THE COMPLETE
TECHNICAL PAPER PROCEEDINGS

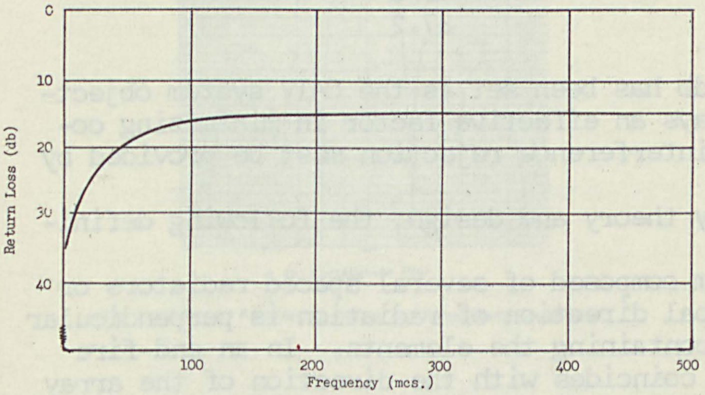
FROM:

of the suckout is the primary feature distinguishing this type of discontinuity from the types discussed above.

Almost unbelievably small cable diameter variations, if periodic, can cause a substantial impedance and attenuation discontinuity. Cable diameter variations in a half inch cable of the order of one mil (0.001") can cause intolerable impedance discontinuities in finished cable.

The fourth column in Table I shows the percent variation in attenuation corresponding to a given return loss value if the impedance deviation resulted from periodic impedance variations distributed uniformly along the length of the cable. Noticee that the attenuation differential (from normal) is proportional to the cable length while that resulting from a single junction is a fixed quantity. If a cable containing a periodicity is inserted into an otherwise uniform system, the distributed attenuation excess would occur and, in addition, junction reflections would occur at the terminal ends of the cable because of the mismatch in input impedance at that band of frequencies.

Figure 5 shows another trait exhibited by a cable with a periodic impedance discontinuity. The effective value of the return loss increases with cable length only over a limited length. This is natural because the attenuation of the reflected energy farther down the length prevents a substantial contribution to the energy reflected from points nearby. A single discontinuity located a reasonably short distance from a cable end can produce the same apparent return loss as would a set of small but periodic discontinuities. Yet, if these should persist, the small variations can accumulate a large attenuation discontinuity while the effect of the single discontinuity would have been negligible by comparison.



Length (feet)

FIGURE 5 - Return Loss at 148 mcs. vs Length for RG 58/U with a Periodic Discontinuity. Period of discontinuity, 26.7". Amplitude of discontinuity, ±0.0008" (Normal attenuation at 148 mcs., 7 db/100 ft.

Conclusions - Undesirable signal reflections occur from all sources of impedance discontinuities in coaxial cable. The most serious sources of reflections for the CATV system are those resulting from double discontinuities which, in turn, arise from any number of sources. The most objectionable problem created by double discontinuities is the frequency sensitivity of the input impedance.

Coaxial jumpers in conjunction with equipment terminal impedances can result in serious double discontinuities in trunk runs, particularly if all jumpers are of equal length. Staggered jumper lengths and well matched and protected connectors will alleviate problems of this source.

For a given input impedance deviation, periodic impedance variations in a cable can produce far more serious attenuation variations than would a single or double discontinuity.

Thank you. (Applause)

MR. COOLEY: Thank you, Mr. Roberts. The next subject on the agenda is "A New Antenna for CATV" and our speaker is a graduate of Mississippi State University with a BSEE. He did graduate work at Southern Methodist and worked for Ling Temco, All Products Company and Scientific Atlanta. He has published papers on a high gain space telemetering array and engineering report on a high frequency rotable log periodic antenna and a VHF log dipole antenna. He is a member of the Institute of Electrical and Electronic Engineers. Gentlemen, this is Thomas B. Smith of Scientific Atlanta. (Applause)

MR. THOMAS D. SMITH: Thank you. Co-channel interference has become an increasingly important problem for CATV systems, due to the rapid growth of CATV popularity and the advent of all-channel distribution. Many systems now operate in the primary coverage area of one or more TV signals and distribute twelve channels of television; thus they are usually required to distribute fringe-station signals in order to fill their channel capacity.

In March 1959, the Television Allocations Study Organization graded viewers' opinions of television picture quality in the presence of co-channel interference as follows:

Picture Quality	Signal-to-Interference Ratio, db
Excellent	47.3
Fine	42.6
Passable	37.2

A signal-to-interference ratio of 48 db has been set as the CATV system objective; and since antenna location is not always an effective factor in minimizing co-channel interference, the largest part of interference rejection must be provided by the antenna array.

In a discussion of basic antenna array theory and design, the following definitions are quite helpful.

Array--A radiating or receiving system composed of several spaced radiators or elements. In a broadside array the principal direction of radiation is perpendicular to the axis of the array and to the plane containing the elements. In an end-fire array the principal direction of radiation coincides with the direction of the array axis.

Directivity--The ratio of the maximum radiation intensity to the average radiation intensity. For an antenna that is 100% efficient (i.e., no conductor, dielectric, or mismatch loss), directivity and gain are the same. For an antenna with losses, gain will be lower than directivity by a factor corresponding to the efficiency. Specifically,

$$G = KD,$$

where G is gain as a power ratio; K is the efficiency factory; and D is directivity.

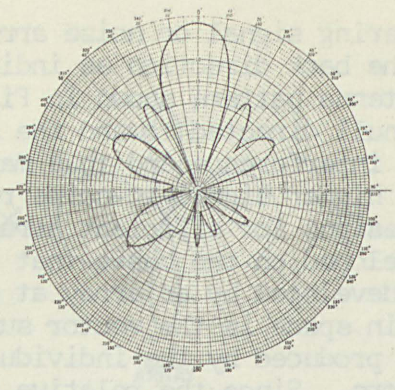
Gain--The ratio of the maximum radiation intensity in a given direction to the maximum radiation intensity produced in the same direction from a reference antenna with the same power input. Gain is frequently used as a figure of merit; it is closely associated with directivity, which in turn is dependent on the radiation patterns of an antenna.

The most common reference antenna used to calculate gain is the isotropic radiator, a hypothetical, lossless antenna that radiates uniformly in all directions. The half-wave dipole antenna is sometimes used, however, and the following formula is useful in converting from either reference:

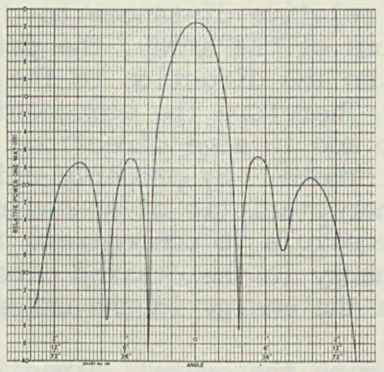
$$G_{iso} = G_{dipole} + 2.15 \text{ db},$$

where G_{iso} is the gain in decibels referenced to an isotropic radiator, and G_{dipole} is the gain in decibels referenced to a dipole antenna.

Radiation Pattern--A graphical representation of the radiation of the antenna as a function of direction. Patterns may be taken in polar form (see Figure 1a, next page) or rectangular form (see Figure 1b). The following three patterns are most commonly used:

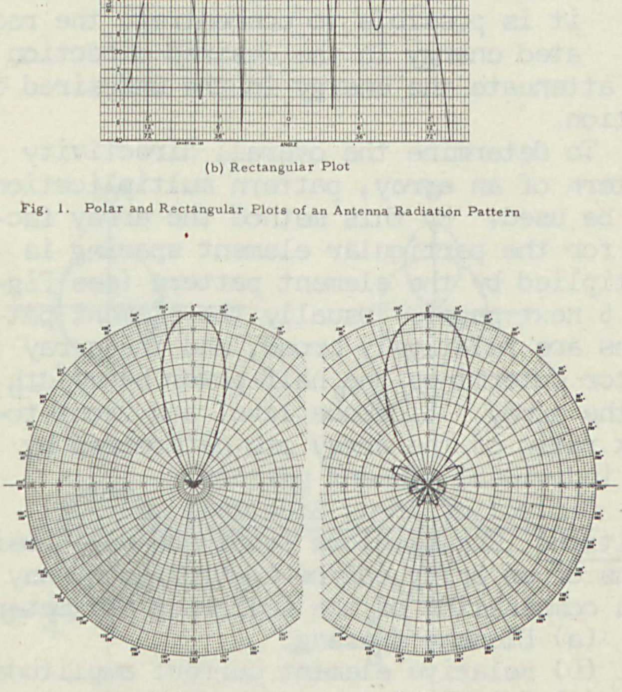


(a) Polar Plot

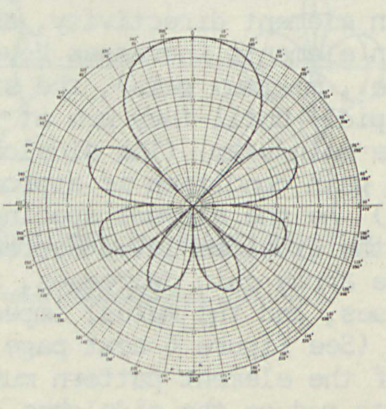


(b) Rectangular Plot

Fig. 1. Polar and Rectangular Plots of an Antenna Radiation Pattern



(a) Power (b) Field



(c) Log

Fig. 2. Power, Field, and Log Plots of an Antenna Pattern

(a) Power Pattern: Shows the variation of power density at a constant distance from the antenna as a function of angle. (See Figure 2a.)

(b) Field Pattern: Shows the variation of the electric field intensity at a constant radius from the antenna as a function of angle. (See Figure 2b.)

(c) Log Pattern: Shows the variation of the logarithm of power density or electric field intensity at a constant radius from the antenna as a function of angle. (See Figure 2c.) The logarithm of field intensity, E, in any direction can be expressed as

$$20 \log \frac{E}{E_{max}}$$

The logarithm of the power P, in any direction can be expressed as

$$10 \log \frac{P}{P_{max}}$$

The same antenna pattern is plotted in three forms in Figs 2a, 2b, 2c. Note how useful the log pattern is in displaying the sidelobes of an antenna.

An antenna radiation pattern is a three-dimensional figure, and patterns can be made in an infinite number of planes. The most important planes in a CATV system are the E-plane (horizontal), in which co-channel signals arrive, and the H-plane (vertical), in which ghost signals usually arrive. (See Figure 3.)

Reciprocity Theorem--A theorem stating that the directional pattern of a receiving antenna is identical with its directional pattern as a transmitting antenna.

CATV Array Design In the early days of CATV, co-channel interference was not a major problem; and CATV arrays and antennas were designed for maximum gain, based on the criterion that signal increases linearly with gain. Today, however, CATV arrays must be designed to operate in receiving systems where interference is present; in these systems gain is desirable only insofar as it improves the signal-to-noise ratio.

The important factor now is the overall directivity pattern of an array. For example, a receiving antenna with the pattern shown in Figure 4a may be preferable to a higher-gain antenna with the pattern shown in Figure 4b if there is an interfering signal or noise arriving from the back direction as indicated. The antenna pattern shown in Figure 4a has a null directed toward the source of the interference and thus may provide a much higher signal-to-noise ratio.

Designs for efficient arrays can be developed on the basis that the total field developed by an array at a distant point in space is the vector sum of the fields produced by the individual array radiators. Since the relative phases of these component fields are determined by the relative distances to the various radiators of the array, the pattern will depend on the direction to the point in space. Therefore the component fields tend to add in some directions and cancel in others. By properly utilizing this characteristic of spaced radiators, it is possible to concentrate the radiated energy in the desired direction and attenuate the energy in the undesired direction.

To determine the overall directivity pattern of an array, pattern multiplication can be used. By this method the array factor for the particular element spacing is multiplied by the element pattern (see Figure 5 next page). Usually the element patterns are relatively broad, and the array factor determines the half-power beamwidth of the array. Sidelobe level and front-to-back ratio of the array are determined by the individual element pattern.

