a binary form from the data terminal or computer. The data rate will be preset and an internal clock will generate the clock signal for the data terminal. As data bits are received they will be separated in pairs. Each pair has only four possible combinations (i.e., 00, 01, 10, or 11). The dibit encoder takes the code of the bit pair and uses this information to select the proper phase advance or retardation to represent this combination. Since a change in modulation takes place only once every two bits of input data, the maximum bandwidth required is halved. Therefore, instead of requiring a bandwidth equal to the baud rate only one half the baud rate is required.

Since the transmitter IF operates at 36 MHz we must supply a source of 36 MHz energy from which we can select four equally spaced phase conditions. In order to achieve this a 72 MHz crystal oscillator is used for timing. Since there is an axis crossing every half cycle we have enough timing information to establish four periods of 90 degrees each at 36 MHz. These four phases are directed to gates which are selected one at a time as required by the output of the dibit encoder. This phase modulated signal is then passed through a low pass filter and mixed with the appropriate local oscillator frequency and translated to the assigned carrier frequency in the T-10 upstream channel. This signal is amplified, passed through a bandpass filter, and trapped to assure complete removal of the local oscillator signal and is ready for insertion into the cable system. The output level of this section will be in the order of +60 dBmv. This level will generally be sufficient to overcome system losses and provide injection at the proper level into the upstream trunk.

The block diagram indicates a tap-off point for local tests. A signal extracted at this point can be fed to the receiver section to accomplish the local loop test previously mentioned.

The receiver section of the data interface accepts the downstream signals in channel R



Block Diagram — Data Interface Transmitter

fig. 2

(264 to 270 MHz). The receiver is equipped with a bandpass filter for this channel and a trap to remove any local oscillator feed-through. The first mixer converts the desired data channel to 36 MHz and the pilot carrier to some frequency between 33 and 39 MHz. This is followed by a broadband linear IF covering this frequency range. The output of this IF is split. One side goes to the AFC phase detector where the pilot carrier is compared to the output of a crystal oscillator whose frequency has been selected (described previously) to center the data channel on 36 MHz.

The output of the AFC phase detector controls the frequency and phase of the local oscillator in the 300 to 306 MHz range. Since the amplitude of the pilot carrier is a good deal greater than any of the data carriers the phase detector will immediately seek and lock onto this signal. The pilot carrier will carry an audio frequency AM modulated at low level. The presence of this synchronously detected AM tone will indicate pilot carrier lock by a pilot lamp.

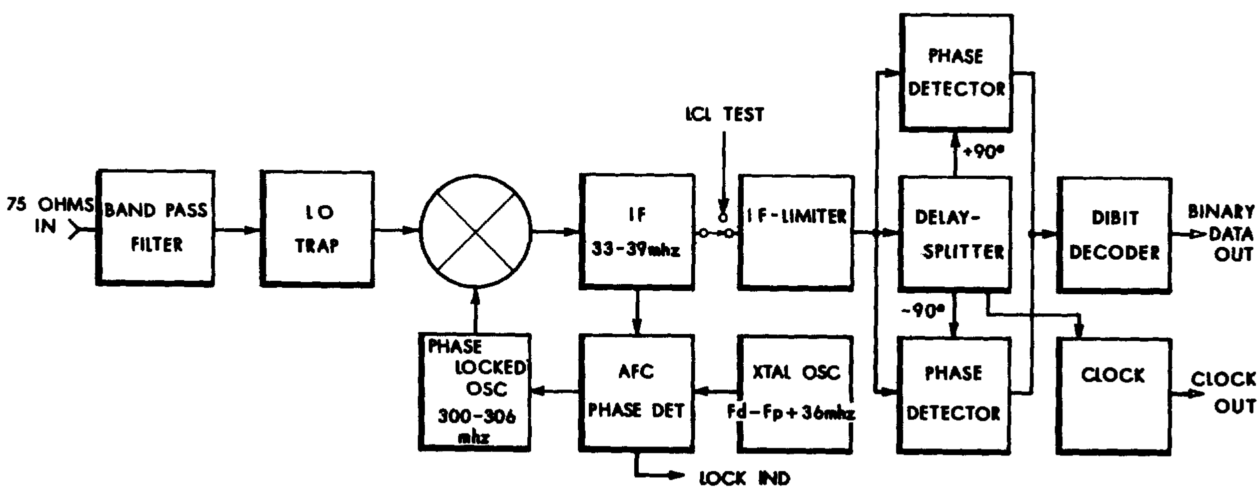
The other output of the wideband IF feeds the 36 MHz narrowband IF amplifier. This bandwidth is controlled to match that of the customer's maximum data rate assignment. This IF selects the single data channel and hard limits to reduce the effects of amplitude disturbances in the system. At the output of this IF the signal branches three ways, the center line goes to a network giving a 90-degree phase shift while the other legs go to separate phase detectors. The phase delay circuit also phase splits the signal resulting in outputs leading and lagging the input signal by 90 degrees. These signals are used for reference in the phase detectors. Combination of these phase detector outputs produces a signal which indicates which phase transition has just taken place. This phase transition, which has been differentially detected, positively identifies the dibit transmitted. The decoder produces a pair of bits for each phase transition thereby reassembling the transmitted message. If a clock output is necessary for the local data terminal this information exists in the phase detected signals and is used to generate the output clock signal.

It can be seen that the electronics of the interface are relatively straightforward. There are no operator controls except for the test switches. Many of the functions are achieved by low cost integrated circuits. Many of the RF functions are achievable by digital techniques producing a straightforward design of high reliability.

One physical configuration of the data interface is illustrated in Figure 4. This is a desk top unit with only two switches and two pilot lights. The pilot lights indicate receiver lock to the pilot carrier and a data being received. One switch allows self-testing in the local loop condition as previously described. The second switch is reserved for a system test feature which is to be incorporated in the future development of the system. These units are maintainable on a plug-in board basis. The power supply, transmitter, and receiver sections are separate and easily accessed and serviced.

SYSTEM CONSIDERATIONS

Several points should be discussed which bear on the operation of the cable system when



Block Diagram — Data Interface Receiver

fig. 3

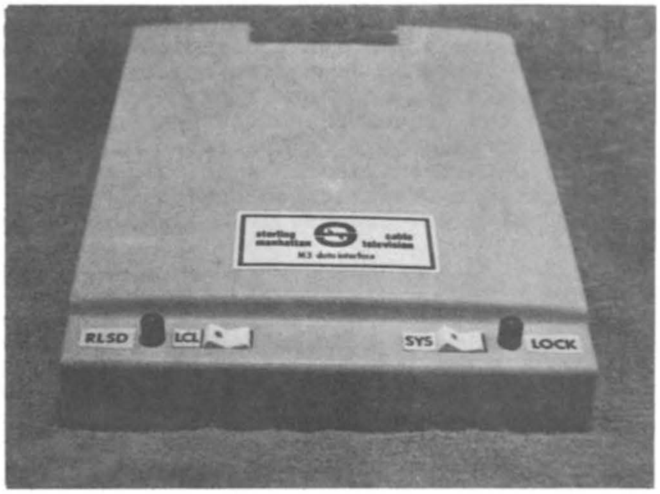


fig. 4

carrying data. The following three items are important considerations.

1. Data channel signal level, signal-to-noise ratio and error rate

2. Upstream noise buildup

3. Incidental system disturbances

The matter of data channel signal level and the consequent S/N ratio of the system must be handled together. As described in the previous section a data rate of 1 bit per second per Hertz of system bandwidth can be accepted when using the modulation system and guard bands described. Let us start by saying that the total power of the full data channel should be roughly the same as the equivalent power in a television channel. For reference use the amplitude of a normal TV carrier and fix it at 0 dB. Assume that the maximum system noise at any point (based on 4 MHz bandwidth) is 40 dB below this. The total power in any TV channel is essentially the picture carrier and there is only one picture carrier for each 6 MHz of bandwidth. The average power per Hertz of bandwidth is the one 6 millionth of the picture carrier or -68 dB. By the same token the noise per Hertz will be -108 dB (-68 dB carrier -40 dB S/N).

On this basis consider the signal levels which are appropriate for the data channels, pilot carrier, and the S/N ratios which will result. Let us start by making the total power in our data channel equal to that of a standard 6 MHz TV channel. This will assure that we will not produce any overload in the system but yet that we will provide maximum possible S/N ratio for data transmission. With the knowledge of the power density which we have calculated above we can simply assign each data channel a power which is equal to its portion of the total TV channel power according to the bandwidth assigned. For instance a 50 kbs channel uses 50,000 times the bandwidth of one Hertz (as established in previous discussion) therefore it can be assigned 50,000 times the average carrier power per Hertz of bandwidth. As 50,000 times is 47 dB this means that its carrier power can be -21 dB (-68 + 47 dB = -21 dB). The noise in the channel will be increased by the same factor so that the 40 dB S/N will be maintained. This is a consistent scheme of proportioning which provides the same S/N ratio for each data channel and therefore should produce the same error rate.

Let us look at the pilot carrier. We said before that it should be greater in amplitude than any other signal; therefore let us arbitrarily assign it one half the total channel power. This will mean that it will operate at a level of -3 dB and that we must then reduce all other carriers by 3 dB in order not to overload the channel. This however does not affect the noise level. Therefore, the S/N ratio is degraded by 3 dB to 37 for all data channels. For the type of modulation we are using and considering various other factors affecting the modulation, Information theory predicts an error rate of one in one hundred million (10^8) for a 17 dB S/N ratio. This means that the 37 dB which we are providing produces a vanishingly small error rate figure. It is so small in fact that it would not be unreasonable to reduce all the levels in the data channel or to allow for noise levels considerably higher than proposed. Obviously data is a lot more forgiving than video. There is also a good deal of headroom for noise buildup in the reverse carriage of the system. Some cases may require that some of this margin be used.

As all who have contemplated two-way CATV systems are aware there is a noise buildup occurring when many inputs are combined into an upstream channel. In the case of SMCTV system the problem of combining 60,000 subscriber terminals is not of immediate concern relative to the data transmission system. In this case a total of perhaps 2000 inputs will comprise the upstream carriage and these are distributed to several localities so that no density is particularly high. Standard techniques will suffice in reducing this effect. One inexpensive expedient which can be used in this application is to sectionalize the system and allocate a small block of frequencies to a given area. This will add noise to only a fraction of the total bandwidth which will not be duplicated elsewhere. Upstream noise buildup although often a big headache, is not considered as a serious problem in this application.

In order to sell CATV data transmission services, it is obvious that high system reliability is required. This means that all possible steps must be taken to increase the system reliability. At SMCTV steps are being taken to provide redundant trunk feeds to critical areas, remote monitoring equipment for better system control and anticipation of problems, automatic switching of standby equipment in case of localized failures, and other high reliability techniques.

Some of the problems which are not yet clearly defined include those of low frequency intrusion and transient conditions which have not been a problem with TV carriage but may well be factors producing data errors. An effort is being made to anticipate and measure this type of problem at the present time. Some low frequency intrusion data exists since the system now uses a 5 to 95 MHz origination trunk traversing one of the longest runs in the city. Some amount of intrusion has been noticed in these channels but the levels are considerably lower than those reported by others, perhaps due to the fact that this is an underground system. Intrusion also has been traced to drop cables, connectors and the like. Fortunately in the SMCTV case, the local signal levels in New York are extremely high and therefore high quality multi-shielded cable has always been employed. The same will be true for wiring of the data service customers, perhaps even to the point of using aluminum sheathed small diameter cable instead of flexible.

There is one traditional CATV ritual which may end up being a culprit in the data business, this is Summation Sweeping. Basically FM modulation systems with hard limited receiver IFs are immune to amplitude type disturbances, however, a coherent swept interference, such as the summation sweep, operating 40 or 50 dB above the data carrier is no mean disturbance and may turn out to be a villain. With this eventuality in mind a simple device for momentarily disabling the summation sweep as it passes through the data block, is being constructed. Initial tests on the system using upstream and downstream carriage have demonstrated high quality data transmission with extremely low error rates a transmission speeds up to 250,000 bits per second.

SUMMARY

The potential for CATV commercial data transmission in New York City is very good. A simple FDM data transmission system has been conceived and is currently being developed to serve this market over the Sterling Manhattan Cable Television System. The data transmission components are simple, straightforward, automatic, and inexpensive. They will handle synchronous data transmission in the range of 1.2 to 50 kbs. Higher data rates can be achieved with the same equipment but at this time are not required. Lower data rates have been considered economically unsuited. The cost of this service to the customers will be less than equivalent telephone charges, while error rates will be at least an order of magnitude better. System reliability will be higher and flexibility to change and particularly to increase the amount of service required by any customer will be far better and faster. The hardware involved is installed at the customer's location and does not require extensive additions or modifications to the CATV plant.

The basic system has been designed and specific hardware development is now under way. Operating tests with interested commercial data users are scheduled for the very near future. Formal inauguration of the data service with a substantial number of subscribers is expected within a 12-month period.

COMPUTER CONTROLLED CATV SYSTEM

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INTRODUCTION

The most crucial parameter of any CATV system is the complete system alignment. Presently each amplifier is aligned by hand using a Field Strength meter or a simultaneous sweep system and, consequently, takes a number of days to complete the entire system alignment. The only problem is that the system alignment does not remain stable over periods of time due to temperature changes, voltage variations, and component degradation.

There are several ways to detect the condition of system alignment, but all require going through the system by hand with a Field Strength meter to make corrections. Usually an alignment problem shows up as a poor picture on a customer's TV set. After a few complaints are made, the system operator determines that it is time to realign the amplifiers. There have been several attempts to curb the variations in system alignment, but none have proven good enough to eliminate periodic system alignments.

One attempt is to place AGC amplifiers every second or third amplifier in the system. The AGC amplifier corrects the gain of the amplifier by sensing the level of a pilot carrier at the output of the amplifier. Theoretically, the AGC function is to change the gain of the amplifier equally at every frequency. However, in practice, there is always some tilt introduced in the AGC circuit. This tilt may or may not be needed to correctly compensate for the given gain change. Another problem of AGC amplifiers is that each amplifier corrects its own gain; and, therefore, works independently of other following amplifiers. Thus, the AGC amplifiers cannot detect overload conditions that occur on down the line. An AGC amplifier might correct its own operating levels but may shift the operating level of following amplifiers out of range of the AGC compensation; or excessive tilt can build up after several AGC amplifiers so that only part of the frequency range is properly adjusted.

Another way to help curb system alignment variation is to use Thermal equalizers. Thermal equalizers compensate for attenuation variations that are introduced in the system by the cable changing temperatures. Thermal equalizers equalize several thousand feet of cable and are usually placed every fourth amplifier. The problem is that the thermal equalizer may be in the sun or the shade, while part of the cable is in the shade and part is in the sun. Therefore, the thermal equalizer cannot properly equalize a length of cable.

Some of the new amplifiers use both automatic gain and automatic tilt circuits. Here the idea is to change both gain and tilt to offset the attenuation variations of the cable. This type of amplifier works best, but even these amplifiers need periodic alignment to keep the system levels optimized.

A system that would automatically align each amplifier in the entire cable system from a central point would eliminate all of the above mentioned problems. Such a system could automatically align a complete cable system in a few hours. The features of such a system will be discussed under the following two topics:

A. Auto alignment.

B. Maintenance and records.

AUTO ALIGNMENT

A proposed method of controlling system alignment is to use a computer at the head end that is capable of determining system levels and can make corrections where necessary. The auto-alignment system requires that the trunk line be a two-way system of some sort. The system must have the capability of sending and receiving information from the amplifiers. A pilot carrier with pulse code modulation can be used to interrogate the amplifiers and change levels. A likewise carrier in the reverse direction would be used to send level information back to the computer. The computer can communicate with each amplifier on an individual basis and align the entire cable system from the first trunk amplifier to the last distribution amplifier. A pulse code modulation system using twelve serial bits is needed to provide 4096 different codes to service up to 1016 amplifiers. Binary codes 0 through 31 are reserved for adjusting gain and tilt of amplifiers. Code 0 represents minimum gain or minimum tilt, while code 31 represents full gain or full tilt. The rest of the 4064 codes are divided between 1016 amplifiers (4 codes per amplifier). Each amplifier has a separate code for each of the following functions:

Code #1 Request output level of high channel.

Code #2 Request output level of low channel.

Code #3 Open memory unit for new gain data.

Code #4 Open memory unit for new tilt data.

The computer will send the first code to the first amplifier via the forward pilot carrier. The first amplifier receives this code and immediately sends a code (0 to 31) back to the computer via the reverse pilot carrier, indicating the output level of the high channel. After receiving and storing this information, the computer sends out the second code to the first amplifier. Again the first amplifier receives the code and sends a code back indicating the output level of the low channel. After receiving the output levels of both the high channel and low channel, the computer calculates corrected gain and tilt values for the first amplifier. Next, the computer adjusts the gain and tilt of the first amplifier by sending out code 3 followed by a correction code. The tilt is adjusted in the same manner except that code 4 is sent followed by a correction code. The codes that are sent between the computer and amplifier that is being adjusted do not affect the gain or tilt of any of the other amplifiers in the system. This is true because of two conditions:

1. Correction codes (0 to 31) are not used for any of the four control codes.

2. The correction codes that are sent to the amplifiers are preceded by a code that opens the memory unit for only one particular amplifier. Thus, the correction code is ignored by all other amplifiers.

The system alignment is adjusted by starting at the front of the cable system and working down each trunk until every amplifier has been adjusted.

MAINTENANCE AND RECORDS

Each time an amplifier requires a correction in gain or tilt, the computer will print the output levels before the correction and after the correction has been applied. This gives the system engineer a complete record of valuable data that will let him analyze each amplifier's performance. Another feature lets the system engineer interrupt the auto-alignment system and request or change output levels at any point in the cable system. If an amplifier requires too many corrections, the system engineer could replace the amplifier before a system fault occurs. If a system fault does occur, the computer will sound a general alarm and print out the improper levels at the point of the fault along with the location or identification of the faulty amplifier. It is even possible to add additional codes so that the computer can switch in a good trunk amplifier where one has failed. This would give the system minimum down time with a high reliability. Reliability of system performance cannot be over emphasized especially when the system is used for commercial purposes.

The system described is not available from any manufacturer, but may be in the near future, especially since other proposed functions of the CATV system will require computers. The system is simple in technology and could be developed to work with any amplifier that can accept auto-gain and auto-tilt modules. The auto-gain and auto-tilt modules would be replaced with other modules containing logic circuits that allow the computer to communicate with the amplifier. The two-way requirement of the system can be either a two-way trunk line or a separate reverse cable going back to the head end. It is estimated that the system would add 50% to the equipment cost. This would be easily offset by a large reduction in maintenance costs.

CONSIDERATIONS FOR SIGNALS IN THE REVERSE FEEDER LINES

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Abstract - Emphasis is placed on system design criteria for subscriber originated signals. Methods for establishing proper system operating levels based on system size are considered and the performance trade-offs are analyzed. System levels are established on an exemplar profile and the resultant component requirements examined. An examination of potential subscriber interference through propagation is made with recommended techniques for correction offered.

Introduction

In CATV systems providing one-way signal transportation, the "quality control" emphasis has been on the trunk line with secondary attention being given to the feeder or distribution line. Such a philosophy is justified, of course, when one considers the relatively complex requirements of headend antenna arrays, signal processors, trunk amplifier distortion and response stability criteria, as compared to the job of the directional multitap and line extender, or even the distribution bridger. In much of the analysis work pertaining to two-way signal transportation again the primary emphasis has been placed on trunk or total system design, with the feeder system assigned to an ancillary position. There are, however, a number of design considerations relating particularly to the distribution or feeder legs of two-way systems which are worthy of special attention. It is the purpose of this paper to present the following points for consideration: 1) the operating levels and performance specifications of the feeder system should be established on the basis of actual trunk to feeder density as well as total system size; 2) the feeder system operating levels should not be higher than the minimum dictated by the desired system performance standards to avoid requiring excessively high outputs from the subscriber return terminals; 3) potential two-way interference paths exist, particularly in installations with high terminal density (i.e. schools, hospitals, etc.) which will require special attention; and 4) return feeder system operating level changes as a result of temperature variations, while less than in the forward direction, are still significant and should be controlled.

Elements of the Feeder System

Illustrated in Figure 1 is a segment of a typical two-way trunk and distribution layout. The hub concept is shown since this is perhaps the most viable scheme for new systems, but the same basic problems confront all types of systems and are simply easier to isolate with the hub concept.

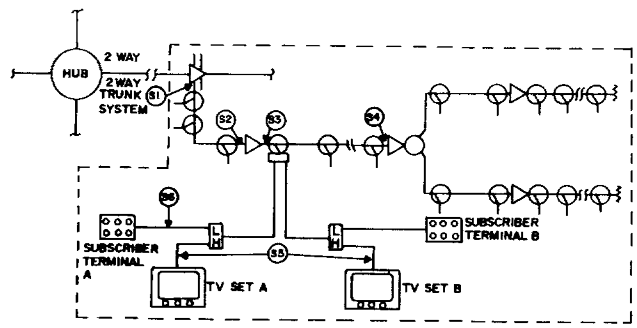

FIG. 1 FEEDER SYSTEM INDICATING SIGNIFICANT POINTS FOR ESTABLISHMENT OF RETURN SIGNAL PERFORMANCE

There are six significant locations (S1 - S6) where feeder levels must be controlled in order to realize an optimum system design. The first of these to be established is the level at S1 (bridger input) and S3 (feeder inputs), which are the system "minimum signal levels". In order to appreciate the level requirements at these points consider the effect which has been termed noise - "summing" or "gathering".

System Noise Level

The basic result of summing non-coherent signals with equal noise using splitters is shown in Figure 2, with the result being that the effective signal-to-noise ratio is decreased 3 dB each time the number of noise sources is doubled. If we carry the analysis one step further it can be shown that the total noise contribution of combining any number of these equal noise sources together is expressed by the relation:

System noise = NS = NT + 10 Log_{10} N

Where NT = Thermal noise (4 MHz) = -59 dBmV

N = Total number of noise sources

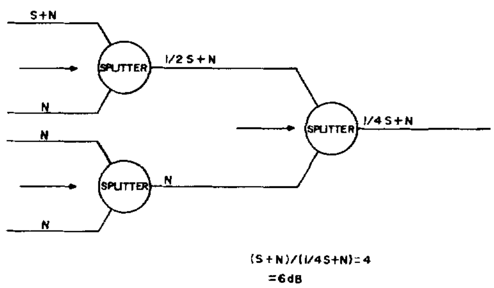

FIG. 2 BASIC NOISE SUMMING EFFECT OF SIGNAL COMBINING

This is really no different than calculating cascade noise build up except that we are now concerned with system density rather than length. For example, in a cascade of 40 amplifiers with equal noise figures, the noise level at the end of the cascade with an 8 dB amplifier noise figure is given by the expression:

$$\text{System noise} = NS = NT + 10\ \text{Log}_{10}\ N + NF$$
$$= -59 + 10(1.6) + 8 = -35\ \text{dBmV}$$

Where NF = Amplifier noise figure
NT = Thermal noise (4 MHz) = -59 dBmV
N = Total number of amplifiers

and the signal-to-noise ratio would therefore be:

$$S - N = S - (-35\ \text{dBmV}) = S + 35\ \text{dBmV}$$

In a similar manner the noise level produced at the summation point due to two (2) cascades of 20 amplifiers feeding into each port of an ideal (-3 dB) line divider with amplifier noise figures of 8 dB is found by the expression:

$$\text{System noise} = NS_1 \oplus^{*} NS_2 = -38\ \text{dBmV}$$

$$\text{Where } NS_1 = NS_2 = (-59 + 10\ \text{Log}_{10}\ 20 + 8)\ -3$$
$$= -41\ \text{dBmV}$$

and the signal-to-noise ratio would be:

$$S - N = (S - 3\ \text{dB}) - (-38\ \text{dBmV}) = S + 35\ \text{dBmV}$$

*denotes logarithmic addition

Since we are interested in the signal or carrier to noise ratio in a CATV system we will need to consider not only the noise build up of the feeder lines, but the required minimum signal levels as well. The accumulation of noise per se would not be a problem if it were possible to subsequently increase the desired signal as needed, thus maintaining a constant noise margin. Such is not the case, however, and promiscuously increasing the minimum operating level beyond that which is needed may place an unnecessary burden on other areas of the system (i.e. requiring excessive subscriber terminal levels or amplifier distortion characteristics).

Signal-to-Noise Ratio

The graph shown in Figure 3 depicts the minimum signal level required at a bridger summation point to maintain a selected signal-to-noise ratio from the feeder system. If we let, for example, the complete feeder system S/N = 49 dB then a total of 100 amplifiers in the feeder system would require a minimum summation signal of +18 dBmV and 1,000 amplifiers would require a minimum summation signal of +30 dBmV.

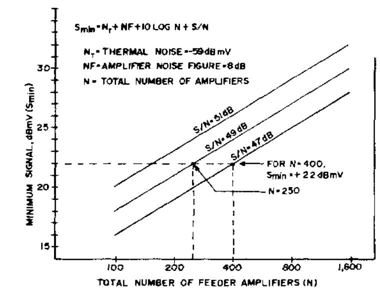

FIG. 3 RELATIONSHIP BETWEEN SYSTEM DENSITY AND MINIMUM SIGNAL LEVEL

If the S/N ratio of the complete return path, (trunk and feeder system) is set, for example, at 46 dB, a design trade-off may now be made.

TABLE I
TABULATION OF TRUNK / FEEDER S/N

TRUNK S/N (dB)	FEEDER S/N (dB)	COMBINED S/N (dB)
46.5	56.0	46
47.0	53.5	46
48.0	50.5	46
49.0	49.0	46
50.5	48.0	46
53.5	47.0	46
56.0	46.5	46

Table I tabulates a few of the many combinations of trunk and feeder S/N ratios which will yield an overall S/N of 46 dB. However, although many combinations of trunk/feeder ratios are possible, a condition of disproportionate loading is quickly encountered. Figure 4 graphically displays this condition, and the shaded area represents a boundary which is equal to ±2 dB from the equipollent position. While this may seem like a meager design trade-off, Figure 3 demonstrates that decreasing the feeder S/N from 49 dB to 47 dB increases the number of permissible feeder amplifiers from 250 to 400. This represents a potential increase of 4,200 subscribers (Appendix I) without sacrificing picture quality or raising the required signal level. Since the composite return system (trunk and feeder) S/N must be held at 46 dB, the trunk system must now yield a S/N of 53.5 dB (Table I). If the feeder to trunk ratio is high (i.e. greater than 4:1) this may be a very reasonable trade-off since S/N ratios of 53.5 dB may be realized for trunk systems of up to 90 amplifiers with equipment currently available (Appendix II). Having demonstrated

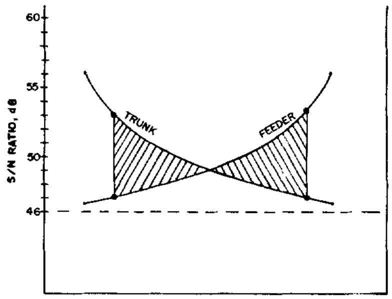

FIG. 4 COMBINATIONS OF TRUNK/FEEDER S/N RATIOS FOR 46 dB SYSTEM S/N

a technique for selecting the minimum system signal level, we need now to consider the maximum signal level (S2, S4, Figure 1) which is required to offset the system losses and maintain this required minimum.

Trunk/Bridger Input Level

Outlined in Figure 5 is a two-way trunk bridger with one output feeding signals to a fully loaded two-way feeder line, followed by one line extender. If we define a total system with the characteristics as shown:

Trunk amplifiers = 80
Feeder amplifiers = 320
N.F. (Trunk/feeder) = 8 dB

we then find by referring to Figure 3 that the minimum signal level must be +21 dBmV for a feeder S/N of 47 dB. This is the minimum level a signal may decrease to before being amplified.

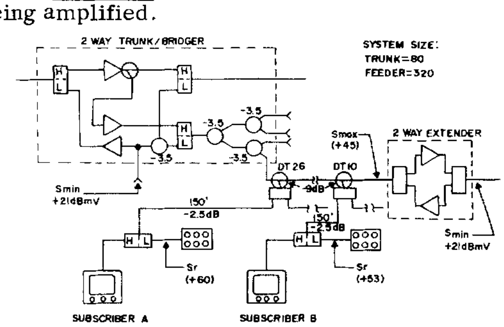

FIG.5 RETURN FEEDER SIGNAL LEVELS—FIRST EXTENDER

This S1 level, referred to as S_{min} in Figure 5, is inside the trunk/bridger amplifier since this is its lowest level point. The signal required at the return extender output (S_{max}) to produce +21 dBmV at the bridger summation point (S_{min}) may be calculated by considering the following:

S_{max} = + 21 + system loss = 45 dBmV

Where system loss = 10.5 (bridger combining loss)
8.0 (Σ directional tap thru losses)
5.5 (Σ cable loss in extender line, 30 MHz)
24.0 dB Total

Additionally, the required return levels at subscribers A, B (Sr) may be calculated since:

Sr A = + 21 + system loss = +60 dBmV

Where system loss = 10.5 (bridger combining loss)
26.0 (DT 26 subscriber drop loss)
2.5 (drop cable loss, 30 MHz)
39.0 dB Total

Sr B = + 21 + system loss = +53 dBmV

Where system loss = 10.5 (bridger combining loss)
4.5 (Σ directional tap thru losses)
4.5 (Σ cable loss in extender line, 30 MHz)
10.0 (DT 10 subscriber drop loss)
2.5 (drop cable loss)
32.0 dB Total

Succeeding Line Extender Levels

Calculation of succeeding amplifier levels, Figure 6, follows the same rules as the first extender. For example:

S_{max} = + 21 + system loss = +34.5 dBmV

Where system loss = 8.0 (Σ directional tap thru losses)
5.5 (Σ cable loss in extender line, 30 MHz)
13.5 dB Total

Sr A = + 21 + system loss = +49.5 dBmV

Where system loss = 2.5 (drop cable loss)
26.0 (DT 26 subscriber drop loss)
28.5 dB Total

Sr B = + 21 + system loss = +42.5 dBmV

Where system loss = 2.5 (drop cable loss)
10.0 (DT 10 subscriber drop loss)
4.5 (Σ directional tap thru losses)
4.5 (Σ cable loss in extender line, 30 MHz)
21.5 dB Total

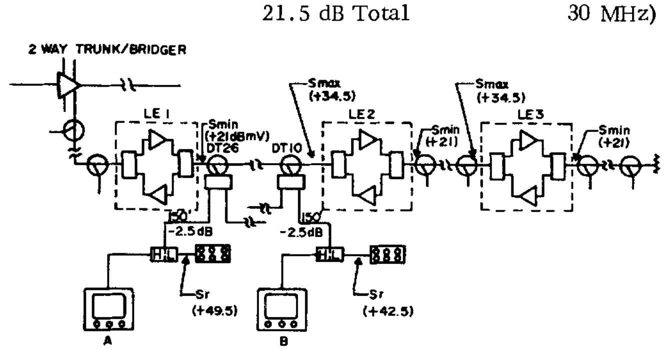

FIG. 6 RETURN FEEDER SIGNAL LEVELS- SUCCEEDING EXTENDERS

As will be noticed, the required system levels above are 10.5 dB lower than those shown in Figure 5. This additionally means that the required extender gain is 10.5 dB lower; this would be true for all succeeding extenders since this difference is due to the absence of bridger combining losses. Operating the feeder amplifiers at two different levels as indicated in Figures 5 and 6 would yield the system design improvements shown below:

1. Operation of succeeding line extenders at a reduced level for improved distortion characteristics. For example, feeder cross modulation for a three amplifier cascade would be:

$$\begin{aligned} &-67 \ @ \ +45.0 \ (\text{LE1}) \\ &-88 \ @ \ +34.5 \ (\text{LE2}) \\ &-88 \ @ \ +34.5 \ (\text{LE3}) \\ = \ &-67 \oplus -88 \oplus -88 = -65.5 \text{ dB Total} \end{aligned}$$

   (Where output capability of each amplifier equals +50 dBmV for -57 dB cross modulation, 2 channels.)

2. The use of a high gain (24 dB) return amplifier in the first extender position, and lower gain (13.5 dB) return amplifiers in succeeding extender positions, which should result in a cost saving.

The removal of the last (LE3) succeeding return amplifier for cost reduction is tempting. However, when consideration is given to the increased source levels required from the subscriber modulators (Sr) to maintain an S_{min} of +21 dBmV at the next extender (LE2), the idea may become less appealing. For example, the return level required at a subscriber terminal feeding into the first directional tap output of LE3 without a return amplifier in this position may be found simply by adding the succeeding amplifier gain requirement of 13.5 dB to the level at the same relative position shown by subscriber A (Figure 6), which would be:

$$\text{Sr A} + 13.5 = 63.0 \text{ dBmV}$$

Subscriber Interference

Referring back to Figures 5 and 6 we note that the subscriber return levels (Sr) are quite high. This is especially true at subscriber A in Figure 5 where a +60 dBmV is required to produce +21 dBmV at the bridger. While it is true that future subscriber transmission of "video quality" return signals will not be as frequent as will transmission of "data quality" signals (which could be sent at a lower level), many video requirements in the areas of security surveillance, schools, hospitals and business already exist and should therefore be considered in system planning.

Figure 7 shows a subscriber interface connection frequently used in one-way systems. The arrangement has been modified to provide two-way capacity to subscriber A. The principal signal flow paths are indicated by directional arrows and designated S_D for "desired signal", with the undesired signal designated as S_U. Consider first the sub-band signal being transmitted

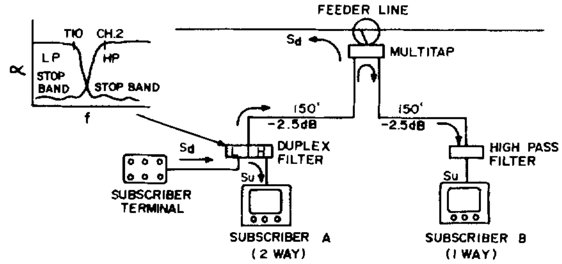

FIG. 7 POTENTIAL SUBSCRIBER INTERFERENCE PATHS

from the terminal. This signal in the desired mode passes thru the duplex filter, drop cable, multitap, directional coupler and back onto the coaxial cable in the reverse direction due to the steering action of the directional coupler. Two additional paths are available however. The first is thru the duplex filter, attenuated by the high pass filters stop band characteristic, and into the "A" subscriber's TV set. The second path is thru the multitap, attenuated by its port to port isolation characteristic, 300 ft. of drop cable and into subscriber B's TV set.

Signals emanating from the subscriber reverse modulator which are within the pass-band of the high pass section of the duplex filter (i.e. harmonics of the sub-band carrier or other spurious) will be attenuated by the stop band characteristic of the low pass section of the duplex filter and then directly into the "A" TV set, and by way of the multitap into the "B" TV set also. Table II lists the frequency spectrums of sub-band signals whose 2nd and 3rd harmonic products fall within the standard TV channel bands. Under the heading of "known sources" are listed a few of the more commonly used return signal sources with the resultant I.F. beat product tabulated. Picture quality tests (1) have shown that beats of this type should be at least 50 dB below the desired carrier to prevent visual interference.

TABLE II

POTENTIAL SUBSPLIT SUBSCRIBER INTERFERENCE SPECTRUM

VIEWING FREQUENCY (MHz)	IN-BAND HARMONIC SPECTRUM (MHz)	KNOWN SOURCE (MHz)	VIDEO BEAT FREQUENCY (MHz)
54-60 (CH.2)	27-30 (2nd)	28.5 (T10)*	+1.75
	18-20 (3rd)	19 (T9)	+1.75
60-66 (CH.3)	30-33 (2nd)	30.25 (SC5)	+.75
	20-22 (3rd)		
66-72 (CH.4)	33-36 (2nd)		
	22-24 (3rd)	22.5 (T9)*	+.25
76-82 (CH.5)	38-41 (2nd)		
	25.3-27.3 (3rd)		
82-88 (CH.6)	41-44 (2nd)		
	27.3-29.3 (3rd)	28.5 (T10)*	+2.25

* INVERTED CARRIER

Table III tablulates the potential harmonic interference bands when using the mid-split return system. There are many terminal frequencies other than those listed which may have interfering harmonics, but it is felt by the author that if appropriate design precautions are taken to provide basic spurious protection they will not generally present a problem.

TABLE III

POTENTIAL MIDSPLIT SUBSCRIBER INTERFERENCE SPECTRUM

VIEWING FREQUENCY (MHz)	IN-BAND HARMONIC SPECTRUM (MHz)	KNOWN SOURCE (MHz)	VIDEO BEAT FREQUENCY (MHz)
174-180 (CH.7)	87-90 (2nd) 58-60 (3rd)		
180-186 (CH.8)	90-93 (2nd) 60-62 (3rd)	61.25 (CH.3)	+2.50
186-192 (CH.9)	93-96 (2nd) 62-64 (3rd)		
192-198 (CH.10)	96-99 (2nd) 64-66 (3rd)		
198-204 (CH.11)	99-102 (2nd) 66-68 (3rd)	67.25 (CH.4)	+2.50
204-210 (CH.12)	102-105 (2nd) 68-70 (3rd)		
210-216 (CH.13)	105-108 (2nd) 70-72 (3rd)		

Table IV presents what can only be labeled as "typical" subscriber interference levels, since the magnitude of the undesired frequencies and exact isolation of taps and filters can only be estimated.

If we assume that most return modulators or data transmitters will have a spurious rejection of at least 60 dB, and port to port isolation of a reasonably good tap to be 25 dB, then we are left with the duplex filter, which should be specified as having a stop band attenuation of at least 40 dB. These specifications are reflected in Table IV, and the resultant interference levels are shown. For purposes of analysis only, one frequency of the in-band and one frequency of the stop band type are used, since all interfering frequencies will be in one of these two categories.

TABLE IV

TYPICAL SUBSCRIBER INTERFERENCE LEVELS

SUBSCRIBER A ORIGINATION FREQUENCY (MHz)	ORIGINATION LEVEL (dBmV)	TRANSMISSION LOSS (dB)		INTERFERENCE LEVEL (dBmV)	
		A	B	A	B
28.5 (T10)	+60	-40	-30	+20	$\boxed{+30}$
57.0 (T10) 2nd HARMONIC	0	-40	-70	$\boxed{-40}$	-70

Refering again to Table IV and Figure 7, we find that the 2nd harmonic of T10 appears at the return modulator A output at a level of 0 dBmV. This in-band spurious signal will pass thru the duplex filter with an attenuation of 40 dB and then be presented to the "A" TV set at a level of -40 dBmV. When a channel 2 desired signal is being received at a level of +6 dBmV, this spurious signal appearing at an in-band level of -40 dBmV will permit only a 46 dB signal to beat ratio - which is not adequate.

In cases such as this where a modulator level of +60 dBmV is required, either another frequency must be chosen which will not have in-band harmonics or else special filtering techniques must be employed (i.e. modulator band pass filter).

The propagation of out of band signals from modulator A will now be considered. These signals are typified by the T10 (28.5 MHz) frequency shown in Table IV. This signal will appear at the TV "A" input, attenuated 40 dB by the duplex filter, at a level of +20 dBmV. Additionally it will appear at the TV "B" input, attenuated by the drop cable loss and multitap isolation, at a level of +30 dBmV. The exact interference tolerance level of TV sets to sub-band frequencies is not well defined and it would therefore be a wise precaution to use matching transformers with built in high pass filters in any two-way installation where high level signal transmission may be necessary.

No attempt will be made to present an analysis of the additional beat problems caused by L.O. radiation or multi-channel set top converters[2], since it is felt that the use of protective filters at the TV set input can correct the majority of beat problems relating to return transmission.

System Temperature Stability

As a final point for consideration in the return feeder system, the effect of temperature on system levels should be examined. For purposes of analysis the following general assumptions will be made:

1. Flat losses (i.e. directional couplers, splitters, combining networks) are constant and not effected by temperature variations.

2. The return signal source itself is not effected by temperature variations.

3. Level variations due to subscriber drop cable temperature variations are not more than $\pm .2$ dB at return signal frequencies (5-30 MHz).

If we additionally assume a feeder system of the characteristics shown:

maximum line extender cascade	= 3
total cable length	= 3,640' of .412
total cable attenuation @ 30 MHz	= 21.8 dB
maximum temperature excursion	= -40^{o} - $+140^{o}$ F.

then the total signal level variation at 30 MHz presented to the return trunk/bridger amplifier input, due to temperature variations, would be: (Figure 8)

$$21.8 - [21.8 \times (1 + 0.0012\,(T-68)) -.2] = +3.0 \text{ dB @ } -40^{o}$$
$$-21.8 + [21.8 \times (1 + 1.0012\,(T-68)) +.2] = -2.1 \text{ dB @ } +140^{o}$$

Since this change is distributed over 3 amplifiers and 4 spans of cable the amount of level correction needed in each return line extender would be:

$$+2.1/3 = +.7 \text{ dB @ } +140^{o}$$
$$-3.0/3 = -1.0 \text{ dB @ } -40^{o}$$

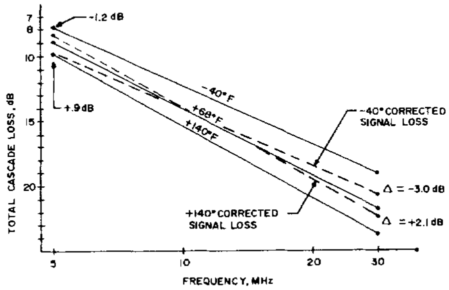

FIG. 8 THERMAL CHARACTERISTICS OF THREE EXTENDER FEEDER LINE CASCADE

If the amount of flat amplitude correction actually applied to each return extender is limited to: (Figure 8)

+.5 dB @ +140°
-.7 dB @ -40°

then the total temperature excursion at the return trunk/bridger input will be less than ± 1 dB (worst case, 5-30 MHz). Individual amplifier level corrections of this magnitude are readily achieved with internal thermal gain control techniques and will serve to maintain the feeder system well within design limits.

Summary

A discussion of system design considerations pertaining to the distribution portion of a bi-directional CATV system has been presented, with the object of giving the designers of both new and existing cable systems: 1) some areas where performance trade-offs may be made, 2) a few of the potential problems, and 3) some of the solutions.

* * * *

APPENDIX

I. Calculated from the following:

Extender increase = 150 amplifiers
Maximum directional taps per amplifier = 7
Maximum number of subscribers per tap = 4
Total subscriber increase = 150 x 4 x 7 =4, 200

II. Return trunk system operating characteristics:

System definition:

Maximum number of trunk amplifiers = 90
Maximum trunk cascade length = 20
Average trunk spacing loss (-3.4 flat, -6 cable, -3.5 bridger combining loss) = 13 dB
Trunk amplifier noise figure = 8 dB
Trunk amplifier cross modulation at operating level (4 channels @ +35 dBmV) = -91

System Performance:

Cross modulation = $(-91 + 20 \text{ Log}_{10} 20) = -65$ dB
S/N = $+22 - (-59 + 8 + 10 \text{ Log}_{10} 90) = 53.5$ dB

Combined Trunk/Feeder Performance:

Cross modulation = $(-65) \oplus^{*} (-65.5) = -59$ dB
S/N = $(47) \oplus (53.5) = 46$ dB

Round Trip System Performance:

Cross modulation = $(-59) \oplus (-59) = -53$ dB
S/N = $(46) \oplus (46) = 43$ dB

*Denotes logarithmic addition.

* * * *

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1) Walding, G., "Spectrum Pollution and the Set Top Converter", TV Communications, Volume 8, pp. 142-148, July, 1971.

2) Levine, N., "The Dilemma of Mixed Systems", Proceedings of 1972 NCTA Convention, Chicago, Illinois.

CROSSTALK AND ISOLATION REQUIREMENTS IN DUAL TRUNK SYSTEMS

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This paper examines the problems of crosstalk in dual cable single feeder two-way systems.

Common frequency crosstalk is examined and calculations are made of what amount of crosstalk is allowable without degradation of system performance.

The paper then describes briefly measurements made on a system meeting the calculated performance specifications for isolation.

Crosstalk due to amplifier distortion is then analysed and shown to be negligible in a system using high quality amplifiers presently available.

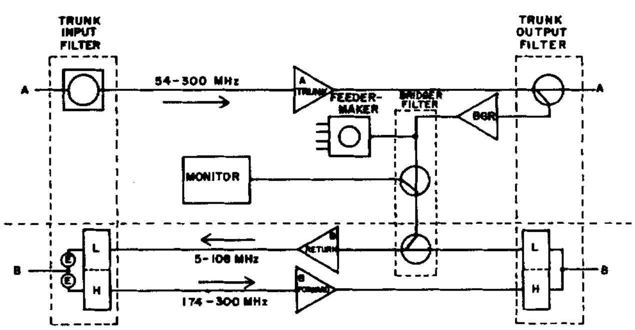


FIG. 1

This paper will examine the problems of crosstalk and isolation in dual cable two-way systems. The major question this paper will attempt to answer is as follows:

"What kinds of crosstalk can occur in a dual cable two-way system, and what isolations are needed to ensure that such crosstalk causes no degradation to the quality of signals passing through the system?"

In this context, crosstalk is defined as any unwanted energy falling in either system from the other. There is a distinct difference between crosstalk from the outgoing system into the return system and crosstalk from the return system into the outgoing system, which I will examine in detail later on in the paper.

Figure (1) shows a dual cable system with one-way performance on the trunk of cable "A", two-way performance on the feeders of cable "A" with crossover for the return signals on those feeders to the two-way "B" cable electronics. The objective of the transmission system is to send signals down cable "A" to the home, and to return signals from the home subscriber back to the head end via two-way performance on the "A" cable feeders with crossover to the "B" cable at trunk locations. You will notice the extra bandwidth on the "B" cable return and the bandwidth available on the "B" cable outgoing. These bandwidths can be used for special kinds of subscriber.

Assume now that the electronics above the line across Figure (1) is in housing no. 1 and that below the line is in housing no. 2. The only form of crosstalk which can occur in this case is via the electronic connection from housing no. 1 to housing no. 2. The cable should have very good isolation so that signals from cable "A" should not be able to get into cable "B" via that path. The housings also should have good isolation which prevents signals from cable "A" getting into cable "B". The only path left is that connection from housing 1 to housing 2 and possibly power supplies, if they are used to feed both cables simultaneously.

Now, consider all the other products to be contained in one housing. There are economic advantages in this mode of operation. For example, a single power supply may be used instead of two. One housing instead of two. One connector chassis instead of two. The module and electronics count remains the same.

What crosstalks can occur in this single housing? You will notice that there are common frequency bands used on the different cables. For example, 174-300 MHz is used on both cable "A" and cable "B", shown going in the same direction in the diagram. The frequency band 54-108 MHz is common to the "A" cable downstream and the "B" cable upstream. Obviously, if energy from either system falls in the other in these common frequency bands, interference can be caused. This is obviously undesirable and must be guarded against. The question is, "What isolation is needed in order to give satisfactory performance?"

Another form of crosstalk which can occur in this system is crosstalk due to distortion products from either direction falling into the frequency band of the other direction and leaking into that other direction. It will be shown later that if the system uses high quality CATV amplifiers operated within the specified limits, this form of crosstalk is negligible. Incidentally, this form of crosstalk occurs in both single housing and dual housing dual cable system.

Let us now consider common frequency crosstalk.

(a) Outgoing to outgoing - that is, "A" cable outgoing crosstalking into "B" cable outgoing, or "B" cable outgoing crosstalking into "A" cable outgoing. The range of frequencies in which this can occur is from 174 MHz to 300. Consider a signal starting at the head end going down the "A" cable to the subscriber, and assume a cascade of 30 amplifiers. If energy from the "B" cable appears in the "A" cable at each station, it will occur on 30 different occasions. The question is, "How will the increments of energy from each station add?" If all stations are uniform in the phase and amplitude of the crosstalk, the power should add on a voltage basis. However, the transmission time is different on cable "A" and cable "B" due to the high/low split filters used on the "B" cable. This time difference will tend to disperse the voltage addition, but for the purposes of this paper, voltage addition will be assumed in order to define an isolation limit which should be achieved for good performance.

The appearance of the interference we are discussing should be that of co-channel interference. Let us set a target of greater than 60 dB signal-to-interference ratio for the system. This measurement is made by terminating the input of cable "A" and observing the output of the station of cable "A". A signal is then injected at the correct level into the cable "B" input and the cable "B" output is terminated. The station, of course, is set to nominal gains such as would be used in a typical system. Cable "B" interference due to cable "A" is exactly the same as that just discussed, and requires the same isolation number.

(b) Cable "B" return crosstalking into Cable "A" outgoing in the band 54-108 MHz. The worst case for this kind of interference is where a signal is injected in cable "B" at a system extremity and flows back to the head end with crosstalk at each intervening station. In the 30 amplifier cascade system, the maximum number of stations which can be affected in this way is 30 in cascade. However, the addition of this kind of distortion is different from the previous example. There is significant time delay between stations in the system, and the signal which is causing the interference is flowing in the opposite direction to that which is being interfered with. Assume that channel 2 is injected at the system extremity on cable "B" and is observed at the same extremity on cable "A". Assume also that there is about 1 microsecond time of transmission between stations so that the "B" signal takes 30 microseconds to get to the head end and the "A" signal takes 30 microseconds to get to the extremity from the head end. Consider now the channel 2 signal leaving the head end. At station 1 it will pick up some crosstalk which originated 29 microseconds before at the system extremity. At station 2 it will pick up crosstalk which originated 28 microseconds before at the extremity, and so on down the system. If, now, channel 2 on the "B" system is, say, a video signal, with changing information, each of these increments of crosstalk will contain different information. They will, therefore, tend to add more like power than voltage. Furthermore, the visible effect of such interference will tend to be more like noise than co-channel interference. If, however, the signal injected into the "B" cable is a CW signal, the interference will tend to add more like voltage, and its effect will be that of a beat. Setting a desirable limit of better than 60 dB for signal-to-beat ratio, the isolation required between the "B" cable return and the "A" cable outgoing is set at 90 dB for a 30 amplifier cascade.

(c) "A" outgoing to "B" return. Assume a 30 amplifier cascaded system. In round figures, such a system would contain approximately 300 stations spread out in the tree fashion shown in Figure (2). Consider energy in the 54-108 MHz range flowing out from the head end on the "A" cable. Assume crosstalk occurs. It will occur in each and every one of the 300 stations in that system. This energy flowing in cable "B" will return to the head end. Assuming that the system is unity gained in both directions and that the crosstalk is uniform from station to station, at the head end there will appear, due to the "A" cable signals, 300 samples of crosstalk information.

These samples, we will assume, will be uniform in level but will have originated at different times in the system. What is the subjective effect of a distortion of this type, and what is the signal-to-interference ratio required for satisfactory performance?

It was theorized that there would be a difference in subjective effect depending on whether the "A" and "B" channel frequencies were exactly the same as in a phase lock situation, or were different by some few kc's as in the more normal type of situation. It was thought that, in the phase lock situation, the subjective appearance would be of a multiplicity of ghosts due to the time delays involved in the round trip for the "A" signal interfering with the "B". In the case of the non-phase lock situation, it was thought that the subjective effect would be more like a beat effect. In order to check out these two theories, a system was set up in which 52 separate echos could be superimposed upon a video picture and subjective judgments made. The results of the subjective testing were as follows:

In the phase lock case, the subjective effect was indeed one of multiple ghosts. Measurements were made of levels for barely perceptible interference. These measurements showed a much greater tolerance to the interference than in the non-phase lock case. In the non-phase lock case the interference effect was indeed a beat effect and was dependent on the difference in frequency between the two television carriers. Measurements were made of barely perceptible interference at that frequency which gave the worst case results. In round figures, the phase lock system was 20 dB more tolerant of crosstalk than the non-phase lock system. The isolation required for the non-phase lock case was 80 dB for 50 interfering sources. That is, at each station the interference was 80 dB below the desired signal. Furthermore, tests also showed that the addition was on a 3 dB per double basis; that is, when 25 of the interfering sources were removed, the ratio needed was now 77 dB below the desired signal so that for 300 stations, the ratio would be 80 dB + 10 log $\frac{300}{50}$, that is, 88 dB. This ratio can be measured by injecting a signal into the "A" cable input at such a level that the bridger is operating at system level and measuring the output in the 54-108 MHz band of the "B" cable return amplifier, and referencing this to the nominal output level of the desired signal at that station.

To summarize, then, the isolations required on a per station basis for the three cases are "A" cable to "B" cable outgoing, 90 dB; "B" cable outgoing to "A" cable outgoing, 90 dB; "A" cable to "B" cable return, 88 dB, for a maximum cascade of 30 amplifiers with a total of 300 amplifiers in the system. It is instructive to compare these isolations with the kind of isolation required in a one-way system. In Figure (3) the station is shown consisting of the trunk amplifier feeding a bridger with one feeder being driven. The levels are as shown on the diagram. The output level of the bridger is set at +45, the input level of the trunk amplifier is set at +10 dBmV. What isolation is required between the trunk input and bridger output in order to obtain satisfactory frequency response performance? If the isolation were 80 dB between trunk in and bridger out, the station would have a total loop gain of -45 dB. This could give a frequency response ripple of .05 decibels. This would add to .5 dB in ten stations, and would probably be very hard to spot in a single station measurement of gain vs. frequency. In contrast, the isolations required for dual cable operation in a single housing are at a ninety dB level except for the bridger filter which has to have isolation of 124 dB to allow for the effect of the high output level from the bridger vs. the low input of the return amplifer.

Figure (4) shows the levels in the two-way station and the required interference level in dBmV in order to meet the 88 dB ratio previously specified. It can be seen that the rejection of 54-108 MHz information which is accomplished in the bridger filter needs to be 124dB or greater.

Are these isolations feasible in a single housing? They are definitely realizable using good engineering practice. Figure (5) shows one realization of a dual trunk single feeder system contained in one housing. The module arrangement is outgoing trunk and bridger at the top of the housing with the return amplifiers in the bottom left hand corner. The input filter is vertically on the left, the output filter is vertically at the far right with the bridger filter next to it on the left. The housing has eight ports for dual cable operation and the ability to feed four feeders from the one housing.

In order to obtain the isolations discussed, the philosophy used was to make each module a very well shielded enclosure, to maintain coaxiality and integrity of ground throughout the housing, to use very careful routing of signal cables in the connector chassis keeping high level cables as far away as possible from low level cables.

One other aspect should be mentioned. Great care was taken in power supply decoupling to prevent any kind of crosstalk between modules via the power supply. All the precautions taken to ensure isolation were aimed at not only obtaining the correct isolation with comfortable margins, but also making the isolation obtained independent of whether the housing was open or closed. In fact, the isolations obtained are independent of whether the housing is closed or not, and the modules are so tight that signal ingress with the housing open is of extremely low level. There is a subtle bonus for this kind of construction which is this:

During the operation of a two-way system, whenever a housing is opened to perform maintenance or adjustment, there is a possibility of ingress. Where careful attention has been paid to module isolation, for example, in order to meet the specifications outlined previously, the ingress is greatly reduced to almost unmeasurable levels with the housing open. Measurements have been made on this type of station using the test equipment shown in Figure (6). The test equipment as shown is capable of a system floor better than 150 dB which makes measurements of 130 dB down quite accurate. Figure (7) shows the system gain flatness and system floor for the test equipment.

Figure (8) is a plot of the common frequency crosstalk, outgoing to outgoing, "A" cable into the "B" cable. The specification per station for this should be 90 dB, as discussed previously, and it will be seen in Figure (8) that this is met with margin up to and indeed above 300 MHz. The very noticeable fall-off below 150 MHz is due to the high/low mid-split filters in the station.

Figure (9) shows the isolation obtained for common frequency crosstalk, outgoing to outgoing, "B" cable to "A" cable. Again, you will notice, the 90 dB specification is comfortably met over the whole frequency range of interest.

Figure (10) shows the common frequency crosstalk "A" outgoing to "B" return. The band of interest is from 54 to 108 MHz and the specification set previously was 88 dB. This is comfortably met over the range 50 to 130 MHz, and then is exceeded. Again, this rapid drop above 130 MHz is due to the mid-split high/low filters.

The cable "B" return crosstalking into cable "A" outgoing in the band 54-108 is not shown, but is of the same order of magnitude, that is 110 dB or better across the band.

<u>Crosstalk due to distortion.</u> Figure (11) is a block diagram of a dual cable two-way system with crosstalk. The output levels of all trunk amps are set at +32 dBmV. The input level to the return trunk is set at +15 dBmV and the output of the bridger amplifier is set at +50 dBmV per channel. The performance of the bridger amplifier gives second and third order products down 75 dB at +50 dBmV per channel output level. Let us assume that the trunk amplifiers perform in the same manner, whether they be "A" or "B" cable trunks. The worst case distortion producer is, of course, the bridger since this has by far the highest level. The number below the output level in the bridger's case is -25 dBmV and represents second or third order distortion products level at that point. The ones of interest as far as the return direction are concerned lie in the range 5-30 MHz and 54-108. In the 5-30 MHz direction, the high/low split filter has 90 dB floors so that a signal input of -25 dBmV to that high/low split filter will come out of the low port 90 dB down, at a level of -115 dBmV. The 3 dB coupler places the signal at -118 dBmV at the input to the return amplifier. With a specified input level of +15 dBmV at that point, the ratio of desired signals to undesired is 133 dB for either second or third order products due to the bridger. The signals in the "B" cable outgoing also produce distortion and the arithmetic there is shown in Figure (11). Second order products are down -61 dBmV at the output of the "B" cable outgoing amplifier, and after passing through the high/low split filter at the output of the station are reduced a further 60 dB by the filtration action to arrive at the input of the return amplifier at -121 dBmV which is a ratio of 136 dB desired-to-undesired signal.

The distortions falling in the return direction caused by the "B" outgoing system will add on a total number of amplifier basis, that is, if there are 300 outgoing "B" amplifiers in the 300 stations there will be power addition of 300 sources of distortion. Why power addition? Consider the distortion arriving at the head end at some instance in time T0. In our system model there will be 300 separate signals arriving at that time. These signals have been caused by the outgoing signal and show a distribution in time proportionate to the round trip time for each single source. This time delay of the order of 2 microseconds per station out from the head end will destroy any coherence of distortion. The distortion, therefore, will add on a power basis. The summation factor for 300 amplifiers on a power basis is 25 dB so the figure shown on the diagram should be raised by 25 dB to give the total power observed at the head end to obtain a signal-to-interference ratio of 111 dB for distortion caused by the "B" outgoing amplifier falling in the "B" return and 108 dB for distortion caused by the "A" system bridgers falling in the return system. Distortions falling in the 54-108 MHz region caused by the "A" cable bridger will be -25 dBmV at the output of the bridger. These signals will undergo an attenuation of 130 dB through the high/low split filter to arrive at -158 dBmV at the input to the return amplifier. These are 40 dB below those distortions in the 5-30 MHz region and can be neglected for all practical purposes. The same thing applies to distortions in the 174-300 MHz region caused by the "A" cable bridger. These distortions at the same -25 dBmV at the bridger output before they are injected into the "B" cable outgoing amplifier suffer an attenuation of 170 dB minimum and would therefore appear at a level of -195 dBmV at the input to the "B" cable amplifier. Again, they can be disregarded for all practical purposes.

There remains one more distortion to be considered which is, distortion products produced by the "B" return amplifier falling in the "B" outgoing amplifier. At an output level of 32 dBmV per channel on the return amplifier, distortion products would be at that point -61 dBmV for second, -76 dBmV for third order products. These would undergo 40 dB of attenuation due to the high/low split filter and appear at the input of the "B" outgoing amplifier at -101 dBmV and -116 dBmV respectively. That is a ratio of signal-to-interference then would be 81 dB and 96 dB for second and third order products.

From the foregoing it can be seen that the crosstalk due to distortion in all amplifiers in this system is very low and can be disregarded.

To summarize, then, in this paper common frequency crosstalk in dual cable two-way systems has been examined, and certain specifications have been set to give good system performance. Measurements have been described which show that these specifications can be met using good engineering practice. Crosstalk due to distortion has been examined and shown, with high quality CATV amplifiers, to be negligible in its effect on the system.

"TREE" TYPE DISTRIBUTION SYSTEM

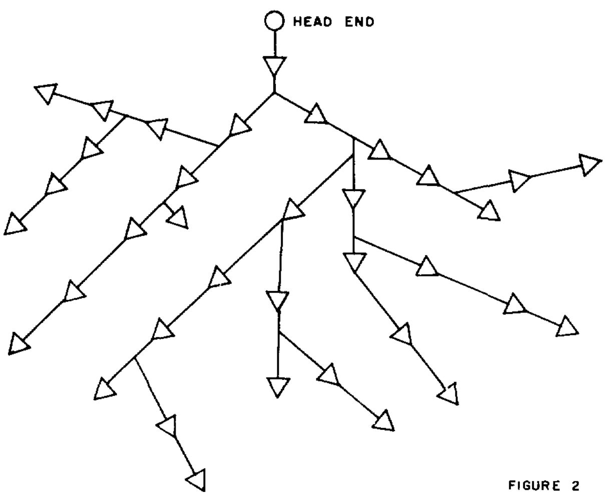


FIGURE 2

ONE WAY TRUNK STATION

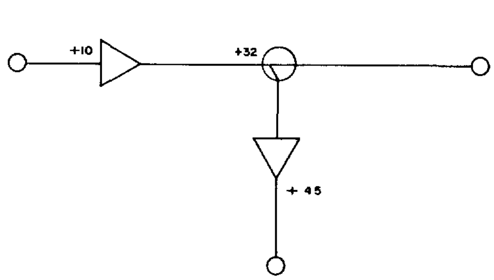


FIG. 3

LEVEL DIAGRAM

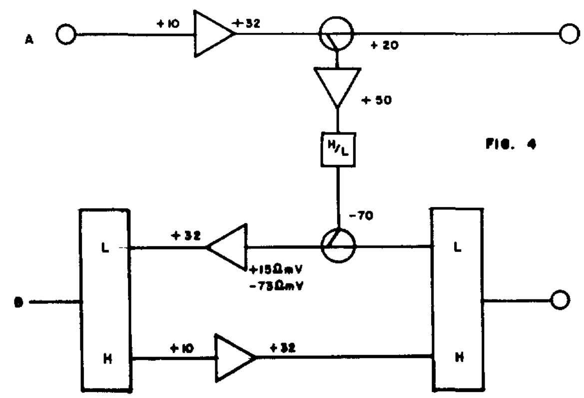


FIG. 4

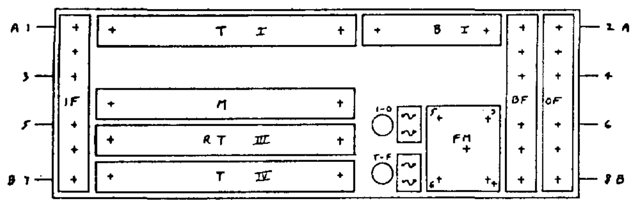
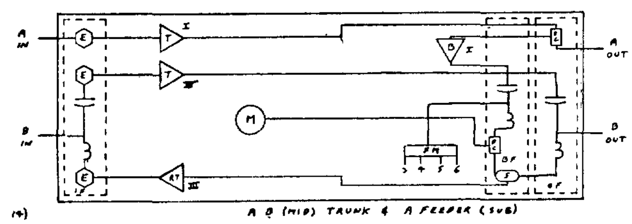


FIG. 5



ISOLATION TEST SYSTEM

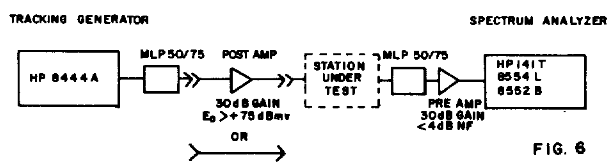


FIG. 6

TEST SYSTEM RESPONSE AND ISOLATION

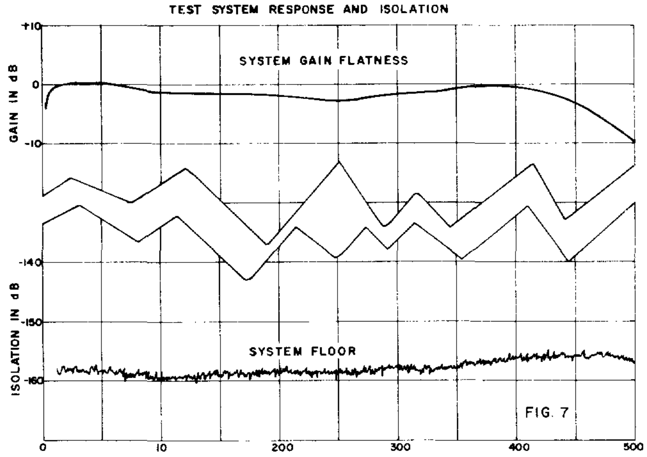
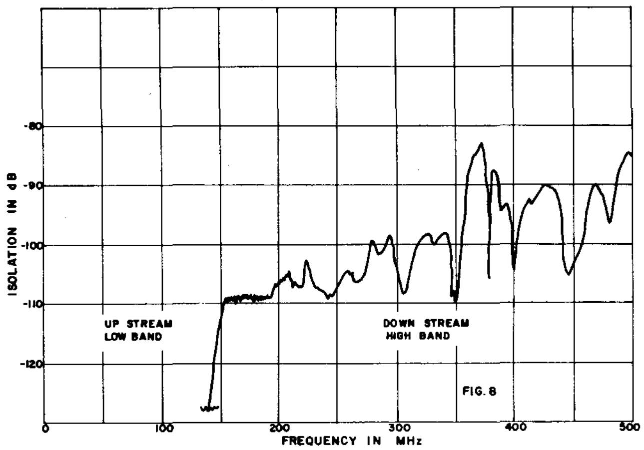
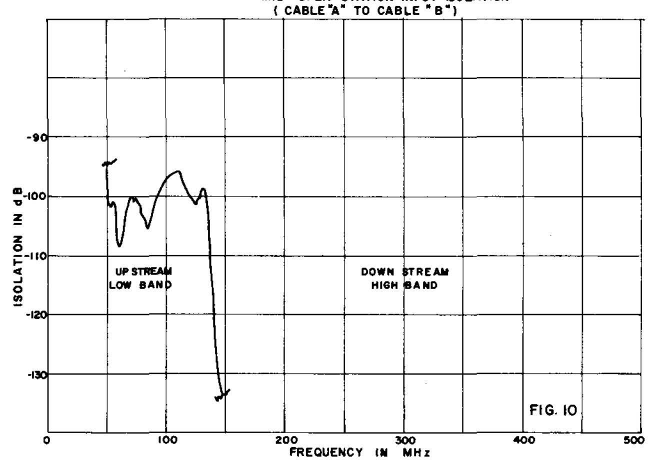


FIG. 7

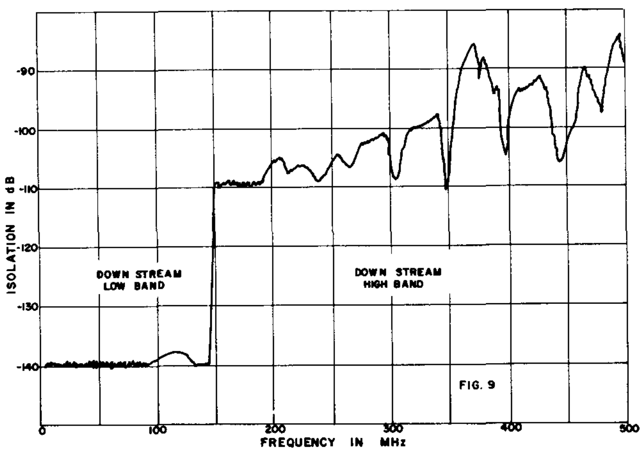
MID-SPLIT STATION OUTPUT ISOLATION
(CABLE "A" TO CABLE "B")



MID - SPLIT STATION INPUT ISOLATION
(CABLE "A" TO CABLE "B")



MID - SPLIT STATION OUTPUT ISOLATION
(CABLE "B" TO CABLE "A")



LEVEL AND DISTORTION DIAGRAM

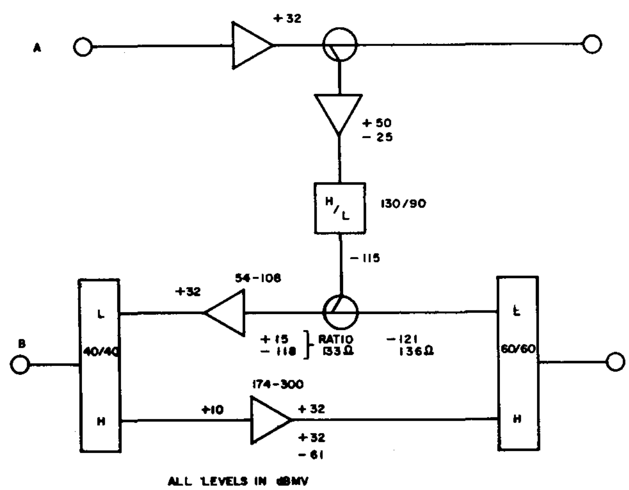


FIG. 11

DESTRUCTIVE CORROSION IN CATV DISTRIBUTION SYSTEM EQUIPMENT

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ABSTRACT

The term destructive corrosion is used here in the sense of corrosion which proceeds to the point of causing an item of equipment to fail, requiring that it be replaced. The principal adverse environments include marine locations and industrial areas with polluted atmospheres. For underground installations, adverse environments include polluted and corrosive drainage, flood and ground waters. The electrochemical nature of most corrosion is emphasized in a brief review of elementary corrosion theory. The various forms of corrosion likely to be encountered in CATV equipment are described, and typical causes are discussed. Sulfur dioxide and chlorides are pinpointed as the most corrosive of the atmospheric constituents. Various locations are compared in terms of severity of corrosion. Examples of equipment-related corrosion are illustrated and discussed. Corrosion testing and evaluation concepts are reviewed. Preventative design, testing, installation and operational principles are suggested.

INTRODUCTION

Corrosion can be a serious problem for CATV distribution system equipment, as it is for most types of equipment fabricated from metal which must operate out of doors in a wide range of uncontrolled environments. The overall magnitude of the metal corrosion problem is indicated by the fact that the cost of corrosion and of protection against it has been estimated recently by various authorities at from 6 to 20 billion dollars annually for the United States alone.

The phenomenon of corrosion has been defined in several ways. A good consensus definition might be:

> Corrosion is the destruction or deterioration of a metal or alloy by chemical or electrochemical reaction with its environment.

Most definitions exclude non-metals from the definition of corrosion; all exclude mechanical deterioration, such as erosion.

The subject of this paper is destructive corrosion of CATV distribution system equipment. Destructive corrosion is used here in the sense of corrosion which proceeds to the point of causing an item of equipment to fail in some manner, requiring that it be replaced or repaired. Corrosion which merely causes a deterioration of appearance will not be considered in any detail here, even though that is not necessarily a trivial consideration.

Corrosion can definitely cause failures in CATV distribution equipment of all types. The various forms of corrosion will be described, largely from a phenomenological rather than a theoretical standpoint, and some of the causes, mechanisms, and preventative design methods which apply to CATV equipment will be discussed.

CORROSION THEORY [1-8]

One common way of classifying corrosion is as either wet or dry. Wet corrosion occurs only when a liquid (including a condensed vapor) is present, while dry corrosion occurs in the absence of a liquid, usually at elevated temperatures. The overwhelming majority of corrosion problems in CATV equipment are of the wet variety - that is, a liquid must be present for corrosion to occur. Only wet corrosion will be discussed in any detail here.

Most wet corrosion processes are electrochemical in nature. The electrochemical nature of corrosion is illustrated in figures 1 and 2. Figure 1 shows how the flow of electric current from a dry cell battery (actually an ammonium chloride moist paste cell) is directly associated with the "corrosion" of the zinc case (the anode). An analogous electrochemical process occurs during the corrosion of a metal or alloy in contact with a conductive fluid, as illustrated in figure 2.

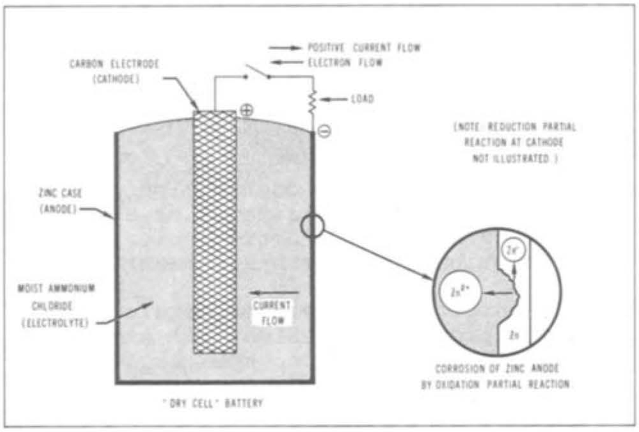


Figure 1. Illustration of electrochemical nature of corrosion - corrosion of zinc anode in dry cell battery.

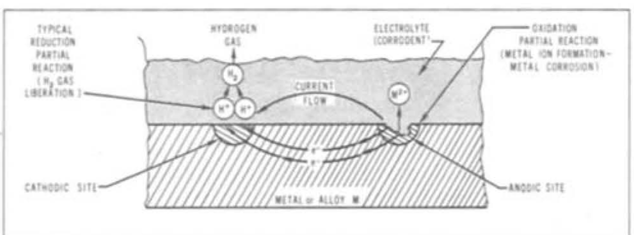


Figure 2. Illustration of electrochemical nature of corrosion - corrosion of single metal in contact with corrodent.

In order for electrochemical corrosion to occur in any metal or combination of metals, there must be a cathodic surface (cathode) and an anodic surface (anode) at different potentials in electrical contact with each other, and with both in contact with a conductive fluid (electrolyte). Direct current must flow between the cathode and anode. Within this electrochemical system an oxidation-reduction (redox) reaction occurs, with the oxidation reaction occurring at the anode and the reduction reaction occurring at the cathode. It should be noted that the anode and cathode can be any two metallic surfaces at differing potentials in electrical contact, ranging from two immediately adjacent surfaces of a single piece of metal (figure 2) to two separate and dissimilar pieces of metal connected by an electrical conductor and in contact with a common electrolyte (see figure 3 in the section on galvanic corrosion).

The anode is the area where current leaves the metal and enters the fluid, and that is where the principal corrosion occurs. The cathode is the area where (usually) no corrosion occurs and where current enters the metal from the fluid. Anodes and cathodes can form on a single piece of metal because of local differences either in the metal or in the electrolyte in contact with the metal.

Any overall oxidation-reduction reaction in electrochemical corrosion can be separated, for purposes of better understanding, into two or more partial reactions of oxidation and reduction. When viewed from the standpoint of partial processes of oxidation and reduction, all corrosion can be classified into a few generalized reactions.

The anodic reaction in every corrosion reaction is the oxidation of a metal to its ion. Letting M_a represent the chemical symbol for the anodic metal, the oxidation reaction can be written as

$$M_a \longrightarrow M_a^{+n} + ne \qquad (1)$$

when n represents the valence of the anodic element. For example

$$Al \longrightarrow Al^{+3} + 3e$$

$$Fe \longrightarrow Fe^{+2} + 2e$$

In these cases the anode metal ions leave the anode surface and go into solution in the electrolyte where they then usually combine with negative ions to form insoluble precipitates which becomes the corrosion product (for example, rust). These oxidation partial reactions are the destructive part of the oxidation-reduction pair. (In some cases, the liberation of hydrogen gas in a reduction partial reaction can damage the cathodic area.)

In the electrochemical corrosion process the rate of electron production by the oxidation partial reaction at the anode must be matched by an equal rate of electron consumption by the reduction partial reactions at the cathode since charge neutrality must be maintained. The reduction partial reactions can be more complex and varied than the oxidation partial reactions. Two examples of reduction partial reactions which commonly occur in an aqueous electrolyte are

$$2H^+ + 2e \longrightarrow H_2\uparrow \text{(hydrogen evolution)} \quad (2a)$$

$$O_2 + 2H_2O + 4e \longrightarrow 4\ OH^- \text{ (oxygen reduction)} \quad (2b)$$

There are several other reduction partial reactions which commonly occur at the cathode, but reduction partial reactions occurring at the cathode will not be emphasized in this paper.

A simple example of the corrosion of a single metal in contact with a liquid is the corrosion of iron to form rust when in contact with aerated (oxygenated) water. The first (corrosive) stage of the process can be written as

$$2Fe + 2H_2O + O_2 \longrightarrow 2Fe^{+2} + 4OH^- \longrightarrow 2Fe(OH)_2\downarrow$$

where the precipitate $Fe(OH)_2$ is an unstable intermediate compound which eventually oxidizes further to form common rust.

In any given corrosion cell (metal + corrodent) the possibility of electrochemical corrosion occurring, and the rate and extent of its occurrence, are all governed by complex relationships involving such factors as electrolyte concentrations, pH values, electrode potentials, electrode film resistances, and electrode polarization tendencies as a function of corrosion current and time. Frequently, several different reduction reactions occur simultaneously at the cathodic surface. Electrode resistance and polarization effects tend to limit (often substantially) the rate at which corrosion actually occurs with various metal combinations, compared to that which would be expected from electrode potential values alone; that is particularly true for the stainless steels. All of these and related considerations form the subject matter for the study of electrochemical corrosion theory in greater depth, but for the most part that is beyond the scope of this paper.

Much can be accomplished in the way of corrosion control from a practical standpoint, however, without a detailed understanding of the more complex aspects of corrosion theory, provided that one is aware of the various forms which corrosion can take and of the more common causes and preventative measures for each form. That is the approach which will be emphasized in this paper.

FORMS OF CORROSION [1-22]

The effects of corrosive action take many different and distinct forms. The form of the corrosion, if it can be correctly recognized, will usually provide a strong clue as to its cause, its mechanisms, and the means that can be taken to prevent or minimize damage that it can cause.

There is no universal agreement among corrosion authorities on exactly how to categorize the various forms of corrosion, but the categories listed in Table 1 seem to represent a good consensus. Most of the categories listed in Table 1 can be broken down further into subcategories for more detailed consideration.

TABLE 1. FORMS OF CORROSION

*	1.	Uniform attack
*	2.	Galvanic (dissimilar metal, two-metal) corrosion
*	3.	Stress-corrosion cracking
*	4.	Intergranular corrosion
*	5.	Concentration cell (crevice) corrosion
*	6.	Pitting
*	7.	Stray-current corrosion
	8.	Dealloying (selective attack, selective leaching)
	9.	Erosion corrosion
	10.	High temperature (dry) corrosion

* Indicates a form of corrosion of concern in CATV distribution system equipment.

In Table 1 the first 7 categories are starred to indicate that they are of concern for CATV distribution system equipment.

Uniform Attack

In uniform attack the metal corrodes rather evenly over the entire exposed surface. It is the most common form of corrosion (the rusting of steel, for example) and it is usually the most obvious and most easily recognized form of corrosion. It usually occurs when a metal surface is exposed over a large part of its area to a fluid which is generally corrosive to that metal.

Galvanic Corrosion

Galvanic or dissimilar metal corrosion occurs when two dissimilar metal parts are in electrical contact with each other and both are in contact with a common body of conductive fluid (electrolyte - liquid, paste, or similar). The extent of galvanic corrosion damage can vary from negligible to extensive, depending on the various parameters. Galvanic corrosion is a rather common and well known effect, at least in principle, but it may not be so readily recognized or easily detected in practice because of the fact that the two (or more) dissimilar metals may be separated physically by quite a distance if they are connected together by a good electrical conductor and both make contact with the same body of conductive fluid. In any galvanic cell (two dissimilar metals in electrical contact with each other and with an electrolyte) one of the metals is anodic with respect to the other, and it is the more anodic of the two metals which is subject to extensive corrosion damage. Normally, the more cathodic of the two metals remains relatively undamaged. In fact, it is protected from even a normal degree of corrosion by the sacrificial action of the anodic metal, which can be destroyed very rapidly under unfavorable conditions. Galvanic corrosion concepts are illustrated in figures 3A and 3B.

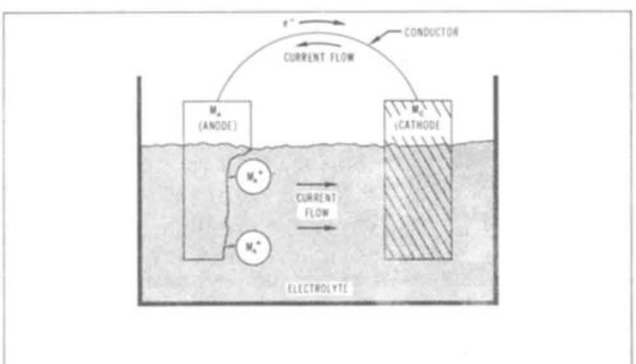


Figure 3A. Illustration of principle of galvanic (dissimilar metal) corrosion, showing the four key elements - anodic metal, cathodic metal, electrical contact or conductor, and electrolyte - which must be present for galvanic corrosion to occur.

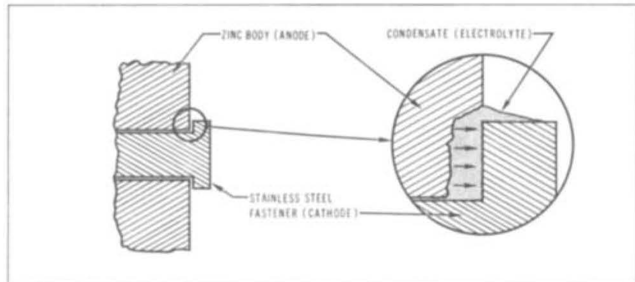


Figure 3B. One example of how galvanic corrosion could occur in practice.

The mass m of metal corroded away from the anode in steady galvanic corrosion in any given length of time is given by the expression

$$m \simeq k\, I_{galv}\, t_c, \text{ grams} \qquad (3)$$

where k = electrochemical equivalent constant for the anode metal, grams/coulomb

I_{galv} = galvanic corrosion current, amps

t_c = duration of corrosion, seconds

For non-steady corrosion current - the usual real-life case - the expression for the mass of metal corroded would be

$$m \simeq k \int_0^{t_c} I_{galv}\, dt, \text{ grams} \qquad (4)$$

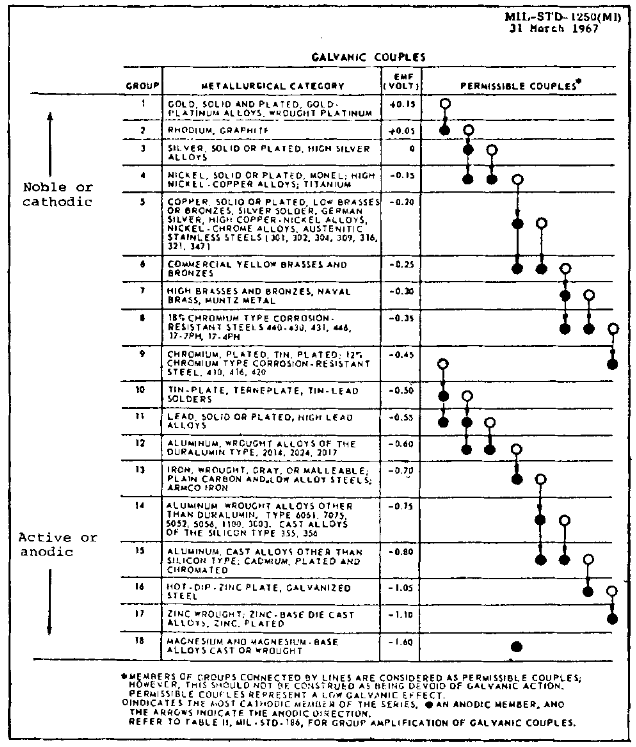
As an example, one ampere of corrosion current flowing for one year would result in the loss of 6.5 lbs. from an aluminum anode. The value of k for aluminum is 9.32×10^{-5} grams/coulomb; the values of k for other metals can be found in tables of electrochemical equivalents.