Control of Array Sidelobes and Null Positions The sidelobe level and null positions of an array can be controlled by any one or a combination of the following parameters:

(a) Element spacing.
(b) Relative element current amplitude.
(c) Relative element current phase.

With a given element directivity, as the spacing between elements increases beyond the optimum (i.e., maximum gain), the sidelobes increase rapidly until they are at the same level as the main beam. (The sidelobe level for maximum gain condition is approximately 13 db down.) As the element spacing is decreased, the sidelobe level decreases; however, the array gain decreases, the main beam increases, and the mutual impedance increases. (See Figure 6 next page) The directivity of the element pattern must be sufficient to reduce the sidelobes of the array factor to the level desired.

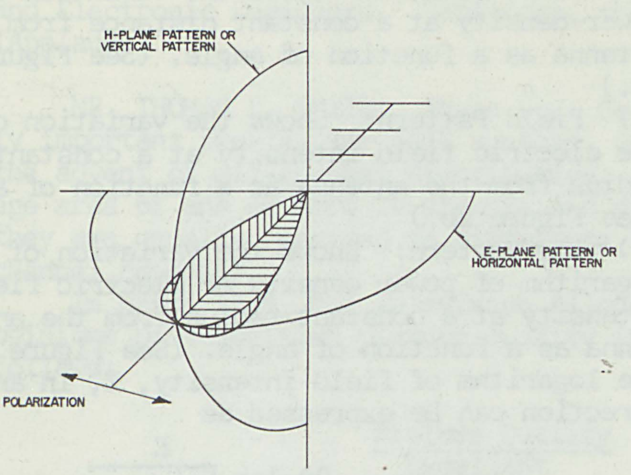
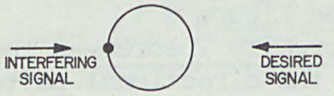
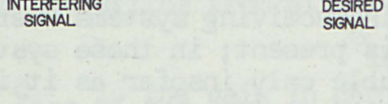


Fig. 3. Antenna Radiation Patterns, E- and H-Plane



(a) Low-Gain Antenna Pattern



(b) High-Gain Antenna Pattern

Fig. 4. Effect of Antenna Pattern on Signal-to-Noise Ratio. Taken from Antennas, by J.D. Kraus (McGraw-Hill, 1950).

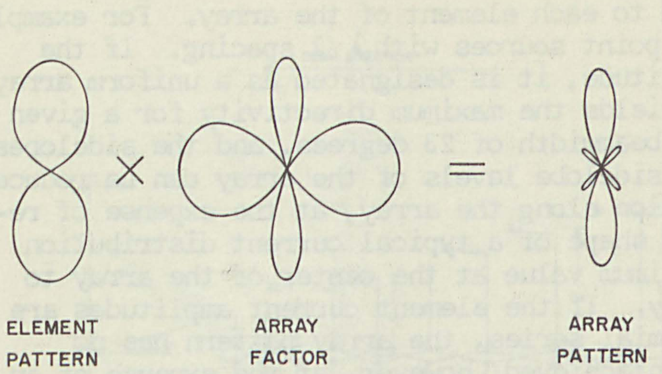


Fig. 5. Pattern Multiplication

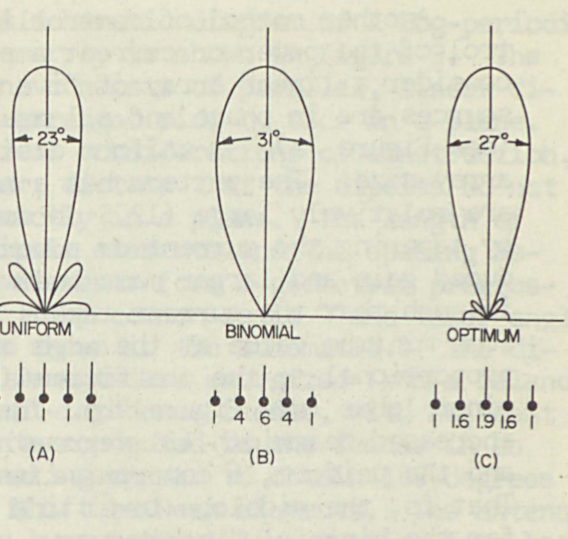


Fig. 7. Control of Sidelobe Level by Current Amplitude. Taken from Antennas, by J. D. Kraus (McGraw-Hill, 1950).

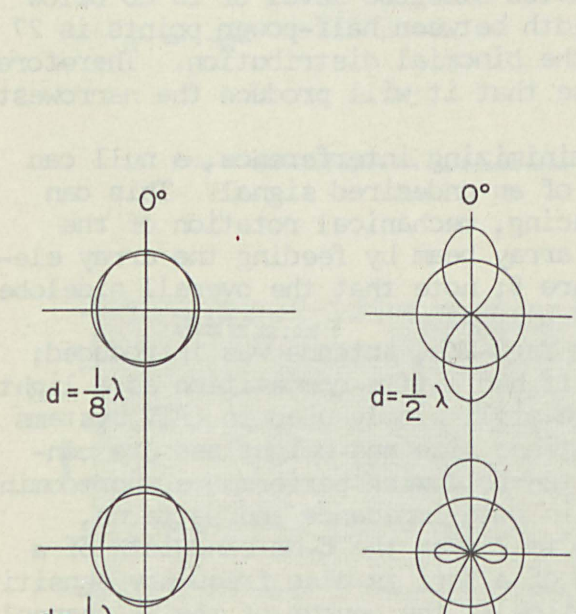
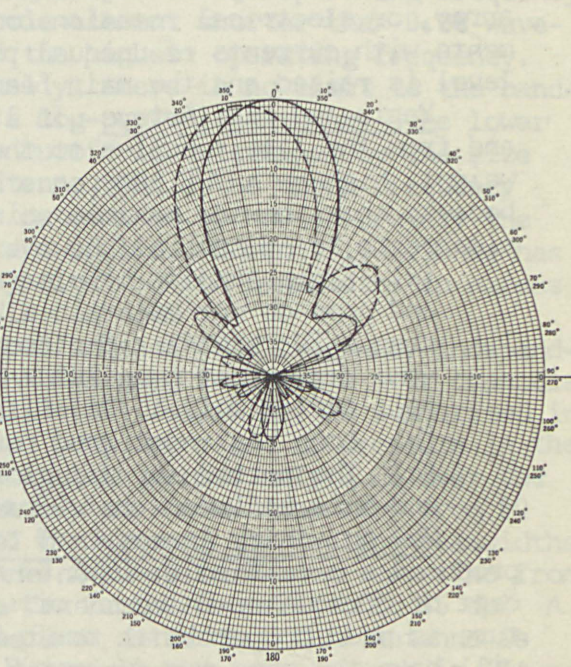


Fig. 6. Effects of Element Spacing on an Array Factor



Solid Line: Zero Skew. Dotted Line: 10-Degree Skew.

Fig. 8. Electrically Skewed Array Pattern

Another method of controlling the sidelobe level of an array is through the control of the power or current amplitude fed to each element of the array. For example, consider a linear array of five isotropic point sources with $\lambda/2$ spacing. If the sources are in phase and all equal in amplitude, it is designated as a uniform array (see Figure 7a). A uniform distribution yields the maximum directivity for a given array size. The pattern has a half-power beamwidth of 23 degrees, and the sidelobes are relatively large (12.5 db down). The sidelobe levels of the array can be reduced by tapering the current or power distribution along the array, at the expense of reduced gain and larger main beamwidth. The shape of a typical current distribution is such that the current tapers from a maximum value at the center of the array to some minimum value at the edge of the array. If the element current amplitudes are proportional to the coefficients of a minomial series, the array pattern has no minor lobes (see Figure 7b). This has been achieved, however, at the expense of an increased beamwidth (31 degrees). If the current distribution is between the binomial and the uniform, a compromise between the beamwidth and the sidelobe level can be made. That is, the sidelobe level will not be zero, but the beamwidth will be less than that for the binomial distribution.. An amplitude distribution of this nature, which optimizes the relation between beamwidth and sidelobe level, is based on the properties of the Tchebysceff polnomials and is referred to as the Tchebysceff distribution. The pattern and current distribution for a specified sidelobe level of 20 db below the main beam is shown in Figure 7c. The beamwidth between half-power points is 27 degrees, which is 4 degrees less than that for the binomial distribution. Therefore Tchebyscheff distribution is optimum in the sense that it will produce the narrowest beamwidth for a given sidelobe level.

In addition to sidelobe-level control for minimizing interference, a null can be placed in the array pattern in the direction of an undesired signal. This can be accomplished by the adjustment of element spacing, mechanical rotation of the array, or electrical rotation or skewing of the array beam by feeding the array elements with currents of unequal phase. (See Figure 8; note that the overall sidelobe level is raised and the main beam is skewed.)

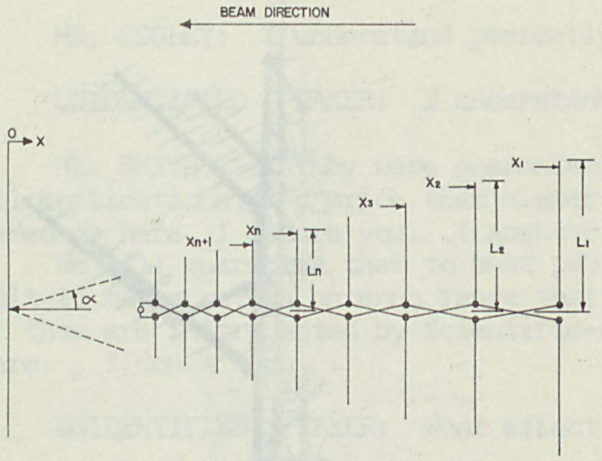
Yagis and Yagi Arrays In 1927 the Yagi, or Yagi-Uda, antenna was introduced; and from the late twenties to the late fifties, it had little competition as a lightweight, high-gain VHF antenna. Yagi antennas are still widely used in CATV systems because they provide maximum gain for a given antenna size and weight and are considered to be economical; however, they do have the following performance shortcomings:

(a) Yagis tend to have a narrow bandwidth in both impedance and patterns, and some do not maintain a VSWR less than 2 to 1 over the 6-Mc bandwidth of a single TV channel. The front-to-back ratio of a Yagi is also frequency sensitive. Some Yagis that have 20-db front-to-back ratios at the center of the TV channel fall off to only 15 db or less at the edges of the channel.

(b) Long Yagis designed for maximum gain have sidelobe levels of 10 to 15 db.

(c) The pattern of a Yagi is susceptible to influence by support structures, and this influence is virtually impossible to predict.

New Antennas, Arrays, and Techniques In the late fifties, Government research produced a breakthrough in antenna state-of-the-art. This breakthrough was the concept of "frequency-independent" antennas and was based on the theory that if a structure is made proportional to itself by scaling of its dimensions by some ratio τ, it will have the same properties at a frequency f and at a frequency τf. Therefore, the patterns and impedance of the antenna are periodic functions of the logarithm of frequency with a period of log τ. By the proper choice of τ, the properties of the periodic type of antenna will vary only slightly over the frequency band f to τf.



$$\tau = \frac{L_{n+1}}{L_n} = \frac{X_{n+1}}{X_n}$$

$$\alpha = \tan^{-1} \frac{L_n}{X_n}$$

Fig. 9. Schematic Diagram of a Log-Periodic Array

A schematic diagram of a log-periodic dipole array is shown in Figure 9. The antenna consists of parallel, linear dipoles arranged side by side in a plane. Practical considerations of construction, however, dictate that the dipoles do not lie exactly in a plane. The length of the dipole elements and the spacing between elements form a geometric progression. (The common ratio τ and taper angle α are shown in the schematic.) The dipole llements are energized from a balanced constant-impedance feeder, with adjacent elements connected to the feeder in an alternating manner to obtain 180 degrees phase shift between elements. The antenna is fed by a coaxial line running from back to front through one of the support members. This type of connection forms an infinite balun, since the external portion of the antenna structure past the resonant element carries negligible current. Radiation from the antenna is end-fire in the direction of the decreasing elements.

For satisfactory operation the antenna must contain a dipole at least 0.5 wavelength long at the lowest operating frequency and a dipole element shorter than 0.38 wavelength at the highest operating frequency. Theoretically, there is no limit to the bandwidth of a log-periodic antenna. The lower frequency cutoff is determined by the size of the antenna, while the upper frequency cutoff is determined by how accurately the elements are scaled. Scientific-Atlanta has made log-periodics with bandwidths in excess of 23 to 1.

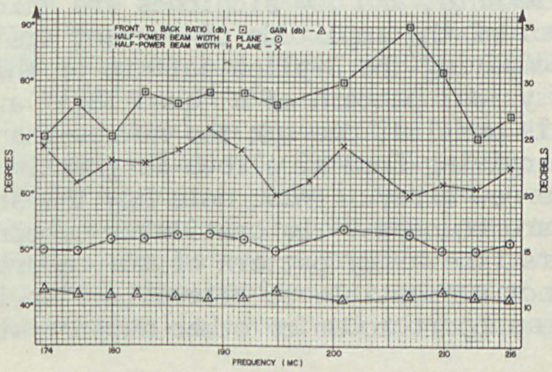


Fig. 10. Performance of Channel 7-13 Antenna

The performance of a frequency-independent antenna designed to operate over channels 7 through 13 (174 to 216 Mc) is summarized in Figure 10. Note there are no dropouts in the performance; gain varies only 1 db over the band. The E-plane beamwidths vary from 50 degrees to 54 degrees, and H-plane beamwidths vary from 60 degrees to 72 degrees. The front-to-back ratio varies from 25 db to 35 db. A typical E-plane pattern of this antenna is shown in Figure 11 and a photograph in Figure 12. (Next page) Similar antennas covering channels 2 through 3 and 4 through 6 are also available.

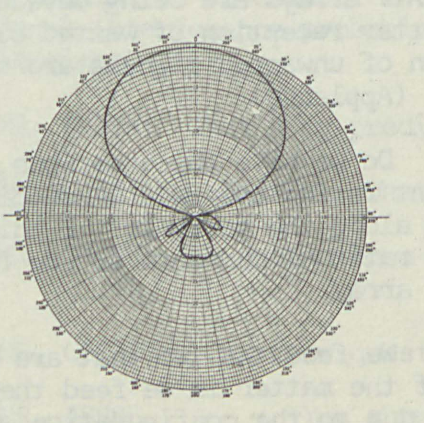


Fig. 11. Typical E-Plane Pattern of Channel 7-13 Antenna

A new array configuration available to the CATV industry is shown in Figure 13 (next page). This array, a "quadrate channeler," is designed to minimize co-channel interference: Frequency-independent antennas are

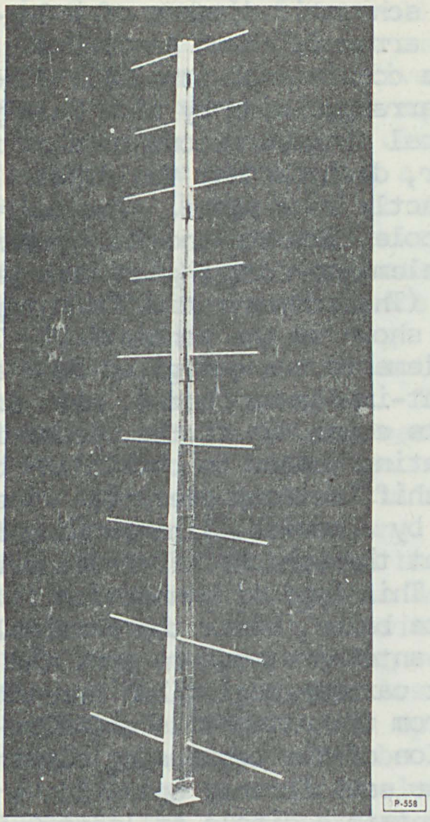
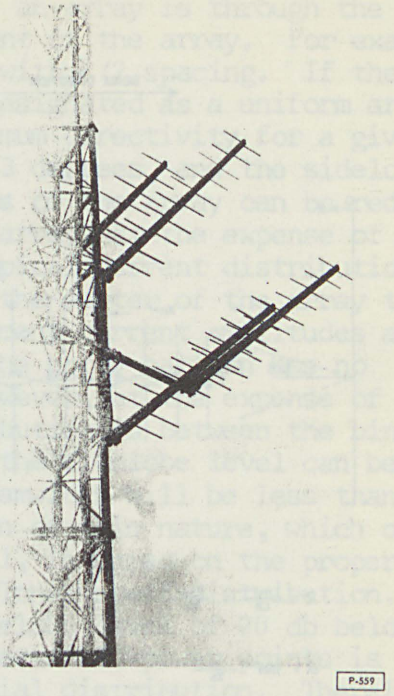


Fig. 12. Channel 7-13 Antenna



Quadrate Channeler Antenna, Installed on Tower

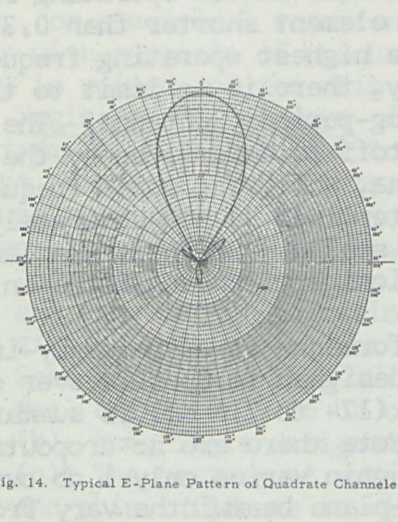


Fig. 14. Typical E-Plane Pattern of Quadrate Channeler

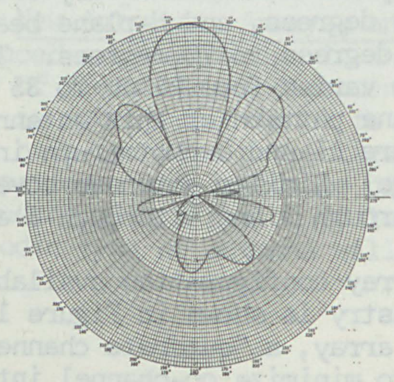


Fig. 15. Typical E-Plane Pattern of Quad-Yagi Array

utilized as elements, and low sidelobes are maintained by control of the amplitude of current distribution. By comparing the E-plane pattern of this array with a typical pattern of a "quad Yagi" array (see Figures 14 and 15), one can see how co-channel interference arriving from sidelobes is greatly reduced by the new array. (Also note how the array and elements are mounted.) By cantilever support of the elements, the array pattern of the quadrate channeler is not susceptible to alterations or influence by the support tower or other support structures.

By the application of basic antenna array theory more efficient CATV arrays are being developed. The objectives of better reception of wanted signals and greater rejection of unwanted signals are now possible.

Thank you. (Applause)

MR. COOLEY: Do we have any questions, gentlemen? What current ratios are used in feeding the various elements along the periodic? I think the question is what ratio of currents do you feed the four elements in array.

MR. SMITH: We feed the two that are stacked, well the truth of the matter is we feed them all equal. However, due to the configuration we mathematically can replace the two that are stacked this way with one at the center which is fed twice the power of that of the two on the edge.

MR. COOLEY: I understand perfectly. (Laughter) Any other questions?

UNIDENTIFIED SPEAKER: I understand there's a guarantee.

MR. SMITH: If they were guaranteed to eliminate all co-channel interference in all applications, I'd price them higher than those of the gentleman who probably preceded me here, I assure you. (Laughter)

We will guarantee them to meet published specifications. It's a little difficult to maybe get an antenna range that may be unbiased because I think about most of them are instrumented by Scientific-Atlanta anyway, so you may have some questions here. I don't know.

UNIDENTIFIED SPEAKER: What effect does ice loading have on your gain?

MR. SMITH: To be quite frank with you I'm not absolutely sure what the ice loading has on the gain. We have analyzed ice loads from structural standpoint. They're structurally safe. We have also looked into the idea of heating these by running a heater along the boom, support boom of the antenna to melt ice, which I think could be done quite readily. But, so far as field tests or actual tests, none to my knowledge have been conducted.

COLONEL DUTCH SCHETZEL: Do I understand that the co-channel performance here of this antenna is superior to that of, say, a couple of good yagis properly stacked, phased, and oriented?

MR. SMITH: Question is, does this array as just shown us, out-perform a horizontal stack that was cut and chosen and designed to put a notch exactly where you need it? (THE COLONEL MADE ANOTHER COMMENT, INAUDIBLE)

It's a little difficult to answer your question. Based on what experience I have, I would tend to answer the question, Yes I believe it does. Let me qualify that. If we have relatively low sidelobes, which we do in the horizontal plane, then we're not required to put this interfering station in such a deep notch. Consequently, the criticalness of the antenna, the transmission line and the sensitivity to slight variations in apparent sources of arrival is not quite as critical. It's similar to, in my mind, the performance curve of a high Q parallel resonant circuit compared to a low Q parallel resonant circuit as far as the criticalness of the notch is concerned.

COLONEL SCHETZEL: What you're saying is that maybe sometimes it may not be as good on minimized co-channel interference, but on the average the amount of timethat co-channel interference probably would be less with this than with the other layout. Is that right?

MR. SMITH: That's my prediction, yes.

UNIDENTIFIED SPEAKER: What was the front-to-back ratio?

MR. SMITH: We guarantee a minimum of 25 db and it's typically 30 db over the band.

MR. COOLEY: One more question. Jesse?

MR. JESSE : You showed four antennas mounted there on that. When you mount antennas up close together even though they're the same channel antennas stacked or if there are other channel antennas above, don't you decrease the quality of your reception somewhat even though there is an increase in signal by stacking antennas? When you get antennas so close together, what I'm trying to say is, you do decrease your quality to a certain extent even though it might not be too noticeable.

MR. SMITH: Are you talking about spacing of antennas in array for single channel reception, or are you talking about spacing of two arrays on the top or for two different channel receptions? I didn't quite follow you there.

MR. JESSE : I'm talking about quality. Either stack them for the same channel or you have two different arrays for two different channels.

MR. SMITH: As far as a single array is concerned, did everybody year the question? As far as array spacing for a given channel reception, we space an optimum distance as far as performance in the pattern is concerned; low sidelobes, beamwidths, etc. And there there is nothing but mutual impedance and the shape of the pattern to come into play, and usually this results in a loss of gain and not necessarily a loss in performance of the picture qualities. However, you are correct in saying that placing other channels or other antennas in the field or the proximinity of this array does, indeed, distort the picture quality from the fact that it does, indeed, influence the pattern of this array and it's no longer what we predict it to be.

UNIDENTIFIED SPEAKER: Are CATV systems using this antenna at the present time?

MR. SMITH: Yes, there's one in Athens, Georgia, that's using this.

MR. COOLEY: I want to thank you very much, Mr. Smith. (Applause) Gentlemen, I'll see you at the Banquet. Good night all. (Session was then adjourned.)

- - - - - - -

Tape Recording of all sessions

and

Transcription of proceedings

supplied by

International Recording Guild

Staten Island - New York

It is questionable whether this additional increase in performance would be justified in light of additional equipment and maintenance costs.

It also appears feasible that return loss figures of 36 and 40 db may eventually be feasible. Present system requirements as established by major development groups in this field, have set a minimum return loss figure of 30 db for feeder and trunk cable, at the present time.

Because of the development of the aluminum sheathed coaxial cable with prevention of longitudinal vapor paths, it would appear that we have also approached optimum shielding efficiency and cable life. Cable life has been shown to be a very important factor in cable performance, coupled with the attenuation, cost, shielding and return loss factors.

MR. TAYLOR: Thank you very much, Mr. Kushner. Mr. Kushner mentioned the papers. We have gotten papers out of the boxes so that all of the papers that are available are here. Those papers that are not available will be available, however, through the transcription service which is taking down all of the presentations both in this room and the other room.