The open-circuit potential difference between the two dissimilar metals in any galvanic couple determines the direction of flow of the galvanic current. The polarization characteristics of the electrodes and electrolyte, in combination with the conductivity characteristics of the electrolyte, and the cathode-to-anode conduction path, determine the magnitude of the corrosion current. In a corrosion situation the corrosion current almost always varies with time. The magnitude of the corrosion current, and particularly the density of current at the anode-electrolyte interface (in amps/sq. in., say), determine the rate at which the anode is damaged. For example, if a given amount of corrosion current is forced to flow through a small exposed area of anode, such as the surface of a very small part, or a scratch in the protective coating on a large part, the small exposed surface can corrode away rather quickly and destroy the part in a short time.

The relative tendency for pairs of dissimilar metals to form galvanic couples in conductive solutions is often expressed for engineering design purposes in the form of galvanic series charts, which lists metals and alloys in descending order from the most cathodic (most noble) to the most anodic (most active) for a specific electrolyte. The practical application of such a series in equipment design and installation lies in avoiding the use of dissimilar metals which are not very close together in the series if there is any probability that they may be exposed to a conductive fluid. One limitation of a conventional galvanic series is that it is more qualitative than quantitative; another is that it does not always reflect the different degrees of polarization which occur in actual galvanic cells with corrosion current flowing.

In order to minimize those and other limitations, various types of galvanic couple compatibility charts have been developed from the basic galvanic series in order to aid the designer. One example of a compatibility chart is shown in Figure 4, reproduced (with slight modification) from MIL-STD-1250(MI) [16]. It is probably overly restrictive for all but aggressive environments. Other more elaborate charts with more gradations in degrees of compatibility and environment have also been published [1, 2(a), 33, 34, for example]. Each of the various methods of presentation has advantages and disadvantages. Probably the best way for a designer to make an important decision on compatibility of any pair of metals, if testing is not feasible, is to refer to as many reliable charts as are available to him.

At least two comments are worth making about galvanic series and galvanic couple compatibility charts. One is that published galvanic series charts - and the compatibility charts derived from them - are really based on a specific electrolyte, almost always seawater, a fact which the compatibility charts often neglect to mention. Other electrolytes can and do cause some differences in relative compatibilities, even to the point of reversing cathodes and anodes in a few instances. However, charts based on seawater as the electrolyte seem to be generally the most appropriate ones for most CATV purposes. Another point worth mentioning is that published compatibility charts do not always agree with each other with regard to the degree of compatibility of certain important pairs of metals. That alone is a good reason for referring to more than one reliable chart before making a decision.



MIL-STD-1250(MI)
31 March 1967

GALVANIC COUPLES

GROUP	METALLURGICAL CATEGORY	EMF (VOLT)	PERMISSIBLE COUPLES*
1	GOLD, SOLID AND PLATED, GOLD-PLATINUM ALLOYS, WROUGHT PLATINUM	+0.15	
2	RHODIUM, GRAPHITE	+0.05	
3	SILVER, SOLID OR PLATED, HIGH SILVER ALLOYS	0	
4	NICKEL, SOLID OR PLATED, MONEL; HIGH NICKEL-COPPER ALLOYS; TITANIUM	-0.15	
5	COPPER, SOLID OR PLATED, LOW BRASSES OR BRONZES, SILVER SOLDER, GERMAN SILVER, HIGH COPPER-NICKEL ALLOYS, NICKEL-CHROME ALLOYS, AUSTENITIC STAINLESS STEELS (301, 302, 304, 309, 316, 321, 347)	-0.20	
6	COMMERCIAL YELLOW BRASSES AND BRONZES	-0.25	
7	HIGH BRASSES AND BRONZES, NAVAL BRASS, MUNTZ METAL	-0.30	
8	18% CHROMIUM TYPE CORROSION-RESISTANT STEELS 440-430, 431, 446, 17-7PH, 17-4PH	-0.35	
9	CHROMIUM, PLATED, TIN, PLATED; 12% CHROMIUM TYPE CORROSION-RESISTANT STEEL, 430, 416, 420	-0.45	
10	TIN-PLATE, TERNEPLATE, TIN-LEAD SOLDERS	-0.50	
11	LEAD, SOLID OR PLATED, HIGH LEAD ALLOYS	-0.55	
12	ALUMINUM, WROUGHT ALLOYS OF THE DURALUMIN TYPE, 2014, 2024, 2017	-0.60	
13	IRON, WROUGHT, GRAY, OR MALLEABLE; PLAIN CARBON AND LOW ALLOY STEELS; ARMCO IRON	-0.70	
14	ALUMINUM WROUGHT ALLOYS OTHER THAN DURALUMIN, TYPE 6061, 7075, 5052, 5056, 1100, 3003. CAST ALLOYS OF THE SILICON TYPE 355, 356	-0.75	
15	ALUMINUM, CAST ALLOYS OTHER THAN SILICON TYPE; CADMIUM, PLATED AND CHROMATED	-0.80	
16	HOT-DIP-ZINC PLATE, GALVANIZED STEEL	-1.05	
17	ZINC WROUGHT; ZINC-BASE DIE CAST ALLOYS, ZINC, PLATED	-1.10	
18	MAGNESIUM AND MAGNESIUM-BASE ALLOYS CAST OR WROUGHT	-1.60	

*MEMBERS OF GROUPS CONNECTED BY LINES ARE CONSIDERED AS PERMISSIBLE COUPLES; HOWEVER, THIS SHOULD NOT BE CONSTRUED AS BEING DEVOID OF GALVANIC ACTION. PERMISSIBLE COUPLES REPRESENT A LOW GALVANIC EFFECT.
○ INDICATES THE MOST CATHODIC MEMBER OF THE SERIES, ● AN ANODIC MEMBER, AND THE ARROWS INDICATE THE ANODIC DIRECTION.
REFER TO TABLE II, MIL-STD-186, FOR GROUP AMPLIFICATION OF GALVANIC COUPLES.

Figure 4. One example of a simple dissimilar metal compatability chart. The basis of the chart is not specified in the source [16], but it appears to be based on a ΔEMF of 0.25 volts or less for compatibility (a criterion which is disputed by other sources).

To summarize the implications of galvanic corrosion briefly, it is not an uncommon occurrence on CATV equipment because all of the ingredients of galvanic cells are frequently present but not always recognized. Fortunately, not all galvanic corrosion actually renders the equipment inoperative, but enough does to make it a matter of serious concern.

Stress-Corrosion Cracking

Stress-corrosion cracking is defined as the spontaneous failure of a metal resulting from the combined effects of corrosion and stress. Stress-corrosion cracking is a particularly insidious form of destructive corrosion because it may develop as very fine intercrystalline cracks within the material, with little or no visible evidence of corrosion until failure occurs suddenly by destructive cracking of the material. Figure 5 illustrates a typical stress-corrosion cracking failure in an aluminum hose fitting.

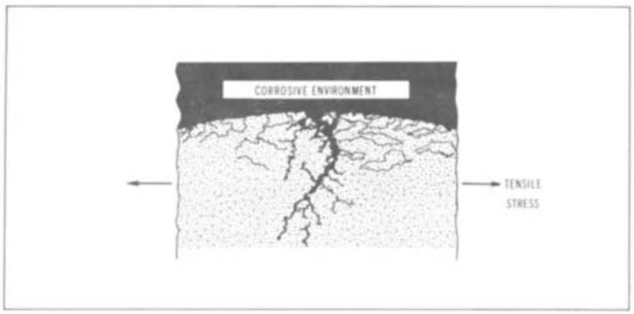


Figure 5. Sketch made from a photomicrograph showing the stress-corrosion cracking of a 2024-T351 aluminum alloy hose fitting loaded in hoop stress.

Like other forms of corrosion, stress-corrosion cracking occurs in specific metal alloys subjected to specific environmental conditions. One common denominator of stress-corrosion cracking is that it occurs only while the material is being subjected to a tensile stress of some minimum or threshold level which depends on the specific alloy and the specific corrodent. Therefore, the possibility of it occurring should be considered for all CATV equipment parts in which any of the material is stressed in tension. It should be noted that unrelieved residual internal stresses in a metal as a result of the fabrication process can create or contribute to the requisite tensile stresses just as readily as can externally applied stresses.

In CATV equipment there are probably only two areas in which the combination of stresses, materials and environments are likely to cause stress-corrosion cracking problems. They are (1) aluminum alloy coaxial cable connector hardware, but only with certain susceptible alloys, and (2) stainless steel fasteners, but again only with certain susceptible alloys. Several references on susceptibility [6, 9-14, 18-22] are available to assist the designer in avoiding the stress-corrosion-prone aluminum and stainless steel alloys. For aluminum, there should be no problem in selecting a non-susceptible alloy with all of the other desirable characteristics. For stainless steel, the otherwise desirable 300 series 18/8 austenitic types are known to be somewhat susceptible to stress-corrosion cracking in the presence of hot chloride solutions, but at atmospheric temperatures the susceptibility is believed to be quite low, permitting their use with low risk.

Certain types of protective coatings can also be effective in minimizing the stress-corrosion cracking tendencies of marginally-susceptible alloys [9].

Intergranular Corrosion

Intergranular corrosion is a form of localized subsurface attack in which a narrow path is corroded out preferentially along the grain boundaries of a metal. The mechanism is electrochemical and is usually caused by the presence of second-phase precipitates in the grain boundaries which differ in potential from the primary phase. In other words, grain boundary material of small area acts as anode in contact with large areas of grains acting as cathode. The attack is often rapid, penetrating deeply into the metal and sometimes causing catastrophic failures. Figure 6 is a sketch illustrating an occurrence of aluminum intergranular corrosion which had not progressed to the point of failure.

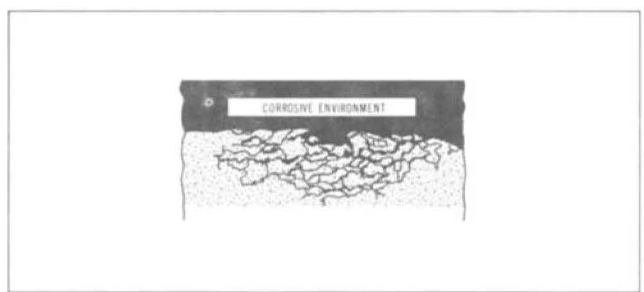


Figure 6. Sketch made from a photomicrograph showing intergranular corrosion in an aluminum alloy.

Improperly heat-treated austenitic stainless steels, most precipitation-hardening high strength aluminum alloys, and certain other aluminum alloys are susceptible to intergranular corrosion in varying degrees. Again references [6, 9-14, 17] are available which indicate the degree of susceptibility of the various alloys, and low-susceptibility alloys can easily be selected for CATV applications. Most copper-bearing aluminum alloys, both wrought and cast, should be avoided in order to minimize the risk of both intergranular corrosion and stress-corrosion cracking.

Concentration Cell Corrosion

Concentration cell or crevice corrosion is corrosion which results from the trapping or stagnation of electrolyte in holes and surface deposits, in crevices under bolt heads, washers, strand clamps and rivets, and in closely fitted regions, such as gasket surfaces, flange spaces and lap joints. In concentration cell corrosion there need not be any dissimilar metals, either on a microscopic or a macroscopic scale. Anodic and cathodic zones can be created on a perfectly uniform single-phase metal surface by local variations in oxygen or metal ion concentration which develop within the trapped, stagnant electrolyte. These variations in composition give rise to a flow of corrosion current, resulting in the corrosion of the anodic zones of the metal. The oxygen concentration form of concentration cell corrosion is illustrated in figure 7.

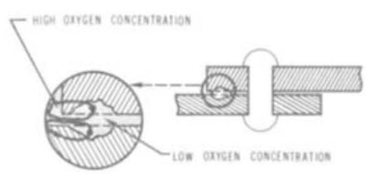


Figure 7. Sketch illustrating the occurrence of the oxygen concentrations form of concentration cell corrosion.

Concentration cell corrosion usually results in an open pitting of the corroded surfaces. Since it usually (but not always) occurs in very narrow crevices, it is almost never visible in a casual inspection of the equipment, only becoming apparent when the parts creating the crevice are disassembled. It can be destructive in CATV equipment, particularly at sealing surfaces.

Pitting

In addition to the formation of pits in crevices, there is a more general form of pitting corrosion to which certain metals are particularly susceptible. That type of pitting occurs most commonly on metals which develop their own protective surface film, under conditions in which the film is almost, but not completely, protective. The two metals most susceptible to pitting of those commonly used in CATV equipment are stainless steel alloys and aluminum alloys. The early stages of pitting corrosion of an aluminum alloy is illustrated in figure 8. In some circumstances, pitting is self-limiting; in other circumstances it continues until the wall is penetrated.

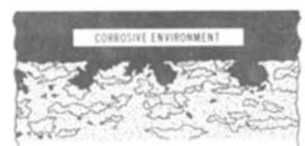


Figure 8. Sketch made from a photomicrograph showing a possibly early stage of pitting corrosion in an aluminum alloy.

Pitting is the result of electrochemical action in local cells on the surface of a metal. At the point of initiation, corrosion occurs at the local anodes, while the local cathode is the immediately surrounding metal surface. One reference [9], quoting a paper by Mears and Brown, lists 18 possible causes of local cell formation leading to pitting. Of those 18, local variations in metal composition due to the presence of either a second phase or impurities and local damage to the protective surface film on the metal from either chemical or mechanical effects are probably the two most important causes. Both stainless steel and aluminum are particularly susceptible to electrolytes containing chloride ions, such as seawater spray or condensate. Among the stainless steel alloys, molybdenum-bearing type 316 provides the maximum resistance to chloride-induced pitting.

Stray-Current Corrosion and Other Current-Induced Corrosion

Stray-current corrosion is corrosion resulting from the flow of current through paths other than the intended circuit of electrical conductors, in conjunction with the operation of electrically powered equipment. The stray current may be either alternating current, direct current, or one superimposed on the other. Destructive stray currents frequently occur in conjunction with multiply-grounded circuits. In such cases, only part of the return current flows through the ground return conductor, no matter how low its resistance, while the remaining current flows through unintended paths which may include structures. If a path through a structure involves a mechanically-connected joint, or a gap, in which an electrolyte is trapped, the metal in the area where the d.c. leaves the surface to enter the electrolyte is subject to stray current corrosion which can be severe if the level of stray current is high.

The amount of metal corroded by stray d.c. leaving the metal and entering the electrolyte is given approximately by

$$m \simeq k\, I_{stray}\, t_c, \text{ grams} \qquad (5)$$

where the variables are as previously defined (equation (3)), except that I_{galv} is replaced by I_{stray}.

As a general rule, stray a.c. causes substantially less damage to most metals than does stray d.c. of the same magnitude under otherwise identical circumstances, and the corrosion damage usually decreases with increasing frequency. For metals like steel, lead and copper, it is estimated that 60 Hz a.c. causes only about 1% of the damage of an equal level of d.c. [5]. For passive metals such as stainless steel and aluminum which develop their own protective films, however, there is recent evidence that 60 Hz a.c. can damage or destroy the protective film and cause much greater than 1% of the damage of the equivalent d.c. Alternating current damage levels of from 5 to 31% of the equivalent d.c. damage levels have been reported for an aluminum alloy under specific test conditions [5].

In CATV equipment, it is possible for both stray d.c. and stray 60 Hz a.c. to be present in ground loops. Damage by a.c. can be increased by partial or complete rectification to d.c. Earth soil often causes rectifier action and aggravates corrosion where a.c. ground loops are working. Corrosion products themselves could cause rectifier action and and corrosion rates could increase with time for situations involving a stray alternating potential, since an increasing percentage of the a.c. would be rectified to the more destructive d.c.

When stray-current corrosion situations occur they are usually both non-obvious and quite destructive. That suggests that some attention should be paid to the problem at or before the time of equipment installation, by both analysis and testing, to ensure that conditions conducive to stray current corrosion do not exist.

There is another potential form of corrosion which is related to stray-current corrosion and which should also be given proper attention, although it does not normally appear among the standard categories of corrosion. For lack of a better name known to the authors, it might be termed either non-stray-current corrosion or current-induced corrosion. It can occur along <u>intended</u> conduction paths at points where current flows through mechanical contacts between separate metal pieces. If the design is such that an electrolyte can accumulate around or between the contacts, current-induced corrosion of one or both contact surfaces is likely to occur.

Virtually all of the discussions concerning the effects of stray-current corrosion is equally applicable to non-stray-current corrosion.

Other Forms of Corrosion

The other forms of corrosion listed in Table 1 are generally not significant for CATV equipment and will not be discussed here.

CORROSIVITY OF VARIOUS ENVIRONMENTS FOR CATV EQUIPMENT [1-15,21-24]

CATV equipment must function in a variety of environments which generally range from mild and unpolluted to aggressive and/or badly polluted natural environments. Aerial installations of equipment are exposed to the full range of weather conditions and atmospheric environments. Underground installations are exposed to atmospheric environments as modified by the weather protection provided by the enclosures, plus - in some instances - to rain water, drainage waters, ground waters, and/or soils.

The general aggressiveness of the atmosphere varies over a wide range from one location and type of environment to another. In the more aggressive areas, it may even vary widely from one point to another within a small locality, depending on the proximity to sources of corrodents, the direction of the prevailing winds, the presence of sheltering terrain, and many similar factors. In short, it is really the micro-environment at each specific installation site which actually determines the general corrosivity of the atmosphere at that site.

The term general corrosivity as used here is convenient for discussion purposes but is actually an oversimplified concept. The concept of corrosivity can really only be applied to the effects of specific corrodents on specific metals and coatings, effects which vary from one type of material to another and from one form of corrosion to another. For example, one metal may be most susceptible to damaging pitting attack by a marine environment, while a different type may be most susceptible to damaging intergranular attack by a polluted industrial atmosphere.

If consideration is limited to the materials usually used externally in CATV equipment - principally aluminum casting alloys, coated mild steel alloys and stainless steel alloys for hardware, zinc casting alloys and cadmium coatings - then it is possible to rank in a very approximate way the various types of environments with respect to their general corrosivity toward those metals and coatings as a group. Table 2 provides such a rough ranking of atmospheric environments, based on the considerations discussed. Except for the urban and suburban examples, the examples cited in Table 2 are ASTM or similar corrosion test sites for which good comparative data are available. However, it should be recognized that comparisons such as Table 2, while useful for orientation purposes, tend to oversimplify a complex situation.

TABLE 2. RELATIVE SEVERITY OF VARIOUS ATMOSPHERIC ENVIRONMENTS TOWARD METALS AND COATING USED IN CATV EQUIPMENT

[9, 10, 11, 13, 21, 22]

Atmospheric Environment	Example	Relative Corrosivity
Severe industrial-marine		Most corrosive
Severe marine	La Jolla, Cal.	
Severe industrial	McCook, Ill.	
Moderate marine	Miami Beach, Fla.	
Moderate industrial	Detroit, Mich.	
Humid subtropical		decreasing corrosivity
Urban/semi-industrial°	Los Angeles, Cal.	
Suburban	Anaheim, Cal.	
Rural	State College, Pa.	
Semi-arid	Phoenix, Ariz.	
Arid desert		Least corrosive

In all cases arid and semi-arid regions (such as Phoenix) cause the least corrosion, closely followed by most rural regions (except rural seacoasts). In many cases, heavy industrial areas at the seacoast can cause the worst corrosion.

In marine environments, the distance from the water, the elevation above sea level, the velocity and direction of the prevailing winds, the variations in dew point, the temperature cycles, and the prevalence of fog, spray and sea mist all strongly influence the rate of corrosion. For example, for some alloys the corrosion rate at 80 ft. from the water can be over 10 times the rate at 800 ft., as found in comparative tests at the ASTM corrosion test site at Kure Beach, N. C.

There is general agreement that, for the metals being considered, the two most aggressive corrosive agents in the atmosphere are (1) the sulfur compounds, principally sulphur dioxide and its acid derivatives, as found in industrial areas, and (2) the chlorine compounds, as found in both marine atmospheres, principally as chloride sea salts (NaCl, MgCl, etc.), and in industrial atmospheres, often as chlorine gas.

In the industrial areas sulfur dioxide is released to the atmosphere by fuel-burning power plants, chemical plants, refineries, diesel-powered vehicles and the like. Sulfur dioxide reacts with moisture in the atmosphere and condensate on equipment to form corrosive sulfurous and sulfuric acid solutions. Gaseous chlorine, also released by some chemical plants, reacts with moisture to form a corrosive combination of hypochlorous and hydrochloric acids.

For underground systems which come into contact with drainage water or ground water, there are any number of possible corrosive agents, including chemicals used for soil treatment. Factors which have a strong bearing on the pitting corrosivity of water toward certain aluminum alloys, for example, include the pH level, conductivity, dissolved oxygen content, and concentrations of sulfate, chloride carbonate and copper ions [9,22].

One potential corrodent which could affect both aerial installations and underground installations is the chloride salts (principally calcium chloride) used in many areas of the country to remove ice and snow from the streets in the winter. Snow plows undoubtedly throw salt-bearing ice and snow up onto aerial equipment installations, while melted ice and snow may drain into vaults.

CORROSION AS RELATED TO CATV EQUIPMENT

[25-28]

In an earlier section of the paper, corrosion was neatly separated into about 10 distinct forms for purposes of analysis and discussion. When corrosion actually occurs in CATV equipment, however, it is not always confined to a single clearly identifiable form, but is more likely to appear as an inseparable and almost unidentifiable mixture of several different forms of corrosion. The end result often is simply a badly corroded and functionally damaged item of equipment which must be replaced.

In the sections which follow, examples of how various types of corrosion may occur in and affect items of CATV equipment are described and discussed.

Investigation Of Corrosion Of Stainless Steel/Aluminum Couples In A Severe Marine Environment*

Although passivated austenitic stainless steel alloys (300 series) and aluminum casting alloys are rather widely separated in the galvanic series, the two materials are nevertheless commonly used in contact with each other in structures intended for outdoor exposure. They are used together because of generally favorable experience with them as a compatible couple in most environments. Stainless steel normally seems to act as a rather inefficient cathode in such couples, causing very little galvanic corrosion of the aluminum anode or itself. The explanations that have been suggested for this seemingly anomalous compatibility include a combination of (1) the presence of a high-electrical resistance oxide film on the surface of the stainless steel and (2) the tendency of the stainless steel cathode to readily polarize at the metal-electrolyte interface.

With regard to CATV equipment, Bell Telephone Laboratories Specification KS-19925, Issue 2 (1967), a specification for Cable Television equipment, requires the use of 304 or 305 stainless steel hardware on aluminum housings for aerial use.

Galvanic couple compatibility charts usually list these two types of materials as compatible in most environments, but urge caution in using them together in marine atmospheres. Since CATV equipment must function in marine as well as non-marine environments, however, it is necessary to know how such a commonly used pair actually performs in a severe marine environment.

In this section the results of exposing stainless steel alloy/aluminum alloy couples to such an environment, including the results of detailed examinations and analyses of the corrosion effects and corrosion products, are presented and discussed. The specimen couples investigated consisted of:

Specimen No. 1: Type 304 passivated stainless steel clamped against type 356 aluminum alloy;

Specimen No. 2: Type 302 non-passivated stainless steel clamped against type 356 aluminum alloy.

Both of these specimens were exposed simultaneously to a rather severe marine environment. After an extensive period the samples were removed from the test site for examination. Specimen No. 1 was sectioned for metallographic examination. The sectioned specimen is shown in figure 9. Figure 10 is a photomicrograph taken at 100X of one small zone of the corrosion products in the specimen shown in figure 9. The corrosion products completely fill the approximately 15 mil (.015 inch) gap between the dissimilar metals in that zone.

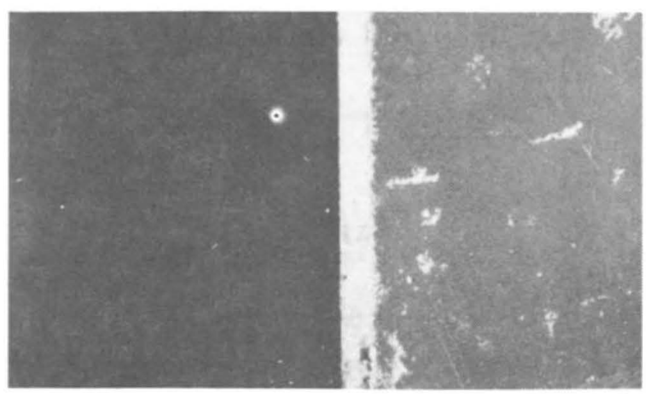


Figure 9. Sectioned view of Specimen No. 1-type 304 stainless steel in contact with type 356 aluminum alloy - showing buildup of corrosion products between the two materials.

*This section has been based in part on work performed and documented by C. R. Halbach of ARTCOR, Irvine, California [25].

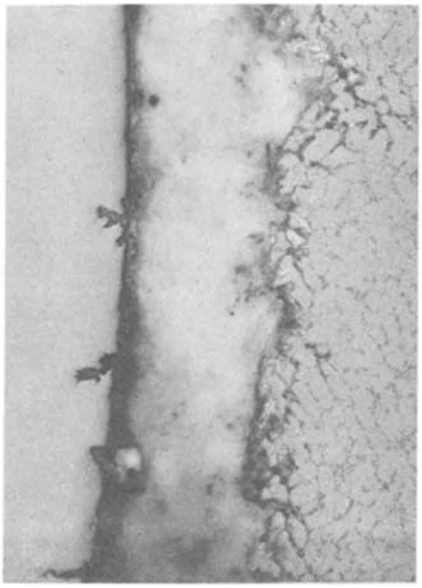


Figure 10. 100X photomicrograph of corrosion products in Specimen No. 1. At the right is the aluminum alloy which has undergone intergranular attack. The white mass in the center is the corrosion product (aluminum oxide + aluminum chloride). At the left is the stainless steel, with major pits visible [25].

The 100X magnification in figure 10 is particularly revealing in that it shows intergranular attack and subsequent dissolution of the grains of the 356 aluminum alloy, and it also shows pitting of the stainless steel.

Specimen No. 1 was then subjected to a scanning electron microscope and probe microanalysis examination of the corrosion products to identify the chemical elements present and their distribution within the region. The elements listed in Part I (A) of table 3 were found to be present in the corrosion products.

Iodine was one element specifically checked for in the scan of the corrosion products because of previous but unverified reports that iodine released into the atmosphere by kelp beds make certain marine areas especially corrosive, and this test site did have kelp beds nearby. No iodine was found, even though it would have been easy to detect with the instrument used.

In addition to the scanning electron probe micronanlysis of Specimen No. 1, arc emission spectrographic and X-ray diffraction analyses were

TABLE 3. ELEMENTS AND COMPOUNDS IDENTIFIED IN STAINLESS STEEL/ALUMINUM ALLOY COUPLE CORROSION PRODUCTS BY ANALYTICAL INSTRUMENTS

[25]

I. Elements Identified in Corrosion Products by Scanning Electron Probe Microanalysis (S.E.P.) and Arc Emission Spectrographic (A.E.S.) Analysis:

Analysis of corrosion products			Presumed source
(A) Specimen No. 1 by S. E. P.	(B) Specimen No. 2 by A. E. S.		
Al	Al	>10%	356 aluminum alloy
Si	Si	> 1%	356 aluminum alloy
	Zn	< 1%	356 aluminum alloy
	Ti	< 1%	356 aluminum alloy
Fe			304 stainless st.
	Fe	< 1%	302 stainless st.
	Cr	> 1%	302 stainless st.
	Ni	< 1%	302 stainless st.
Cl	Cl	> 1%	sea water
Na	Na	< 1%	sea water
Mg	Mg	< 1%	sea water
S	S	< 1%	sea water
Ca			sea water
K			sea water

II. Compounds Identified in Corrosion Products in Specimen No. 2 by X-ray Diffraction:

1. Aluminum oxide hydrate $Al_2O_3 \cdot 5\ H_2O$
2. Aluminum chloride $AlCl_3$

conducted on the corrosion products found between the dissimilar metals in Specimen No. 2 to further document the chemistry of the corrosion products. The arc emission spectrographic analysis was used to identify elements present, while the X-ray diffraction analysis was used to identify compounds. The results of those analyses are shown in Parts I (B) and II respectively, of table 3. For the most part, the corrosion products found in Specimen No. 2 coincided with those found in Specimen No. 1.

The results of the examinations of the corroded specimens, including the chemical analysis results listed in table 3, demonstrated that dissimilar metal (galvanic) corrosion can occur when austenitic stainless steel/aluminum casting alloy couples are employed externally in a severe marine environment. It was concluded that the galvanic corrosion was induced by an accumulation of seawater electrolyte in the small clearance spaces and crevices between the dissimilar metals in contact, probably deposited by some combination of wind-blown spray, sea mist, fog, and moisture condensation at night. There had also been a significant amount of rain during the exposure, but it is not clear whether the net effect of the rain was to accelerate or retard the rate of corrosion. One might expect the rain to tend to wash the salt water electrolyte away and thus retard corrosion, but the net effect may not really be that straightforward.

The overall results of this project, a part of which is reported above, were subsequently applied in the materials selection and design of CATV distribution equipment.

Cracking of Cable Connectors* [26]

A number of coaxial cable connectors have cracked in field use because of corrosion and have had to be replaced. Typical cracks in the connectors are shown in the Figure 11 photograph. In each case the part which cracked was in hoop stress because of the method of assembly used in the connector, in which the part which cracked was assembled in the connector by press fitting over a mating silver-plated part. The material from which the cracked part was machined is 2011-T3 aluminum alloy, a free-machining alloy containing about 5.5% copper. It was reported that the connectors were removed from service near the seacoast, but additional details are lacking.

It can be concluded that each cracked segment of the connectors shown in Figure 11 was fabricated from a stress-corrosion-susceptible aluminum alloy (2011-T3 aluminum alloy) and then stressed in tension by press fitting during assembly of the connector, which loaded the cracked segment in hoop stress (a tensile stress). Finally, the connectors were installed in an area where the environment apparently provided a corrodent capable of causing stress-corrosion cracking. The result of all of those factors was stress-corrosion cracking of the connectors to the point of destruction, necessitating their replacement.

It is frequently found that chlorides are the corrodents responsible for stress-corrosion cracking, and in the case illustrated it is probable that chlorides present in a seacoast atmosphere were the culprits. However, it should not be assumed that this type of stress-corrosion cracking will only occur at the seacoast. Chlorides and other potential corrodents are also present in the atmosphere in most industrial areas, and the use of chlorides for snow removal is common in many areas of the country.

*Information for this section was provided by Mr. Robert Hayward of Gilbert Engineering Co., Inc., on connector models (now obsolete) which were not manufactured by Gilbert [26].

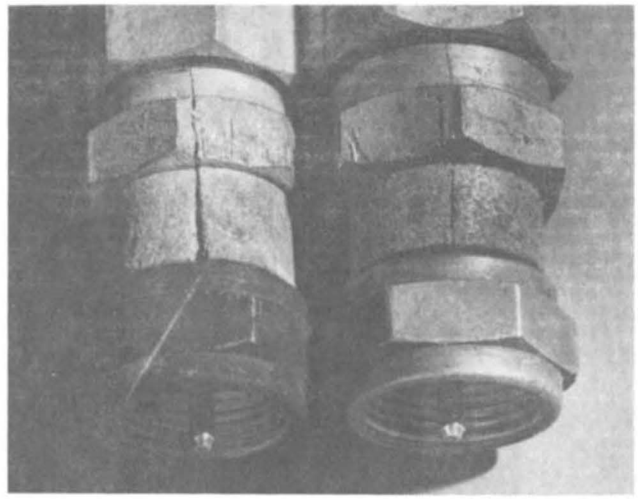


Figure 11. Photograph of two of the connectors removed from field installations near the seacoast after failing from stress-corrosion cracking. The cracks shown penetrate completely through the walls of the segments [26].

The safest procedure is to assume that the corrodents will be present, to fabricate equipment from low-susceptibility alloys, to minimize tensile stresses (including residual stresses) wherever possible, and, in the case of connectors, to install heat shrink boots over the connectors for maximum protection from the environment.

Corrosion Problems in EMI/RFI Gaskets

The necessity of using EMI/RFI gaskets for shielding in high signal level equipment creates a potential corrosion problem because the metal materials used in the gaskets are invariably different from the housing materials, but there must be metal-to-metal contact for the shielding to function effectively. That, of course, creates the potential for galvanic corrosion at the gasket, and corrosion can in fact occur in that area unless care is exercised in the selection of the gasket materials, in the design of the sealing area of the housing, and in the tightening of flange bolts in the field.

This subject is too specialized to discuss in more detail in this paper, but the interested reader is referred to the papers which have been previously published on this subject two of which are referenced [27,28].

CORROSION TESTING AND EVALUATION

Corrosion Testing

The primary metals industry has been conducting extensive corrosion testing and evaluation for about a century, both in corrosion laboratories and in field test sites all over the world. Field corrosion tests of over 25 years duration are not uncommon. The results of most of this research is available in journals and books.

The CATV industry must rely primarily on this published data for guidance in the design of equipment. After a new design has been turned into hardware, however, there may be a need to check its ability to withstand severe field environments before releasing it for full-scale production. That requires corrosion testing by (or under the direction of) the CATV equipment manufactuer.

Corrosion testing in general includes both field testing and laboratory testing. Field testing, if carefully planned and conducted, provides the most accurate information on the corrosion resistance of any test specimen or item of equipment. Unfortunately, field testing doesn't usually provide much in the way of significant results for many months, or even years, a time scale not very useful in the rapidly progressing CATV industry. Given that situation, there is a natural tendency to rely on laboratory corrosion testing, particularly the so-called "accelerated" testing, to try to predict corrosion behavior in service.

Table 4 lists some of the more common forms of general corrosion testing which can be performed in a laboratory, together with various specifications used to standardize those tests.

The tests listed in Table 4 can be useful only if properly performed and, particularly, if properly interpreted. Unfortunately, there is some misunderstanding about the significance of such tests and how to interpret them.

For example, the salt fog (salt spray) tests are often regarded as representing an accelerated form of seacoast exposure; in that view, an item of equipment which survives X number of hours of normal or elevated temperature salt fog exposure with only limited corrosion and no destructive damage has been proved suitable for indefinite exposure in a severe marine environment.

TABLE 4. LABORATORY CORROSION TESTS

Type of Test	Typical Standard Test Specifications
I. Salt spray or salt fog	1. MIL-STD 810B, Method 509: Salt Fog.
	2. FED. TEST METHOD STD. NO. 151b, Method 812.1: Synthetic Sea Water Spray Test.
	3. ASTM B117: Method of Salt Spray (fog) Testing.
II. High humidity	1. MIL-STD 810B, Method 507: Humidity.
III. Immersion	
A. Total immersion	1. FED. TEST METHOD STD. NO. 151B, Method 821.1: Intergranular Corrosion Tests for Aluminum Alloys.
	2. NACE TM-01-69: Laboratory Corrosion Testing of Metals for the Process Industry.
	3. ASTM A279: Total Immersion Corrosion Testing of Stainless Steels.
B. Alternate immersion	1. FED. TEST METHOD STD. NO. 151b, Method 823: Stress-corrosion Test for Aluminum Alloy.
C. Partial immersion	--

While not totally wrong, that concept is a misinterpretation of the purpose and significance of salt fog testing. Those and similar tests are designed to be primarily accelerated quality control and acceptance tests, which first requires that meaningful criteria have to be established for passing the tests. Those tests are not life expectancy tests for some severe environment such as a marine environment, but instead are simply "pass - no pass" tests on materials, coatings, assemblies, etc. The reasons for these deficiencies and limitations in the applicability of the test results include the fact that the tests do not accurately duplicate all of the corrosive aspects of field conditions, and do not accelerate all forms of corrosion equally. Salt fog and similar laboratory tests on electrical/ electronic equipment might, however, be made more realistic by supplying electrical power to the equipment during the test.

Although accelerated corrosion tests performed in a laboratory are not truly reliable for comparing the corrosion resistance of different materials, coatings, assemblies, etc. they are nevertheless commonly used for that purpose and can provide a reasonably good qualitative comparison most of the time if intelligently applied and interpreted. Two simple examples of such comparative testing, performed at Gilbert Engineering Company by R. Hayward [26] on different designs, materials and surface finishes for cable connectors, are shown in figures 12 through 15. One of the tests, illustrated in figures 12 and 13, was an alternate immersion test in which all of the connectors

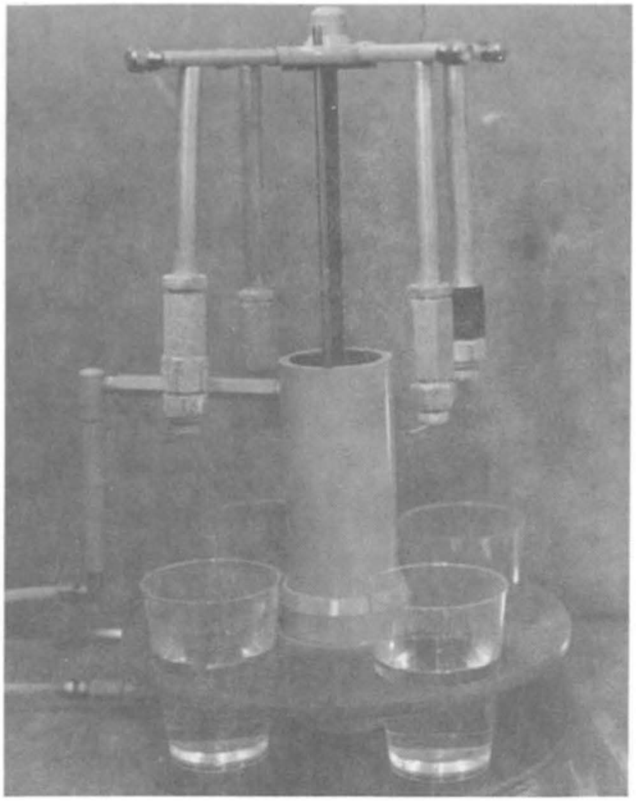


Figure 12. Photograph of alternate immersion test rig used for testing cable connectors of various materials and finishes in individual NaCl solutions [26].

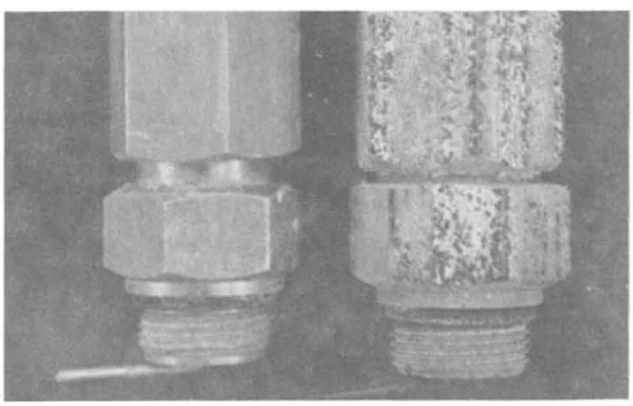


Figure 13. Comparison of appearance of two of the connectors tested in the alternate immersion test rig (figure 12) after 180 days of testing. The connector on the left was fabricated from 6262-T9 aluminum alloy and finished with a chromate conversion coating; the connector on the right was fabricated from 2011-T3 aluminum alloy and was not coated [26].

were submerged in concentrated (20%) NaCl solutions at room temperature for 1-1/2 minutes, then automatically withdrawn and exposed to room air for 1-1/2 minutes, with that cycle repeated continuously for 180 days in accordance with a procedure described in reference 1. The results (figure 13) demonstrated that one combination of aluminum alloy and coating - 6262-T9 alloy with chromate conversion coating - withstood this particular concentrated salt solution accelerated corrosion test with much less general corrosion than another alloy - 2011-T3 - without a coating.

The second test, illustrated in figures 14 and 15, was an alternate high humidity/condensation test performed in a closed glass vat with a small quantity of water in the bottom. This testing device was placed outdoors in the summertime in

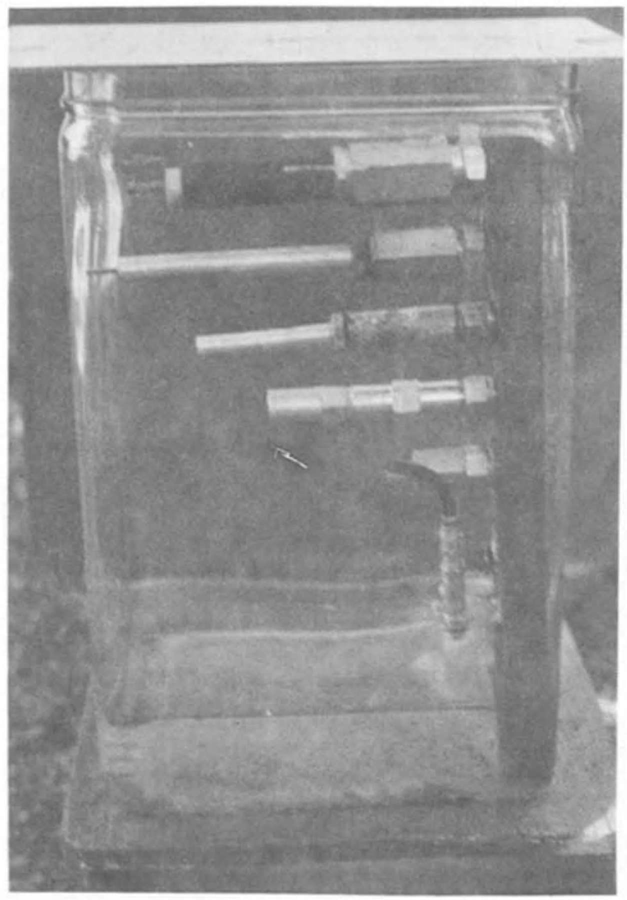


Figure 14. Closed test rig for testing of cable connectors of various materials and finishes in 24 hour cycles of alternating high temperature-high humidity (daytime) and reduced temperature-condensation (nighttime). The evaporating/condensing liquid was ordinary water. The heat source was the sun [26].

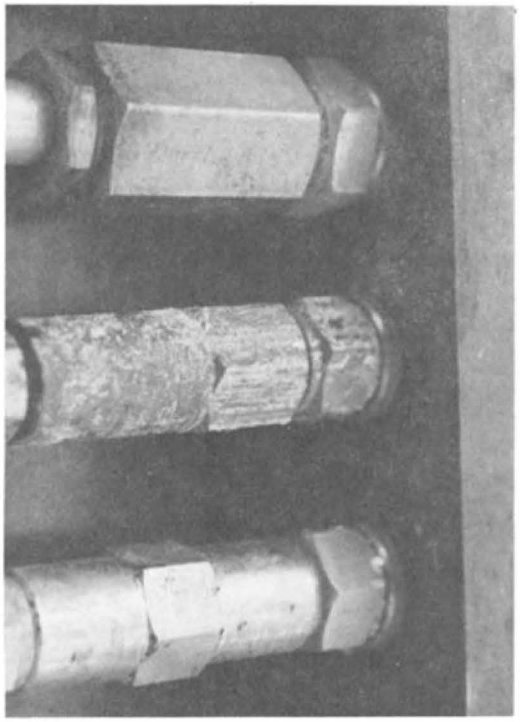


Figure 15. Appearance of three of the cable connectors after 90 days of high humidity/ condensation testing. Top: 6262-T9 with chromate conversion coating. Center: 2011-T3 with no coating. Bottom: Unspecified aluminum alloy with bright tin plating [26].

Phoenix and was heated by the sun to temperatures as high as 150°F, thereby producing both high relative and very high absolute humidities within the vat. Each night the vat would cool off and water would condense on the connectors. Figures 14 and 15 are photographs taken after 3 months of such testing. The results were at least qualitatively similar to those of the first test.

Overly simple corrosion tests can sometimes produce misleading results when there is inadequate control of test conditions or inadequate simulation of the controlling parameters. However, even very simple corrosion tests are usually better than no tests at all if they are interpreted with good judgment.

Evaluation Methods

There is only a limited amount of information which can be gained from a visual examination of corrosion-damaged items of equipment, and often it is impossible to accurately identify the true forms, mechanisms and causes of destructive corrosion without resorting to an analysis using laboratory analytical equipment, some of it rather sophisticated. Table 5 lists some of the analytical techniques which can be employed in order to identify such factors as the forms of corrosion and the compositions of the corrosion products and the corrodent residues, in order to determine and correct the real causes of the corrosion damage. Although such detailed analyses require the expenditure of both time and money, they are justified in many instances because of the danger that the wrong conclusions will be drawn from superficial examinations, resulting in ineffectual "corrective" action.

TABLE 5. EXAMPLES OF INSTRUMENTS USED IN THE ANALYSES OF CORRODED PARTS

[22]

Instrument or Technique	Uses and Advantages
1. X-ray diffraction	Principal use is in the identification of corrosion product oxides. Its major advantage is that it identifies compounds present, rather than just elements. It is capable of distinguishing between different oxides of a single metal.
2. X-ray fluorescence spectroscopy	Used in the identification of elements present in corrosion products, by analysis of the wavelengths emitted by irradiated products. Sensitive method for detecting elements present in amounts greater than 1%.
3. Scanning electron probe microanalysis	Also used in the identification of elements present in corrosion products. Irradiates specimen with electron beam finely focused to about 1 micrometer diameter. Used principally on sectioned and polished specimens to measure the variation in composition through the cross-section of a layer of corrosion. products.
4. Scanning electron microscope	Often used in conjunction with scanning electron probe microanalysis to obtain a high magnification graphical image of the corrosion products being analyzed by the probe. Superior in resolution and depth of field to optical microscopes.
5. Optical photomicrographic techniques	Usually used in the familiar high-magnification photography of sectioned and polished (or etched and polished) specimens for the visualization and study of the morphology of the corrosion effects. Illustrates the form of the metal-oxide interface and the homogeniety of the oxide itself. Permits identification and study of pitting, intergranular corrosion, stress-corrosion cracking, etc.

In an earlier section of the paper the typical use of several types of analytical equipment was described in connection with the investigation of stainless steel/ aluminum alloy galvanic couple specimens.

SUGGESTED PRINCIPLES FOR PREVENTION OF CORROSION IN CATV DISTRIBUTION SYSTEMS

Some specific conclusions which have been drawn regarding destructive corrosion and its prevention in CATV distribution system equipment can be catagorized and summarized as follows:

1. Environmental Effects

a. For aerial installations, very corrosive environments may exist either near a seacoast or in a fume-polluted industrial area. A combination of the two may be even worse. Sulfur dioxide and the chlorides are the two most aggressive agents in the atmosphere. Concentration of corrosive agents may be highly localized because of local wind, spray or fume conditions, and degree of local sheltering.

b. For underground vault installations without bell jar type protective covers (liners), any flooding of the vaults is likely to create corrosive conditions. The corrosivity of the flooding water toward aluminum (as an example) is a function of such factors as the pH of the water, the dissolved oxygen content, the conductivity, the concentrations of carbonate, sulfate, and chloride ions and the concentrations of copper and other heavy metal ions. The source of these constituents may be polluted or brackish ground water, or chemically-polluted drainage water.

2. Design Principles for Corrosion Resistance

a. Equipment should be designed on the assumption that common corrodents will be present in an aggressive atmosphere.

b. The use of incompatible dissimilar metals on exposed parts of equipment housings should be avoided if possible by referring to reliable galvanic couple compatibility charts.

c. If incompatible dissimilar materials need to be used together in aggressive environments, the more cathodic material should be plated or otherwise coated with a metal compatible with the anodic material.

d. The use of individual alloys which are not intended for outdoor exposure in severe environments should be avoided. Coatings should not be depended upon to protect unsuitable materials in aggressive environments - the coatings will corrode or deteriorate eventually.

e. Caution should be exercised in coating the more anodic materials. Under some conditions it may cause serious pitting at porous sites in the coating and do more harm than good.

f. Designs which permit stray-current corrosion conditions to exist should be avoided as much as possible.

g. Unnecessary crevices should be eliminated in equipment designs.

h. Stress-corrosion susceptible alloys should not be used for parts subjected to external or residual tensile stresses.

3. Corrosion Testing and Evaluation

a. Maximum use should be made of the vast amount of corrosion research data available in journals and books in the selection of materials and in the design of equipment.

b. Laboratory "accelerated" corrosion tests can be used - but with caution - to screen new equipment designs and materials for certain types of corrosion susceptibility. The tests must be selected, planned, executed and evaluated with a sound understanding of the deficiencies and limitations of such tests. They should not be construed as predicting life expectancy in a corrosive field environment, or as "proving" corrosion resistance.

c. Consideration should be given to powering equipment during laboratory corrosion testing in order to simulate field conditions more realistically.

d. A variety of sophisticated analytical instruments and procedures is available to aid in the identification of corrosion forms, mechanisms, products and agents. Effective use of those techniques should be made in the investigation of important corrosion problems.

e. On-going efforts are needed to monitor corrosion problems in the field in order to obtain as much significant data as possible, and to try to correlate that data with the results of related laboratory tests.

4. Installation and Operation

a. Selection of equipment intended for installation in severe environmental areas (seacoasts, heavy industrial areas, etc.) should be limited to designs in which corrosion resistance has been seriously considered and emphasized, even though the first cost may necessarily be higher. Replacement of unsuitable equipment can be even more expensive.

b. For underground vault installations, equipment should be mounted inside of bell jar type plastic internal covers (liners) if possible, in order to keep the equipment dry in the event of flooding of the vaults. The installation of a liner of that type is illustrated in figure 16. The distribution equipment must be supported high in the vault in the trapped air pocket created by the internal cover.

c. All service technicians should be alerted to the importance of minimizing corrosion damage by properly installing and maintaining equipment and protective enclosures. The importance of properly torquing housing fasteners to maintain sealing integrity should be emphasized.

CONCLUSION

Destructive corrosion has been encountered in all types of CATV equipment installed in a wide variety of environments. It has been found in both aerial installations and underground installations, and it is almost certain that no equipment manufacturer has been immune to the problem.

There are definite costs associated with maintaining on-going corrosion-prevention programs, and in utilizing good practice in the selection of corrosion-resistant materials and designs. For the equipment manufacturer, it usually means incorporating more expensive materials, processes, and tests in the fabrication of his products. For the system operator, it may mean paying a higher first cost for such equipment and possibly also providing more protective but more expensive enclosures. On the other hand, there can be significant costs to both if a major error is made and a sizable number of corrosion-damaged items of equipment have to be replaced.

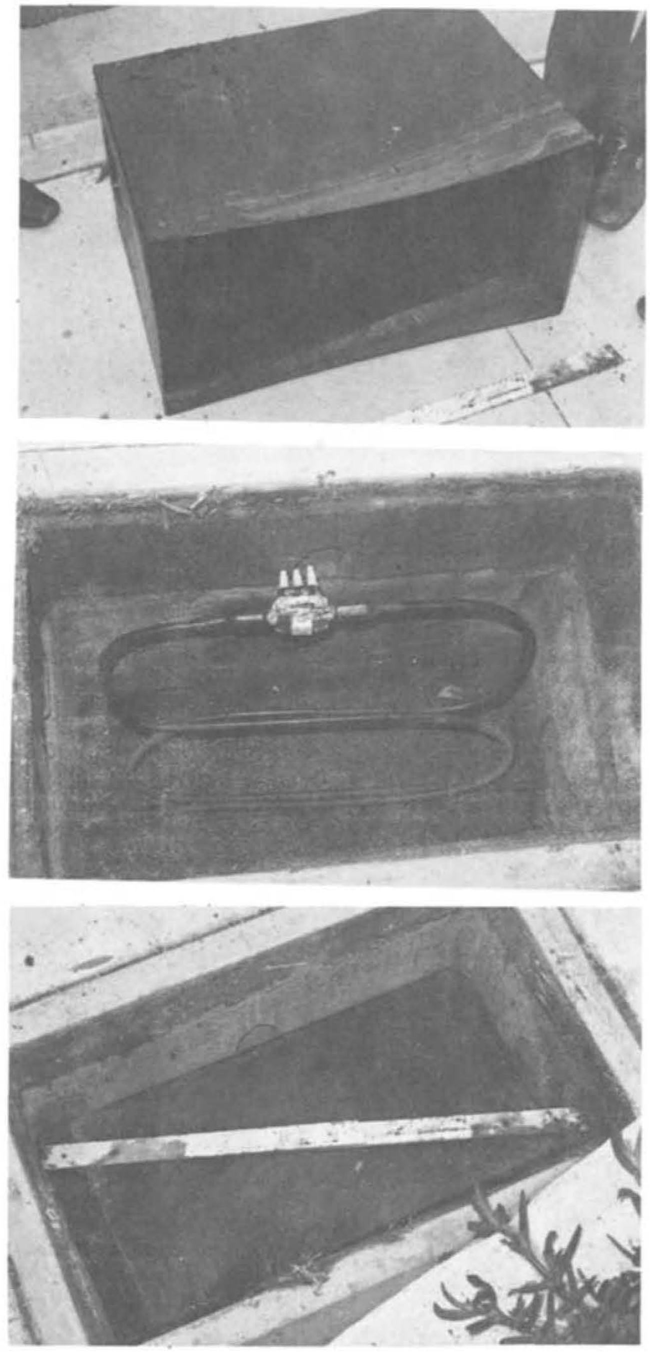


Figure 16. Use of liner in underground vault to provide air trap to protect distribution equipment from water.

Obviously, there is a need to avoid both gross overdesign and gross underdesign from the corrosion standpoint, but unfortunately the dividing line between overdesign and underdesign can vary considerably, depending on the intended location.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contribution of Mr. Carl Halbach of ARTCOR, Irvine, California, in conducting and documenting the investigation of some of the corrosion specimens. They are also indebted to Mr. Robert Hayward of Gilbert Engineering Company, Inc., Phoenix, Arizona, for supplying the previously unpublished information presented in this paper on field stress-corrosion problems and laboratory corrosion testing of coaxial cable connectors. Thanks are also due to Mr. Wayne Briggs of Chomerics, Inc., for supplying copies of both published and unpublished reports on EMI/RFI gaskets corrosion studies for reference.

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DETERMINING RADIATION LEVELS IN CATV CABLE SYSTEMS FOR COMPLIANCE WITH FCC REGULATIONS

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ABSTRACT - This paper presents an analysis regarding specific problems encountered in measuring radiation levels of CATV cable systems for FCC radiation compliance. Methods of testing and measurement techniques through the use of various types of test equipment are discussed in locating radiation sources. Many fault conditions are traced and analyzed. These are itemized and defined as to type of radiation and their characteristics.

Based upon information obtained from actual field measurements and examples, it is possible to identify and locate unrelated radiating sources. The possibility of multi-radiating sources causing readings in excess of specification, yet not necessarily adjacent to the measurement location, can be shown with physical layout diagrams. Additionally, it is possible to predict meaningful "effective shielding" factors for many CATV system components, including connectors, housings, and cable.

INTRODUCTION

The FCC has set forth definitions and standards for cable television under Part 76 of the Federal Rules and Regulations. Sub-part K contains the technical standards and Paragraph 76.605 (12) outlines the maximum allowable radiation levels in microvolts/meter over the frequency spectrum at a specified distance. The radiation limits are:

Up to and including 54 MHz	15 uv/m @100'
Over 54 MHz up to and including 216 MHz	20 uv/m @ 10'
Over 216 MHz	15 uv/m @100'

The cable television system operator must conduct performance tests at least once a year and maintain this data on file for at least five years.

In the process of measuring radiation, many pitfalls present themselves and thereby cause erroneous data to be recorded. This paper is not a theoretical study, rather a compendium of radiation sources and problems encountered in the process of radiation testing. A knowledgable cable system operator armed with this information should be able to locate, accurately measure, and correct any particular radiation problem relative to the CATV system.

METHODS OF MEASURING

There are three basic instruments used to measure radiation:

1) Field Strength Meter

2) Spectrum Analyzer

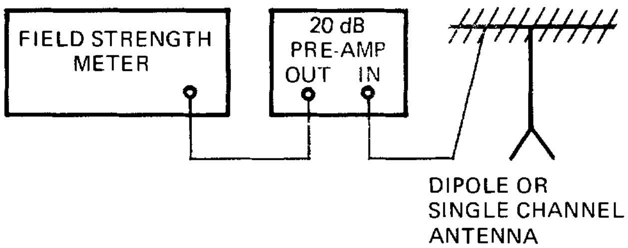
3) Field Intensity Meter

All three involve the use of a calibrated antenna. Depending upon the sensitivity of the instrument used, some may require a preamp also.

The use of a field strength meter such as a Jerrold Model 704 or 727, is illustrated by Figure 1. However, the basic sensitivity of this test equipment is inadequate and, therefore, a preamp with at least 20 dB gain is required. This method is the most economic and simple using components available to most cable systems. If a single channel antenna is used, its gain must also be entered in the calculation shown.

The diagram of the measurement set-up using a spectrum analyzer is illustrated by Figure 2. Again, because the sensitivity of some units falls short of that required, a preamp must be used. Since 20 uv/m at Channel 13 is equal to approximately 4.5 uv of signal, the instrument to be used must be able to measure at least half that level with some degree of accuracy.

The same calculation used with the FSM is used here. The main advantage of the spectrum analyzer is the ability to see the spectrum adjacent to the frequency of interest and thereby aid in rejecting false signal measurements.



$E_{FI} = E_{FSM} - [G_{PA} + G_{ANT}]$

$E_{\mu v/M} = E_{FI(\mu v)} \times .0207 \times f_{MHz}$

E_{FI} = Field Intensity in dBmV

E_{FSM} = Field Strength Meter Reading in dBmV

G_{PA} = Gain of Pre-Amp in dB

G_{ANT} = Gain of Antenna in dB

$E_{\mu v/M}$ = Field Intensity in μv/Meter

E_{FI} = Field Strength Meter Reading in μv

f_{MHz} = Freq Measured in MHz

Figure 1. Radiation Measurement Using Field Strength Meter.

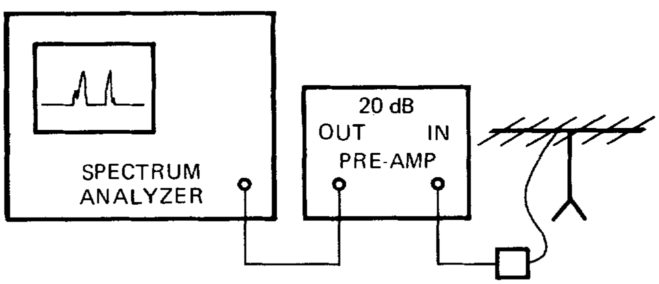


Figure 2. Radiation Measurement Using Spectrum Analyzer.

The field intensity meter (FIM), as illustrated by Figure 3, is the only active item needed along with the tunable dipole. The FIM indicated directly in db/uv. On some field intensity meters, the antenna is an integral part of the meter. Such is the case with the compact and simple-to-use Rohde & Schwarz (R&S) VHF test receiver Model HFV 203.6018.04.

The features of the FIM, including the R&S, are:

1) Sensitivity is in the vicinity of 1 uv - well beyond that required.

2) Accuracy is kept constant over the spectrum by use of an internal calibrator.

3) Built-in audio allows monitoring of signals to help determine the actual frequency being measured.

4) Battery operation allows complete portability with the antenna being integral.

The R&S FIM mentioned is the instrument recommended and used to gather background information for this report. It is by far the simplest to use. The main disadvantage is the cost to purchase which is in excess of $4000.00.

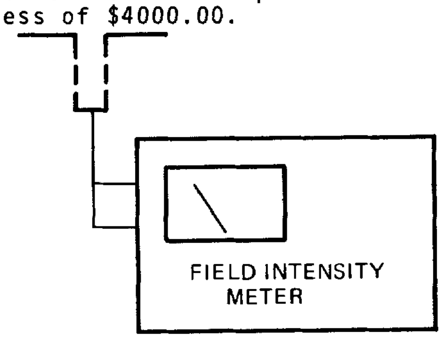


Figure 3. Radiation Measurement Using Field Intensity Meter.

An example of the data sheet used to record radiation levels in cable systems tested is illustrated by Figure 4. The meter reading in dB/uv is recorded and a correction factor is subsequently added which yields dB above a microvolt per meter.

This is then converted from dB's to microvolts per meter. Other pertinent information is also recorded such as equipment present (amplifiers, taps, splices, drops, feeders) and environmental conditions (power line noise, spark static, unknown sources). Pilot tone carriers may also be measured and recorded if deemed relevant, but should not be the sole criteria for radiation testing.

RADIATION TESTS θ______

EQUIP. PRESENT ______ CITY ______

______ DATE ______

ADDRESS ______

CHANNEL	f_{MHz}	dB/μv	C.F.	dB/μv/M	μv/M	
2	55.25		1.16			20 μv/M MAXIMUM
3	61.25		2.16			
4	67.25		2.88			
5	77.25		4.06			
6	83.25		4.72			
7	175.25		11.18			
8	181.25		11.48			
9	187.25		11.72			
10	193.25		12.06			
11	199.25		12.30			
12	205.25		12.56			
13	211.25		12.86			

NOTES:

Figure 4. Radiation Test Form

RADIATION SOURCES & CAUSES

The cable system, which on the whole can be suspect of radiation, is divided into three areas for ease of discussion and attack. These are:

1. Headend Area
2. Trunk and Feeder Area
3. Drop and Subscriber Area

In that headend buildings are usually constructed with material to keep spurious signals out, the reciprocal is also true. The headend processors operate at levels between +50 and +60 dBmV making it a likely source for radiation, but buildings of concrete or steel generally preclude any concern for radiation. However, it is possible to have local oscillator radiation from antennae at the headend and should be checked. Processor and converter manufacturers generally specify this parameter and should be consulted if a high level of signal is found.

High signal levels operating in the combining process within the headend put strigent requirements on the coaxial cable used to interconnect the equipment. The ability of the coax to contain and not radiate signals is related to "shielding effectiveness" and is discussed subsequently. The point to bring out here is that most of the available economically priced drop cable is not adequate for headend use. Not only will they radiate in excess of FCC specifications, but are susceptible to external sources.

The area encompassing trunk and feeder cable equipment probably represents 80% of the radiation sources. Wherever a discontinuity is inserted in the cable, such as an amplifier, splice, tap, splitter, power inserter, or basically anything with connectors for cable, the possibility of radiation exists. With the higher signal levels operating in the feeder portions of the system, an even greater chance exists. Past experience in measuring cable system radiation has yielded the following distribution:

AREA	% of TOTAL RADIATION FOUND
1) Feeder Cable	60%
2) Subscriber (drop)	20%
3) Trunk Cable	15%
4) Headend	5%

As shown above, a good portion of cable system radiation is found to exist between the tap and the subscriber's TV set. The subscriber himself may cause radiation by altering his hook-up in some manner. The following list of radiation causes has been accumulated from testing and correcting problems in more than 15 cable systems throughout the U.S.

RADIATION CAUSES

A) HEADEND AREA

1. Local oscillator radiation
2. Non-shielded signal processors
3. Non-filtered power (115 VAC)
4. Defective or inadequate shielding on interconnecting cable.

B) TRUNK CABLE AREA

1. Loose connectors
2. Stripped connectors
3. Parts missing from connectors
4. Loose housing covers
5. Broken cables (cracked, kinked, scored)
6. Bonding defective
7. Unterminated lines

C) FEEDER AND SUBSCRIBER AREAS

1. Loose connectors
2. Stripped connectors
3. Parts missing from connectors
4. Loose covers on housings, splitters, DC's taps
5. Broken cable (cracked, kinked, scored)
6. Poorly installed "F" Fittings
7. Defective drop cable
8. Corroded ground blocks
9. Staples in drop cable
10. Indoor splitters used outdoors
11. Unterminated splitters
12. Outdoor/indoor antennae paralleled
13. Miscellaneous wires attached to TV
14. Corroded connections
15. Unterminated drop

METHODS OF LOCATING RADIATION

After trying several approaches that would give definitive answers as to suspect radiating component(s), the following method seems to be best. Radiation can be traced quite accurately using both a TV set and an FM receiver. First, a TV set, which can be powered from 12 vdc, is used to note radiation by observing both a high and a low band channel which are not local or off-air frequencies. Most TV sets have sensitivities that are near 10 uv or better on VHF channels. Signals radiated at this level (approximately 43 uv/m @ Channel 13) generally appear as sync bars slanted across the screen. In other words, most TV sets will not quite sync on this signal level. Since 10 uv is more than twice the radiation spec at Channel 13, one can see the TV set can only be used to locate medium to high levels of radiation. This method has worked quite well. When driving near the component which radiates, the picture will peak stronger and gradually disappear as the distance increases from the radiation source. Some sources radiate quite badly and blanket a 2 to 5 block area. It is then necessary to turn off or disconnect areas to zero in on the source. The TV set is very useful with this approach.

After reworking connectors, housings, and other related parts until the picture has disappeared from the TV set, a second test has proved helpful. An FM carrier introduced on the cable system at 109MHz will allow the use of a hand-held FM receiver to spot radiation sources more definitively as illustrated by Figure 5. The sensitivity of some FM receivers of this type will vary between 0.5 and 1 uv of signal. Using a 1000-Hz tone to modulate the 109-MHz carrier, and operating the carrier equal to or 2 to 3 db higher than the highband or highest level on the system, the signal can be picked up on the hand-held receiver at lower level radiation sources. The whip antenna can be used as a "sniffer" to spot radiation from sources such as groundblocks, loose fittings, leaky drop cable, etc. One is able to determine whether the signal is getting stronger or weaker by the intensity of the 1000-Hz tone.

When the cable system parts have been reworked until the signal vanishes from the FM receiver, one has some reasonable assurance of radiation levels being in the vicinity of specification limits. The operator is then ready to make absolute measurements with one of the methods described previously. There are some exceptions that would not necessarily be found by the above procedure, and will be discussed subsequently.

Radiation faults in the cable system are very much affected by temperature and humidity. Customer complaints often originate in the evening, but are unable to be located the next day on a trouble call. This is mainly due to temperature variations which cause cracks or gaps to increase at cold temperatures, and decrease when warmer ambients exist. Unfortunately, the converse is also true, ie., when heated ambients exist during the day, radiation faults are caused, but cooler air at night cause the faults to disappear. Loose connectors are usually the culprit greatly affected by temperature extremes.

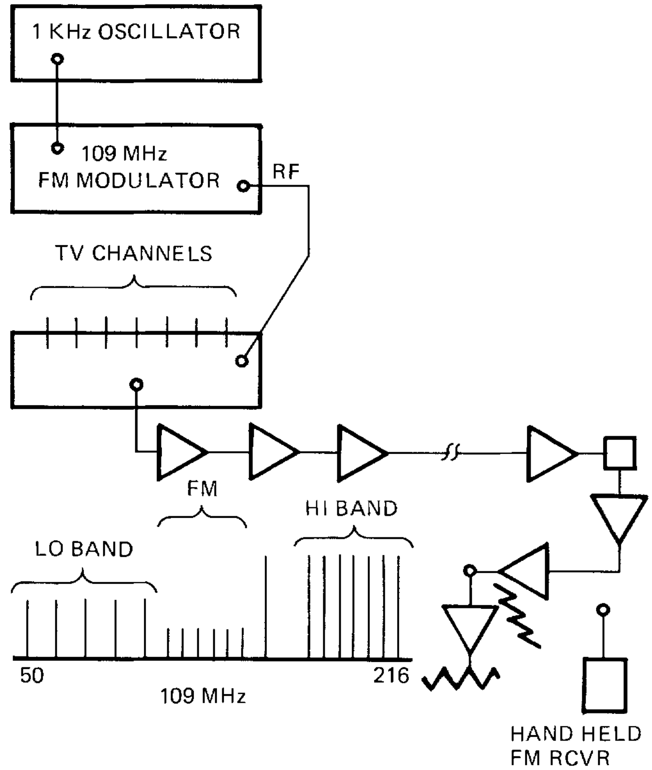


Figure 5. Test Signal System Configuration.

Humidity will generally attenuate radiation from a fault condition compared with a dry ambient. Therefore, radiation location in rain or snow/freezing conditions is more difficult if not, at times, impossible. Another parameter to consider is cable tensions during construction. If tensions are too tight, excessive strain and flexing of drip loops are caused. Eventually a gap or crack will appear and radiation starts. Tensions that are too slack will also cause similar radiation faults.

After reviewing the types of faults found and comparing the radiation levels with the fault, some characterization of radiation profiles can be made. Most leaks exhibit a capacitive type profile, i.e., the higher frequencies are attenuated less than the lower. Some other fault types have electrical "holes" in the spectrum.

A test set-up was made to simulate and more accurately analyze the spectral profile of the different fault types. Figure 6 shows the test diagram. The test results are definitely not absolute, but are relative to each other, and can be compared with good conditions versus a fault. The antenna used was a broadband VHF antenna with unknown gain. Figures

8 and 9 show the data from faults generated to simulate problems found in the cable system.

ing measured could be turned off at the headend for a moment while monitoring the FIM level. If the school has its own an-

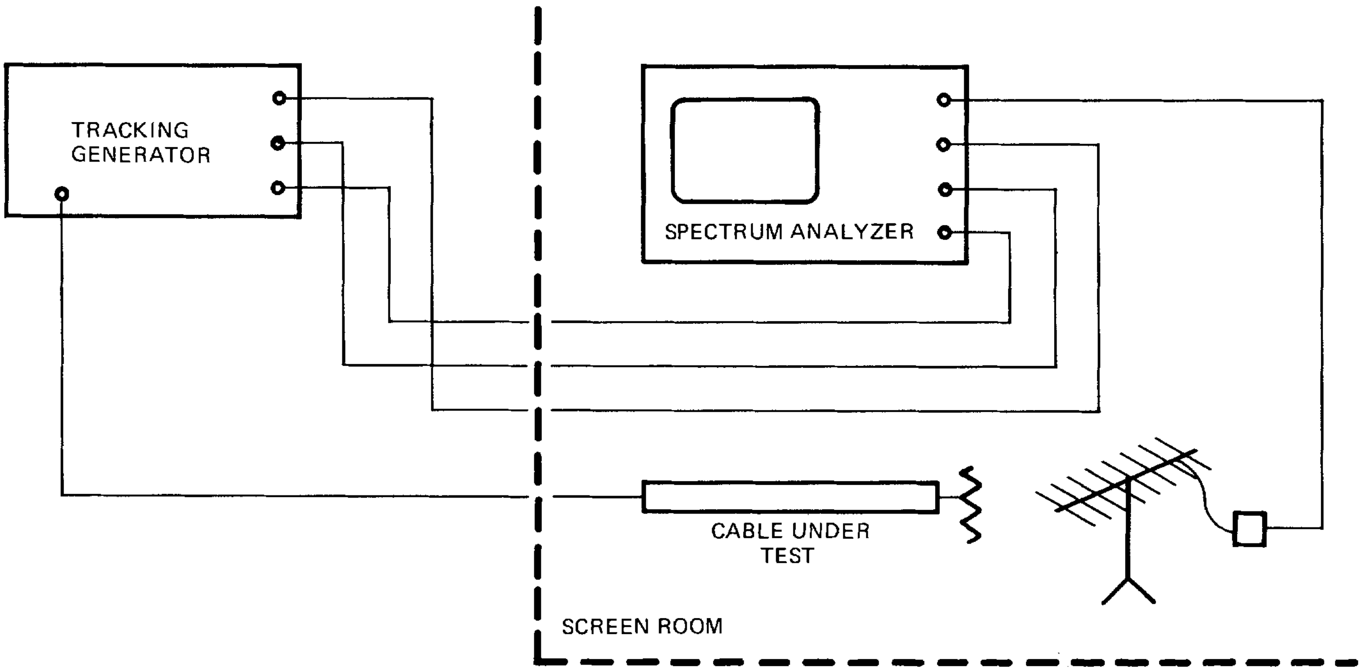


Figure 6. Fault Condition Simulator
Test Set-Up

Some attention should be given to determining the source of a specific radiation level being measured. To just assume a signal level measured as emanating from the cable system is a bit naive. Figure 7 shows a plot plan of a radiation test set-up. Four possible sources of radiation are shown and their respective location (direction). Assume the following conditions:

f = Channel 13 (211.25 MHz)
CF = 12.82 dB

and

E_1 = 10 dB/uv
E_2 = 35 dB/uv
E_3 = 12 dB/uv
E_4 = 7 dB/uv

Then: The FIM will indicate the highest level received: E_2 at 35 dB/uv.

E dB/uv + CF = E dB/uv/m
35 dB/uv + 12.82 dB = 47.82 dB/uv/m
47.82 dB/uv/m = 246 uv/m

This would lead the operator to believe the cable system to be at fault. To verify this, the specific channel be-

tenna system, the answer would become apparent immediately. If the school is a subscriber with their own distribution system, the answer is not so apparent. The next step might be to look at the radiated signal with a TV set and rabbit ears. This too would lead one to believe the cable system was radiating. The only possible indication of error might be the fact that the FIM dipole would peak at an angle not parallel to the cable system as is the case in most radiation examples. However, this factor has not been very reliable in tracing radiation in the past.

The best method to locate radiation of this type is by using the hand-held FM receiver as described previously. By walking the area near the measurement site, the RF leak could be "sniffed" out and located almost exactly.

It should be remembered at this point that all radiation sources, if in excess of FCC limits, must be located and corrected before a "true" system radiation measurement can be made.

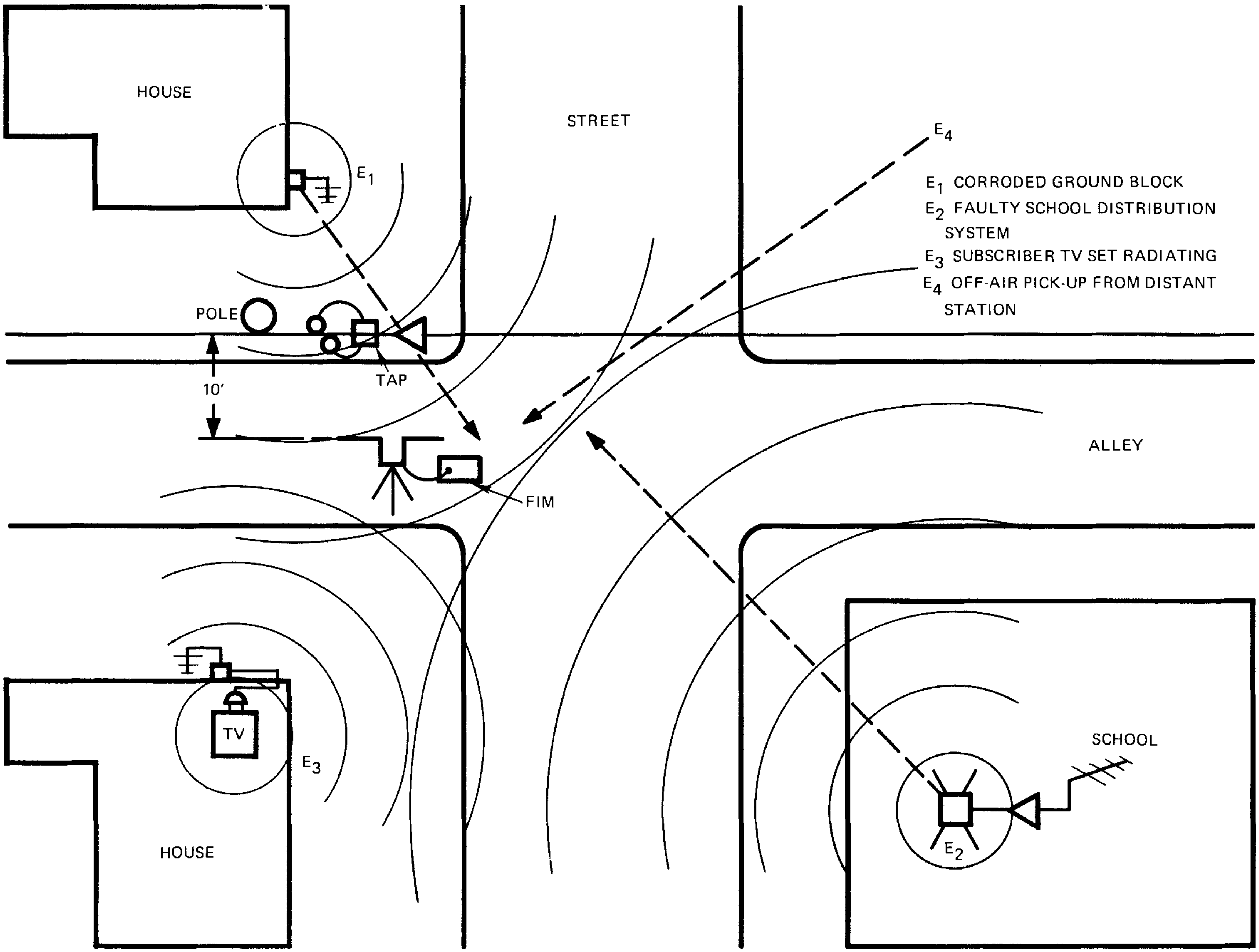


Figure 7. Multi-Source Radiation Plot Diagram

Another symptom to watch, as an indicator of multi-source radiation, is co-channel beat. Using the R & S FIM, the video signal coupled to the built-in speaker will indicate a high pitched squeal (co-channel beat). This should alert the operator to check for more than one source. Usually the second source is a distant station which is either too weak to be considered local or, on low channels, is received under skip conditions which exist occasionally. If the field intensity is high enough to cause indications, the actual radiation cannot be measured until the distant station either fades or goes off the air.

Power line noise, or random spark noise, may create a situation which on the surface may make a radiation test look impossible. The R & S FIM has a feature which aids immensely in this predicament. An option of measuring peak or average potential is available to the operator. Normally, the peak function is used. But in the case of high ambient noise, the average function can be used along with a correction factor. The correction factor is the addition of 6 dB to the reading. This is equal to the average modulation (87.5%) of a TV signal measured in peak function. The correction factor is an approximation and usually not more than ± 1 dB from peak or true value.

ATTENUATION FACTOR AND SHIELDING EFFECTIVENESS

It is now apparent that keeping radiation at a minimum in a cable system requires attention to details at every point

TABLE 1

ATTENUATION FACTORS FOR 5-300 MHz

	dB/uv	CF	dB/uv/m	uv/m*	dBmV	u/v	A.F. dB
5 MHz	43.41	0.09	43.5	150	-16.5	147.9	61.5
30 MHz	42.98	0.52	43.5	150	-17.0	140.9	62
Ch 2	24.86	1.16	26.02	20	-35	17.50	80
Ch 3	23.96	2.06	26.02	20	-36	15.78	81
Ch 4	23.14	2.88	26.02	20	-37	14.35	82
Ch 5	21.96	4.06	26.02	20	-38	12.53	83
Ch 6	21.30	4.72	26.02	20	-39	11.61	84
Ch 7	14.84	11.18	26.02	20	-45	5.52	90
Ch 8	14.54	11.48	26.02	20	-45	5.33	90
Ch 9	14.30	11.72	26.02	20	-45	5.18	90
Ch 10	13.96	12.06	26.02	20	-46	4.98	91
Ch 11	13.72	12.30	26.02	20	-46	4.85	91
Ch 12	13.46	12.56	26.02	20	-46	4.71	91
Ch 13	12.20	12.82	26.02	20	-47	4.57	92
250 MHz	29.22	14.28	45.5	150	-31	28.91	76
270 MHz	28.56	14.94	43.5	150	-32	26.79	77
300 MHz	27.64	15.86	43.5	150	-32	24.10	77

*ALL uv/m LEVELS ARE AT 10' FOR EASE OF COMPARING NUMBERS

$E_R = \frac{D1}{D2} Em$

E_R = Intensity Required in uv/m

D_1 = Measuring Distance

D_2 = Required Distance

E_m = Intensity Measured

a connection is made. This means that the connection and the equipment being spliced or connected must have a certain attenuation factor to maintain radiation levels within FCC requirements. Table 1 lists the minimum attenuation factors for frequencies between 5 and 300 MHz. It should be noted that the maximum attenuation is required at Channel 13 where 20 uv/m at 10' is the most stringent.

Assuming +45 dBmV to be the highest signal level ever required, 92 dB at Channel 13 is the absolute minimum attenuation to remain within FCC levels. A 10-to-15 dB margin is usually considered to be minimal, yielding a number of 107 to 102 dB. Most systems have been specifying on the order of 110 to 120 dB, which is safer yet. Most housings will pass this requirement without much trouble. The connectors require more attention during construction with respect to repeatability and ease of assembly.

Crosstalk and shielding effectiveness become factors to consider also. Many papers have been written on these subjects and are referenced herein. These parameters are important when considering dual cable and bidirectional systems. They are only mentioned here for reference and indication of importance. No attempt to relate the material of this report and these parameters was made.

CONCLUSION

It becomes quite apparent that for a cable operator to maintain and accurately measure the level of system radiation, he must be aware of many factors which can cause and/or create the illusion of unacceptable radiation levels.

The examples and data contained here should aid in determining the true radiation and also help in locating sources of radiation which might cause trouble calls for the system operator.

The main item to remember in maintaining a system which will pass FCC requirements is to keep ALL connections in the system tight - including equipment covers and grounding. The second item is to require the use of equipment which can pass the 92 dB minimum attenuation factor.

Last, is to educate the subscriber not to alter his installation in any manner. Subscribers should be made aware that any disturbance of the cable installation could cause improper performance.

With these three factors under control, the cable system operator has a good chance of passing FCC radiation tests at any location in the system at any time.

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Special appreciation is given to Mr. Frank Baxter of General Electric Cablevision Corp. in Schenectady, New York, for the loan of their field intensity meter which was used in gathering data and background information for this report.