We're running right about on schedule. Unless somebody has an urgent question for Mr. Kushner, I would like to move on to the next speaker. You have the biographical sketch on your chairs so I will not take a particular time to introduce Dr. Theodore Hafner, who is going to speak on the "Breakthrough With Microwave by Wire". Dr. Hafner.

DR. THEODORE HAFNER (President, Surface Conduction, Inc.): I am somewhat embarrassed. I have to talk about something which is entirely different from what you have just seen. It is, in a way, fundamentally new. This has a certain advantage, but it also has a certain disadvantage. The disadvantage is in the difficulties of an explanation.

Now, if I may, I hope my predecessor here in speaking will forgive me if I use some of his figures. He's talking about improvements from 50 db per mile to 40 db per mile. And, I am going to speak about improvements from 40db per mile to 10 db per mile.

HISTORY AND THEORY

Wire or wireless. The surface wave, a third medium combining privacy of wire with the low loss of radiation. The surface wave, a fundamentally novel wave mode. Simple (though only theoretical) derivation of existence of surface wave; its low loss and wide applicability.

What is the G-Line? Where does it come from? Where does it go?

I am reminded of the famous Austrian General Radetzky. At one of the war games of the Austrian army, one of the participating army groups was commanded by an Archduke who was not too well known for his intelligence. After the battle, Radetzky surveyed the happenings

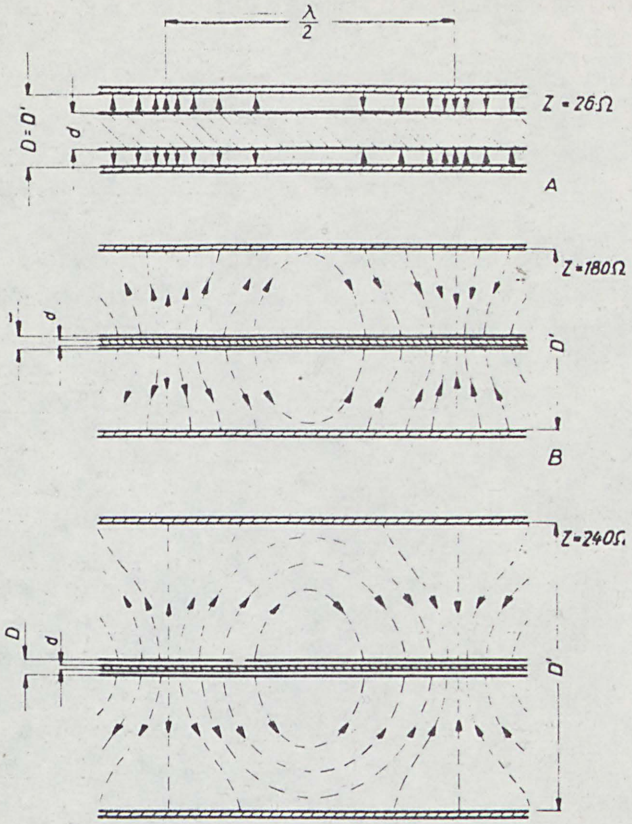


FIG. 1: From Coaxial to Surface Wave

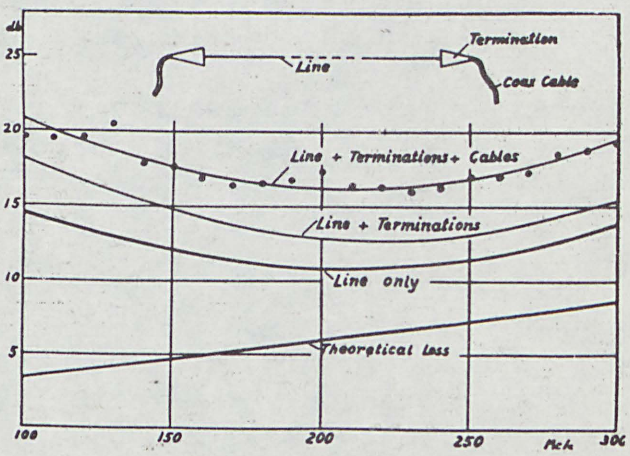


FIG. 2: Loss of 2-mile G-Line

and remarked to the Archduke: "The problem you faced had two solutions; Your Imperial Highness selected the third one."

This, of course, was facetious; there was no third solution.

In choosing between wire and wireless, is there a third solution?

Until recently, there were known only two ways of guiding a signal from point to point: either within a cable or without a cable. We have now a third way: a surface wave around a cable.

This evolution should place the use of surface waves by CATV in the proper perspective. It is part of a historic development and, as every real achievement, it affects every important field of communications, railroads, power distribution, broadcasting, and one day, perhaps all types of long distance transmission.

What is a Surface Wave? How is it produced?

At least mentally, it can be construed from a coaxial cable. (Figure 1.)

By increasing the outer conductor of a coaxial cable, we reduce the loss, as is well known, but something else happens: With increasing outer diameter some of the coaxial field lines between inner and outer conductor will not reach the outer, but since they have to end somewhere, return to the inner conductor.

By further increasing the radius of the outer conductor, more and more of these field lines will close on the inner conductor. Finally, if the

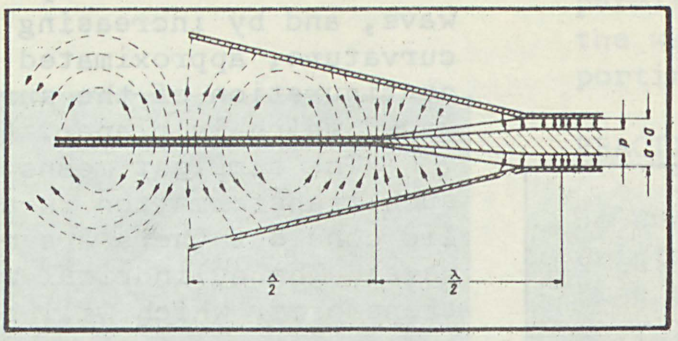


FIG. 3: Transforming Coaxial to Surface Wave

outer conductor is large enough, almost all of the field lines will terminate along the inner conductor. The wave, eventually, will be propagated substantially only by the inner conductor, sliding on its surface in an air channel of a diameter, as determined by Dr. Goubau, of wavelength dimension. Under these circumstances, of course, the outer conductor could be omitted with relatively little, if any, energy loss.

What remains is a single wire of a closed wave configuration. In a similar way, one of the two wires of a twin line can be moved away and finally omitted.

It is obvious from a comparison with this twin line that the remaining single wire must have not more than half the loss of that of a twin line. Actually, the loss of the G-Line is much less: around 8 - 10 db per mile at VHF and UHF. (Figure 2.)

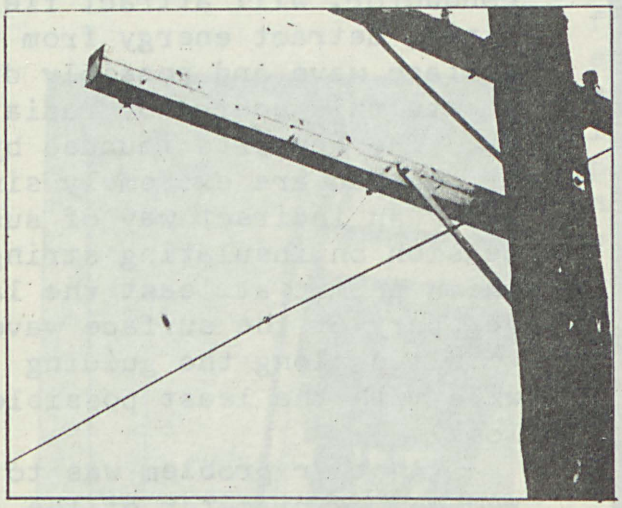


FIG. 4: V-Shaped Nylon Suspension: Helena, Montana

REALIZATION OF SURFACE WAVE IS DIFFERENT FROM VISUALIZATION

The launching of the surface wave. Indirect suspension. Concentration of the surface wave by special cable structure.

While this mode of creating a surface wave from a coaxial cable is easily understood, it does not present a practical way of producing a surface wave.

Dr. Goubau found such a way. He started out from a coaxial line section and then transformed the impedance of the coaxial line into the impedance of the surface wave - which is that of air. At the same time, he

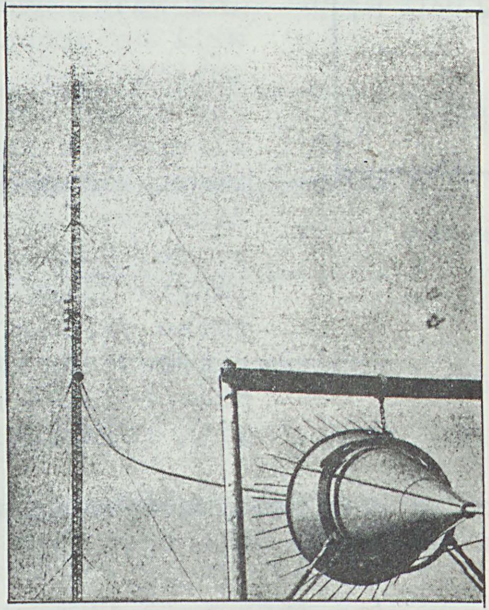


FIG. 5: G-Line for 10 kw 500mc
Federal Broadcasting System
Sigmanningen, Munich, West Germany

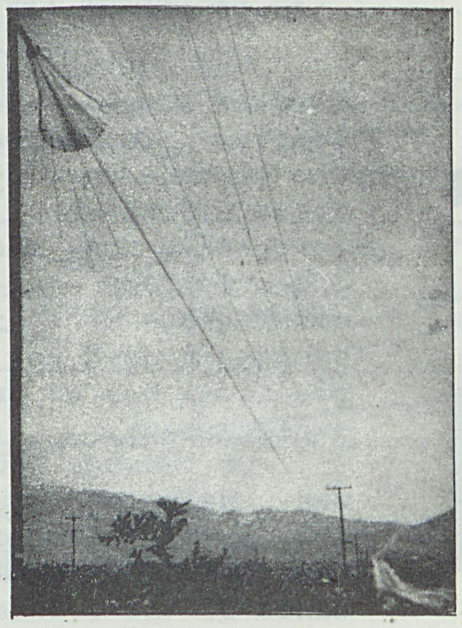


FIG. 6: Launching horn—Yucca Valley

gradually transformed the coaxial wave into a spherical wave, and by increasing its curvature, approximated the configuration of the surface wave, which is planar. (Fig. 3)

The simplest means for such transformation is a metallic cone but there are other ways: The cylindrical wave transformer which will be discussed later on.

It is one thing to imagine the mere possibility of the existence of a surface wave. It is another thing to realize a surface wave and it is a third problem to apply a surface wave transmission line in a practical way.

Obviously, a surface wave sliding outside the cable must proceed unimpeded by anything which may affect its transmission. How then support the cable?

From the previous derivation of the surface wave from the coaxial wave, it is apparent that another conductor, arranged near the surface wave conductor, will attract field lines, detract energy from the surface wave and possibly dissipate this energy by radiation.

The supports founded by Dr. Goubau are extremely simple: an indirect way of suspension on insulating strings which permit at least the larger part of the surface wave to slide along the guiding wire with the least possible loss.

Another problem was to reduce the diameter of the airchannel. Obviously, the smaller its diameter, the smaller the launching devices for producing the surface wave to permit practical dimensioning of the wave producing and wire supporting devices.

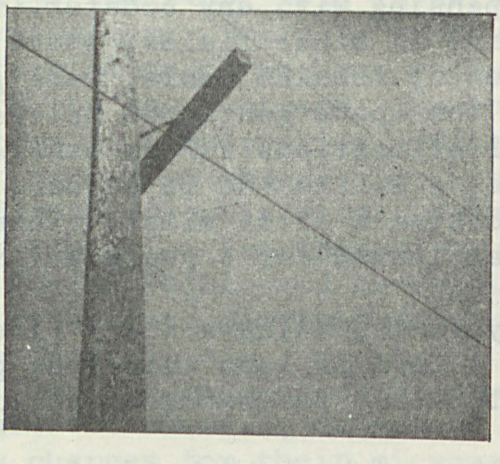


FIG. 7: V-Suspension - Yucca Valley

PRACTICAL APPLICATIONS

The Community G-Lines at Helena, Yucca Valley, Lewistown. Originally provisionally used, G-Line becomes permanent feeder line.

Thus we find, as a classical means of suspension, the V-shaped nylon string, which was applied in CATV, for the first time in the Helena (Montana) G-Line by Archie Taylor, which was constructed under our license. (Fig. 4)

The G-Line, therefore, as a wire line, can be important for CATV, as an industry substantially relying on wire techniques. It combines the good features of wire and wireless and produces a broad, low-loss transmission path which is essentially private and easily expandable.

In this respect, CATV is not alone. Other industries have similar requirements. You can profit from their experience.

Among the many uses the G-Line found in practice, was, at the outset, a quick substitute for a coaxial cable or a wave guide to a radio transmitter.

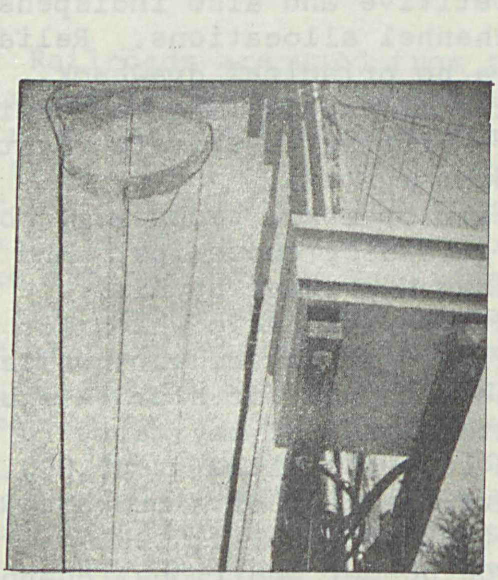


FIG. 8: Cylindrical Pickup-Yucca Valley

The U.S. Signal Corps produced the first G-Lines in the form of antenna feeder lines for their mobile radio equipment. Here already, the remarkable simplicity of the G-Line, its lightweight, easy handling, were put to such use, or rather abuse, as no coaxial cable could ever have withstood.

The German government found it convenient to start TV broadcasting and testing immediately and prior to the permanent connection of the coaxial cable or the wave guide, which generally took several months to install; the G-Line took as many days. Some of these substitute G-Lines became permanent, as in Sigmanningen, Germany. (Fig. 5)

Another example of G-Line, in operation for almost 10 years, is

3000 ft., 2500 MC antenna feeder at Florence, Alabama; two 3000 ft. 2000 MC feeder lines for ITT, Brazil.

In this connection we may add our UHF home G-Line, indispensable for fringe area UHF reception; a #12 wire, with a loss of 1 db/100 ft. only over 400 to 1200 MC, therefore, dispensing with any booster.

Similar uses were found for the G-Line in other fields, where for one reason or another immediate connection by coaxial cable, wave guide or Air was not available. Among them is the above mentioned Helena G-Line, where due to the absence of channel allocations for an otherwise more convenient and more direct air route, a G-Line had to be used to bring a channel down a mountain, over a distance of 14 miles. This provisional installation, using a #8 wire, lasted for 8 years before the FCC channels were granted.

Another G-Line, at Lewistown, Pennsylvania, using a No. 6 wire, runs for 3 1/2 miles without an amplifier, at a loss of less than 9 db per mile, suspended on the poles of a power line and following a railroad track.

In this G-Line we applied a cylindrical pickup which permits branching off from the G-Line cable into a coaxial cable, without interfering with the surface wave.

Similarly, in Yucca Valley, Microwave channels were not available in time to assure the contractual TV service to a housing area. A 35-mile G-line was found economical, with amplifiers every 2 miles. (Figures 6, 7, 8)

All these installations, born from necessity rather than intrinsic planning, have now shown that there is more to the G-Line than just an occasional feeder to a coaxial cable or a short time substitute for a Microwave Relay. The G-Line is quite capable to replace and supersede both coaxial and Microwave Relays.

MICROWAVE BY WIRE vs. AIR AND SPACE

Comparison of economics, G-Line competitive and also indispensable because of independence from government channel allocations. Reliability to come with experience, and therefore no principal drawback. Convenience of Air and Space deceptive in view of expense and complexity involved. G-Line as wiring technique more fitting to private right of way users, such as CATV, railroads and power systems.

It is not my intention to disparage air or space technology, but we on this earth and in this country are guided by economics. And the G-Line fits economically into CATV more than Microwave by Air.

We need not defend the G-Line against coaxial cable which for long distance is at least four times as expensive. It may be worthwhile, however, to briefly compare cost of G-Line with that of Microwave by Air. Since the VHF G-Line with a bandwidth of 200 MC may carry 20 TV channels or more, we may assume cost of G-Line installed at $2,000.00/mile, regardless of number of channels; average cost of Microwave Relaying is given (See Paul McAdam, NCTA Bulletin, December 1, 1961) at $28,000.00 per hop per channel, plus $9,000.00 per additional channel.

For one TV channel, therefore, the G-Line will be competitive at any distance less than 14 miles; for seven TV channels, at any distance of less than 41 miles. Freedom from FCC channel allocations favors G-Line for any distance.

Admittedly, in favor of Microwave Relaying is its proven reliability. However, this is an advantage any old system has against any newcomer. There is no reason to assume non-radiating cylindrical surface waves to be less reliable than radiating spherical waves which, on the contrary, due to their very expansion, should be more exposed to atmospherics, reflection and fading.

Microwave through Air and Space, which seems so convenient for bridging large distances, depends on so fickle a matter as government control. Its transmitting equipment is complex. Admittedly, the G-Line requires a new wiring technique, but this is still a wiring technique, mastered more easily than the operation of a Microwave Relay.

The convenience of Microwave Relaying is, therefore, more apparent than real, as may be its reliability. The telephone company charges for their microwave as much as for their coaxial channels. ATT and Western Union provide several alternative microwave routes for every point-to-point connection.

While Microwave through Air and Space has now become sort of a fetish and the poor land wire somewhat neglected, we should not forget that this is accomplished at tremendous cost for which bear witthe common carrier rates of ATT, now also extended to transmission by satellite.

RAILROADS AND POWER DISTRIBUTION AS SPECIALIZED MARKETS

Essential interest in wiring technique. Historic autonomy on own right of way includes communications. Nature of operation requires flexibility in expansion and privacy of transmission medium.

And yet, important interests exist, which demand permanent communications by wire, foremost among them railroads and power systems.

Railroads are used from their beginnings to communicate over their own property. Frequently they were the physical carriers of circuits for the telephone companies and Western Union. Gradually, our telephone and telegraph systems grew independent from the railroad's right of way. The increasing communication traffic forced them to establish wire and cable lines on their own land and later on to expand into the public space, using Microwave through Air.

Railroads and power companies, on the other side, also growing, were at first satisfied with what they had in the way of communications: the railroads with wires on their own tracks, and the power companies using carrier frequencies over their own high tension wires.

In the last few years, however, railroad and power systems alike had to expand communications and signaling; the railroads needed quick data transfer from one point to another, in accordance with increasing train speed and freight processing. The increased demand for electrical power forced the power companies to enlarge their systems and system controls. Both railroads and power companies are now at the point where they have to consider using either Microwave by

Air or Microwave by Wire.

RAILROADS' SPECIFIC REQUIREMENTS

G-Line for tunnel communications; data transmission; Japanese and English speed controls by G-Line; train automatization. Railroad radar and security fence.

As far as the railroads are concerned, their communication and signaling demands are complex.

In Tunnels, for instance, Radio transmission has been found impractical. Due to the shape of the expanding radio wave, the radiated wave suffers so many reflections that, after a few hundred feet, a voice or signal will become distorted. The non-radiating surface wave, with its essentially tubular shape, concentrated around a wire mounted in the tunnel, fits aptly into the more or less cylindrical shape of the tunnel. By means of suitable pickups, the surface wave can be picked up, without physical contact, from people or trains passing through the tunnel.

Such a tunnel G-Line has been built for the New York Central Railroad over a distance of 3 1/2 miles.

Tunnel communication is important. The railroad freight yard in question, which is now open, will soon be covered up to permit building construction to go up in the valuable air space above the yard. In order to conserve the function of the yard, personnel and engines in and outside the tunnel must be able to communicate with each other in the same manner as in open freight yards with the aid of normal walkie-talkies.

Especially important is the use of the G-Line in underwater tunnels. In Japan as well as in Great Britain, and recently in this country, attempts are made to increase the train speed to 150 miles/hour and more. At these high speeds, control of the train becomes difficult and cannot be made dependent upon visual observation alone. Therefore, the possibility has been considered of observing the track from the engine by means of a radar-type beacon.

In the usual type of radar, a radiating beam reflected from any subject located in its path is used; for example, to locate aircraft. This type of radar is not readily applicable, due to the manifold reflections occuring near the ground, which distort the signal. In this type of application, surface wave conduction was used first by the Japanese and now by Ferranti in England. (Fig. 9)

Ferranti has built a G-Line mounted along the railroad track, which produces a surface wave field that envelops the train. When the train passes, the field is disturbed and the position of the train will be indicated at a distant station as a pip on a cathode ray tube.

FIG. 9: Curve Trolley – Yucca Valley

Similarly, any obstacle ahead of the train can be indicated in the central station, as well as on the train itself. Naturally, this signal could not only be used for observation, but also to control speed, brakes, etc. to automatize the train. The same G-Line along the railroad track could also carry, because of its bandwidth, a great deal of other information, such as freight data, voice, tec.

Such a system is now under study by ourselves, our Belgian licensee, ELECTROBEL, and the British Railways Board for a 200 mile data transmission system, connecting Manchester and Glasgow, to carry 760 data channels. It is intended to be installed simultaneously with the electrification and speeding up of a vital portion of the British Railways System.

Similar radar-type G-Line installations have been used as security fences to observe from a remote position the entry of persons or objects into sensitive areas surrounded by such G-Line fence.

POWER DISTRIBUTION CONTROL

The ELECTROBEL study. The specific needs of power distribution systems. Rapid increase of consumption and equipment requires increase of controls, channels, and bandwidth of transmission medium, especially in highly industrialized areas in Belgium. Difficulty of planning ahead and obtaining government channels for expansion. The G-Line a flexible private transmission medium, fitting into operation of power distribution system operation.

A development of equal significance is taking place in the field of communications along electric power lines. As mentioned before, this is an industry which traditionally had a certain autonomy in communications.

Until now, these communications and signals were carried as high frequency currents superimposed on the high voltage lines. Here again with the increasing size and complexity of the power networks, and especially in the highly industrialized areas of Western Europe, the need arose to increase the number of channels: The various power stations of a network had to be inter-connected and controlled in such a way that any such station was in operation only when it would produce power at the cheapest price, compared to other stations of the network.

These operations, ever growing in number and in complexity, with increasing power demand, led to a progressive automatization and to the use of computers. This required an increase of the bandwidth of the communication medium and also an increased purity of signal which could not be found in the relatively low frequency range of the carrier currents superimposed on the high tension wires.

The power companies were forced to seek other transmission media, and many of them started to use Microwave by Air.

As with the railroads, this was a policy not easily accepted, because it forced the power companies to abandon their autonomy in communication over their own ground. They had to apply to governmental authorities for public channels, buy new land for construction of antenna towers, incur further expenses to connect these towers to their high tension lines, etc., and what is more important, it also restricted their freedom and facility of expansion.

In CATV, also, once you have acquired a Microwave system for say seven TV channels, the bandwidth is fixed. If, years later, you need additional channels, you will have to apply and pay again, unless you had foreseen and built for such an expansion, and provided the government had given you sufficient bandwidth.

This, of course, is as difficult to foresee as it is to obtain. The expansion capability given by the G-Line is within your control.

The G-Line, running on the power company's own masts, gives it all the expansion it may ever want.