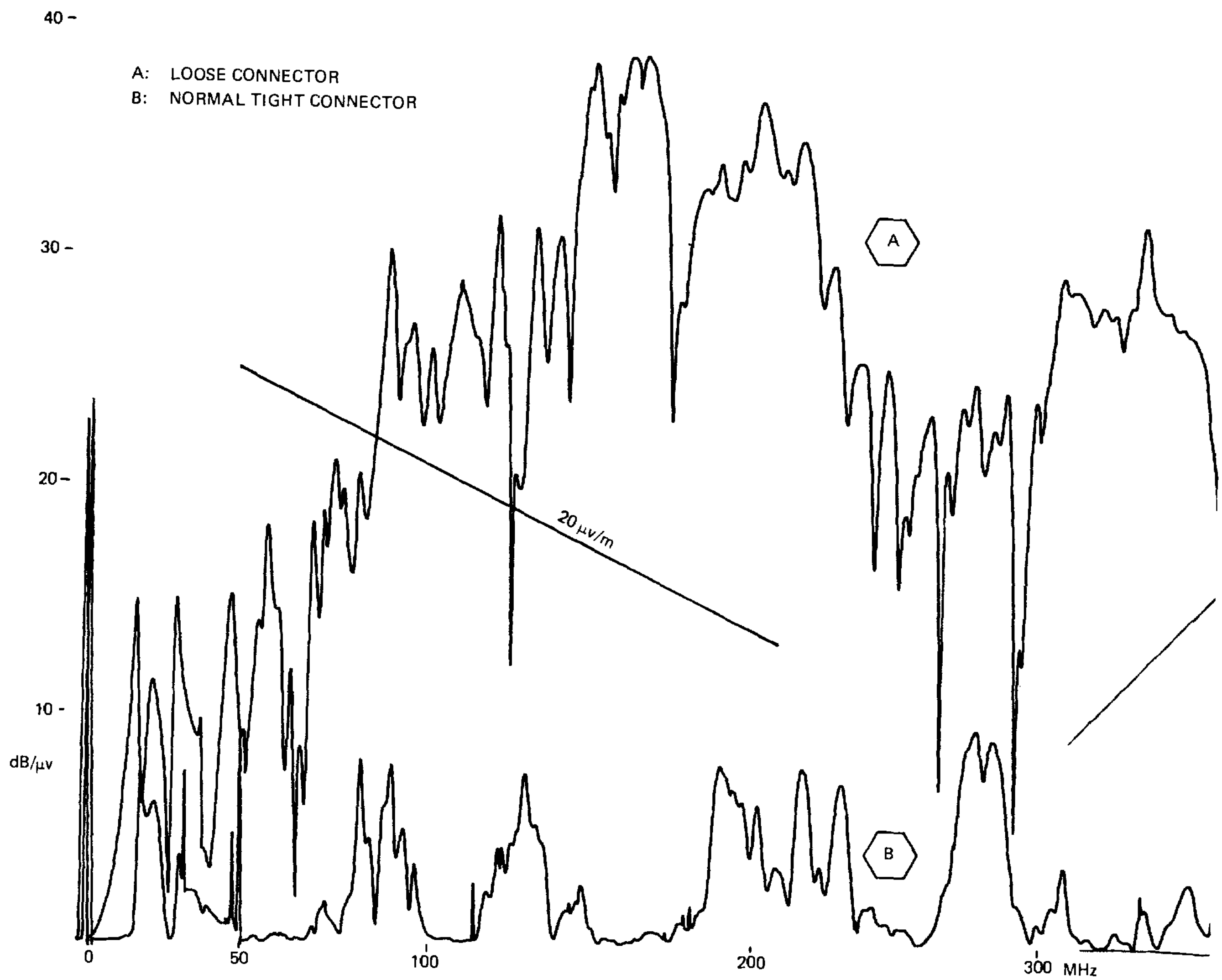
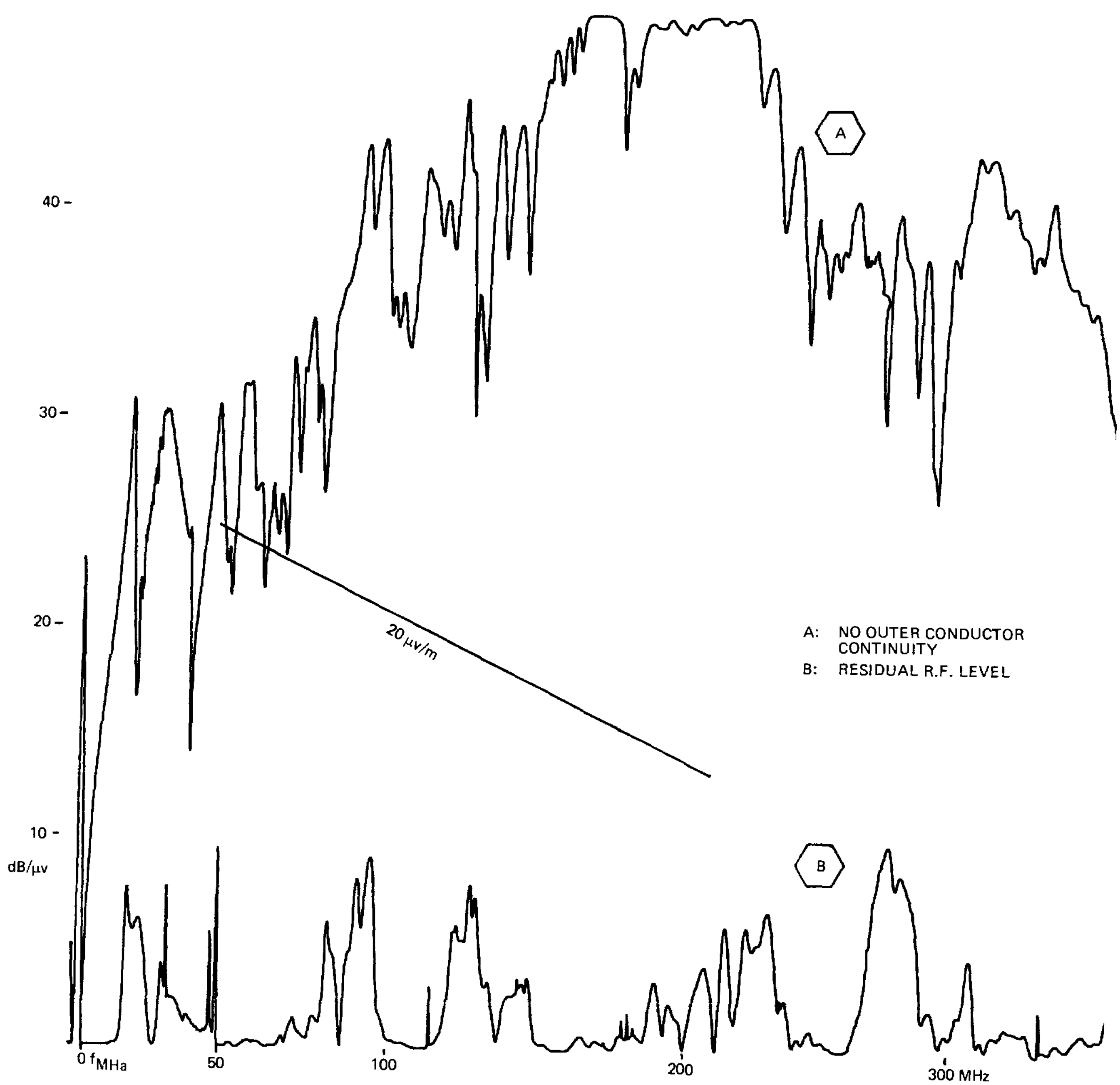

40
30
20
10
dB/μv
A: LOOSE CONNECTOR
B: NORMAL TIGHT CONNECTOR
A
B
20 μv/m
0
50
100
200
300 MHz

Figure 8



40 -
30 -
20 -
10 -
dB/µv
A
B
20 µv/m
A: NO OUTER CONDUCTOR CONTINUITY
B: RESIDUAL R.F. LEVEL
0 fMHa
50
100
200
300 MHz

Figure 9

LIGHTNING AND SURGE PROTECTION OF CATV FACILITIES

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Copiague, N. Y.

CATV facilities, generally, operate in an exposed condition to both power and lightning influence. All CATV systems require protection, not only for the system components but, also, for the connecting power service and subscriber drops. Proper application of voltage-limiting devices, such as gas tube arresters, and the proper use of bonding and grounding methods will provide the required protection.

Everyone, like it or not, is in the communications business. In talking to people, as I am to you, selling things, getting ideas or opinions across, handling work, and just about anything else you can think of, communication is an integral part. It is a basic ingredient in the recipe for living, and success in life depends largely on one's ability to handle it.

The CATV industry has recorded a remarkable growth in a short span of time. No doubt this is just the beginning. The capacity of the CATV facility to deliver information, in both one and two-way systems, is limited only by the imagination and man's own ability to conquer the associated problems.

For many reasons, systems builders in the past have paid very little attention to or made adequate provisions for lightning and power surge protection. Proper coordination and bonding procedures are, in most cases, either nonexistent or not maintained after they are installed initially.

In an effort to simplify the situation to the fullest extent, the following discussion of problems, which no doubt most of you, as I, have seen, will begin with a review of Ohm's law.

$$E = I \times R$$

E = Electromotive Force or Voltage
I = Amount of Current Flow or Amperes
R = Resistance, or Impedance, when dealing with anything other than Direct Current (Impedance is the combination of Resistance, Capacitance and Inductance, in any combination, when Alternating Current (AC) is flowing in the circuit)

Question No. 1: If we have a cable whose surge impedance is 100 ohms and it is in contact with 15,000 volts, 60 cycle AC, what is the current flow?

Answer:
$$E = I \times R$$
$$15{,}000 \text{ v.} = I \times 100 \text{ ohms}$$
$$I = \frac{15{,}000}{100} = 150 \text{ Amperes}$$

Question No. 2: What is the current flow if a cable whose surge impedance is 100 ohms is in contact with 1,000,000 volts?

Answer:
$$E = I \times R$$
$$1{,}000{,}000 \text{ v.} = I \times 100 \text{ ohms}$$
$$I = \frac{1{,}000{,}000}{100} = 10{,}000 \text{ Amperes}$$

The first question above can be easily related to CATV plant in contact with ordinary, primary power company distribution voltages. The second question can be related to a very weak lightning surge.

Power related surges in CATV plant are destructive in that they are relatively long in duration and produce large amounts of heat wherever shield resistance is highest. This usually results in fusing (melting) of the shield, metal separation, then arcing and possibly fire, if around low temperature or kindling materials such as wood and polyethylene.

Lightning related surges differ from power related surges in that they are of very short duration, very high voltage, and very high current. Voltages in the millions of volts. Current in the hundreds of thousands of amperes. Duration, several hundred milliseconds or at most, or longest, one-tenth of a second.

Time does not permit a thorough examination of lightning. We will simply accept the fact that it exists, discuss how it can damage CATV facilities and devices connected to CATV facilities, and what can be done to effectively reduce damage and outages to a minimum.

Cloud-to-earth lightning strokes are the specific "lightning" which is most damaging to exposed plant. Lightning may contact directly any part of the CATV system. This is the most damaging form of influence, as a part of the CATV plant is in the direct path, or circuit, between the cloud and the earth. The impedance of the CATV plant is so low in comparison to the overall circuit that we can simplify the situation and say that the cloud is a constant current generator during the stroke. Lightning strokes, as seen by the human eye, consist on the average of five strokes, the first being the most severe. Lightning, therefore, is AC; and its noise properties or influence extend upward several hundred kilohertz in the power spectrum. Lightning surge current peaks can reach magnitudes of several hundred thousand amperes. This produces forces which have a crushing effect upon conductors and which build to explosive levels in insulators or semiconducting materials, such as wood or brick. Persons struck by lightning receive a severe electrical shock, usually accompanied by burns. These persons can be safely handled <u>immediately</u> and should be administered artificial respiration <u>immediately</u> to restore normal respiration and pulse or heart beat.

CATV plant damage due to lightning allows the exercise of economic discretion with regard to protection requirements. From Weather Bureau charts and stroke factors, predictions can be made as to how many times per year any portion of the CATV plant will be affected by lightning. The protection against electrical shock to operating personnel and users is of uncompromising importance. Practical protection engineering will provide adequate protection and prevent needless expense or overprotection.

CATV "Head-Ends" usually employ very high structures to support antennas to receive signals. These structures provide favorable discharge points for lightning strokes that would otherwise strike the earth in the same vicinity. The higher the structure, the more the influence. These antennas conduct very high surge currents into the head-end facility and, also, into the trunk and distribution facilities, if the head-end facility is not adequately bonded and gounded. A single pointed rod, with the point upward, several feet above the highest antenna, metallically connected to the steel tower or bonded by straight wire down a wooden pole, and connected to a good "earthing" electrode, will diminish appreciably if not eliminate direct hits on high antenna. Insulated antenna elements can be effectively "grounded" to lightning by using quarter-wave shorted stubs attached at the antenna terminals. All coaxial downleads should be bonded at the top and bottom of the tower or pole structure. At the bottom, before entrance to the head-end facility or building, bonds should be placed to the "earthing" electrode, power company neutral, and water system metallic piping, if available. All coaxial cables extending from the facility should likewise be bonded in the same way. <u>Straight</u> #6 copper wire should be used and is sufficient, if not buried in the earth below ground level. Buried ground conductors should be #2 copper or equivalent.

Large currents introduced into CATV head-end equipment may be affected to a great degree by many electrical factors. In order to protect personnel from hazardous voltages, each component part mounted in each rack should be bonded together with a #6 ground wire and this wire ultimately terminated at the same point as the other ground conductors. Keep all ground conductors as short as possible.

A discussion of conductor impedance to lightning at this point should be helpful. If we compare a copper wire that contains twice the copper as another copper conductor (#3 CU vs. #6 CU), the large conductor will only improve our surge impedance to lightning about 28% over our small conductor! If we use two #6 CU conductors in parallel, we improve the surge impedance to lightning by about 68% over one #6 CU conductor. Therefore, if we bond everything together, we greatly reduce the surge impedance to lightning and reduce our susceptibility to damage from lightning. This is also true with power contacts to CATV facilities. The higher the fault current, the faster the operation of the fault current devices.

CATV transmission line is unbalanced and, therefore, very susceptible to any electrical impulse by induction, capacitive coupling, or direct contact. The susceptibility can only be reduced by reducing the "shield" current, and the most effective way is to provide as many parallel conductors as possible. Bonding of the CATV shield to the power company multi-grounded neutral, the telephone company cable shield, and the pole ground effectively reduces the surge impedance of the CATV plant to lightning.

Periodically, depending on system design, amplifiers are inserted in the transmission line to amplify the useful information. Today these devices are completely solid-state and are very susceptible to surge effects. Gas tubes provide effective means for protecting these devices from lightning and power-induced surges. Two, two-element devices are now used, but a superior three-element device is now available which can be employed to more effectively by-pass all surge conditions. The three-element device exhibits very low capacitance to the input and output of an amplifier and can carry several magnitudes of current greater than existing two-element devices. It is virtually transparent from zero to 300 megacycles; however, some redesign of amplifier cases may be necessary in order to keep lead lengths as short as possible.

Distribution and trunk line power supplies connected to power company distribution facilities offer another use for three-element gas tube protection. Unsymmetrical phase voltages, between two CATV power sections, may cause very high voltages to appear on the CATV conductors. These voltages can be effectively suppressed by three-element gas protectors installed on the power supply units. By careful design, with surge protection as one of the paramount criteria, systems can be made much more reliable than envisioned today and, possibly, with much reduced maintenance costs to the operator. System reliability will begin to be more important as time passes.

Terminating a CATV system in the customers' premises presents an interesting exercise in how surges on the system can cause outages. If we admit that the power company and telephone company have bonded their station grounds together and to the water system, if possible, then how do you, as CATV operators, do the same? It does take persistence in most cases. First, the shield of the CATV drop should be metallically bonded to the power company's neutral and the water system, if metallic. (The power company and telephone company grounds, normally, will already be connected to a good ground and bonded together; and by connecting to this common ground, an effective common ground is maintained on the CATV facility also.) Routing of the CATV drop to the customer's premises to allow short bonds should be planned and executed.

Connection to the customer-owned television set is usually made through a transformer (75 ohms to 300 ohms). This transformer usually has very low insulation resistance or voltage breakdown. In addition, the input to the television set tuner is not much better. Power or lightning surges make "smoke" out of these two devices, because no attention is placed on common bonding at the television set. The shield of the CATV drop should be metallically connected to the chassis of the television set, and the chassis of the television set should be connected to the "common ground." The easiest and simplest way to accomplish this is to provide a three-conductor line or power cord to the television set. If this cannot be effected in its entirety, then a #6 copper wire must be run from the TV set chassis, as straight as possible, to the "common ground." This bond will prevent the TV chassis and CATV drop from being at different potentials and causing the television set's power supply from "arcing over" or puncturing the insulation on the transformer windings.

In conclusion, I hope that I have shared with you, in simple language, ways in which you can improve the reliability of your CATV systems and prevent damage to your equipment and your customers' connected equipment.

As Dave Bodle so aptly puts it, "No longer should lightning damage be accepted fatalistically as an 'act of God,' since the know-how and hardware exist today to minimize the adverse effects. The major aspect of the problem now is economics."

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LOCAL ORIGINATION: LAYING IT ON THE LINE

by OLIVER BERLINER
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The ability of the cableman's local originations to compete with the slick productions carried on other channels of his own system, is controlled by economic, legal and personal factors. Here are thoughts about getting into origination as inexpensively and effectively as possible, while minimizing the differences in budget and showmanship between your originations and the retransmissions.

The furor created by an article of mine which appeared in the March - 1973 BM/E Magazine under the title, "The Hell With Helicals," has prompted this further review of the entire subject of the technical capabilities... and limitations... with respect to the CATV operator who dives into origination because the FCC said he must, because he wants to keep community bigwigs (and pressure groups) "off his back", through a desire to be a showman either via his own creations or thru the airing of programs produced elsewhere, or finally... for commercial revenue.

Whatever your motivations are, unless you're a Teleprompter, a Theta, a Sterling or one of the few other "monster" MSO's, you have little chance of competing with the artistically and technically superior programming from Hollywood carried on your very own system. I am not here to tell you of any solution to this dilemna... because at present there is none. The Los Angeles -- Orange County area is, however, unique in that there are a number of cable companies located relatively near each other. Months ago I recommended to all of them that they make no origination-equipment investment of any consequence, but instead utilize my studio on a contract basis. In this way they would all have access to production personnel and equipment superior to anything they could provide individually. Not a single one of them was interested. Later on I shall show you what they missed; something which I believe exquisitely points-up the addage that if you don't hang together, you will all hang separately.

One of the questions I'm often asked is, "With my limited budget, should I invest in lavish monochrome equipment or modest color facilities?" The answer is that I know of one California community where a network affiliate with old, outmoded monochrome facilities is now being "killed" by an independent UHF transmitting in color. Even the color network feeds are unable to sustain him. Clients are no longer willing to buy time on his local black-and-white originations... even network "adjacencies"... because the viewers in the area will no longer settle for less than color -- and there isn't enough revenue for him on the network feeds alone (as all "affils." will testify).

Luckily, when the FCC required certain CATV systems to originate, they simultaneously encouraged them to sell commercial time. In view of this, and because live color video equipment is costly, you might consider the purchase of a film chain, color -- of course, incorporating a good 16mm projector with both optical and magnetic audio, plus a 2 X 2 slide projector. 16mm prints of major entertainment productions may be rented; there is a wealth of brilliantly produced educational film available at little or no cost; you can shoot 35mm color slides of local events while simultaneously recording audio on a good home recorder. You then run your local news via these slides with sound, plus local voiceover, if desired. There are innumerable fine amateur photographers who would be thrilled to shoot your slides for you in return for on-the-air credit and a "press card" in their pockets. Later, you may even afford to shoot single-system super-8 film with synchronous sound... and get a sponsor to pay for it.

You'll notice that I've avoided mention of live cameras and video tape. The reason is that film combined with an inexpensive but FCC-approved sync generator gives you broadcast-grade transmission... something you cannot get from your video tape recorder unless you wish to spend some twelve to thirty thousand dollars on it alone, to say nothing of color cameras, monitors, tripods, lighting, support equipment and crews to run it. All this is the raison d'etere for film and slides. When your local origination prospers you can augment your optics with teleproduction equipment, yet your film chain will continue to get plenty of use ... never fear... for film is so well-established as to be very indispensable. Furthermore, why not provide a film-to-tape transfer service available to all who wish to pay for it? Advertise the availability of your service by way of spot announcements on your own cable system, and elsewhere.

I have pointed out that optics may be your best way of getting into origination -- all things considered. When the time comes for live video, you are faced with problems in video tape playback... problems not present in film. You could avoid these problems by doing everything live, but this would soon prove unwieldly. Herein lies the rub, because no inexpensive video tape recorder, even when augmented by a helical processor, can deliver the time-base stability needed to synchronize the sweep circuits of your viewers' receivers to your video tape recorder's playback. Now, much ado has been made over this bugaboo called "time base". In essence, this instability is caused by irregularities in tape motion and helical-scan motion further aggravated by tape stretch and shrinkage. Quadruplex recorders avoid this problem by using high tape speed, expensive transport mechanisms, correction circuitry and a transverse scan system.

But what of these cablemen who are laying video cassette playback on the line? Well, simply, they're "getting away with it"... for the time being. But since most home receivers don't have the fast AFC time constant to accomodate helical VTR transmissions, you can expect that viewer indifference will not long last. At one time a viewer was content to marvel at a test pattern of dubious resolution. Perhaps cable originations are in this stage at present. But eventually you'll be "tuned out", with all the reception difficulties blamed on you -- including some that aren't your fault. There is no question in my mind that eventually the FCC will be as tough on you as it is on commercial broadcasters as far as sync specifications are concerned; and then I guess we'll see thousands of used video tape recorders up for sale across the country. But for the time being, the decision in this area is left to you. I might venture to offer this rule of thumb: Let your video tape recorder cost at least as much as your best tv camera.

In conclusion, let me take a moment to show you some views of a sophisticated color television production center incorporating the least-expensive broadcast-grade equipment available... although we did splurge in a few areas, as you will see.

MUTUAL INTERFERENCE EFFECTS IN DATA/CATV SYSTEMS

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ABSTRACT

The addition of data channels to CATV systems raises several problems for system designers. Among these are the determination of the best frequency slots and the proper signal levels for the data channels.

From a general intermodulation and distortion analysis this paper presents an evaluation of the mutual interference between data and TV channels. Undesired signal levels are presented for various frequency schemes and as a function of relative signal levels. By coupling this analysis with the susceptibility to interference of TV and data channels, suggestions are made regarding the design of the composite signal spectrum.

1.0 INTRODUCTION

With the increasing prominance of CATV systems, new services are being proposed that require data transmission on CATV systems. To engineer systems that accomodate data it is necessary to understand the mutual interference properties of data and TV channels which propagate over a common amplifier chain. In general, DATA/CATV system performance will be limited by the effects of noise and distortion components. The performance of television channels and data channels in the presence of noise is well understood and predictable. On the other hand, little work has been done which directly investigates the performance of television and data channels when contaminated by complex distortion products, i.e., it would be difficult to determine the effect on either a data or television channel by a DXT component (the intermodulation product produced from a data channel intermodulating with a television channel). Depending on the contributing components of the distortion product (D.P.) the product can have a wide range of characteristics and in this paper all interfering signals are given equal weight in terms of their relative effects.

Section 2 presents a general treatment of the distortion problem including the frequency distribution of DXT components within a 6 MHz band and the approximate expressions for distortion levels which are used in the system analysis presented in Section 3. In Section 3 an approach is presented for determining allowable amplitude levels for data channels in a CATV system. The approach for determining allowable levels is based on the strategy that a certain percentage of the allowable TV channel, interference (noise and distortion) budget be allotted to effects resulting directly from the addition of data channels. This approach appears viscerally sound and has the further advantage of related precedent.

With the advent of the communication satellite, tolerable flux density levels were based on a percentage of allowable noise levels in a reference telephone circuit. This was appropriate since the satellites shared the 4 and 6 GHz bands with terrestrial microwave facilities and were a source of interference. It should be noted that this sharing arrangement resulted in certain standards for the terrestrial facilities which were the first to occupy the band. An example is the limitation on radiation towards points on the synchronous belt. Similarly it is reasonable to expect certain requirements for TV related equipment to allow dependable data transmission.

2.0 DISTORTION COMPONENTS

A basic procedure for characterizing amplifier operation is to represent its transfer characteristic with a power series expansion and the amplifier can then be characterized by the coefficients (a_j) of the terms of the power series, i.e.,

$$e_o = \sum_j a_j e_i^j \qquad [1$$

where e_o is the set of output signals and

e_i is the set of input signals. Expressions for each component of e_o, both desired and undesired, can be obtained by substituting for e_i its frequency components, expanding the terms of the power series and collecting coefficients which contribute to a particular output signal. In summary, each term, in the power series representation of the transfer characteristic, whose order is equal to, or exceeds by a multiple of two, the order of a D.P. contributes to the level of the D.P. For near linear operation only the lower order terms contribute significantly with the higher order terms contributing for highly nonlinear operation.

It can safely be assumed that lower order terms predominate for CATV systems and approximate expressions for second order—DP(2)—and third order—DP(3)—distortion components will be

$$DP(2) = \gamma_2 A_1 A_2$$
$$DP(3) = \gamma_3 A_1^2 A_2 \qquad [2$$

γ_2 and γ_3 characterize the amplifier and A_1 and A_2 are input signal levels in volts-RMS. Expressions for signal harmonies are similar with $A_1 = A_2$.

In a cable system which is operating properly in a relatively linear mode, D.P.'s of order greater than three should be minor relative to second and third order products. Further analysis in this section will therefore deal with the second and third order products. Push-pull amplifier operation results in cancellation of even order products and for this class of systems third order D.P.'s may be the dominant consideration.

Figure 1 illustrates the general shape of the D.P. resulting from broadband signals. As can be seen, second order D.P.'s bandwidth would be twice that of the bandwidth of the basic signal for the case where the products are due solely to one signal and are the sum of individual signal bandwidths when the D.P. is due to the interaction of two separate signals. Similarly, third order products are triple the bandwidth of the contributing signals.

The distribution of D.P.'s for two separate frequency schemes on a cable system is illustrated in Figures 2 and 3. Figure 2 considers a basic twelve channel TV complement and two data channels spaced between 24 and 36 MHz. The location of second and third order products is shown together with a very rough distribution of the composite distortion. Figure 3 presents the distortion components for a broadband system in which the midband also has TV channels. It is observed generally from these two figures that distortion results in broad spectrum interference and that it is impossible to locate the data channels such that they are completely free of TV channel related distortion products.

In addition to the general disposition of the envelope of distortion products over the total system frequency band it is helpful to understand the position of individual products within a given 6 MHz TV channel since the basic frequency scheme for placing data on broadband cable systems will follow an arrangement of channels related to 6 MHz frequency blocks. Figures 4 and 5 illustrate the distribution of distortion components resulting from various portions of the TV signal and an anticipated data signal. The TV signal is considered for this analysis to consist of three basic components: (1) the luminance carrier at 1.25 MHz, (2) the chrominance carrier at 4.83 MHz, and (3) the sound carrier at 5.75 MHz. A TV channel consists of frequency components across the 6MHz band; however, for periods of low information content signal energy will be concentrated at the above three frequencies and they can be considered as most important for the analysis of D.P. products. When two TV channels interact, intermodulation products are produced from all combinations of the above carriers. That is, the video from Channel 1 can mix with the sound carrier of Channel 2 to create either a second or third order D.P. The frequencies within a 6 MHz band at which the D.P.'s will occur is predictable and independent of the actual channels involved. Figure 4 presents a spectrum for all second and third order distortion products resulting from TV channels alone. The amplitudes of the individual components are established via an ordering procedure. The ranking of component amplitudes is considered relative to the largest anticipated intermodulation product which is the second order product achieved from two luminance carriers. Reductions in ranking reflect the carriers involved and the order of the D.P. The sound carrier is one order less than the luminance carrier and the chrominance carrier is one order less than the sound carrier. Third order products are two orders less than second order products. For the case of a sound carrier mixed with a chrominance carrier and creating a third order product, a ranking of 6 is achieved. This qualitative ordering procedure is used in lieu of a detailed analysis for which system specifications must be assumed and which would only serve to limit the amplitude spectrum to that system.

Further analysis assumed the inclusion of data channels and the data cross TV components are shown for second and third order products in Figure 5 for the case of a data channel at 2.0 MHz. Similar results were achieved for locations of the data channel 2.0, 3.0 and 4.0 MHz.

If the data channel is such that it will not include a full 6 MHz band Figure 4 illustrates desirable locations within the channel for minimal interference to the data channels from TV channel D.P.'s.

3.0 SYSTEM PERFORMANCE

The question of interest is, "How do data channel design parameters relate to TV channel interference and is sufficient latitude available in the selection of data system design parameters?" Figure 6 presents performance curves for data channels contaminated by noise and by noise plus a number of carriers. The latter is appropriate since it has application to the noise plus distortion analysis which follows. It is apparent that basic data channels are far more rugged than TV channels and that this fact can be used to advantage in structuring the spectrum of a DATA/CATV system.

It is useful at this point to investigate the levels of noise and distortion and the following definitions will apply in this analysis.

N_D = Number of data channels

N_T = Number of TV channels

V_D = R.M.S. voltage of data signal at amplifier output (volts)

V_T = R.M.S. voltage of TV signal at amplifier output (volts)

γ_2 = Second order intermodulation coefficient (volts^{-1})

γ_3 = Third order intermodulation coefficient (volts^{-2})

η = Signal-to-noise plus distortion ratio

K = Boltzman's constant

F_e = Amplifier noise figure

T = 290° Kelvin

B = Channel bandwidth (Hz)

G = Amplifier voltage gain

R = System Impedance=75Ω

α = That portion of the total distortion component power which is assumed to fall in a 6 MHz band $\approx 10^{-2}$

The second order distortion products from a single data channel are at a voltage level that can be represented by

$$V_2(DxD) = \gamma_2 V_D^2 \qquad [3$$

For η_D data channels, there are η_D^2 components which are effectively non-coherent

$$V_2'(DxD) = \gamma_2 V_D^2 \eta_D \qquad [4$$

The contributions to a specific product from each amplifier are assumed coherent, therefore, the total distortion measured over the system bandwidth is

$$V_2''(DxD) = \gamma_2 V^2 \eta_D m \qquad [5$$

Similarly for TV channels

$$V_2''(TxT) = \gamma_2 V_T^2 \eta_T m \qquad [6$$

For data and TV cross products, we have

$$V_2''(TxD) = 2\gamma_2 V_T V_D \sqrt{\eta_D \eta_T}\, m \qquad [7$$

and the noise power at the output of the last amplifier of a string of m amplifiers is

$$N_p = G^2 KTBF_e m \qquad [8$$

From these expressions for the noise and distortion components and the fact that their powers add, an expression can be written for the signal-to-noise ratio in a data channel

$$\eta_D = \frac{V_D^2}{\alpha\gamma_2^2 m^2 (V_D^2\eta_D + V_T^2\eta_T)^2 + N_p R} \qquad [9$$

Equation 9 is plotted on Figure 7 for parameters typical of CATV operation, 10 data channels, a data channel level of 20 dBmV and bandwidth of 6 MHz. Comparison of Figures 6 and 7 indicates that signal-to-noise is sufficient after a long string of amplifiers to allow good data channel performance at an operating level well below that of the TV channels.

If is further interesting to define the interference ratio—K_2—by the following equation.

$$K_2 = \frac{(V_D^2\eta_D)^2 + (V_D V_T)^2 \eta_D \eta_T}{(V_T^2\eta_T)^2 + N_p R/\gamma_2^2 m^2} \qquad [10$$

K_2 is the ratio of the second order distortion created by the presence of η_D data channels to the total noise plus distortion existing for TV only. Considering the most significant distortion products, the ratio for third order distortion effects can be written as

$$K_3 = \frac{(V_D^2\eta_D)^3 + (V_D V_T)^3 \eta_D \eta_T^2}{(V_T^2\eta_T)^3 + N_p R/\gamma_3^2 m^2} \qquad [11$$

Figures 8 and 9 present K_2 and K_3 plotted with the major data channel parameters—η_p, V_D—as independent variables and with the other parameters fixed at values reflecting CATV system operation.

4.0 RESULTS AND CONCLUSIONS

The interference ratio suggested in this paper provides a flexible procedure for investigating the effects of additional channels in a broadband cable system. Proper frequency allocations and level control must be based on distortion considerations and distortion analysis of complex signal structures is not tractable. This has necessitated several simplifying assumptions which restrict the results to general guidelines with more specific analysis required for specific problems.

Basically, data channels are far more rugged than TV channels and as a result the most favorable frequency bands should be reserved for TV with the data channels allocated to those positions which are least favorable from a noise and distortion point of view. Also the distribution of individual distortion components within 6 MHz channels does not form a pattern which indicates preferable positions for data channels unless the channels are very narrow band. Care should be taken, however, with the positioning of key signals within the data band such as synchronizing signals and order wire channels.

The selection of operating levels for data channels is based on a trade-off of

- Additional overall system distortion to TV channels
- Design flexibility for the data modem.

From the data presented here, it appears that an operating level 10-15 dB below that for TV would be appropriate since the added distortion would be approximately 1% and satisfactory data channel performance can be achieved with unsophisticated modems.

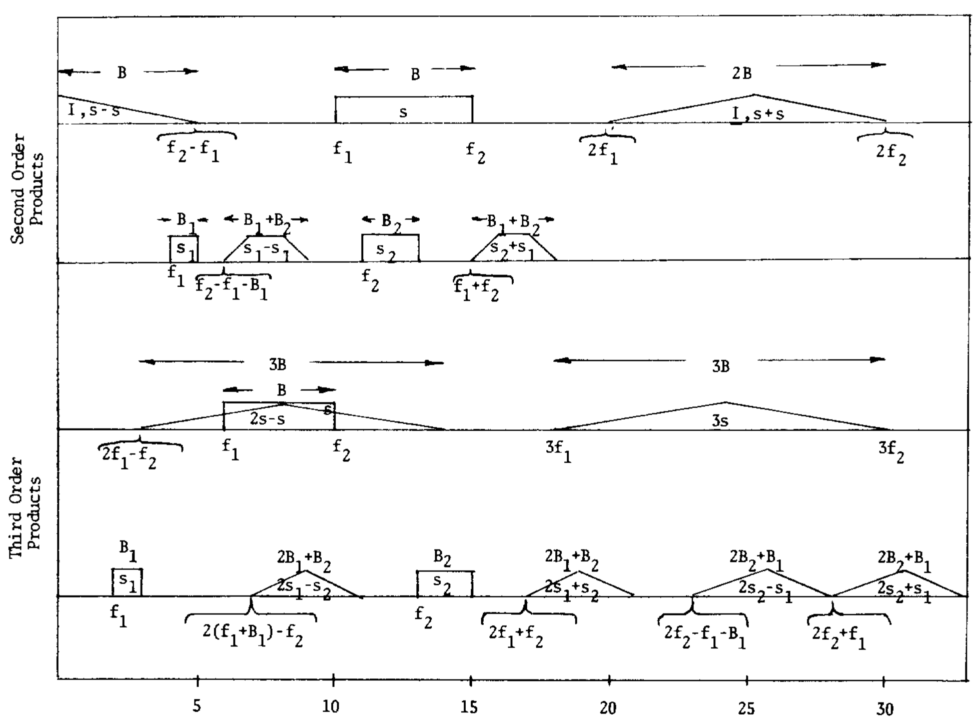


Figure 1. DISTRIBUTION OF SECOND AND THIRD ORDER INTERMODULATION PRODUCTS OF BROADBAND SIGNALS

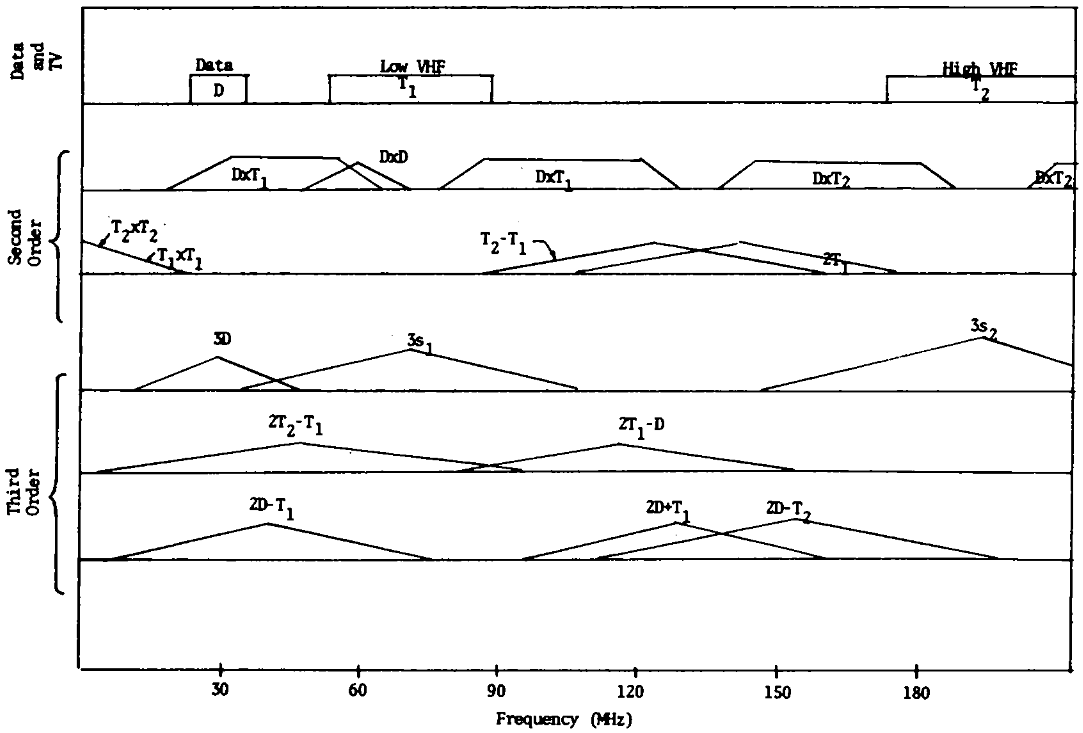


Figure 2. APPROXIMATE D.P. DISTRIBUTION FOR DATA AND 12 CHANNEL TV

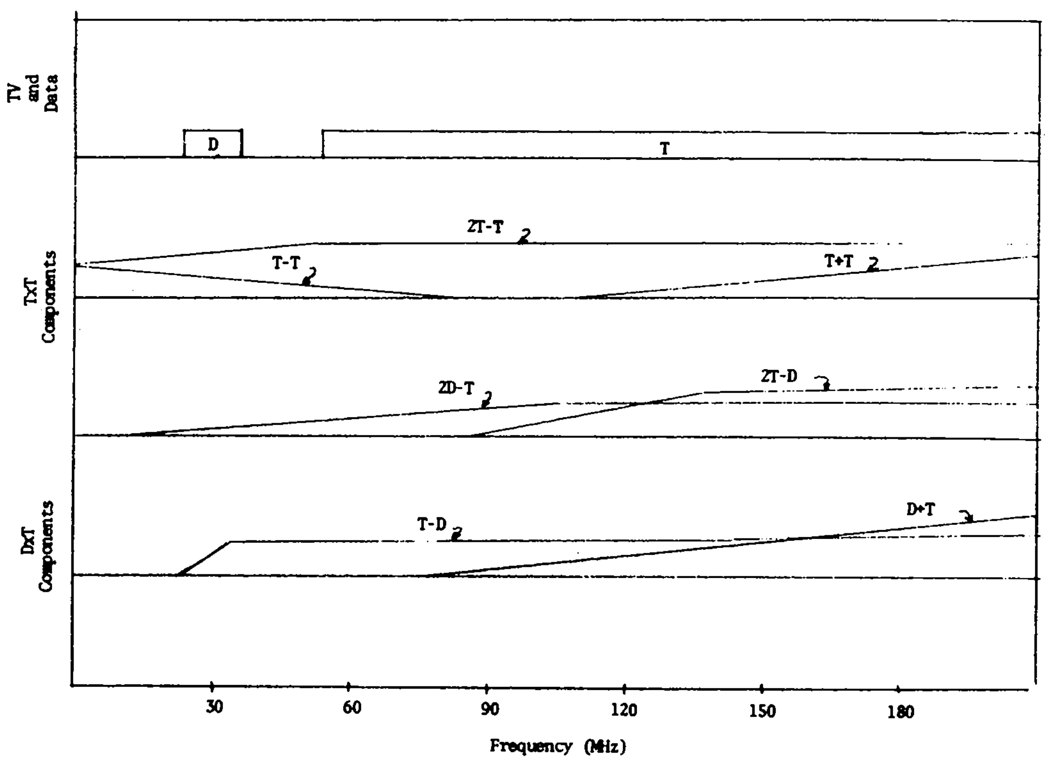


Figure 3. APPROXIMATE D.P. DISTRIBUTION FOR DATA AND 18 CHANNEL TV

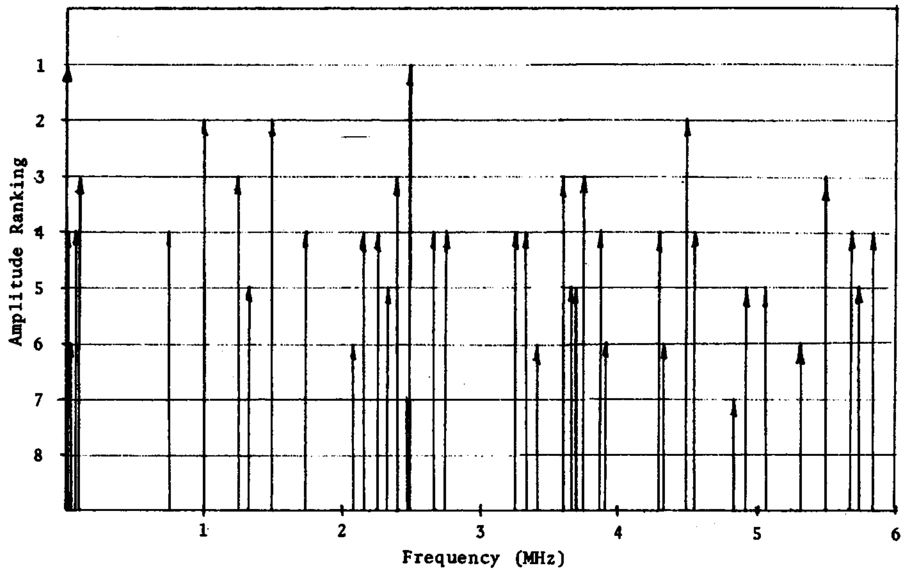


Figure 4. DISTRIBUTION OF SECOND AND THIRD ORDER D.P.'s WITHIN A 6 MHz BAND FOR TVxTV

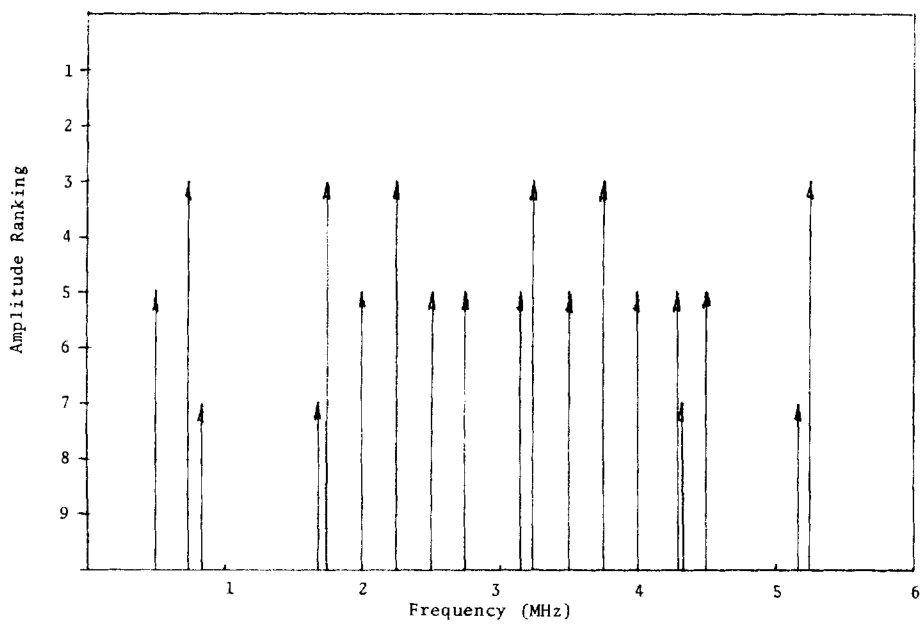
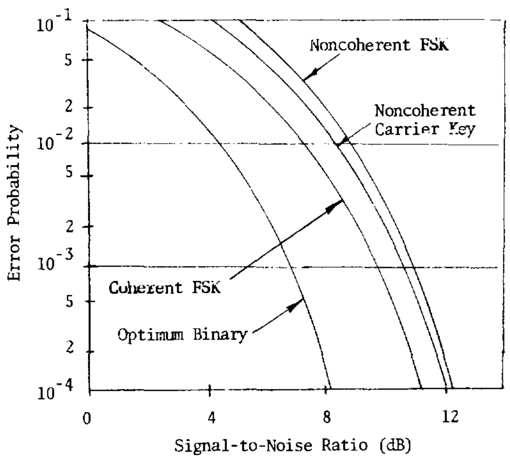
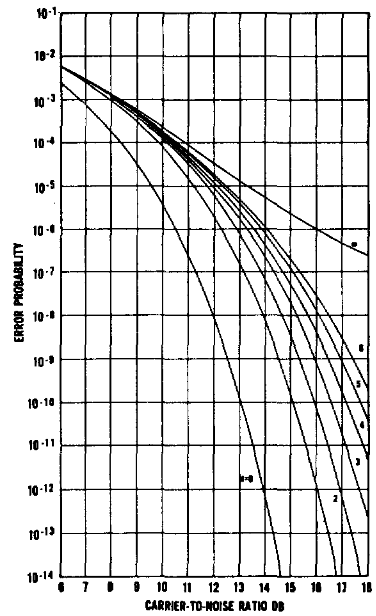


Figure 5. DISTRIBUTION OF SECOND AND THIRD ORDER D.P.'s WITHIN A 6 MHz BAND FOR DxTV AND DxD, DATA CHANNEL AT 2.0 MHz



a. Performance of Data Channels
In the Presence of Noise



b. DPSK Channel Performance in the Presence of Noise and Multiple Tones, Carrier-to-Interference=12dB

Figure 6. DATA CHANNEL PERFORMANCE

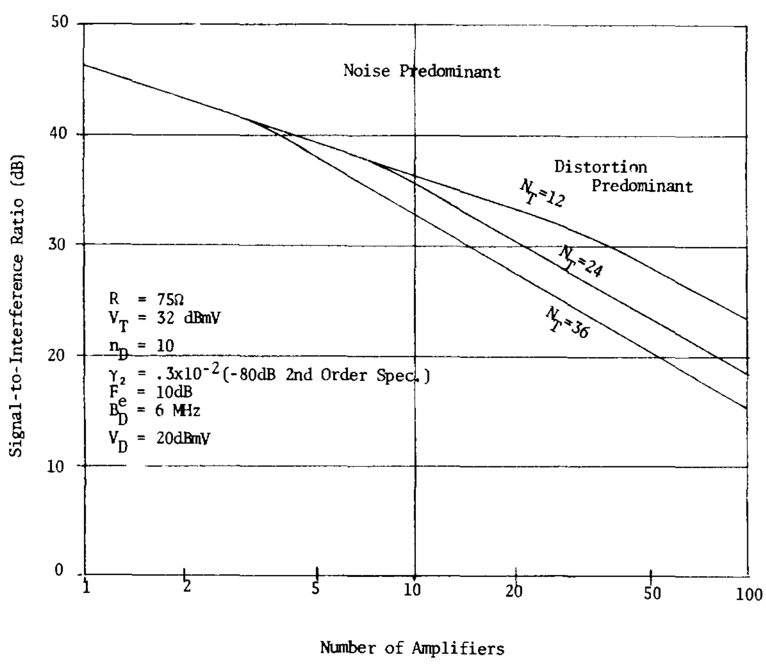


Figure 7. PERFORMANCE OF DATA CHANNELS

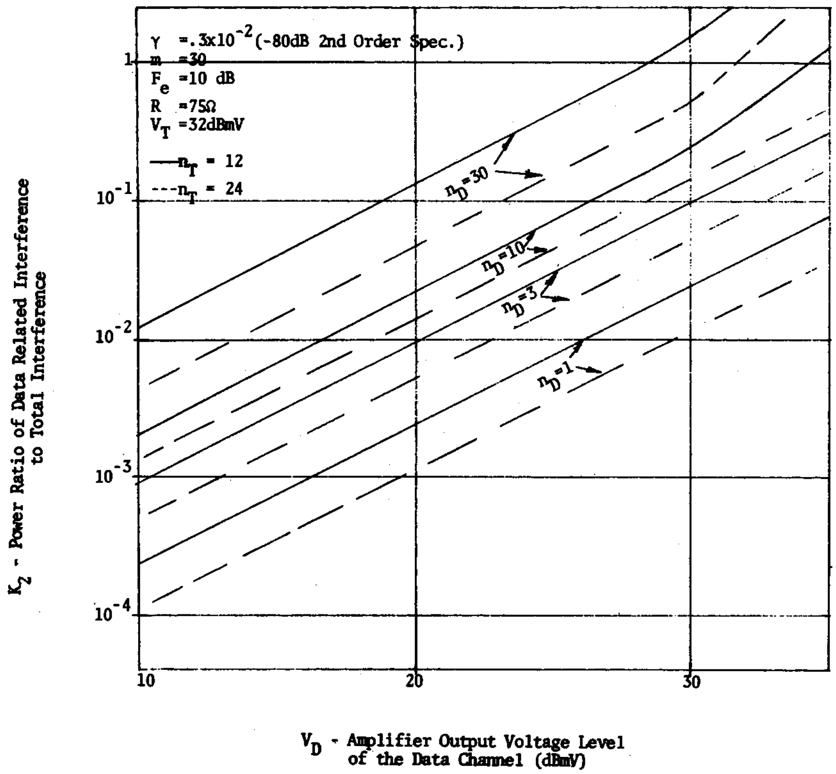


Figure 8. DATA RELATED INTERFERENCE EFFECTS VERSUS DATA CHANNEL PARAMETERS, SECOND ORDER DISTORTION

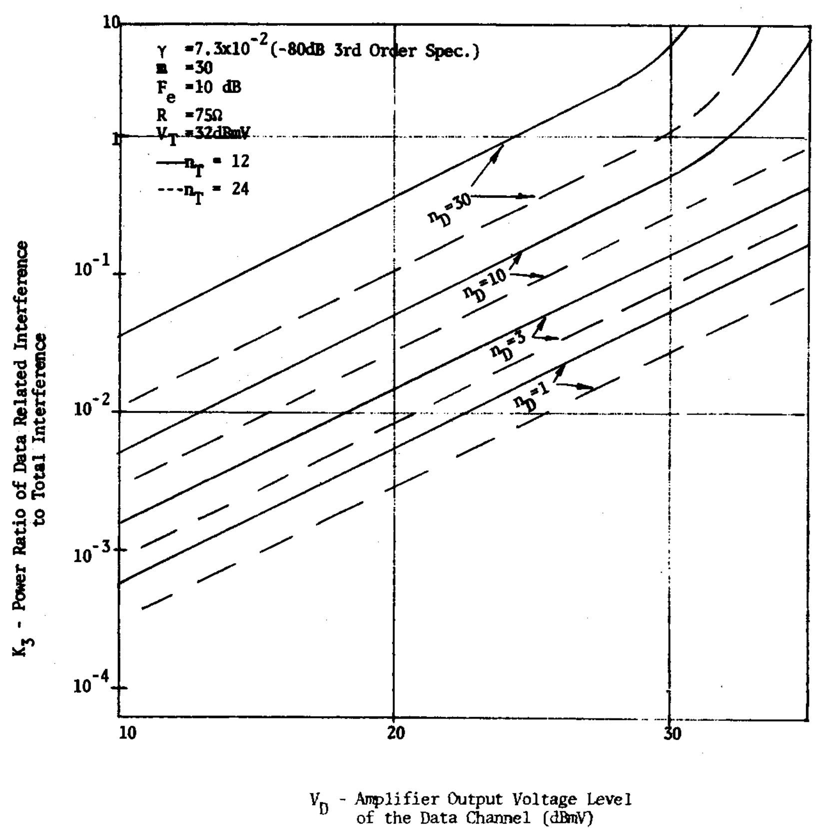


Figure 9. DATA RELATED INTERFERENCE EFFECTS VERSUS DATA CHANNEL PARAMETERS, THIRD ORDER DISTORTION

ON THE REALITIES OF NON-LINEAR DISTORTION IN CATV AMPLIFIERS

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INTRODUCTION

Look at the following statements, and try to mark each one as true or false:

- Triple beats and third-order cross modulation increase by 2 dB for each dB increase in carrier level.
- When the input levels are the same on all channels, the third harmonic component is 15.5 dB weaker than the triple-beat component.
- The cross modulation in an N-channel system is 20log(N-1) dB higher than that measured in a 2-channel test.
- In a wide-band multi-channel system, where the spacing between any two carriers is an integral multiple of a basic frequency, the worst triple-beat interference is in the channel at the center of the band.

We have all been using these and similar rules as a basis for system design and for evaluating equipment, and the fact that we are still in the business shows that there must be at least some truth in each of the above statements. But we have to recognize that, although the statements are correct deductions from certain assumptions, their truth depends on the validity of these assumptions:

1. The output y from a single amplifier, or from the cascade that forms any point-to-point portion of a transmission system, can be represented by a power series of the input x,

$$y = k_1x + k_2x^2 + k_3x^3 + k_4x^4 + k_5x^5 + \ldots$$

   where the k's are defined as independent on the input x.

2. The distortion that limits the operation of an amplifier, and the length of a cascade, is due to the third term in the series. (The effect of the 2nd and higher even order terms can be reduced by push-pull circuitry. The 5th and higher order odd terms are assumed small enough to be disregarded at the levels at which the amplifiers operate).

3. The coefficients k are real numbers and do not depend on the frequencies of the signals.

The only legitimate way to decide the truth of any statement is to subject it to a direct test. If the results are not in complete accord with the statement, we have no choice but to reevaluate the basic assumptions and modify them to agree with reality.

This paper is a report on two experiements that I recently conducted while studying the non-linear distortion in wide-band transistor CATV amplifiers, and my interpretation of the results.

I. THE CASE OF THE ILL-BEHAVED AMPLIFIER

The Motive

I think that we will all agree that the first statement, about distortion vs. level, is not universally true. We have had experience with amplifiers that do deviate from the 2:1 law, and we have been rewarding those that follow this law by the mark of "well-behavior". The "ill-behavior" of amplifiers really poses an intriguing problem, because a 3rd order effect must by definition follow a strict 2:1 law. For example, let a be the amplitude of each of 3 carriers at frequencies f_1, f_2 and f_3, producing a triple-beat at the frequency $f=f_1+f_2-f_3$; the amplitude of the beat would be k_3a^3, and the carrier-to-intermodulation ratio is $1/k_3a^2$. In a dB/dB plot, this is a straight line with a 2:1 slope. How then can the amplitude of a triple-beat deviate from this rule?

Let us look more closely at the problem. We compute the frequency f of the beat, and measure the distortion product which is generated at that frequency. Now it is true that the particular triple beat of the three given carriers can occur only at that frequency and nowhere else, but the converse is not true at all: it does not follow that what we observe and measure at that frequency must be that triple-beat and nothing else. The mere fact that the measurement deviates from the 2:1 law indicates that we must be measuring something else.

I suggest that the deviation from a 2:1 law is due to the effects of higher order intermodulation products, whose magnitudes (at the levels at which the amplifier is tested) are close to those of the 3rd order effects. To justify the assumption, I shall proceed in 3 steps:

1. Prove that higher order terms can contribute distortion products at precisely the same frequency f of the triple-beat.

2. Compute the interaction between third-order and higher-order distortion products occurring at the same frequency.

3. Design an experiment to produce a single isolated triple-beat interacting with different amounts of higher order distortion, and compare the measured results with the theoretical computations.

The Method

A 5th order intermodulation product is generated by the interaction of 5 "parent" carriers; its frequency is a sum and/or difference combination of the frequencies of the carriers, and its amplitude is proportional to the product of their amplitudes. Any given carrier can play the role of one or more of the parents, so that 5th order effects can be generated even if there are less than 5 carriers. In particular, an amplifier processing 3 carriers can produce 5th order products whose frequencies can be computed by A+A-A+B-C, A+B+B-B-C and A+B+C-C-C; this is precisely the same frequency as that of the 3rd order A+B-C combination, no matter what A, B and C are.

If all carriers have the same amplitude a, the amplitude of a 5th order product is proportional to a^5, and the carrier-to-intermodulation ratio would be proportional to $1/a^4$. Plotted on a dB/dB scale vs. carrier amplitude, this would be a straight line with a 4:1 slope. When a 3rd order and 5th order effect produce a product at the same frequency, the resultant beat would be the sum of the two distortion products. At any one given signal level, one or the other component may predominate; but, no matter how small the 5th order coefficient k_5 may be compared to k_3, the 4:1 line must intersect the 2:1 line and overtake it at some carrier level. Fig. 1 shows some of the possible combined characteristics. All the curves start as a 2:1 line on the left, and end up getting close to the 4:1 line on the right; the shape of the curve in the transition region will depend on the phase between the 3rd

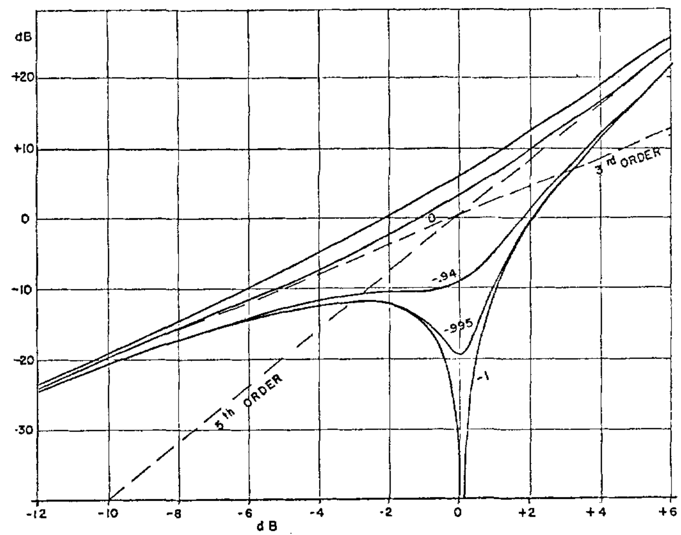

Fig. 1

order and 5th order products. The parameters marked on the curves are the cosine of the phase angle, and a positive value will result in a montonically increasing curve. A cosine of -1 produces a sharp null at the crossover , and any value between -.95 and -1 will produce a curve with a minimum point. The curve resulting from a cosine of -.94 has a flat portion, where the intermodulation is independent of level.

Any curve of this family can be completely characterized by the position of the 2:1 and 4:1 lines, and the phase angle between the two components. Fig. 2 shows a convenient set of such parameters:

X dB - the value of the 3rd order component at an arbitrarily selected level (in this case, 50 dBmV),

Y dBmV - the level at which the two lines intersect, and

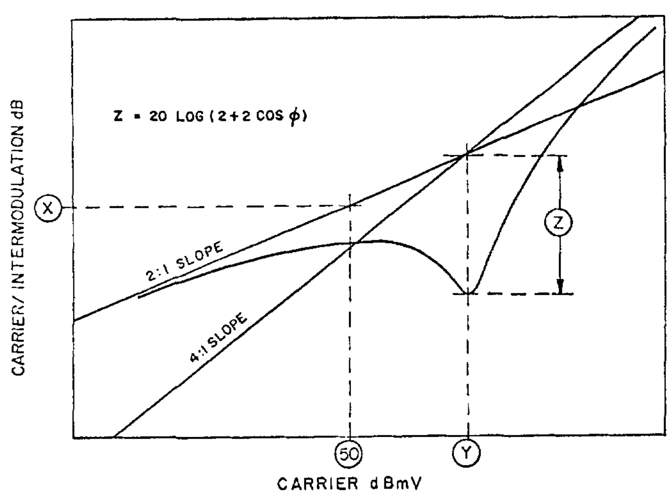

Fig. 2

Z dB - the vertical displacement of the curve from the point of intersection. (This parameter, whose value may vary between + 6 dB and $-\infty$, indicates the phase between the two components.

The curves of Fig. 1 should look very familiar to anyone who has done any measurements of cross modulation or triple-beat. I have successfully matched the curves to the records of numerous measurements made over the years in single transistors and complete amplifiers. However, some interesting features of the interaction can best be studied in a specially designed experiment, which I shall describe here.

In a 12-channel system, with the standard VHF assignments, there is a single "isolated" triple-beat at 119.25 MHz, produced by the intermodulation of the picture carriers of channels 6, 7 and 13. Because channels 5 and 6 are off the uniform scheme of 6 MHz steps, no other triple-beat falls at that frequency, (the closest ones are at 113.25 and 139.25 MHz). It is therefore possible to study the behaviour of a single triple-beat in a multi-channel system. The existence of 5th order components that may contaminate it does not depend on the regular channel spacing, and as the band is gradually filled in (from 3 to the full 12 channels), the amount of 5th order interference, and its effect on the measurements, will keep increasing.

The Clues

The ratio of the measured intermodulation at 119.25 MHz to the carrier level, for various carrier levels and carrier combinations, is shown in the table of Fig. 3. The carrier combinations used were:

MEASURED INTERMODULATION AT 119.25 MHz
IN dB BELOW CARRIER LEVEL

dBmV EACH CARRIER	6, 7, 13 ONLY	12 ADDED	11 ADDED	10 ADDED	9, 8 ADDED	2, 3, 4, 5 ADDED
48	68.5	68.5	68.5	69.5	68.5	68
50	64.5	65	64.5	65.5	65.5	64
52	60.5	61	60.5	62	61.5	59
54	56.5	57.5	56.5	57.5	58	54
56	52	53.5	51.5	51.5	52	47
58	48	49	46	43.5	46	40
60	43.5	42.5	39	35.5	38.5	33

NOTE: THERE IS ONLY ONE COMBINATION OF STANDARD VHF CARRIERS THAT PRODUCES A TRIPLE BEAT AT THIS FREQUENCY
211.25 − 175.25 + 83.25 = 119.25
(13) (7) (6)

Fig. 3

(a) Channels 6-7-13.
(b) Channels 6-7-12-13.
(c) Channels 6-7-11-12-13.
(d) Channels 6-7-10-11-12-13.
(e) Channels 6-7-8-9-10-11-12-13.
(f) All 12 VHF channels.

A cursory examination of the table, by column, will show that in all cases the intermodulation increases with level, although not on a uniform 2:1 rate. Scanning the table horizontally we are due for a surprize: adding channels does not necessarily result in increased intermodulation at the same carrier level. Before you try to dismiss this as a possible error of measurement, let me add that this fact was demonstrated and checked out very carefully. For example, the beat was observed on a spectrum analyzer with all carriers at 52 dBmV, and when the carrier of channel 10 was switched on, going from condition (c) to (d), the level of the beat dropped a very visible 1.5 dB.

When the measurements are plotted in the conventional manner (Fig. 4), they are seen to curve away up from the straight 2:1 line, but the curves are too clustered to show the effect in detail. The same curves are redrawn in Fig. 5 on a distorted grid, in which a pure 2:1 3rd order characteristic would appear as a horizontal straight line, and any deviation from that line is accentuated.

The measurements were analyzed by computer to find how well they could fit a curve of the family in Fig. 1, described by the paramenters of Fig. 2, with these results:

Carrier Combination

	(a)	(b)	(c)	(d)	(e)	(f)
Parameters of matching curve						
X dB	64.6	64.2	64.3	64.5	64.5	64.5
Y dBmV	65.9	58.6	57.4	54.9	56.4	54.3
Z dB	4.5	-0.1	2.1	1.2	1.0	3.1
cos Ø	.41	-.51	-.19	-.35	-.37	.01
Match between measurement and curve						
Peak deviation dB	.20	.18	.15	.21	.59	.36
Rms deviation dB	.10	.11	.09	.14	.37	.26

Observe the last two lines in the table. Taking into account that the measurements were made to the closest 0.5 dB (see Fig. 3), the fit must be considered excellent.

The most interesting result of this experiment is in the "X" values, which are practically identical for all 6 measurements. This means that all the different curves of Fig. 4 or 5 have the same 3rd order component, the difference between the curves being due only to the amounts of 5th order contribution to the measured values. The 119.25 MHz beat was chosen to check this point, because no other combination of any 3 of the 12 channels could contribute a 3rd order intermodulation at this frequency.

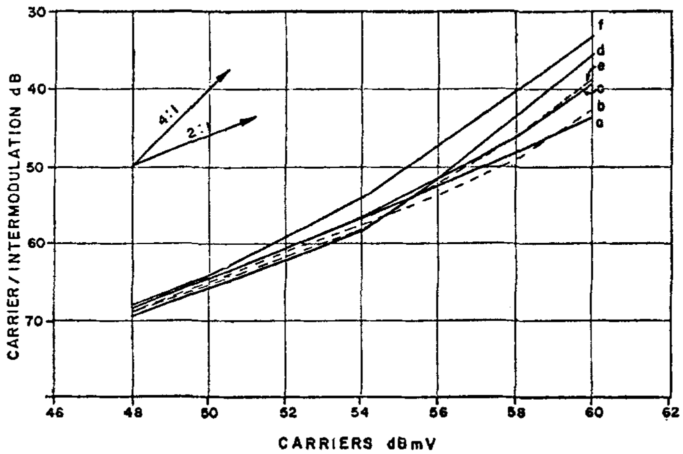

Fig. 4

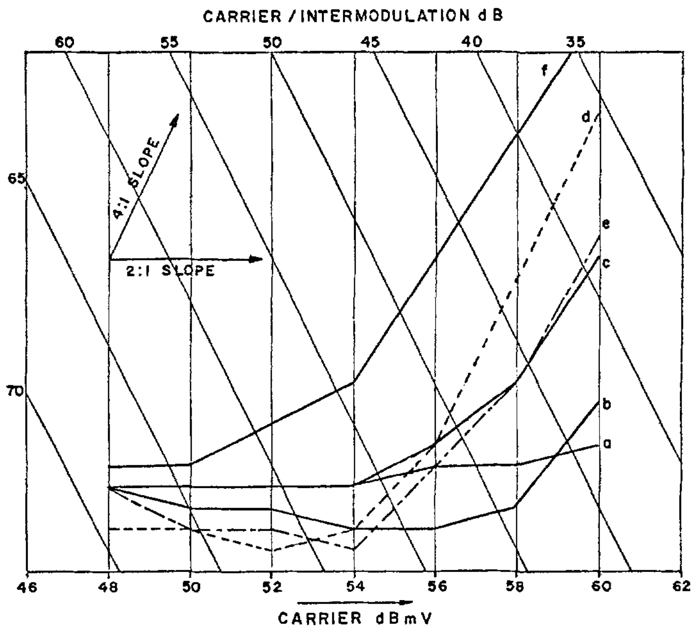

Fig. 5

The "Y" value of the table indicates the magnitude of the 5th order effect, and Fig. 6 shows the 5th order contribution of the various carrier combinations. We see that even in case (a), with only three carriers present, the 5th order effect at 60 dBmV is enough to cause a deviation of 1 dB from the 2:1 line. Adding channel 12 increases the 5th order contribution by 14.5 dB, moving the intercept 7.3 dB to the left; however, at the levels measured, curve (b) is almost everywhere below curve (a)! This is explained by the cosine factor, which is positive in (a) but negative in (b). Curve (a) results from adding a small amount of 5th order to the basic triple beat; curve (b) results from a much higher contribution of 5th order being subtracted.

When channels 11 and 10 are added, the 5th order component keeps increasing, with the intercept moving to the left. But when channels 8 and 9 are added, we suddenly observe the 5th order line receding. Although 8 channels can produce many more 5th order combinations than 6 channels, the relative phases of the contributions must be such that the resultant has a lower magnitude.

The Verdict

The experiment shows that it is impossible to measure a pure triple-beat. The measurement will always be contaminated by higher order distortion products that fall exactly at the same frequency, and this is the reason for the deviation of the measured intermodulation from the simple 2:1 law. (A similar argument can be made about the measurement of a distortion of any order).

The accumulation of beats of the same order, and the interaction of beats of different orders, have to be computed by complex number arithmetic (amplitude and phase). This means that the coefficients in the power series are frequency dependent complex numbers.

No amplifier deserves to be described as "well-behaved" or "ill-behaved". Unless the amplifier characteristic is a pure 3rd order function, it must deviate from a 2:1 law at high enough levels, because a 2:1 line and 4:1 line must intersect somewhere. Unless the amplifier characteristic totally lacks the 3rd order term, any amplifier will behave "well" if the levels are low enough.

Is anything left from the notions we held until now? Fortunately, it seems that we can still extrapolate the measured intermodulation and cross modulation to lower levels, if we are sure that we have measured it at levels below the crossover with the 5th order effects. If

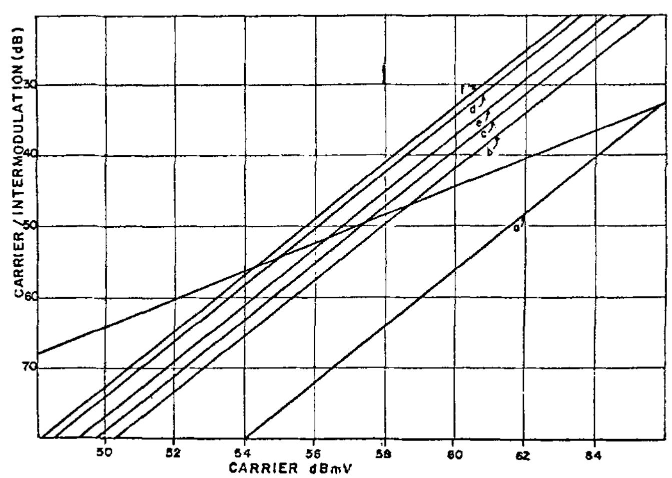

Fig. 6

the measured characteristic follows a strict 2:1 line over a range of, say, 20 dB, we can safely extrapolate to any lower level. Even if the measurement is made where there is 5th order interaction, we can be sure that there will be no anomalies at lower levels.

II. THE CASE OF THE PILED-UP BEATS

The Motive

In a transmission system with regularly spaced carriers, the triple-beats (of type A+B-C) tend to pile up close to the carriers, and the number of beats in any channel increases much faster than the number of channels. If we assume that the number of separate beats that occur at a given frequency also represents the amplitude of the resultant beat, we may very easily be discouraged from increasing the number of channels in the system. While in a standard 12 channel system the largest pile-up is 19 beats (in channel 10), it increases to 107 (Channel E) in a 21 channel system, and 202 (in channels F, G and H) when the system carries 27 channels. The pile-up is worst in the channels at the center of the band, as can be seen in column (a) of the table below, computed for 21 channels (channels 5 and 6 at 2 MHz higher than the standard assignment):

Channel	(a)	(b)
2	59	59
3	67	66
4	70	69
5	76	76
6	78	78
A	96	91
B	101	95
C	104	97
D	106	100
E	107	101
F	106	101
G	104	98
H	103	96
I	102	95
7	100	94
8	99	94
9	97	93
10	98	91
11	89	87
12	84	83
13	76	76

The purpose of my second experiment was to verify this phenomenon.

The Method

The combination of over 100 beats that occur at approximately the same frequency is very difficult to measure. If the carriers are spaced precisely 6 MHz apart (by phase-lock techniques), all the beats occur at the same frequency, and their resultant is a stable, measurable signal; however, its frequency is exactly that of the carrier of the channel where they occur. I therefore modified the experiment by removing one carrier at a time, and measuring the resultant beat which was generated by the remaining 20 carriers at that frequency. Column (b) of the table shows the number of triple-beats that pile up at each carrier frequency under these conditions. The measured beats are plotted in Fig. 7 for two different values of the carriers. (Only the discrete points, shown as circles and crosses, are significant. The lines connecting the points are included only to bring out the pattern).

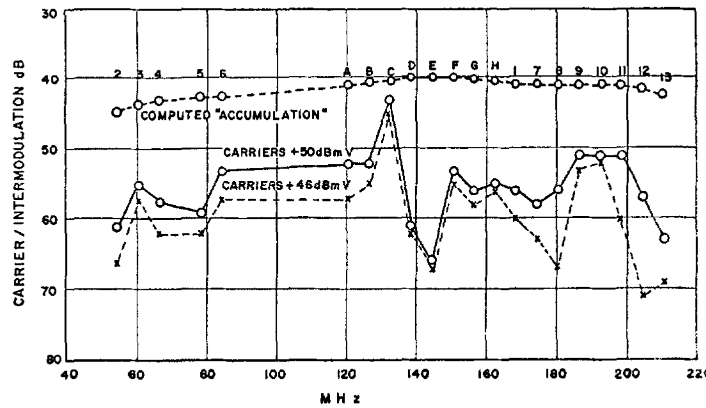

Fig. 7

The Clues

The points on the upper curve, marked "accumulation", represent values proportional to the numbers in column (b) of the table. The curve is intended to show the variation that would be expected if the amplitude of the resultant beat were proportional to the number of triple-beats that combine to produce it. (For the purpose of the discussion, only the shape of the curve is significant, but not its vertical placement in relation to the other curves).

It is clearly evident that there is no simple correlation between this gradually changes curve, and the results of the measurements which show significant up-and-down variations between adjacent channels. The combined beat in channel E, which is supposed to be at the peak of the curve, is almost at the lowest measured point. The interference in channel E, which is a combination of 101 different triple-beats, is 23 dB lower than the combined 97 beats in channel C. The measurements also show that a 4 dB change in the level of the carriers caused the accumulated beat in some channels to change by 1 dB only, and by 14 dB in other channels.

The Verdict

Given any combination of carriers, the number of beats that fall into any channel can easily be computed. We may use exact formulas of combinatorial theory, or try for approximations such as $0.162N^{2.21}$, and express the result in logarithmic form (as "voltage dB" or "power dB").

Unfortunately, these numbers have no correlation to the amplitude of the resultant beat.

It can easily be verified that the magnitude of any particular triple-beat depends on the frequencies of the 3 carriers that generate it, so that the 100 or more beats that accumulate at one frequency are not of the same amplitude. This experiment forces us to conclude that the different triple-beats must differ in phase as well as in amplitude. Consequently, there is no way to predict the measured results plotted in Fig. 7 short of measuring (or computing) the amplitudes and phases of each one of the hundreds of possible triple-beats that combine to produce the total effect.

CONCLUSION

The simple series representation for amplifier distortion, assuming real, frequency-independent coefficients, seems to be invalid for transistor amplifiers as used in CATV. Direct measurements force us to the conclusion that the coefficients are functions of frequency, and have to be complex numbers. (Mathematically it means that the Volterra series, rather than the Taylor series, is to be used in the representation).

In view of this, some of the statements at the start of this paper are neither true nor false, but meaningless. For example, how can you compare "third harmonic" to "triple beat"? The third harmonic of which carrier is supposed to be 15.5 dB below the triple beat of which 3 carriers? The cross modulation in a 12 channel system is supposed to be 20log(11) dB above that measured with which 2 channels?

If we do not know the exact frequency dependence of the coefficients, we cannot predict the distortion of one combination of carriers from measurements with another combination. There is no way to predict a combined effect unless we know the amplitudes and phases of all the components in the combination. If we want to approve an amplifier for the trunk of a 27 channel system, we have to measure the distortion produced by the same 27 channels in the amplifiers, and not extrapolate from 12 channel behaviour (unless we want to accept a "worst-case" estimate which will be completely unrealistic). I would not be surprised to find that an amplifier which was operating well in a 27 channel system, is found to have too much distortion in one or more channels when it is tested for use in a 20-channel system.

The effects of 5th and higher orders are far from being negligible at the levels at which CATV amplifiers are operated. The higher-order distortion products are the cause of the deviation from "well behavior". Depending on the phase between the 3rd order and the higher-order products, the effect may be a slight variation from a strict 2:1 law, or result in deep minima and sharp nulls. However, it is possible to extrapolate the measured distortion to lower levels, provided we have properly extracted the 3rd order component from the higher order effects.

The complex-number, frequency dependent mathematical model is more complicated than the simplified assumptions that we have been used to. But when our computed predictions, based on any one model, seem to be at variance with the reality brought out by measurements, there is no question as to which of the two should be modified to conform to the other.

OPTICAL WAVEGUIDES - FUTURE CABLE FOR CATV

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Abstract

Low-loss waveguides are solid fibers of glass only 5 thousandths of an inch in diameter. Information is transferred over optical waveguides by appropriately modulating near infrared source such as an LED or laser and detecting the change in the output flux with a compatible solid-state detector such as PIN or avalanche photodiode. Measurements of such fiber waveguides in lengths over 3000 feet show total attenuation as low as 2 dB/km and bandwidth capability as high as 500 MHz in one Km length.

Transmission characteristics of optical waveguides are independent of operating frequency and temperature, promising relatively simple and reliable systems.

Corning expects to develop waveguide cables which will be cost competitive with coax on a per foot basis.

Availability of practical light sources and detectors limits current capability to construct useful systems. From the input/output devices' point of view, digital rather than analog operation would be preferred in most cases.

Introduction

The technology of optical waveguides presents major new possibilities. Optical waveguide conductors are applicable to all kinds of CATV systems. They will be especially useful in interactive CATV. Conventional system configurations such as the "Party Line" or "Rediffusion" can be constructed using optical waveguides to offer considerably greater system capability and improved performance. Optical waveguides make it also appropriate to consider entirely new system configurations seeking effective use of waveguides unique properties for improved system/cost performance. One such novel configuration, the radially extended star, can be used as a system model commensurate with the key requirements of interactive CATV.

Unique Capabilities

Great Bandwidth. Optical waveguides are capable of multigigabit bandwidth in less than one thousandth of an inch of conductor cross-sectional area. The initial systems will clearly be limited by the available input/output devices rather than conductors. The transmission plant will be capable of taking advantage of continuing technological progress in sources and detectors resulting in system upgradability. Space and wavelength division multiplexing represent additional means of further upgrading the system. Thus, a transmission plant installed today can be expected to meet the growing requirements literally decades ahead.

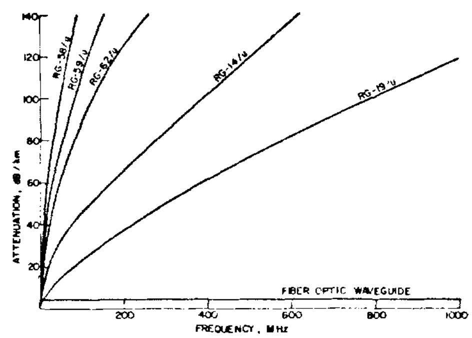

FIGURE 1. Relative dependence of attenuation on operating frequency, Optical Waveguide vs. Coax.

Low Attenuation. Optical waveguides characterized by total attenuation of only 2 dB/km have been achieved recently. Attenuation in optical waveguides is not only much lower than that of any available coax cable but it is virtually independent of the signal frequency. This allows repeater spacing of several miles instead of a fraction of a mile in conventional systems, resulting in correspondingly increased permissible trunk lengths or for a fixed distance, in savings of amplifier costs. The performance of existing systems is limited by the accumulated distortion, noise and phase and amplitude nonlinearities. The degree of degradation tends to be proportioned to the number of amplifiers in a trunk. System based on optical waveguides will require fewer amplifiers resulting in an immediate improvement in performance. Further, the waveguide system probably will not require frequency and delay compensation, again saving costs and improving the system's performance.

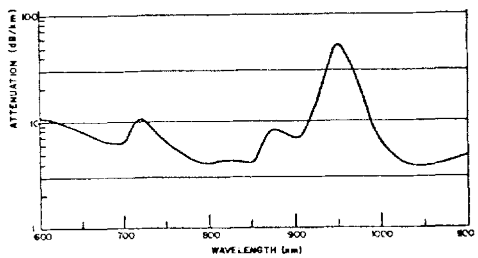

FIGURE 2. Typical spectral attenuation of recent multimode waveguides.

Dielectric Conductor. Waveguide cables will be immune to electromagnetic interference and high temperature, as well as free of ground loop problems. This should result in high performance, reliable systems, as well as yielding immediate savings by system simplification such as elimination of the need for temperature compensation which is required in conventional systems.

Small Size, Low Weight. Waveguide cables will be much smaller and lighter than conventional conductors. This should decrease installation costs and make it possible to construct systems in areas where existing duct space cannot accommodate conventional systems.

State of Development

Corning has achieved total attenuation in long samples of waveguides as low as 2 dB/km in the near infrared. Multikilometer individual low-loss fibers have been made. Such fibers have been packaged into long jacketed bundles suitable for use with LED's. Low-loss bundles (1,000 ft. long) have been delivered to Federal Government laboratories starting in March, 1972. Preliminary experiments with individual fiber coating and high-temperature jacketing have produced successful results. Experiments with armored cables consisting of several metal conductors and one fiber optic bundle strongly suggest compatibility of fiber optics with cable-making processes and equipment. On the basis of successful experience with modified standard connectors such as BNC, UHF and OSM, extensive use of developed connector hardware is expected. Engineering prototypes of splicers for bundle joining or repair and passive couplers for use in data bus environment have also been constructed.

Corning is developing techniques and processes for packaging these waveguides in cable form with terminations suitable for optical, electrical and mechanical coupling. We expect these cables to be competitive with coax on a per foot basis, which combined with waveguides low-loss and large bandwidth will provide a remarkably low cost-per-channel-mile technology.

Input/Output Limitations

Semiconductor sources and detectors are generally assumed in considering communication links based on waveguides. At this time, they severely limit the practical usefulness of optical waveguides.

Sources

Since low-loss waveguides have small cross-sectional area and low numerical aperture, it is important to reduce the angular and spacial spread of the source power, thus the key parameter of the source is its radiance ($W/sr\text{-}m^2$). The ideal source would be a CW, room temperature, solid-state injection laser. This device, although reported on a laboratory basis, is not available at this time. The alternatives are to operate the available lasers at cryogenic temperatures or on a low duty cycle basis - neither of them seems satisfactory. Other lasers, either "mode-locked" or externally modulated, are regarded as inherently costly and probably inadequate in respect to life expectancy and reliability and thus inappropriate in most CATV applications.

Light emitting diodes (LED's) are readily available and relatively inexpensive but are deficient in several major respects. From the device point of view, LED's are slow - generally operable only at well below 100 MHz, highly non-linear and limited in respect to power output - typically low milliwatts. In respect to waveguides, the available LED's require use of many fibers - typically 50 to 100 in a bundle to keep input losses to a tolerable level. This is so because LED's are much larger than waveguide fibers and emit light in a broad angular distribution. Use of many fibers in a bundle increases its cost without any benefit in respect to its bandwidth or attenuation.

Detectors

Avalanche photodiodes and PIN diodes are proposed as the corresponding solid-state detectors. Quoted in the literature, gain bandwidth products of 80 GHz appear adequate for most CATV purposes. However, the avalanche photodiodes are highly non-linear. Coupling detector to optical waveguide is a minor problem. Its noise characteristics are of prime importance.

It is informative to view the source/waveguide/detector system in terms of the minimum discernible signal (SNR = 1), or the minimum light flux which produces an output current just equal to the noise current.

From published data, typical MDS values for PIN and avalanche photodiodes at 100 MHz are 10^{-6} W and 10^{-8} W, respectively. Assuming SNR of 40 dB, the incident optical power at the detectors must be 10^{-4} W and 10^{-6} W, respectively. (Note these are square law devices.) Allowing for input coupling losses, at this time only a marginal link could be constructed using these devices in conjunction with available LED's. Power levels associated with lasers would clearly solve the problem.

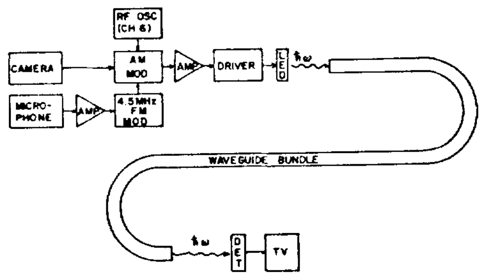

FIGURE 3. Video link demonstrating transmission at channel 6 over 1000 ft. low-loss waveguide bundle using commercially available source and detector.

PEDIATRICS AND CABLE TELEVISION

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ABSTRACT

The Department of Community Medicine of the Mount Sinai School of Medicine (New York, New York), in cooperation with the TelePrompTer Corporation and with funding from the Health Services and Mental Health Administration of HEW, has developed a bi-directional television system using coaxial cable which links a pediatric office at the Medical Center to an outreach pediatric clinic in East Harlem, about a mile and a half away.

The pediatric staff at the Medical Center can be in audio-video contact with the clinic staff and patients and vice versa. Although the system has been in operation for only six months, its value is unquestioned. CATV can be used as an extender of medical expertise to the medically disadvantaged.

Although CATV is almost 25 years old, its full social impact is still not apparent. It has not, as the Sloan Commission suggested, had an impact on the order of the printing press some 500 years ago.

It has long been recognized that of all the media, only CATV has the potential for true bi-directionality. But this application of CATV has been limited, largely because of costs and commercial viability.

If the optimun social impact of CATV is to be realized, its capacity for bi-directional video should be stressed. One area in which this capacity is of prime importance is health.

The thrust of this paper is to describe this application of CATV which the Department of Community Medicine of the Mount Sinai School of Medicine (New York, New York) has been utilizing in pediatrics.

We at Mount Sinai are in a unique position vis-a-vis CATV in that we are located in the franchise area of the TelePrompTer Corporation. Because of this, the Department of Community Medicine has established a Section on Communication for the express purpose of exploring ways to establish a unique partnership between a voluntary medical setting and the private sector of CATV.

The fields of pediatrics and geriatrics were chosen for our first projects because these are the areas of greatest medical risk. They also lend themselves particularly well to the type of application we will describe. The pediatric project which we will discuss today is already in operation. We hope to have the geriatric project operational by fall 1973. Perhaps we can report on that activity at next year's NCTA Convention.