THE ELECTROBEL G-LINE

UHF G-Line, replacing UHF Microwave Relay. The same terminal equipment is connected by a G-Line, mounted on power masts. Surface wave transmission line adapted to stress and grounding regulations of high voltage line.

Such a power G-Line has been built by ELECTROBEL in Belgium.

The ELECTROBEL G-Line replaces an existing Microwave by Air system. The old Microwave Relay system consisted of a transmitter-receiver unit, at the station of Gouy operated at 450 to 460 mc, feeding an antenna located on top of the station.

A similar transmitter-receiver unit, located 8 miles away, fed another antenna located on a mast on Monceau.

Now, the two antennas have been disconnected and the transmitter-receiver units directly connected through a G-Line mounted on the masts of a 70 kv high tension line, connecting Gouy and Monceau (Fig. 10)

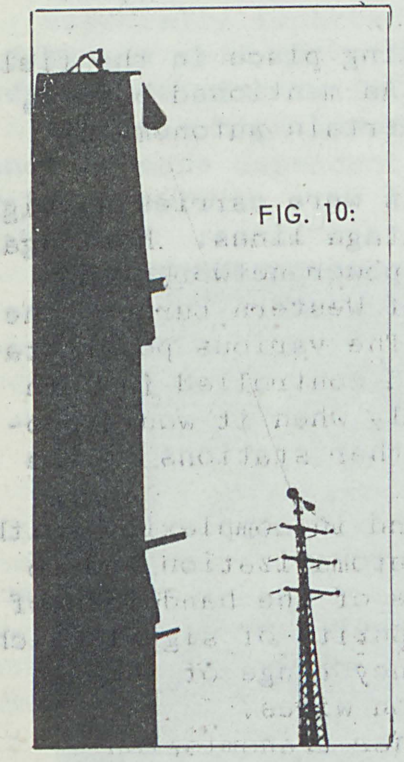


FIG. 10:

G-Line, Bi-Directional for Power Line ELECTRI BEL Brussels Terminal at Gouy

SPECIFIC DESIGN OF ELECTROBEL INSTALLATION

The G-Line, as a multi-conductor cable, with horns of extremely low loss, low-standing wave ratio, low overall loss safety against current increase. Mechanical requirements imposed by high power line regulations. Installation by power line crews; signals found not different from Microwave Relaying. No intermodulation; no additional noise. 8 db/mile at 450 mc.

This terminal equipment has a capacity of 24 channels of which, at present, 6 channels are utilized to transmit the following information: 1 telephone channel -- 6 telemeasuring channels -- 24 telecounter channels -- 3 telesignaling groups -- 2 teleprotection channels -- 2 transmissions of production data.

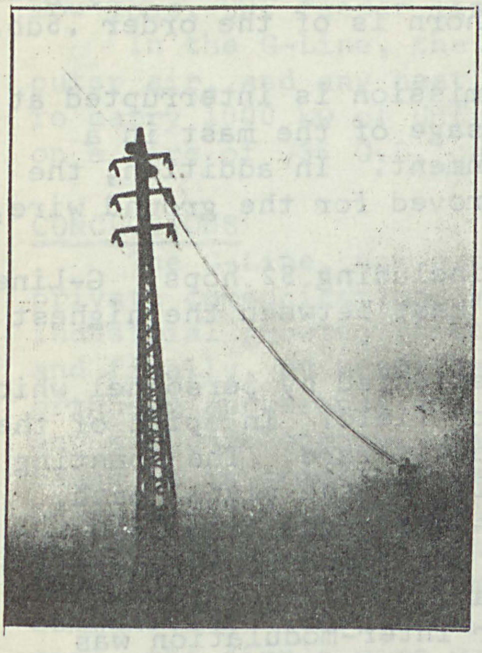


FIG. 11: G-Line on Power Masts: Gouy-Monceau

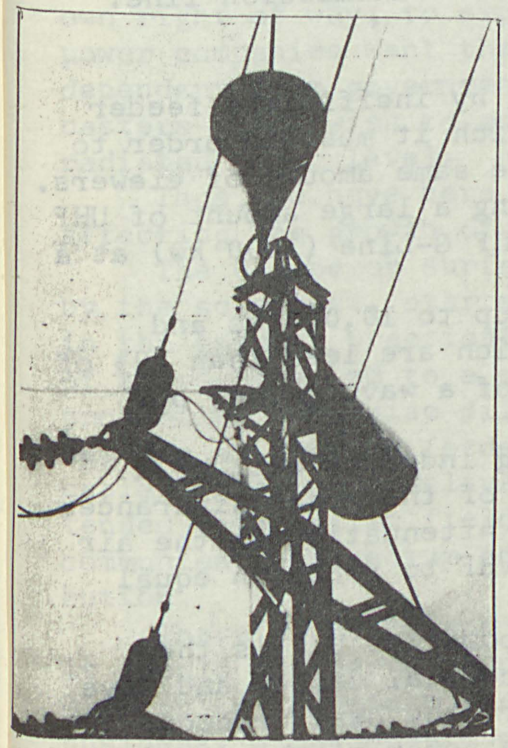


FIG. 12: Mast Assembly on Corner: Gouy-Monceau

The cable utilized in this system consists of a galvanized steel core, imposed by the Belgian regulations for ground wire, covered by an insulation layer, which in turn is surrounded by a copper foil, forming the surface conductor proper. Then follows an uncolored plastic layer, coated by a black protection sheath, leading to an outer diameter of .64".

The attenuation expected was of the order of 8 db/mile at 450 to 460 mc.

Power line regulations imposed upon the installation of this cable certain stringent conditions which were mechanical as well as electrical.

Tensile strength had to be adjusted to hops of 800 to 1200 ft. length. The cable running parallel and rather close to the power conductors, is continuously subjected to the induction of very high voltages.

In order to protect the terminal equipment, these induced voltages must be led to the ground. It is necessary; therefore, to connect the surface wave conductor to a ground galvanically. Moreover, there must be assured around the surface wave conductor a free space of about one wavelength diameter. Since it was difficult to comply with this condition on the existing masts and in view of the necessity of grounding the induced charges, you will notice (Fig. 11) that on the top of each mast the G-Line is not supported by nylon V-shaped suspensions, but coming out of a horn on one side of a tower and connected by a coaxial cable to another horn on the other side of the tower.

In this assembly, the horn proper transforms the surface wave into a wave which can be normally propagated in a coaxial cable. The horn is connected to a transducer which adapts the impedance of the G-Line (about 230 ohms) to the impedance of the coaxial cable (50 ohms) and also assures the necessary galvanic ground connection. The attenuation per horn is of the order .5db. It can be reduced to .15 db per horn.

Due to this arrangement, the G-Line transmission is interrupted at each mast by a coaxial cable which permits passage of the mast in a manner not subjected to restrictions of environment. In addition, the cable can be fixed in a manner, officially approved for the ground wire, of high voltage power lines.

The Power G-Line has a length of 8 miles including 52 hops. G-Line cable and horns are attached to the top of the mast between the highest power conductors and the ground wire.

The installation of the power G-Line was effected by personnel which were in no way specialized in the high frequency field. In spite of the great number of connections, defects were extremely rare. The mounting personnel itself was able to check the continuity of the signal path.

After the terminal equipment had been connected, the line loss was measured (Fig. 12). A satisfactory regularity was found as a function of the distance; i.e., a good homogenity in quality of installation. In operation, until now, neither distortion nor inter-modulation was noticeable. It is planned to leave the G-Line in permanent service and add a bi-directional amplifier at the midpoint of the line, to demonstrate the possibility of extending the G-Line with the aid of conventional repeaters, to any desired distance.

Eventually, the G-Line will be raised in place of the ground wire, which is on the top of the high tension lines. There it will serve two functions: as a ground wire, and as a broad-band transmission line.

OTHER DEVELOPMENTS

TV broadcasting, at UHF frequency hampered by inefficient feeder lines, also incapable of carrying high power which it must in order to compete with existing VHF stations and reach the same amount of viewers. The G-Line, with surface wave capable of carrying a large amount of UHF power, without being overheated. A mega watt UHF G-Line (1000 kw) at a loss of .5 db/100 ft.

Further applications are in antenna lines up to 10,000 mc and which provide antenna transmission at losses which are less than 50% of that of a coaxial cable and comparable to that of a wave guide, but costing much less.

Of particular interest for the broadcasting industry will be a UHF antenna line of extremely large power. One of the great hindrances of UHF is the fact that UHF is subject to great attenuation in the air and, therefore, needs more radiated power than VHF to reach an equal number of viewers.

One of the main factors limiting radiated power at UHF is the antenna feeder line. At UHF even the heaviest coaxial cables and wave guides have excessive losses. In Coax, moreover, the heat produced by the power cannot be dissipated. This limits the power of the coaxial cable. In addition, cost of installing the heavy coaxial cable and wave guide structures are prohibitive.

With the G-Line, we expect to produce, at reasonable cost and low loss, UHF feeder lines, carrying from 100 to 1000 kw.

In the G-Line, the surface wave carries the energy through the outer air, and any heat produced is readily carried off. We expect to carry 1000 kw of UHF power at a loss of less than .5 db/100 ft., on a wire of .36 O.D. only.

CONCLUSIONS

The G-Line, now a practical tool for industries, requiring a private communications medium. The scientists directly affected industrial growth, first by mere speculation, then by experiment and finally, by practice. Practical application hampered by unorthodox appearance and lack of proof of reliability, inherent in any new development. G-Line should overcome prejudice, first because it is sometimes irreplaceable, has been demonsrated and is now being used as a permanent communication medium in the power industry. Why not in CATV to which it is well adapted as a wiring technique, independent from government handout, as well as old established communication carriers. In the power field fitting to its application, the simple wire wave guide has become a sophisticated multiconductor cable.

Summarizing, we see surface waves developing from an abstract concept into a practical tool capable of serving a number of industries, like CATV, which need low cost to reach into wide and low density areas.

Other industries like the railroads need better use of their own right of way, to expand speed and freight requirements: The power companies want the surface wave for communications, also independent from government, and finally, there are the UHF TV broadcasters which wish to compete with the VHF stations on the same radiated power level.

Thus, we have here the living proof of the scientist directly affecting the growth of an entire series of industries.

The G-Line or surface wave transmission line, as it is called by the scientist, started as a purely mathematical conception, and in the ensuing practical applications, the unorthodox appearance of the G-Line led to a slow, albeit progressing, recognition of properties otherwise difficult to believe. First, the line was used as an antenna feeder line, temporarily replacing coaxial cables, Microwave Relays and other media. Gradually, its use extended to specific fields, and now it is about to become a general communications medium for entire industries such as power distribution.

There is no reason why the G-Line should not go further, why it should not serve young industries like CATV which have so much difficulty to retain their rightful place in the communications business, a business dominated to a great extent by its senior members the large common carriers on one side and the broadcasting stations on the other. Is it not logical that the newcomer should turn to new techniques so well adapted to his operations and that the G-Line should become for long distance what coaxial cable is for short distance wiring: a permanent instrument in CATV installations? This tool, in spite of its unorthodox suspension methods, is much closer to the wiring techniques of CATV than microwave towers.

The new technique could give Community and Pay Television relative independence not only from the FCC, but also from the old communication carriers in possession of established rights.

It has become a transmission medium in its own right, usually superior and frequently irreplaceable. It has also become more sophisticated.

The development of the G-Line parallels the development of modern solid-state technique. This also started around 1950 with the introduction of germanium diodes used at the outset only as detectors, but gradually penetrating the entire amplifier technique in the form of multi-electrode transistors.

What was once a single wire G-Line has now become a multi-conductor cable, adding to the surface wave, the conduction of high tension currents, the grounding for safety, and the capability of coupling in transit.

It can combine the functions of several components into a single unit having all these functions.

This is progress.

MR. TAYLOR: Thank you very much, Dr. Hafner, for a very interesting talk on a very interesting subject, which I have had some opportunity to fool with myself, as you said. I think that we had best move along. We started a half hour late because of the very remarkable performance we had at noontime and we have two very interesting and important papers to hear this afternoon.