To understand this project in pediatrics, some background is necessary. The Mount Sinai Medical Center is located on the edge of East Harlem, a typical inner city with all the attendant problems. Although East Harlem has two medical schools and four hospitals, the people in this community do not adequately avail themselves of existing health services. This is not unique to East Harlem; this problem is replicated across the United States and even abroad. In Britain, where hea th care is free, a study revealed that only one person out of four with specific symptoms sought medical assistance.

Health institutions, therefore, have found it necessary to establish outreach facilities, saying in effect: If the people don't come to us, we will go to the people.

One such outreach facility in pediatrics was established in the heart of East Harlem at the Wagner public housing project. This Clinic sees both well and sick infants.

Most clinics have a physician in charge, assisted by nurses, who in turn are assisted by para-professionals. The Wagner Clinic follows a different organizational pattern, that of a team approach to health care delivery.

The Clinic has two co-directors, a physician and a nurse practitioner, who share equal responsibility. They spend only part of their time at the

Clinic, inasmuch as they must spend time at the Medical Center where they have patient care, teaching and administrative duties as well.

Another unique feature of the Wagner Clinic is the expanded role of the nurse who administers most of the health care procedures, utilizing the services of physicians in perhaps 25% of the cases for the more complex medical problems.

When we say we go to the people, we mean that literally. It is not enough to establish an outreach clinic for people to come to. Patients must be actively sought. At the Wagner Clinic, teams of specially trained community health workers, coordinated by the nurse practitioner, spend one week in the field visiting patients and prospective patients, and the next week at the Clinic.

The problem of providing health care is very complex. No one has ever satisfactorily defined "good health." When we apply the term, we use the World Health Organization's definition: "The state of physical, mental and social well-being, not merely the absence of disease or infirmity."

This means in order to provide health care, we must pay attention to the social, economic, and emotional aspects of a patient's problem. In fact the kinds of problems presented to outreach facilities in inner cities rarely relate to purely physical illnesses. In most situations, illness cannot be satisfactorily treated without relating to the social and family problems. One of the difficulties is that physicians are not prepared to deal with this aspect of health care, while the nurses at the Wagner Clinic are. These specially trained nurses can relate to the total patient problem.

The difficulties of providing appropriate personnel for an outreach facility are manifold. Although the facility requires the services of physicians, pediatricians, orthopedists, psychiatrist, social workers, etc., they are not required on a full-time basis. Not only would it be impossible to provide such full-time personnel, but it would be a waste of much of their time.

It is, of course, possible to have these highly skilled individuals travel to outreach facilities for an hour or two on specific days. However, this, too, would be a terrible waste of time spent in travel which should be devoted to treatment. For example, we found that one psychiatrist was spending more than 25% of her time just traveling between a medical center and a number of health clinics.

Here, then, we have the Medical Center with all the vital expertise, and the outreach Clinic in need of such expertise, but only on a part-time or ad hoc basis. The problem is how to make the most effective and efficient use of such personnel. This is where cable came in.

What did we do? The TelePrompTer Corporation, intrigued by our project, has provided excellent cooperation and assistance for which we are indeed appreciative. They agreed to lay a bi-directional cable line, linking the Wagner Pediatric Clinic in East Harlem to the office of the Clinic co-directors at the Medical Center about two miles away. This cable link provides audio-video contact between these two points throughout the working day.

At each cable terminal, we have a Telemation camera with a 9-inch direct video monitor, an RF modulator (Channels 3 and 8 are used) and a 19-inch receiver to pick up the signal from the sending source. Ancillary equipment such as a sync generator, audio mixers, lavalier and fixed microphones, wide-angle and zoom lens, were provided as required.

The equipment at the Clinic is mounted on a movable cart and cable outlets were installed at each of the eight clinic rooms, thus allowing for reciprocal contact from any point in the Clinic to the co-directors' office at Mount Sinai.

The equipment at the co-directors' office is mounted on a console which includes a special effects generator with a genlock and a videotape recorder.

The cable amplifiers have a capacity of 300 MHz of which we are using only 6 MHz in each direction. This allows us ample room for future expansion to multiple locations and will permit the addition of a variety of diagnostic instruments.

The project was funded by The Health Services and Mental Health Administration of HEW. It became operational in December, 1972 and has been used continuously since then.

Getting the physicians and nurses to use the equipment was not an easy task. Health-care providers, although skilled in handling the intricacies of the human body, were fearful of television equipment. They were convinced that touching a dial or switch would surely result in breakage. It took several months to convince them otherwise, and even now some are more hesitant than others to use the system. One health provider responded negatively because she thought she "looked terrible" on the television screen. It took some time to convince her that this was not really so.

The children, as we anticipated, are delighted to be on television. They are more willing to come to the Clinic and it is occasionally difficult to get them away from the system. This can, at times, create a minor inconvenience to the physicians and nurses, particularly when they examine ears. For instance, the child might be viewing himself on the monitor and refuse to turn away from it in order for the doctor or nurse to look at the other ear. The health provider must then walk around the table to complete the examination.

Our greatest concern was the acceptance of the system by the parents of the children. It would be very easy for telemedicine to be viewed as second-class health care in a ghetto community. We wanted to convince the parents that what we were doing was enhancing health delivery, not reducing it.

Long before the system was put into operation, meetings were held with mothers to explain what we were doing and to answer questions. The community rapport is such that there was ready acceptance of the system which has been further enhanced with its continued use. Interestingly, one of the questions of concern to mothers was, "Now that we are going to be on television, do we have to get dressed up when we come to the Clinic?"

One indication of acceptance of the system is the fact that over 300 mothers have signed the release form to appear on television and be videotaped. Only two have refused and these were very special situations.

The system is left on throughout the working day. The cable link provides the co-directors with the feeling that they are also present at the Clinic when, in fact, they are really in their Medical Center office. At such times, the Clinic staff can reach them almost instantly without having to go through the hassle of a hospital telephone switchboard. The face-to-face contact via video is far superior to telephone both in ease of explaining, and knowledge gained, through facial expression and body language, that what has been explained has been understood.

Physicians and nurse practitioners at the Clinic can obtain back-up when needed from the Clinic co-directors and others at the Medical Center. Health providers can consult with Clinic patients and parents as well as Clinic staff. Specialists at the Medical Center, who would ordinarily not be able to travel to the Clinic without considerable time loss, are now available on a regular basis for teleconsultation. These include areas of orthopedics, nutrition, psychiatry and social service.

Triage is accomplished by designating those children who can be treated at the Clinic and those requiring specialized services administered at the Medical Center. This has already resulted in reduction in the number of patients referred to the Medical Center. Such visits involve considerable difficulty for parents in terms of travel time, waiting time, transportation costs, need for baby sitters, etc.

We have added several components to the system, including a Hewlett-Packard heart sound amplifier, and we are discussing with NASA the possibility of adding various physiological monitors for which there is ample channel space on the cable.

We have learned much over the past six months, but we have a long way to go. We have made challenging telediagnosis in a small number of cases, but to play it safe, we still seek clinical confirmation. Thus far, every such telediagnosis checked out accurately. We are batting 1,000.

As noted previously, the system has the capability to videotape transactions. Our initial experience with this was slightly disasterous. We attempted to use split-screen in order to have the health providers and patient appear at the same time. However, we found it impossible to get either the physician or the patient to stay within camera range or focus because we do not employ a technician. We believe we have the world's greatest collection of videotapes of decaptiated individuals. We are now using a fade in/fade out technique which is much more effective. However, it is still taking time for the physicians and nurses to use this technique while simultaneously providing health care.

The videotapes have been used to give the health-care providers a second look at their treatment modalities. We feel this has been helpful in improving health-care delivery. We have also used videotape for recording unusual cases, for staff training and, eventually, we will use the tapes for longitudinal research.

Many problems remain to be worked out. There are not adequate funds to convert the system into color, to hire technicians, videotape editors, etc. which would enhance the system's usefulness. We would also like to obtain a remote control pan, tilt and zoom system so that the providers at the Medical Center can control what is viewed at the clinic.

There is a need to develop special instrumentation for diagnosis over cable such as fibreoptic otoscopes for ear examinations. But this has been too costly for manufacturers to do in view of the limited market potential.

The question frequently put to us is, how can a physician or nurse at one end of the cable see into the child's ear or determine color of a skin lesion via a black and white system. The answer is that they cannot; and yet they can. This is so because the personnel at the Clinic can serve as an extension of the provider at the Medical Center by describing the condition of the middle ear, the morphology of a skin lesion and the result of palpation of a patient's abdomen.

Telemedicine, particularly via bi-directional cable, has important implications in the delivery of health care. The field is in its infancy. We have much to learn, but based upon our experience to date, we can say to you, in the words of Lincoln Steffans, "We have seen the future, and it works."

We plan to expand the cable link to other child health stations, to schools, day-care centers and the like. Eventually we hope to be able to reach parents in their homes to provide health education.

Thus we say to you, "Go ye and do likewise."

PRACTICAL METHODS OF TESTING CABLE SYSTEMS UNDER PRESENT FCC RULES

Robert C. Tenten

Home Box Office

In order to test a cable system according to FCC rules, we must first look at Subpart K of the Rules and Regulations for Cable Television Service; Cable Television Relay Service. This section tells what, when, where, and to a certain extent how to measure a cable system.

Subpart K directs that tests are to be made on all Class I cable television channels. A Class I channel is defined as "a signalling path provided by a cable television system to relay to subscriber terminals television broadcast programs that are received off the air or are obtained by microwave or by direct connection to a television broadcast station."

These tests must be made at least once a year at intervals no to exceed 14 months. Measurements must be made at a minimum of three widely separated places in the system at least one of which is representative of the longest system cable run. These measurements can be made at a point on the sytem other than the subscriber terminal provided data is included which would show what the performance would be at a nearby subscriber location. Another technique would duplicate the hardware that appears between the test point location and a typical subscriber terminal. Measurements would then be made after this equipment and would simulate the signal at the subscriber.

Data should be written in report form. Descriptions and serial numbers of equipment used must be included. Procedures used for each test must be included in the report as well as the qualifications of the person performing the tests. The resulting report must be kept on file in the local cable system office for at least five years.

These basic ground rules cover the things that must be done before and after making the required measurements. These procedures are in fact no less important than the measurements themselves, since they are set up to show the person who looks at the report everything that went into making the tests. Without this information the validity of any test could be subject to question.

After making the proper preparations for the tests, the next question is what tests have to be made and what equipment is required. The requirements are listed in Table I. Equipment and techniques used are described in the following sections.

Frequency Measurement

The first test to be made is a check of the frequency accuracy of all Class I channels carried on the system. There are a number of ways to check this, each with its own level of cost and ease of measurement. A simple way which probably requires the least expenditure of money for test equipment is the "zero-beat" technique. This method requires a frequency counter, generator and Field Strength Meter. The equipment setup is shown in figure 1a. Since a frequency counter is a broadband device, it doesn't know which frequency to measure when either one or a number of channels are fed into it. The "zero-beat" technique allows the counter to measure only the single frequency of the oscillator after it has been adjusted to match the carrier frequency of the channel. Matching is accomplished first by tuning the FSM to the video carrier of the channel to be measured. The generator is set up so that the frequency is close to the expected channel frequency. The output level is adjusted to make the level going into the FSM about equal to the level of the video carrier. With both the signal to be measured and the generator output combined and connected to the FSM, adjust the frequency of the generator until an audio "beat" frequency is heard in the headphone. Further adjust the oscillator to reduce the frequency of the beat to 100HZ or less. Disregard the weaker sounding beats heard as the generator is tuned through the 15.75KHZ sidebands above and below the stronger beat of the main carrier. If desired, the zero beat can be determined with greater accuracy by watching for it on the TV set tuned to the channel being measured. The generator frequency is then read from the counter directly.

This corresponds to the channel frequency with an accuracy dependant upon the time base accuracy and the frequency of the zero beat. For example, assume Channel 13 is measured with a video carrier of 211.25 MHZ, that the counter used has an overall accuracy of 1ppm and the zero-beat is adjusted no better than 100 HZ. The possible error could be as much as ±211.25 HZ from the counter and ±100 HZ from the zero beat, or a total error of ±311.25 HZ. This accuracy is better than required by the FCC for either visual or aural carrier measurements. The aural carrier is measured in the same way as the visual, with the exception that you must make the measurement during a period of silence on the audio, since during normal FM modulation a zero beat measurement connot be made.

Should the counter used have an upper frequency limit below the channel to be measured, the generator can still be set so that it falls within the frequency range of the counter, while the zero beat is produced by a harmonic of the oscillator. To determine the generator setting, divide the frequency to be measured by 2, 3, 4 or 5 etc. until the number falls within the range of the counter. This then is the frequency to which the generator must be set so that the harmonic will zero beat with the frequency to be measured.

Additional techniques can be used to measure frequency. A spectrum analyzer can be used as a zero beat detector in place of the FSM. Zero beat is observed when the analyzer is tuned to the carrier frequency and set to the zero sweep mode. The analyzer then acts as a tuned receiver, and a zero beat is displayed on the screen as the oscillator is tuned properly. The oscillator is measured on the counter as in the case of the FSM technique.

Another technique (Figure 1b) uses a tuner and limiter which selects the one frequency to be measured and through limiting action strips the sync from the carrier. The pure carrier frequency can then be measured directly. The same units generally provide a detector and 4.5 MHZ filter so that the intercarrier frequency can be measured directly. If this signal is fed into the counter and the 10 second measurement period is used, the aural intercarrier frequency can be measured in the presence of modulation.

Visual and aural signal levels

The measurement of visual and aural signal levels must be made at three widely separated points in the system. One of these points must be at the longest cable run from the head-end. Although these tests need not be made in a subscriber's home, all of the cable and equipment loses between the point of measurement and a "typical" nearby subscriber must be included in the measurements whether by calculation or actual insertion of the equipment. A conventional FSM can be used for these measurements. However, the qualified person making the test must be reasonably certain that the unit is accurately calibrated. Comparison with recently calibrated meters or calibration against a signal generator with metered output and standard attenuator is generally acceptable.

No video carrier on the system should differ in level by no more than 12db from any other video carrier, and by no more than 3db from any visual carrier within 6MHZ (Figure 2).

Channel Frequency Response

The measurement of frequency response within each Class I channel on the system can be done in a number of ways. Tests can be run from the antenna input through all head end preamplifiers, processors, filters, converters, etc. to the system test locations, or response measurements for the head end and the system can be made separately and then combined to give the overall response.

A simple overall test can be made with a CW signal generator and FSM at the head end and a FSM at the test locations (Figure 3). Radio or telephone communication is required for this type test.

The processor output for the channel under test should be measured, and the unit switched to manual mode. The gain should be adjusted to give the same output level as measured previously. The standby carrier in the processor should be disabled, and the CW generator should be connected in place of the antenna. Care should be taken that this test signal is inserted prior to all devices associated with the channel to be tested. The generator is now tuned to the visual carrier frequency of the input channel, and the level adjusted to give the same output as measured before. The signal is then measured at the test location and recorded. The generator is then moved in .5MHZ increments to cover the required - 1MHZ to +4MHZ range. For each frequency the level is recorded at the test location. This procedure is followed for each Class I channel on the system.

Hum and Low Frequency Disturbances

With the processor input terminated and the standby carrier on, adjust the level to be equal to that of the TV visual carrier. The lower adjacent channel should be turned off or disconnected while making the measurements.

The equipment required at the test location includes a FSM and DC coupled oscilloscope. The FSM is tuned to the standby carrier and the oscilloscope is connected to the video output of the FSM. With the scope in the DC mode measure and record the DC voltage out of the FSM, this voltage represents the level of the standby carrier. The scope is then switched to the AC mode and the gain is increased so the peak-to-peak hum voltage can be measured. Hum modulation in percent is then calculated from the formula:

$$\text{Modualtion } (\%) = \frac{100\ E_{ac}}{2\ E_{dc}}$$

where Edc is the dc output recorded from the FSM, Eac is the peak-to-peak voltage output recorded from the FSM.

Prior to making these measurements at the test locations, it would be helpful to check the equipment at the head-end to see how much hum is generated or picked up by the test equipment setup. Obviously, this should be well below the hum level of the system if the measurements are to be meaningful.

Hum can also be measured on the spectrum analyzer by using it in the zero sweep mode and linear rather than log display.

Carrier to Noise

The measurement of carrier to noise is done at the system test locations and should include head-end equipment. This measurement can be made with a FSM or a spectrum analyzer.

The head-end processor should be set in the manual mode and controls set for normal operating levels. After the carrier is measured, the input of the processor (or preamp) is terminated and the standby carrier is disabled. The FSM is then tuned to the center of the channel and a noise reading is made. The difference between carrier level and noise level is the uncorrected carrier to noise ratio.

A correction factor must now be applied to account for bandwidth, detector response and meter responses. The uncorrected signal to noise ratio should be reduced by the following charts for Jerold 704B and 727 meters. Corrections for other FSM's should be found in the respective manuals for the particular meter.

Meter Reading	704B Correction (db)	727 Correction (db)
0	4.2	3.5
+2	4.0	3.3
+4	3.9	3.1
+6	3.7	2.9
+8	3.6	2.7
+10	3.5	2.6

Measurements using a spectrum analyzer can be made without removing the standby carrier by setting the analyzer bandwidth to 300KHZ and setting 1MHZ/division to show the entire channel.

Carrier level is set to Odb reference on the analyzer and the noise level is read directly as so many db below carrier level. The correction factor for bandwidth and logarithmic display response is 13.5db and must be subtracted from the reading taken. Care should be taken to note that the analyzer noise level is to 10 db lower when no signal is applied. This means the correction due to signal to noise combinations is less than about .5db. The noise level increase if less than 10db can be noted and the proper corrections made from a signal to noise combination chart.

Offset Co-Channel

Offset co-channel can be measured on a spectrum analyzer set up with 300 Hz bandwidth and 5KHz/division frequency span. The co-channel is then observed 10KHz (2 divisions) above or below the channel visual carrier, and the level is measured and recorded.

It should be noted that if there is no visually observable co-channel interference as indicated by a "venetian blind" effect when each Class I channel is checked on a normally operating CATV system with a properly adjusted TV set, then it may be assumed that the system meets the 36db FCC requirement.

Carrier to Coherent Frequency

The term carrier to coherent frequency includes spurious responses such as 2nd and 3rd order products, harmonics, crossmodulation, etc.

Measurements can be made with a spectrum analyzer either in the presence of a TV signal, or with the input to the preamp or processor terminated and the standby carrier on. Spurious signals at the FCC maximum level of 46db below visual carrier are easily seen with the frequency span set at 1 MHz/division and a bandwidth of

300 KHz. Reducing the bandwidth further will allow greater resolution of lower level spurious signals for quantitative measurements.

Cross-modulation should be looked for at 15.75KHz from the visual carriers and the levels recorded. However, since cross-modulation is normally measured with synchronics 15.75KHz square wave modulation on each channel, an accurate measurement would require all standby carriers to be modulated by the same source, except of course the channel being measured.

It is also possible to observe on a properly adjusted TV receiver whether beats, bars, or background video are visible. If none are observed, it is likely that any which do exist are more than 46db below visual carrier as required by the FCC. The same holds true for a blank screen observation of cross - modulation if no windshield wiper effect or background video is observed.

The FCC at this time has not indicated whether subjectives tests as indicated are acceptable. However, precedence at the FCC indicates that alternate tests may be used at the discretion of the engineer making the measurement, if in his judgement such tests will produce reasonably accurate results.

Terminal Isolation

This test must be performed at the three selected system test locations for each Class I channel. It would also be a good practice to duplicate or make actual measurements at the subscriber installation having the least amount of isolation.

For this test, a signal generator and FSM are required. The CATV signals are removed from the distribution leg to be tested. The generator is tuned to the channel to be measured and the output adjusted to a convenient level (+30dbmv). This signal is then back-fed to the system from the subscriber terminal location (or simulation). The signal is then measured at the closest (in terms of least isolation) subscriber tap. This procedure is repeated for each Class I channel.

In addition to this test, a test at the same locations should be made with the CATV signals on. The subscriber terminal location should be both open-circuited and short-circuited and observations made of a TV receiver at the same point the FSM readings for isolation were taken. There should be no visible degradation in the picture due to reflections.

Radiation from CATV System

Radiation measurements should be made at the three system test locations with a dipole antenna and a FSM or spectrum analyzer. In the event that measurements exceed the FCC requirements, immediate action should be taken to correct the problem.

The antenna should be adjusted to 1/2 wavelength at the channel to be measured. The dipole should be positioned 10 feet below the system components and 10 feet or greater above the ground. The dipole must be rotated around its vertical axis to obtain a maximum reading. Readings should be taken in microvolts and multiplied by a conversion factor applied to obtain microvolts/meter. A list of dipole lengths and conversion factors for the standard VHF channels is given in Table II. The voltage in microvolts corresponding to the FCC maximum field intensity of 20 μV/m is also included for convenience. It is assumed that a 75 Ω or FSM is used for the measurements.

Data Recording and Reporting

As indicated at the beginning of this paper data must be taken and put on file in a report form. To facilitate this, sample data sheets have been prepared and are shown in Figures 4 through Figures 9. Procedures used for each particular test should also be written up and included with the report. Finally the qualifications of the person performing or supervising the tests must be included.

TABLE I

TEST	REQUIREMENT
Frequency	
Visual Carrier Frequency	1.25 MHZ ± 25 KHZ above lower channel boundary
Aural Carrier Frequency	4.5 MHZ ± 1 KHZ above the frequency of the visual carrier.
Signal Amplitudes and Flatness	
Minimum Visual Carrier Level	Odbmv
Maximum Visual Carrier Level	Below overload degradation
Overall Visual Carrier Level Variation	12 db (maximum)
Variation of Visual Carrier Levels with 6 MHZ separation	3 db (maximum)
Maximum Aural Signal Level	13 db below visual carrier
Minmum Aural Signal Level	17 db below visual carrier
Channel Response	± 2 db (-1 to +4 MHZ of Visual Carrier)
Spurious Responses	
Hum or low frequency disturbances to Carrier	5%
Carrier to noise	36db
Carrier to Co-channel	36db
Carrier to Coherent Interference (2nd Order, Intermod, Discrete Frequency, Etc.)	46db
Isolation	
Subscriber - Subscriber Isolation	18 db (Must also be sufficient to prevent reflections due to open or short circuit to any other subscriber.)
Radiation	
Up to 54 MHZ	15 uV/M @ 100'
54 to 216 MHZ	20 uV/M @ 10'
over 216 MHZ	15 uV/M @ 100'

TABLE II

TV Channel	Dipole Length (inches)	Conversion Factor 75 Ω Termination	FCC Requirement µV o FSM
2	89.8	1.16	17.2
3	81.8	1.29	15.5
4	73.7	1.41	14.2
5	64.2	1.62	12.4
6	59.6	1.75	11.4
7	28.3	3.68	5.4
8	27.4	3.81	5.3
9	26.5	3.93	5.1
10	25.7	4.06	4.9
11	24.9	4.18	4.8
12	24.2	4.31	4.6
13	23.5	4.44	4.5

FREQUENCY MEASUREMENT USING A FSM OR SPECTRUM ANALYZER

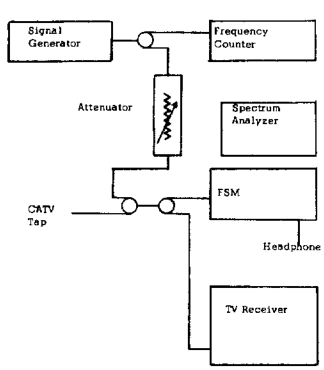


Figure 1a

FREQUENCY MEASUREMENT USING A LIMITER - DEMOD

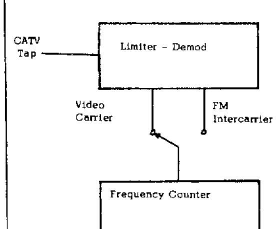
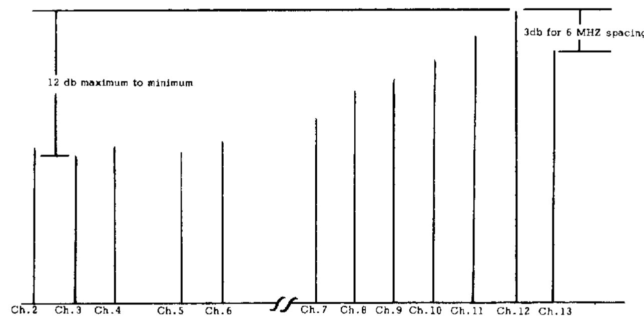
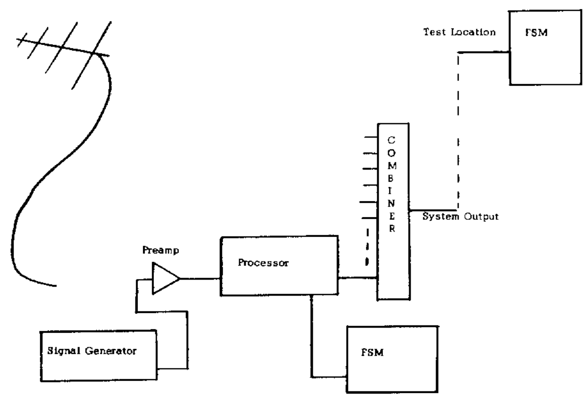


Figure 1b



VIDEO CARRIER LEVEL VARIATIONS

Figure 2



CHANNEL RESPONSE TEST SETUP

Figure 3

FREQUENCY MEASUREMENTS

Channel	Visual Carrier Frequency (MHz)	Measured Visual Carrier Frequency (MHz)	Deviation (KHz)	Aural Carrier Frequency (MHz)	Measured Aural Carrier Frequency (or Intercarrier) (MHz)	Deviation (Hz)

Equipment:

Date____________

Signed____________________

Figure 4

SIGNAL AMPLITUDES

Channel	Visual Carrier Level	Level Difference of 6 MHz Carriers	Maximum Difference of Any Channel	Aural Carrier Level

Equipment:

Date:__________
Location:__________
Signed:__________

Figure 5

CHANNEL RESPONSE

Levels at .5 MHz Spacing from Carrier

Channel	-1.0	-0.5	0	+0.5	+1.0	+1.5	+2.0	+2.5	+3.0	+3.5	+4.0	Maximum Deviation (db)

Equipment:

Date:__________
Location:__________
Signed:__________

Figure 6

SPURIOUS RESPONSES

	HUM			CARRIER TO NOISE				CO-CHANNEL	
Channel	Volts DC	Hum p-p AC	% Hum Modulation	Carrier Level	Noise Level	Correction Factor	Carrier to Noise(db)	Co-Channel Level	Carrier to Co-Channel

Equipment:

Date:__________
Location:__________
Signed:__________

Figure 7

SPURIOUS RESPONSES (CONT'D)

Channel	Carrier Level	Frequency	Level	Frequency	Level	Frequency	Level	Frequency	Level

Equipment:

Date:__________
Location:__________
Signed:__________

Figure 7

ISOLATION

Channel	Generator Level	Subscriber Level	Isolation	Visual Observation Open Circuit	Short Circuit

Equipment:

Date:__________
Location:__________
Signed:__________

Figure 8

RADIATION

Channel	Reading (μV)	Correction Factor	Field Strength (μV/M)

Equipment:

Date:__________
Location:__________
Signed:__________

Figure 9

PROGRAMABLE CALCULATORS AS AN AID IN SYSTEM DESIGN

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An accurate layout in a cable television system has become an absolete necessity, now that CATV involves a highly sophisticated communications network. We now have to consider all FCC rules; we are talking about carrying 30 channels; and, we need to allow for return signal considerations. In short, we can no longer do the electronic design as we do the actual construction. The "best guess" method of system design worked when we were only carrying low band channels or even up to 12 standard channels, but these days are over.

Now that we are talking in terms of 20 channels and up, cable design should be done by a knowledgeable and skilled engineer. Naturally, the more knowledgeable and skilled this person is, the more valuable his time becomes. He may also be running an existing system and have many other duties in addition to the layout and design, so time becomes more critical.

Even if the design is done by outside engineering concerns, the work should be checked. There will always be several changes required in even a correctly designed system; for example, there will be several field changes that a design company cannot be aware of, and of course, once the actual construction begins, there will be many field changes that could not have been anticipated. Sometimes these changes will require major reroutings. These design changes must be done quickly and of course, with complete accuracy.

The design itself is becoming very complex in terms of concepts, but the actual method of arriving at the end product is generally just a combination of simple mathematics, such as addition, subtraction and multiplication. Why not let a machine do the automatic and simple calculations for you?

Programmatical calculators can greatly increase the speed and accuracy of design or checking layout. Depending upon how large a machine you buy, you can increase the speed anywhere from 2 to 10 times over adding machines or non-programmatical calculators. The accuracy is also much improved, because more potential errors, such as those in human addition, subtraction or multiplication are eliminated, and the need to check charts or special attenuation slide rules is also removed. All attenuations can be figured by machine.

Basically, a programable calculator is a mini, or micro, computer that can closely resemble a standard calculator. It can be programed to follow a series of steps to preform many different mathematical functions. It can even interpret its answers and make logic type decisions.

The machine that we use at Warner Cable Corp. is a Wang 60014. It is capable of following up to 1847 commands or have a 246 data storage registers, or any combinations of the two, as they are intertradeable. The printer and tape cassette units are optional. The peripheral memory is also an option, which doubles the size of the memory to approximately 3700 commands or 500 data storage registers. In comparison to computers, this would be considered approximately a 4 k memory. As a comparison, an IBM System 3 is a commonly used business computer. It is generally considered a full computer, and its base model has an 8 k memory. So you can see that this Wang is not to far from being classified as a small computer. The total price of this unit with options is $5,500.

The machine as described can do all layout in a cable system. It can do the trunk lines, feeder lines and power supplies. It can figure the optimum operating levels for any type amplifier. It can provide a complete bill of materials. It can also be used for checking layout done by others. It can check anything associated with system design, and it can do it all in a matter of seconds.

The calculations that are the most time consuming, because of the quantity, are those for feeder lines. The first step is to input the raw date from a strand map. (See Figure 1)

The data the machine will need will be the house drops required at each pole and the footage between the poles or pedestals. After this has been entered, (See Figure 2) the machine will then start its calculations.

FIGURE 1

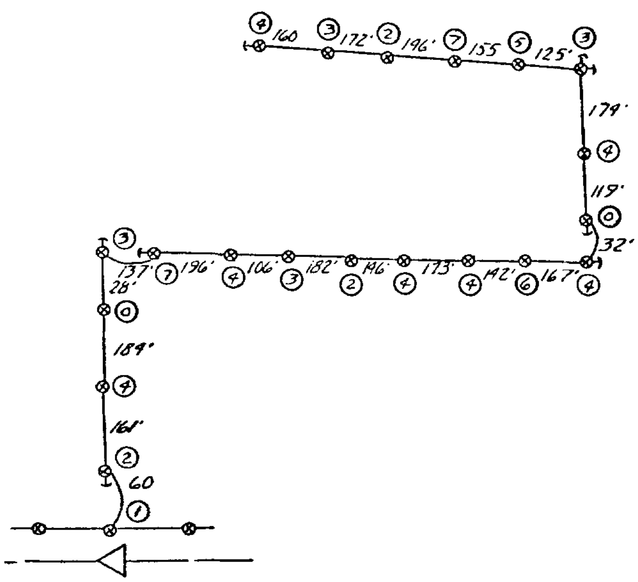

FIGURE 2

Footage Between Poles

House Count From Poles

1.
60.
2.
161.
4.
184.
28.
3.
137.
7.
196.
4.
106.
3.
182.
2.
146.
4.
173.
4.
142.
6.
167.
4.
32.
119.
4.
174.
3.
125.
5.
155.
7.
146.
2.
172.
3.
160.
4.

It will read the first number entered. It will determine if it requires a tap or it it is a footage. If it is decided that a tap is needed, it will then determine the type required to feed the homes from that pole. This is a fairly simple process. You can pick a number such as 12, and anything that is 12 or below, will be considered as drops. Anything 13 or above will be considered as a footage. If you get into a high density area, you can raise this number higher and still not interfere with your footages. You will very seldom have a footage less than 20.

When it is determined that the first bit of raw data is the house count from a pole, the calculator will decide what type of tap configuration will satisfy the requirements. Will it take a 2 output, 4 output, an 8 output or some combination of these? After this decision is reached, the machine will then determine what value tap is needed.

It will first try the highest tap available with the required number of spigots. If this will not provide the minimum output, the next lower tap value will be tried and so on until it finds the appropriate tap output level. After this is done, it will subtract the pre-programed insertion loss of that tap from the signal level, and proceed to the next piece of information entered with the raw data. It then again will go through the process of determining if a tap is required or if it is a footage.

This time, let's assume it is a footage. All the machine does is simply multiply the footage by the attenuation per foot of cable and subtract this from the signal level. Also, during this entire time, there are many checks on the signal level. The machine has been programed with minimum line extender inputs, and it is constantly checking the signal level for this input. If it finds that the input of the line extender will be too low, then it backs itself up, basically just reversing the process that it has done before, until it reaches a point where the line extender input is above the minimum level. It will then total the footage to that amplifier, give the line extender input, raise the signal level to the preprogrammed line extender output, and start on the next bit of raw data, again determining if it is a tap or a footage. It will repeat this entire process until it reaches the end of the line. (See Figure 3)

Throughout this procedure, each tap used is sorted in a memory. When it is determined that the feeder line method is the way it is to be built, the calculator then takes the taps used from the memory and records them on a cassette tape. At the end of the job, this information is read off the cassette tape and bill of materials can be made from this. The machine will automatically read its tapes, tally up all taps used, and count them at the rate of hundreds per minute. (See Figure 4)

FIGURE 3

Attenuation Per Foot of Cable-----.0163		C
Bridger Output------------------41.5000		A
Tap Value & No. of Outputs---------27.2		D
Footage-----------------------------60.		F
	27.2	D
	161.	F
	24.4	D
	184.	F
	28.	F
	20.4	D
	137.	F
	17.8	D
	196.	F
	11.4	D
	106.	F
Footage To Line Extender-----------872.		F
	20.486	I
Line Extender Input & Output----43.0000		A
	30.4	D
	182.	F
	27.2	D
	146.	F
	24.4	D
	173.	F
	20.4	D
	142.	F
	17.2	D
	17.4	D
	167.	F
	14.4	D
	32.	F
	119.	F
	11.4	D
	961.	F
	20.035	I
	43.0000	A
	174.	F
	27.4	D
	125.	F
	24.2	D
	24.4	D
	155.	F
	21.8	D
	146.	F
	17.2	D
	172.	F
	14.4	D
	160.	F
	11.4	D
Footage From L.E. to Termination---932.		F
Termination Level--------------20.30840		E

FIGURE 4

Cable Size-----------.412		C
Amount In Feet----147159.		F
Amount In Miles-----27.87		M
	.500	C
	123456.	F
	23.38	M
Tap Value & Outputs--30.2		D
Quantity------------175.		A
	27.2	D
	210.	A
	24.2	D
	265.	A
	20.2	D
	295.	A
	17.2	D
	317.	A
	14.2	D
	245.	A
	11.2	D
	210.	A
	7.2	D
	141.	A

Programming is really not as complicated as some people believe. What it requires is a high degree of logic and common sense. The machine will do exactly what you tell it to do, no more, no less, and I do mean exactly . GIGO, or G.I.G.O. is an expression that is widely known in computer programming. It's short for "garbage in, garbage out." This applies both to the program and to the data inputed to it. To be effective, the program must be well thought out and well planned. However, with a good program, the machine can do almost anything you want it to do.

Computers make decisions by comparing data to each other. For instance, if X is greater than Y, then proceed to step 25. If X is equal to Y, then proceed to step 30. If X is less than Y, then proceed to step 50. Is X positive? Is X equal to 0, or is X unequal to 0? Each of these logic decisions would be followed by a command to perform a certain function if the preceeding condition was met. Generally, these commands would be to go to a sub-routine.

A sub-routine is basically just a program within a program. It will be a series of steps in one program run which may be run through several thousand times. For instance, selecting the tap value is basically a sub-routing of my main program.

So, although the machine is capable of 4,000 steps, in order to accomplish just one feeder line it may actually run through more than 10,000 steps or calculations by repeating some sub-routines several hundred times.

There are many other programable calculators on the market in addition to the Wang. In fact, there are approximately half-a-dozen manufactures that make machines with basically the same capabilities. There are machines available in all price ranges with all memory sizes. Again, the Wang as I use it costs $5,500. You can get machines ranging from 100 steps to 10,000 steps, and costing from $1,000 to $10,000. The optimum price range is probably somewhere between $4,000 to $7,000.

Another often used machine is the Hewlett-Packard 9820. The price of the comparable model to Warner Cable's Wang would be approximately $7,000. The Hewlett-Packard does have certain advantages over the Wang. For example, it features a non-impact thermal printer, which is much quieter and which, instead of a printing action uses a heat sensitive paper. In addition, it also has better alpha capabilities and can label answers completely. This feature becomes very useful when printouts are used by people who are familiar with the program.

Regardless of the machine chosen, anyone who is involved in large amounts of system design should be aware that a programable calculator is not a luxury but rather a necessity, and the more design work being done, the more of a necessity such equipment becomes.

REDUCTION OF CO-CHANNEL INTERFERENCE BY USE OF PRECISION FREQUENCY CONTROL IN THE ORIGINATING TRANSMITTERS

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Television coverage plans in the United States originally used geographic spacing to provide protection against co-channel interference. Subsequent allocation plans improved the protection by use of offset channels. It was recognized at an early date that an offset of an odd multiple of the horizontal scanning frequency would be optimum, however consideration of the problem of providing protection where more than two channels are involved required the use of an offset which compromised the optimum. An offset of 10 KHz was chosen and stations were assigned "on channel", "+10 KHz offset" and -10 KHz" offset" in a pattern which generally assured that overlapping stations would be separated by either 10 KHz or 20 KHz. Frequency tolerance was set at +- 1 KHz in recognition of the practical difficulties of operating television transmitters, particularly high band and UHF transmitters with lesser tolerance.

There was also early recognition that tighter tolerances would provide more protection . Figures 1 and 2 adapted from a paper by Wendell C. Morrison show the differences in protection afforded by more precise control of carrier frequencies. Changes of 20 or 30 Hz in the beat between two interfering carriers can produce from 10 to 16 db difference in protection tolerance. Even though the ratios of desired to undesired carriers remain the same, the visibility of the beat produced can vary by this amount, 10 to 16 db. Best results are obtained when the beat frequency is an even multiple of the vertical frame frequency and close to the nominal 10 or 20 KHz. The offsets usually chosen is 10.010 KHz and the resulting co-channel beats are either 10.010 KHz or 20.020 KHz. A "zero beat" is of course possible during freak propagation conditions. This 10.010 KHz offset is the 334th harmonic of the vertical frame frequency (29.97 Hz in an NTSC color system). It is considered that frequency tolerance for best results should be +- 5 HZ or even better. This is a tolerance of only 1 part in $6X10^8$ in the low band, 1 part in $2X10^8$ in the high band 1 part in $6X10^9$ at the high end of the UHF band.

Although the principles of co-channel interference reduction by precision offset have been known for some time - almost twenty years - the technique has been applied only by major market stations operating on low band channels, particularly channel 2. Precision oscillators were expensive and difficult to maintain and precision frequency measurements were very difficult. In recent years there has been some resurgency of interest in precision offset due to the availability of good quality oscillators at moderate cost and improved easier techniques for precision frequency measurements. High quality quartz crystal oscillators and precision rubidium vapour oscillators are available as practical frequency standards for the control of television transmitters. Digital counter techniques and precision phase comparators make measurement and reference to National Bureau of Standards easy and practical.

The principles of precision offset and details of the equipment and techniques available for its implementation have been widely discussed within the television broadcast engineering fraternity in recent years. This presentation has been intended to acquaint cable television engineers with these principles and to suggest precision offset as a technique for alleviating co-channel problems in CATV reception.

Cable television systems often find themselves equidistant from two co-channel stations, struggling heroically to select the desired station by use of directional antennas, bucking arrays and special baseband traps and filters. If the television stations involved are not both using precision offset it is possible to get a 10 to 16 db improvement in interference rejection by persuading the two television stations involved to install precision offset frequency control equipment. Cost is less than $51,000 per station and the benefit extends to all receivers affected by co-channel between these stations, whether receiving by CATV or direct. The benefits apply to all channels, low band, high band and UHF. Although the technique has usually been used only by low band stations and particularly those on channel 2 it works just as well on any channel.

When you have tried every other co-channel reduction technique consider an appeal to the television stations involved. I realize that some very complex and touchy situations might arise. One of the stations may see no advantage in co-operating even if the other parties offered to pay for the equipment. Documentation of such cases might build a case for a petition to the FCC to make precision frequency control mandatory on all television transmitters. Although I am not aware of it ever having been done, it might be possible to control only one transmitter in such a way as to keep it spaced from a second transmitter by the required offset. This would require a complex feedback loop over a long geographic distance, but could be done if the situation warranted the expense and trouble. A possible implementation of such a technique is shown in figure 3.

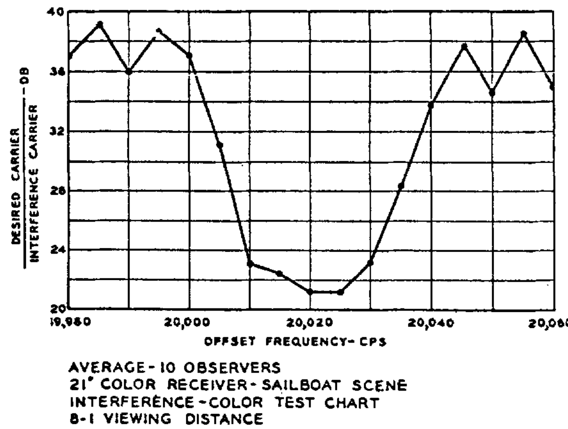

FIG. 1. The difference in db required to produce a tolerable picture with carriers offset by approximately 2 0 KHz.

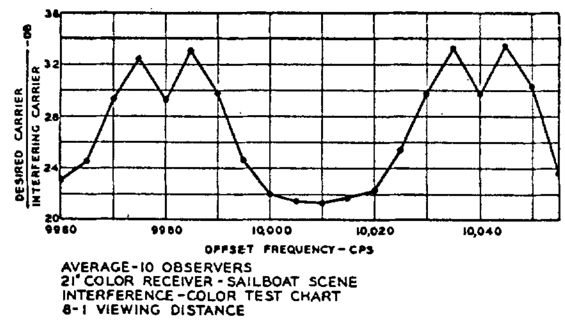

FIG.2. As above but carriers offset approximately 10 KHz.

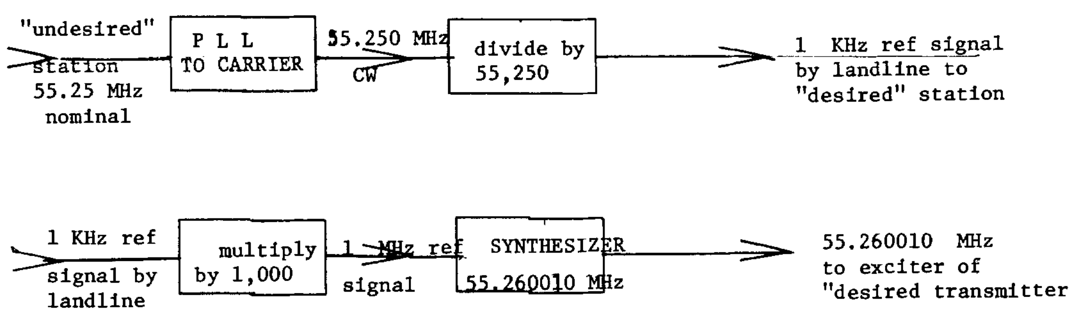

Figure 3. A receiving station within range of the "undesired" station receives the signal, locks a CW carrier to it and divides by 55,250 to produce a 1 KHz reference signal derived from the "undesired" station which is then transmitted by land line (or radio link) to the"desired" station.

At the desired station the 1 KHz reference signal is multiplied up to 1 MHz to drive a synthesizer (or may be used directly in a special synthesizer) which is set to produce the desired offset carrier, 55.260010 MHz in this case, to drive the exciter of the desired transmitter. The "desired" transmitter is referenced to the "undesired" but is offset by the desired amount.

REPORT ON SOURCES OF VARIABILITY IN COLOR REPRODUCTION AS VIEWED ON THE HOME TELEVISION RECEIVER

By

K. Blair Benson, Chairman,
Ad Hoc Color Television Study Committee of the JCIC

The Ad Hoc Color Television Study Committee was organized in 1968 by the SMPTE under the authorization of the Joint Committee on Intersociety Coordination (JCIC) representing EIA, IEEE, NCTA, SMPTE in order to pinpoint the causes of the serious degradation in color television pictures as viewed in the home, particularly as regards variability in hue, saturation and color quality and to initiate appropriate corrective action by the industry. The continuing investigations have been concerned with every element of the television system from the staging and lighting for electronic and film production, through studio and network transmission, and lastly through the home receiver. Both air and cable transmission have been included in the study. The work has not been limited to paper or theoretical studies, but has involved extensive field tests in several cities in the U.S., laboratory measurements, and detailed surveys of operating practices in over 250 television stations.

The initial examination of the problem areas causing variations, and frequently an accompanying loss of quality, in color pictures indicated that the studies could be classified under three broad categories, viz:

a) Video Signal Parameters and Tolerances

   Covering effect on performance of broadcasting equipment and receivers of variations, within the bounds of FCC Rules and Regulations, in parameters such as pulse timing and amplitude, hue and saturation, and color-burst characteristics.

b) Transmission and Transmission Paths

   Covering signal processing and transmission from encoding to the home receiver.

c) Picture Origination and Signal Generation

   Covering stage, lighting and make-up, electronic camera design and operation, motion-picture production and processing, and all related functions up to the point of signal encoding.

The findings to date emphasize the complexity of the problem - in fact, the causes of color variability. Shortcomings have been found to be so numerous, and to originate from so many elements in the overall system, that in only relatively few instances can any significant improvement be realized by the introduction of fixed corrections at intermediate points. For example, color balance can vary widely from program-to-program, and in fact from scene-to-scene in any single program. Furthermore, differences can be found from station-to-station, and recent data confirms the existence of unacceptable differences among cameras in any one station.

System Field and Laboratory Tests

To attack the first two of these three categories, in December 1968, an extensive combined laboratory and field test was conducted in Chicago to investigate questions of signal parameters and tolerances, variations among transmitters, effects of different signal paths, and the differences in performance of different receiver designs under these various signal conditions. Observations and picture quality grading were made by over 30 observers at Hazeltine Research Laboratories using four different top-of-the-line receivers, all operating with automatic chroma control. The demonstration consisted of 16 closed-circuit tests using Hazeltine facilities, and 6 off-air tests over the local NBC, ABC, CBS stations, all using a common signal source provided by NBC. Slides selected as representative of a wide gamut of program material were used for the picture source.

A total of 5,139 ratings from the observers was processed. An analysis of the data indicated several important problem areas warranting further investigation and corrective action. These were:

1) FCC signal tolerances permit wide excursions in hue and saturation which can be very objectionable, depending upon receiver design.

2) Transmitters can introduce phase errors which result in objectionable differences among stations. For example, ABC and NBC differed in burst phase by 18-degrees; CBS was midway between.

3) Reports from Zenith, Motorola and Warwick provided phase and saturation errors different from those observed at Hazeltine which could be accounted for only because of differences in propagation and receiving antenna characteristics.

4) Receivers are affected in varying degrees, depending upon circuit design, by differences in burst timing (back porch), duration, amplitude, and energy.

As a result of these findings, action was initiated by the EIA to specify more rigorous signal specifications, taking into account receiver design characteristics, and to develop means to control the significant parameters in the television transmission system.

Furthermore, to explore the transmission variations and resultant problems in greater depth, another more extensive test was conducted in Chicago in April 1969, again using the three network transmitters. This test employed several widely separated receiving sites and included measurements throughout a cable television system in Ottawa, Illinois.

The specific characteristics tested were:

Burst-to-Chroma Phase Shift

Chrominance-Luminance Ratio

Differential Gain and Phase

Chroma-to-Burst Amplitude Ratio

Duration, Amplitude, and Position of Burst

Multipath Effects

Unfortunately, because of difficulties in making measurements under conditions of high noise levels and spurious beat signals encountered in the Ottawa cable television system, this portion of the field test did not yield any meaningful quantitative data. Therefore, another test was conducted by NCTA in July 1969, on a system in Charleston, West Virginia. An analysis of the results of the latter test was more fruitful. Several serious system problems were pinpointed which contributed to the initiation of the development of system performance requirements by the NCTA.

The findings in Chicago test, after computer analysis, confirmed those from the previous field, and provided more conclusive quantitative data for guidance of the EIA BTS Committee in developing improvements in system specifications and test procedures.

Vertical Interval Reference Signals

An extremely important development undertaken by EIA as a result of the Chicago tests has been the development of a Vertical Interval Reference (VIR) Signal. This signal provides a quick go, no-check of luminance and chroma levels, chroma and burst phase, and luminance level corresponding to that of an average skin tone. It also can be used to control automatic luminance and chrominance correction amplifiers which may be located in strategic points in the studio and, master control, and network transmission systems.

The VIR was tested successfully on the ABC, CBS, and NBC networks from August through November 1970. The effectiveness for use in correcting errors in transmitter operation was confirmed in tests over four stations in Portland, Oregon in April 1971. In this test it was found, by means of the VIR, that chroma level on some transmitters was varying as much as 20% with a change in average picture level from 18 to 65%, and thus suitable corrections could be made for this error, as well as other significant errors encountered in burst-to-chroma phase.

Automatic equipment to utilize this signal presently is available, and it appears that sometime this year the FCC will authorize use of this signal.

Processing Amplifier Usage

The Chicago field tests indicated a potential source for signal distortion in the many processing amplifiers used throughout all television systems, including transmitters. Therefore, a subcommittee was organized to study the problem and to make recommendations for their proper use. Data on 696 processing amplifiers in 284 stations was compiled. In May 1971, a report of the subcommittee's findings and recommendation was released to all NAB member stations.

Subcarrier Distortion and Chrominance/ Luminance Crosstalk

Further under the category of transmission problems, a subcommittee has been assigned to study the significance of distortion and crosstalk of the chrominance and luminance carriers. The study has been directed toward three specific potential areas. These are:

(1) The effect of quadrature distortion.

(2) The effect of transmitter monitoring demodulator characteristics on the VIR signal.

(3) The results of the tests made on microwave transmission systems.

The findings show that techniques and test signals exist which can identify the problems and indicate the correction necessary. A complete report is being prepared and will be released later this year.

Colorimetry

Although the committee activities have continued to cover a broad range of subjects, in the past year particular emphasis has been placed upon the need for standard color measurement and alignment procedures for cameras and monitors. However, the work has been partially stymied by the question of what chromaticity parameters to use for camera taking characteristics. The FCC Rules and Regulations for color broadcasting specify these in terms of picture tube phosphor values. On the other hand, there has been a movement under way to depart from these, taking characteristics in order to accommodate the more restricted gamut of chromaticities provided by present-day phosphors. The principle argument raised in support of such a change has been that present-day phosphors, which provide the high brightness level demanded by the television viewer, cannot be produced with the NTSC/FCC chromaticity values.

The strongest support for a change in camera characteristics has come from the European Broadcasting Union and the Canadian Telecasting Practices Committee. The salient points of the EBU proposal are the following:

1) It may be desirable to modify the agreed-upon characteristics at a later date because of technical progress, i.e. new phosphors.

2) The spectral analysis characteristics of picture-signal sources should be unified on the basis of present phosphors.

3) The signal coding, i.e. the derivation of E'y and the color difference signals should continue to be based upon the FCC reference stimuli.

The EBU recommendations have been referred to the CCIR for consideration as an international standard.

In order to resolve the question, the committee set up a demonstration last year to determine the feasibility of modifying receiver and monitor characteristics by matrixing to compensate for differences in phosphors, rather than that of cameras. The demonstration was arranged for the Committee by RCA at Camden wherein pictures were viewed on two monitors with present-day phosphors, one of which was matrixed to simulate the NTSC/FCC reproducing chromaticities. Since several members of EIA committees concerned with receiver and phosphor characteristics were on hand to view the demonstration and to participate in the ensuing discussion, the meeting represented a total industry involvement.

The picture signals used for the demonstration were generated from a three-channel camera using Plumbicon pick-up tubes. Studio scenes illuminated by 3100K incandescent light were the subject matter. The camera colorimetry characteristics were trimmed with a matrix to reduce color errors to roughly one JND unit. Encoding of the signal was in accordance with FCC specifications.

Both monitors were adjusted to a white balance of D6500 at a reference highlight brightness of 25 foot-lamberts. The transfer characteristic of both monitors was equal to an exponent of 2.2. Hue and saturation were adjusted in the conventional manner for uniform brightness from the red, green, and blue phosphors when driven with a 75% color-bar signal and observed individually. The normal matrix was used in both monitors during these adjustments.

After adjustment, the special matrix which simulated color reproduction of the NTSC/FCC phosphor characteristics was switched in one monitor. It should be pointed out in this case, that the color errors were not zero because of the impracticability of matrixing linear signals, rather than non-linear signals which are present in the monitor before the characteristic is modified by the picture tube gamma of 2.2. Nevertheless, the errors are reduced substantially, in fact to nearly a 4-to-1 improvement.

The outcome of the demonstration was unanimous agreement among committee members and guests present that the FCC primaries should continue to be followed and that receiver and monitor manufacturers should be responsible for incorporation of the necessary corrections for any differences in phosphor characteristics.

In order to assist the U.S. Delegation, the SMPTE Colorimetry Subcommittee of the Television Committee is preparing a document to be taken under consideration as support for the U.S. position at the Plenary Meeting of the CCIR in 1974. In the meantime, with this matter in hand as far as agreement in the U.S. is concerned, subcommittee work in the development of reference camera and monitor characteristics, as well as related measurement techniques, can proceed.

In regard to practical studio monitor setup procedures using the matrix for simulated NTSC-phosphors, as was noted earlier in this paper, the monitor used in the demonstration in 1972 was set up with the standard NTSC matrix, using standard color bars. The special matrix was switched in for the demonstration. Thus, in order to avoid broadcasters having to acquire special color bar generators which complement the new matrix, it will be necessary to provide a matrix switchable between the conventional characteristics and that which is suitable for present-day phosphors. At least one manufacturer of monitors has announced his intention of monitors has announced his intention of providing such a feature in all new production, as well as a suitable retrofit kit for monitors presently in use. Fortunately, it appears this can be done by merely switching a few fixed resistors -- no active elements are required.

Receiver White Balance

An investigation of receiver color balance was conducted at Eastman Kodak with the cooperation of Motorola to determine if a viewer's tolerance to color variation differs for the usual receiver white balance of 9300K or for the warmer 6500K recommended for studio monitors and referenced in the FCC Rules and Regulations.

For the experiment two good-quality television receivers balanced to 9300K and 6500K respectively were used for display of the picture material. Each receiver was equipped with the optimum matrix for its white balance. In this case, the results showed that significantly more pictures are considered to be good or excellent when displayed on a receiver adjusted to 6500K white balance. A complete report has been published in the April 1973 SMPTE Journal.

Color Film Characteristics

In 1969 extensive measurements were made by Eastman Kodak of density, and skin-tone hue and saturation on several hundred samples of television films - programs, commercials, and news - supplied by the network. This survey was repeated with samples from 1972 programming. The preliminary findings are the following:

1) In general, program films made for television today have less color variations than were found in the earlier study.

2) Films made on the West Coast are balanced noticeably "warmer" than those from the East Coast.

3) Density of program films is closer to recommended values than commercials, the latter having lower or thinner highlight values.

4) Picture quality definitely decreases with decreasing highlight density.

5) There is a continuing tendency to use undesirable production practices in commercials.

6) Most news films are well within recommended ranges of density.

Telecine Camera Characteristics and Operating Characteristics

Presently a broad investigation of telecine characteristics is under way. A subcommittee under Mr. Zwick has gathered data on telecine operation and performance as the first step in an investigation of the need for more precise alignment specifications, and for standard telecine characteristics. A questionnaire distributed to stations asked the following questions:

1) Brand of equipment used.

2) Operating practices (automatic or non-automatic).

3) Test used for balance, patterns, etc.

4) Use of image enhancement.

5) Type of maintenance.

6) General questions for improvements.

In essence, it has been found that there are serious variability problems associated with telecine equipment and practices. The variation in transfer characteristic has been well documented, and a need for specification of a standard or ideal transfer characteristic is apparent. Variations in color balance and saturation are significant and further work is needed to measure and explain these. In addition, the question of standard operating procedures may need consideration. The contribution of nonstandard picture monitors to the telecine variability problem has been pointed out. The influence of the problem of excessive shading on telecine variability is noted.

It may seem paradoxical that the committee has uncovered serious variability problems in telecine operation, and yet the results of the questionnaire show that broadcasters feel they have no real problem with telecine. This comes back to the contention that because the broadcaster tends to attribute all problems with the output of his telecine to the film input only, he fails to recognize any weakness of the telecine operation. The work of the subcommittee will draw attention to these problems inherent in telecine design and operation.

Conclusion

The foregoing has covered the highlights of the investigations over the past several years to reduce the variability in color television reproduction. In brief, it may be stated conclusively that through the diligent efforts of our Ad Hoc Committee and subcommittee members, as well as other committees of the JCIC member organizations, substantial progress is being made toward better, more uniform color pictures for the home viewer.

REQUIRED SYSTEM TRIPLE BEAT PERFORMANCE

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A curve showing the triple beat level required in a system for high quality performance versus the number of triple beats per channel is given in this paper. The curve is the result of subjective tests conducted at EIE in which the threshold of perceptibility of the third order intermodulation (triple beat) is observed on a TV receiver. The paper discusses the development of the curve and substantiates it by probability theory.

A table is also given which lists from 1 to 30 channels and the number of triple beats that would be generated from these channels on the worst channel. This gives the system designer the necessary triple beat performance required to design a multichannel system.

GLOSSARY

Beats - Sum and difference frequencies produced from the product of two or more frequencies.

Coherent Headend - A headend in which an identical frequency spacing exists between the various picture carriers of the various channels.

Intermodulation - In a nonlinear transducer element, the production of frequencies corresponding to the sums and differences of the fundamentals and harmonics of two or more frequencies transmitted through the transducer.

Carrier to Intermodulation Ratio - The ratio between the carrier level and the level of the Intermodulation.

Intermodulation Distortion - The impaired fidelity resulting from the production of new frequencies that are the sum and the differences between frequencies contained in the applied waveform.

Intermodulation Products - The frequencies produced by Intermodulation.

Third Order Intermodulation - Intermodulation resulting from the cubic, X^3, characteristics of a nonlinear transducer element. Includes two-frequency beat ($2f_1 \pm f_2$) and triple beat ($f_1+f_2 \pm f_3$), and third harmonic (3f).

Third Order Spurious Signals - Unwanted signals resulting from the cubic, X^3, characteristic of a nonlinear transducer element. Third Order Intermodulation.

Triple Beat - Sum and difference frequencies produced from the product of three frequencies. Third Order Intermodulation resulting from three frequencies, $f_1+f_2 \pm f_3$.

Equivalent Triple Beat - The total number of triple beats plus one-fourth the total number of two-frequency beats.

Individual Triple Beat - One of many triple beats produced from the product of three frequencies.

Threshold of Perceptibility - The level at which an effect (i.e., Intermodulation Distortion) is first observed on a TV receiver.

Introduction

Third Order Intermodulation products (triple beat) have been much discussed (and cussed) over the past couple of years in the CATV industry. Most manufacturers now include third order intermodulation (triple beat) in their specifications, many CATV operators are considering their effects in proposal requests and some manufacturers are offering coherent headends to reduce the effects of all intermodulation distortion. Up to now the industry has depended on educated guesses with regard to the visibility of third order intermodulation products (triple beats) in a TV channel. This paper presents the results of subjective tests conducted at EiE which allows the system designer to accurately determine triple beat specifications that will provide the protection needed to avoid picture impairment.

Number of Spurious Beats

A computer run (Reference b) has been made giving the exact number of beats on each channel. Table 1 summarizes the worst case for various number of channels. The computer run (Reference b) showed that the center channel in a group of channels will be the worst case for the number of spurious beats. The two types of third order spurious signals given in the table are the signals resulting from two carriers ($2f_1 \pm f_2$ type) and the signals resulting from three carriers or triple beat ($f_1 + f_2 \pm f_3$ type). The spurious signals resulting from the two carriers are one-fourth (-6 dB) the level the spurious signals resulting from the three carriers (Reference a). The effective or equivalent total number of triple beats would therefore be the sum of this number of triple beats plus the sum of one-fourth the number of two channel beats.

Intermodulation Threshold

A limited amount of subjective testing has been done in determining the threshold of perceptibility of third order intermodulation distortion, and the data that is presented in this paper is based on experiments performed at EiE. A block diagram of the test setup is shown in Appendix A. Channel 10 was chosen for the subjective viewing since there was no "off air" signal in the area to interfere with the test and it is the center channel in the high band. Channel 10 was modulated with staircase modulation (grey scale) and other channels were unmodulated. The unmodulated carriers are a worst case condition for viewing third order intermodulation distortion, but it provides for more consistent results just as synchronous modulation does for cross modulation testing. The unmodulated carriers would represent the synchronous tip power in the worst case condition where all channels were synchronously modulated. If the carriers were modulated there would be an improvement in the threshold, but the amount of improvement would depend upon the characteristics of the modulation. The threshold given in Figure 1, therefore, provides some safety factor for an actual system just as synchronous cross modulation does. The threshold of perceptibility is not necessarily an acceptable level that the average viewer would tolerate, but is the worst case condition. Also, no attempt was made to space the channels so that the spurious signals fall within the null points around the carriers. The interferring effects of intermodulation on the television screen are reduced when the spurious signals are offset at frequency intervals about the carriers at approximately the half-line scanning frequency, or 8 kHz. The channels and frequencies used in the test are given in Appendix B.

Figure 1

Figure 1 is a plot of two curves, Curve 1 being the required system level of an individual triple beat as a function of the total number of beats per channel. The measured points on Curve 1 were found by observing the threshold of perceptibility on a TV receiver of the total third order intermodulation on one channel and then measuring the level of an individual triple beat with the spectrum analyzer.

Curve 2 is a plot of the actual threshold level of perceptibility of the total third order intermodulation per channel as a function of the total number of equivalent triple beats per channel. Curve 2 is derived from Curve 1 by summing levels of the third order intermodulation products that fall on one channel using the formula:

$$V_{rms} = \left[\Sigma v_i^2\right]^{1/2}$$

(see Reference c). Curve 2 is given for reference since it is very difficult to measure the summation of the third order intermodulation products in a system due to the level of system noise. The bandwidth cannot be reduced enough to eliminate the system noise and still sum the intermodulation products; therefore, Curve 1 or the individual triple beat should be used when specifying or measuring third order performance in a system.

The unusual shape of Curve 1 in Figure 1, requires some explanation. When one spurious signal was beating with the viewed channel, the threshold of perceptibility was a carrier to intermodulation ratio of 60 dB. This value agrees with most of the testing that has been done in the past with a single beat frequency. Increasing the number of random spurious signals to two, the worst case threshold increases to 66 dB due to the periodic summing of the peaks of the two spurious signals. As the number of spurious signals is doubled, the theoretical threshold level would increase 6 dB due to the periodic summing of the peaks of the spurious signals, but subjective viewing has shown that the periodic summing of more than two spurious signals becomes quite random. The curve makes a sharp transition after two spurious signals and crosses over to another line which is a power addition (10 log N) of the spurious signals.

The shape of the curve in Figure 1 is substantiated by Probability Theory. The central-limit theorem (Reference d,e) in probability states that as the number of independent random variables approaches infinity, the density approaches the normal density curve (gaussian distribution) which is the density for white noise. This would explain why after a large number of random signals (which the triple beats are) the signals add on a power basis or the same as random noise.

Several authors (Reference d,e) of Probability Theory have pointed out that since the central-limit theorem involves a limit of infinity, one might feel that the number of random variables must be large before an approximation of the normal distribution can be made.

However, the convergence for many of the ordinary density functions is surprisingly fast. In fact, the normal distribution curve is closely approximated by just 3 random variables and 4 random variables is an "extremely good" (Reference d) approximation. This explains the sharp transition in Figure 1 after just 2 spurious signals.

Since the large number of spurious signals are all clustered about the signal carrier within ± 20 kHz, the effect is narrow band random noise as compared to wideband (4 MHz) random noise. Extrapolating the 10 log N slope of the curve in Figure 1 back to the vertical axis, one finds that the threshold for narrow band random noise would be 53 dB. In order to compare directly the visual effects of noises having different power spectra a weighting factor (Reference f) must be used. The weighting factor of a specific noise spectrum is obtained by integrating the noise spectrum multiplied by the weighting function, over the video bandwidth to be considered. The weighting factor from narrow band flat noise to wideband flat noise is -6.1 dB. Therefore, the random noise threshold in Figure 1 would be approximately 47 dB for wideband (4 MHz) random noise.

Intermodulation Reduction

Some of the methods that can be used to reduce the third order intermodulation distortion in a system were discussed in the earlier paper (Reference a), and will be mentioned again for clarity. Device manufacturers are constantly being urged to develop more linear transistors in order to reduce intermodulation distortion. Until more linear transistors are developed, the power will have to be limited to maintain good quality pictures. The power can be reduced by operating the amplifier with a tilted output, that is, the low channels operating at progressively lower levels than the higher channels to equalize for the cable attenuation.

Another obvious method to reduce the power is to reduce the output level of all amplifiers, but in order to maintain the signal-to-noise ratio, the spacing must be reduced an equal amount. Figure 1 shows that there is an approximate 8 dB degradation in the threshold level when changing from standard 12 channels to 30 channels, which means that for 30 channels the output level of each amplifier should be reduced 4 dB for equal performance to a standard 12 channel system.

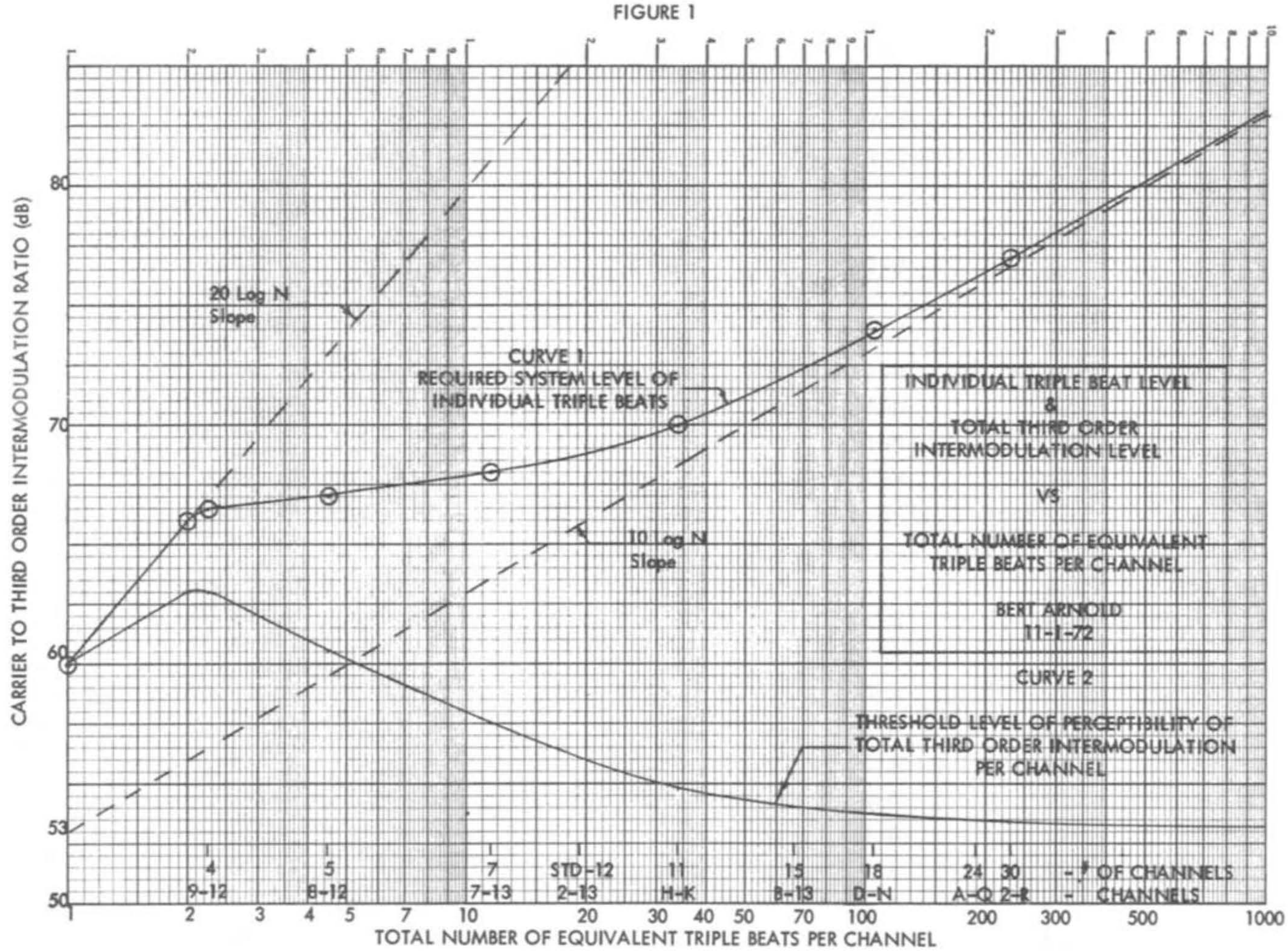
The beat between the third order products and the signal carrier could be eliminated by utilizing a coherent headend, but this would not eliminate the side bands resulting from the modulation of the spurious signals. The improvement in picture quality in a system with a coherent headend will depend upon the relative threshold of intermodulation and cross modulation distortion. A problem with the coherent headend would be in the case where it was desired to phase lock to two or more "off air" channels (VHF broadcast) in a high signal level area, only one channel could be used. The most practical way to deal with the intermodulation problem is to consider it when designing a system to insure that the picture quality is not degraded by the intermodulation.

TABLE 1

THIRD ORDER SPURIOUS

NO. OF CHANNELS	CHANNELS	CENTER CHANNEL	MAX.NO.ON CENTER CHANNEL $2f_1 \pm f_2$	$f_1 + f_2 \pm f_3$	TOTAL EQUIVALENT TRIPLE BEAT
0	0	0	0	0	0
1	13	13	0	0	0
2	12-13	13	0	0	0
3	11-13	12	0	1	1
4	10-13	12	1	2	2.25
5	9-13	11	2	4	4.5
6	8-13	11	2	7	7.5
7	7-13	10	2	11	11.5
8	I-13	10	3	15	15.75
9	H-13	9	4	20	21
10	G-13	9	4	26	27
11	F-13	8	5	33	34.25
12	E-13	8	5	40	41.25
12 STD	2-13	10	2	19	19.5
13	D-13	7	6	47	48.5
14	C-13	7	6	56	57.5
15	B-13	7	7	65	66.75
16	A-13	I	7	77	78.75
17	A-J	I	8	88	90
18	A-K	I	8	100	102
19	A-L	I	9	112	114.25
20	A-M	7	9	125	127.25
21	A-N	7	10	139	141.25
22	A-O	8	10	157	158.25
23	A-P	8	11	170	172.75
24	A-Q	9	11	187	189.75
25	A-R	9	11	204	206.75
26	6-R	10	12	204	207
27	5-R	10	12	206	209
28	4-R	9	12	212	215
29	3-R	9	12	219	222
30	2-R	8	13	226	229.25

FIGURE 1

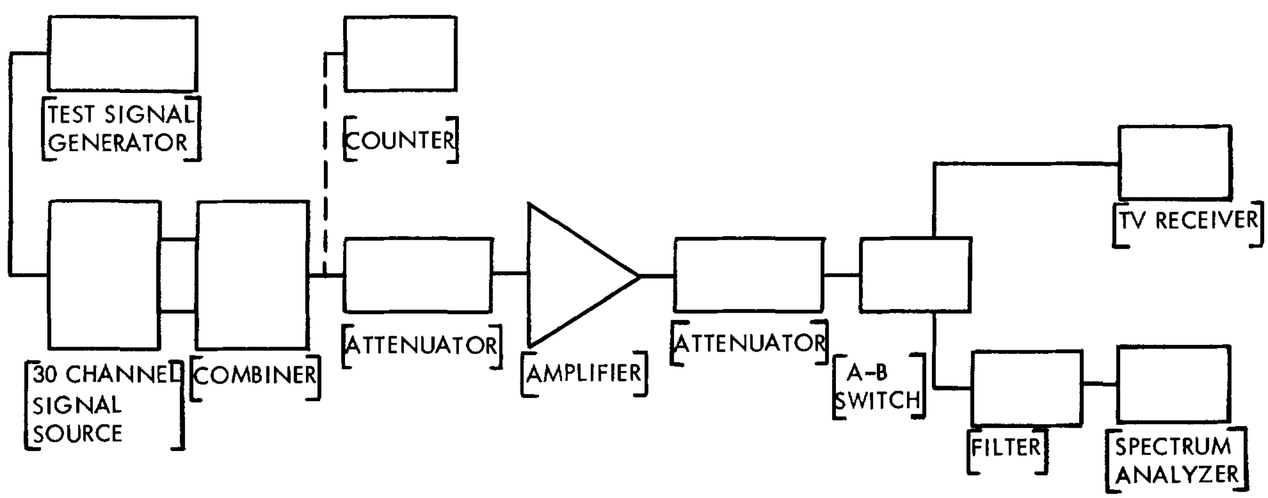


CARRIER TO THIRD ORDER INTERMODULATION RATIO (dB)
20 Log N Slope
CURVE 1
REQUIRED SYSTEM LEVEL OF INDIVIDUAL TRIPLE BEATS
10 Log N Slope
INDIVIDUAL TRIPLE BEAT LEVEL & TOTAL THIRD ORDER INTERMODULATION LEVEL VS TOTAL NUMBER OF EQUIVALENT TRIPLE BEATS PER CHANNEL
BERT ARNOLD
11-1-72
CURVE 2
THRESHOLD LEVEL OF PERCEPTIBILITY OF TOTAL THIRD ORDER INTERMODULATION PER CHANNEL
4 9-12
5 8-12
7 7-13
STD-12 2-13
11 H-K
15 8-13
18 D-N
24 A-Q
30 2-R
- # OF CHANNELS
- CHANNELS
TOTAL NUMBER OF EQUIVALENT TRIPLE BEATS PER CHANNEL

APPENDIX A

TEST SET-UP FOR TRIPLE BEAT MEASUREMENT

EQUIPMENT:	MANUFACTURER:	MODEL:
30 MODULATORS	EiE	CTMI
1 NTSC TEST SIGNAL GENERATOR	Tektronix	R140
1 COUNTER	Eldorado	1450
2 COMBINERS	EiE	151125-1
2 ATTENUATORS	Texscan	SA-78
1 TEST AMPLIFIER (HYBRID MODULE)	TRW	CA613
1 A-B SWITCHES	EiE	AB5-75
1 TV RECEIVER	RCA	XL-100
1 SET OF FILTERS	Hamlin	BPF10
1 SPECTRUM ANALYZER	H.P.	8554L/8552A



APPENDIX B

TEST CHANNEL FREQUENCIES

CHANNEL	FREQUENCY MHz	Δf khz
2	55.2515	+1.5
3	61.2469	-3.1
4	67.2449	-5.1
5	77.2480	-2.0
6	83.2493	-0.7
A	121.2469	-3.1
B	127.2492	-0.8
C	133.2423	-7.7
D	139.2461	-3.9
E	145.2504	+0.4
F	151.2496	-0.4
G	157.2504	+0.4
H	163.2503	+0.3
I	169.2493	-0.7
7	175.2407	-9.3
8	181.2450	-5.0
9	187.2421	-7.9
10	193.2452	-4.8
11	199.2500	0.0
12	205.2396	-10.4
13	211.2500	0.0
J	217.2497	-0.3
K	223.2476	-2.4
L	229.2454	-4.6
M	235.2428	-7.2
N	241.2464	-3.6
O	247.2517	+1.7
P	253.2520	+2.0
Q	259.2550	+5.0
R	265.2521	+2.1

APPENDIX C

DETERMINATION OF SYSTEM TRIPLE BEAT

FROM FIGURE 1

Example

Let's assume that an operator plans to operate his system with 24 channels, A-Q, on one cable. The determination of the system triple beat (carrier to triple beat ratio) is as follows:

In Table 1

The first column is labeled "Number of Channels." Find 24 channels in this column and read across to the last column labeled "Total Equivalent Triple Beat" to find the total number of equivalent triple beats that the center channel has.

From Table 1

24 channels = 189.75 spurious signals on the center channel 9.

In Figure 1

The Horizontal Axis is labeled "Total Number of Equivalent Triple Beats per Channel" and the Vertical Axis "Carrier to Third Order Intermodulation Ratio." Find the Horizontal Axis 189.75 spurious signals and the intersection with Curve 1. From the intersection of Curve 1, read across to the Vertical Axis for the triple beat required in a system.

From Figure 1

The system triple beat specification for 24 channels would be approximately 76 dB.

Note:

As mentioned in the text, this specification is for the threshold of perceptibility for unmodulated carriers. If the carriers were modulated there would be an improvement in the threshold, but the amount of improvement would depend upon the characteristics of the modulation. The unmodulated carriers are a worst case condition for viewing third order intermodulation distortion, but it provides for more consistent results just as synchronous modulation does for cross modulation testing. Many systems have been able to operate with a less than worst case triple beat specification mainly because of the modulation carriers, but there is no safety left for variations in system levels due to temperature changes, or aging.

APPENDIX D

DETERMINATION OF SYSTEM TRIPLE BEAT

FROM AMPLIFIER SPECIFICATIONS

Example

Assume a system cascade of 20 trunk amplifiers, one bridger and one distribution (line extender). The number of channels will be 30, Channel 2 through Channel R.

EiE Series 50 triple beat specifications are:

	Triple Beat	Output @300 MHz
Trunk	116 dB	30 dBmV
Bridger	82 dB	47 dBmV
Distribution	88 dB	44 dBmV

The degradation for a 20 amplifier cascade would be 26 dB.

20 Trunk = 116 - 26 = 90 dB
20 Trunk + Bridger = 90 dB + 82 dB = 79 dB
20 Trunk + Bridger + 1 Distribution =
79 dB + 88 dB = <u>76.5 dB</u>

The system specification of 76.5 dB for practical purposes meets the required triple beat specification in Figure 1 of 77 dB.

If 2 distribution amplifiers are cascaded the levels can be reduced 2 dB to maintain the specification.

20 Trunk + Bridger + 2 Distribution
= 90 dB + 86 dB + 92 dB + 92 dB = <u>76.6 dB</u>

Note: See note in Appendix C.

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e. Papoulis, Anthanasios; Probability, Random Variables and Stochastic Processes; McGraw-Hill Book Co., pp. 266-268, 1965.

f. J. R. Cavanaugh; A Single Weighting Characteristics for Random Noise in Monochrome and NTSC Color Television; Journal SMPTE, Vol. 79, Feb. 1970, pp. 105-109.

SCAN LOSS AND ITS ELIMINATION IN CATV SWEPT FREQUENCY MEASUREMENTS

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Gill Cable, San Jose, California

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This is a tutorial article on Scan Loss. Good construction and maintenance practices in conjunction with FCC and DOC specifications have emphasized the need for increased swept frequency measurements. Swept frequency measurements to determine: return loss, component isolation, flatness, spurious responses, probable causes of group delay as well as bench alignment and preinstallation checkout of passive or active system components.

Unfortunately, the possibility of amplitude error does exist especially in the case of severe amplitude changes (dB/MHz) through the mechanism of Scan Loss.

Please note the folowing photos of the swept response of a 0-300 MHz spectrum -- in which a Jerrold TLB-2 trap is inserted. Using a standard sweeper with variable sweep speed, an H-P 8471A detector, 3 feet of RG 58/u cable, and a storage oscilloscope calibrated 30 MHz per devision, two photos were made.

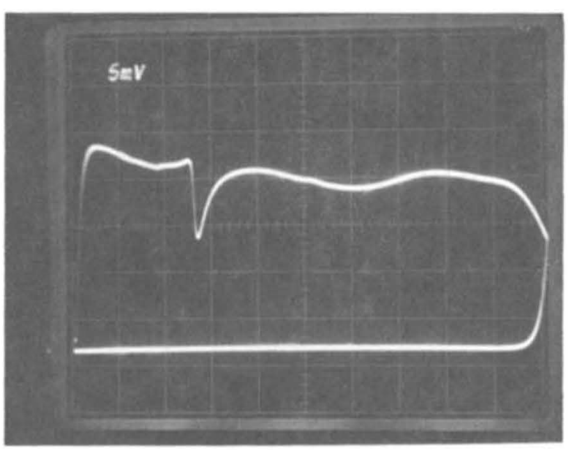


Photo A   Sweep duration = 7 ms

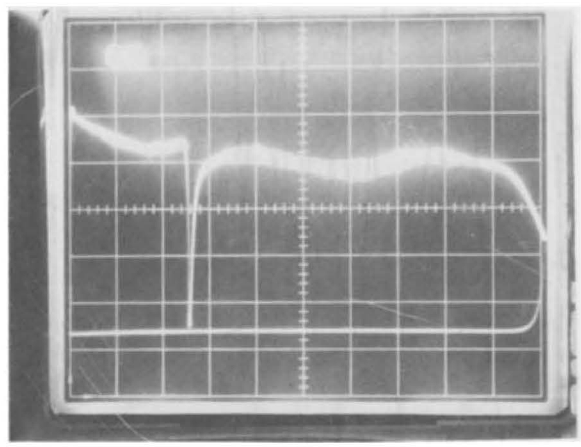


Photo B   Sweep duration = 140 ms

When viewing the above photos, the question which comes to mind is: Which display is correct? Or, even possibly, Is either display correct ? Interestingly enough, the only variable in either case was sweep duration.

In plant construction and maintenance, you may frequently see severe amplitude changes as in the case of Photos C, D and E, taken with a log display CATV Sweep System known <u>not</u> to exhibit scan loss of a 12-channel plant

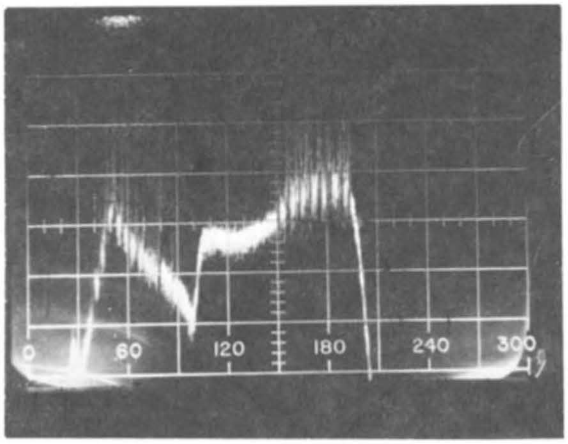


Photo C Vertical Sensitivity = 2 dB/cm

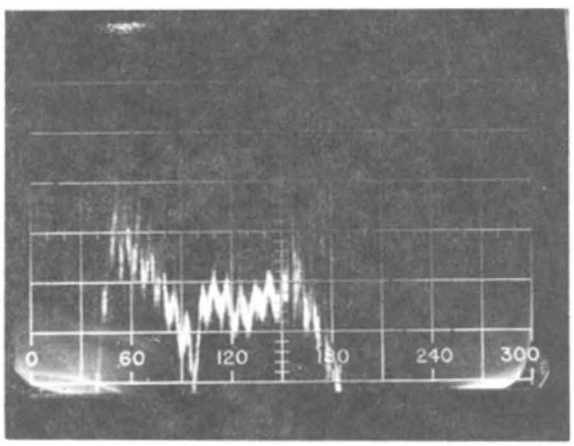


Photo D Vertical Sensitivity = 2 dB/cm

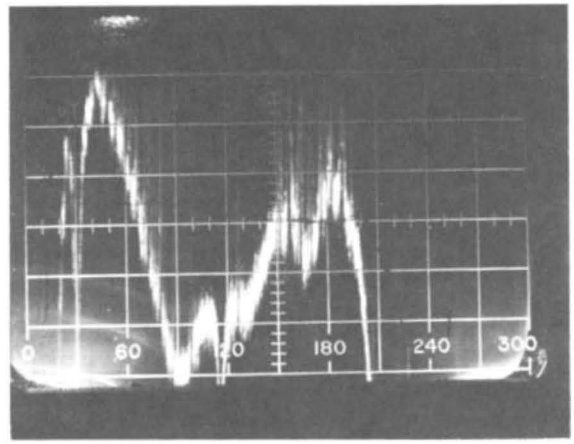


Photo E Vertical Sensitivity = 2 dB/cm

The problem is that if scan loss is present in our measurements (compare photos A and B), our construction and maintenance decisions are influenced by inaccurate information. In the case of Photos C, D and E, if scan loss were present, most of the problems could very well be masked or hidden.

The purpose of this paper is to make CATV Technicians aware of the scan loss phenomenon through definition and discussing its causes, recognition and elimination.

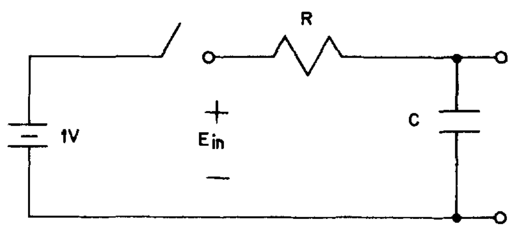
Definition (1)

Scan loss is the loss of amplitude resolution due to scan/sweep speed and is caused by the time constants associated with the detector, bandwidth of the receiver and response characteristic of the plant or device under test.

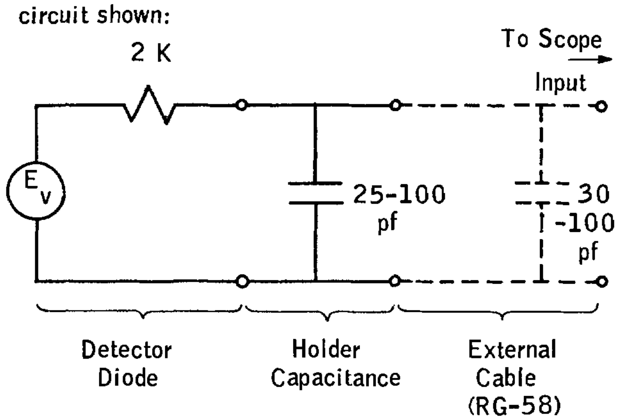
(1) Russell D. Anderson, "So, You're Finally Going To Buy Some New Test Gear?" TV Communications, February 1973 Volume 10, Number 2, pp 69-80.

Scan loss is aggravated or increased by faster sweep rates (MHz/sec) or reduced bandwidth. In either case, a large voltage change associated with a sharp change in system response may occur too rapidly for the filters (limiting bandwidth) to fully respond, giving an inaccurate replica of the voltage change.

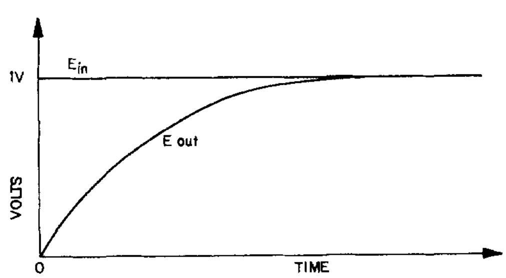
An example to consider would be the following RC filter:



Detector circuit — video frequency equivalent circuit shown:



At time 0, the switch is closed. The wave form is shown below:



The equation for E_{out} is

$$E_{out} = 1 - \epsilon^{\frac{-t}{RC}} \tag{1}$$

The bandwidth of the RC filter can be shown to be

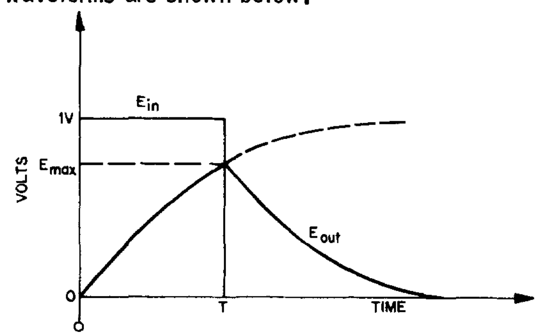
$$BW = \frac{1}{2\pi RC} \tag{2}$$

The formula for E_{out} can be rewritten

$$E_{out} = 1 - \epsilon^{-t2\pi BW} \tag{3}$$

In this case if we let t become very large, the output voltage will nearly equal the input.

Suppose, however, we have a pulse input. The waveforms are shown below.



The input pulse width is T. The maximum value E_{out} reaches during the pulse is

$$E_{max} = 1 - \epsilon^{-T2\pi BW} \tag{4}$$

The loss in amplitude can be expressed in dB:

$$\text{Loss} = |20 \log E_{max}| \tag{5}$$

or

$$\text{Loss} = |20 \log (1 - \epsilon^{-T2\pi BW})| \tag{5a}$$

Now consider the case of a signal (whose frequency is being swept) driving a filter whose bandwidth is BW. If we know how long the signal is in the band BW, we can draw an analogy to the above example and determine how much loss there will be in the filter to a swept input signal.

Let the input signal frequency range be Δf Hz. Let the input sweep rate be SR sweeps per second.

The numbers of Hz swept in 1 second is $\dot{f}$

$$\dot{f} = \Delta f \times SR \frac{Hz}{second} \qquad (6)$$

To find the time that the signal is in the BW, let T_B be that time:

$$T_B = \frac{BW}{\dot{f}} = \frac{BW}{\Delta f SR} \text{ seconds} \qquad (7)$$

If (7) is substituted for T in 5(a):

$$\text{Loss} = \left| 20 \log \left(1 - \epsilon^{\frac{-2\pi (BW)^2}{\Delta f SR}}\right) \right| dB \qquad (8)$$

This is called scan loss (loss due to scanning).

TABLE I

$$\text{Scan loss} = \left| 20 \text{ Log } \left(1 - \epsilon^{\frac{-BW^2 2\pi}{\Delta f \times SR}}\right) \right| dB$$

Scan Loss as a Function of Sweep Speed

Case 1

Δf = 300 MHz
BW = 50 KC

SR:		LOSS:
	10 S/S	.05 dB
	20 S/S	.66 dB
	50 S/S	3.75 dB
	100 S/S	7.8 dB
	200 S/S	12.8 dB

Scan Loss as a Function of Bandwidth

Case 2

Δf = 300 MHz
SR = 60 sweeps/sec.

BW:		LOSS:
	10 KHz	29.3 dB
	20 KHz	17.7
	50 KHz	4.7
	100 KHz	.27
	200 KHz	.000007

Scan Loss as a Function of Sweepwidth

Case 3

BW = 50 KHz
SW = 60 S/S

Δf:		LOSS:
	300 MHz	4.7 dB
	100 MHz	.66
	60 MHz	.11
	30 MHz	.0014
	6 MHz	0

NOTE: This table was calculated with the assumption of putting a pulse into an RC filter.

The generalizations that can be derived from this data apply qualitively to spectrum analyzers, and approximately quantitatively when BW is half the IF bandwidth.

In Table 1, some scan loss data are presented showing how it changes as BW, SR and Δf are varied.

The obvious conclusion to be drawn from the above is that any sweeping system will have some amount of scan loss. The real question is how much and how can it be effectively eliminated, which is answered in Table 1.

Consider the following example taken from Table 1, Case 3.

Example 1:

a) BW = 50 KHz
SR = 60 S/S
Δf = 300 MHz
Scan Loss = 4.7 dB

b) BW = 50 KHz
SR = 60 S/S
Δf = 30 MHz
Scan Loss = 0.0014 dB

In Example 1a) above, the scan loss is more than could generally be tolerated, however, scan loss 1b) is small enough to be practically unmeasurable.

To calculate scan loss for a given system the above equations are used; but two considerations must be made:

A. Is loss occurring because the cable response is active as the limiting filter? If so, this would principly be factor of sweep speed.

B. Once the cable plant is charged to any given value - will the receiver respond to the complete charge?

For example assume that a plant has a 1 MHz notch somewhere in a spectrum of 300 MHz and that sweep speeds of a) 25 ms and b) 2.5 ms are used.

Question, Will the cable charge to the full value? Using the equation in Table I above

$$\text{Scan Loss} = \left| 20 \log (1 - \ell^{\frac{BW^2 2\pi}{\Delta f \times SR}}) \right| \text{dB}$$

we find that scan loss is essentially zero in both cases.

This calculation assumes an infinate video bandwidth due to the matched impedance of the transmission system.

Since either sweep rate is adequate for seeing the 1 MHz notch, we must then determine what amount of scan loss will be contributed by the receiver bandwidth. To do this, we must use equation 5a above.

$$\text{Loss} = \left| 20 \log (1 - \ell^{-T2\pi BW}) \right|$$

where T = time sweep is in the 1 MHz bandwidth and BW = video bandwidth of the receiver.

In example A above with a 25 ms sweep duration

$$T = 25 \text{ ms}/300 \text{ MHz or } 83.3\ \mu\text{sec}$$

and

$$BW = 50 \text{ KHz}$$

$$\text{Scan Loss} = 20 \log (1 - \ell^{-83.3 \times 10^{-6} \times 2\pi \times 50 \times 10^{3}})$$

$$= 20 \log (1 - \ell^{-26.1})$$

$$= \text{Approximately zero loss}$$

If the sweep speed is increased by a factor of 10, example B (2.5 ms sweep duration) above the equation is now

$$= 20 \log (1 - \ell^{-2.61})$$

$$= .68 \text{ dB of loss}$$

Now assume that a crystal diode detector is used with a high impedance load (high impedance scope with 1 megohm input impedance) and that the total capacity of the scope detector and cable equal 100 pf. The resultant receiver BW is approximately 2 KHz.

$$\text{Scan Loss} = \left| 20 \log (1 - \ell^{-.104}) \right|$$

$$= 20.4 \text{ dB}$$

Therefore a significant amount of scan loss would be present. The obvious conclusion from this example is that a wider video bandwidth is needed for the receiver to see the 1 MHz notch. This can be accomplished by:

a) Detector biasing
b) Shorter cable between detector and scope
c) Lower capacity cable
d) Loading of the detector with external resistance but this reduces detector output voltage
e) Addition of a detector post amplifier without any cable length to lower output impedance without decreasing detector voltage
f) Slow sweep (approximately 10 sec.) with a high-resolution with X-Y plotter.

Recognizing Scan Loss

To maintain reasonable accuracy in flatness measurements or to insure that a true response is noted, one must be able to recognize scan loss.

The easiest way to accomplish this is to slow down the sweep speed when ever in doubt. If scan loss is present, the response shape will change (get worse). If this is the case, the sweep speed should be slowed until no further change can be detected.

A good way to accomplish this is to trace the sweep reference on the oscilloscope with a grease pencil before going to 1/2 sweep speed. The reference allows easy recognition of any response change.

Elimination of Scan Loss

Once Scan Loss is understood it is easily recognized and,therefore, can be essentially eliminated through one or may ways.

A. Selection of good quality sweep components

B. Use of very slow sweep rate

C. Slowing of sweep speed when in doubt.

Conclusion

Scan Loss, the loss of amplitude resolution due to time constant effect, is all too common in swept frequency measurements. This tutorial paper had discussed scan loss and its causes, recognition and elimination in hopes that it may be eliminated in CATV swept frequency measurements.

STAGING PRINCIPLES FOR TELEVISION

Richard L. Williams

TeleMation, Inc.

Proper utilization of good staging principles is one of the most important earmarks of a professional television production. It is surprising to find, therefore, that very little has been written to instruct television directors in good staging practices.

The definition of television staging to be used in this article is quite simple: Staging is the placement of visual elements in the TV studio--both that which the viewer will see and that which will affect how he sees the scene. This includes props (anything in the foreground) and scenery (anything in the background), as well as the talent and the cameras.

Unfortunately, there is no single set of staging rules that works for every situation. The television director must consider staging a production from aesthetic (or artistic), psychological, and practical points of view. Oftentimes, the best psychological effect is not practical to produce with the equipment available. Nor may a very artistic staging be possible with a limited production system. It is the job of the director to consider every aspect of the situation and to reach a compromise which will most closely produce the desired effect.

Staging the Cameras

The positioning of cameras in television production is critical.

When placing cameras in a multiple-camera production, Camera 1 should be placed to the left and Camera 2 to the right (as viewed from behind the cameras). In the control room, the director's monitors and inputs on the production switcher will also be positioned left to right. This creates a perspective uniformity for director and cameramen which will avoid any misunderstandings. (It should be noted that this seemingly "natural" order is actually determined by our western culture custom of reading from left to right. In some other cultures, other arrangements may be more "natural.")

To avoid "crossing the cameras" and the confusion that results, the cameras should be labeled with a large "1," "2," etc., for cameramen and talent to see. Then, if a performer is requested to give his introductory speech into Camera 1, he can locate the camera quickly. In short, consistent positioning of the cameras is important to everyone in the studio.

Physical Barriers

Physical barriers, such as desks, produce the same effect as increasing the distance between people. It is simply a different kind of separation. Much of the success of staging has to do with a proper understanding of the psychological effect of positioning such items, in addition to their artistic effect as "props."

Physical barriers are often placed between performers, and between the performer and the audience. It should be noted that the effect of these barriers upon the TV audience is often greater than one would expect by looking at the object in the studio. Also, a barrier placed for a positive reason may end up being a negative barrier in another, perhaps unforeseen, sense. In other words, one must always consider all resulting effects, or the total pattern.

The most common prop used in staging is a desk or table. A desk or table affords a measure of protection to the speaker--he doesn't have to think of the positioning of his legs or the part of his body which is shielded. A desk or table can also give the speaker something to hold on to, and it allows him to relax. If a show appears on a regular basis--perhaps weekly--a desk can clearly distinguish the moderator from the guest panelists and provide a semblance of permanence and stability. Desks and tables can also be used to hold papers, a water pitcher or glasses.

However, it is important to use barriers in moderation. A large dark desk can be overpowering and should be avoided, whereas a light-colored, low coffee table is not only an acceptable barrier, but a desirable one.

In the example of a large table with three people positioned around it, the table separates them from each other and is a barrier as well between the panelists and the camera (thus the audience). The table in our example is too large and creates an impression of separateness, so it probably is not a good prop to use for an informal discussion.

At times, the producer will want to create a formidable barrier to add formality and authority. A judge, for example, always appears behind a large dark bench. If he were not set apart from others, he--and the judicial process--would lose some of the psychological power which the bench gives him.

How does all this apply to a small studio? During the taping of a speech by the mayor, it would be natural to establish his authority by placing him behind a large dark desk. In the opening scene, the cameraman might frame the desk with the mayor behind it, and then zoom past the desk to the mayor. The cameraman could establish the authority of the mayor again once or twice during the production, and establish it at the end of the show. However, the viewers might be a little tense and not feel as cooperative about accepting the mayor's message if the cameraman were to keep that large desk in the foreground the entire time.

Of course, physical props--or barriers--are important for aesthetic reasons, as well as psychological ones. They prevent a scene from appearing bare and stark. Props and scenery function to fill up space and balance a scene. They help to establish a time, place, mood or sensation. Without any scenery or props (which is a situation referred to as a "limbo setting") all interest is focused upon the speaker. A limbo setting with dramatic lighting might be aesthetically pleasing for a poetry reading, but a limbo setting for a TV cooking class would appear strange and make viewers uneasy.

Staging is, in essence, bringing together the various aesthetic, psychological and practical elements of a production. Camera, monitor and input placement in a logical "1-2" sequence from left to right is a critical practical application of staging technique. An example of aesthetic and psychological application is the physical barriers concept in which props placed between the performer and camera set the mood of the scene as well as give the audience a clue to react by showing distance.

STANDALONE TIME BASE CORRECTOR SYSTEMS FOR CATV PROGRAM PRODUCTION, DUPLICATING, AND CABLECASTING

C. Robert Paulson
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Bloomfield, Connecticut

Several VTR formats incorporating both monochrome and color performance are now being used in CATV systems for program production, duplication, and playback. (Figure 1.) The 1/2-inch and 3/4-inch formats offer the benefits of relatively low cost, portability, operating simplicity, reasonable reliability, long tape and head life, and subjectively satisfactory picture quality, compared to 1-inch and quad "broadcast standard" VTRs. The three-quarter inch cassette format is also attractive because of the availability of libraries of "software" for purchase or rental, as well as its simple slot loading and automatic programming features.

1/2-inch EIAJ and 3/4-inch U-cassette

PROGRAM PRODUCTION – MOBILE

Battery-pack camera/VTR combinations
Transportable cassette VTRs
Mini-wagons and maxi-vans

PROGRAM PRODUCTION – STUDIOS

All formats including 1-inch helical and 2-inch quad

IN-HOUSE PROGRAM DUPLICATION

Any format to any other format

CABLE CASTING

Public Access Channels – 1/2-inch EIAJ – B/W
Company Channels – Anything available
Pay Program Channels – 3/4-inch cassette

Figure 1.
New Video Tape "Standards" in CATV.

However, these VTRs have well-known time base instability and head switching dropouts or discontinuities. And to get a share of audience on the company free or pay-program channels (a necessary prerequisite for making money) the operator must distribute as stable a signal on these local origination channels as is available on the TV station originated channels.

Up to this year, the only solution to the problem of unstable pictures was to buy a stable (much more expensive) VTR. And if you wanted to do any fancy program production mixing tape and camera pictures, you bought an even more expensive VTR with a built in time base corrector.

"Broadcast quality" VTR costs--their size and complexity--the need for highly skilled technicians and lots of maintenance time--no interchangeability among 1-inch VTR formats--all these factors worked together to foster the CATV industry's "standardization" on the 1/2-inch EIAJ and 3/4-inch U-matic formats. But now you've discovered a new set of problems, which require a time base corrector in these VTRs for their solution.

What's Time Base Correction?

"Time Base Correction" is a new technical term for most people in CATV/CCTV/MATV operations. Up until recently a Time Base Corrector was an expensive electronic gizmo that was built into the expensive broadcast video recorders. If you knew about it at all, perhaps you understand it was required by the FCC to fix up a video tape playback so it could be put on the air.

How Does That Help Me?

Those assumptions used to be true about TBCs, but Television Microtime, Inc. changed all that starting a year ago. Now there's a DELTA Series Time Base Corrector from TMI to work with every kind of Video Tape Recorder from broadcast quad to quarter-inch, and all the tape widths in between--1", 3/4", and 1/2"--(Figure 2). They handle signals in "NTSC direct color" --"NTSC type" (heterodyne) color--and gray old black and white--from back pack portables, cassettes, and elaborate studio teleproduction VTRs.

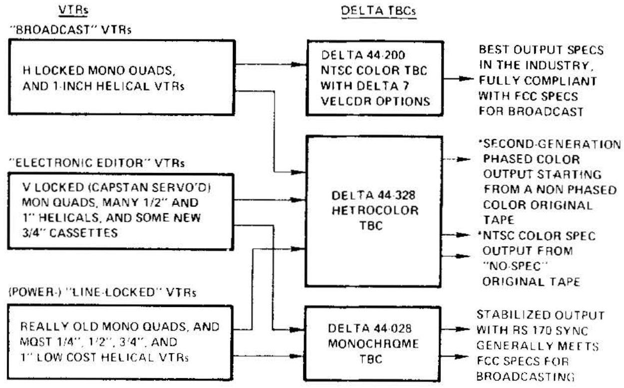


Figure 2.
Categories of VTRs and DELTA TBCs.

Two of these Delta models in particular elevate the low-cost VTRs to co-equal status with much more expensive 1-inch and broadcast VTRs in CATV applications. The CATV operator can now select a time base corrector system tailor-made to work with his VTRs in either monochrome or color. One system, the Delta 44-328 HETROCOLOR™ TBC, can process the jittering signal of <u>any</u> VTR fed into it for stable distribution throughout the system. All the models also permit VTR playback integration with other picture sources for post-production processing. The low-cost Delta 44-028 system works with EIAJ 1/2-inch VTRs playing tapes made on battery powered portable VTRs. The -028 and -328 models both accept tape playbacks containing sync generated by either an EIA specification RS-170 sync generator or a camera with built-in 2:1 interface sync. The -328 color system will accept either NTSC or "NTSC-type" color signals and heterodyne color signals (recorded with "color under"). Depending on the system selected and the techniques used, the output signal from the Delta 44 system may either be a phased color signal with coherent sync and subcarrier, fully compliant with FCC specifications for broadcasting, or a non-phased color signal whose burst frequency and stability meet FCC specifications for broadcast, and whose sync information is in accordance with EIA specification RS-170 but containing a low frequency drift component generated by the source VTR.

These Delta 44 systems are each packaged in a single seven-inch rack cabinet with front panel controls for complete correction of non-standard input signals. They require no operator attention after initial set up. The completely adaptable Delta 44-328 HETRO-COLOR™ TBC allows all VTRs from two-inch quad to one-half inch EIAJ to "talk to each other" without propagating residual time base jitter from one tape generation to the next.

How Does A TBC Work?

The DELTA TBC is a standalone electronic system you install in a rack at your head end--or master control or production studio. Its specific location is a matter of your local preference and operating patterns. It accepts jittering, tearing signal from your VTR (Figure 3. upper left) analyzes its time base errors (upper right--note blurred stairsteps compared to reference sync), corrects them and processes the signal with new sync information (lower center--note how black to white transition has sharpened). It's extraordinarily useful as a VTR picture processor for program playback, re-recording mixed with new picture material, one-to-one or mass duplication and even broadcasting.

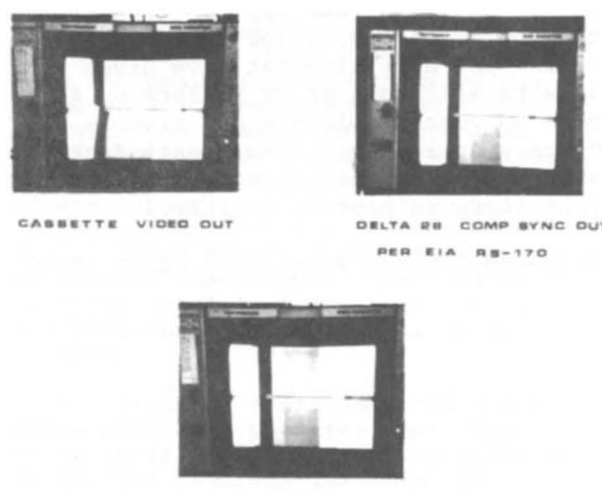
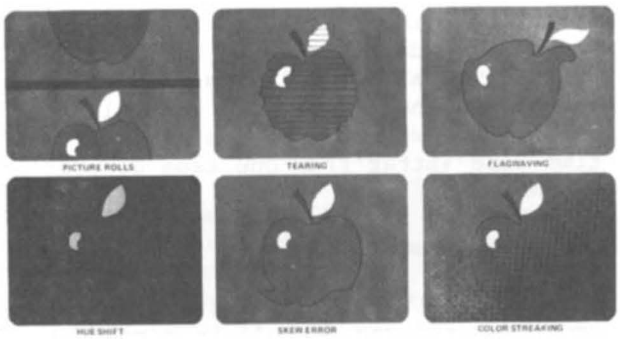


Figure 3.
Pulse-cross monitor photos of
Delta 28 TBD and Delta 44 TBC in action.

™Trade mark of TMI.

How Do I Know I Need A TBC?

The time base errors in the picture, created during its recording and playback on a VTR, are like bad apples in a barrel. It doesn't take many to spoil the whole barrel (Figure 4).



How do you like them apples?

THESE TIME BASE ERRORS – I.E. PICTURE PROBLEMS ARE CREATED EVERY TIME A TAPE IS

RECORDED OR PLAYED BACK

WHY? 1. THE TAPE IS ELASTIC

2. THE VTR IS FULL OF ECCENTRIC ROTATING MOTORS, PULLEYS, AND PARTS.

Figure 4
How do you get rid of them bad apples?

There's a DELTA Series TBC to get rid of all those bad apples--flagwaving, tearing, wobbling, color changes, vertical rolls--you name it--that have given your viewers all kinds of TV jitters up to now. Down go your complaints and trouble calls. Up go your ratings, viewer satisfaction, and sponsorship billings, right along with your improved picture quality.

Where Do I Learn More About DELTA TBCs?

All the models described and several accessories to add further performance improvements to your VTRs are in production (Figure 5) at TMI's headquarters at 1280 Blue Hills Avenue, Bloomfield, Connecticut 06002. They are sold, installed, and maintained throughout the United States by a competent organization of factory authorized distributors. Demonstrations of all DELTA Series capabilities will be scheduled at your facilities at your convenience, by these distributors. They are also qualified and equipped to supply your varied needs for cameras, special effects, switchers, and other TV production hardware and services.

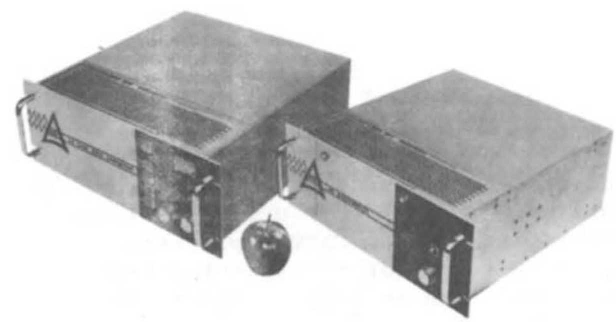


Figure 5
The Delta 44 TBC Cabinet (left) and Accessories Cabinet are 7-inch rack units with front panel controls.

SUBSCRIPTION SERVICES FOR CATV

MODERATOR:

Henry Harris
Cox Cable Communications, Inc.
Atlanta, Georgia

PANELISTS:

Richard Lubic
Home Theatre Network, Inc.
Los Angeles, California

James T. Ragan
Athena Communications Corp.
New York, New York

William Butters
Trans-World Productions, Inc.
Hollywood, California

Gerald Levin
Home Box Office Inc.
New York, New York

Frank Cooper
Gridtronics, Inc.
New York, New York

Gary Christensen
Hogan & Hartson
Washington, D.C.

SUBSCRIPTION SERVICES FOR CATV

MR. HENRY HARRIS: Good morning. Welcome -- unofficial welcome -- to the home of Mickey Mouse and movies, and that's what we will be talking about this morning.

To introduce you to the panel this morning, starting on my far right is Gary Christensen, former NCTA General Counsel and now with the firm of Hogan & Hartson.

Next to him is Frank Cooper, head of Gridtronics, the Warner Communications subscription service subsidiary.

Next to him is Gerry Levin, with Home Box Office, part of Sterling Communications in New York.

Next to him is Bill Butters with Trans-World Communications, subsidiary of Columbia Pictures.

On my far left is Jim Ragan, President of Athena Communications Corporation and involved in subscription cable through a project they call Indicode.

And next to Jim is Dick Lubic, who is President of Home Theatre Network, another subscription service for cable television.

I think you will be quite interested in what these gentlemen have to offer, because we have got probably as much experience as this industry has got represented on this stage.

So, without further ado, I would like to start with Gary Christensen, who will sort of set the regulatory tone for the environment in which this business now operates and, beyond that, we will just swing around the table, and end with Jim, and each of you speak in turn. Thank you.

Gary.

MR. GARY CHRISTENSEN: Thank you very much. It's a pleasure to be here and see all your shining faces this early in the morning.

The regulatory atmosphere for pay TV is controlled solely at the federal level; in other words, the regulation of pay television has been pre-empted by the Federal Government, so that all state and local regulations which are contrary to federal regulations are void. So when we consider CATV and pay TV on CATV as a mode of distribution, what we have to consider is the federal regulatory picture.

The present federal regulations are relatively simple, although in their application they may well become and have become somewhat complicated.

There are three elements that we have to consider when we talk about pay television, because what we are talking about here is the software rather than the hardware of the pay television system.

The three elements are feature films, sports events, and series programs. Very briefly, the federal rules provide that feature films which are more than two years old or less than ten years old are not allowed to be shown on pay TV. Now, there are occasional exceptions, but, for purposes of simplicity and so that we can get into a general picture of the program, we won't go into those exceptions.

Sports events which have been available on broadcast television, that is, in quotes, free TV, for the last two years are not allowed to be shown on pay television by CATV.

Lastly, series programs are not allowed to be shown on pay television. Series programs are those which have a central character or a central plot or a continuing type of program. I'm sure all of you are familiar with a layman's definition of a series program.

There is presently pending before the FCC a rule making docket in which the FCC asks questions as to whether these rules should remain the same, whether they should be strengthened or increased, or whether they should be lessened or softened, so that pay television via cable has a better economic chance of providing service to the public.

It is the position of some people in the industry that all regulations of pay TV ought to be eliminated, not only because they are unjust in a free and competitive market place, but because there are some modes of pay television or some future modes of pay television which will not be under these same kinds of strictures.

If the pay television regulations on CATV are not lifted or eliminated in their entirety, then there have been suggestions made to the Federal Communications Commission that the times involved in the showing of movies should be reduced, so that, for example, one of the suggestions was, the two to ten-year prohibition should should be changed to provide that only movies which are more than five years old would not be shown on pay TV if those movies were not available to a broadcast television station serving a CATV community.

With respect to sports there have been suggestions that the entire sports rule be eliminated.

And, lastly, the series programs. Because the practical marketing aspects of series programs to pay television distribution methods do not lend themselves to the siphoning of these series programs from broadcast television there have been suggestions that those series program restrictions should be eliminated altogether.

In essence, the CATV industry's position before the Federal Communications Commission is that the CATV industry only asks the right to compete with other entertainment forms on an equal basis and that a free and unregulated market place is the best approach.

Of course, the free television, again in quotes, the broadcast television, interests are attempting to have the nature of the rules strengthened so that fewer programs would be available to pay television.

This particular rule making will not be concluded until late July, which means that, at the very earliest, any changes in the rules will be considered in late August. And if the FCC runs true to form, it is unlikely that any changes in the rules, either for the better or for the worse, will be made until perhaps early winter.

That is generally the regulatory atmosphere within which this new form of entertainment has to operate.

And, with that, I will turn it over to Frank Cooper.

MR. FRANK COOPER: Thank you, Henry. Thank you, Gary. Good morning.

Exactly four years ago when this Convention last assembled in California, Warner Cable Corporation, then known as TVC, proposed the Gridtronic Diversity Plan now known as pay cable. When we proposed it, the idea was treated in many quarters as amusingly naive. And now we frequently hear it described as the salvation of CATV. The truth, of course, is somewhere in between.

Pay cable is no joke and it is not salvation.

Obviously, pay cable is capable of increasing revenue but is not a substitute for good system practice. And if a system is inefficient, pay cable will not suddenly render it viable.

Furthermore, the razzle-dazzle technology of 2001 which is implied in the promises made by some of pay cable's proponents serves only to confuse the issue, which is what role can premium services play in a CATV system and for whose benefit?

Perhaps a brief description of the experience of Warner's subsidiary, Gridtronics, Inc., would be helpful.

Beginning last February, we supplied a movie channel, the Star Channel, to four company-owned systems. At this point in time seven systems carry the Star Channel, and by September there will be ten. These systems reach from New York to Florida to Oregon.

The software consists of new motion pictures which have never been seen on TV before. There are no interruptions during the cablecast. The films are shown in color and are repeated four times daily.

The subscriber costs vary from $5 to $6 per month. During that period eight different movies are shown. The titles range from epics such as "Nicholas and Alexandra" to thrillers like "The French Connection" to outdoor themes such as "Living Free."

We practice no editing whatsoever.

From the outset we committed ourselves to a monthly charge for service as opposed to a per-picture or per-program charge. We felt that our tender young marketing plan needed every advantage. Our marketing assumption was that the subscriber was already familiar with cable TV and had developed a friendly attitude towards it and confidence in it.

Since he had accepted the idea of a monthly service for a monthly fee, it appeared only logical that additional monthly service would carry an additional monthly fee. By way of contrast, there was ample historical evidence of public hostility to the per-program charge.

We have, of course, introduced a horn of plenty. If a subscriber misses a given showing in a given week, he has innumerable opportunities to see it later, repeatedly even, at no extra charge. But this cornucopia does not represent a lost charge, as some of our critics claim; actually it is the seed of sales success. It inspires confidence in the value of our offering.

Most importantly, we have based our decision on operating realism, on what we perceive to be the industry's state of the art and on the public's state of mind. We are not immune to change. The importtant issue is not how to charge, but, rather, how to start.

First, of course, it is necessary that the system be capable of carrying an added signal sufficiently discrete that a charge can be made for its reception.

We have accomplished this economically by the use of a midband plus a converter. Most solid state CATV systems are amenable to this technique.

We originated our headend signal with three-quarter inch tape recorders. They are also economical and durable.

We have convinced most of the major producers of film to supply the programming material. And in this area, of course, traditions have been the hardest to change. But change is irresistible, because more movies mean more employment, mean more production, mean more revenue.

So, from headend to tuner, important new breakthroughs have been made. We suggest that now is the time for your system to participate.

Of course, we cannot promise you a delightfully easy road. There are start up costs. There is the expense of learning. But earlier in these remarks we suggested that the important considerations are not how to charge, but how to start, and for whom. And the answer is for the benefit of the guy who really controls your system - your subscriber. He has an insatiable desire for the better things in life, and if he is served well, he will reward us.

Thank you.

MODERATOR HARRIS: Thank you Frank.

Gerry Levin of Sterling.

MR. GERALD LEVIN: Thank you, Henry.

On the dark and stormy night of November 8th, Home Box Office became the first company to launch a cable pay TV service, an NHL game from Madison Square Garden and a motion picture appropriately and prophetically entitled "Sometimes A Great Notion." These historic events were transmitted to a limited audience in Wilkes-Barre, Pennsylvania. And, to be very truthful, the winds blew and the rains fell with such fury that night that we very nearly became the first company not to launch a cable pay TV service.

But we have been perservering since that time in November, and last night we logged our 222nd night of operation.

Our subscriber total has grown since that point to more than 12,000 homes in a dozen Eastern Pennsylvania cable systems.

Limited as this may be, I think it does qualify us to pose as a voice of experience in this aborning industry. We certainly don't need to spend much time on the quickening interest in cable pay TV. You will notice that I call it pay television without pretense, without euphemism and without circumlocution.

I think there is a broadening realization that cable pay television's time has come. Even the recent attacks by the television networks' top executives in reality are just one more evidence of its burgeoning impact.

The justification for cable pay television is quite logical. There is a growing demand for cable TV to provide program enrichment and broader consumer services. We know that cable TV can provide such services, that it should do so, and, in fact, it must do so, if it is to fulfill the promise so many of you in the industry have labored so hard to project.

But cable TV cannot provide these benefits within its historic revenue parameters. It has to develop a system for incrementally increasing revenues in order to sustain each new program service, whether it happens to be sports, entertainment, armchair shopping or meter reading.

The pay television medium as it is evolving today is the first link in this chain of new services for cable. It happens to be a service that can be provided now, today, without waiting for the full refulgence of promised and promising new technology, although I should be quick to point out that what is now being done in the pay television industry will some day cause us to blush at the memory of its lack of sophistication.

Like almost everyone else here, we at Home Box Office believe that the best of all pay TV worlds would involve a two-way, interactive delivery system and the capability for a program by program choice by the customer. However, we don't believe that we should mark time waiting for the fulfillment of these conditions. Therefore, we have gotten under way with a service that we think best fits today's situation.

Let me outline the characteristics of our Home Box Office service.

First, not unlike what Frank has told you, we offer our service on a monthly basis, rather than program by program.

Our service has been likened to an electronic magazine through which the subscriber may browse, selecting what he wants to see. Another analogy that we have used referring to our Home Box Office name would be that we offer a season ticket rather than a single-event admission.

You might ask, does this work? Well, our Wilkes-Barre subscribers who were asked in a survey to put a price tag on the events they watched during the course of the month estimated a median value of $23 per month for the service as against a $6 additional fee which they are paying. And I think this is very important because the subscriber is now being asked to establish a new cost-value relationship in his mind where he really has very little existing frame of reference for this. We are at least pleased to see this kind of value assessment on the part of the consumer.

Secondly, Home Box Office does not lease channels. We consider ourselves the supplier of a programming package to the cable operator.

Our aim is to be a wholesaler, to develop a compensable middle man's function, and at times we have analogized ourselves to a franchiser.

You can see that I too am searching for analogies or for an appropriate frame of reference in this new business.

Frankly, we think that the cable operators generally should oppose leasing their channels instead of providing this service themselves.

A third feature of Home Box Office is that our service consists primarily of current movies and live sporting events. We are offering essentially the same selection of motion pictures available to other pay TV entrepreneurs. However, we have concentrated also upon obtaining rights to major sports events on an exclusive basis.

This, we believe, is what the marketing experts refer to as our unique selling proposition. The Home Box Office sports package includes approximately 200 events from Madison Square Garden, which includes the Knicks and the Rangers, weekly Monday night boxing, wrestling, roller derby, the horse show, Westminster Kennel Club

Dog Show, college basketball, NIT, track -- we recently did the conclusion of the pro track meet at Madison Square Garden -- special sporting events such as the recent United States/Peoples Republic of China gymnastic competition, also a U.S. team against a Russian wrestling team.

We also include basketball games from the American Basketball Association, other NBA teams, the Boston Celtics, Milwaukee Bucks, Cleveland Cavaliers; World Hockey Association games, as well as Major League baseball which we have been carrying from Cleveland. Also this summer and fall we have had a schedule of professional bowling association tournaments. Two weeks ago we held a tournament out here in Downey, California. And we do a weekly night of trotting from Yonkers Raceway.

I should mention tonight that we are making one of our regular Monday night boxing events available to all the attendees of the Convention via the Canadian satellite. This is not only what we hope will be an outstanding heavyweight fight between Jimmy Ellis and Earnie Shavers, but it will also be an historic occasion, the first domestic satellite transmission across the continent of a live sporting event. It will be received in the structure out in the parking lot and transmitted into the closed circuit system at the Disneyland Hotel.

We hope all of you will join our announcers tonight at seven o'clock in watching this fight. Our announcers are Don Duffy and Floyd Patterson at ringside. There is a kind of historical niceness about having Don Duffy do this fight. The first network broadcast that Don did was the radio broadcast of the Louis-Conn fight in 1941. He can be remembered for being the announcer on the early boxing shows on commercial television. He has made the transition into closed circuit, big-screen boxing, and now he appears as the announcer on the first spacecast of a sporting event.

In regard to sports, our research indicates that obviously interest is largely confined to the male members of the family. However, our research also makes it pretty unmistakably clear that the ultimate go, no-go decision in the family on subscribing to this kind of service is made by the male head of the household.

Thus, while the whole family enjoys the movies, uncut and uninterrupted, the sports events may or may not be likely to tip the scales of decision making in the family.

The fourth aspect of our Home Box Office service is this: We are indeed a pay cable network. Because we offer live sporting events, our service depends upon real time delivery by microwave or cable rather than the unspooling of a film or roll of tape at the system headend. While this creates obvious initial problems of distribution for us, we also believe it gives us a particularly strong quality control over the origination of our product.

Furthermore, as should be evident at this convention, we consider ourselves to be in a unique position to take advantage of the new domestic satellite technology to form pay televesion networks, and that technology is here today.

I think that other participants in this discussion and the reprise this afternoon will probably take issue with some or all of the operating premises that we have at Home Box Office. And I think it is interesting that almost every one of the pay TV systems now in operation or hoping to go into operation represents a different approach to what is really a common goal. I believe that is very fortunate, because out of the pioneering efforts of all of us, the knowledge and expertise should emerge that will be essential to the development of future subscriber-supported services of all kinds.

At Home Box Office we have been experimenting with new programming, children's programming, for example, and new marketing techniques. But we are definitely willing to acknowledge that there is nothing sacred about our own format and philosophy, and we expect continuing change in the months and years ahead.

Before I close, I would like to comment briefly on two particular points.

One, the question of the, quote dirty movie, unquote, and also to give you some of our recent market experience.

Like everyone else, we are aware of the flak concerning our use of "R" movies over pay cable television, or dirty movies, as they have been characterized.

Why do we carry these "R" movies? For one reason, because that is basically what is available. The reason for this is that the studios are producing these films for theatre audiences, largely young audiences, now-generation audiences. But pay television audiences are different. The profile of our customer is that of a 35 to 49-year-old, middle-income family man who prefers to stay home and watch family type movies with his wife and children. In fact, in our most in-depth survey to date we discovered that 79 percent of our customers prefer to see movies at home rather than to go out.

There definitely is an opportunity, then, for the studios to swing back to making "G" and "PG" films. This potent market undoubtedly must be in the minds of the film industry as it makes its product presently available to what is a very thin pay cable market that now exists.

In the meantime we are limiting our schedule of our films, hopefully to one a month, and we play that in the late evening program slot.

However, don't overlook the fact that not everyone feels outraged about dirty movies. There is also a pay television audience out there that wants such fare.

In general our research has also indicated to us, and the direct reaction that we have received from subscribers seems to indicate, that almost exactly the same numbers of people want more "R" films and "X" films as object to them.

Let me just close on the subject of marketing. It is basically our policy to lend marketing support to the cable system operator.

Our experience, first of all with door-to-door marketing, using an outside marketing company, was very similar to that of most cable operators I have talked to - very high initial acceptance but a higher than desired disconnect rate. Direct mail and media advertising have been very effective. We have not achieved the penetration of door-to-door marketing, but indications are that subscribers achieved in this fashion are sturdier customers, that they are stayers, and provide a solid foundation for steady growth.

Telephone solicitation was almost totally unproductive except when used in conjunction with a tightly integrated marketing program. Word of mouth advertising obviously is extremely helpful.

We really came in from the cold in our early systems, but each day gives us gratifying proof that people are getting educated to what we are about and that a seller's market is being created.

And, finally, a discovery that I think you will find very important: We are beginning to see clear evidence that offering a strong supplemental program package, such as Home Box Office, does bring in new cable subscribers. In one 15,000-subscriber system, in the first two weeks of marketing the Home Box Office service we isolated 290 cases of HBO subscribers who had not previously been on the cable. In a 10,000-subscriber system, just the first new newspaper ads brough in 150 requests for Home Box Office from people who were non-cable subscribers.

Think of that in any terms you wish - cash flow, additional market value for the system. The implications are obviously intriguing.

We are still too young at the game to have complete answers, but we are willing to learn and we hope you are too. Cable pay television is alive and well, thank you, and we think we have something very important to contribute to your future.

MODERATOR HARRIS: Thank you, Gerry.

The next speaker is Bill Butters, Trans-World Productions, a subsidiary of Columbia Pictures.

MR. WILLIAM BUTTERS: Thank you, Henry. Good morning, ladies and gentlemen.

Trans-World Communications, as you have already been told, is a division of Columbia Pictures Industries, and we are most commonly referred to as the hotel pay TV system. We are the largest operators of pay TV in the world, operating from London, England, throughout the entire continental United States and Canada.

Trans-World is devoted to a philosophy in marketing which is pay per program.

We started in the hotels in Atlanta, Georgia, in 1971, at the Recency Hyatt House.

Our entire philosophy is to provide programming at the subscriber's leisure, primarily current motion pictures, uncut and without commercials, live sporting events. As some of you probably know, we have taken many of the heavyweight fights into our hotel systems around the country live.

I would like to talk a moment, about Teletheatre and how it works. It is a total marketing philosophy and that same market philosophy is being introduced to cable at this moment.

There are over 40,000 hotel rooms throughout North America that are now equipped with Teletheatre and people are enjoying movies and entertainment in the comfort of their hotel room.

Every ten minutes a hotel room somewhere in North America, 24 hours a day, seven days a week, is being equipped with our services. Every 60 minutes, starting now, a cable home is being equipped with Teletheatre service.

The philosophy is a simple converter box, if I may call it simple, that is made to accommodate the one-way systems that exist today but is not confined to today's systems; it is expandable to two-way systems.

The converter box either contains four controllable channels and one off-air channel for hotel rooms or some cable systems who don't need additional channel space, or it contains four controllable channels and 22 off-air channels, or a standard home-type converter.

Total control is maintained at the headend of the CATV system, utilizing midband frequencies, we program four channels daily, 23 hours a day, one channel being devoted entirely to previews.

As a division of Columbia Pictures, we feel the only way to sell programming properly, especially movies, is the way we have sold them in the theatres for the past 50 years, and that is through professionally produced trailers.

We also believe the marketing concept for pay TV -- and I am glad to hear Gerry voice the same opinion -- is per program. Impulse buying. Make it easy for the customer to buy.

We do that by means of a preview trailer that runs 24 hours a day, and for about 4-1/2 minutes the total preview content is exposed to the viewer. So any time the subscriber wants to watch Teletheatre and wants to determine what is playing on the channels, he simply turns the selector box to a channel marked Previews. And, as I said, in 3-1/2 to 4-1/2 minutes he sees total previews of what is available to him on the three pay channels.

We operate on the basis of a theatre. If you tune to Channel A -- and we might be playing "French Connection" or "Nicholas and Alexandra," or whatever -- you will have a starting time listed for that movie, and it will play continuously throughout the day; there is no interruption, there are no breaks in programming. It is available totally at the leisure of the viewer.

Some of you might be interested in some of the results that have been obtained for the past 18-19 months in the hotel field, which we think are probably going to hold true in the homes.

If you recall when we started our test experiment in the Regency Hyatt Hotel in Atlanta, we said we would program the system 24 hours a day but only for a test period, for three months, feeling that our computer could then tell us what the viewing curve was and we could confine our programming to that viewing curve.

I guess the most startling revelation was that 67 percent of our viewing was taking place during the non-prime hours of the late, late night and early morning. I don't know whether that is accounted for by the traveling salesman who can't sleep or who has other things to do other than sleep, or whether we are going to find the same thing in the home.

After completing a ten months' test in the Regency, we were playing to one out of four of the guests at that hotel, who paid $3 to see a Teletheatre movie. Twenty-five percent.

Today, operating now in seven cities, and the eighth city goes on the air this month in San Francisco, and over some 40,000 hotel rooms, we are playing to better than one-third.

Now, we picked the Hyatt because it was a highly competitive hotel -- bars, nightclubs, every possible competition within the hotel itself -- and we wanted the test to be as tough as possible.

Last month in Miami, Florida, which was one of our worrisome areas as to whether people going to Miami really wanted to watch pay movies, 52 percent of the people in our hotels bought Teletheatre. Thirty-six percent of the people in our London hotels last month bought Teletheatre. So we are running about a third of the total guests who are buying our programming from $3 to $3.50 per market.

The philosophy, as I said, of Teletheatre is a preview channel and jammed pay channels, controllable from the headend with an RF carrier, so that when the customer has watched the preview channel and determined the programming he or she chooses to watch, he picks up the telephone and dials the telephone number that is posted on the front of the converter box, gives his discrete subscriber number or his confidential code number, and, in three milliseconds under the new equipment, his set turns on in front of his eyes and he can watch that movie for as long as he likes that day, until sign-off the next morning at seven a.m.

Our computer, then, which controls each city, goes through and turns off every subscriber set in that city and starts the new programming for that day. If he chooses to buy another channel, he repeats the same process of picking up the telephone and dialing the operator and ordering that channel.

As most of you probably know, in the hotels we were asked to put this ordering service through room service, because the hotel would like to sell food and beverage, so they want contact with the guest.

I'm sure you have seen the trades and you know that we will be on the air July 10th in the Viacom system in Suffolk County, New York, with this same philosophy. The problem always comes up as to how many telephone orders an operator can accommodate and is the CATV operator going to have to have a battery of operators there to take the calls?

As you know, there are only three ways to communicate with a subscriber. The most ideal way, of course, would be an interactive two-way cable system, but unfortunately, there are very few of those in operation, where you can electronically talk to the subscriber and he can order that way.

The second way is by telephone, which is the most common way and the fastest. And the other way is by mail, which, of course, is subscription television.

Since we are working on a per-program system, we had to use the telephone. It is the most readily available. And, to eliminate the operator stage that we have in the hotels, we use the first interactive dialing system, utilizing computer-access dialing which K'Son Corporation has developed to count the dials on a telephone, the clicks on a telephone, so that we do not need the touchtone type dialing, which is not available in many areas.

So our process now is from the CATV subscriber's home. He picks up the telephone and dials in to our computer a normal telephone number. When he reaches our computer, the computer either gives him a recorded message that says Thank you for calling and Your choice, please, or gives him a beep, as most normal computers do for data information. When he gets the beep, he then has three dial codes for the three channels playing. He dials in the channel of his choice, which takes a click of the finger. Then he has his subscriber number, which is his own number and no one else knows, and he dials that into the computer. And I assure you, before you can take the telephone from your ear, your movie will be playing.

Simultaneously with that, we create a billing system two ways. In the CATV headend we provide him with a hard copy billing. We have found as we have gone through the years in this business that the hotel people like to watch the box office, and we find that we are getting the same reaction from the CATV operator: Can I have that box office in my office? So if you come by the booth, you will see the electronic box office that spits out a hard ticket billing for him every time an order comes in from one of his subscribers. He knows immediately, within milliseconds, about that order.

At the same time, at the headend in our studio, is a 360 IBM-compatible tape which records every transaction throughout the day for the entire city.

We take that tape off and hand it to him once a week or once a month, whatever his billing procedures may be. We supply him with the computer programming, or, if he wants us to run it on our 360 here or in New York, we will even run his statements for him. He places that IBM tape on the computer; the programming is already provided. Statements are then issued direct to the customer, addressed and ready to go in the mail.

That is the general tone and philosophy of the Teletheatre system. In the Viacom installation in Smithtown, New York, out of the 40,000 subscribers which Mr. Baruch has, we have taken one leg of the system for a concentrated marketing effort and we will confine 7,000 subscribers to that leg. If you step out the front door you will see a big 55-foot remote sitting out there, and that is a full Trans-World studio, with computer origination consoles and everything, and that is rolling out of here Thursday to Suffolk County, New York to power that system.

And by confining our first marketing effort to 7,000 subscribers, our planned marketing approach, briefly, is this: A direct mail campaign is already under way. We believe in utilizing the CATV system to do what all of the people who have been called blue skyers have been saying it will do for a long time. We believe it can be used for marketing, and that is the purpose of the preview channel, is to sell the product. We also believe it can be used to sell Teletheatre to the subscriber.

Professionally produced spots are now being prepared. They will go on the system over the origination channel of the Viacom system. The direct mail piece will tease the people and tell them to watch Channel 12 for new and exciting news of something that is available. And then they will see those spots every half hour all day long, telling them all about Teletheatre, showing them the operation, showing trailers of the product that is going to be available, and telling them that it is a service that is installed in their home and there is no monthly subscription fee. A dollar-and-a-half a month maintenance is all they pay. And then, if they don't buy, they don't pay.

We have great hopes for this marketing philosophy, of using the CATV system or the television tube to sell it. From there, of course, we will use mass demonstrations and other electronic means of selling the system throughout Suffolk County, New York.

We hope by the next convention to be able to give you a more update report on what is happening in the world of cable. I know you get bored listening to hotel numbers, so we won't go any further into those.

But we do think that the future of pay TV lies in per-programming. It gives you control of the box office and enables you to bring in live events and many other things that we are planning to do.

I might say this, that on two of the channels in cable we are going to be programming movies, top-run movies, all day long. On the third channel we will be programming everything from live sporting events, on Channel C, to packaged children's programming in the morning, to educational series programming in the afternoon. So it will be changing rapidly, rather than the 24-hour format.

Thank you very much.

MODERATOR HARRIS: Bill, thank you.

Our next speaker will be Dick Lubic.

MR. RICHARD LUBIC: Ladies and gentlemen. Good morning.

Now that the HTN network system has been explained as to control by Mr. Levin and now that our PERK has been made obsolete and since Touchtone is not available, at least not in three milliseconds nationally, I would like to present to you this morning a basic philosophy that will seem foreign to some but I hope make sense to you on how pay television, not subscription or premium, can affect you and your future -- that is, if you feel pay television is vitally related to your future.

You may be here representing investors who are taking a long, hard look at the cable industry, or a motion picture firm which has invested heavily in product, film product, or as a cable system operator whose future depends on the best use of his system.

The basic problem is the real lack of ingenuity on the part of many people in our industry. It is easy to follow the patterns of past forms of businesses, but pay television is a new and unique business and has an unproven past.

The subscription fees that you collect as cable operators to maintain, operate, and hopefully make a profit consist mainly of one income source, the subscriber.

I think you will easily understand that what I am explaining to you is not a downstream dream, but a fact. It is quite important at this point in the development of pay television that we get on the right track for the future, or there may be a very limited and narrow one, based on past history.

It has become increasingly difficult for each and every one of you in the cable television business to increase monthly subscription rates from, say an average of $5 to 10 or 20 percent more without going to the authoritative bodies and the subscribers themselves, or even because of price controls and other unknowns. And by the time anything happens, it will be like the Select Committee of the Senate having the President testifying at Watergate. It becomes a very difficult problem to raise rates once they have been established.

Therefore, I present the following question: Is subscription or premium television the best form of pay television?

I am not a negative person by nature, but I cannot be true to myself and tell you this morning that subscription or premium television is the future.

Consider the following: The concept of subscription purchases is not new. Subscriptions were being bought, magazine subscriptions, before anyone ever heard of pay television. Look up the word "subscription" in Webster's and you will find: To agree to receive and pay for a periodical.

When an industry is marketing a new product, it often looks at an earlier successful approach to merchandising. In this case the advocates of subscription or premium TV looked back and saw only one aspect of the magazine concept. Time Magazine sells for 50 cents an issue,or, if you buy a subscription, $14 a year. Special offers through the year cut prices even further. Newsweek sells for 50 cents an issue, or, if you buy a subscription, $14 a year. In all magazine sales, the magazine price is not the major source of revenue. The advertising is.

An inexpensive package sale of a magazine generates large readership and the large number of readers increases the advertising rate a magazine can charge. We have all heard of cost per thousand. The game plan is in the numbers, not the item price. Free TV is much the same. Ratings are important only because they lead to a higher rate card. But in pay TV it is illegal to both charge for a program and then sell ad time. This means that subscription TV bought the magazine approach to sales but disregarded the source of magazine profit which makes reduced sales possible.

This whole issue of volume sales is questionable. Bob Huston in the May 14th issue of Cable News printed the results of an FCC study on the size of cable systems last year. There were approximately 5,000 cable communities in the United States in 1972. Of these, about 90 percent had less than 3,000 subscribers. Approximately 70 percent had less than 1,000 subscribers. And half of these systems had less than 500 subscribers.

Obviously, the answer in pay TV has to be on a fair return from each subscriber. The volume for reduced package sales does not exist.

Let's take a look at the assumptions involved in subscription or premium television. Let's assume that a system charges $5 or $6 a month and provides six to eight new movies or programs a month. If a motion picture company receives as much as 50 percent of the gross, they will receive approximately 40 cents per home per film. They will have taken a product which heretofore was worth $2 to $3 on the open market and they have depreciated it to absurdity.

The pay TV or cable company will take the $2.50 per subscriber remaining and, out of that, they will have to provide origination equipment, facilities, converters, dubbing costs, billing costs, studios, maintenance personnel and the replacement of faulty equipment. Again, negligible profit.

You can be sure that you, the cable operator, will receive the calls when maintenance is required, regardless of whose equipment requires maintenance. You are the one who will accept the abuse when a subscriber is irate about an "R" rated film which was shown, and you will be munificently rewarded with an additional 30 cent net for each subscriber each month. There is no rip-off in subscription or premium television. There is never enough to rip off.

As a result of this factor, programming has to suffer. Certainly no one is going to produce an extravaganza for pay TV at 40 cents a showing. But, aside from this, the very concept of a package will lead to the least common denominator. When you buy a bag of mixed nuts, how few almonds or cashews there are, compared to the peanuts. Packaging products for all subscribers has to lead to a package with mass appeal. Thus, in free television we have the year of the Western or the year of the mystery. "Ironside" yields a "Barnaby Jones," which yields a "Mannix" or a "Cannon," and so on.

Recently they have turned to the ethnic detectives to broaden their programming, an Italian Columbo or a Polish Banacek. George Stein and I have decided to do a pilot on a new ethnic detective. We are going to call him Izzie Goldfarb. Izzie will only accept the most dangerous, the most hazardous and the most expensive clients. Then he will hire Columbo and Banacek to solve them.

One of the early promises that pay TV made was the promise that even a small audience could receive unique programming -- opera, ballet, symphony -- if they were willing to pay the program price. Subscription or premium television returns the viewer to one more channel of programming, preselected for him, which he can either take intact or refuse, almost the same as regular TV. Again, lack of ingenuity or real choice.

Advocates of premium or subscription, perhaps a lot of people here today, say, Sure, subscription television has its drawbacks; that is all that the present state of technology will allow. In the meantime we are in business and pay TV is a reality. Or is it that my investors and stockholders want to see more dollars? This is a half-truth.

Pay per-programming requires a tremendous investment in research and development, as well as an investment in time and education.

The temptation is great to buy an armful of existing converters, some playback equipment, and get into the market place first and with a minimum investment.

If someone buys his own converter and cheats, how much will really be lost? Maybe this whole business. They can rationalize and say that in time they can change over to more advanced systems of pay TV. It never works that way.

The subscriber who has been paying less than a dollar for a new film will not want to pay the $2 or $3 that that new film can and will demand. Anxiety to get in first with a minimum investment and to capture the markets can destroy the future of pay television.

The motion picture companies would do well to stop and consider what their film product is really worth to the home subscriber. Once the major motion picture companies start selling their product this cheaply, it may be casting a die that is going to be very difficult to break.

The Federal Communications Commission, the Federal Trade Commission, the Justice Department, and Congress, as well as all those subscribers, will be watching this spectacular.

What are the motion picture production companies going to do when all the cable companies request their movies so that they can show them at these cheap prices? This could well be the most costly loss that ends the movie industry's in-home distribution and that elusive audience.

The cable operator would do well to stop and consider what his channels are really worth. I have complete faith in the future of pay TV. I have invested too much of my life in it not to be a believer. Subscription television or premium television is not the future. Pay per program offers the following decided advantages:

One, it allows different pricing. "The Panic in Needle Park" and "Cabaret" need not be sold at the same prices as part of a package.

Pay per program can create a need basic to cable television, and that is the utilization of multi-channel operations, rather than the reliance on just one-channel delivery for programming.

Pay per program allows greater freedom from censorship. "R" rated movies are selected by the home viewer. They don't have to be part of a package and available on the screen at all times. Those who object can keep these films out of their home. The subscription package will result in many excellent but controversial films being excluded from many packages.

A diversity of cultural programming can be offered at a price which makes this kind of programming feasible. Similarly, a cultural event, a heavyweight championship fight or another sports spectacular, a once-a-year event, can be specially priced.

The techniques of scrambling usually lead to a home unit which offers a much tighter security system. It is no longer possible for a veiwer to buy a standard or off-shelf converter and beat the system.

Six, perhaps the most important -- pay per program allows for impulse buying. Americans are not geared to pre-purchasing entertainment in less expensive packages. Years ago film studios experimented with ten-tickets sales for movies. It failed. The average viewer will look at his TV fare on a certain night, find nothing he or she really wants to see and will order a pay television movie or programming.

People are accustomed to spending $2 to $3 for a single theatre seat. Many factors have contributed to the decline in motion picture attendance: Fear of going into urban areas at night, the high price of family attendance, babysitters, parking problems, standing in line for tickets and perhaps not even getting in.

The $2 to $3 per-program charge for the family eliminates these problems and still offers a price people are willing to pay, unless subscription or premium TV creates a market which feels that 50 cents is too much for a first-run movie or outstanding sporting event.

You sitting in this audience who control the abundance of communications and entertainment needs in your communities' future certainly don't want to make a failure of what could potentially be one of your biggest profit-makers and your future and mine.

Thank you.

MODERATOR HARRIS: Thank you, Dick.

Our last panelist this morning is Mr. Jim Ragan of Athena Communications.

MR. JAMES T. RAGAN: Good morning, all.

I would just like to put my comments in the context of a system operator, a hardware supplier for pay TV and hotel theatre systems and also as a potential program distributor and supplier.

Now, briefly, I just want to put a couple of economic facts on the table and tell you what we did this past year.

Our focus has been on the economics of the delivery system, getting the product to a couple of small systems. I would just like to tell you what we did in a couple of instances.

As a programming distributor and a system operator, this past winter we conducted what we thought at the time was the first experimental live pay TV presentation of a major sporting event -- bringing the home games of the St. Louis Blues National Hockey team to Jefferson City, Missouri. Jefferson City has a system of about 8,000 subscribers. From late December through the playoffs in March we had live telecasts of the games carried by leased telephone lines to our system, which is a distance of about 135 miles. We shared the video feed with the Hughes Sport Network, which was carrying the game to the visiting team's home city. We used our own announcer and color man for the play-by-play production.

Now, costs. For this series of games -- and I believe it ran to 20 -- there was a one-time fixed installation charge of approximately $1200. And for each game the recurring production charges and the leased time were about $1300.

Now, this was a subscription, or a monthly subscription channel, and we were working on a fully loaded 12-channel system, so for the technologists here, we were using Channel G.

We charged $2.50 per game for the complete season or $3.50 per game if the subscriber paid on a monthly basis. There was a $3 installation charge and a $20 deposit for the subscription box.

I might add, the test from a technical and marketing point of view was a complete success. The economics looked right. We also discovered that those who like hockey or like a particular sporting event will come right up and plunk down the full charge for the whole season.

I also can say that those who did not like it just didn't pay for it.

Now, we did another thing. We have been working on our Indicode system, which is a per-channel subscriber system. This can go on either a standard or non-standard channel. And this past year we spent the time reaffirming the costs.

The scrambling device that goes into the headend as one per-scramble channel is $2700 installed. The decoding function in the home as an integral part of either a converter or as a separate device is $40 to $25.

This equipment has been production-tested. We have tested it on our own systems. And at the present time discussion is under way to integrate it into a pay TV test in Canada.

We have also been concentrating on the delivery economics of the hotel theatre system. We elected when we went into this business to look at the small end of the economic scale, the smaller inns, the 150-room inns, which is basically the average size.

When we started in, we estimated the total installed cost was $138. Today we can install a system complete for $78 a room. So the economics there are favorable.

We have conducted numerous surveys. We have talked to systems operators about what they wanted to have on cable, premium cable. And in some cases we found surprising resistance, particularly among the smaller operators. And I think that there are two points we should look at in this business.

I personally believe the technology is here; I personally believe the economics are right and it can be done. But there were two very good comments made. One comment from my right which says that the market for this type of service at the present moment is thin, and the other point that was made by Dick in his very strong comments, parts of which I happen to completely agree with: Please take a look at the size of the system. Most of them are very small.

But I think this is the time we should turn it over to questions, Henry.

MODERATOR HARRIS: Thank you, Jim.

We will now take questions from the floor. And if you want to address them to a panelist, fine. If not, I will try to direct them to a panelist.

Yes.

MEMBER: The gentleman who talked about the hotel business gave a figure that one-third, 36 percent or something like that, of the guests in the hotel had paid for it.

Can you break that down as to how that relates to guests nightly, which is of importance? If a guest stays for three nights and only uses the system once, you have lost something.

My understanding of the hotel business is that you need somewhere around 13 percent or something like that to break even.

And the head of one of the major hotel chains who put it in told me he only had 6 percent in the particular hotel in which they tried it, so they had half of what they needed to break even.

Can you relate your numbers to any of those?

MR. BUTTERS: Yes, I can. Unfortunately, in the hotel field there have been too many figures thrown around that have no relationship. When you say 14 percent, 14 percent of what?

The hotel business today is based upon equipped rooms. You have to weigh that against occupied rooms. Let's take the Regency Hyatt in Atlanta as a typical example. That is a 1,000-room hotel. The average stay in that hotel is 1.9 days. The average occupancy per room is 1.7. The average hotel occupancy is 97 percent.

When you are playing to 25 percent of those quests, you are playing to better than 12.5 to 13 percent of equipped rooms. So when you start throwing numbers around, you must base them either against equipped rooms, occupied rooms, or length of stay.

When I said in Miami we were enjoying 52 percent of the guests, you can readily see that the average stay in Miami is not 1.9 days; it's 3.2 days.

The average stay in London, England is 2.7 days.

And I don't know what any hotel man says he needs to break even, because with our concept we completely equip the hotel, he has no investment and he is taking his off the top side.

We expect to run a minimum of 10 percent viewing level per equipped room.

MEMBER: Mr. Lubic, we have heard from the other gentlemen as to how this works and where they have experimented and what they are doing.

Could you please tell us what HTN is doing?

MR. LUBIC: We are experimenting right now to put our system into Redondo Beach, California. We are having problems, to be honest with you, problems in what we call the box because of the technology of a two-way system by telephone. But I think we have overwhelmed it and whipped it this week.

We had a lot of changes in our box. A box cannot cost a lot of money to get it into the home; everybody here in the pay TV business knows that the hard costs of financing it are the boxes in the home.

That is why some people have merged together or are doing joint ventures, because they started out on the path to give free boxes away and found out that they can't because they cost a lot of money. Others have been experimenting with boxes that can't seem to work and they must change their system.

We have the availability of watching what they do, and we have the availability of putting the system in the right way.

That is why we are still experimenting with our system in Century City, and it will probably be in in Redondo Beach some time in September. It is a matter of just getting the lines in now.

MEMBER: Mr. Lubic, in your talk it was just a brief comment. You said PERK is obsolete. What does that mean?

MR. LUBIC: Our system, when we first designed it --

Okay. I'm sorry that a lot of people don't know what PERK is.

But basically, when we designed our system we used an acoustic coupling device to talk through any standard telephone, a dial type telephone. We found that a dial type telephone will take 14 different numbers to dial seven numbers to get the computer; then an access code, and then seven or eight numbers more to get into the computer: It's hard enough for me to remember my driver's license number.

So we developed a PERK, which was a programmed ordering device which now has been replaced by the touchtone telephone or touchtone pad, which is available basically in almost any telephone company. And they are putting in new equipment to receive it now.

So PERK is portable electronic response keyer. It's a device we made up the name for.

MEMBER: Dick, if you've got 7 or 10,000 homes who take advantage of impulse buying and at five minutes to eight you've got 5,000 customers who decide they want to watch the movie, how in the world is the computer going to be able to handle, or how are you going to have enough lines to handle a large number of people ordering the same programming?

MR. LUBIC: Basically I think you have got to go back to marketing of the system.

All people that watch movies will not dial in at one minute to eight to watch that one movie. Let's assume you had six programs on a 24-hour basis. Whenever they watch it, it's a new movie, a new program.

So let's assume that 6,000 people dialed in to the computer. The basic problem in our system and anybody's system who uses the telephone is the telephone company or the network of the telephone company itself. Getting from the home to our computer is the hazardous part, because if everybody in Anaheim, California, picked up their phone at one minute to eight, nodody would have a dial tone. You have to know the function of the telephone company.

So, to compensate that, we put CPUs right at the telephone company. CPUs are processing units that process the lines into the computer in a high-speed form so that it activates these homes. Some of them get a busy signal and they will have to redial.

MEMBER: I'm curious about an area where there is also a lot of activity, which is over-the-air pay television. It's not off the ground yet, but there are a lot of people talking about it.

Do you see this as being competitive with pay cable or friendly? What is your reaction to over-the-air pay TV?

MR. COOPER: Yes. I quite agree. There will be starts in the over-the-air pay cable field. And I think from the standpoint of people in the cable television business, we have to welcome it. I think we have to welcome every form of free enterprise. We are in that kind of business ourselves. And I am not concerned. I am more than willing, as we have always said in the cable business, to let the market place decide. I think there is a message there for the broadcasters.

MEMBER: Mr. Ragan, you mentioned your prices to the viewer. Could you also elaborate to some extent on what the fee-splitting arrangements were between the teams and the cable company and your own operation?

MR. RAGAN: All right. I would like to answer it this way. The fee-splitting race makes a point that I think is the most exciting thing about that whole test.

There was no fee-splitting. What we did is that we treated it as experimental, recognizing that costs would be incurred that may not be covered. The St. Louis Blues were very active. They think highly of expanding their -- expanding the market, and they wanted to try the cable route.

We asked permission of the visiting teams if we could do this. So basically it was strictly an experimental basis, and a memorandum of agreement and no fees.

MEMBER: Gerry referred to Channel 100 Systems in San Diego and said that people wanted to see more X rated movies and more R rated movies and wanted to pay for that. People are willing to pay for it and the market place wants it. It is not consistent with what you want to do, Gerry.

R rated movies are standard programming fare for a lot of pay cable companies. In our system we will have R rated movies so that people have a choice: they can either order it or not.

Do you see with your technology, the standard block converter technology, that you have to be more selective in your programming fare? Number one.

And, number two, will you ever go from the GP into the R or the X?

MR. LEVIN: First of all, Home Box Office is basically a program supplier, we are not wedded to nor do we provide any particular kind of box technology.

What we are seeking to do is to provide a program service to the cable operator that he, in turn, can market to his subscribers.

We have begun with the total package, for many different reasons. But, as I indicated in my remarks, it is not the kind of thing that we are wedded to

For example, on the question of the R and the X movies our research did indicate that while there is a substantial body of consumers that wants to see the family affair -- the family fare -- there is a consumer appetite for the R movies and the X movies.

Certainly as a startup industry, we have articulated a policy of not showing X movies in the home as yet.

What we hope happens in terms of technology, which we hope will follow the programming and marketing lead, is that there will ultimately be a box which will permit a number of services to be sold through the cable on what I will describe as a per-service and per-program basis, so that the consumer does have the kind of choice that everyone is groping for at this point. And by per service, I mean simply that perhaps the technological concept of channel may evaporate and people may be buying very discrete kinds of services, but there should be a per-program option available.

Now, when that box appears and it is available on a standardized, mass-produced basis, I think the program suppliers, the program packagers will welcome this, because ultimate consumer choice is important.

I think as a going-in proposition what we found is that the consumer initially not only is highly critical of each particular program but needs some entity to characterize. After all, you will never reach the point of infinite consumer choice. So somebody is doing the editing or the selection of programming for the consumer. And at least in this initial stage, it is important how that consumer, how the subscriber characterizes the nature of the service that is now coming into his home. You are reorienting, you are re-educating the subscriber, and one of the things we have tried to do as an opening proposition is simply to get good solid family traction into the home so that this particular thing is something that people will talk about, people will accept and people will look upon as a kind of dynamic new choice medium of providing programming.

That's a long-way-around to say that, at this point in time, I think it would probably be inadvisable for the pay cable entrepreneurs to show X movies into the home.

At the same time I think we need to see the development of cost-efficient box technology which will rise to support the market place demand for selecting out program choices.

And I will say in conclusion that from a program-by-program point of view, the movie industry will have to supply that kind of per-program movie that will sell on that basis.

MEMBER: Dick made a point that he feels that not enough is being charged for the fare.

In light of the Home Box Office study showing that the subscribers felt that they were getting $23 worth of programming, what is the feeling in retrospect of knowing that information, that you would charge more if you had the opportunity? In other words, would you charge closer to $23? Do you think your subscriber, while he feels he is getting $23 worth, would pay anywhere near that amount?

MR. LEVIN: This goes back to this kind of cost-value relationship that I was referring to. Let's remember that this is a very difficult business that we are talking about, this pot of gold that is seemingly here for everyone. The consumer knows what it costs him to go to the movie theatre. He also knows what it costs him to see a Knicks playoff game at Madison Square Garden. But when that same program comes into his home via the television set through which he has been accustomed for many, many years to be receiving programming that -- in his mind he has thought has been coming through for free -- he is going to have a tough time figuring out exactly what the value relationship is of that programming in the home.

What we have sought to do is to make it a little easier for him, to begin with, by providing enough variety, enough programming, so that he can more adequately come to grips with evaluation of the programming.

Again, the $23 is very heartening to us. But, of course, it is kind of a research figure to indicate the value assessment by the subscriber.

We have still found a lot of price-sensitivity in this business, particularly since, as everyone has indicated, you are talking about relatively small cable systems. And even having the home pay an additional $6 a month on top of the $4 or $5 basic cable charge is a lot of dollars in today's economy.

MR. RAGAN: Excuse me. Would you buy another used car from that type of salesman? Because when he comes back again, his price goes up. And I think you can't do that.

MEMBER: A question for Mr. Butters. How do you feel about the teenage prankster, the adult nut or the malicious competitor who sits there all day dialing your computer and using other people's identification numbers, the last four digits at random, if you will, and thus creating a billing nightmare for you at the end of the month when you bill people for programs that they themselves have not ordered?

MR. BUTTERS: That was a three-part question. How do we deal with the teenager and how do we deal with the malicious vandalism and the competitor?

Number one, this discrete code number that is assigned to this customer is really no different from the Bell Telephone credit card number that you have. In fact, it's a little more discrete. Now, if you want to pass that out to your child, you're going to find a telephone bill loaded with long-distance telephone calls. I know. My daughter has access to this number.

I think the same thing is going to apply here. If you want to pass that discrete code number out, it's like handing out an American Express card. That's your problem.

As far as the prankster dialing in: to get our combination of numbers would be pretty hard to do. And I think you should talk to our engineering people at our booth and see this system in operation and see the qualification, electronic qualification, that it goes through before you can even get into the computer bank.

MEMBER: May I clarify my question. I did see the demonstration in the hall yesterday. And as I understand it, after dialing the computer, which is a standard telephone call number -- you then dial a three-digit prefix to indicate the channel and then a four-digit suffix which is your identifying number.

MR. BUTTERS: Yes.

MEMBER: I'll just make up four digit suffixes and dial them all day -- one will be his, one will be his, et cetera, I do don't care whose it is -- and dial them into the computer. I am ordering a program for him and him and so on, and you are going to bill those people at the end of the month.

MR. BUTTERS: Well, I suppose you have that with computer access being done today with data terminals. I don't know. And I am really not a digital engineer. I know we don't assign them at random. So it's possible that he could find certain combinations, but he's got a lot of numbers to deal with.

MEMBER: Could we get some idea about the market penetration on cable systems that are now trying the subscription route? In other words, how many homes have subscribed?

MODERATOR HARRIS: Frank, do you want to try that first?

MR. COOPER: Gridtronics passes.

MODERATOR HARRIS: I'll see if I can find an answer. Gerry.

MR. LEVIN: We told everyone who is manning our booth today to answer every question that is asked.

Our penetration, to use the standard cable term -- in the startup systems, ones that we have at least been operating for a couple of months, to give some data -- has been in the 25 to 35 percent range, that is, of existing cable subscribers.

Again, I think we have the feeling, as we have experimented with various marketing techniques, that that is just the first phase in subscriber acquisition for pay cable.

What we believe we will see and we seem to be seeing now is a continuing addition of subscribers to the pay cable service, and we have some projections as to what we think might be the ultimate penetration. But that is the way it seems to be beginning.

MODERATOR HARRIS: Jim, do you want to take a crack at that in your Jefferson City system?

MR. RAGAN: Yes.

Remember that the purpose of the test to determine the economics of the delivery system, was an experimental test. It only lasted through the St. Louis Blues home games.

The response was not as satisfactory as we would like it. The people who enjoy hockey came right up and paid the full shot. But I can assure you there are many more who did not.

From a technical point of view, it was fine.

MEMBER: Yes. For Mr. Levin.

The people that have access to subscription television, are they using it each night and does their consumption of it go up the longer they are subscribing? Do they watch it more and more? Do they accept it as a network?

Do they watch it alternatively to, say, a major network, or do they use it just maybe once a month?

MR. COOPER: Yes. I won't try to dazzle you with terribly accurate numbers. But the viewers who take the service see nine out of ten of the movies. They watch nearly every movie.

MEMBER: Do they watch the same movie again?

MR. COOPER: I don't have the exact figures on how often they watch it. Some of them watch it frequently. After they get used to the service, there is a slight decline.

MODERATOR HARRIS: Gerry, do you want to try a quick answer? And then we will have one more question.

MR. LEVIN: What we have found in taking ratings on our service is that, first of all, there are two types of product. The film product or tape product that is repeated -- and repetition, incidentally, will be one of the backbones of pay television to provide accessibility to the consumer. The subscriber seems to be watching the programming to almost a frightening extent. And I say that only because, since repetition is important in order to provide convenience and accessibility, it appears that the appetite is rather enormous, so that people are continuing to watch even if they have already seen the film which is played seven different times.

On the question of live sporting events which we have, what we have found is kind of interesting -- these sporting events provide an alternative program for the viewer to watch, so that if on a Sunday might he happens to feel like watching a hockey game, there may be one there; or on a Monday night instead of watching something else, he may want to watch boxing. And from a traditional rating point of view, the figures are rather interesting in terms of subscriber viewership.

And I don't think we see any pattern of initial novelty to the service. If the service is getting traction in the home, it becomes a part of the habit structure in the home and they use their monthly calendar and they are checking off about the same number of events each month that they really want to watch. You are trying to stmulate ticket psychology anyhow.

MEMBER: Supposing in a given community you have the homes, the hotels and motels hooked up and you don't decide to subscribe to any of these services and a motel or hotel in that community would like to have these services. What happens then, since we are hooked up to the amplifers and the distribution in the hotel? How do you plan to supply that service?

MODERATOR HARRIS: I'm not sure I quite understand the question. Could you rephrase it?

MEMBER: Well, if you were to hook the cable system into a big hotel and the hotel wants it just for that -- their own use, would that be available to them?

Does the hotel have the option of taking only the pay service as opposed to both the cable and the pay service?

MR. BUTTERS: Well, as you may or may not know, Cox Cable handles all of our service on their system in Atlanta. They serve a all of our hotels on a leased-channel basis, and the hotel has an option of taking just our discrete channels and we choke out the off-air, or they have an option of taking the Cox Cable service and our service.

The same thing with Viacom in San Francisco. They handle our distribution there.

MODERATOR HARRIS: Thank you.

Thank you, audience and thank you, panelists.

HIGHLIGHTS

TECHNICAL EYE OPENER WORKSHOP

THE ELUSIVE SUBSCRIBER TERMINAL - HOW MUCH AND WHEN?

Sponsor

Society of Cable Television Engineers

National Organizer

Robert Bilodeau
Suffolk Cablevision
Central Islip, New York

Organizer/Moderator

Steven Dourdoufis
Vision Cable
Ft. Lee, New Jersey

Panelists

Caywood Cooley
Magnavox, Co.
Manlius, New York

Jerry Crusan
Television Communications
Pennsauken, New Jersey

Mike Paolini
St. Petersburg Communications
St. Petersburg, Florida

Dr. Pat Nettles
Scientific-Atlanta
Atlanta, Georgia

Abe Reiter
Athena Communications
New York, New York

Dr. John Sie
Jerrold Electronics
Horsham, Pennsylvania

Gene Walding
Oak Electro/Nectics Corp.
Crystal Lake, Illinois

Reporter

Robert Bilodeau
Suffolk Cablevision
Central Islip, New York

Moderator Steven Dourdoufis opened this session with an introduction of the panelists followed by a brief positional statement from each.

Jerry Crusan set the stage with a Chicken and Egg analogy to the arrival and definition of software vs. hardware for the complete home terminal picture. The decision to purchase any specific hardware should be evaluated in terms of the overall capability of the supplier to maintain back-up at the same time keeping the cost factor in perspective, he said. Some of the key features to look for are "human engineering, reliability, availability, electrical performance, field adjustment ease, etc."

Dr. Pat Nettles directed his question to the market place - "Just really what terminal do you want?" Confronted with abundant technology the question he felt appeared to be one of marketing. He added the additional considerations for terminal hardware selection of actual two-way systems capability and output compatability of the device.

Caywood Cooley spoke of the absence of demonstrated services upon which to build the two-way network citing pay movies as the vehicle upon whose back the other services would have to be ushered in.

Abe Reiter illustrated the difference between the economic model for home terminals and the basic CATV system from the standpoint of its revenue generating capability. He also urged industry and user alike to strive for standardization of reverse and forward channel assignments, bandwidth, etc. Divergent energies, he felt, diluted the overall effort and precluded the development of inexpensive hardware.

Mike Paolini stated his position as one which places the operator dependent upon the development of a business around each phase of hardware - that in the absence of a specific use the hardware could not or would not be developed. He felt it was incumbent upon the manufacturer to develop hardware in such a manner as to accommodate each incremental requirement as it became viable. Dr. Nettles supported this approach more specifically by replying that pay TV would of itself be able to carry the freight for the initial terminal investment that could provide the basic building block up front with smaller proportional costs required of the add-ons.

Dr. Sie brought the title of the program back into focus by demonstrating and describing the hardware that his company had developed assuming the role of the Chicken and not the Egg. Extrapolating the concept of the home terminal through its potentially ultimate configurations reveals not only video services but places a mini-computer in the hands of the subscriber, he explained. He described how with the use of MOS/LSI techniques his company was able to bring the price and size of this terminal within a reasonable range. The design objective he stated were four in number - to preclude rapid obsolescence, provide flexibility of service, insure reliability of operation, and maintain low cost. The most reasonable approach to the fourth is through the use of LSI with its inherent cost and size reduction. Dr. Sie pointed out that no application in the computer field required one terminal to talk to many, many thousands of others but suggested that this type of problem had been resolved at a lower numerical level.

Gene Walding described a more immediately available kind of (addressable one-way) terminal that in his opinion is needed now to deliver software that is available now. In Mr. Walding's opinion the three most important design features of his terminal are a high degree of security, head-end control and minimum degradation due to signaling. While he recognized the ultimate development of the full interactive terminal he emphasized that the "quantum leap" in that direction was not justifiable at this time.

A question and answer period ensued.

Paul Kagen asked the panel to describe what hardware was available for purchase considering the almost non-existent two-way market conditions. Several panel members responded by describing their "available" one-way scramble, de-scramble addressable hardware. Mike Paolini estimated about 40,000 single channel converters and 5,000 one-way addressable devices were in actual use. An attempt to buy anything more sophisticated would meet with failure, he felt. Responding to a question on standardization of scrambling techniques, Paolini stated there were at least five to his knowledge with no cross-reference to each other - and none in sight.

Dr. Sie injected a personal opinion with regard to the ultimate viability of two-way services. His belief is that merchandising in its various forms is going to be the significant revenue generating feature of the two-way cable system of the future. A second and very interesting aspect of the two-way interactive system is in the field of education, he said.

One Q/A exchange described the capability limitations on telephone lines as an upstream input vehicle resulting in a concensus that ultimately wideband CATV type networks would provide the upstream growth requirements.

The soft security aspects of some of the one-way pay schemes was illuminated by discussions vis-a-vis multichannel converters and recent availability of 24, 25 channel TV sets (RCA, Magnovox). The conclusion, assuming the proliferation of these multichannel devices, would be a more expensive delivery system.

HIGHLIGHTS

TECHNICAL EYE OPENER WORKSHOP

STAND BY POWER - WHAT PRICE RELIABILITY?

Sponsor

Society of Cable Television Engineers

National Organizer

Robert Bilodeau
Suffolk Cablevision
Central Islip, New York

Organizer/Moderator

Loyal C. Park
T-V Transmission Inc.
Lincoln, Nebraska

Panelists

A. Robert LeServe
Interstate Telephone &
Electronics Inc.
Dallas, Texas

Robert Schultz
Glentronics
Glendora, Ca.

Selig Lenefsky
Coral Communications
Hoboken, N.J.

Robert Cowart
Gill Cable, Inc.
San Jose, Ca.