Mr. Rudy Riley, President of Systems Engineering, Inc. is sponsored in this paper by Phelps-Dodge Electronics Products Company and he is speaking on "Just Twelve Inches Away". Mr. Riley.

MR. RUDY RILEY (President, Systems Engineering Inc.): A casual glance at a well-constructed CATV plant reveals the striking similarity to its neighbor, just 12 inches away. Since the beginning of our industry, telephone research, techniques and equipment have contributed immeasurably to the success of CATV.

Historically, the basic problems experienced by the telephone companies have proved to be common to all cabled communication networks.

This paper will discuss the two factors that effect the economics of a cable system most: Cable and its maintainence.

Cable

The advent of color television and all band transmission has created a demand for CATV cable with minimum frequency and delay distortion.* An air-insulated rigid coaxial cable meets these requirements. In this cable the center conductor is supported with a minimum number of carefully spaced, low-loss insulators. However, this type of construction is not practical for use in strand supported CATV systems.

give another noise wave form 3 db higher than each of them by itself. So when we make a measurement this way, all we have to do is subtract 3 db from the results and then we get the cable perfectly balanced against the best thing it could be balanced against, which is itself.

MR. TAYLOR: Did anybody have another question they would like to ask?

MR. SHIELD: Don Shield, Vancouver. Ken, I was wondering if you have come up with a practical limit to the length of cable for which your testing technique is useable? I know that 2000 feet is a typical length for a reel, but it seems to me that the length of the cable or the attenuation will have an effect on your results as well. Am I clear on that, or is that a confusing thing?

MR. SIMONS: The answer to that question is that the return loss method gives you a view into the first 500 to 1000 feet, depending on the loss of the cable. Of course, it doesn't matter how much longer than that it is, but you're not looking at the middle of the cable. You get a decidedly prejudiced view of each end of the cable and if the manufacturer, under the present circumstances, could make cable that was very good at both ends and bad in the middle and save money that way, I suppose you could get away with it. But it doesn't generally happen, if you have a cable that is good at both ends. All things being equal, it's apt to be good in the middle.

MR. TAYLOR: Thank you very much, again, Ken. We'll proceed onto the next paper by Mr. Allen Kushner of Times Wire and Cable, who is going to continue the discussion of cable by talking about, "Coaxial Cable Performance for CATV". This is a substitute for Dave Karrmann who was listed on the program. I introduce Mr. Kushner. [Applause]

MR. ALLEN M. KUSHNER (Times Wire & Cable, Division of The International Silver Company): Dave Karrmann was originally scheduled to write this paper. However, since the time we submitted his name he was taken off this particular project. I was assigned the job of writing the paper. I watched with great interest Ken's paper because since I came with the Company my primary responsibility has been really to watch over the testing of cable. So I have seen some 300,000,000 feet of test reports reflecting basically what Ken has had on the board and it was quite interesting.

PURPOSE

The purpose of this paper is to discuss the characteristics of coaxial cable which are of major importance in CATV system performance. We shall attempt to accomplish this by showing how the cable affects system design and customer pciture quality. We also shall attempt to show the substantial improvements which have been made in cable design and manufacture in the past 15 years, and to discuss what remains to achieve the optimum cable design of the future. As a result of this discussion we hope to have underlined those cable characteristics most critical to system performance.

ILLUSTRATIVE AMPLIFIER and CUSTOMER HOOKUP

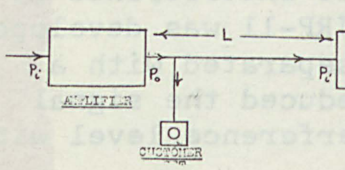


Figure 1

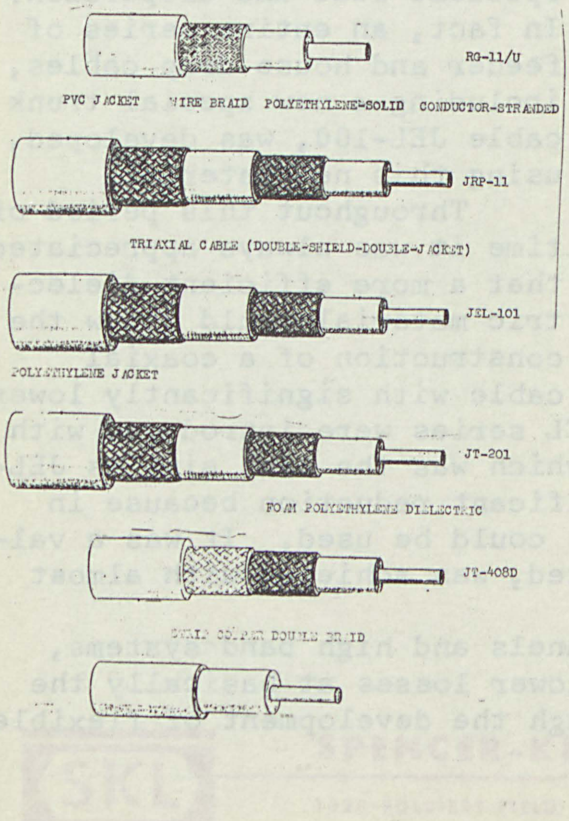
IMPORTANT CABLE CHARACTERISTICS

In Figure 1, a typical section of a feeder system is shown. The following important factors of this system should be noted:

1. For a minimum amplifier input signal, and a maximum amplifier output signal, the attenuation (loss) in the cable determines the distance between amplifiers. The lower the attenuation, the less the number of amplifiers to cover a specific distance.
2. Signals within the cable can escape. Such signals could exceed regulatory levels or disturb adjacent equipment. By the same means local interference due to ignition systems, ham operators, etc., could enter the cable and affect picture quality.
3. If there are reflections in the cable, these reflections will cause additional picture images to arrive at the customer's set after the main signal arrives, causing fading or ghosts.
4. It is not only necessary to have the cable meet specific performance requirements on installation, but it is also necessary to be certain that the cable meets these requirements throughout the system life.

IMPROVEMENTS IN COAXIAL CABLE DESIGN

Figure 2

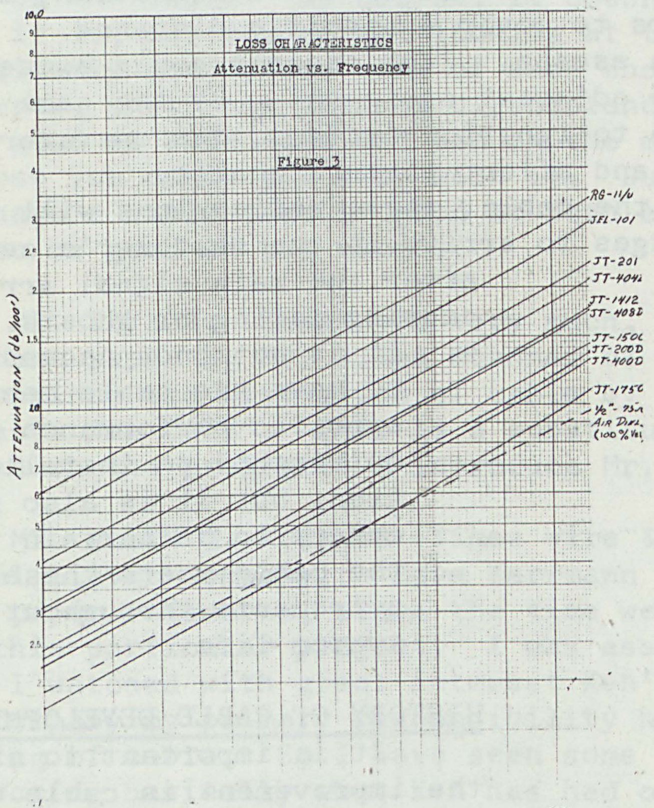


HISTORY OF CABLE DEVELOPMENT

It is important to study the improvement in cable characteristics over the years because these improvements were based on the changing system requirements and from feedback from field experience. In noting the trends in cable design and the reasons for the trends, we have an excellent foundation for selection of present day cable design as well as future cable development.

Let us trace first the changes in the cable constructions most commonly used and note the reasons for them. In Figure 2 we see the various cables and the approximate year in which they were first used. Prior to 1952, the cable first used as feeder cable was RG-11/U with stranded center conductor, solid polyethylene dielectric, a single braided outer conductor, and a polyvinyl chloride jacket. The most serious shortcoming of this design at that time was its shielding efficiency. The single braided outer conductor allowed significant cable interference as well as signal escape. To overcome this drawback, JRP-11 was developed, which was a triaxial cable having two outer braids separated with a layer of polyvinyl chloride. This triaxial cable reduced the signal escaping or entering to approximately 1% of the interference level with RG-11/U.

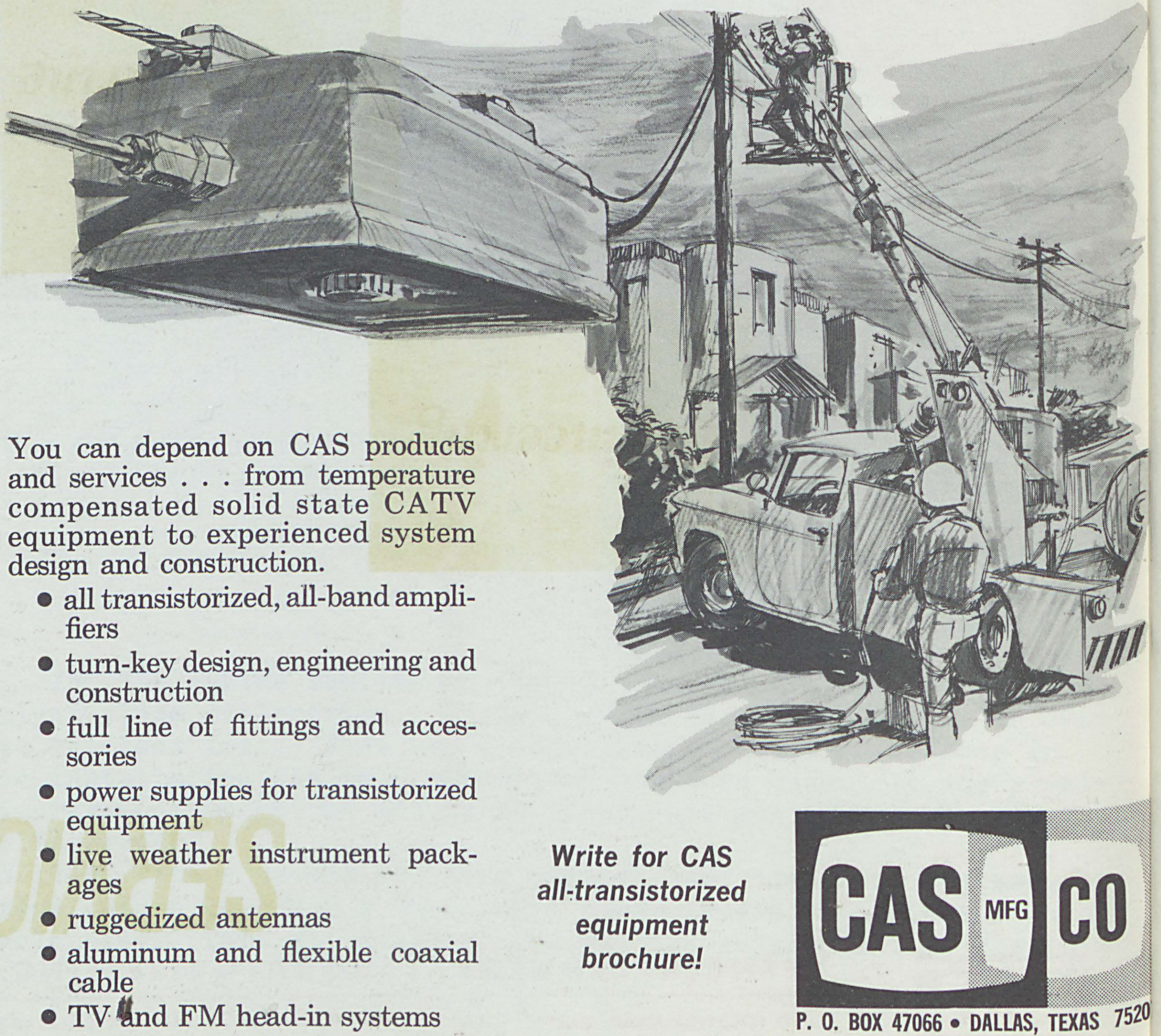
JRP-11/U, while an improvement over RG-11/U, still suffered from two major deficiencies. First, the polyvinyl chloride jacket material caused contamination of the polyethylene and an attenuation increase. In addition, the life expectancy of the PVC when exposed to sunlight was limited. In 1954, JEL-101 was introduced with Xelon, a long-life, non-contaminating polyethylene jacket and life expectancy of 20 to 30 years. This was a special high molecular weight polyethylene containing a predetermined percentage of carbon black of a specific size and dispersion. In fact, an entire series of feeder and house drop cables, including a new special trunk cable JEL-100, was developed, using this new material.