E. Harold Munn, Jr.
E. Harold Munn, Jr. Assoc.
Coldwater, Mich.

Reporter

Robert Bilodeau
Suffolk Cablevision
Central Islip, New York

The session convened with a statement by chairman Loyal Park comparing the traditional cable situations with their emerging large system requirements to a need for greater emphasis on system reliability and specifically stand-by power. Following introductions, panelist R. Cowart, representing the operators' viewpoint, delivered a paper* that focused on the gap between available solutions (hardware) and the operators' real needs. Drawing from his extensive use of stand-by power units in San Jose, Mr. Cowart cited experiences with battery incompatibility, local power failure patterns, subscriber attrition caused by outages and system design considerations of cost, layout and powering techniques. In addition, he described the pros and cons of switching vs. floating systems and the elapsed time switching interval as it relates to amplifier output levels, data carriage and switching circuits. Improvements in SCR switching and power handling capacity was noted. All new stand-by units in San Jose feature SCR switching.

Mr. Cowart concluded his remarks with an excellent statement on battery types, chargers and their relationship to battery characteristics, trade offs vs. costs per volt amp/hour and a formula for selecting the right battery for each system's anticipated back-up requirements. An evaluation of data for the San Jose dual cable system yielded a 3600 VAH output requirement. This number was derived from:

1. An average 28 minute power outage duration.
2. The desire to protect for 1 1/2 hours.
3. A 60^V cable powering voltage.
4. Power supply ampere ratings.
5. 60% inverter efficiencies.
6. Customary safety factors.

This system would provide back-up for 95% of power outages and has a life expectancy of 10 - 20 years. Outages of greater duration than design would be covered by utilization of gasoline-driven generators.

Selig Lenefsky described Coral's unique approach* to reliability improvement. This twofold solution features redundant trunk modules and DC power packs with external battery back-up per trunk location. He emphasized that utilizing lower cost DC systems more frequently without inverter mechanics could have some engineering and economic advantages over the AC back-up technique. The Coral battery units are continuously recharged with a built in system energized from the normal cable AC. By choice this scheme provides trunk back-up - not associated distribution. At a cost of $100.00 per trunk location cost comparisons can be made with the AC system when related to system design, i.e. amplifiers per power supply.

A lively question and answer period revealed a substantial interest in this subject.

Selected condensed verions of questions and their replies are listed:

Q. Mr. Munn: How does the operator of systems smaller and less densely populated than San Jose determine the value of and extent of stand-by power?

A. Mr. Cowart: Operators must determine their own requirements tailored to their system design and market strategy.

Q. During a power loss situation, does the AC side disconnect from local power and what visible indication to power company personnel appears?

*Copies available from authors.

A. Mr. Shultz: This did arise as a problem and the (mfgs.) unit was then equipped with a large relay physically observable as to switch position.

Q. What considerations must be given to the matching of charger voltages to battery voltages for optimum charge conditions?

A. Mr. Cowart: The operator must be sure that the charger used does not void the warranty of the battery due to incompatibility, etc.

Q. Is anyone considering a return to all DC powering?

A. Mr. Shultz: Yes, research is under way; reality some 5 years away. Dissimilar metals is a major problem.

Q. Mr. Hale: What about brown outs up to 15% instead of complete loss of power?

A. LeServe: What point to switch at and not lose useful power is a difficult decision. Light hum might be better than stand-by battery drain. Power companies could have severe problems at 15% with its own system and customer appliances. Brown outs don't usually exceed 8%. Power phase staggering can be used to minimize hum.

Q. Mr. Braun: How does the operator detect the status of stand-by power?

A. Mr. Shultz: Potentially with the use of two-way return capability, several mfgs. provide this capability via encode/decode technique.

Q. How generally do computer mfgs. protect against incoming transients and could these techniques be used for studio and amplifier protection.

A. Mr. LeServe: Via floating systems using battery stand-by, which provides the back-up and isolation from power company transients. Computer systems typically convert back to AC for general powering.

Q. Are flush mount (below ground level) stand-by units available?

A. Mr. Shultz: Not yet. Pedestal mounts are available.

HIGHLIGHTS

TECHNICAL EYE OPENER WORKSHOP

THE RELATIONSHIP BETWEEN FEDERAL/STATE/MUNICIPAL CONTROL IN TECHNICAL STANDARDS

Sponsor

Society of Cable Television Engineers

National Organizer

Robert Bilodeau
Suffolk Cablevision
Central Islip, New York

Organizer/Moderator

Joe E. Hale
Cable Dynamics
Burlingame, California

Panelists

Sydney Lines
FCC
Wash., D.C.

Delmer C. Ports
NCTA
Wash., D.C.

Vic Nicholson
Cable Television Information Center
Wash., D.C.

Michelle Rosen
Cable TV Office
Newark, N.J.

Reporter

Robert Bilodeau
Suffolk Cablevision
Central Islip, New York

Moderator/Organizer Joe Hale set the stage for this controversial issue with an analogy that dramatized the irreversible nature of government regulation. After noting the absence of Ken Foster of the New York State Cable Commission, due to illness, four panelist presented their respective viewpoints. Vic Nicholson, on behalf of the municipal interest in the subject, recited from a paper prepared for the event. Representing the Cable Television Information Center, he advocates and encourages the dualism between municipal authority and the Federal Communications Commission with regard to jurisdiction-to the exclusion of the state. Further the Center disagrees with the NCTA position that a single authority (FCC) can set up and administer standards that can universally apply to both the rural and urban situations. The Center recommends that local authorities accept or expand upon established FCC guidelines to adapt to their local requirements. The example of tighter standards specified by consultants and manufacturers alike in the urban markets supports this argument Mr. Nicholson contends. He singled out carrier-to-noise and intermodulation as two technical areas of genuine concern for local authorities plus the need for additional standards (not yet defined by the FCC) for echoes, color quality, etc. Citing anticipated delays of several years by the FCC to adequately provide all applicable standards Mr. Nicholson recommended that municipalities should step in and fill this void. Such factors as quality of construction, safety and compenent selection for the environment may be a matter of genuine concern for local authorities also, he said.

Mr. Sidney Lines next described the genesis of the technical standards and the role that the FCC intends to play to fulfill its obligations to the public. Mr. Lines pinpointed the opening of the doors to state and local regulation by quoting from an FCC statement issued in early 1972. "We see no reason why franchising authorities may not now require more stringent technical standards than in our rules." In retrospect Mr. Lines felt this an "incredible naive position." The FCC is presently disturbed, he felt, by the expansive use of this implied license that local and state authorities have aimlessly assumed without a complete understanding of the "delicate" balance between cable economics and cable technology." Furthermore he suggested there is no evidence put forth of the expertise necessary to generate and enforce technical standards. On the other hand, the FCC is preceeding "as promised" drawing from competent technical advice via the Technical Advisory Committee and will revise and augment its technical standards as requirements indicate.

Mrs. Michelle Rosen, representing the State of New Jersey CATV Cable Office described the role of New Jersey in the development of standards. Opting to the state's rights posture Mrs. Rosen said that states could expand on a set of federal standards as they saw fit if they acted in the public interest and such extensions were deemed economically and practically feasible. In her opinion the federal role would then be limited to the setting of <u>minimum</u> performance standards aimed at facilitating national interconnection capability. New Jersey's present standards she said are skeletal by nature and will be expanded with inputs from a task force to be set up within the state. She described in detail New Jersey's definition of public interest specifically as it differed from some popular definitions. "Public interest is not synonomous with strict standards." "It is not a consumer item at minimum prices." "It is not a CATV company's be damned credo." "It does imply the existence of no special interest toward favored groups and must consider the financial character of CATV operators." "By pursuing this definition the cable office of New Jersey is not structured merely to demonstrate its ability to promulgate rules." The advantages of <u>local</u> <u>awareness</u> and subscriber access, she felt, favored the State vis-a-vis the Federal government as the primary regulatory body pointing out that present New Jersey State law <u>limits</u> the role of the municipalities in the area of technical standards. Mrs. Rosen summarized the position of the New Jersey cable office as one which is coincident with FCC comments and the direction of the Federal/State Advisory Committee.

Delmer Ports stated the position of the NCTA which is one often stated by operators concerned with regulation. The optimum situation, he felt, was one that compares the best possible performance consistent with the public interest and economic viability. "How to arrive at that point is the real issue." Mr. Ports differentiated between the broadcaster (who functions to serve his customer, the advertiser), and the CATV operator (who functions to serve his customer, the viewer). This distinction, in his opinion, places more directly the onus of <u>quality-of-service</u> on the cable operators back, and uniquely preempts the need for strict standards. Citing the four variables of public interest, competition in the market place, the economics of viability and state-of-the-art, Mr. Ports suggested that control of any one individual element will not suffice - that proper control and balance of all four must logically take place at a <u>national</u> level instead of piece meal fragmentation on a town-by-town basis.

A variety of other opinions were then put forth from the floor during a question and answer period. Hub Schlafly (TPT) brought the definition of "minimum standards" into focus by stating that the FCC minimum standards are not those for the norm of the system but for the extremities and that the majority of subscribers would logically receive higher quality than the standards imply. He also expanded on the quantitative and qualitative make up of C-TAC and its obvious ability to perform as charged.

Bob Bilodeau queried aloud the noble purpose of regulation and cited examples of its absence in areas of broadcasting, manufacturing, etc. that also confront the "public interest". Citing the lack of performance by non-CATV interests to adequately serve the viewer or "public interest" on a substantial scale throughout the country he pointed out that regulation should have approached these "public interest" problems. To support this argument he noted widespread co-channel interference and powerline interference that the viewer has no control over and more importantly no recourse-except to the FCC.

Warren Braun spoke of the voluntary co-operation that should exist between the successful franchisee and its community and the right of self determination over minimal standards that should belong to the cable operator. At the same time he punctuated the obligation of the community to become involved in whatever regulatory scheme develops.

Ken Simons described the difference between a simple regulatory situation of a clear cut situation like a power company vis-a-vis the CATV situation which is extremely difficult even for the most qualified persons attempting to do so.

Bo Lessa of Video Cable cited the inability of the typical home receiver to deliver cable TV product and was quickly rebuted by Ed Chalmers of Zenith Radio.

Sruki Switzer (Canada) described a possible situation based on statistical delivery of service and measurement techniques that would lead one to conclude that at best a percentage reliability is the ultimate situation and that this compared to the generally poor condition of home TV sets is perhaps out of perspective.

Sid Lines responded that the FCC standards in the U.S. were not based on a statistical approach but were incumbent upon every outlet. He confessed to an inability on the part of the FCC at present to effectively enforce its own and additional future standards.

Delmer Ports suggested that local regulatory agencies can play a very useful role in assisting smaller systems that lack internal capability to meet the present FCC standards and provide better service. Joe Hale closed the session with a reminder that it is quite important to understand just who is wielding the instrument of regulation and what force motivates their action.

THE CASE OF THE DISAPPEARING HEAD ROOM

Warren L. Braun, P.E.
ComSonics, Incorporated
Harrisonburg, Virginia

Experienced CATV technicians are quite aware of the phenomenon of decreasing system dynamic range, although they may not know the reason why this occurs.

This phenomenon is traced to its source, the typical system bench repair of active devices. Improved reliability and system performance is available by more sophisticated device rehabilitation.

This paper details such processes.

Today's CATV system performance must be superior to that of previous years, both for new and older existing systems. This statement is valid because:

* Subscriber television set fidelity is steadily improving.
* Viewers are becoming more critical.
* Franchising agencies are becoming more critical of and knowledgable about system performance.
* Increased competition in new and renewal franchise proceedings.
* System technical performance standards imposed by--
    ** FCC
    ** Franchising Agencies
    ** State PUC's (or equivalent agencies)

With new systems, proper attention paid to design criteria and implementation can assure reasonably distortion free CATV transmission at least at the inception of system operation.

A large percentage of subscriber complaints traceable to system malfunctioning have their origin in the increased visibility of system contaminants, i.e., cross modulation, beats, noise, etc.

The majority of these system malfunctions are directly traceable to a loss of system dynamic range. Experienced CATV system chief technicians are all too familiar with the day to day reality of short term and long term effects of shrinking CATV system dynamic range. They may not know all the causative factors involved, but they are very aware of the increased frequency of trouble calls associated with degraded performance indicators, such as visible cross modulation, beats, and excessive noise.

Even with the best system maintenance and repair, certain factors have caused originally acceptable system dynamic range to become unacceptable, i.e., the system requires excessive maintenance to achieve acceptable subscriber performance. A partial list of the factors deteriorating the technical performance of the plant with no equipment malfunction is:

* Added equivalent channel loading from multi-channel stereo FM, carried at a higher system level than monaural FM to achieve noise free carriage.
* More actual channels of carriage. Many 12 channel plants started with less than 12 TV channels, are now fully loaded with no change in plant design. (Total triple beat products rise in proportion to P^3, and for 2 A-B components, total components rise proportioned to P^2, so added channels of carriage add significantly to system spurious signals).
* Television station conversion to 3.58+ MHz tightly controlled color scanning sources, changing signal status to quasi synchronous from quasi non-synchronous.
* The effects of simultaneous non-

duplication. Channels so involved are in effect synchronous, increasing the equivalent system signal burden.

In addition to the factors just presented which bring about an apparent decrease of dynamic range of the system, there is the very real decrease in dynamic range due to deterioration of the plant over a period of time. The principle causes of shrinking dynamic range are:

1) Increasing amplitude versus frequency response roughness, due to partially defective system components and cable.
2) Increased system attenuation due to partially defective cable and/or connectors and moisture immigration.
3) Addition of system legs or branches without proper system re-engineering.
4) Improper repair of amplifiers.

The latter item is the most serious long term deterioration.

Since the amplifier repair is the most serious source of dynamic range loss, it is prudent to examine why this is so. Typical amplifier repair is accomplished as follows:

1) Removal of amplifier in question from the system.
2) Repair of the obvious deficiencies by replacement of apparently defective components.
3) Realignment and gain measurement (sometimes return loss) of the device.
4) Return of repaired device to spare stock or to system.

It is quite evident that the two most important parameters of the amplifier have not been measured, namely, the cross modulation and noise figure. While relatively expensive equipment and skilled personnel are necessary to make meaniful measurements of these important parameters, it is instructive to inspect the enormous penalty the system operator pays for not making such measurements.

In the following table, data is shown comparing typical field repaired amplifiers (Jerrold TML series) with those repaired under carefully controlled conditions including cross modulation and noise figure tests.

TABLE I

Output Level 43/40

Worst Case Average Cross Modulation[1]

	61 Units	53 Units
Ch.	Repair Without Cross Modulation & N. F. Test	Repair With Cross Modulation & N. F. Test
2	-51 db	-63 db
6	-50 db	-64 db
9	-52 db	-65 db
11	-52 db	-64 db

Worst Case Noise Figure

Ch.		
2	10	8.0
11	11	10.0

1 NCTA Synchronous 12 channel loading.

While the above data is not presented in a statistical form, the tabulated date does present a correct representation of the true contribution to total system performance. From the previous, it is evident that field repair without cross modulation and noise figure analysis costs the typical system operator 14 db in dynamic range!

The system technician who is of the opinion that his "head room" has decreased since construction is entirely correct, and in most cases, the source of the decreasing head room has come from the in-house field repair or outside repairs made by others not working to fixed cross modulation and noise figure criteria.

Since this problem was brought on by the need to repair the amplifier, it would be useful to research some of the factors involved in amplifier failure.

Amplifier failures traceable to source of supply are:

* Flaws in original design.
* Vendor problems in manufacture.
* Inadequate quality control in production.
* Mishandling in shipment.

These sources of failure can be reduced radically by:

* Detailed and careful evaluation of devices before purchase for selection of an optimum vendor.
* 48 hour burn in upon receipt prior to equipment test.
* 100% QC check of all significant amplifier parameters after burn in.
* Storage of amplifiers in a proper environment until safely inside the properly waterproofed housing in the system.

A recent average taken from our laboratory notebooks indicate the following reasons for new amplifiers of various manufacturers failing to meet published specifications:

TABLE II

PERCENTAGE SHOWN OF TOTAL POPULATION NOT MEETING PUBLISHED SPECIFICATIONS

Trunk Amplifiers

* Test points - 39% (out of tolerance)
* Cross Modulation - 15% (3% seriously defective)

Distribution Amplifiers - All Types

* Test Points - 27% (out of tolerance)
* Cross Modulation - 20% (4% seriously defective)

It would be totally erroneous to assume from these data that the manufacturers are doing a sloppy job. The fact is that these tests were conducted after storage, shipment, and a 48 hour burn in. It behooves the wise system operator to set up a product acceptance testing system, either in house, or contracted, for any new system construction, or new equipment purchase.

Obviously, tight system performance criteria tend to ferret out marginal equipment performance, and this technique does assure greater longevity of initial system performance than "boiler plate" performance criteria.

Unfortunately, the majority of the cross modulation failures in the previous data were marginal (approximate average 3 db), and therefore, when comingled in the system, would have a relatively small overall effect initially. What is serious was discovered when detailed analysis was made of the amplifiers failing to meet the cross modulation standards. In almost all cases, the poor performance was traceable to partially defective active devices, or components which had drifted out of tolerance after manufacture. In other words, each of these amplifiers would contribute to the "disappearing head room" after installation.

After the equipment has been installed, additional environmental factors lead to loss of head room.

Although not truly representative of all systems, the following data has been developed from a composite of systems located in the Southeastern U. S., which systems have been subjected to close scrutiny. Keep in mind that these devices under this analysis had "failed" by the usual system definition.

* Transient Intrusion	33%
* Improper Field Installation (11%) Improper Diagnosis (device operative) (17%)	28%
* Water damage	6%
* Component Failure (Other than obviously transient related)	16%
* Alignment Drift (Including technician maladjustment)	8%
* Residual Manufacturing Defects	4%
* Misc.	5%
	100%

It is quite evident that transient intrusion is a large factor in the system reliability problem.

It is important to note that the second category of problems does not appear until a technician attempts to locate a problem! From the previous it is quite evident that beyond the prior checkout of equipment upon receipt, a very large percentage of the system outages can be prevented simply by improving transient intrusion immunity of the system. It is also quite obvious that proper technician training and supervision can avoid much unnecessary system equipment "maintenance". It is also interesting to note that most water damage is due to poor system workmanship, or a lack of proper moisture-proofing technology.

Transients find their way into the CATV plant via the cable powering points and through direct injection, due either to instantaneous sheath potential drop, or via collapsing magnetic flux, or both. In most cases, the transients via the cable power point tend to be of the asymmetrical half supply cycle--roughly 3X applied voltage variety. The latter variety of pulses are extremely high speed pulses of very high amplitude. The former type of over-voltage can be controlled by careful attention to amplifier power supply design (or revision), and appropriate protective circuitry at power insertion points.

The latter type of transient intrusion is most destructive in its subtlety. By example, if the original source of transient intrusion was lightning, the cable sheath can experience "pin hole" puncturing. Quite often the effect of such sheath puncture is not seen until months later when the cable dielectric becomes water soaked.

Jacketed-flooded cable is a great assist in reducing damage from this source.

If the source of the transient is from adjacent AC power company primary breaker operation, the sheath current can become large enough to destroy or seriously damage passive devices for several thousand feet in each cable direction from the area of transient origin. Reducing co-mingling of plant grounding is of enormous assistance in reducing the system vulnerability to transients of this source.

Irrespective of the origin of the high speed transient, the rise time and energy content of these transients are such that R. F. transistors and power supply devices alike are damaged by their presence. Most insidious of all is the "secondary breakdown" effect, where the R. F. device dies slowly, after being exposed to this type of transient, with failure usually precipitated by the next high temperature stress period. Various attempts have been made in the past to improve the transient resistance of amplifier circuitry, but unfortunately, only careful analysis after failure is of any real value in determining circuit revisions necessary to improve transient resistance.

In any case, this is the point where conventional bench repair fails most miserably. After an active device has been exposed to a high speed transient, several of the active devices, diodes, I.C.'s, discrete devices alike, even regulators, will have been overstressed. Unless the amplifier is carefully checked for performance after repair there is a substantial opportunity for the device to be returned to service with <u>partially</u> defective devices still in the circuitry. The only sensible solution to this problem is to completely check every amplifier for compliance with performance criteria (or have it done). It should be obvious that critical criteria are cross modulation and noise figure, as these parameters are the most device performance sensitive. For systems with beyond 12 channel capacity, a second order performance test is imperative as well. Recent experience with implementation of such system practices has shown over a ten fold improvement in amplifier reliability. I must hasten to add that this experience involves systems in the Southeastern U. S., with high lightning exposure. A secondary benefit of the system reliability has been the substantial improvement in system dynamic range, and consequently higher overall day to day quality.

<u>Conclusion</u>

From the previous it can be seen that CATV system dynamic range can be assured by:

- * Adequate initial quality control of
  - ** System design
  - ** System devices
  - ** System proof
- * Initial system implementation of
  - ** Optimum system grounding
  - ** Optimum power protective devices
  - ** Proper training of maintenance personnel
  - ** Proper calibration of system measurement equipment.
- * Careful and sophisticated repair and rehabilitation with all device parameter qualification <u>after</u> a 48 hour burn in.
- * Failure analysis coupled with device reengineering to improve transient immunity where needed.
- * Periodic surveillance of total system distortion with particular emphasis on second and third order product evaluation.
- * Plant reengineering to solve dynamic range problems not uncovered in original design.

From the previous, it should be obvious that the past practice of simple repair and alignment of active devices is the principle cause of "the disappearing head room". Capital and personnel commitments commensurate with these requirements are a must for any knowledgable CATV operator. If these requirements are too stringent for in house implementation, he may wish to retain an independent laboratory to provide such service.

Case of the disappearing headroom solved!

"THE DESIGN OF EXPANSION LOOPS FOR REDUCING FATIGUE IN COAXIAL CABLE INSTALLATIONS"

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ABSTRACT

The mechanisms of fatigue in non-ferrous metals and designing against them in coaxial cable is a complex subject and one which can be especially difficult when designing for a 25-year plant. The life of any one expansion loop is determined by a plurality of variables, such as environment, installation temperature, span length, cable size and expansion loop position and dimensions, all of which are discussed. The use of brittle coatings for full-field strain analysis, strain gage measurement, and extensive fatigue testing have been conducted to better establish the mechanics of various expansion loop designs and to evaluate their potential worth. This data has then been transformed into analytical approximations for the engineer in order that loops of better known life can best be designed to the particular system.

INTRODUCTION

The existence of a differential thermal expansion between coaxial cable and associated steel support wire in aerial cable plants is a subject well known by CATV systems engineers for many years. Its presence has been manifested in a number of undesirable forms such as cable snaking, connected pull-out or loosening, and outer conductor and lashing wire failure. To circumvent as many of these problems as possible the industry has formed two design philosophies; one utilizing the addition of expansion of various sizes and shapes to accommodate the changes in cable length, the other to install no expansion loops and to lash doubly tight to restrain the cable expansions and contractions.

The successes of both approaches to date have shown to be only limited in number and for those systems which have survived the first few years, only extended years will demonstrate their virtues. For the better part, a proportionately large number of systems have experienced fatigue failures and for this purpose the following project was initiated in June of 1972. Its objective was to investigate thermal fatigue failures in coaxial cable and to make recommendations to reduce their occurrence toward a plant design life of 20 - 25 years.

INITIAL INVESTIGATION

In order to begin the investigation, resolution of the preferred design philosophy was of first consideration. The concept of no expansion loop is one which upon first observation was the more desirable. For the argument of simplicity the thermal expansion of the coaxial cable was assumed to be that of aluminum, $\alpha_a = 13.3 \times 10^{-6}$ in/in °F. This would discount the influence of the center conductor through the dielectric which would certainly be negligible in consideration of the low pull-out strengths and use of copper clad aluminum center conductor in many cables of .500 inches and larger. The thermal expansion of the support wire was established as that of steel, $\alpha_s = 6.0 \times 10^{-6}$ in/in °F, which results in a thermal differential coefficient, α_d, of $\alpha_d = \alpha_a - \alpha_s = 7.3 \times 10^{-6}$ in/in °F. Under the assumption that the cable and support wire were perfectly lashed together, the resulting stresses, σ, within the cable would be approximately $\sigma = E\varepsilon = E\alpha_d \Delta t$ where E is modulus of elasticity of aluminum, ε, the strain of the aluminum and Δt the change in temperature. The strain term, ε, represents a unit elongation, or contraction, $\Delta l/l$ and is more commonly expressed in terms micro strain, $\mu\varepsilon$, representing 10^{-6} in/in, ft/ft etc. From this it could be seen that the resulting strains and stresses in a no loop design are relatively low compared to that found within expansion loops. For this reason, along with installation ease, the no loop concept appears desirable.

However, further considerations demonstrated the opposite to be true. Unlike ferrous metals, aluminum does not exhibit an endurance limit, that is, there exists no stress below which a fatigue failure will not occur. The resistance to fatigue in aluminum is therefore given by a fatigue strength figure, in psi, which corresponds to the stress range at 10^8 or 5×10^8 cycles to failure. By staying within the elastic or lower elastic limits of the material, it does increase the expansion loop life, but for this reason does not insure that the expansion loop will not fracture as may have been assumed. By lashing the support wire and cable into a integral unit, it becomes a load bearing unit of the span to experience not only all stresses resulting from daily and seasonal temperature changes, but also span vibration and galloping, Because of the unknown cycles associated with the latter, much uncertainty lies in estimating cable life in light of the absence of an endurance limit. This uncertainty coupled with knowledge that no system can be perfectly lashed, and that large accumulated displacements will be transmitted to small areas not designed to accept large displacements, such as unlashed areas beside a pole or at equipment, plus the existence excessively large forces increasing with the square of cable diameter acting upon connectors made the approach undesirable.

The utilization of expansion loops however, recognizes the existence of changes in cable length with changing temperature and is designed to accommodate them. Its purpose is to efficiently "absorb" the strain energy of the expanding cable span and to evenly distribute it over its own length. By doing so cable stresses can be minimized, connector loading significantly diminished and system life extended.

It is for this reason that all further investigations were related to expansion loops. The validity of the expansion loop concept does presuppose a properly designed expansion loop and it is for this purpose much of the work was conducted.

In the sequence of investigation, the first tests conducted were fatigue life testing. These tests were conducted to establish the initial elementary relationships between loop size and design, and life. They consisted of taking an expansion loop of known size and extending and contracting them given distances in repeated cycles until failure occurred. This was accomplished through the use of the apparatus shown in Figure I. The relatively simple device

FIGURE 1

consisted of a zinc diameter pneumatic cylinder, counter, limit switches, and cable clamps. For a condition of 1 inch excursion the sample was placed into the apparatus at its free length, clamped to the moving end at the left, and stationary clamp at the right. The limit switches were placed .50 inches to either side of free or neutral position. The test was then turned on and permitted to cycle until failure.

The fatigue life of any expansion loop, or any structure for that matter, is a function of numerous variables. Many of these variables are material properties such as ultimate tensile strength fatigue strength and surface roughness, physical dimensions such as cable diameter, wall thickness, and stress profile or environment. In an attempt to isolate as many variables as possible all tests were conducted with cable taken from the same reel except, of course, in those tests specifically conducted to evaluate the influence of material or cable design variables. All tests were also conducted about the free or neutral length of cable. This means that for any excursion half of that excursion was toward loop extension and half toward loop compression. The influence of a stress bias or mean stress has a considerable influence in extending or reducing the fatigue life of an element. For this reason, the conditions of zero mean stress was selected.

By taking each particular expansion of interest and cycling it to failure at each of several excursions, curves somewhat similar to the conventional S-N curve could be generated for each design. Some of this data is shown in Figure 2. In the early work, the curves for the round bottom loop or drip loop, and shallow extended expansion loop were the first to be run, and their relative fatigue lives are much shorter than the remainder of those on the figure. Once the general nature of the expansion loops were established, the improved loops were developed based upon qualitative and analytical data.

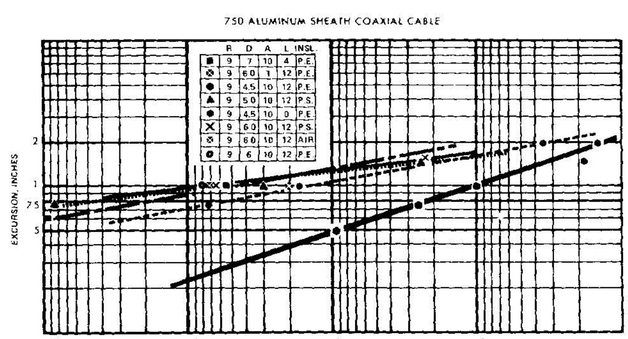

FIGURE 2

The data presented in Figure 2 is an excellent illustration of the relative performances of various design configurations in terms of low cycle and higher cycle characteristics, but says nothing about stress distributions, bending moments, or force requirements to displace the loop, all of which are important to the placement of connectors; nor does it say to assume that one cycle per day of excursion amplitude equivalent to the variation in mean annual daily high and mean annual daily low would be a gross over assumption. To determine the strain distributions, force requirements, and estimated life will require an understanding of its mechanics.

BRITTLE COATING ANALYSIS

In the preliminary mechanics study, brittle coating were utilized to examine the full-field strain distributions. Brittle coatings are nothing more than lacquer of controlled sensitivity which are sprayed on the particular surface of interest. Unlike a strain gage, the brittle coating is capable of providing strain distributions over a complex surface as opposed to a single point. When the structure is loaded, or expansion loop compressed, the tensile strains on the surface of the outer conductor cause the coating to crack when the strain level has reached its calibrated sensitivity level. The formed cracks are normal to the principal tensile strain direction and the area covered by the cracks maps the area at or above the calibrated strain level. By incrementally increasing the loads and tracing the cracked areas at the end of each increment it is possible to obtain qualitative analysis of the stress distributions within the expansion loop. The loops examined by the brittle coating techniques were classified into three general groups illustrated in Figure 3. They are the extended expansion loop, drip loop, and 360° expansion loop.

GENERAL SHAPES

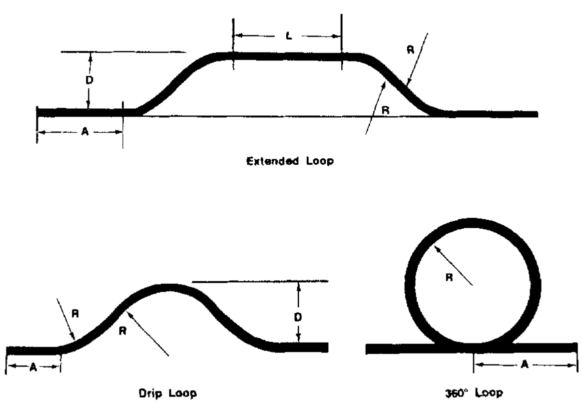

FIGURE 3

The drip loop type expansion loop illustrated is probably the most commonly used expansion loop. The extended expansion is also presently used in some systems and the 360° expansion loop probably not at all. The results of the brittle coating examination on these three basic designs are shown in Figure 4. Although the strains are not shown in exact proportion, some quantitative data was derived from the testing and a number of interesting points were found and are illustrated in Figure 4. One of the most important of these points is the existence of what has been called the nodal point. They are signigicant because - 1. they represent a point of zero stress, and 2. the vertical distance measured from a horizontal line passing through them to either the center line of cable or bottom of the loop regulates, for the better, the bending moments and stress at that point.

STRAIN DISTRIBUTIONS

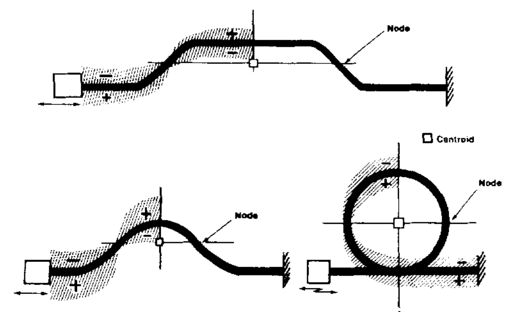

FIGURE 4

The location of the nodal point for symmetrical expansion loops of the three general forms mentioned is found by passing a line (horizontal in this case) through the centroid of the expansion loop. The technique for location of the centroid will be discussed later. The actual existence of this point is not academic and represents the point at which the stress switches from tensile to compressive or compressive to tensile. Verification of this point was found by accident in tests designed to evaluate the significance of cable dielectric to fatigue life. In this particular test, an expansion loop was formed from cable with no center conductor or dielectric. In the formation of the loop, a deep buckle was formed in the cable by accident at the nodal point. Had this same buckle been at a point of maximum stress, mid-position on the flat length of an extended expansion loop, it would have never survived 100 cycles. As it was, the loop was cycled to its anticipated life of approximately 7300 cycles and the failure did not occur at the buckle but rather at the point of maximum stress, the mid-point of the straight section.

Locating the points of maximum stress is important not only in terms of locating the point of failure, but also in terms of selecting the point to or not to place connectors. Connectors for aluminum have historically been trouble spots, not only in the CATV industry but in the telephone and power industries. The inherent properties of aluminum, specifically high coefficient of expansion, relatively inert oxide, and high creep and relaxation rates make it most difficult to connect to much less aggravated by large bending moments and thrust loading. Refering to Figure 4, the maximum bending and stress points are located at the top of the radius for the drip loop and

360° loop, and at mid-point of the straight section, L, on the extended expansion loop. It is at these points that connectors should never be attached. By placing a connector in the center of the drip loop type expansion loop, a situation very similar to bends created at equipment results. Any time the cable deviates from its standard centerline, bending moments and high stresses will result if the cable is subjected to thrust loading from thermal expansion. The magnitude of these stresses will vary with the thermal strain of the cable and the distance in which the cable deviates from the centerline to the equipment closure connector. If this distance becomes excessive, it should be isolated with the use of expansion loops at either side or at least one side and tightly lashed or clamped between the expansion loop and the equipment closure. The next highest stress location is found at the expansion loop ends. These stresses are also the result of an applied bending moment and vary with vertical distance measured to the centroid of the expansion loop. So long as these stresses are less than those at the maximum stress point, they are of little consequence. If it is necessary to apply a connector in this area, the connector can be isolated from the bending moment by installing a two cable spacers and straps inline between the connector and the expansion loop end.

The 360° expansion loop, although somewhat of an academic novelty, was useful in demonstrating several important factors about expansion loops. The first is that the expansion loop performance does not necessarily vary with expansion loop size nor does expansion loop optimization relate with the design of a universal expansion loop which will operate at maximum utilization (minimizing the required number per system) in all systems. Such a loop cannot exist. Optimization should refer to designing the highest performance, longest lived, out of the smallest possible loop. The 360° loop is a highly optimized loop, but as mentioned earlier represents, for the better part, an academic exercise in that the installation of the loop is not possible in large diameter cable where there is not access to a free end. In those locations where an end is accessible, the depth requirement of loop would often make it undesirable in terms of maintaining clearance with existing aerial telephone plant. To illustrate the improvement between the efficiently designed and less efficiently designed expansion loop, the 360° loop and drip loop type expansion loop of equal radii were compared in brittle coating analysis. The drip loop design was first compressed .125 inches and the entire length from node to node cracked representing greater than 500 μ in/in strain. Since the entire area cracked with the first small excursion, no quantitative assessment could be made of the point of maximum strain at the bottom of the loop. The mechanics of loop would predict that it was much much higher. The same testing was conducted on the 360° loop but the initial compression was set at .250 inches, twice that of the earlier. The resulting strain field greater than 500 $\mu\varepsilon$ was a narrow strip approximately 1 inch long located at the bottom of the loop. It was not until a compressive displacement of .625 inches that the 500 $\mu\varepsilon$ strain field approached the nodal points of the loop. The same loop was the best performing loop in life cycle testing where the test was terminated after reaching well beyond the 100,000 cycle range.

All of the data generated for the particular classes of expansion loops was conducted upon what may be referred to as a laboratory model in that they were properly formed. The lives obtained from these loops would also represent the maximum possible in that they were properly formed. From those failures that returned from the field it was obvious that much of the problem was associated with proper formation of the loop. This is especially true of those loops that failed in less than one year. The drip loop type expansion loop which was the poorest performing loop of all those tested now became much much worse with improper installation. For this particular loop, the problem of proper installation is aggravated by having the point of maximum strain in the middle of a radius which is hard to properly form in large diameter cable with or without the use of a tool. Those loops of the drip loop design which returned from the field were often of what was referred to as a "jerk" loop - indicative of the installation procedure only. Because of the relative rigidity of large diameter cable and unavailability of properly designed tools, it was much easier to form the drip loop type expansion loop by pulling downward on the cable or pushing upward in two points over a wooden form. The resulting shape of the loop was much closer to a "V", characterized by three tight radii with straight sections between them. The strain distribution of the loop as represented in Figure 4 would then become completely distorted. Those strains at or adjacent to the nodal points would be very small but rise rapidly to the center of the radius at the bottom of the loop. The strains at this point would be highly concentrated and would extend well into the plastic regions of the aluminum. In this condition, the loop is capable of only a few cycles.

The approach of removing the point of maximum strain from a radius is an important design criteria. By doing so, the life of the loop is not critically dependent upon the skills of the particular installer. In the extended expansion loop, this is an important design benefit besides its low profile and improved life.

STRAIN GAGE ANALYSIS

Once the full-field strain distribution had been determined the next approach was to further refine the analysis with the use of strain gages. Although the strain gage does not provide a full-field strain distribution, once the point of interest has been located, the point of maximum strain in this case, the gage can be applied to that point to obtain a highly accurate quantitative evaluation of strains at that point.

The data derived from this particular testing is of considerable usefulness, not only for supplying much of the required data necessary to make approximate life calculations, but as an evaluation of the aluminum used in the outer conductor of the cable. By placing a strain gage at the point of maximum strain and measuring the strain versus varying excursions the data presented in Figure 2 can be readily converted to the conventional S-N curve for fatigue in bending. It can also be used for a very quick A-B comparison of various loop designs. Taking any two, or more, loops and placing the strain gage at the points of maximum strain and compressing or extending the loops to the same given displacement, the loop with the lowest strain will be the longer lived loop at that particular displacment. This procedure should be carried out at a number of varying displacements extending to the point of maximum design displacement to insure that the relative magnitudes of strain between the loops in comparison are true over the entire range.

This same technique was used to evaluate the significance of many design variables. Most of these variations could be justified analytically, but their true significance can be accurately measured with the strain gage and recorded on a strip chart recorder. In general, it was shown that increasing any of the dimensions D, L, R, and A (refer to Figure 3) would result in a decrease in strain as measured at the point of maximum strain and consequently increase loop life. The increase of dimensions R and A is of extreme interest because their increased length does not require additional cable in the formation of the loop and does not affect the profile dimension D. The influence of A and L on life specifically can be seen in Figure 2. The condition of L=0 is illustrated by the drip loop type expansion loop and for an expansion loop of dimensions R=9, D=6, and L=12 the number of cycles to failure are shown for A=1 and A=10. The life is much longer for A=10. The significance of A and L can also be calculated and will be demonstrated later. Increasing dimensions A and L also contributes to expansion loop life in another manner not readily calculated, and is in terms of the loops ability to accommodate excessively large displacements associated with environmental extreme conditions. By increasing dimension A, measured from the first cable strap to the point of tangency of the cable leaving center line, this part of the loop becomes an active contributor to the overall strain energy "absorption" of the loop plus provide an additional mode of loop distortion. This can best be illustrated in Figure 5.

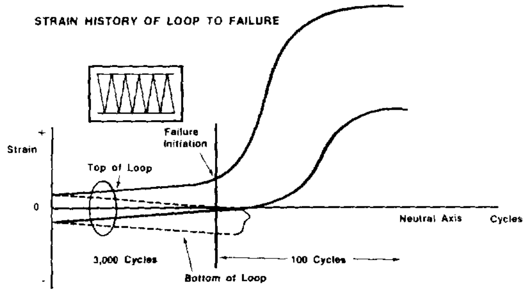

FIGURE 5

In Figure 5, a test was conducted to observe the entire life operation of an expansion loop through the point of failure. The test was performed on an extended type expansion loop with two strain gages mounted at the points of maximum strain. The lower channel, outlined by dotted lines, was mounted on the side that would normally be closest to the support wire. The second gage was placed on what would normally be the bottom side of the loop. The two lines given for channel is used to outline the limits of strain range measured peak to peak. On the actual recording, inside these limits are the strain cycles as depicted in the figure insert. For sake of illustration, the first 3,000 cycles have been highly compressed and the cycles beyond the initial point of failure expanded. However, the relative amplitudes of the strains within the illustration are maintained.

The most significant data derived from the region from 0 to 3000 cycle is the observance of the drift in strain range of the two channels. The occurrence of this phenomenon is the result of the loop dimension being distorted by the large excursion and the loop is seeking a new equilibrium shape and stress distribution. In the initial cycles this drift occurs at a high rate and continues to reach an equilibrium condition asymptotically. The particular test illustrates a condition where the loop failed prior fully approaching its equilibrium condition. This is normally the case in high displacement. For low levels of displacement, the observed drift occurs rapidly, meets its equilibrium conditions and continues to cycle at that level.

The ability of a loop to favorably distort when subjected to an excessively high excursion, or the likelihood of the strain ranges to drift is, for the better part, dictated by dimension A. The influence of A can be calculated for lower displacement where there is little distortion of the loop geometry, but is not so easily done for large displacement. Therefore, it can be said that the increase of dimension does contribute to loop life for low amplitude displacements but its greatest contribution is at high amplitudes of displacement. In tests conducted on the drip loop type expansion loop with a minimal A dimension, there was little evidence of drifting in the strain range and the stresses resulting from high displacements where heavily concentrated a point of maximum strain.

Once failure occurs, as indicated in Figure 5, the strains on the side of failure approach zero, and the entire geometry, and mechanics, of the system is altered. With the fracture on one side, almost always the side closest to the strand, the neutral axis of the cable is shifted, and the mean strain and strain amplitude of the remaining side increase rapidly until failure occurs. The stresses in this area reach far into plastic regions of the material and failure is more the result of gross deformation.

ANALYTICAL EVALUATION

Often, the engineer in the design of a system may envision what in his mind appears to be an improved expansion loop which better meets the requirements of the particular system presently in design, but because of possibly the unavailability of strain measurement equipment, and test fixtures, or the unavailability of time required to perform life testing, an analytical means is required to evaluate the concept. Once this relatively short operation is performed, the engineer can decide in a first order approximation whether the proposed technique is better, worse or further investigation is justifiable.

In order to perform such an analytical solution, a good understanding of the fundamentals of applied mechanics is necessary and specifically familiarity with the use of Castigliano's theorem. As it often is, people familiar with applied mechanics are not available and those that have been familiar with it have long since forgotten it from the lack of application. As an alternative, S. W. Spielvogel[1] has developed techniques for determining thermal stress in pipes in a simplified method based upon Castigliano's theorem.

As an example calculation, the stress distribution for the extended expansion loop of dimensions A=10, R=9, L=12, and D=6 in Figure 6 will be calculated. For brevity, the derivation of the general equations will not be made and it will be left to the reader to obtain verification from reference (1) if desired. The use of this technique assumes that the material remains within the elastic limits of the aluminum outer conductor and it is for this reason that the technique is applicable basically for comparative purposes. The stresses within even well designed expansion loops can reach plastic proportions but this is only upon large displacement and their calculation is of little consequence since this technique will only be valid at small displacements.

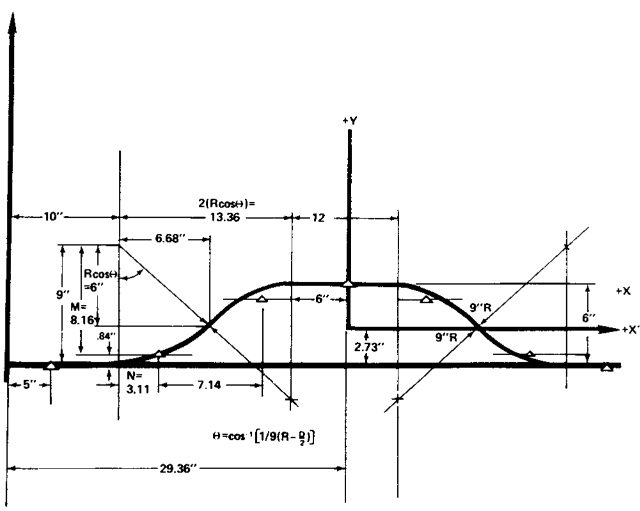

Figure 6

[1]S.W. Spielvogel, Piping Stress Calculation Simplified. New York: Byrne Associates, Inc., 1955, fifth edition, pp. 1-21.

In order to begin the sample calculation, some initial information must first be obtained. The first is the dimensions of the cable to be used and for this example a .750 inch diameter cable of wall thickness, t = .033 inches was used. From this, the moment of inertia, I, of the cable can be calculated from the equation,

$$I = (d_o^4 - d_i^4)/64 \tag{1}$$

where d_o = outside diameter and d_i = inside diameter.

$$I = \pi(.750^4 - .684^4)64 = .00478 \text{ in}^4$$

The next step required determining the thermal expansion, or contraction, of the cable length capable of expanding into the loop. This was calculated under the conditions of a 50°F temperature increase for an effective cable length of 115 feet. The resulting change in length, Δx, was then

$$\Delta x = l\alpha_d \, \Delta T \tag{2}$$

where l = effective cable length, α_d = differential coefficient of expansion, and ΔT = change in temperature.

$$\Delta x = (115)(7.3\times10^{-6})(50) \times 12 = .5 \text{ inches}$$

The last remaining data is the modulus of elasticity, E, for aluminum which is 10×10^6 psi.

The next step in the procedure is the calculation of the centroid of the expansion loop. The best method for doing this is by constructing a sketch of the loop as in Figure 6, locating a convenient coordinate system X',Y', and dividing the loop length into straight and curved segments as illustrated. The calculation of the location of the loop centroid is performed simply by multiplying the length of the straight cable segment times the distances from the cable segment centroid, midpoint, to the origin of X', Y'. In order to do this for curved section a modified length, l, and arc centroid must be found. Taking arc CD as an example, the modified length, l, is computed for an arc radius, R, of 9 inches.

$$K = \frac{1.65\ (d_o - t)^2}{4tR} = 2 \tag{3}$$

The modified length, then becomes,

$$l = R\theta \times K = 15.12 \text{ inches}$$

where θ is the angle θ expressed in radians.

The calculation of the centroid is somewhat more involved, but again simple. In order to do this, again for arc CD, the distance from the arc center to centroid, c, is found from the equation,

$$c = \frac{R\sin 1/2\ (\theta_2 - \theta_1)}{1/2\ (\theta_2 - \theta_1)} = \frac{R \sin 1/2\ (\theta)}{1/2\ (\theta)} = 8.76\text{in.} \tag{4}$$

Knowing c, the coordinates (m,n) of centroid from a coordinate system whose origin is located at the center of the arc can be calculated from equations 5 and 6,

$$m = c \sin 1/2\ (\theta_2+\theta_1)$$
$$= 8.76 \sin 1/2\ (90 + 48.2)$$
$$m = 8.16 \text{ inches} \qquad (5)$$

$$n = c \cos 1/2\ (\theta_2+\theta_1)$$
$$= 8.76 \cos\ (69.1)$$
$$n = 3.11 \text{ inches} \qquad (6)$$

Where θ_2 is the angle measured from the horizontal to line segment OC and θ_2 is the angle measured to line segment OD if O is the center of arc CD.

The centroid can now be calculated in a simple tabular form as shown below:

	l	x'	lx'	y'	ly'
AB	10	5	50	0	0
BC	15.12	13.11	198.2	.84	12.7
CD	15.12	20.25	306.2	5.16	78.0
DE	12	29.36	352.3	6.00	72.0
EF	15.12	38.47	581.7	5.16	78.0
FG	15.12	45.61	689.6	.84	12.7
GH	10	50.61	506.1	0	0
TOTAL	92.48		2684.1		253.4

The coordiantes of the centroid, $\bar{x}$, $\bar{y}$, are found as follows:

$$\bar{x} = \frac{\Sigma lx'}{\Sigma l} = \frac{2684.1}{92.5} = 29.02 \text{ inches} \qquad (7)$$

$$\bar{y} = \frac{\Sigma ly'}{\Sigma l} \quad \frac{253}{92.5} = 2.73 \text{ inches} \qquad (8)$$

From this, a new coordinate system X, Y will be placed with its origin at the loop centroid.

The next step, much like the first, involves calculating moments of inertia, I_x and I_y, and product of inertia, I_{xy}, for each segment of the expansion loop and summing them in a tabular form to find the moments and product of inertia of the expansion loop.

The designation I_x indicates the moment of inertia about the X-axis, and I_y about the Y-axis. For a straight cable segment perpendicular to the axis,

$$I_{(x,y)} = \frac{l^3}{12} + la^2 \qquad (9)$$

where "a" is the distance from the cable segment midpoint to the axis. If the cable segment is parallel to the axis,

$$I_{(x,y)} = la^2 \qquad (10)$$

The product of inertia, I_{xy}, if found by the equation

$$I_{xy} = lxy \qquad (11)$$

where x is the cable segment center to Y-axis distance and y is the cable segment center to X-axis distance.

In order to calculate the moments and product of inertia for the curved section other general equations must be followed again, for cable arc CD,

$$I_x = \frac{RK}{2}\left[\theta - 1/2 \sin 2\theta\right]_{\theta_1}^{\theta_2} - l\ (y^2 - m^2) \qquad (12)$$

where all symbols are as before and y is the perpendicular distance from the X-axis to the arc centroid. These dimensions are shown in Figure 7.

$$I_x = \frac{9x2}{2}\left\{[2.412 - 1/2\ (\sin 276.4)] - [1.572 - 0]\right\}$$
$$+15.12\ (2.43^2 - 8.16^2)$$
$$I_x = +57.04$$

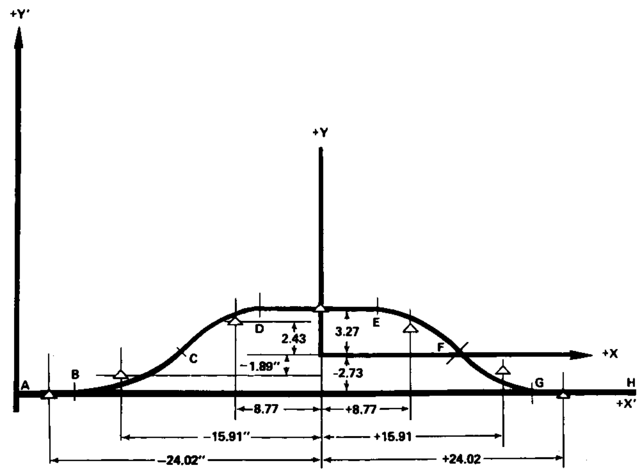

Figure 7

To calculate I_y,

$$I_y = \frac{RK}{2}\left[\theta + 1/2\ 6 \text{ in } 2\theta\right]_{\theta_1}^{\theta_2} - l\ (x^2 - n^2)$$
$$= \frac{9x2}{2}\left\{[2.412 + (-.497)] - [1.572]\right\}$$
$$+15.12\ (9.11^2 - 3.11^2)$$
$$I_y = +1358.6 \qquad (13)$$

The product of inertia I_{xy} is given by,

$$I_{xy} = \left[hkR\theta - hR^2\cos\theta = kR^2\sin\theta = .5R^3\sin^2\theta\right]_{\theta_1}^{\theta_2} K \qquad (14)$$

where h and k are the coordinates (h,k) of the center of the arc from coordinate system X,Y.

The products and moments of inertia of all the segments can now be tabulated and added to find the product and moment of the expansion loop.

	l	x	y	lx^2+I_o	ly^2+I_o	lxy
AB	10.0	-24.02	-2.73	+5853	+74.5	+655.7
BC	15.12	-15.91	-1.89	+4103	+12.33	+436
CD	15.12	-8.77	+2.43	+1358	+57.04	-299.4
DE	12.0	0	+3.27	+144	+272.3	0
EF	15.12	+8.77	+2.43	+1360.1	+53.36	+299.4
FG	15.12	+15.91	-1.89	+4104	+13.1	-435
GH	10.0	+24.02	-2.73	+5853	+74.5	-655.7

$I_y=22.78\times10^3$

$I_x=+557.1$

$I_{xy}=0$

From this, the forces X and Y required to compress the expansion loop .50 inches are computed.

$$X=\frac{I_y\,(\Delta xEI)+I_{xy}\,(\Delta yEI)}{I_x\,I_y-I^2_{xy}} \tag{15}$$

and

$$Y=\frac{I_x\,(\Delta yEI)+I_{xy}\,(\Delta xEI)}{I_x\,I_y-I_{xy}^2} \tag{16}$$

The expansion of the loop in the Y-direction from thermal expansion is assumed negligible compared to Δx and is assumed equal to zero. Therefore from equation 15,

$$X=\frac{\Delta xEI}{I_x}=42.73\text{ lbs.} \tag{17}$$

$$Y=0$$

Once this is completed, the bending moments at all points in the loop can be calculated by summing moments from X and Y about the loop centroid. This was done at points A thru H and is illustrated on Figure 8. The technique now provides a full-field moment, or stress, distribution of the expansion loop under evaluation, locates the points of maximum stress, and indicates the location of nodal points. A comparison with the stress distribution found by brittle coatings in Figure 4 shows nearly identical results.

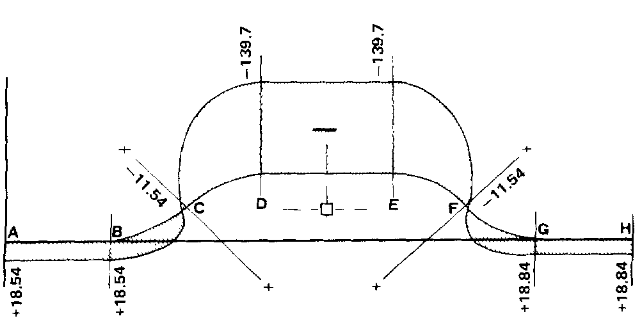

Figure 8

If desired, the strain or stress at any point may also be calculated. For an examination of the point of maximum strain, the bending moment at point $\overline{DE}/2$ is found by summing the moments at that point.

$$M_{DE}=-42.73\text{ lb.}\times3.27\text{ inches}=139.7\text{ in-lb}$$

The strain, ε, can be readily found from equation 18,

$$\varepsilon=\frac{Mc}{IE}=\frac{139.7\times.75}{2\times4.78\times10^{-3}\times10\times10^6} \tag{18}$$

$$\varepsilon=1096\mu\varepsilon$$

where c now is the distance from the neutral axis to the outer fiber of the tubing or assumed to be $d_o/2$.

Performing the same calculations for a drip loop type expansion loop under the same conditions and dimensions A=10, D=6, R=9, and L=0 yielded a maximum strain of $2777\mu\varepsilon$.

As mentioned earlier, the accuracy of these calculations varies with increasing displacement but it is still most helpful as a comparative technique. Theoretically, the accuracy of calculation will approach 100% as the displacement approaches zero. To place this in perspective, the measured strains at the point of maximum strain were 33% higher than those calculated at a .50 inch compression for the extended expansion loop. Reducing the displacement to .125 inches reduced the deviation to 19%, and the error continues to decrease with decreasing displacement.

The estimation of the fatigue life of an expansion loop will be the most difficult task in the design of an expansion loop; difficult in the sense of finding a meaningful technique that will be as accurate as possible with the limited amount of information that is available to the system engineer. Historically, one of the major problems of design engineering has been the necessity to work with limited and sometimes meager information because of the unavailable time to perform extended testing, or that the complexity of the variables required to obtain each individual solution makes a particular technique impractical. For these reasons, the engineer must use approximate relations. However, approximate relations can serve a very useful purpose provided the limitations of these approximations are fully recognized.

LIFE ESTIMATION

As mentioned earlier, the number of variables involved in the calculation of fatigue strengths, the stress environment, and the fatigue life of a particular structure are numerous, to say the least, and only a few of which have been incorporated into this study. Even under highly regulated and known conductions of fatigue testing of materials of a rotating beam test device, a certain amount of scatter accumulated data is anticipated.

Probably the one largest unknown variable that will affect the accuracy of the life calculations performed in this application is that of stress corrosion. The discussion of techniques of applied mechanics to compensate for stress corrosion or any involved discussion of its mechanisms is beyond the scope of this paper. It should be said though, that stress corrosion is the reduction in fatigue strength of a material which is subjected to the simultaneous environment of stress and a corrosive atmosphere. The resultant reduction of the fatigue strength is much greater than the sum of the two factors acting one at a time. Basically, the reduction in fatique evolves from a change in the surface condition of the aluminum resulting from corrosion. The presence of the roughness and minute pits generates stress risers at which very large stresses causing the material to yield. But, the true problem is not quite so simple so it is not even practical to calculate fatigue strengths for corroded samples. The only compensation that will be made at this time can be in the factor of safety applied to the overall system.

In transferring the data from the laboratory test to the field environment, the most significant contribution will be in the adjustment for stress biasing. Looking at Figure 9[2], the three general types of fatigue stress are illustrated. Where

σ_{min} = minimum stress	σ_m = mean stress
σ_{max} = maximum stress	σ_r = stress range
σ_a = stress amplitude	σ_s = static stress

FATIGUE STRESS TYPES

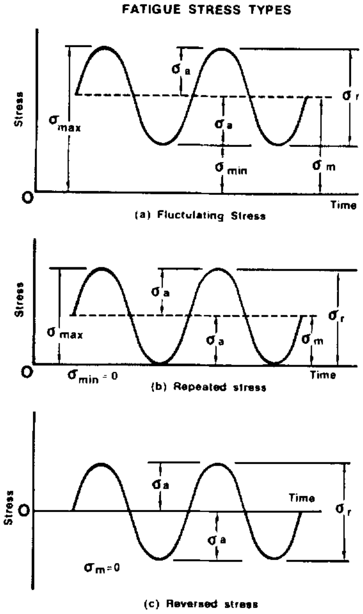

Figure 9

[2]Joseph Edward Shigley, Mechanical Engineering Design. New York: McGraw-Hill, 1972, second edition, pg. 269.

Those tests conducted to determine the number of cycles to failure versus excursion were conducted in reversed stress, σ_m=0, representing the conditions of repeated and fluctuating stress is done by adjusting for an increasing mean stress, σ_m.

In Figure 10, a representation of the environmentally induced strains is shown in simplified. The seasonal temperatures have been simplified to two temperatures with a transitional season between them. Superimposed on the seasonal temperature are shown the daily temperature changes. The sum of the seasonal and daily temperature change is identified as the theoretical strain curve. The strains within the cable and expansion loop will follow this curve and their magnitude will vary with that curve and the difference between the mean annual temperature and installation temperature. It can be seen that if the mean annual temperature and installation temperature were identical, the mean strain would be zero and the strain cycle would closely approximate the laboratory testing. The importance of installation temperature now becomes apparent. If, for example, the cable was installed the coldest day of the year, the mean stress on that day is zero, but for every remaining day the mean strain would increase as would strain amplitude. During the warmest day of the year the maximum stress will be reached. The same is true in reversing the situation.

ENVIRONMENTAL STRAIN PROFILE

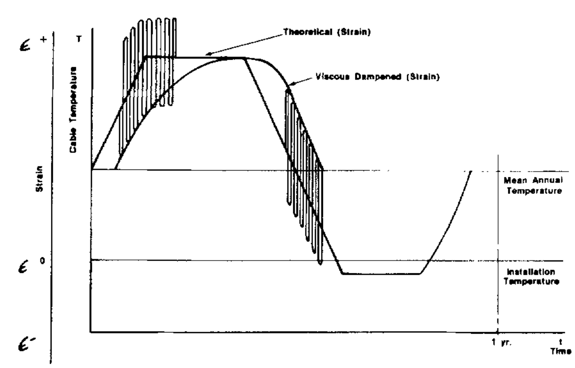

Figure 10

The viscous dampened curve in Figure 10 represents the strain in an expansion loop which is installed in a system where the cable is tightly lashed. Because of lack of freedom of movement, the daily temperature excursions are dampened out, but the seasonal excursions still exist with a given amount of lag. What actually exists in the field at present, would range over the entire spectrum between the theoretical and dampened curves. For design consideration, the theoretical curve should be used since its higher number of cycles represents the worse condition.

The reduction in life, resulting from stress biasing, of course varies with the magnitude of bias, and it is understood that not all conditions are as severe as previously illustrated. To evaluate the reduction in life at any level of bias, the Langer modified Goodman Diagram[3] is useful. This is illustrated in Figure 11. In this diagram, the curve to the left of the vertical axis is the S-N curve constructed from the composite of strain measurements made and the fatigue life testing. It is plotted stress versus number of cycles to failure (non-logarithmically). The right side is constructed by drawing a line from the yield stress, σ_y, plotted on both the ordinate and abscissa. To find the modified life for a particular alternating stress at a level of bias, A, calculate or measure the strain amplitude associated with the alternating strain and compute the corresponding stress. This must be done from the stress-strain curve of the aluminum outer conductor and not taken from conventional wrought aluminum data. Corresponding to this stress, will be the life at that stress, N, for a mean stress of zero. Next, draw a line from the alternating stress valve, σ, on the ordinate to the ultimate tensile strength of aluminum, σ_u, on the abscissa. For the particular mean stress, σ_{mA}, associated with the difference between the installation temperature, and the mean annual temperature and seasonal temperature, point A can be located by the intersection of σ_{mA} and line $\overline{\sigma\sigma_u}$ or $\overline{\sigma_y\sigma_y}$ whichever is less. The modified alternating stress, σ_{aA}, for point A, then corresponds to the modified life N_2 on the S-N curve. The reduction in life is the ratio of N_1 and N_2.

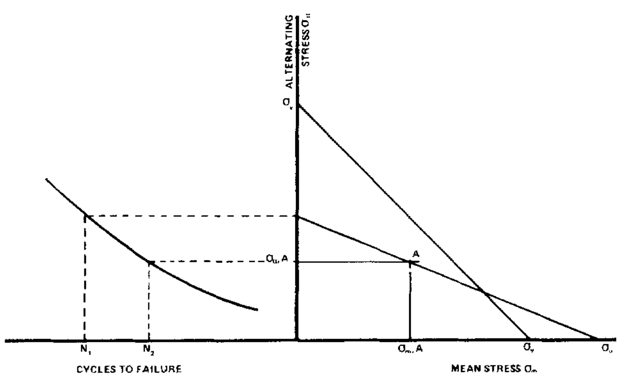

Figure 11

The final step in determining the life of the expansion loop is the combining of all the various different lines corresponding the number of various bias level calculations which have been made, and the number of cycles occuring at each level. One of the most popular theories for accomplishing this is the Palmgren-Miner Theory.[4] This theory states that the portion of the total cycles to failure applied at one stress level plus that portion of the total number of cycles to failure applied at any other stress equals a constant. This constant, K, is found experimentally and normally ranges from 0.7 to 2.2. For simplicity K=1 is most often used. Stating this theory mathematically,

$$\sum \frac{n}{N} = 1$$

where n is the number of cycles applied at a single stress and N is the number of cycles to failure at that stress.

The results from this technique, as with the others, must be qualified. In evaluation with experiment, the theory often fails to be in agreement; however, other more accurate and complex theories are available with improved correlation. The use of these improved theories is not required at this time in light of what is to be gained and the number assumption already operating. Again the use of this theory is intended as an improved guideline and not for use in obtaining absolute valves.

CONCLUSION

The problems associated with fatigue in coaxial cable is a highly complex problem which will require much more testing before the problem can be comfortably handled, if ever. Until that time, the engineer must take full advantage of the limited data availability to insure the maximum reliability of their system. By applying many of the experimental and analytical techniques already available, and large factors of safety, the life of present cable systems can be vastly improved.

ACKNOWLEDGEMENT

The author wishes to acknowledge the contributions of Mr. Gordon Huffman, Environmental Engineer, Superior Continental Corporation, R & D, Hickory, North Carolina, for his assistance and development in much of the life testing presented.

[3]S.S. Manson, Thermal Stress and Low-Cycle Fatigue. New York: McGraw-Hill, 1966, pp.177-180.

[4]A. Palmgren, DieLebensdauer von Kugellagern, ZVDI, pp. 339-341, 1924; M.A. Miner, "Cumulative damage in fatigue," J.Appl. Mech., vol. 12, Trans ASME, pp. A159-A164, 1945.

THE EFFECTS OF SATELLITES ON CATV

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D. W. Lipke — Comsat

Since the world's first commercial communications satellite was placed in service in 1965, space system technology has made tremendous advances. Indeed, the technological advance has been so rapid that a number of CATV operators are concerned that CATV systems may soon be rendered obsolete by the delivery of video signals directly into the home via satellite.

This paper examines the potential of future satellites by considering the major technical and economic factors that influence system design. Consideration is given to the choice of launch vehicle, frequency, spacecraft communications subsystem, propagation, and earth station capacility.

The conclusion is that direct to the home satellite broadcasting systems are not likely to be introduced in the U. S. in the near future. Satellite systems can, however, provide economical video signal distribution to CATV head-ends.

INTRODUCTION

There appears to be considerable interest on the part of some CATV operators in the possibility that CATV systems may become technologically obsolete in the near future. These operators hear that satellites may be able to beam video signals directly to home receivers and thereby obviate cable signal delivery. This paper examines this possibility and investigates certain technical and economic factors which relate to the choice among alternative satellite systems for CATV signal distribution.

The first part of the paper is devoted to providing background information on the development of the existing International Telecommunications Satellite Organization (INTELSAT) system, the Canadian domestic system and the proposed United States domestic satellite systems. The proposed ATS-F/Rocky Mountain States experiment is then briefly described and the next part is devoted to technological factors involved in system design. This is followed by an economic analysis and, finally, concluding remarks.

The INTELSAT System

Early Bird, the first INTELSAT spacecraft, was launched in 1965 and was capable of providing 240 voice circuits between one earth station in the United States and one in Western Europe. Alternatively, a single, one-way television channel could be transmitted which introduced live transoceanic television on a commercial basis. The latest INTELSAT spacecraft, INTELSAT IV, can provide up to twelve television channels to all earth stations in the coverage area.

Pertinent characteristics of the four generations of satellites are given in Table 1.

TABLE 1.

SUMMARY OF INTELSAT SPACECRAFT CHARACTERISTICS

	INTELSAT I	INTELSAT II	INTELSAT III	INTELSAT IV
Nominal Weight in synchronous orbit (pounds)	85	190	334	1610
Launch Vehicle	Thrust-Augmented Delta (DSV - 3D)	Improved Delta (DSV-3E)	Long-Tank Delta (DSV-3M)	Atlas/ Centaur
Nominal Capacity (4kHz circuits)	240	240	1200	5000
Design Lifetime (years)	1.5	3	5	7
Number of Transponders	2	1	2	12
Multiple Access Capability	No	Yes	Yes	Yes
Transponder Bandwidth (MHz)	25	126	225	36
Spacecraft e.i.r.p. (dBw per transponder)	11.5	15.5	23	22.5 (global) 34.2 (spot)
Earth Coverage Pattern	North-Atlantic	Quasi-Global	Global (17°)	Global (17°) (plus 2 steerable spot beams) (4.5° each)
Year Placed in Service	1965	1967	1969	1971

Standard earth stations operating with INTELSAT satellites have also changed significantly with time, although the figure of merit, i.e., the effective antenna gain divided by the effective system noise temperature (G/T), has remained constant. The first U. S. earth station used a radome enclosed, folded-horn antenna and a narrow-band super-cooled MASER as the first amplifier. It was located at Andover, Maine, hundreds of miles from the circuit termination point in the New York City area, to avoid any possibility of radio frequency interference (RFI).

Subsequent U. S. earth stations have used unenclosed paraboloidal antennas with diameters of 90-100 feet. Cost factors, increased bandwidth requirements and improved performance capabilities have dictated the replacement of MASERS with cooled parametric amplifiers. In addition, the use of "stationary" orbits for the satellites greatly simplifies the RFI problem and, as a result, earth stations can be located closer to the desired circuit termination point.

The TELESAT System

The TELESAT System provides a complete telecommunication service to communities throughout Canada. Each satellite has twelve transponders, although only ten are usable during eclipse. Each transponder will relay one color video channel, two audio channels and one cue channel between properly equipped earth stations.

Several earth station designs are used in the TELESAT System but perhaps the most interesting to this audience is the "remote television" class of station. This station uses a manually steerable, paraboloidal antenna with a diameter of 26 feet, an uncooled parametric pre-amplifier and the G/T is 26 dB/°K or better. The stations are equipped to receive one or two video channels initially and the output video S/N is 55 dB.* Transmission capability is not provided.

Another type of earth station in the TELESAT System of interest to this audience is the "Network Television" class. This station uses an antenna with a diameter of 33 feet, an uncooled parametric pre-amplifier, has a minimum G/T of 28 dB/°K and provides an output video S/N of 57 dB. These stations transmit, as well as receive, video programs.

*The signal/noise (S/N) is defined as the ratio of the peak to peak signal (including sync.) to weighted RMS noise.

United States Domestic Satellite System Proposals

Listed below are the six active proposals for domestic satellite systems currently being processed by the Federal Communications Commission.

American Satellite Corporation
American Telephone & Telegraph/Comsat General Corp.
CML Satellite Corporation
GTE Satellite/National Satellite Services
Radio Corporation of America
Western Union

American Satellite Corporation (ASC)

ASC is 80% owned by Fairchild Industries and 20% owned by Western Union International. It plans to obtain three, 12 transponder, 4/6 GHz satellites based on the TELESAT design and to establish two of these in orbit using Thor-Delta rockets in the third quarter of 1974. Four to eight earth stations equipped with single antennas, 33-feet in diameter, are planned for the initial system. ASC has leased space segment capacity in the Canadian system to offer an earlier service capability.

American Telephone & Telegraph/Comsat General Corp. (AT&T/COMSAT)

AT&T plans to lease the entire capacity of three in-orbit satellites to be owned and operated by COMSAT GENERAL Corporation, a wholly owned subsidiary of the Communications Satellite Corporation. Each satellite is to contain 24 transponders, in the 4/6 GHz frequency band, and is to be launched by an Atlas/Centaur rocket. Each of the five initial earth stations is to have at least two 100-foot diameter antennas. Under FCC rules, AT&T may not use these facilities for the normal provision of commercial video services for the first three years.

CML Satellite Corporation

CML is equally and jointly owned by COMSAT GENERAL, MCI and Lockheed Corporations. At the present time, it has not announced its system plans.

GTE Satellite Corporation/National Satellite Services (NSS)

GTE is a wholly owned subsidiary of General Telephone and Electronics and plans to lease capacity in satellites owned by the National Satellite Services Corporation, a wholly owned subsidiary of Hughes Aircraft Company. The satellites are based on the TELESAT design, contain 12 transponders at 4/6 GHz and are to be launched by Thor-Delta rockets. GTE would utilize ten transponders and would have service continuity priority in the event of transponder and/or satellite failures. The GTE earth stations would be equipped with at least two antennas, each one 100-feet in diameter. NSS plans to use any capacity available in excess of GTE requirements, including the spare in-orbit satellite, to provide video distribution services primarily for CATV.

RCA

RCA plans to lease space segment capacity initially from the Canadian Satellite System. RCA has applied for the future provision of its own space segment capacity along with the alternative of leasing capacity in another system. It has applied for a number of earth stations with various antenna sizes.

Western Union (WU)

WU plans to orbit two, 12 transponder, 4/6 GHz satellites based on the TELESAT design. It also plans five earth stations, each with one antenna 50 feet in diameter. WU is scheduled to launch its first satellite in the spring of 1974.

The ATS/F-Rocky Mountain State Experiment

In 1974/5, the National Aeronautics and Space Administration (NASA) and the Health, Education and Welfare Department (HEW) plan to conduct experiments involving video transmission via satellite to schools and institutions in the Rocky Mountain region (1). NASA is to provide the satellite (ATS/F) and HEW is to furnish both the programming material and the small earth stations.

These stations are to use antennas 10-feet in diameter, tunnel diode pre-amplifiers, and the output video S/N at the earth station is expected to be 47 dB. Perhaps the most exciting aspect of these earth stations is that the "front end" (i.e., the antenna and pre-amplifier) is expected to cost on the order of $2,000 each. Since the remote television earth station in the TELESAT System is about two orders of magnitude more costly, it might seem to some that this experiment is likely to usher in the age of truly inexpensive satellite telecommunications.

The technical and economic factors that bear on cost-effective satellite system designs will be developed subsequently, but it might be useful to look now at one of these factors in the ATS/F-Rocky Mountain States experiment. It should be kept in mind that no satellite system can be designed to provide maximum flexibility and capacity with minimum complexity and cost although any system can be optimized with respect to these criteria. Any satellite system which emerges from the design process is the result of a great many compromises, or trade-offs, between existing component performance capability; the confidence of achieving improvements in performance, the degree of added complexity required to achieve the added performance, the cost of the increased performance and the value of this increased performance in terms either of an improved system or of relaxed performance requirements in other components.

In the ATS/F experiment, for example, the concentration of spacecraft power into a relatively small area, permits high effective radiated power levels and, in turn, allows the use of low performance/low cost earth stations. An ATS/F beam covers approximately 170,000 square miles and a simple calculation shows that more than 20 such beams would be required to cover the United States. If we assume that a domestic satellite system must serve all of the continental United States, then it is entirely possible that lower total system costs could result from the use of a larger coverage area in the spacecraft beam and higher performance earth stations.

II. TECHNOLOGICAL FACTORS

Useable Frequency Bands

At the 1971 World Administrative Radio Conference (WARC), several new frequency bands were allocated to the Fixed Satellite Service. This is defined as a radio communications service between earth stations at specified fixed points; the INTELSAT satellites operating with a global network of earth stations is a good example of this service.

For the first time, allocations were made to the Broadcasting Satellite Service, defined as one where transmissions from the satellite are intended for direct reception by the general public. Two types of reception are recognized. For individual reception, simple domestic installations with small antennas are used; for community reception, the satellite transmissions are received by installations having larger antennas and are intended for use by groups of the general public at one location or through a distribution system covering a limited area.

A summary of WARC frequency allocations of interest for the fixed and broadcasting satellite services is given in Table 2. The 4 and 6 GHz frequency bands are used extensively today for international communications and all announced U. S. domestic satellite systems plan to use these bands initially.*

TABLE 2

FREQUENCY ALLOCATIONS OF INTEREST

FREQUENCY BAND GHz	SERVICE	FLUX DENSITY LIMITS	REMARKS ON BAND USE
2.5-2.69	Broadcast Satellite (Community)	$-152\ dBW/m^2/4kHz \quad 0° < \theta \leq 5°$ $-152 + \frac{3(\theta - 5)}{4}\ dBW/m^2/4kHz \quad 5° < \theta \leq 25°$ $-137\ dBW/m^2/4kHz \quad 25° < \theta \leq 90°$	Use of this band is limited to domestic and regional systems for community reception, subject to agreement between the administrations concerned and those having services which may be affected
3.7-4.2	Fixed Satellite	$-152\ dBW/m^2/4kHz \quad 0° < \theta \leq 5°$ $-152 + \left(\frac{\theta - 5}{2}\right)\ dBW/m^2/4kHz \quad 5° < \theta \leq 25°$ $-142\ dBW/m^2/4kHz \quad 25° < \theta \leq 90°$	Shared with terrestrial common carrier radio relay
11.7-12.2	Broadcast Satellite Fixed Satellite		1. Terrestrial use in this band introduced after space services to insure compatibility 2. Use of this band for satellite service is limited to domestic systems subject to agreement between the administrations concerned and those having services which may be affected
10.95-11.2 11.45-11.7	Fixed Satellite	$-150\ dBW/m^2/4kHz \quad 0° < \theta \leq 5°$ $-150 + \left(\frac{\theta - 5}{2}\right)\ dBW/m^2/4kHz \quad 5° < \theta \leq 25°$ $-140\ dBW/m^2/4kHz \quad 25° < \theta \leq 90°$	Shared with terrestrial common carrier radio relay

θ = Angle of arrival (in degrees) above horizontal plane

Two frequency bands in the broadcasting satellite service are of some interest for U. S. applications. The 2.5 to 2.69 GHz band has limited interest due to its limited bandwidth and the fact that it is restricted to educational television use in the United States. The ATS/F experiment described earlier will use frequencies in this band. The 11.7 to 12.2 GHz band which is also allocated to the Fixed Satellite Service has considerable interest for the following reasons:

1. The band is not shared with terrestrial facilities so that the earth station can be located at the CATV head-end where site geometry and local zoning permit.

2. It is expected that high flux density levels will be permitted thereby allowing the use of small, low cost receiving stations.

For the reasons discussed above, the use of the 4 and 6 GHz bands and the 11.7-12.2 band will be considered.

System Configurations and Frequency Factors

Two satellite system configurations are examined in this paper. In one the satellite interfaces with CATV systems through an earth station which can be located at a head-end or remote from it. For the second configuration, transmissions are direct from the satellite to the home.

In the United States, satellites used for CATV applications would transmit in either the 3.7-4.2 GHz or 11.7-12.2 GHz frequency bands; the broadcasting satellite service would use the 11.7-12.2 GHz band. Transmissions to the satellite would be in the 5.925 - 6.425 GHz or 14.0 - 14.5 GHz bands.

For the satellite/CATV configuration, each frequency band has advantages and disadvantages as shown in Table 3 and described below.

Earth Station Siting - At 4/6 GHz, operational regulations have been established to permit shared use of the band by satellites and an extensive network of established terrestrial microwave systems. The existence of microwave facilities in many areas (usually most dense in urban areas), necessitates careful earth station site selection and available sites are typically on the order of a microwave hop from the desired location. Thus, an interconnect facility is needed and may take the form of either microwave or cable. In the 12 GHz band on the other hand, terrestrial services are not allocated in the United States so that an earth station could be placed at any desired location (e.g. CATV head-end).

Propagation Factors - At 4 GHz, transmissions are affected very little by precipitation. During heavy rains the attenuation at these frequencies is less than one dB and is not a major consideration. At 12 GHz on the other hand, propagation conditions are a major factor in designing an overall satellite system. Figure 1 shows typical results of precipitation attenuation measurements for frequencies near 12 GHz during sunlight hours when the attenuation is the most

*The CML Corporation has not announced its system plans at this time. It is possible that CML will incorporate the use of the 12/14 GHz bands in its initial system.

pronounced. The effect of these propagation factors can be overcome by increasing the power radiated from the satellite or by using diversity stations separated sufficiently to ensure that high attenuation caused by precipitation is not suffered simultaneously at both stations. For CATV applications, it is conceivable to have dual earth stations which interface with the existing cable at widely separated points, thus avoiding the necessity for establishing a new terrestrial interconnect link between the earth stations.

TABLE 3

COMPARISON OF 4 AND 12 GHZ BANDS
FOR CATV APPLICATIONS

4 GHz — ADVANTAGES	12 GHz — ADVANTAGES
• Developed E.S. and satellite technology and equipment • Insignificant propagation effects • Uncooled paramps now with noise temps of 55-60°K.	• No site selection problems. E. S. can be located at CATV head-end • Frequency band is not shared with terrestrial facilities

4 GHz — DISADVANTAGES	12 GHz — DISADVANTAGES
• E. S. site selection could be difficult in certain locations thus requiring extensive interconnect facilities	• Components are being developed • Significant precipitation attenuation of signals-need either S/C power margin or diversity stations to overcome rain attenuation • If diversity is needed, interconnect advantage is lost

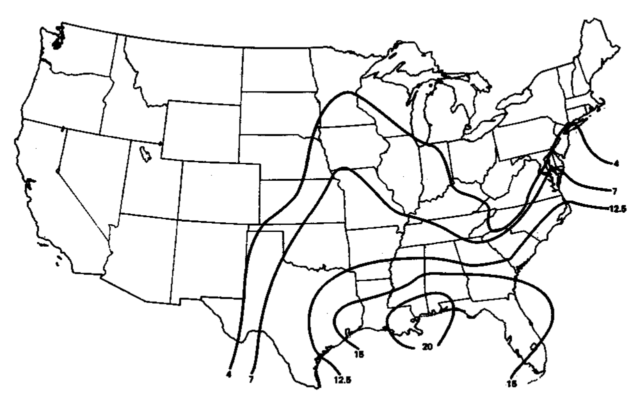

FIGURE 1 REGIONS WHERE INDICATED DB OF ATTENUATION AT 12 GHZ IS EXCEEDED FOR 0.05 PERCENT OF THE TIME PER YEAR

G-9518

(TAKEN FROM REF. 2)

System Design

Typical parameters are shown in Table 4 for three cases of interest, CATV at 4 and 12 GHz and individual reception at 12 GHz. These values have been selected on the basis of both past studies and various trade-offs; in all cases frequency modulation is used (Ref. 3, 4, 5). For CATV at 4 GHz, the satellite eirp is taken to be essentially the same as that specified in several domestic satellite applications.* A signal-to-noise ratio of 53 dB would require an antenna having a diameter of about 22' and an uncooled parametric amplifier. For full United States coverage, a Thor Delta launched satellite could supply 12 television channels without frequency reuse.

TABLE 4

TYPICAL PARAMETERS

	CATV		INDIVIDUAL RECEPTION
Frequency (GHz)	4	12	12
S/N (dB) (1)	53	53	42
Eclipse Operation	Yes (2)	No	No
Path Margin (dB)	<1	4	1
Antenna Diameter (Ft.)	22	16	3.5
Beamwidth (Deg.)	.73	.35	2.1
Antenna Gain (dBi)	46.5	53.5	40.5
Pointing Loss (dB)	.25	1.3	.2
S/C Station Keeping (Deg.)	.1	.1	.1 (3)
Receive System Noise Temp. (°K)	100	200	1000
Satellite Beamedge eirp per TV Channel (dBW)	33	41.8	60

NOTES
1. Frequency modulated signal with S/N defined as the ratio of the peak-to-peak signal (including sync.) to weighted RMS noise
2. It is assumed that a CATV distribution service at 4 GHz would utilize one of the currently proposed domestic systems which provide for some eclipse operation.
3. Station keeping is not as critical in this application due to the relatively wide beamwidth of the earth receive antennas.

At 12 GHz, because of the propagation factors mentioned previously, a sizable margin is introduced. Even with a 4 dB margin, however, a relatively large portion of the country would require diversity earth stations in order to meet a video signal-to-noise ratio of 53 dB which is taken as the performance objective.

*Due to flux density limitations as shown in Table 2, very high satellite eirp's and very low performance earth stations are not feasible at 4 GHz.

This is particularly true in the southeastern part of the country where precipitation rates are the greatest, as indicated by the contours shown in Figure 1. At 12 GHz, a Thor Delta launched body stabilized satellite could provide 6 wideband television channels and an Atlas-Centaur satellite could provide 14 channels with no eclipse operation.

If a lower value of signal-to-noise were acceptable, or if the signal-to-noise ratio were allowed to fall below the assumed value of 53 dB for more than .05% of the time (the value used in this paper), then it would be possible to achieve a higher satellite capacity and/or the use of lower performance earth stations. This would change the equipment design requirement and could also change the relative economics.

For each of the two frequency bands, a relatively small diameter earth station antenna would be sufficient. The beamwidths of these antennas together with a constraint of allowable satellite movement of no more than ±0.1° in the east-west and north-south directions, allow the antenna to remain pointing in a fixed direction (i.e., no tracking is required). This is a governing factor in the design of simple unattended earth stations.

Satellite designs for CATV in this paper use a single spacecraft antenna beam for coverage of the contiguous 48 states which is similar to the designs now being implemented for domestic service. Future systems, however, may effectively utilize multiple spacecraft beams as a means of allowing different margins for precipitation at selected regions within the United States.

For direct to the home transmissions, parameter values based on CCIR examples have been assumed. (Ref. 5) A signal-to-noise ratio of 42 dB would result in a good picture quality, but is 11 dB lower than that considered typical for CATV services. Also, the percentage of time that the quality would be less than 42 dB could be as high as 1%, a value considered unacceptable for CATV. To achieve higher service availability (i.e., to overcome precipitation attenuation), considerably more satellite power or larger home terminal antennas would be required, since diversity cannot be used with direct to the home broadcasting.

The terminal for a direct to the home system would consist of a small outdoor antenna, a pre-amplifier located at the antenna, a down-converter and a demodulator. The output would be fed directly to an existing television set. An antenna diameter of three and one-half feet is typical of a size which would pose no roof mounting problems. Considerable research of front-end devices for home receivers has been conducted recently leading to designs having a system noise temperature on the order of 6 dB. (Reference 6)

Even with lesser performance objectives, the broadcasting satellite radiated power at 12 GHz would be about 60-70 times as high as that required in the CATV example (per channel) for the values considered. For U. S. coverage, only one channel could be provided by a Titan IIIC launched satellite.

Technology Availability - Both spacecraft and earth station technology are well developed and widely available for applications at 4/6 GHz. Component refinements (e.g., lower noise uncooled paramps) are still in progress but major research and development for use of this band has already been accomplished. For operation at 12/14 GHz, research and development is underway. A significant step in accomplishing this is being provided by the Communications Technology Satellite Program, a joint undertaking by the Canadian Government and the National Aeronautics and Space Administration. The program objective is to advance the state of the art in spacecraft and earth terminal technology for operation at 12 GHz and the mission includes the development and flight test of a 200 watt transmitter tube.

III. Economics

All satellite telecommunication systems require significant investments to get started. A Thor-Delta launched satellite, for example, costs about 15 Million Dollars in-orbit and at least two satellites are required to provide service continuity in the event of satellite in-orbit failure. The possibility of launch failure adds to potential start-up costs. Thus, a minimum of $30 to $45 Million Dollars is needed to provide just the space segment of a satellite system.*

*The six proposed systems for U. S. domestic satellite services have start-up costs ranging from approximately 70 to 220 Million Dollars. The high figure is for the AT&T/Comsat system which provides the most capacity. ASC anticipates expenditures of 85 Million Dollars in the start-up of their system, while the equivalent figure for WU is 70 Million Dollars.

The ground stations needed for tracking, telemetry and command and those needed to transmit program signals to the satellite add at least $5,000,000 more to start-up costs. Earth stations to receive the satellite signals may cost as little as $70,000 each if they are located at a cable system head-end and, at these sites, the cost of connecting the cable system to the earth station is negligible.

The high costs of the space segment argue against a satellite system solely for CATV purposes unless there is a large number of receive-only stations in the system. A space system which costs $35 to $50 Million Dollars to bring signals to a few $70,000 receive earth stations is absurd. The number of stations would have to be in the hundreds to made economic sense.

The start-up costs of a moderate capacity satellite system are on the order of $75 Million Dollars. These are only the distribution costs and do not include the costs of programming material to fill the distribution channels.

Given the high start-up costs, it is much more likely that initial satellite system services for the CATV industry will be provided, at a minimum, via a shared space segment. This means that the CATV industry will most likely lease capacity in a satellite system owned by others.

All of the initial United States satellite systems are based solely on the use of the 4/6 GHz frequency bands.* Thus, it is also clear that services to the CATV industry provided in the next few years at least will be in these frequency bands. The question then becomes whether the 12/14 GHz frequency bands offer economic advantages that justify delaying the introduction of satellite distribution services for the CATV industry.

Tables 5 and 6 have been constructed to compare the annual costs of various system configurations in the two frequency bands. The number of receive earth stations is assumed to be in the 100 to 1500 range and the number of space segment channels varies from 1 to 64.

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*As previously stated, CML Corporation has not stated its system plans at the present time. It could be that CML may offer service at 12/14 GHz.

Inspection of the Tables indicates that the least cost alternative between frequency bands depends upon the system configuration.*

TABLE 5

ANNUAL COSTS - CATV SYSTEM @ 4/6 GHz

($000,000)

Number of Receive-Only Stations	Number of Channels Per Station	Number of Space Channels	Space Segment Cost	Receive-Only Station Cost	Terrestrial Link Cost	TOTAL System Cost
100	1	1	$ 1.8	$ 2.7	$ 1.8	$ 6.3
800	1	1	$ 1.8	$21.6	$14.4	$37.8
1500	1	1	$ 1.8	$40.5	$27.0	$69.3
100	2	3	$ 5.4	$ 2.9	$ 1.8	$10.1
200	2	3	$ 5.4	$ 5.9	$ 3.6	$14.9
300	2	3	$ 5.4	$ 8.8	$ 5.4	$19.6
400	2	3	$ 5.4	$11.8	$ 7.2	$24.4
500	2	3	$ 5.4	$14.7	$ 9.0	$29.1
100	4	8	$14.4	$ 3.4	$ 1.8	$19.6
800	4	36	$64.8	$27.4	$14.4	$106.6
1500	4	64	$115.2	$51.3	$27.0	$193.5

NOTES: 1. Western Union has announced estimated rates for satellite services. These rates are, in part, 1 to 1.2 Million Dollars per year for the annual use of one transponder on a pre-emptible service basis, and 1.7 to 1.9 Million Dollars per year for a non-interruptable service. The higher figure is used here since an on-going CATV distribution service would require a high service availability.
2. The investment cost of receive-only stations is $90,000 for a one-channel station. Each additional channel adds $8,000 per station. The annual cost is assumed to be 30% of the investment cost.
3. The investment cost of the terrestrial link is taken to be $60,000 for one to four channels. The annual cost is assumed to be 30% of the investment cost.

TABLE 6

ANNUAL COSTS - CATV SYSTEM @ 12/14 GHz

($000,000)

Number of Receive-Only Stations	Number of Channels Per Station	Number of Space Channels	Space Segment Cost	Receive-Only Station Cost	Terrestrial Link Cost	TOTAL System Cost
100	1	1	$ 3.6	$ 2.8	$ 0	$ 6.4
800	1	1	$ 3.6	$22.4	$ 0	$26.0
1500	1	1	$ 3.6	$42.0	$ 0	$45.6
100	2	3	$10.8	$ 3.1	$ 0	$13.9
200	2	3	$10.8	$ 6.2	$ 0	$17.0
300	2	3	$10.8	$ 9.3	$ 0	$20.1
400	2	3	$10.8	$12.4	$ 0	$23.2
500	2	3	$10.8	$15.5	$ 0	$26.3
100	4	8	$28.8	$ 3.8	$ 0	$32.6
800	4	36	$129.6	$30.1	$ 0	$159.7
1500	4	64	$230.4	$56.4	$ 0	$286.8

NOTES: 1. The space segment cost is based on the ratio of capacities as calculated in Section II. A Thor-Delta launched spacecraft is assumed and, while eclipse operation exists at 4 GHz, eclipse operation is not provided at 12 GHz.

2. The investment cost of receive-only stations is $70,000 for a one-channel station. Each additional channel costs $8,000 per station. The annual cost is assumed to be 30% of the investment cost. One-third of the locations are assumed to require dual installations, geographically separated, to meet service continuity criteria.

If the satellite distribution system for CATV is primarily a means of providing a single nationwide video channel to all receive earth stations, then the 12 GHz band is economically favored. The use of three space segment channels is an interesting case, as shown in the Tables. Here, the 4 GHz band is more economical if less than approximately 300 earth stations are involved, while

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*Similar calculations have been made for a system at 12/14 GHz using tunnel diode, rather than uncooled parametric, preamplifiers in the receive earth stations. This saves approximately $11,000 at each station but the loss in space segment capacity results in higher costs for all system configurations shown in Table 6.

the 12 GHz band is more economical with larger numbers of earth stations. When large numbers of space segment channels are utilized, the economic balance tips in favor of the 4 GHz band.

If three space segment channels and 100 to 500 earth stations is a reasonable CATV system assumption, then the system is more likely to evolve at 4 GHz than at 12 GHz. This is so for a number of reasons.

First, the assumption in Table 6 is that terrestrial link costs are zero in the 12 GHz band. Clearly, this is an optimistic assumption since problems of size, space, line of sight geometry and local zoning will prevent the location of all 12 GHz receive stations at the head end. This is particularly true where space diversity earth stations are required.

Secondly, the CATV satellite distribution ststem will have started at 4 GHz. Some number of earth stations will have been installed and operating and changeover costs will be involved in the switch to 12 GHz.

Thirdly, there will exist, in many communities, a 4 GHz earth station providing services to users other than the local CATV operator. Thus, it will be possible for some operators to effectively share the costs of the 4 GHz station which could be less costly than the alternative of an independent 12 GHz station.

Tables 5 and 6 indicate that the distribution costs of a three channel space segment, 300 receive earth station system, are approximately 20 Million Dollars per year, either at 4 GHz or at 12 GHz. Assuming each receive earth station serves one CATV system, and that each system serves an average of 4,000 subscribers, the distribution costs amount to $1.39 per subscriber-month ($0.70 per subscriber-channel-month). A single space segment channel, with 50 receive earth stations, would cost $1.69 per subscriber-month for distribution at 4/6 GHz and $2.08 at 12/14 GHz.

These cost levels are a significant increase over present subscriber fee levels which could suggest a relatively slow introduction of widespread satellite distribution services into CATV operations. If this is so, then it might be possible to design a viable satellite system to permit the reception of video signals directly at the home receiver.

There are approximately 62 Million TV households in the United States (7). This is a current upper limit on the number of earth stations needed but clearly, the actual number would be less than that. It would seem, for example, that all apartments in a single structure would be served by a single earth station and a master distribution system.

The installed cost of a 3.5 foot antenna, a 12 GHz pre-amplifier and a frequency/modulation converter is probably in the range of $100-200 when production quantities in the millions are assumed. Keep in mind, however, that each one million earth stations means a total investment of $100-200 Million Dollars.

The cost of a Titan IIIC launched satellite is probably around 25 Million Dollars and the launch vehicle cost is around 28 Million Dollars*. The launch of two satellites is a minimum of 106 Million Dollars and, with a launch failure, would be 159 Million Dollars. This provides one video channel in the continental United States.

A one million earth station, two satellite, one channel broadcasting satellite system would require start-up costs of 206 to 359 Million Dollars. A system based on reaching one million TV households via earth stations serving 250 CATV systems at 4/6 GHz would cost about 44 Million Dollars for the earth stations and interconnect facilities. In addition, about 1.8 Million Dollars per year would be required for the space segment channel.

Concluding Remarks

Domestic satellite systems are certain to aid in the development of CATV operations in the United States. This is due to the ability of the satellite system to interconnect all earth stations in the United States through a single space channel. It is also due to the great flexibility available in a satellite system, which permits the almost instantaneous reconfiguration of existing networks.

The satellite system facilities which must be provided to meet future CATV requirements cannot be accurately predicted at this time. An optimum system design requires knowledge of the number of earth

*Research and development costs of around 30 to 50 Million Dollars would be required in addition to the costs mentioned.

stations and the number of space channels to be furnished as well as the service quality requirements. This information is not currently available and is likely to be gathered from embryonic satellite system operations.

The high start-up costs associated with any satellite distribution system suggest that its introduction into CATV operations will be gradual. This paper has addressed only the physical facilities and it could well be that the larger problems will be connected with the economics of obtaining the programming material to fill the distribution channels.

The direct-to-the-home broadcasting satellite system would be based on the use of 12 GHz. While technically feasible, the enormous start-up costs, and the limited capacity of the system, discourage its introduction. The implementation of such a system on a commercial basis is highly unlikely in the foreseeable future.

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THE JCIC AD HOC COMMITTEE ON TV BROADCAST ANCILLARY SIGNALS -- WHY IT WAS ESTABLISHED, AND WHAT IT EXPECTS TO ACCOMPLISH

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ABSTRACT - Over the years, the Federal Communications Commission has authorized the transmission of a variety of special signals inserted into or "piggybacked" along with the television program signal. Several proposals are currently pending at the Commission which request authorization for additional such signals, and, what is of most importance, there is an awareness within the industry of the wide variety of special signals that could be accommodated within the time and frequency domains of the television signal -- without, of course, in any way adversely affecting the integrity of the program signal itself. In view of an obvious need for an overall system study of the entire question of these "ancillary" signals, the JCIC Ad Hoc Committee on Television Broadcast Ancillary Signals was established to study the overall question with the goal of a recommendation to the FCC , for their consideration, of a master plan to accommodate the various requirements in the most efficient and desirable manner. Some of the special signal functions under discussion relate directly to the cable television industry--virtually all involve a common industry interest.

I. INTRODUCTION

Some of the special "piggybacked" signals that have been authorized in the past include unobtrusive audio tones for alerting network affiliates to special announcements or for starting station tape or telecine equipment; vertical interval test and reference signals for the surveillance of video quality on the networks, and more recently, on the signals radiated by remotely-controlled television broadcast stations; time-diplexed signals in the picture area intended for electronic identification of programs and commercials; and frequency diplexed signals in the picture area, to provide an emergency backup for the associated audio. Many other types of special signals are currently under consideration, and still others continue to surface.

It appeared to many in the industry that the techniques that have been authorized to date on a piecemeal basis do not, necessarily, at this point in time, represent the most desirable or efficient methods of accomplishing the desired functions. Also, there existed considerable concern as to the affect on the industry of the emergence of a variety of conflicting proposals for the "valuable real estate" contained within the television signal. Consequently, the Joint Committee for Inter-Society Coordination (JCIC), established an ad hoc committee to study the overall question of these special signals -- now referred to as "ancillary" signals -- with the goal of a recommendation to the FCC from the industry, of an overall plan for efficiently accommodating the various requirements. The Committee was designated the JCIC Ad Hoc Committee on Television Broadcast Ancillary Signals, and the National Association of Broadcasters (NAB) was selected as the host organization to administer the project. Mr. George W. Bartlett, Vice President for Engineering at NAB, was designated as Secretary, and the author was appointed Chairman.

Membership has been drawn from the JCIC organizations primarily, as well as from other organizations. Additionally, two members of the FCC staff, and a representative of the Canadian Broadcasting Corporation sit on the Committee as observers.

For those who might not be familiar with the JCIC, this is an industry committee comprised of the five leading technical organizations which meets on call, to deal with a particular problem which embraces all disciplines within the industry. The membership consists of the Electronic Industries Association (EIA), the Institute of Electrical and Electronics Engineers (IEEE), the National Association of Broadcasters (NAB), the National Cable Television Association (NCTA), and the Society of Motion Picture and Television Engineers (SMPTE).

II. CHARGE GIVEN THE COMMITTEE

In its Reply Comments to the FCC in Docket 19314 (which concerns a proposed revision or deletion of the FCC Rule regarding the active picture area space available for coded program identification patterns) the SMPTE pointed out some of the possible functions in addition to the familiar test and reference signal functions, which could be served by the use of video or audio signal coding. An abbreviated version of this list of 13 suggested functions is shown on Slide No. 1.

POSSIBLE ADDITIONAL FUNCTIONS

1. NETWORK ALERTING	8. CATV NON-DUPL, UHF ID
2. EQUIPMENT CUE	9. EMERGENCY NOTIFICATION
3. LOG PRINTOUT	10. VT START IN SCHOOLS
4. PROGRAM ID	11. DATA
5. MAIN SOUND	12. FACSIMILE
6. OTHER AUDIO	13. PRECISE TIME, FREQUENCY
7. CAPTIONING	

SLIDE 1

In these same comments, the Society indicated its intention of calling a meeting of the JCIC to set up an industry committee to study the overall question of these ancillary signals. Such a meeting was held and a charge to the new Ad Hoc Committee was prepared. An abbreviated version of the seven-point charge is shown in Slide No. 2.

COMMITTEE'S CHARGE

1. EXAMINE REQUIREMENTS	5. DELEGATE TASKS
2. ESTABLISH PRIORITY	6. EVALUATE RESULTS
3. IDENTIFY AVAILABLE DOMAINS	7. RECOMMEND OVERALL PLAN
4. ESTABLISH TESTING GUIDELINES	

SLIDE 2

III. FOUR POTENTIAL "HOMES" AND WHAT HAS BEEN DONE TO DATE

With respect to the identification of possible "homes" or locations within the television program signal technically available for the accommodation of ancillary signals, the committee has identified the following four areas:

- the horizontal blanking interval
- the vertical blanking interval
- the program audio signal, using time and/or frequency diplexing techniques
- the program video signal using time and/or frequency diplexing techniques.

It should be noted that the possibility of additional subcarriers on the broadcast aural carrier is not included in this list. There are two other industry committees looking into the possibility of using this technique for additional sound channels. It may be, however, that some additional capacity would remain for ancillary signals, and accordingly, the ancillary signal committee is maintaining liason with these other two committees.

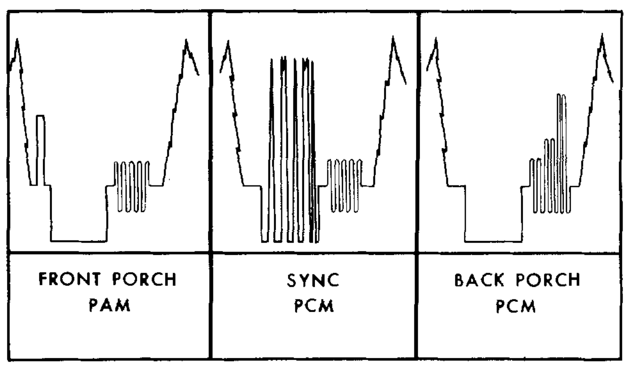
Four subcommittees have been established to study these areas and, quite logically, the studies have started with a review of what has already been done or proposed.

A. The Horizontal Blanking Interval

Obviously this section of the video waveform contains the potential for much additional information, based on the various proposed time division multiplex techniques for adding the program audio, or perhaps a second audio channel. These techniques to date involve the transmission of the audio over network distribution facilities -- but not the subsequent broadcast of any such signals by the transmitter. However, after the program audio has been stripped and the horizontal blanking interval restored at the network affiliate's studio, it would appear feasible to re-use the space for some ancillary functions -- particularly such functions as would relate to the local station (and not the network). One such possibility might be a relatively simple channel identification signal for the automatic tuning of receivers which could also provide, at desired intervals, a momentary flashing of the station's channel number on the picture tube. Such a system could help maintain the identity of a UHF station, which is carried on a VHF channel on a cable system.

As an indication of the potential communication capacity, and some of the techniques for exploiting this capacity, Slide No. 3 shows the basic concept for a few of the systems.

ILLUSTRATIVE H-BLANKING SYSTEMS



SLIDE 3

1. TIDI Sound (TIme DIvision)

This system was developed by the Bell Telephone System many years ago. The technique employs a positive-going pulse, 0.5 usec wide, which is added on the front porch and amplitude modulated in accordance with the sampled audio. For various reasons, the system was never implemented but it remains an imaginative technique for adding about a 6-7 kHz signal to the video.

2. Sound-In-Syncs

This system is now installed in both networks of the BBC in Great Britian. The audio signal is sampled at twice the line frequency and information is stored and coded into two groups of positive-going binary-coded pulses inserted in the tip of sync. The leading and trailing edges of the horizontal sync pulse are retained with the remainder of the time allocated to 20 2T sine-squared pulses, plus a marker pulse. Because of the double sampling rate, an audio bandwidth of 14 kHz is possible. This system was developed by the BBC for the 625-line television system, but equipment is now also made for the 525-line system, and some studies have been conducted on its possible use in the U.S. and Canada.

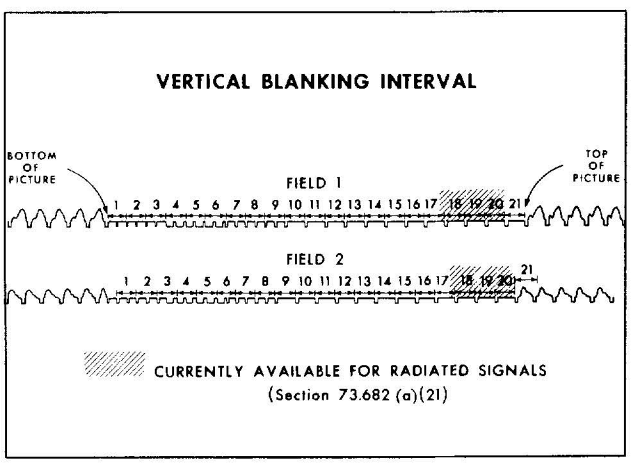
3. Japanese PCM System

In this system the audio signal, coded into two groups of six digit, ternary-coded pulses, modulates an elongated reference burst. The system is capable of accommodating two quality sound channels with an upper frequency limit of about 14 kHz.

Several other techniques have been developed in other countries, but these three examples -- one involving the front porch, one the sync pulse and the other the back porch -- attest to the communications potential of the horizontal blanking interval.

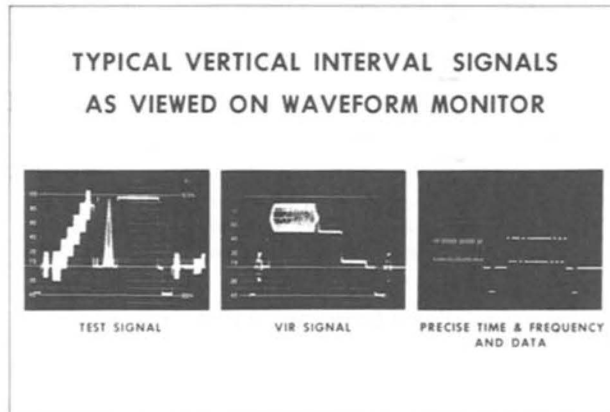
B. The Vertical Blanking Interval

Perhaps the greatest relatively untapped portion of the television signal for future additional communication is the vertical blanking interval, where up to twelve lines of each field -- each line having a potential communication channel capacity, if fully exploited, of 12 kHz -- are technically available for special signals. Slide



SLIDE 4

4 shows a diagram of the entire vertical blanking interval, as well as the area permitted under current FCC Rules for radiated signals, for the specific uses of test, reference, cue and control signals. Actually, after the second set of equalizing pulses has been completed, the only function of the remaining time is to allow the scanning beam to be returned to the top of the picture without being visible on the home receiver. However, for this reason only a few lines, near the end of the blanking period, may be used for ancillary signals which must be radiated, in order to prevent any such signals from being visible on the home receiver. As indicated on the slide, present FCC Rules set aside the last 12 microseconds of Line 17 plus all of Lines 18, 19 and 20 for such signals. One of the major problems at hand will be a suitable allocation of these lines for the various ancillary signals. Some of the proposed vertical interval signals are shown on Slide 5 -



SLIDE 5

1. The new combination test signal.
2. The vertical interval reference signal.
3. Precise time, frequency signals and data signals.

C. The Program Audio Signal

Several systems have been informally authorized by the FCC which permit the national networks to transmit "subliminal" audio tones to their affiliates in order to alert them to news flashes and program changes, and to start station projectors or tape machines. Additionally, the FCC has under consideration formal proposals to use similar techniques for program or commercial identification. Slide 6 shows the basic details on these various systems.

ILLUSTRATIVE PROGRAM AUDIO SYSTEMS

SYSTEM	DETAILS	FUNCTIONS
A	3 tones, 2100-3100 Hz, 50msec, -30dB	1,2
B	2 tones, about 4900 Hz, 1 sec, -30 dB	1,2
C	tone in 200 Hz window about 2900 Hz, 3 sec, -40 to-50 dB	3
D	tone in 90 Hz window, about 150 Hz, 60-120 msec over 4 sec, +10 dB	3
E	16-mode "subliminal signalling"	1,2,3,4

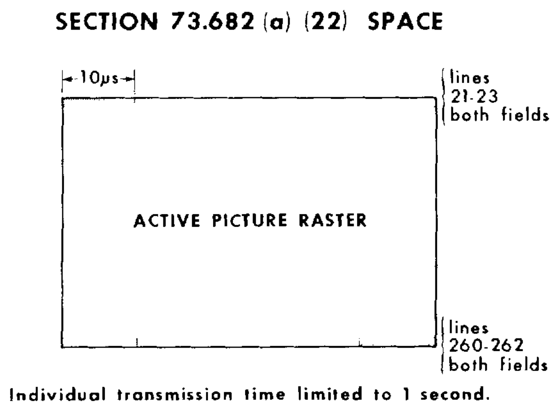
1. ALERTING 3. PROGRAM ID
2. CUE 4. PERFORMANCE TESTING

SLIDE 6

These various techniques are potentially capable of providing some of the ancillary signal functions -- although obviously to a more limited extent than the other areas under consideration. Some of these techniques have been used by radio networks, which in general, use the same audio transmission facilities as do the television networks, namely, the basic Schedule A service involving a nominal bandwidth of 100-5000 Hz. Serious considerations are currently in progress, looking towards a greater bandwidth for television network audio transmission. In view of this development, the techniques just described may have to be reconsidered, and perhaps new techniques, geared to a greater audio bandwidth, will evolve.

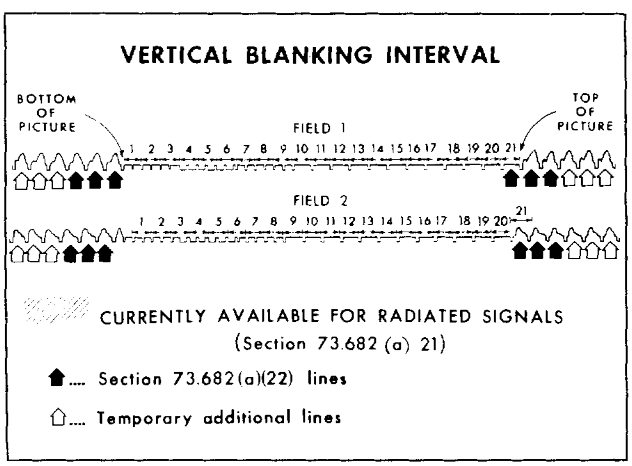
D. The Program Video Signal

Section 73.682(a)(22) of the FCC Rules currently permit a certain portion of the video signal to be used for "coded patterns for the purpose of electronic identification of television broadcast programs and spot announcements".



SLIDE 7

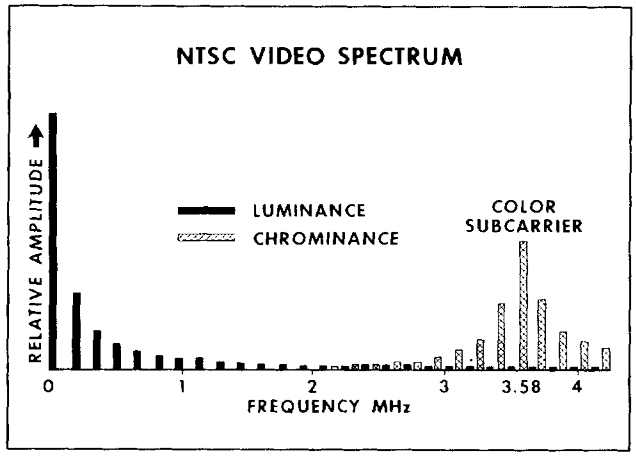
Slide 7 shows this area which is located in active picture time. As an indication of how these lines relate to the vertical blanking interval, Slide 8



SLIDE 8

shows the previously shown chart of the vertical interval on which has been added the lines permitted by Section 73.682(a)(22), as well as some additional lines permitted under a temporary waiver of the rules currently in effect.

The above described Rule provides for a time division diplexed signal. Another technique for adding information in active picture time would be a frequency diplexed system -- which is, of course, the method used to add the entire dimension of color to the television signal, without any increase in the required bandwidth.



SLIDE 9

By way of review, Slide 9 shows a greatly simplified spectral display of the monochrome television signal, shown in black, with relative amplitude as the ordinate and frequency out to 4.2 MHz as the abcissa. Since the scanning process determines the basic energy distribution of the signal, this frequency domain display shows bundles of energy centered about harmonics of 15 kHz, the nominal line scanning frequency. (If each of these bundles were displayed in greater detail, there would also be shown 60 Hz sidebands on both sides of the line-frequency harmonics, representing modulation by the field scanning process.) When NTSC color was added, the color subcarrier frequency was chosen to be an odd multiple of half-line frequency so that the subcarrier and its components, shown crosshatched, fell in the "troughs" or "slots" between the components of the luminance signal, and in an area of the baseband spectrum where there is little luminance information. The "slots" below the chrominance information, that is below approximately 2 MHz, represent a tremendous information potential for added signals. One of the major television networks has for many years used one of these slots, the one between the 113th and 114th harmonic of H, to provide an emergency program audio signal on their New York to Los Angeles network. Just recently a new system has been developed and demonstrated that can provide up to 25 kilobits per second of information, frequency diplexed in the picture in such a fashion as to be completely invisible to the home viewer.

IV. COMMITTEE'S FUTURE WORK

The Committee has held four meetings to date and considerable progress has been made, particularly with respect to the first three (3) points of the seven-point charge:

1. The Committee has examined existing and future uses of ancillary signals and has a reasonably complete feeling for overall requirements.
2. The Committee has established that program-related functions should bear a higher priority over non-program related functions.
3. The Committee has identified the above described time and frequency domains of the television program signal as being technically possible for meeting ancillary signal requirements.

The remaining four points -- admittedly the most difficult aspects of the study -- deal with: 1) establishment of guidelines for the testing and evaluation of new techniques; 2) delegation to industry committees, as appropriate, the task of evaluation of specific proposals; 3) the development of an optimum overall plan to meet all requirements; 4) a recommendation of an overall plan to the industry and to the FCC. This overall study will, of course, require a fair amount of time to complete. However, in view of the considerable input available to the Committee with respect to <u>vertical interval</u> signals, the Committee expects to issue a preliminary report by September 1, 1973 relating to this aspect of its overall study.

V. CABLE TELEVISION ASPECTS

As was indicated in the original list of possible requirements for ancillary signals, two suggestions dealt specifically with cable television: automatic operation of non-duplication switchers and UHF station channel identification. It may be that through NCTA's participation in the work of the Committee, additional requirements will evolve. However, a fact of even greater importance is the common interest that the broadcasting and cable television industry share in providing television service of the highest quality to the viewing public. The prime function of these suggested ancillary signals relates to that objective.

THE KEY ASPECTS OF SIGNAL-TO-NOISE IN TELEVISION VIEWING.

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Summary

This paper discusses the various types of noise that are encountered in the transmission of television picture signals from the studio camera to the home receiver. A number of different methods of measuring and computing signal-to-random noise ratios are then discussed and are then compared in a normalized fashion using the CCIR* recommended method of measurement. Subsequently typical random noise levels measured on television systems and equipment are reported. Finally, some signal-to-noise targets for CATV systems are suggested.

Introduction

Noise being a major cause of picture quality degradation in television broadcasting has been the focus of much attention and subjective evaluation since the early days of television. Schade [1] showed that, in the perception of random noise in television, the eye is much less sensitive to the high frequency components than to the low frequency components. Mertz [2] confirmed this phenomenon and further suggested a weighting function corresponding to the visibility of random noise as a function of its frequency and at a viewing distance equal to 4 times the height of the picture. Subsequently, Barstow and Christopher [3] proposed an electrical noise weighting network for the measurement of random noise in monochrome television pictures.

Later, additional work by Barstow and Christopher [4] with both color and monochrome television pictures led them to propose a modified monochrome network and a separate network for color television pictures. The monochrome network has since become known as the "CCIR weighting network" as it became the recommended network by that body for both monochrome and color television transmissions [5]. The Electronics Industry Association adopted the color weighting for radio-relay facilities [6]. The frequency response of the Barstow and Christopher monochrome and color weighting networks are reproduced in Figure 1. These networks have proved to be invaluable to the television systems designer in that the cumulative effects of noise having different power spectra in systems operated in tandem can readily be predicted. Cavanaugh [7] has recently shown that the Barstow's and Christopher's results are still valid today and that their monochrome weighting is acceptable for color pictures. This supports the CCIR contention of a single weighting network for both types of transmission. In the United Kingdom a 'weighting' method was developed, applicable to linear waveform distortions, by Lewis [8]. This permitted linear distortions to be rated as to their subjective effect on picture quality. Later Lewis and Allnatt [9] suggested that the 'Impairment Unit' (imp); a method whereby unrelated distortions can be assigned an imp rating and that the resulting composite imp rating would be equal to the sum of the individual imps.

*International Radio Consultative Committee.

Siocos [10] using differential gain and differential phase subjective data reported by Cavanaugh and Lessman [11] found that the summability of imps at least for these two types of distortions proved to be reasonably valid.

The subjective effect of video-to-video crosstalk can be very severe even when the interfering signal level is relatively low. Fowler [12] reported a need for up to 60 dB flat coupling loss across the video band to obtain a "just perceptible" response from his 'median observer'. Fowler did indicate that a greater degree of coupling could be tolerated at the higher end of the video band but added that many of the mechanisms that caused crosstalk, such as near-end crosstalk on cable circuits, between an outgoing video and an incoming video, where the incoming video is low in level and also requires high frequency compensation, tends to negate the tolerance at higher frequencies to crosstalk. Fowler conducted his tests with monochrome pictures only, and therefore his findings are not fully valid for color pictures. CCIR [13] recommends that for color and monochrome pictures the coupling loss between video channels should not be less than 58 dB and should be flat across the video band.

Periodic noise which is noise occurring at a single frequency is generally considered most disturbing if it lies in the 1 KHz to 1 MHz frequency range. The CCIR objective for this type of noise is 59 dB. Fowler [14] in subjective tests conducted to determine tolerable levels for low-frequency periodic noise (power frequency pickup) showed that it was most objectionable when the interfering signal caused a 5 cycles/sec flicker on the interfered with picture. Such interfering signals require to be 54 dB down from the picture signal in order to be adjudged "just perceptible" by the "median observer" For a low flicker rate (~0.5 cycles/sec) or a high flicker rate (~30 cycles/sec) a 40 dB difference between the picture signal and the interfering signal was comparable in impairment to the 5 cycle/sec rate at the level mentioned above.

Impulsive noise which is defined [5] as noise of sporadic or infrequently occurring nature has always been a difficult type of noise for which to stipulate tolerable levels of interference. To the authors' knowledge there never has been a definitive study on the subjectives effects of impulsive noise on television pictures. The CCIR [5] merely states that the peak-to-peak amplitude of impulsive noise should be 25 dB below the peak-to-peak amplitude of the television picture signal (excluding synch.). No mention is made of the time distribution of the noise. Recently however [15] an attempt has been made to state objectives for impulsive noise in terms of both amplitude and time allowing higher amplitude impulsive noise to occur with less frequency than lower amplitude impulsive noise. Perhaps as was the case for telephony the need to transmit some form of digital data [16] will spur a more definitive study of this type of noise in television.

Random Noise Computations and Measurements

The CCIR [5] recommended method of specifying signal-to-weighted random noise is "the ratio in decibels of the peak-to-peak amplitude of the picture signal (see Figure 2) to the r.m.s. amplitude of the noise, within the range between 10 KHz and the nominal upper limit of the video frequency band of the system f_C". For the 525-line NTSC color system f_C = 4.2 MHz. [17]. The weighting network that should be used when taking the noise measurement is the Barstow and Christopher monochrome network shown in Figure 1.

The random noise data reported by the Bell System over the last twenty years or so has always referred the noise level to the over all video signal as shown in Figure 2 i.e. including the synchronizing signal. Accordingly signal-to-noise ratios quoted using the Bell method appear to be approximately 2.9 dB better than those using the CCIR method. Today in North America the CCIR method seems to be in greatest use. Therefore for the purpose of this paper the CCIR method will be used when stating signal-to-noise ratios except where otherwise indicated.

The Barstow and Christopher monochrome network has the following effect on noise within the 4.2 MHz video signal bandwidth:

White noise - 6.2 dB
Triangular noise - 10.3 dB

[White noise has a flat power spectrum and triangular noise has a power spectrum which increases at a 6 dB/octave rate.]

Frequency modulation (FM) is used in both terrestrial radio-relay and satellite radio-relay systems to transmit television signals. In both types of systems the identical signal pre-emphasis is used [18]. The shape of the pre-emphasis characteristic is shown in Figure 3. The use of signal pre-emphasis (and its complementary de-emphasis network) effects a net improvement on the signal-to-noise ratio in the above systems of about 2.5 dB [19]. [The random noise power spectra in both terrestrial and satellite systems are nominally triangular in shape. Signal emphasis tends to flatten this noise while at the same time it emphasizes the high frequency components of the television signal.] In consequence, the signal emphasis and signal weighting combined improvement factors in both terrestrial and satellite FM radio-relay systems is 10.3 + 2.5 = 12.8 dB. [Barstow and Christopher's monochrome weighting is assumed in the above.]

In calculating the signal-to-noise ratio in an FM system it can be shown, after Downing, [20] that for a television signal,

$$\frac{s}{n} = 3\,D^2 \left(\frac{B}{2}\, fv\right)\left(\frac{C}{KTB}\right)$$

where $\frac{s}{n} = \frac{\text{average sine-wave signal power}}{\text{r.m.s. noise power}}$

D = modulation index of FM system

$= \frac{f_d}{f_v}$

where f_d = Peak frequency deviation (Hz)

f_V = Top video frequency (Hz)

B = Pre-detection noise bandwidth (Hz)

C = Received carrier power (watts)

K = Boltzmann's constant $= 1.38 \times 10^{-23}$ WS/°K

T = noise temperature of total system (°K)

In dB the equation becomes

$$\left[\frac{S}{N}\right]_{dB} = 1.76 + 20 \log_{10} D + \left[\frac{C}{T}\right]_{dB} - \left[f_v\right]_{dB} - 10 \log_{10} K$$

The conversion factor of the power ratio of a peak-to-peak sine wave to average is

$$\left[\frac{2}{0.707}\right]^2 = 8 \text{ or in decibels} = 9\text{dB}.$$

Further, to convert from peak-to-peak video signal to peak-to-peak picture signal one must subtract 2.9 dB.

Thus

$$\frac{\text{Peak-to-peak Picture Signal}}{\text{r.m.s. noise power}} = 236.46 + 20 \log_{10} D + \left[\frac{C}{T}\right]_{dB} - \left[f_v\right]_{dB}$$

Adding pre-emphasis and weighting improvement which is 12.8 dB the

$$\frac{\text{Peak-to-Peak Picture Signal}}{\text{r.m.s. weighted noise}} = 249.26 + 20 \log_{10} D + \left[\frac{C}{T}\right]_{dB} - \left[f_v\right]_{dB}$$

for f_v = 4.2 MHz,

$$\left[F_v\right]_{dB} = 66.2 \text{ dB Hz}$$

$$\therefore \frac{\text{Peak-to-Peak Picture Signal}}{\text{r.m.s. Weighted Noise}} = 183.06 + 20 \log_{10} D + \left[\frac{C}{T}\right]_{dB}$$

Typically satellite radio-relay systems employ a high modulation index. For example in the present generation of satellites in the Intelsat* System (Intelsat IV) the modulation index used for 525-line NTSC transmissions is D = 2.57 (8.2 dB) and the carrier-to-noise temperature $\left[\frac{C}{T}\right]_{dB}$ of the total system is -137.6 dB. Thus the Intelsat IV television channel

$$\frac{\text{Peak-to-Peak Picture Signal}}{\text{r.m.s. Weighted Noise}} = 53.7 \text{ dB}$$

*International Telecommunication Satellite Consortium.

The carrier-to-noise ratio $\left|\frac{C}{N}\right|_{dB} = \left|\frac{C}{KTB}\right|_{dB}$

and the Intelsat*IV television channel pre-detection noise bandwidth B = 30 MHz = 75 dBHz

$$\therefore \left|\frac{C}{N}\right|_{dB} = -137.6 + 228.6 - 75$$
$$= 16 \text{ dB}$$

It is interesting to note that despite the fact that the Intelsat television channel is provided in the 'C' band [earth-to-satellite link is at 6 GHz and the satellite-to-earth link is at 4 GHz] the carrier-to-noise margin above threshold is small as fading is not a significant problem.

Terrestrial radio-relay systems contrast sharply with the satellite systems in that the carrier-to-noise fading margins are often in the 35 - 40 dB range. Another difference is that at or near the FM threshold $\left(\frac{C}{N} \simeq 10 \text{ dB}\right)$ when the carrier-to-noise is in the 10 - 15 dB range, the random noise level becomes very high in the terrestrial system. 'Thresholding' on the other hand in the satellite system can be characterized more as a sudden increase in impulsive noise. It was this aspect of satellite transmissions that lead PBS and the three commercial networks to specify an impulsive noise objective for the satellite link as a function of time [15].

Probably the most frequently used reference on the subjective effects of random noise on television picture quality is the TASO** data. In the TASO tests that were conducted more than fourteen years ago almost 200 observers were used to make about 38,000 individual assessment of picture quality. While other forms of interference were also assessed, random noise type interference was exhaustively evaluated over a wide range of signal-to-noise ratios [21]. Fine [22] in a subsequent analysis reduced the signal-to-random noise ratio measured by TASO which was in fact the ratio of the r.m.s. carrier (on synch. peaks) to the unweighted r.m.s. noise voltage measured in the 6 MHz TV channel radio-frequency bandwidth.

Two subsequent independent studies by Bisaga [23] and Jansen et al [24] showed that the TASO signal-to-noise ratio equated to within ~0.6 dB of the CCIR signal-to-noise weighted noise ratio as previously defined. To convert from TASO to CCIR one would add 0.6 dB. An exceedingly small difference when one is dealing with subjective data results. Siocos [25] showed that a straight mathematical conversion of the TASO signal-to-noise to CCIR signal-to-weighted noise gave a conversion factor of -1.1 dB

It is clear from the above that the difference between the TASO and CCIR signal-to-noise ratios is indeed small and can be ignored in any practical application. Accordingly the right hand coordinate of Figure 4 shows the CCIR signal-to-weighted-noise ratio against what is otherwise TASO data.

Typical Signal-to-Noise Measurements

Using the CCIR method of specifying signal-to-weighted random noise, a list of typical measurements have been tabulated below in Table 1.

Table I - Typical Television Noise Measurements. [Peak-to-Peak Picture Signal-to-Weighted* r.m.s. noise.]

A. Transmission Systems

1. Intra-City Video Channel (A2A type)	57 dB
2. Long-Haul Radio-Relay** (TD-2 type)	
a. Single hop	73 dB
b. Multi-hop (1600 Miles or ~50 hops).	56 dB
c. Multi-hop (4000 miles or ~130 hops).	52 dB
3. Studio-to-Transmitter Link	60 dB

*International Telecommunications Satellite Consortium.

**Television Allocations Study Organization.

*Barstow and Christopher monochrome weighting.

**Under non-fading conditions.

4. Satellite Systems

Intelsat I & II	45 dB
Intelsat III	49 dB
Intelsat IV	54 dB
Domestic*	56 dB
Canadian Telesat	54 dB

B. Broadcasting Equipment

1. Video Recorders	
a. Quadruplex -	
1st Generation	49 DB
2nd Generation	47 dB
3rd Generation	45 dB
b. Helical -	
1st Generation	44 dB
2. Cameras	
a. Vidicon	50 dB
b. Image Orthicon	45 dB
3. Broadcast Transmitter	54 dB

In 1959 TASO [21] reported that commercially available TV receivers had a noise factor N_f as follows:

Low channel	VHF = 5.5 dB
High channel	VHF = 7.5 dB
	UHF = 13 dB

There is no real evidence that the performance of today's receiver has improved any. Although as reported by O'Connor [26] the use of antenna-mounted low-noise, preamplifiers has probably helped some in fringe area reception. In Europe, however, Mertens [27] has reported commercially available receivers having a noise factor of N_f = 8 dB in the UHF band. A 5 dB improvement in the noise factor of UHF on commercially available TV receivers would translate, in TASO terms, for the median viewer, a 'marginal' picture into a 'passable' picture or a 'passable' picture into a 'fine' picture.

Suggested CATV System Performance Targets

In the previous sections of the paper the following types of noise have been discussed:

a) Video-to-Video crosstalk
b) Periodic noise
c) Impulsive noise, and
d) Random noise

An attempt will be made in this section to assign performance targets for these noise types for CATV systems.

Video-to-Video Crosstalk

Using the data reported by Fowler [12] and choosing his median observer response at a comment level of 3 (i.e., "Definitely perceptible but only slight impairment to picture") would suggest a requirement of 54 dB on 'flat' crosstalk.

Periodic Noise

Again using Fowler's data [14] for low-frequency periodic noise interference, a comment 3 from the median observer would be evoked with the noise at a -49 dB level.

Impulsive Noise

No real data is available on impulsive noise which could be applied herein. As defined by CCIR [5] a -20 dB level for at least 99% of any month would seem to be adequate.

Random Noise

Using Barstow and Christopher's data [4] the median observers' comment 3 would require the video channel noise (weighted) as defined by CCIR to be at a -44 dB level. Allowing for noise to be present elsewhere in the overall broadcasting system at an equal level would provide the CATV system subscriber with a signal having a signal-to-noise ratio of about 41 dB.

In summary, the following performance targets are suggested for future CATV systems:

a)	Video-to-video crosstalk	54 dB (flat)
b)	Periodic noise (< 1 kHz)	49 dB
c)	Impulsive noise (90% of month)	20 dB
d)	Random noise (weighted)	44 dB

*Specified by PBS and the commercial networks.

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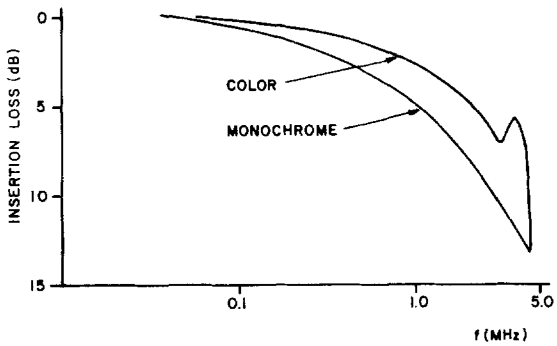

FIGURE 1
BARSTOW & CHRISTOPHER MONOCHROME & COLOR WEIGHTING NETWORKS

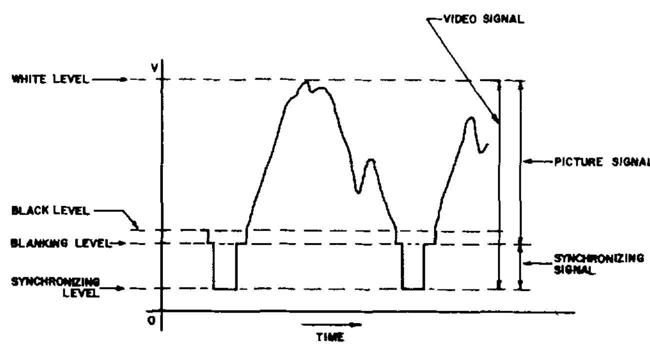

FIGURE 2
CCIR DEFINITION OF VIDEO SIGNAL

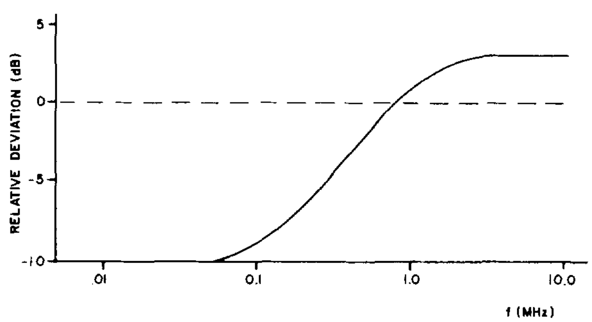

FIGURE 3
CCIR VIDEO PRE-EMPHASIS CHARACTERISTIC

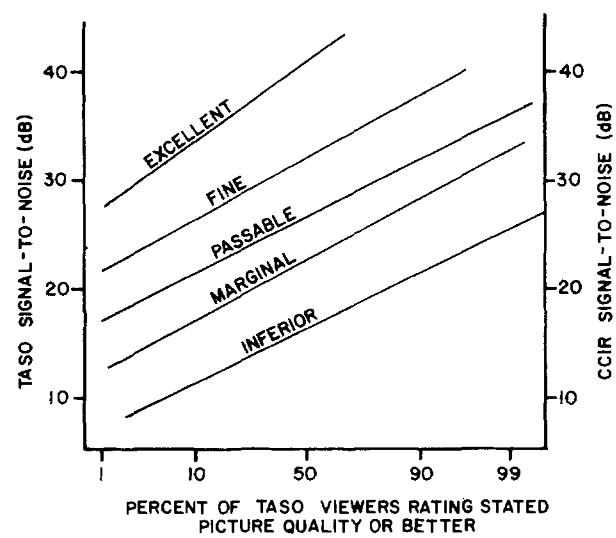

FIGURE 4
TASO VIEWERS RATING OF RANDOM NOISE INTERFERENCE

THE MAGNAVOX PREMIUM T.V. SYSTEM

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The Magnavox Company believes that to a great extent the future growth of the cable industry is tied to CATV's ability to introduce new services beyond the delivery of standard off-the-air T.V. channels. Many ideas for creating additional revenue producing services have been published over the last five years. Some examples of these proposed services are listed below.

1. Premium TV
2. Restricted TV
3. Subscriber Polling
4. Specialized Advertising
5. TV Games
6. Specialty Marketing
7. Home Education

A great deal of effort has been expended by a number of manufacturing companies in an attempt to develop devices and systems which would be capable of providing these services. However, we feel that it has become increasingly clear that the problems of bringing additional services into being are much greater than was initially anticipated. These problems not only have been in the definition and design of hardware but have also included development of software and programming sources, as well as in developing the techniques required to establish a profitable business. As you know very well, the CATV industry is extremely capital intensive. It is doubtful that even the largest MSO's can afford to introduce, on a large scale, whole blocks of services prior to gaining revenue from any of them. Further, the marketability of any of the advanced services mentioned previously has yet to be proven. Thus, it is unreasonable to expect a CATV company to risk the large amounts of capital required for full service operation until a sufficient number of experiments have been conducted to establish that money could be made from such a venture. Because of these difficulties, we believe that the development of advanced services will come as an orderly progression, each service being defined and proven individually. The wired nation will come but we do not believe that it will happen all at once.

Premium T.V. falls into a rather special category when compared with other potential services. First, it is one of the few services which can be established over one-way cable plants and we must remember that today well over 90% of all CATV systems are one-way. Premium T.V. is also one of the simplest services to implement from a technical standpoint. Further, at this point in time, there does appear to be a substantial market demand for the kind of programs which could be supplied over pay T.V. channels. There are today, a number of experiments in this area which appear to be achieving a certain amount of subscriber acceptance. In addition, producers of film material and other software have recently become considerably more willing to sell their products to the CATV industry for an acceptable price. For these reasons, we at Magnavox feel that pay T.V. can serve as the vanguard in the creation of new services providing increased revenue for the cable operator. We would like to emphasize that this growth is only achievable if the basic premium T.V. system is designed to allow for future expansion.

We would like to discuss some of the other system considerations involved in providing pay CATV services. One of the first factors which must be considered is the number of channels which should optimally be supplied over a pay T.V. system. There are two ways of approaching this; one is to examine availability of channel space within the system and the second is to look at the trade-off between number of channels versus the revenue which could be realized from each additional channel.

The only frequency bands that are currently available for pay T.V. services are between 120 and 178 MHz which constitutes channels A through I, and the superband above channel 13. In most existing systems, the trunk and distribution amplifiers do not have sufficient bandwidth to carry superband channels. Furthermore, in many systems, cross modulation products from the low band channels, two through six, preclude operation on the lower midband channels in many systems. Typically there are only two, or at most, four channels which can be used for pay T.V. Data on a number of systems around the country indicate that channels H and I can be used on almost all systems and channels F and G are useable with a minimum of system modification.

From the point of view of programming requirements, cost of supplying software increases directly with the number of premium channels, while the number of viewers who watch each added channel decreases. There is little market research available to indicate the minimum number of channels which would be acceptable in a premium T.V. system. However, there is at this time, a number of experiments in progress using one, or two, or three channels that appear to be having a fair degree of success. We feel that there is little doubt that in the future there will be requirements for three or more premium channels, although at present two should satisfy early market needs.

A second factor to consider in premium T.V. is security of the program material. There are two aspects of security which we would like to consider. First from the point of view of the system operator it would be undesirable to have a system in which a subscriber could obtain premium programming without charge merely by installing a standard multichannel converter. Second, we feel very strongly that the subscriber has the right of not being exposed to programming which he may feel is offensive. It is not acceptable to our way of thinking if a subscriber could view a program merely by turning a channel select knob.

In general, there are two techniques of blocking reception of premium signals in the home. The first is scrambling. This is any technique whereby the video signal is destroyed or deteriorated at the origination point. This signal is then reconstructed prior to reaching the subscriber's television set. Jamming is a technique whereby unaltered video is transmitted down the CATV distribution system. This signal is then distorted at a point between the subscribers tap and television set. Jamming has the advantage of being removable upon purchase with a minimum amount of degradation to the premium channel. However, jamming requires decoding devices at all subscriber drops prior to the time that premium programming can be provided to any subscriber. In the case of scrambling on the other hand, since the signal appearing at subscriber's taps has been previously distorted, the unscrambling device is placed only in the homes of those subscribers who wish to participate in the premium T.V. service.

A third facet of any premium T.V. system is the need to collect revenues accruing from the pay T.V. service. A number of different approaches have been devised to achieve this function. All of these techniques however, fall into two general categories, subscription programming and per-event selection of programming.

Subscription programming has the advantage of system simplicity and low cost. There is no requirement to obtain any information from the subscriber other than his agreement to participate and pay a monthly fee, thus, subscription premium programming is nothing more nor less than a direct expansion of cable channel space for a fixed incremental charge. A major disadvantage of subscription systems is that revenue is not directly related to subscriber usage. Thus, the program operator has no direct feedback on subscriber's acceptance of his material. Further, in the case of showing major attractions, there is no mechanism for achieving the incremental revenue gathering potential of a per-event system. Possibly the greatest disadvantage of subscription systems is that inherently there is no capability of upgrading the system for additional services.

Per-event selection of programming is essentially a two-way service and thus, is inherently somewhat more complex than subscription programming, however, per-event program selections provide direct feedback on the marketability of premium material and allows the subscriber a choice as to the amount of programming he wishes to view and thus, the cost of the service to him. Potentially, this promises an automatic mechanism for achieving a growth of revenues as programming material improves in quality.

There are a number of techniques for implementing per-event selection of programming. For example, tickets could be purchased for special events which would activate the subscribers terminal device. Also, the subscriber could be enabled from the head-end after phoning a service request or, destructible script could be purchased periodically. Probably the most desirable technique, however, would be to allow for purchasing special events by the subscriber's merely activating the home terminal.

Examination of the system trade-offs briefly described above has led to the establishment of the following design constraints which were applied to the development of the Magnavox Premium T.V. system.

1. Any premium T.V. system intended to be economically viable within the next few years must be capable of operation on existing one-way cable systems.

2. The premium T.V. system should employ scrambling both to prevent pirating of programs through use of midband converters and to allow subscribers to avoid exposure to material which would be considered distasteful by them.

3. A keylock will be incorporated to prevent unauthorized use of the subscriber terminal.

4. It is desirable for the premium T. V. system to have the capability of providing both subscription and per-event billing.

5. The preferred method of billing should allow for impulse buying and not require either tickets or the use of the telephone for subscriber authorization.

6. The premium T.V. system should be designed in such a manner as to allow for orderly expansion, both with respect to additional numbers of channels and with respect to allowing for future growth to provide for full two-way services.

7. Program origination equipment should be designed such that a minimum of operator training is required for operation.

8. Preparation of bills should be adaptable both to the manual practices of small system operators and to the automated billing practices of large MSO's.

9. The pro-rated cost of the premium T.V. system should not exceed an amount which would make the operation of the system unprofitable.

We would now like to take this opportunity to describe the Magnavox Premium T.V. system. This system is currently undergoing engineering field tests in the San Bernardino system of TPT (TelePrompTer).

A general block diagram of this system is shown in Figure 1. The main components which are provided by Magnavox are described below.

The central processor and billing computer are located at the head-end or system studio. The central processor controls the operation of the premium T.V. system. The billing computer reduces billing information for cable operator use. Various IDEM units are located throughout the CATV distribution system. Typically, an IDEM (Interactive Data Exchange Module) serves approximately 32 subscribers to the premium T.V. service. IDEM's are located after main distribution amplifiers or immediately following line extenders. It should be noted at this time, that the cable plant between amplifiers is inherently bi-directional, thus, by strategic location of IDEM units, interactive communication can take place between this device and the home terminals. The home terminal units are designed to be small, reliable, attractive, and as inexpensive as can be achieved within the state-of-the-art of present technology. The IDEM is equipped with a read-out unit such that the system operator can periodically retrieve subscriber billing information.

Primary features of the Magnavox Premium T.V. system are listed below.

1. Premium Service Channels
2. Free or Premium Operation
3. Preview Capability
4. Instant Purchase
5. Keylock Authorization
6. Remote Billing
7. Monthly Collection
8. Computer Bill Preparation
9. Automatic Programming

The Magnavox system is designed to offer two additional channels for premium programming. The number of channels may be modularly increased in future units as market demand develops. Any of the premium channels are capable of operating in a variety of modes. First, free programming can be shown unscrambled on any premium channel. Second, unscrambled previews can be inserted at the beginning or during various points in a premium presentation. Third, any premium channel can be restricted by the central processor as to the particular subscribers' who may be allowed to purchase programming on this channel. Thus, if a subscriber does not wish to view questionable material he can cause that his terminal be deactivated when over this material is presented. In addition, the system operator has the opportunity of presenting programs only to special interest groups for example, doctors or other professionals. With the restricted channel capability, only members of these particular groups will be able to purchase specialized programs.

Another feature of the Magnavox system is the capability of providing instant acceptance of a premium program without being required to make telephone calls or to purchase a ticket. A subscriber merely presses a premium accept button if he wishes to purchase a program. In order to prevent use of the terminal by unauthorized people such as children or baby sitters, the Magnavox Premium T.V. terminal is provided with a keylock switch which may be positioned to provide any of the possible combinations of services. The use of the IDEM allows the system operator to collect subscriber billing information on a monthly basis without entering the premises of the individual subscribers. The Magnavox billing process provides the system operator with the capability of generating bills in his own office or through a billing service. An outstanding feature of the central processor unit is its capability to automatically program premium material for both channels including preview periods and alpha-numeric announcements for an entire day's operation of the system, or for as far ahead as the operator has definite plans.

We would like to describe in more detail the functions of the key elements of the Magnavox Premium T.V. system. The central processor unit (Figure 2) is designed to provide control of origination material and of the operation of the system at a minimum cost and complexity. The primary programming input to this device is via punched paper tape. In operation, the control processor is a sequential machine whereby the commands are stored on the tape and processed individually at specific event times. Thus, to activate the central processor, the operator would merely turn the unit on, prepare the program video tape recorders, and then at the appropriate time, start the real-time clock. In the event of failure of the equipment, or last minute program changes, the central processor is equipped with manual controls which can be used to change or bypass any particular section of the premium program.

The IDEM (Figure 3) serves as an on-line switching center for commands being routed from the head-end to the various subscriber terminals. It also acts as an intermediate processor for scrambling codes which are transmitted from the central processor unit. These codes are retransmitted only to those subscribers who purchase the premium program. The IDEM stores the subscriber billing information at specific times under control of the central processor, thus, information can be retrieved relating not only to which programming subscriber's have purchased but also the IDEM can record the particular segment within the premium program at which the subscriber made his purchase. The IDEM is capable of serving up to 32 subscribers and reduces the cost of the total system by sharing much of the equipment which must otherwise be provied in the subscriber's home. Thus, the IDEM greatly reduces the complexity of the home terminal unit.

Figure 4 shows a photograph of a prototype billing readout unit. The data are retrieved from the readout box through use of a standard audio cassette tape recorder. Collection of billing information is made simply by plugging the recorder into the readout terminal and pressing an operate button. The readout terminal is needed only on existing one-way cable systems and not on two-way systems. For operation in a two-way system the billing information may be transmitted directly from each IDEM to the head-end computer. It might be noted that a low data rate passive return link over a "shadow" cable or a conventional telephone circuit may be employed to connect the IDEM module with the head-end, eliminating the need for the readout terminal.

The subscriber's home terminal as shown in Figure 5 contains the MOS logic for switching, communications, and for descrambling of the pictures and sound normally transmitted as scrambled information from the head-end. It also contains the RF devices which provide signals between IDEM and subscriber, and which receive and convert the audio/video signal to a standard VHF channel on the subscriber's own television receiver. The terminal also permits keylock switch control of the premium programming. There are four switches other than the keylock switches: "Standard TV" which permits normal viewing of any non-premium channel, "Premium A", and "Premium B" each of which permits viewing of premium programming if the appropriate keylock switch is "on" for that channel, and "Accept" which causes descrambling of the audio/video signal, and authorizes the cable operator to make a charge for the premium program selected.

In summary, the Magnavox Company expects that in the relatively near future we will have in production what we believe to be the most advanced premium T.V. system available on the market. A great amount of effort has been spent in attempting to design a system which is not only economically viable in today's market but which offers the promise of expansion to full two-way service capabilities in the future. We would like to acknowledge the cooperation of the TelePrompTer Corporation in defining and developing this system and to note that special appreciation is due to Messrs. Tom Ritter and Hub Schlafly, whose participation has gone well beyond the requirements of our contractual agreements.

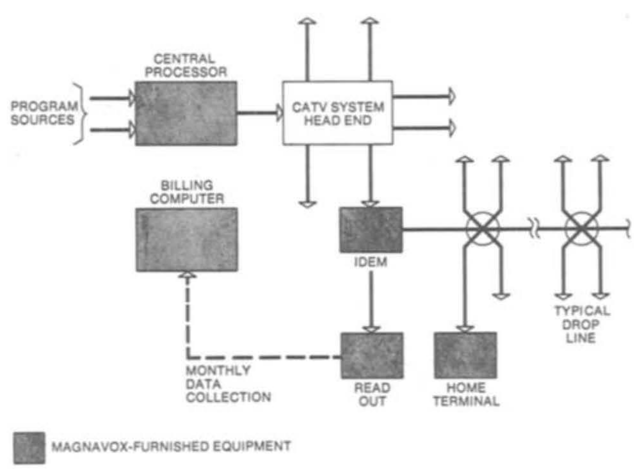

Figure 1. System Block Diagram

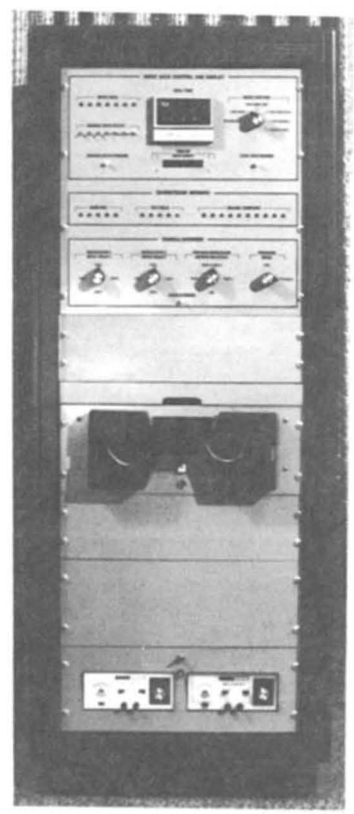

Figure 2. Central Processor

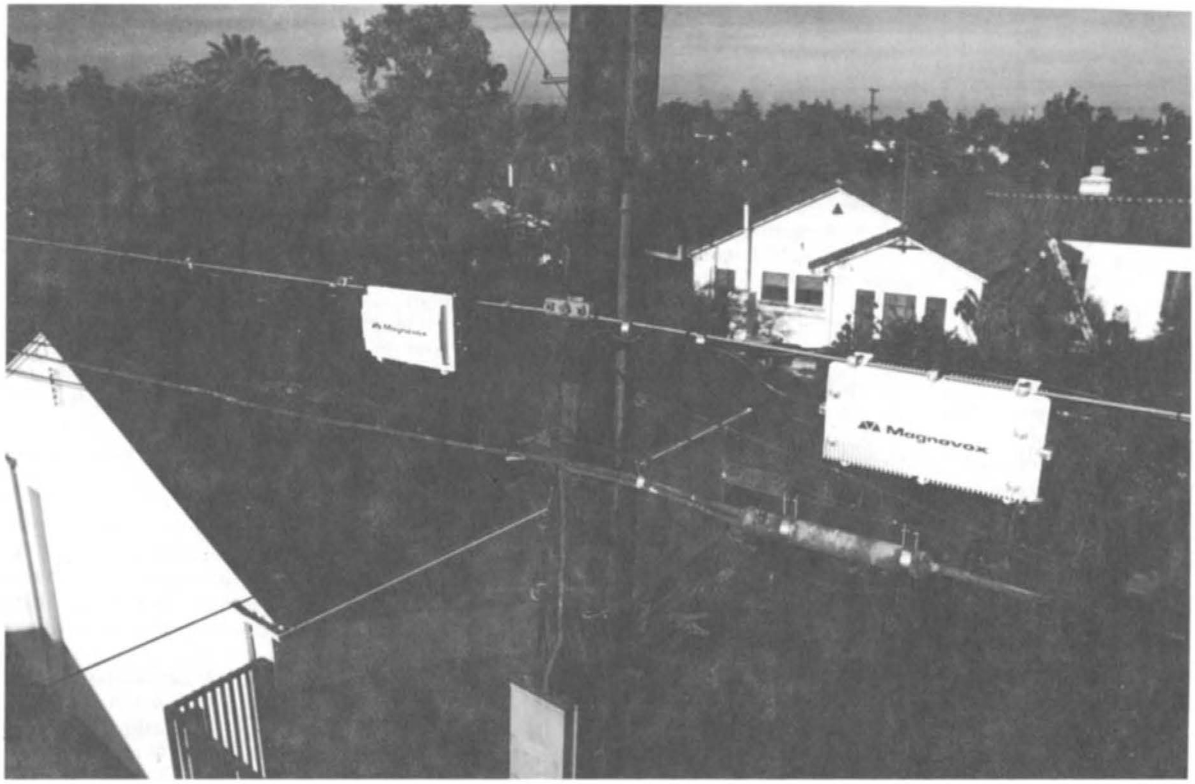

Figure 3. IDEM

Figure 4. Readout Box

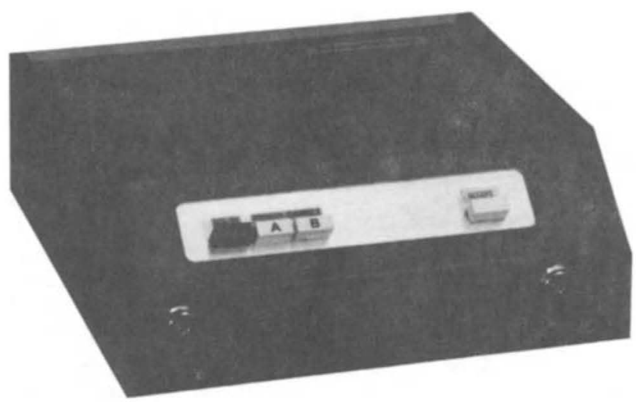

Figure 5. Subscriber Terminal

THIRD ORDER DISTORTION BUILD UP IN A MULTI-CHANNEL CASCADE

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There have been several papers presented in the past dealing with nonlinear distortions in tube and transistor devices and amplifiers.[1] Papers by Reynolds[2], Thomas[2], Akgun and Strutt[3] discuss the various forms of distortion cancellations that can occur in devices. Nearly all of these papers have dealt with two dominant nonlinearities at the component level. Lambert[4] has addressed the cancellation of second order effects in CATV amplifiers and Lieberman[5] in Systems. Because of the wide spread acceptance of amplifier hybrids we have frequently been called upon to aid in the explanation of distortion build-up behavior. What we aim to illustrate here are several unique cross-modulation and triple beat cancellations that may occur in actual systems. It will be demonstrated that these cancellations, or "poorly behaved nulls" may be extremely sensitive to any of the following operating conditions such as level, temperature, amplifier spacing, channel loading or channel spacing. Also we would like to propose a new test method which may give a better indication of a systems multi-channel capability.

Before getting into the testing methods and test results lets take a look back at how nonlinearity has been classically described. Historically the first paper dealing with the prediction of intermodulation products was by Brockbank and Wass[6] in 1945. The authors proposed that the amplitude transfer characteristic of a nonlinear thermionic amplifier, at that time, could be expressed by the power series

$$V_o = a_1 V + a_2 V^2 + \ldots\ldots a_n V^n$$

where V_o = output voltage

V = input voltage

$a_1\ a_2, \ldots\ldots a_n$ = constants independent of frequency.

Nearly all investigators to date have concerned themselves mostly with the first three terms of the series. This was done in part because of the belief that succeeding constants decreased rapidly enough in magnitude with increasing order that sufficient accuracy could be obtained with the initial three terms. Also, as Wass[7] pointed out in another paper in 1948, that for three sinusoidal input waves the number of products resulting from consideration of fourth and fifth order coefficients would be 277 versus the 37 resulting from second and third order. For 5 input signals the number of products increases dramatically to 1486. Because of the labor of carrying out the substitutions the higher order effects have been mostly ignored.

Today with transistor devices improving in second and third order linearity the effects of the higher order terms become visable. In previous work[8] we have illustrated the interaction of third order nonlinearity on second order distortion. In a paper in press[9] we show the contribution of fourth order nonlinearity on third order distortion. Thanks to the computer, the labor of calculating out the great number of products resulting from the fourth and the fifth order distortions, is considerably easier. Now we've increased the problem from the initial 3 carriers on 1 channel to 40 channels or 120 carriers. The number of beats resulting from second and third order nonlinearity becomes 1,166,440. When fourth and fifth order terms are large enough to be prevalent the number of products increases dramatically. (Table I gives the number of beats produced by "N" carriers)

Simons[10] has defined the one form of cross-modulation that we base so much of our industry upon. However, in true observation, the measured cross-modulation is the complex addition of modulation information from other sources and not necessarly just the expansion and compression of the carrier in question. For example, consider the case where there are four signals present as indicated in Figure 1. Assuming only second and third order nonlinearities are present and that there are no cancellation mechanisms present, there will be a triple beat, a second order I.M. beat and third order I.M. beat falling on carrier "C". Because the modulated beats fall on the unmodulated carrier there appears to be information on the carrier. A typical cross-modulation measurement could contain a great deal of measurement error. The error would depend upon the degree of modulation on carriers A,B and D, their phase shift, and the phase shift of the beat products through the system to the point of measurement.

Lieberman[5] had indicated that the second order I.M. beat component could be reduced by amplifier spacing. In this case the cross-modulation sidebands would not contain modulation from that beat resulting in a different cross-modulation level depending on their level of contribution. To further illustrate the possibility of this phenomenon occuring Figure 2 shows the amount of cross-modulation measured through a constructed cascade. Because of the unique combination of phase shifts and the cross-modulation contributed by each amplifier, the cross-modulation at the end of the cascade appears to be better then it was after the second amplifier.

With cascade systems carrying 35 channels, at the standard assigned video carriers, most of the beats will build up about the carrier. The FCC specification on carrier frequency accuracy is $\pm$ 1 kHz. Second order beats could be up to $\pm$ 2kHz away from the carrier and a third order beat as far as $\pm$ 3 kHz away.

Computer calculations n our part indicate that for a 35 channel system the largest number of third order beats due to video carriers falling on a video carrier is 350 and occurs on channel 11. When the channel loading is reduced to 12 channels the number of beats about the carrier falls to 21 on channels 9,10 and 11. Table 2 gives the number of beats for several other channels[11].

With the standard frequency assignments (and tolerance) the large number of beats will build up about the carrier and appear as baseband noise a few kHz wide. In a system where the carriers are harmonically related the beats would accumulate in a power manner, versus a voltage manner, due to their random phasing.

The degradation in third order beat level can be expressed in dB for N beats falling on the same frequency as the carrier as $10 \log_{10} n$, where n is the number of additional beats.

For the case of 350 beats each of -70 dB, a new signal to noise level would be:

$$\text{T.B.}' = -70 + 10 \log_{10} 350 = -44.6 \text{ dB}$$

If a 35 channel system was using carriers harmonically related, all of the 399 beats, some of which are second order, would now fall on the carrier in question. Assuming again that each would be -70 dB (highly unlikely) the signal to beat noise level would be:

$$S/N = -70 + 10 \log_{10} 399 = -43.99 \text{ dB}$$

On the other hand if the carriers were randomly spaced the generated products would be distributed across the bandwidth of the channel and fewer would build up.

It has been shown by Switzer[12] that the video carriers can be harmonically related to a 10 kHz fundamental to conserve peak output capability of an amplifier. As mentioned, all the beats would fall on the carrier with complex modulation sidebands appearing as noise on the TV screen. However, since the modulation sideband is noise-like, if the signal-to-noise (or distortion) level is greater than 40 dB a good picture will result.

To experimentally describe these forms of distortion build up a sixteen mainline amplifier cascade was constructed. Amplifiers with 22 dB gain at channel 13 were fabricated using standard TRW CA100 and CA200 hybrid modules. (Table III). Each amplifier contained a passive gain and cable equalizer control. (Figure 3). Specifications on the completed amplifier are given in Table IV.

Each amplifier was firmly mounted to a fan-cooled heatsink and spaced by 550 feet of foamed 75 ohm cable.

The majority of cross-modulation and triple beat testing was done with a DIX HILLS/Model SX-16 32 channel generator and Model R-12 phase lock receiver. Second order testing was done on a TRW designed four channel distortion analyzer (Fig.4). In each case initial data was verified with a HP8554L Spectrum analyzer.

Second order cross-modulation and triple beat data was obtained at +35, 40, 45 and 50 dBmV output levels at each amplifier. The cross-modulation data was taken on channels 2 and 13 for the 12 channel tests, 2, G and 13 for the 20 channel tests and on 2, G, 13, R and V for 32 channel tests.

The second order performance of the system at +35 dBmV is indicated in Figure 5. Build up of the distortion is accuring at a 3 dB rate and appears well behaved across the frequency domain. Projection of the worst case performance, which occurs on channel 2, indicates that the maximum system length, due to a second order beat exceeding -66dB, is 58 amplifiers, or 1276 dB.

As Lieberman has indicated in his previous work second order products may cancel if the phase intercept of the systems response is an odd multiple of π. Figure 6 illustrates the intermodulation products present at the output of amplifier 8 about a channel 13 carrier in a 32 channel system. The spectrum of the output of amplifier 16 (Figure 7) indicates that several of the second order products have decreased in magnitude.

Cross-modulation performance is indicated in Figures 8, 9 and 10. The twelve channel cross-modulation build up is slightly less than a 6 dB rate with the performance being limited by the channel 2 levels. Projection to the point where the cross-modulation level is -57 dB illustrates that the system length would be 58 amplifiers (1276 dB); the same limit as indicated by second order performance.

Increasing the number of channels decreases the maximum system length as shown in Figures 9 and 10. A 20 channel system would be limited to 32 amplifiers (704 dB) and a 32 channel system to 16 amplifiers (352 dB). It should be pointed out that these figures are for a system operated at +35 dBmV, flat and block tilting would increase the system's length.

Extreme care must be taken in selecting the cross-modulation test method. A common test method incorporates the use of a video frequency phase detector. When the output indicator is dependent upon phase comparison the phase shift through the cascade can generate considerable error in the measurements as is indicated in the comparison of Figures 10 and 11.

The cascades triple beat performance and channels 13 and R is indicated in Figure 12. In each case the adjacent channels were slightly detuned so that the $\alpha+\beta-\gamma$ beat would fall close to the center carrier. The beat was then measured on the phase locked receiver. It's not generally recognized that two forms of triple beat may cancel due to phase shift through the cascade. Figure 13 describes the $\alpha+\beta+\gamma$ triple beat throughout the cascade resulting from channels 4, 5 and A falling on R and channels 2, 3 and 6 appearing on 11. Both forms can cancel as theory would indicate[13].

As can be seen from Figure 10 the measured cross-modulation on channels "V" and "R" appears 10 dB or better than channel "2". Although the measured "cross-modulation" is lower the number of beats falling about the channel 13 carrier are greater than channel 2. (Figures 13 and 14). The beats generated by 32 carriers undergo considerable phase shift throughout the cascade and the resultant effect may be the reinforcement or cancellation of apparent cross-modulation if the beat falls directly upon the carrier. If the beat falls along side the carrier the typical video beat interference can be observed upon the TV set. It should be mentioned that both of these conditions may appear at the same time. When a great number of beats fall about the carrier the end effect is a horizontally noisy picture. Figures 13, 15 and 16 display the number of beats that fall with the video bandwidth of channel 2 after 16 amplifiers for a channel loading of 12, 20, and 32. Figure 14 displayed the beat spectrum on channel 13 after 16 amplifiers for the 32 channel case. As would be expected the observer might not notice this "Intermodulation noise" provided that the noise was somewhat random and the signal to, beat caused, noise level remained better than 40 dB. It is possible that if the system was reduced to fewer channels then any single beat above -66 dB may be observed as beat interference.

In summary, what we have tried to show, here today, is that theory predicts that several forms of third order distortion can cancel and that the present test methods may not be adequate to accurately describe the performance capability of the system. We've indicated that highly loaded systems are limited by intermodulation noise rather then by purely cross-modulation or beat interference.

Several years back we learned of the noise method of distortion measurement used by the telephone companies. They have very similar problems where the system loading is intermodulation noise limited. In the past we suggested that CATV should consider utilizing this approach and are now gratified to learn of the increased interest in this area. There is a great amount of effort necessary before this approach can be considered for use by the industry. We plan to further investigate this test method along with our customers in the joint interest of improving our products and providing the industry with, what may prove to be, a more meaningful indicator of system performance.

The scope of our involvement as a component supplier with our customers, and end user, is considerably more complex than if we merely made carbon resistors. It is our hope that this information is of direct benefit and that our communications will continue to be two-way.

Acknowledgements

The authors are indebted to Gary Pumroy for his assistance in the fabrication of the cascade and to Margaret Stavros of UCS, Inc., for her aid in the development of the computer programs.

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TABLE I NUMBER OF BEATS PRODUCED BY "N" CARRIERS

Number of Product by Type.

N CARRIERS	$\alpha\pm\beta$	$\alpha\pm\beta\pm\gamma$	$2\alpha\pm\beta$	2nd, 3rd. HARMONICS	TOTAL
1	-	-	-	2	2
2	2	-	4	4	10
3	6	4	12	6	28
4	12	16	24	8	60
5	20	40	40	10	110
6	30	80	60	12	182
7	42	140	82	14	278
12	132	880	264	24	1300
15	210	1820	420	30	2480
20	380	4560	760	40	5740
21	420	5320	840	42	6622
25	600	9200	1200	50	11050
30	870	16240	1740	60	18910
35	1190	26180	2380	75	29825
40	1560	39520	3120	80	44280
120	14,280	1,123,360	28,560	240	1,166,440

TABLE II NUMBER OF VIDEO BEAT PRODUCTS FALLING ON EACH VIDEO CARRIER IN A 12, 21 AND 35 CHANNEL SYSTEM.

(STANDARD FREQUENCY ASSIGNMENT)

CHANNEL	CHANNEL LOADING 12	21	35	CHANNEL	CHANNEL LOADING 12	21	35
2	13	40	159	9	21	90	348
3	15	45	171	10	21	87	349
4	13	47	180	11	21	84	350
5	8	17	31	12	18	78	349
6	8	17	31	13	13	72	348
A	-	74	274	J	-	-	345
B	-	85	288	K	-	-	342
C	-	89	299	L	-	-	337
D	-	91	308	M	-	-	332
E	-	92	316	N	-	-	326
F	-	92	323	O	-	-	321
G	-	92	329	P	-	-	315
H	-	92	334	Q	-	-	309
I	-	92	338	R	-	-	301
7	15	92	342	S	-	-	293
8	18	91	345	T	-	-	283
				U	-	-	273
				V	-	-	260

TABLE III MAINLINE MODULE SPECIFICATIONS

		CA100	CA200
Operating Bandwidth		30-320MHz	30-320MHz
Gain & Flatness		16-17dB (± .2)	16-17dB (± .2)
Cross Modulation @ +32dBmV	12CH	-93dB	-100dB
	20CH	-87dB	- 94dB
	32CH	-84dB	- 91dB
Triple Beat @ +50dBmV		-68dB	- 75dB
2nd Order I.M. @ +50dBmV		-66dB	- 70dB
Noise Figure	CH13	7.5dB	10dB
Return Loss	Input	18dB	18dB
	Output	18dB	18dB
Current Requirement @ +24 VDC		180mA	220mA

TABLE IV COMPLETE AMPLIFIER SPECIFICATIONS

Operating Bandwidth	30-320MHz	
Gain & Flatness	20.5 ± .3dB	
Cross Modulation @ +35dBMV	12CH	-94dB (Worst case CH2)
	20CH	-86dB
	32CH	-83dB
Triple Beat @ +50dBmV	CH13	-74dB
	CH R	-68dB
2nd Order I.M. @ +50dBmV	CH 2	-90dB
	CH G	-85dB
	CH13	-77dB
	CH R	-71dB
Noise Figure	CH13	6.6dB (1MHz Bandwidth)
Return Loss Input	18dB	
Output	18dB	
Current Requirement @ +24 VDC	400mA	

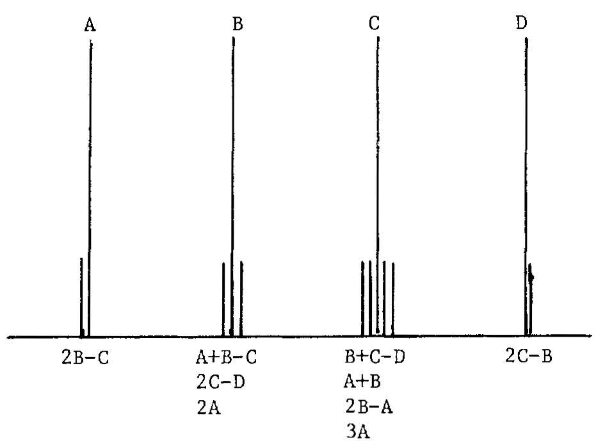


Figure 1. Four carriers spaced to produce four types of beats on carrier C.

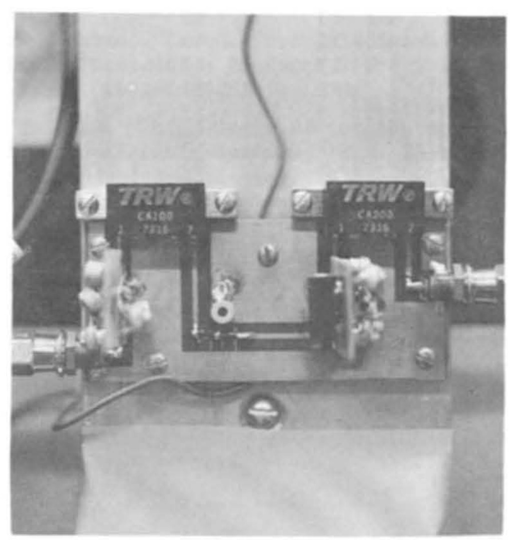
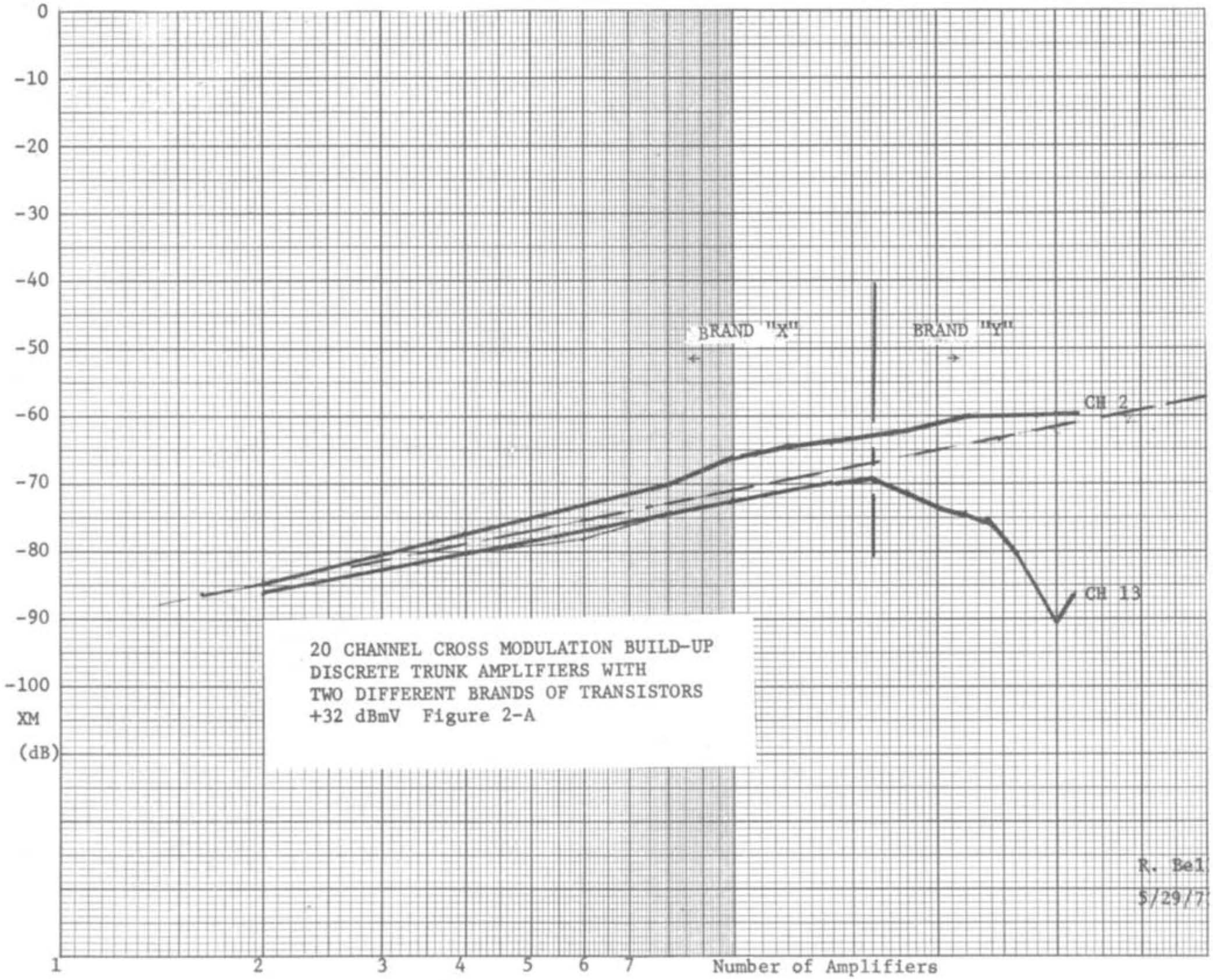
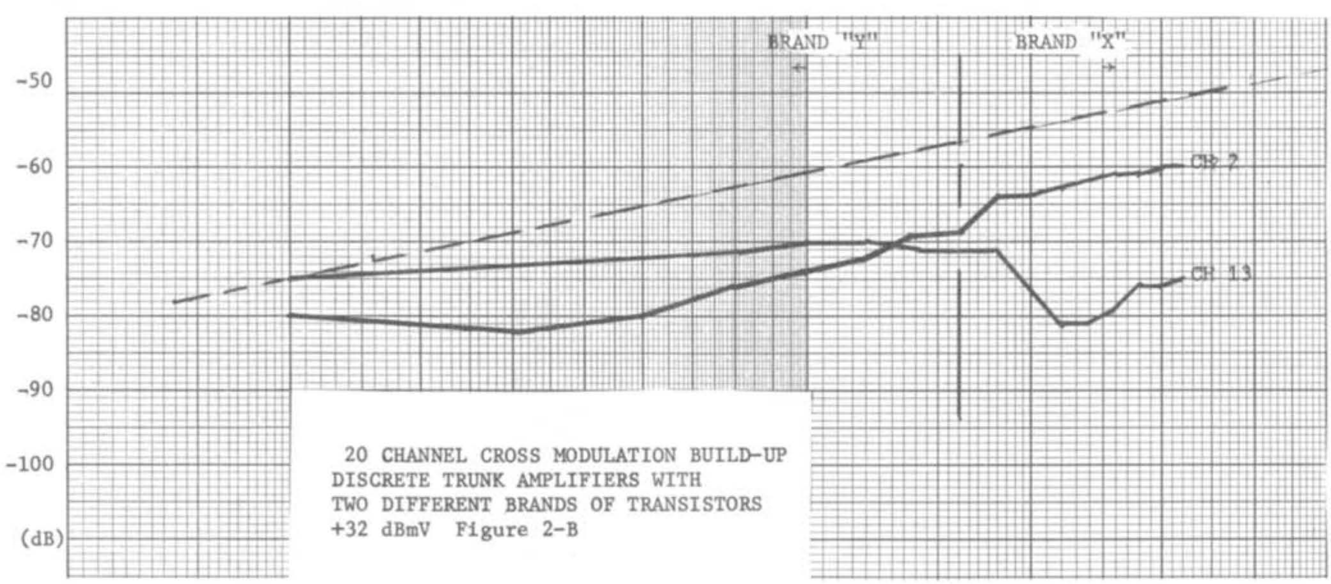


Figure 3. Mainline Amplifier with equalizer and gain-tilt controls.



20 CHANNEL CROSS MODULATION BUILD-UP
DISCRETE TRUNK AMPLIFIERS WITH
TWO DIFFERENT BRANDS OF TRANSISTORS
+32 dBmV Figure 2-A



20 CHANNEL CROSS MODULATION BUILD-UP
DISCRETE TRUNK AMPLIFIERS WITH
TWO DIFFERENT BRANDS OF TRANSISTORS
+32 dBmV Figure 2-B

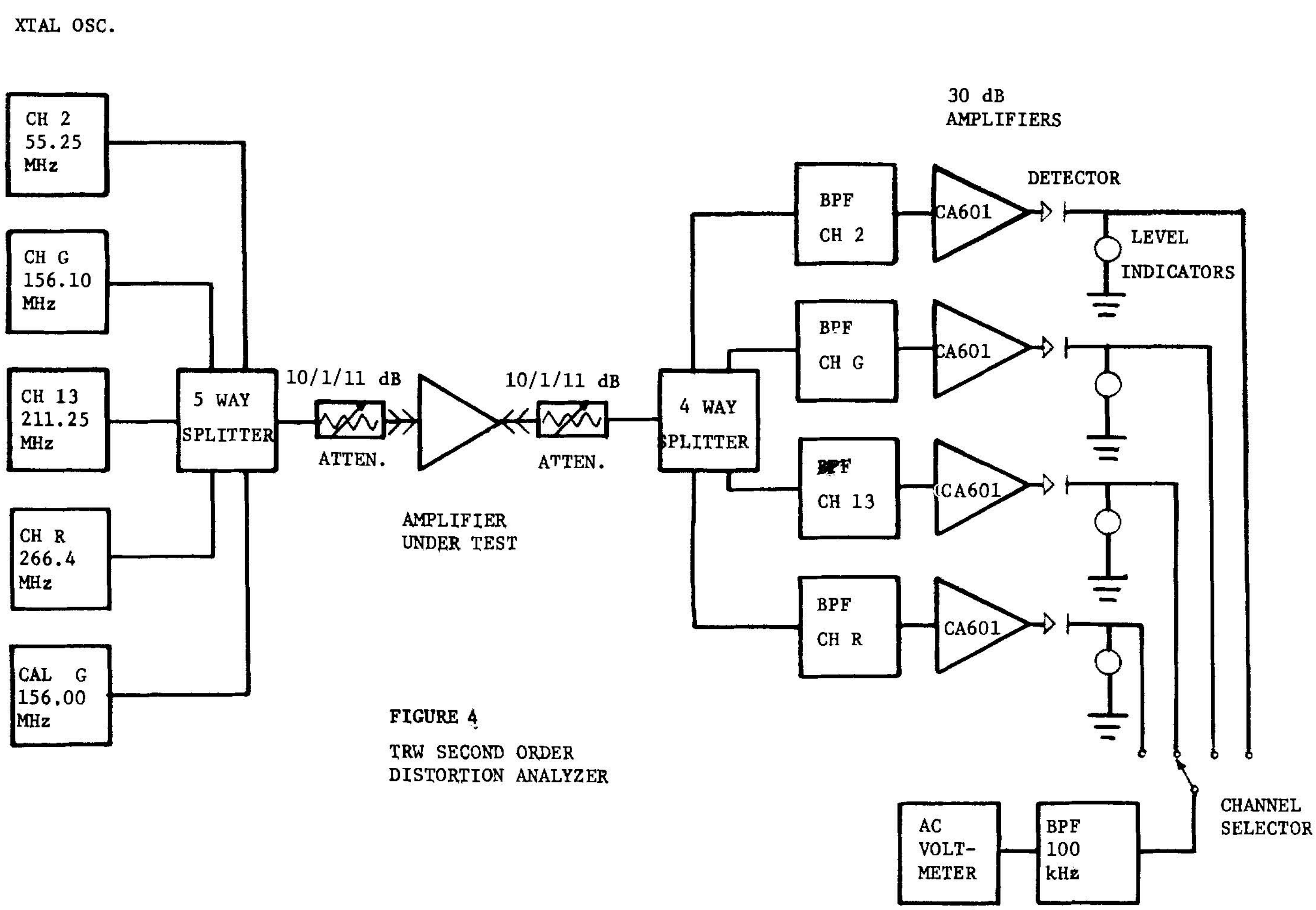


FIGURE 4

TRW SECOND ORDER
DISTORTION ANALYZER

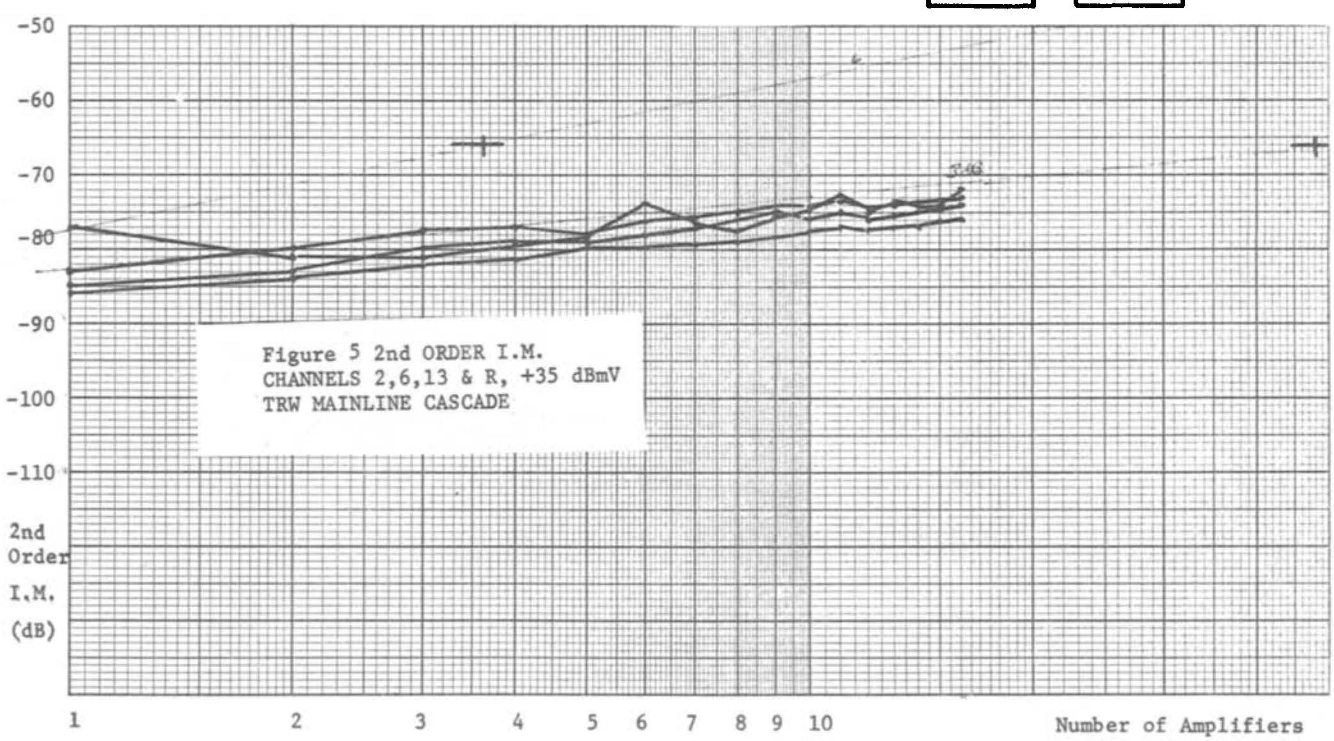


Figure 5 2nd ORDER I.M.
CHANNELS 2,6,13 & R, +35 dBmV
TRW MAINLINE CASCADE

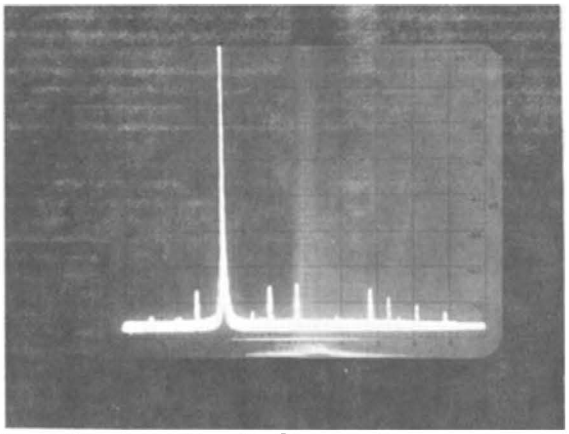


Figure 6. Amplifier No.8

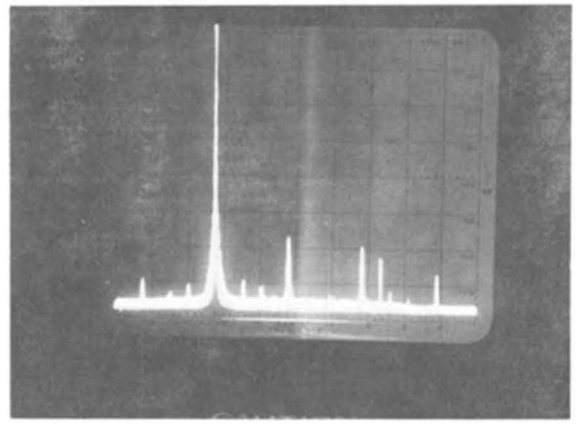


Figure 7. Amplifier No.16

Channel 13 Spectrum, 32 Active Carriers @ +45dBmV
10dB/div. vert., 1MHz/div. Horizontal.

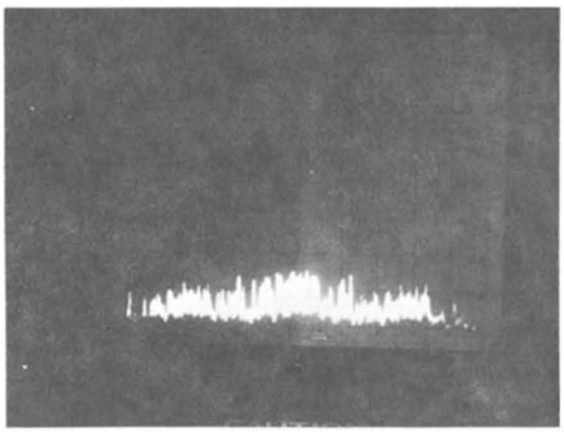


Figure 13. CH2

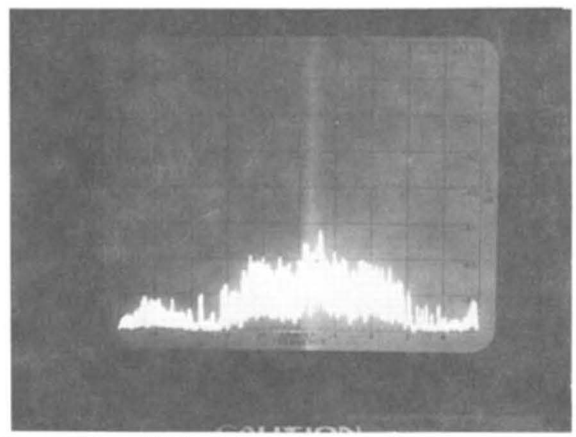


Figure 14. CH13

Beat build-up from 32 carriers @ +45dBmV, Amplifier No.16
10dB/div. vert., 5kHz/div. Horizontal.

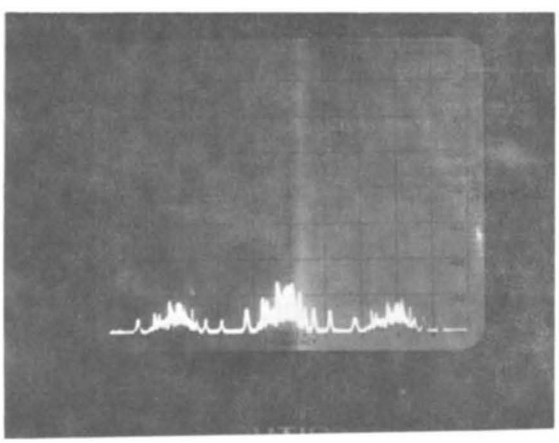


Figure 15. CH2

20 carriers @ +45dBmV

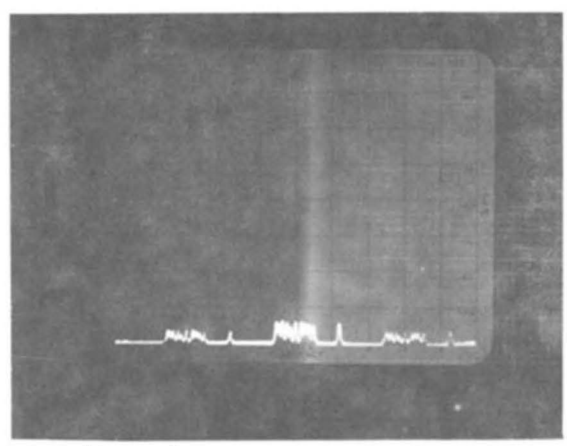


Figure 16. CH2

12 carriers @ +45dBmV

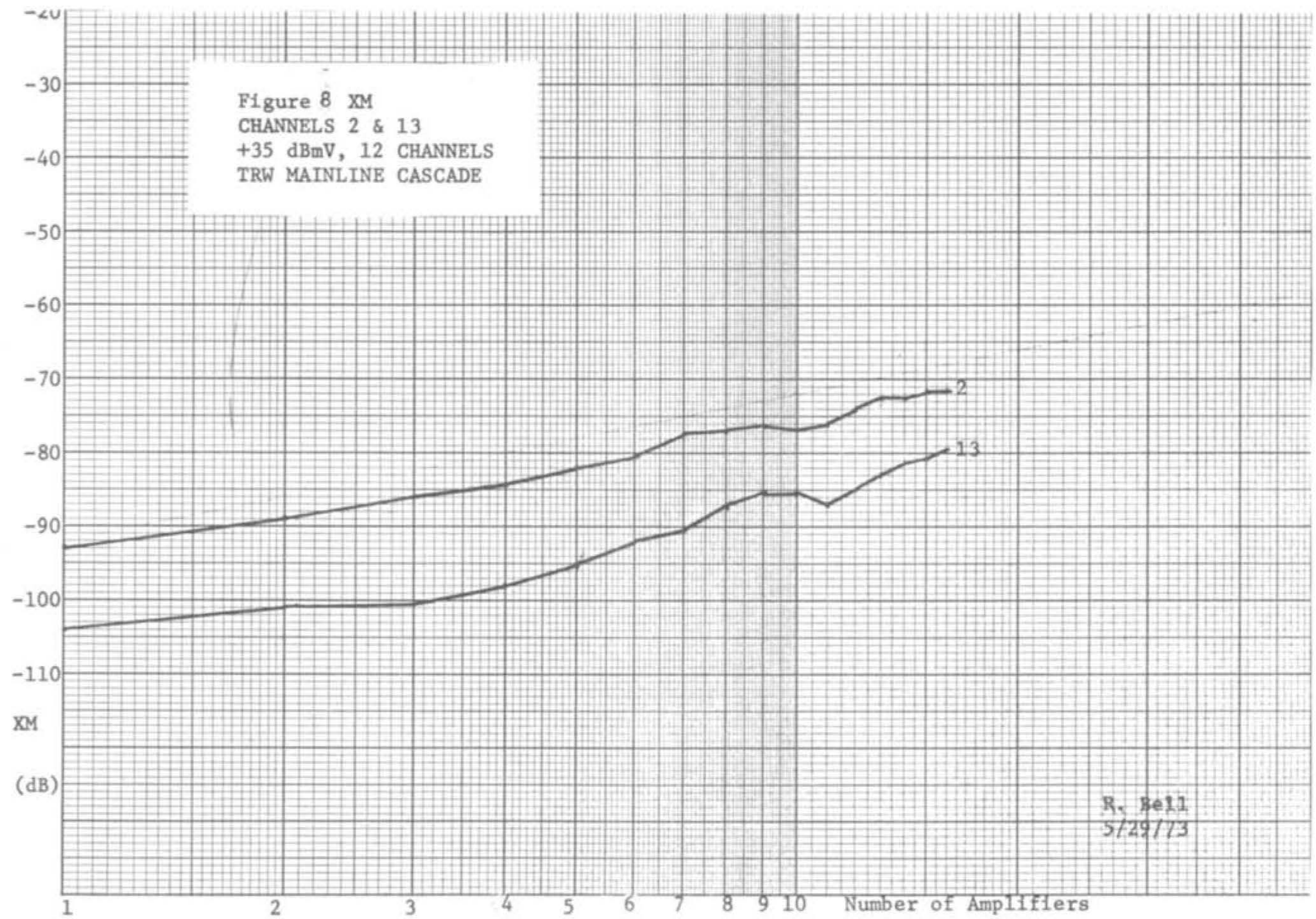


Figure 8 XM
CHANNELS 2 & 13
+35 dBmV, 12 CHANNELS
TRW MAINLINE CASCADE
-30
-40
-50
-60
-70
-80
-90
-100
-110
XM
(dB)
2
13
R. Bell
5/29/73
1
2
3
4
5
6
7
8
9
10
Number of Amplifiers

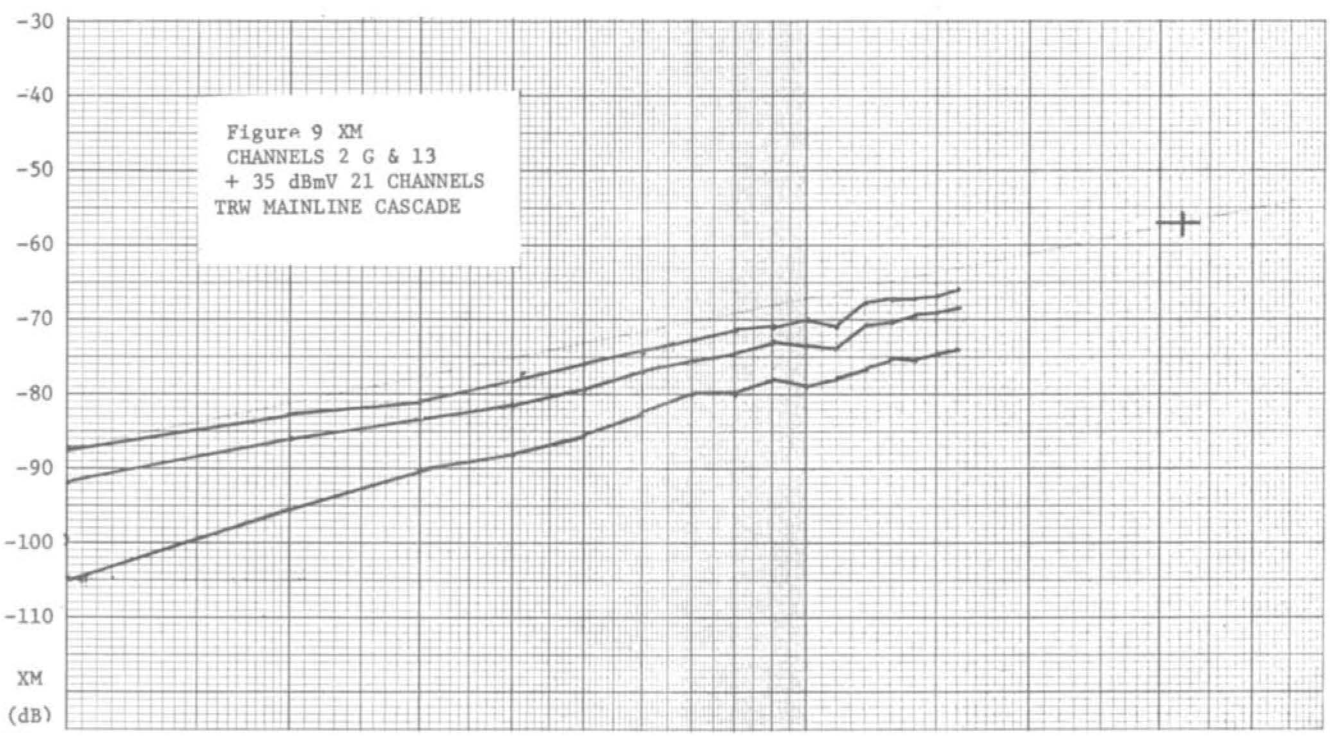


Figure 9 XM
CHANNELS 2 G & 13
+ 35 dBmV 21 CHANNELS
TRW MAINLINE CASCADE
-30
-40
-50
-60
-70
-80
-90
-100
-110
XM
(dB)

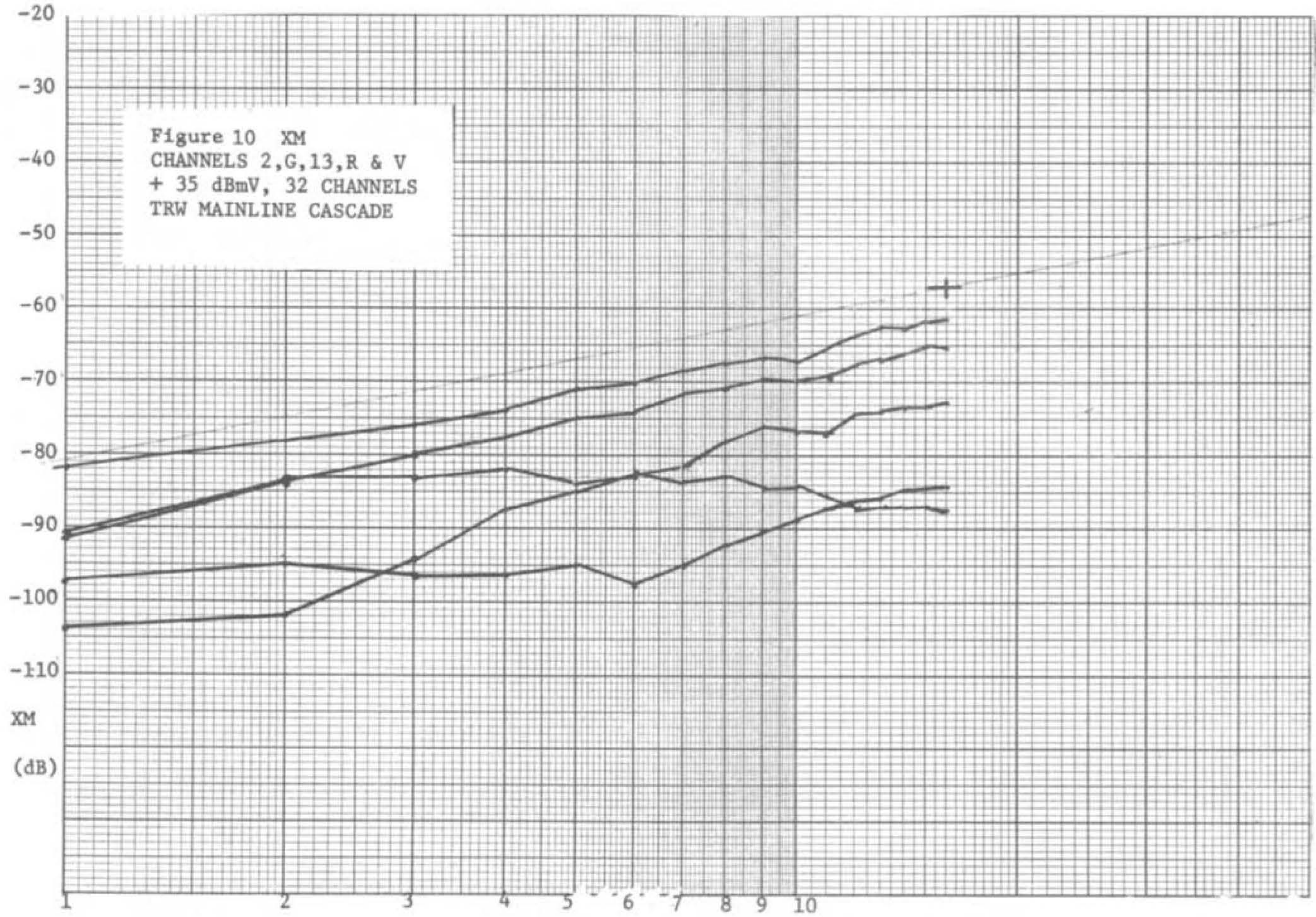


Figure 10 XM
CHANNELS 2,G,13,R & V
+ 35 dBmV, 32 CHANNELS
TRW MAINLINE CASCADE
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
XM
(dB)
1
2
3
4
5
6
7
8
9
10

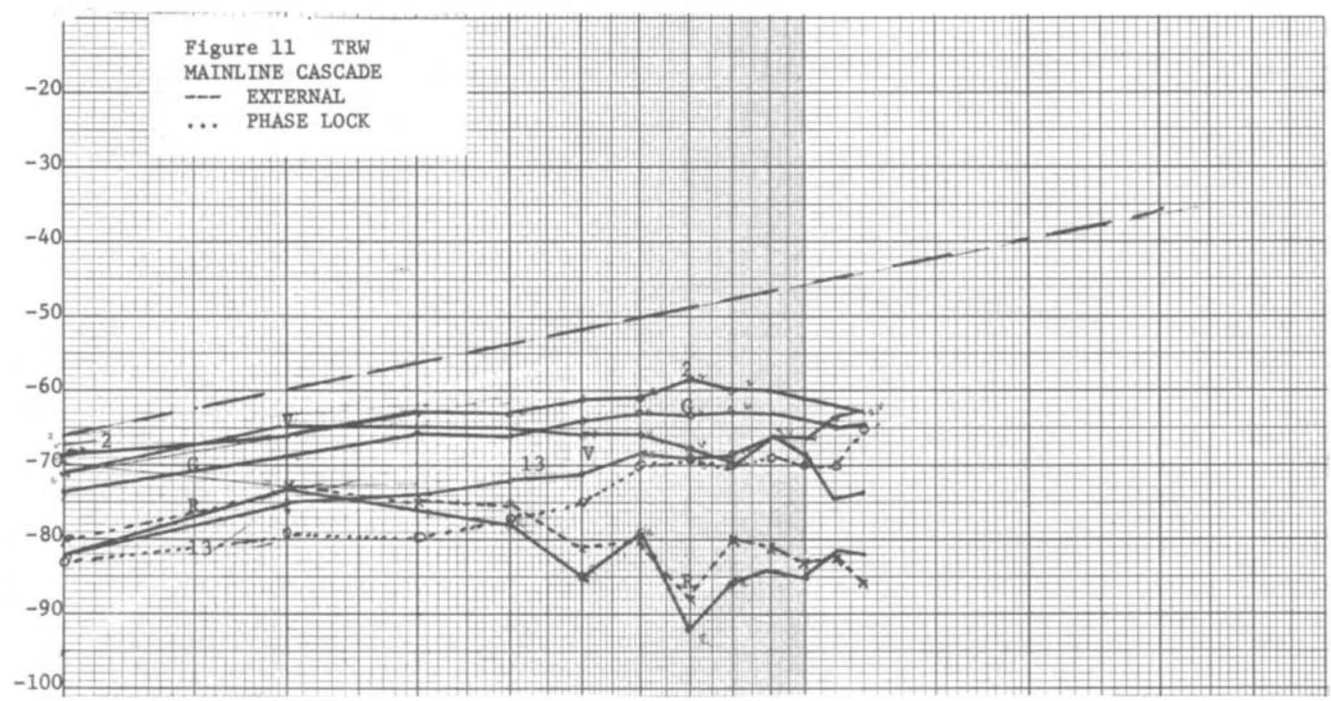


Figure 11 TRW
MAINLINE CASCADE
--- EXTERNAL
... PHASE LOCK
-20
-30
-40
-50
-60
-70
-80
-90
-100
2
G
13
V
R

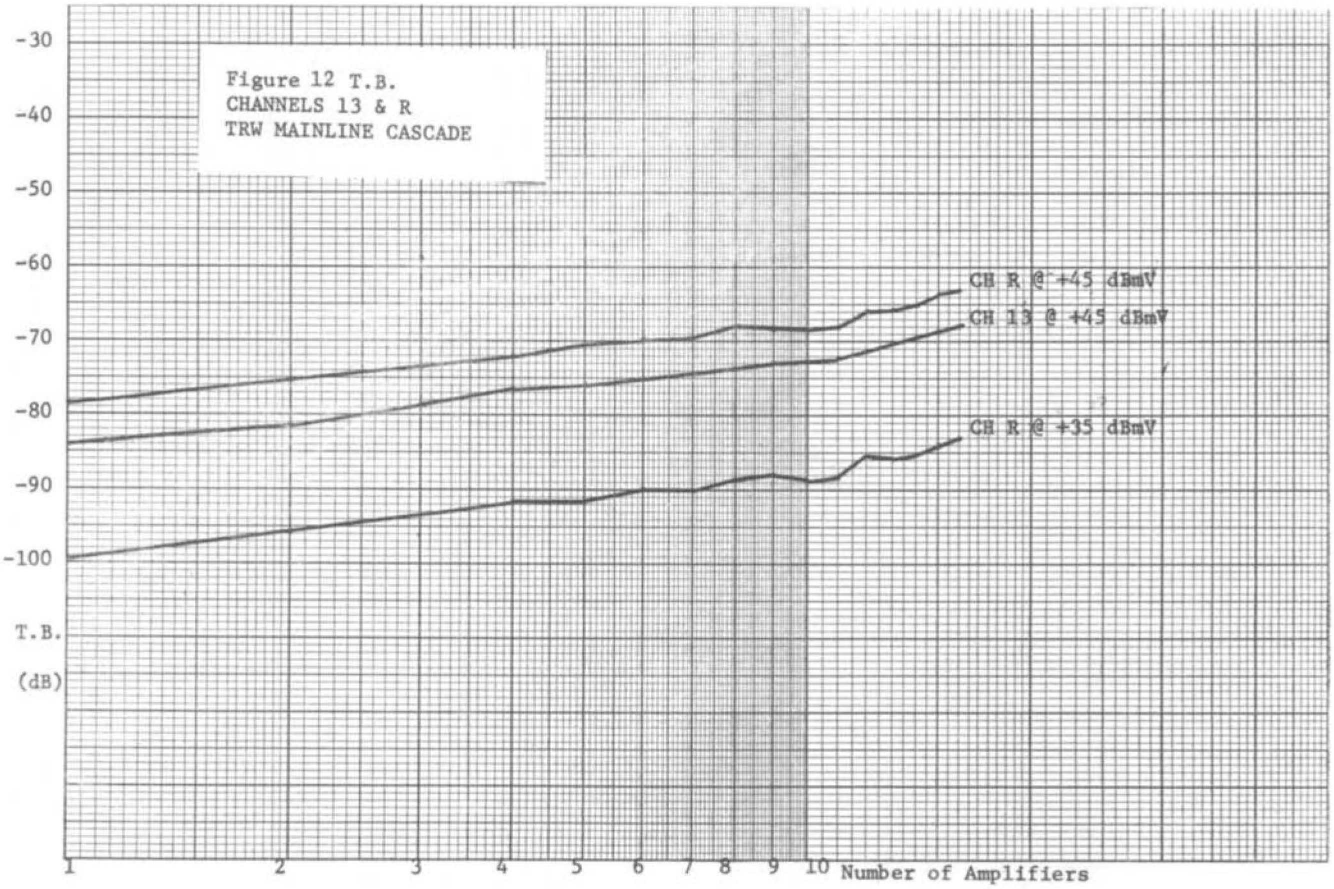


Figure 12 T.B.
CHANNELS 13 & R
TRW MAINLINE CASCADE
CH R @ +45 dBmV
CH 13 @ +45 dBmV
CH R @ +35 dBmV
-30
-40
-50
-60
-70
-80
-90
-100
T.B.
(dB)
1
2
3
4
5
6
7
8
9
10
Number of Amplifiers

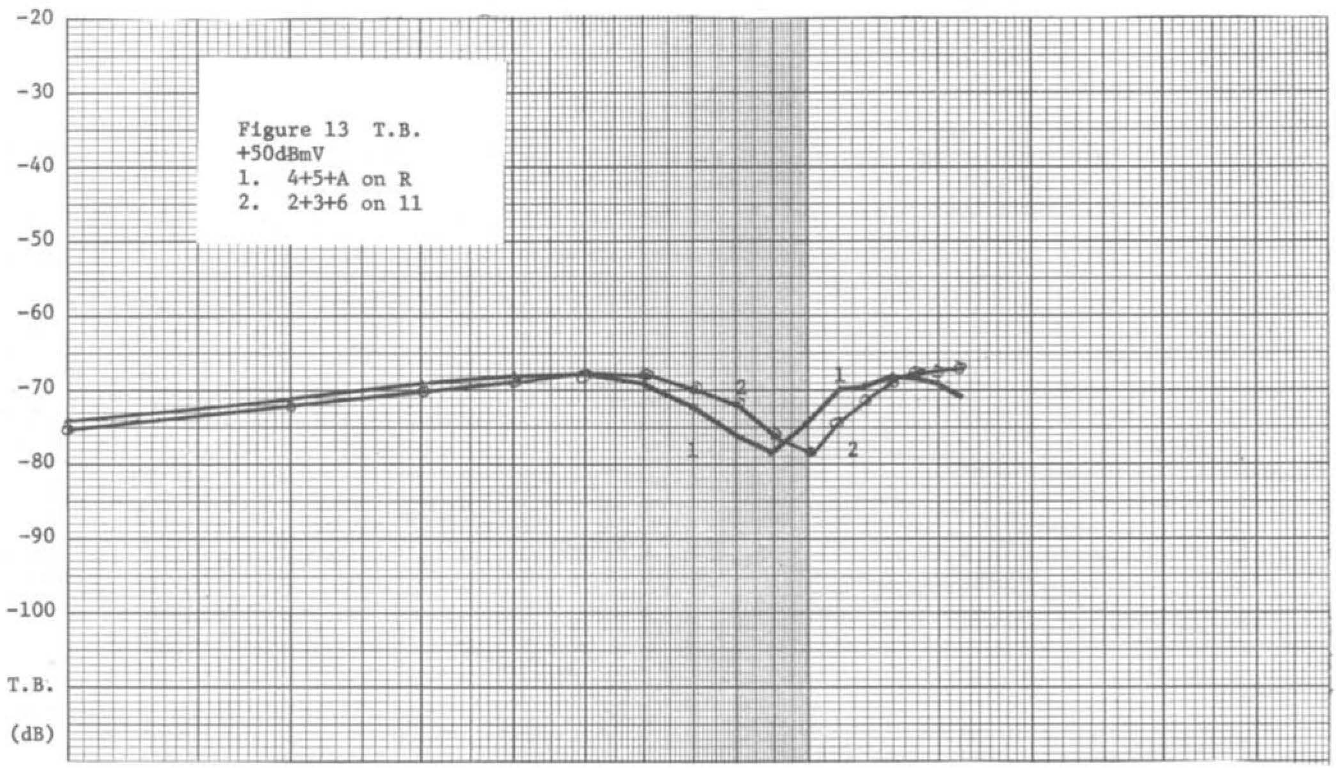


Figure 13 T.B.
+50dBmV
1. 4+5+A on R
2. 2+3+6 on 11
1
2
-20
-30
-40
-50
-60
-70
-80
-90
-100
T.B.
(dB)

TOWARDS A MORE ECONOMIC MICROWAVE SYSTEM FOR CATV

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ABSTRACT

Microwave system specifications have evolved from either handbook criteria or rigorous requirements for common carrier systems. While SSB and FM systems have been designed to satisfy some of the unique needs of CATV systems, in many instances there are not suitable design criteria or off-the-shelf equipment available.

Standards tailored for the industry can lead to the development of systems optimized for CATV.

One item which should be looked at is consideration of fade margins for CATV. What is a realistic acceptable outage? What are the resulting appropriate fade margins for specific path lenghts? This paper focuses areas where industry action can result in more economic systems.

INTRODUCTION

Design of microwave systems for CATV use are heavily influenced by the requirements of other services because of the absence of specific criteria pertinent to the specific needs of CATV.

In this paper attention is given to those areas where system design requirements, generally applied to communications, can be relaxed without danger of compromise of the needs of CATV service while achieving considerable savings.

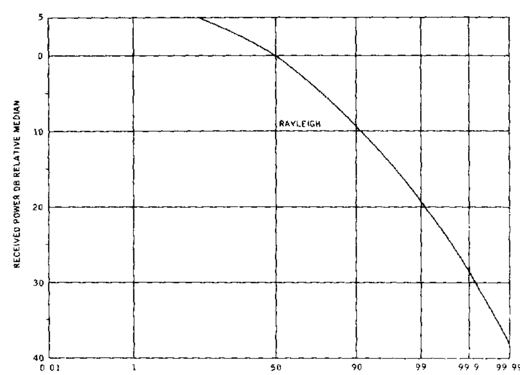
The objective is not to recommend specifications but only to identify those areas where savings are possible through reduction of over-design.

Consideration is given to path loss criteria, clearance requirements, tower design and equipment configuration.

Projected savings such as these cited can be realized through an industry created mechanism to formalize the requirements for CATV in appropriate standards and specifications.

PATH LOSS AND FADE MARGIN

In specifying microwave systems, great emphasis has been placed on path loss and fade margin to provide a given level of reliability. The most commonly used criterion is a Rayleigh distribution. This distribution which is illustrated in Figure 1 states that a 40 db margin provides 99.99% reliability, etc. In actuality, the cases where a Rayleigh distribution can be applied validly are limited and have no physical basis.



Distribution of Signal Level Received Over 8-10 Mile Path

Figure 1

Rayleigh developed his distribution as a description of the resultant amplitude produced by an infinite number of vectors of equal amplitude and random phase. There are few cases where such conditions are satisfied in actual application. In fact, there are many cases where long-term data indicates the Rayleigh distribution is not borne out.

As shown in Figure 2, a 99.99% reliability can be achieved with a 20 db margin. This indicates that a 40 db margin is an over-design of 10000% which certainly is not consistent with other reliability required.

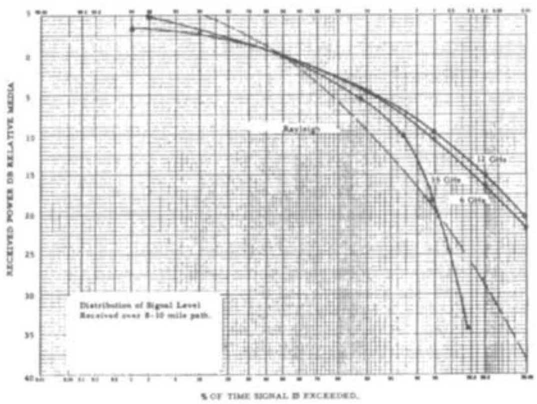


Figure 2

At this point one might also raise the issue of the sanctity of the 99.99% reliability issue. For example, is the increase in reliability from 99.95% to 99.99% important enough to the users to justify a 7 db or 6 times increase in system gain? This is especially important when one considers that most CATV systems are not operated 24 hours a day and further, the greatest probability of occurrence of outages is at hours outside the normal operating hours.

The effects of precipitation is another factor which probably has been overemphasized, especially in view of the paucity of rainfall rate and spatial correlation data. Almost all reference to rainfall attenuation goes back to the work of Hathaway and Evans[1] who demonstrated that operational systems confirmed the theoretical and empirical works of Ryde & Ryde[2] and Bussey[3].

Attenuation is stated in terms of db/km/mm per hour of attenuation based on statistics whose data base is not of sufficient size to justify universal application. A change of attenuation rate of 00.02db/km/mm will result in a 9 db increase in required margin over a 10 mile path. The derivation of the attenuation rates are not accurate to $\pm$.02 db/km/mm, and should not be used as the basis of adding increase system gain.

It also should be noted that the atmospheric conditions which produce fading are not likely to occur simultaneously with precipitation.

PATH CLEARANCE

A second area of potential savings is path clearance. It is currently in vogue to use path clearance requirements assuring SUB-refraction conditions.

The modified earth radius concept was introduced as a tool to account for refractive effects. This has been expanded to attempt to account for cases of SUB-refraction. The unfortunate use of the term "earth buldge fading" has been used indiscriminately to describe all types fading supposedly attributable to SUB-refractive conditions. Little simultaneous data of radio and atmospheric conditions are available.

Use of the true earth radius and .6 fresnel zone clearance will provide 99.98% reliability for 20 mile paths except in unusual cases. Such cases should be individually analyzed; but a severe clearance requirement should not be necessarily applied unless a clear relationship of improved reliability and increased clearance can be supported.

References:

1. Hathaway, S.D. and H. W. Evans, "Radio Attenuation at 11 kmc and Some Implications Affecting Radio Relay Engineering", BSTJ, Vol. 38, No. 1, Jan. 1959, pp. 73 - 97.

2. Ryde, J.W. and Ryde, D., "Attenuation of Centimetre and Millimetre Waves by Rain, Hail, Fog and Clouds", Gen. Elec. Corp., Res. Labl, London, Rep. No. 8670 (1945).

Reference:

3. Bussey, H.E., "Microwave Attenuation Estimated from Rainfall and Water Vapor Statistics", Proc. IRE, Vol. 38, pp. 781 - 785, 1950.

An example of the effects of clearance requirements on antenna heights are shown in Table 1.

TABLE I. ANTENNA HEIGHT REQUIREMENTS FOR VARIOUS DISTANCES AND EARTH CURVATURES

PATH LENGTH MI	ANTENNA HEIGHT REQUIRED (FT)		
	K = 4/3	K = 1	K = 2/3
10	31	35	47
15	50	61	80
20	78	97	128
40	238	298	438

(.6 FRESNEL ZONE CLEARANCE ASSUMED)

Table 1

TOWER DESIGN

At the present time, we have only EIA RS222 as a guide for tower design. This specification essentially requires sufficient freedom from deflection to maintain antenna position so that degradation due to wind does not exceed 10 db. In view of the fact that during high winds there is little likelihood of fading, this requirement greatly exceeds the margin necessary to maintain communications.

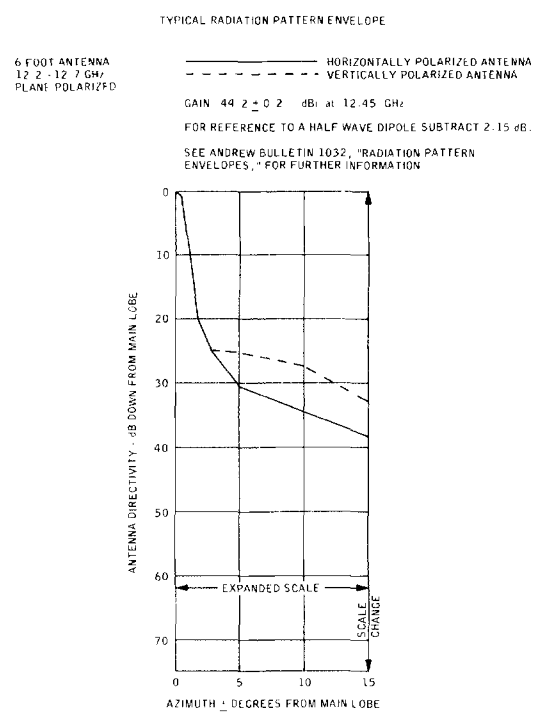


Figure 4

A degradation of as much as 30 db could still exceed the system threshold by 10 db. As shown in Figure 4, angular deviations up to 5^{o} could be tolerated if 30 db degradation were acceptable. There, of course, could be conditions where rain attenuation and high wind occur simultaneously. Data which established the probability of such simultaneous occurance is not available.

The exact saving resulting from relaxation of deflection specifications is not readily identifiable. In one case, a reduction of 20% of the cost of a tower could be achieved with a relaxation of 20 db. There are probably many instances where towers designed for broadcast antennas could be shared for microwave systems without costly tower reinforcement.

EQUIPMENT CONFIGURATION

In addition to establishing equipment power requirements consistent with the needs of CATV, configuration of equipment in an optimum manner for all CATV services has not been achieved. Some manufacturers have developed systems which satisfy some of the needs of the operator but not all.

For example, how many video channels are typically required to be transmitted via microwave? A few studies have been carried out indicating that four channels could be a requirement in many cases. If this is confirmed and indicated as a need, it is quite likely that manufacturers will bring such a configuration to the market with some cost savings.

SUMMARY

In the foregoing, the areas where possible savings can be realized with modifications in the design of systems have been discussed qualitatively and quantitatively. These include path loss, path clearance, tower design and equipment configuration. The attendant reduction in system performance associated with relaxation of standards which have been developed for other services will not significantly affect services to subscribers. Operators of CATV services should have the opportunity of making these decisions through microwave system standards developed for its needs rather than being forced to design systems to the standards of other services.

This approach is not to suggest that we abdicate engineering principles, but rather that we develop standards consistent with the needs of the users and not saddle one service with the requirements of another because that is the only available standard.

UTILITY GROUNDING PRACTICES

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General Electric Cablevision Corporation

San Antonio, Texas

The basic reasons for being concerned about the resistance of grounds are presented from a practical viewpoint. It is explained how safety is affected by the resistance of the ground connection. Statements are made as to what is a "good ground".

Grounding practices are discussed as how they relate to initial ground resistance, long term stability of grounds, ease of installation, etc. Also, it is shown that several factors affecting ground electrode resistance vary from one location to the next.

It is then concluded that the only sure way of obtaining a low resistance ground is through field measurement during installation. One instrument for doing this is described.

It is also shown that this low resistance ground can lead to serious corrosion problems in other parts of the cable system. Several possible solutions to this corrosion problem are presented.

Utility grounding practices are of concern to a cable television company for several reasons. The first reason that comes to mind is that since cable TV usually rents pole space on utility poles, the cable TV company is most often permitted, or required, to bond its messenger and grounding system to the utility's existing pole grounds. It is only reasonable to assume that it would be good if the cable TV operator were aware of the utility's grounding system and how effective it is. A second reason for looking into grounding practices is that OSHA now makes the National Electrical Safety Code law and the safety code does cover grounding practices. The third and most important reason is safety to the cable TV company's linemen and installers, the general public and electronics equipment. This safety can be best assured by bonding all pole-mounted non-current carrying metal parts to a low resistance earth ground.

That brings up the immediate question: What is a low resistance ground? As I previously stated, the National Electrical Safety Code does set forth in Section 9 rules and methods of grounding power and communications lines. Paragraph 96A states that "made electrodes" shall have a ground resistance not to exceed 25 ohms. That is one definition of a low resistance ground. Quite often, power companies choose to require lower resistance grounds where certain types of equipment are located. One power company requires a maximum ground resistance of 5 ohms on any pole that supports a transformer, capacitor bank, voltage regulator ... essentially any pole on which there is equipment that is subject to high voltage surges (primarily from lightning strokes).

There is a very good reason why many power companies require such a low ground resistance. A statement is often heard that electricity takes the path of least resistance to ground. This is true enough; however, that is not the only path to ground that electricity takes. Electricity takes all paths to ground whether they are high or low resistance. Pole lines are continually subject to fault current flow to ground; the fault current is usually a result of power company equipment failure, temporary phase-to-ground faults from animals, or lightning surges. This fault current is usually in the order of magnitude of thousands of amperes. While the largest part of the fault current flows through the grounding system (path of least resistance); any other path to ground, such as strand-mounted equipment or linemen working on such equipment, will be subject to some fault current flow. This is the importance of low resistance grounds; the lower the ground resistance, the less the fault current will divide to take the other paths to ground.

Power companies have still another benefit from low resistance ground connections. Lower ground resistances result in higher fault currents which in turn enable fuses and circuit breakers to operate faster. Fast operation of protective devices greatly reduce voltage strain on equipment and exposure time to personnel.

Having discussed some reasons for needing a low resistance ground, I would like to describe the grounding practices of several utilities with which I have been associated. I would like to show how ground resistance is affected not only by the particular grounding technique but also by several variables that can be dealt with but not controlled.

Utility pole grounds are usually either driven ground rod or pole butt ground. The power company in Tampa, Florida is Tampa Electric Company. Tampa Electric's primary distribution system is a 13KV grounded wye. This distribution system uses a common neutral; one neutral for both primary and secondary circuits. The common neutral (as used by Tampa Electric) is also multi-grounded. This means that there are at least 4 ground connections per mile. At grounding points, the neutral is bonded to a #6 soft drawn copper ground wire. The copper ground wire is run vertically down the pole and connected to a driven ground rod. The ground rod that Tampa Electric uses is a slightly oversize 1/2" rod of the Copperweld type. The Copperweld ground rod is a rod with a steel core and a molten welded copper exterior. The steel core gives the ground rod good driveability. Tampa Electric went to the oversized 1/2" rod after having driving problems (bending) with the standard 1/2" rod. It was not necessary, in Tampa, to go to the stiffer and more expensive 5/8" Copperweld rod. Ground rod diameters are usually chosen in this manner; the stiffness rod needed to drive in any given area is found by trial and error in the field. Note that the safety code, paragraph 95D, sets the minimum size of Copperweld (non-ferrous) ground rods to be 1/2" in diameter while ground rods of iron or steel (only) must be at least 5/8" in diameter.

Tampa Electric's standard ground rod is 8 feet long; which is also in accordance with safety code requirements. The safety code states, in paragraph 95D, that driven ground rods" ... shall preferably be of one piece, and, except where rock bottom is encountered, shall be driven to a depth of 8 feet..." In addition to driving ground rods in this standard length of 8 feet, Tampa Electric's ground rod is threaded on both ends. Many times the 8 foot rod does not provide the specified ground resistance, such as 5 ohms at equipment installations. When this happens the groundman threads on another 8 foot section and resumes driving. (See Fig. 1) Tampa Electric, in trying to drive a low resistance ground, finds it easier (in Tampa) to drive deep grounds rather than to use multiple grounds.

This is essentially the grounding system used by Tampa Electric Company. Copper is used as the grounding electrode due to its good conductivity and superior corrosion resistance. Ground rods are also made with stainless steel replacing the copper in the Copperweld style rod and also of galvanized iron. I have no experience with either type rod and I would appreciate hearing from any of you that have.

The other common type of pole ground is the butt ground. (See Fig. 2) It can either be wire wrapped around the butt of the pole or a plate stapled to the bottom of the pole. In both cases the butt ground is installed prior to the pole being set. If the wrapped wire method is used, the safety code requires that at least 12 feet of wire be buried.

The municipal power company in San Antonio, City Public Service, use a 6" diameter copper plate as their butt ground. In contrast to the usual driven grounds of 4 per mile, CPS installs a butt ground on every distribution pole that is set. This is the only practical way of grounding in this area since almost 40% of CPS's service area is solid rock underneath the top soil.

Given these standard and fairly similar grounding techniques, I would like to briefly touch on some of the factors that can cause quite large variations in grounding resistance values just within a fairly small area.

The resistance of any ground connection is made up of 3 factors:

1. Resistance in electric connections
2. Resistance of the ground wire
3. Resistance of the surrounding earth

Careful installation of electrical connectors will insure that connection resistance is negligible. Copper ground wire and manufactured ground electrodes also do their part in not adding any appreciable resistance. That leaves the third item as the biggest culprit in ground rod resistance; resistance of the surrounding earth.

In order to be sure that a grounding system minimizes, as much as possible, the earth's resistance, it will be helpful to look at the factors that affect it. Basically, there are three:

1. Type of soil
2. Moisture content
3. Temperature

The type of soil is probably the biggest variable of the three. In general, sandy soils have a very high resistivity while soils of clay, shale and loam content have a much lower resistivity. While it is possible to lower soil resistivity by the addition of salts and other chemicals, this is not too widespread of a practice. One problem with soil treatment is that it is usually a temporary measure and its effects do not last. You essentially just have to live with the type of soil in which you are trying to ground.

For any given soil type, moisture content greatly affects earth resistivity. The reason for this is that the increased moisture better dissolves any natural salts present and makes the earth a better conductor. The temperature of the earth also affects its resistivity. Higher soil temperatures decrease earth resistivity. Knowledge of these factors affecting earth resistivity helps in designing operating procedures which will insure that each ground is low resistance and will stay that way for a reasonable period of time.

I have stated that you usually just have to live with the type of soil in which you are trying to ground. This is only partially true. (See Fig. 3) At any given location, soil type varies with depth below the surface. This explains the success of the sectional ground rod. If the first 8 feet of ground rod doesn't put you into low resistivity soil, the second or third section usually does.

Next, let us see what grounding practice will be of most help in taking advantage of the other two factors affecting earth resistivity. Moisture and temperature are primarily seasonal in nature and seasonal variations are most reduced with increased depth below the surface. (See Fig. 4) This means trying to put your grounds below the frost level and permanent moisture level, if practical in your area. Again, sectional ground rods are a convenient tool for doing this.

So far my recommendations have been to drive reasonably deep grounds in order to get stable, low resistance grounds. As you know, this is not possible in many parts of the country where there are large amounts of rock. The approach here has to be through multiple grounds at each ground location or just many more individual grounds along the pole line. If 8 foot rods can be driven (but not anything longer), then multiple rods, all tied together at this one location, are effective in lowering ground rod resistance. However, the effectiveness of multiple ground rods is diminished if the rods are driven very close to each other. (See Fig. 5) The other alternative in these rock areas, is more frequent grounding; such as the practice in San Antonio with pole butt grounds on every pole.

I have been talking about how important it is to have a low resistance ground connection and how utilities achieve low resistance grounds. What I haven't said anything about is how you can know when your ground resistance is low enough. The only way to know is to measure it.

I'm not going to go into the theory of earth resistance testing; there are several good sources for this. (See Ref. 3) I would just like to describe one instrument that is designed for this purpose. The manufacturer of this instrument calls it a Megger, Null Balance, Earth Tester. Utility people just call it a megger. In its most common use, a method called the "Fall-of-Potential" or "Three Terminal" test is used. (See Fig. 6) Two reference electrodes are driven into the ground some distance away from the electrode or ground rod under test. One reference electrode is called the "potential" electrode and is positioned just over halfway between the ground rod and the other reference electrode (called the "current" electrode). The reference electrodes are so named because the megger actually uses them as current and potential references in arriving at the ground rod resistance. After setting up the test in this manner, all that has to be done is to turn a hand driven generator within the megger and turning resistance dials on the megger in order to null a meter. The ground rod resistance is then the resistance that was dialed in to null the meter. This instrument is easy to use and lets you know exactly how good a ground you have just installed. Take note that individual grounds should be meggered before being connected to the power or telephone company's system ground. Otherwise you would be measuring the ground resistance of the entire grounding system.

Having reviewed methods and reasons for getting low resistance grounds, I would now like to point out a serious corrosion problem that is present in San Antonio.

As I have indicated a multi-grounded neutral with copper being the grounding conductor is a very common power company practice. An equally common practice is to bond down guys (for safety reasons) to the multi-grounded neutral. A classic galvanic cell is then formed. (See Fig. 7) There are two dissimilar metals (copper ground electrode and galvanized iron anchor rod) electrically connected (bonded together on the pole) and emersed in an electrolyte (soil). In some areas of the country, an extremely potent battery is created. The first metal to start corroding is the zinc galvanizing on the anchor rod. The zinc enters the soil as corrosion current flows. As the zinc is eaten up, the iron from the anchor rod then starts sacrificing itself. While you may be maintaining an excellent grounding system, the system's anchoring could be disappearing.

In San Antonio, City Public Service's policy has long been to keep their copper grounding system isolated (not bonded) from their anchoring system. However, Southwestern Bell, in this same service area, went through a period of time, when on joint use poles with power, they bonded their down guys to their messenger which in turn was bonded to power neutral. Consequently, Southwestern Bell began experiencing severe corrosion of anchor rods. During one year alone, 1968, approximately seventy-five anchor rods were replaced due to corrosion failure. Corrosion measurements were taken on over one hundred down guys thus bonded. Corrosion currents between 2 and 85 milliamperes were found; indicating extensive corrosion forces at work. Southwestern Bell reversed themselves and went to the practice of isolating their down guys from the grounding system.

There are several ways of isolating the down guy in order to break up the corrosion circuit. One way, used by both City Public Service and Southwestern Bell is to install an insulator (called johnny-ball) in the guy lead. A second way is to guy off of a separate "through bolt" from the one used for the neutral; and not install a bonding jumper. Still a third way is by using an insulated anchor rod. This is currently under trial by Southwestern Bell in San Antonio.

Now I would like to tell you about another part of the country that has successfully used the same bonding and grounding practices that failed in San Antonio. In Tampa, Fla., Tampa Electric Company, with its multi-grounded neutral, and General Telephone Company both bond all down guys to the copper grounding system.

To this date, neither company has lost any anchor rods due to corrosion. An obvious question is: why not? The same conditions for creating a galvanic corrosion cell are present in grounding practices in the Florida utilities as in the Texas utilities. The only significant difference is the type of soil. I can only conclude that the soil characteristics are such that the soil in the Tampa area is generally of pretty high resistivity and limits the corrosion currents to very small values. Conversely, San Antonio must have some pretty low resistivity soil which allows for a fine grounding system but creates potential corrosion problems.

Getting back to grounding, I would like to end with this statement: It is only through field resistance measurements that you can be absolutely sure that you are installing a low resistance ground and it is only through periodic field measurements and inspections that you can be sure that you are maintaining a good, low resistance grounding system.

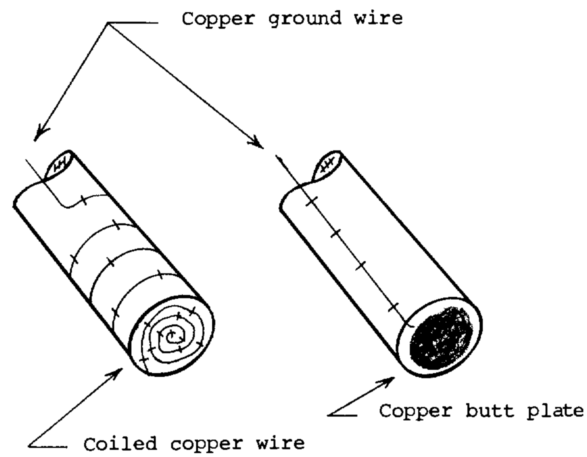

Figure 2. Pole Butt Grounds

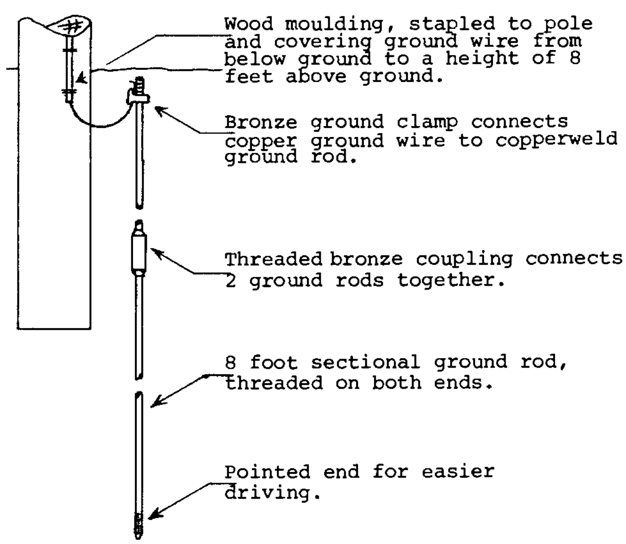

Figure 1. Typical installation of a sectional ground rod.

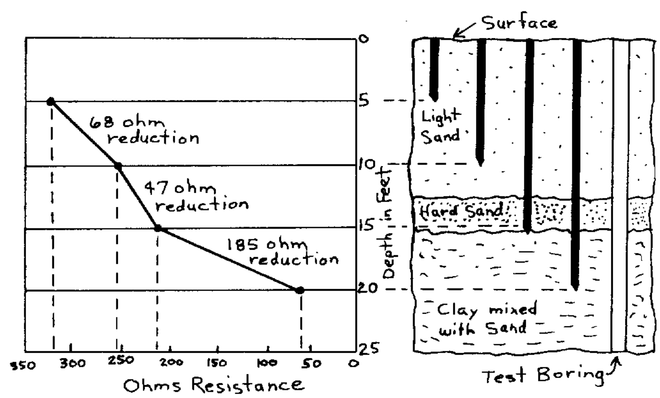

Figure 3. Relation between type of soil and resistance of driven ground rod at different depths. (Source: Ref. 4)

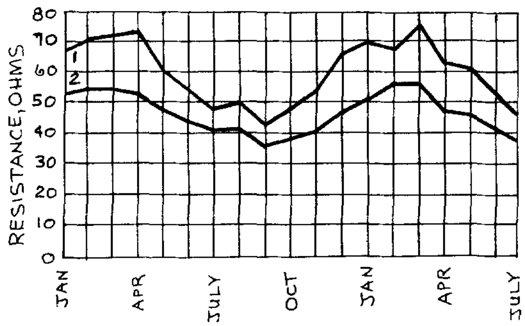

Figure 4. Seasonal variation of earth resistance. Depth of ground rod is 3 ft. for curve 1, and 10 ft. for curve 2. (Source: Ref. 3)

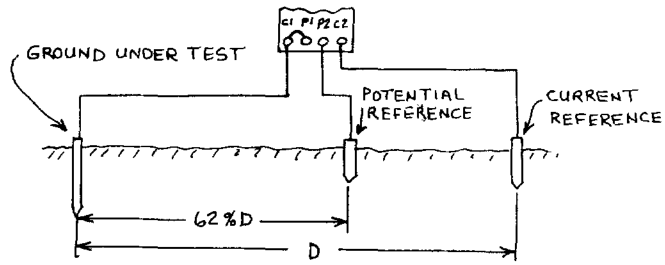

Figure 6. "Fall-of-Potential" or "Three-Terminal" earth resistance test. (Source: Ref. 3)

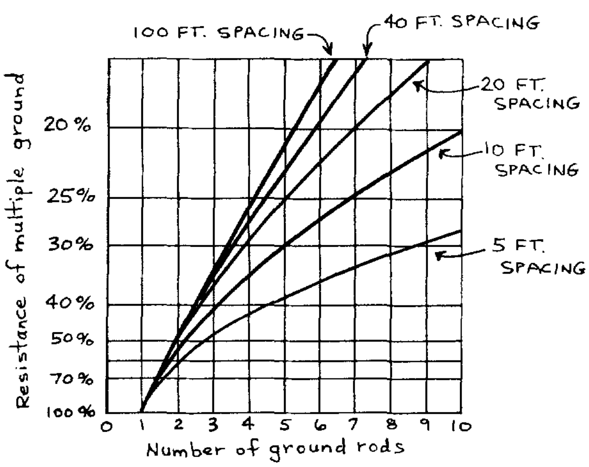

Figure 5. Effectiveness of multiple ground rod. Single rod equals 100 percent (Source: Ref. 4)

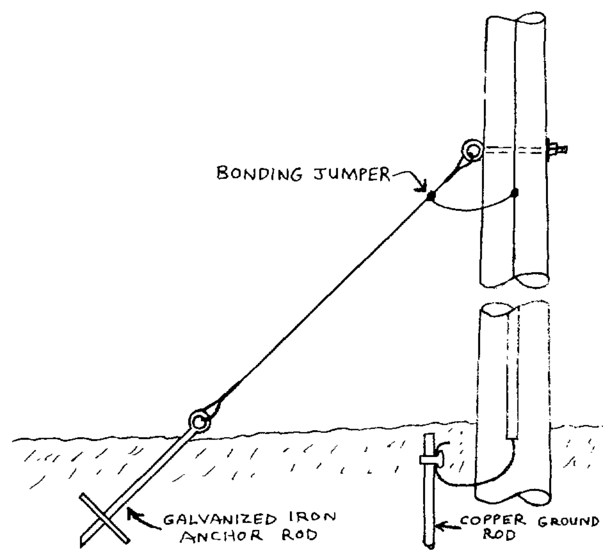

Figure 7. Grounding practice that can lead to corrosion problems.

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WIDE-SCREEN SCANNING SYSTEM FOR FILM-TO-TAPE TRANSFER

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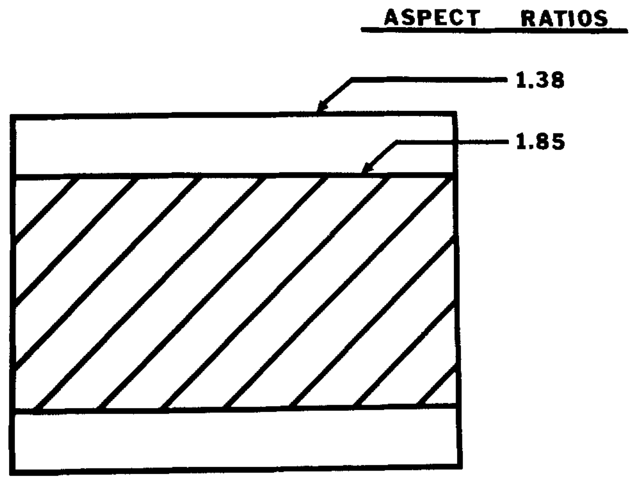
ABSTRACT

A high percentage of feature motion picture films intended for theatrical release are produced in a format intended for a wide-screen presentation. For television transmission, a special print normally is provided wherein the film frame is masked to the narrower format. The masking is moved horizontally to follow picture information essential to the story.

The system described herein accomplishes the scanning operation during real-time transfer of film to tape. An optical system, controlled automatically from recorded cues, moves the wide-screen image to specific horizontal positions relative to the camera aperture at the appropriate film frame.

By the elimination of the film processing laboratory scanning operation and production of special prints, substantial cost savings are achieved in the transfer of a feature film program to the television format.

The two most commonly used projection aspect ratios of wide-screen motion-picture films produced for theatrical release and presentation are 1.85 and 2.35. In the 1.85 format the increased width, relative to height, is achieved by the simple expedient of reducing the frame height and increasing the magnification of the projection lens. The relationship between the 1.38 and 1.85 film frames is shown in Fig. 1.

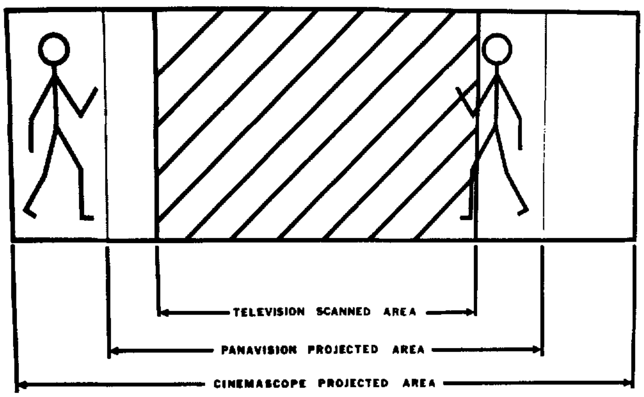


FILM FORMATS

Fig. 1. The full image area of the film frame is used in projection of a 1.38 aspect-ratio format and in anamorphic projection of a wide-screen 2.35 aspect-ratio format. Non-anamorphic wide-screen projection in a 1.85 aspect-ratio is achieved by a reduction in the height of the image area.

In the wider 2.35 aspect-ratio used for Cinemascope, slightly more than the conventional film frame height is used and the increase in scene width relative to height is obtained by squeezing the image horizontally with an anamorphic lens which has a two-to-one greater magnification vertically than horizontally. In projection, the image is expanded horizontally by means of a lens which is the inverse of the camera lens.

Since the aspect-ratio of television transmission called for in the FCC Rules and Regulations is 1.33, if the full scanning frame is to be utilized for picture information, a significant portion of the film frame will be lost. The degree of cropping is shown in Fig. 2. In the extreme case, for example, participants in a dialogue on the left and right sides of the frame may be lost completely by the confines of the television aperture.



WIDE–SCREEN PROJECTION

Fig. 2. Scanning the full height of the projected wide-screen image area by the normal television roster results in a substantial loss in picture content.

Thus, in order to reduce either of these wide-screen formats to the narrower television frame-size, without loss of picture information essential to the story, it is necessary to scan the film horizontally with the television aperture. This normally is done by the film processing laboratory in the production of a special print for television transmission. Selection of the horizontal position of the television aperture is determined by a film editor, and this information is entered onto a punched tape which, in turn, is used to control the operation of a step-printer to produce an internegative. In the first system of this type developed by Twentieth Century Fox, the printer operated at a slow speed and was stopped at each cue for repositioning. This obviously results in an expensive, time-consuming operation. Nevertheless, it has served the purpose for many years in providing a means for converting theatrical film to the television format.

An improvement on the early Fox process was introduced in 1969 by Technicolor wherein the television print is produced directly from the original wide-screen negative without the need to stop for repositioning. This is accomplished by moving the printer head during pull-down of the film frame. Although the Technicolor system eliminates the need for an internegative and operates continuously, the process is costly in that the film printing and processing operations are not avoided, and time-consuming since the speed of the printer is limited to less than half the real-time speed of 90 feet per minute. Furthermore, the end product in both film systems is a film which, for television use, must either be transmitted by means of an expensive telecine projector and camera system, or transferred to video tape.

In the GCC system, on the other hand, the scanning positioning operation is accomplished during the real-time transfer of the motion-picture film to magnetic tape. The information prepared by a film editor which specifies the horizontal position, and number of feet and frames from the start-of-play, is entered on a keyboard and recorded in digital form on a magnetic tape cassette. A magnetic recording system is used, rather than punched tape such as is employed by film laboratories, in order to simplify correction of any errors in entry or revisions in the editors cueing decisions.

During the transfer operation a rotatable mirror in optical path between the projector and television camera, controlled in accordance with the digital cueing information recorded on the magnetic tape cassette, positions the wide-screen image appropriately relative to the narrower aperture of the television camera at the indicated film-frame count.

Consideration was given to positioning the television aperture relative to the projected film frame by varying horizontal centering in the camera. This approach is attractive, since it would eliminate the need for an anamorphic lens with film in the 2.35 aspect-ratio. However, it would result in a substantial loss in horizontal resolution because of the need to reduce horizontal scanning size by a factor of two-to-one. In the case of the 1.85 aspect-ratio, an additional loss in vertical resolution would be encountered. Furthermore, horizontal registration would be difficult to maintain because of variations in tracking of electrical centering among the three color channels. Therefore, electrical positioning was discarded in favor an an opto-mechanical system.

During the scanning operation, the mirror moves to any one of nine equally-spaced positions for Cinemascope prints (five for films in 1.85 aspect-ratio) during the intermittent pull-down of the film frame, at which time the projector light is blanked by a rotating shutter.

The relationship of the blanking of the projector light, the film pull-down, and the mirror movement are shown in Fig.3. The projector shutter provides pulses of light at a rate approximately equal to that of the television field scanning rate of 30 per second. Alternately, successive film frames are projected for six and four television fields; this sequence provides the conversion between the film frame rate of 24 per second and the 30 per second rate of television. Horizontal positioning, when called for by the cueing information, is initiated at the start of pull-down and completed before the end of the shutter blanking.

The shutter blanking duration is 10 ms, whereas the mirror movement is completed in 8 ms. Thus, since the television camera is exposed to only a stationary film-frame image, there is no blurring or smearing of the televised picture as a result of the mirror movement. In other words, the effect in the televised picture is equivalent to an instantaneous change in horizontal positioning of the film frame.

The timing of the projector is sensed by a light-sensitive transistor mounted next to a disc on the drive-shaft for the intermittant geneva movement. Metallic tabs on the disc pass the transistor at the start of pull-down and reflect light to generate a pulse which is used for both frame-count from the start-of-play and for timing the start of the mirror movement.

Fig. 4 is a view of the keyboard and a magnetic tape cassette. A two-position switch selects the mode of operation--write or read. The digital read-out above the keyboard indicates the footage, frame number, and horizontal position number of the cue being entered when in the write mode of operation. During transfer, when the rotatable mirror is controlled by the recorded cues, the read-out indicates the next cue. Another read-out, not shown in the illustration, shows the footage and frame count of the film running in the projector as indicated by the light transistor sensor in the projector.

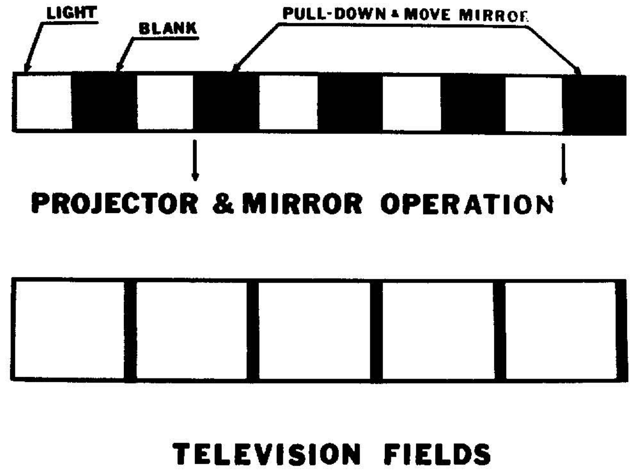


Fig. 3. The projector shutter produces pulses of light at the television field-rate of 1/60-second. Film pull-down is accomplished at an average rate of 1/24-second during shutter blanking. Horizontal repositioning occurs during film pull-down.

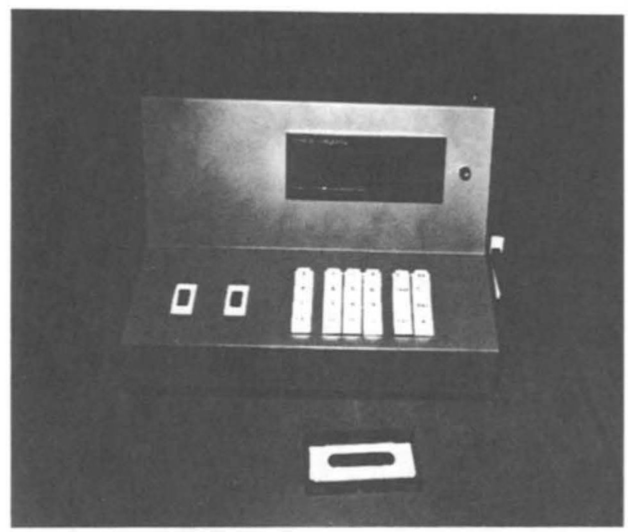


Fig. 4. Scanning cue storage and control system, consisting of magnetic cassette record/playback keyboard for cue entry, frame-count read-out, and next-cue read-out. A cassette is in the foreground.

At the left in Fig. 5 is shown a 35mm projector fitted with an anamorphic lens designed especially for this application by Panavision, Inc. The procurement of a lens for this application posed a unique problem since currently available anamorphic lenses are designed for the long throw and large screen of theater projection, rather than the short throw and small image required for a television camera. The resolution and contrast are equivalent to the non-anamorphic lenses used for films of 1.85 and 1.38 aspect-ratios.

The rotatable mirror and the stepping motor are mounted on a cantalever extension to the television camera mount. The second 35mm projector at the right is used for transfer of films in the 1.38 aspect-ratio. In this application, the mirror is repositioned by 90 degrees. At the right is a rear-projection screen from which the film image is picked up by the television camera.

Behind the lens, and not visible in the illustration, is a light and light-sensitive transistor which is used in automatically indexing the mirror to position zero prior to the start of a recording transfer.

The control system, while complex in solid-state circuitry, is comparatively simple in basic concept. Essentially, it consists of means to store cueing instructions and to compare these with current status information as to frame count and horizontal positioning of the mirror. This is shown by the simplified block diagram in Fig. 6.

Stored in digital form on a magnetic tape cassette are cues specifying the timing at which a horizontal repositioning is to be made and the position number. The timing is in feet plus frames from a start-mark on one frame in the leader. The position number is the horizontal relationship between the film frame and the television camera aperture. For Cinemascope with an aspect-ratio of 2.35, nine equally-spaced positions are used. For the narrower aspect-ratio of 1.85, only five of the nine positions are required to cover the full width of the film frame.

The cueing information is determined by examination of the film in a viewer equipped with a footage and frame counter and a moveable graticule marked with the television aperture for the particular format in use.

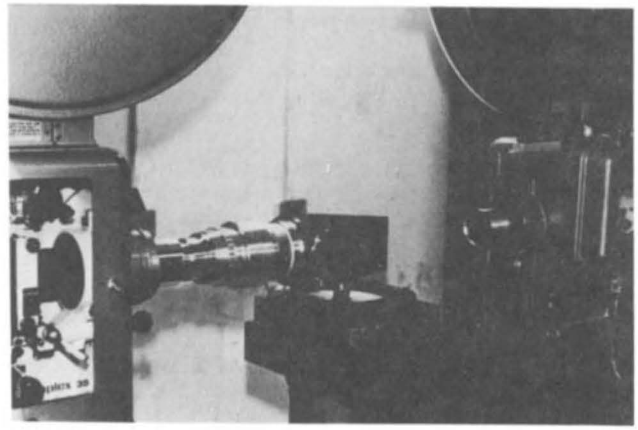


Fig. 5. A rotatable mirror in the optical path between the 35mm anamorphic lens and the television camera, controlled by a stepping motor, provides a variable horizontal positioning of the projected film frame.

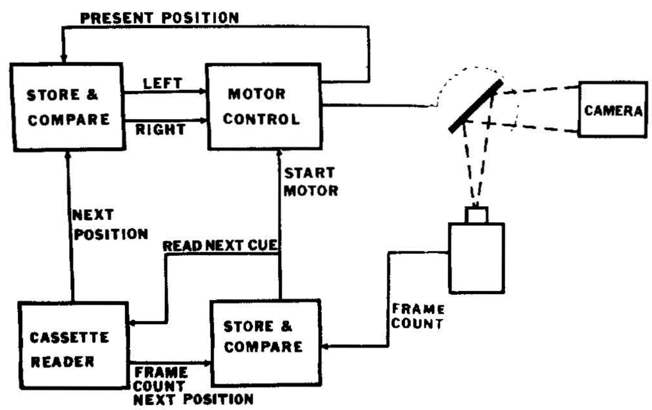


Fig. 6. Block diagram of control system.

In the transfer operation the film is threaded in the projector with the start-marked frame in the gate. Upon start of the projector, the first cue is read out, the footage and frame count converted to total frames and stored in the frame comparator. Concurrently, the position number for the next cue is read out and stored in the position comparator. In addition, the mirror rotates to position zero, as indicated by the light-dependent transistor sensor. The position zero is compared with the position of the next cue and an instruction as to direction and number of steps transmitted to the motor controller.

When the frame count received from the sensor on the projector intermittant equals the stored count, three actions take place:

1) The motor movement is initiated. Since all the frame-count pulses are at the start of shutter blanking, the movement occurs during blanking.

2) The cassette reader is stepped to the next cue and cues are read out to the comparators.

3) The cue read-out changes to indicate the next cueing information.

The system then is ready to repeat to operation at the next coincidence of frame counts.

At present, the system is being used in conjunction with a three-Plumbicon color camera for transfer to the U-Matic 3/4-inch wide cassette tape format or IVC 1-inch format. The camera control, monitoring and operating control and one rack of the bank of recorders are shown in Fig. 7. The operation is conducted in essentially a hands-off manner. In other words, once the start button is pushed, only a surveillance of the operation for occasional adjustment of signal levels and color balance is required.

Fig. 7. Recording control and monitoring in center, camera control at left. At right, two of twelve recorders and quality-control player.

The system has been in operation since February of this year supplying feature and supplementary programming for Warner Cable, Inc.

The video tape product is providing a conversion from the wide-screen film format to the television aspect-ratio with a degree of precision equivalent to that achieved by a film laboratory at a fraction the cost.

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