Throughout this period of time it was always appreciated that a more efficient dielectric material could allow the construction of a coaxial cable with significantly lower losses. In 1955 cables similar to the JEL series were introduced with foam polyethylene dielectrics. JT-201, which was the same size as JEL-101, had 25% less loss. This was a significant reduction because in the same installation 25% less amplifiers could be used. It was a valuable improvement which, it should be noted, was achieved with almost no cost increase.

In 1960, with a demand for more channels and high band systems, there developed a need for a cable with lower losses at basically the same cable cost. This was achieved through the development of flexible

specify CAS for performance-proved CATV products and services!



You can depend on CAS products and services . . . from temperature compensated solid state CATV equipment to experienced system design and construction.

- all transistorized, all-band amplifiers
- turn-key design, engineering and construction
- full line of fittings and accessories
- power supplies for transistorized equipment
- live weather instrument packages
- ruggedized antennas
- aluminum and flexible coaxial cable
- TV and FM head-in systems

Write for CAS all-transistorized equipment brochure!

CAS MFG CO

P. O. BOX 47066 • DALLAS, TEXAS 7520

braids of copper strips which achieved somewhat lower losses, but significantly greater shielding efficiency. Because of the improvement in shielding efficiency, two braids in contact could be used rather than a triaxial cable. This allowed a reduction in cost which, when coupled with the inherent economy in the strip itself, allowed the manufacture of a cable with larger dielectric than JT-201. This new cable, JT-408D, was primarily responsible for the development of all band systems at low band costs.

By 1963, with the increased installation of high band systems, it was noted that cable attenuation and useful cable life could be affected by aging of the cable components in the presence of moisture vapor.

It was determined that the metallic-type barrier achieved with a seamless aluminum tube was sufficient to prevent vapor entry. However, it was also noted that the dielectric must be compressed sufficiently to prevent longitudinal vapor entry through taps and fittings. In 1963 an economical technique was developed for producing 1000-foot lengths of cable with a seamless aluminum outer conductor properly applied.

The limitation of 1000-foot lengths did require the splicing of lengths, causing additional costs, reflections and maintenance problems. In 1965 the manufacturing techniques for producing up to one-half mile, continuous splice-free lengths was developed to reduce costs and improve performance.

This, then, is the history of the development of the coaxial cable. Please note that the key factors are: Shielding efficiency, jacketing materials, low loss, cable life (moisture resistance) and cable lengths.

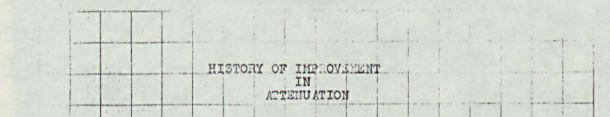


Figure 4

IMPROVEMENT IN CABLE ATTENUATION

The attenuation versus frequency response of all the cables are shown in Figure 3. It is interesting to note how the attenuation of the feeder and trunk cables was improved over the years. Figure 4 shows the attenuation of the trunk, feeder-trunk and feeder cables most commonly used and the year in which they appeared.

Though the purpose of this paper is to present the technical aspects of cable development, it is pertinent to this discussion to talk of the improvements which have been made in light of the cost for the various cables. To make this meaningful it is helpful to create an Amplifier Spacing/ Cable Cost Figure of Merit. This figure of merit is created by determing the number of feet of each type cable which we would have between amplifiers with 20 db spacing at Channel 13:

$$\text{F of M} = \frac{20/\alpha \text{ per foot}}{\text{cable cost per 1000 ft.}}$$

The higher the Figure of Merit, the more efficient is the cable construction. Figure 5 shows the improvement in amplifier spacing/cable cost Figure Of Merit over the years. It should be noted that this is a comparison on cable characteristics only, which is justified in the case of feeder cable, and does not take into account any costs due to amplifier requirements.

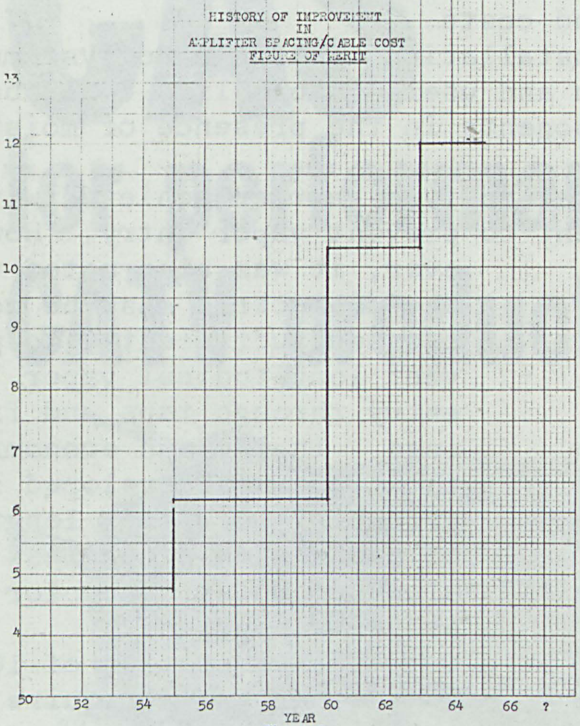


Figure 5

In the case of trunk cable, we must take into account the effect of amplifiers. In this case it is helpful to talk of an effective cable cost per 1000 ft. The cost of trunk cable and amplifiers is approximated by this relationship: Cable and amplifier cost =

$$\text{Length of Cable X Cable Cost} + \frac{\text{Lgt. of cable x atten. x ampl. cost}}{20 \text{ db}}$$

The amplifier cost consists of initial cost, plus installation cost, plus pole rental, power and maintenance cost. If we consider the life of the system to be five years, a conservative cost of \$760. is used. Since the length of cable is common to both factors, we can rewrite this expression as follows:

$$\begin{aligned}\text{Cable and Amplifier Cost} &= \text{Length of Cable}\left[\text{Cable Cost} + \frac{\text{Atten.}}{20} \times 760\right]\\ &= \text{L (Cost/1000 ft.} + 38 \text{ attenuation/1000 ft.)}\\ &= \text{L (Effective Cable Cost)}\end{aligned}$$

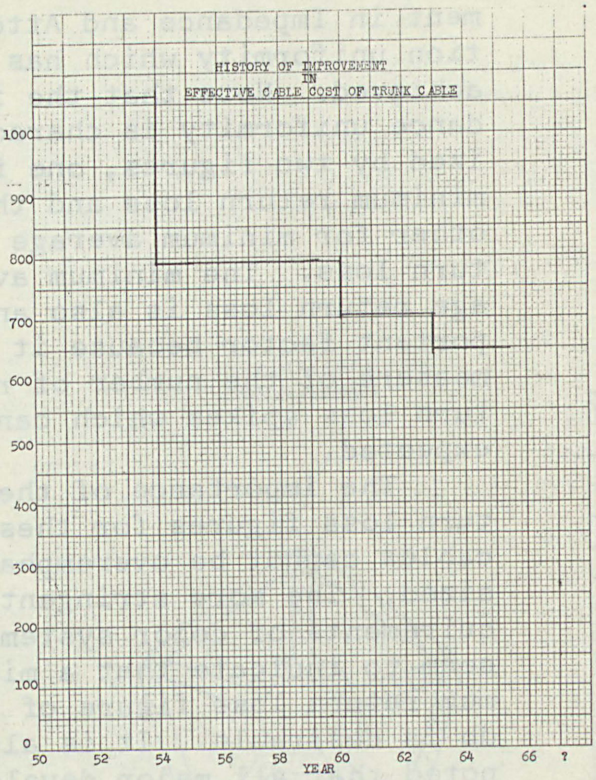


Figure 6

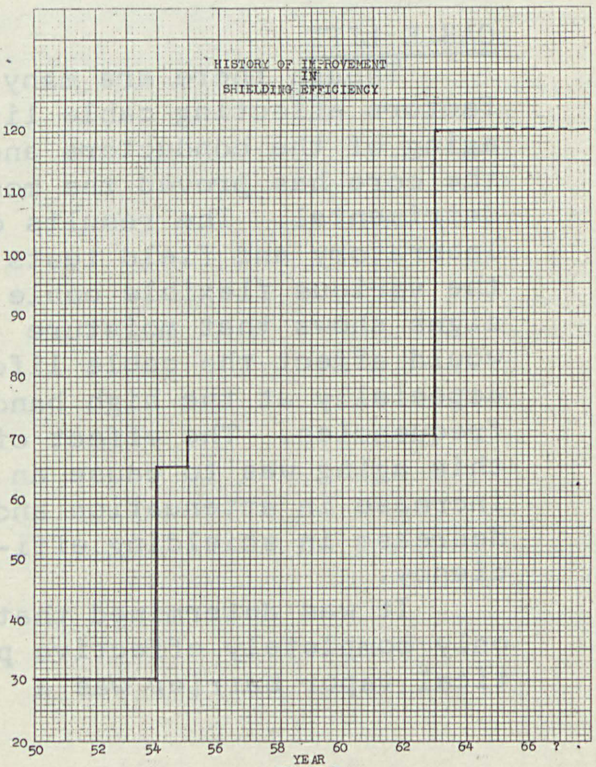


Figure 7

Figure 6 shows the reduction which has been achieved in Effective Cable Cost for trunk cable.

IMPROVEMENT IN SHIELDING EFFICIENCY

It was determined in 1952 that a triaxial version of RG-11/U was necessary to meet the limits of system interference requirements. This requirement has not truly changed to the present time. However, the shielding efficiency of present day constructions are vastly improved so that it is interesting to chart the change in shielding efficiency. Figure 7 shows the shielding chamber. It should be noted that the limitation of present day cable is in the connectors used. In fact, our present test equipment is not sensitive enough to measure radiation from the aluminum sheathed cable.

IMPROVEMENT IN RETURN LOSS FIGURE

Any variation of dimensions or velocity of the dielectric will cause reflections within the cable. If there are enough of these reflections, and if they are evenly spaced, we will find that the reflections will add at specific frequencies to give attenuation increases and impedance variations. We determine the attenuation variation by sweeping the cable and looking for attenuation "suckouts". We determine the impedance variation by using a bridge and measuring the db difference

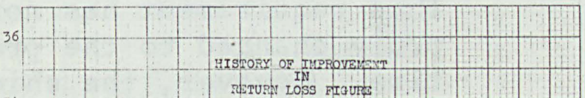


Figure 8

between the signal in and the signal reflected, and by looking for return loss spikes.

Figure 8 shows the improvement in Impedance and Attenuation uniformity which has been achieved. Note that the impedance uniformity is characterized by two figures, one for minimum return loss and the other for minimum average return loss. The minimum average return loss is also an important factor because it is a measure of the number of return loss spikes which can be expected.

The importance of the return loss figures for these cables cannot be overemphasized. The more stringent requirements of color systems seem to indicate that a minimum return loss figure of 30 db is desirable. It is also noted that all major developmental work being performed today is being done with 30 db as the minimum acceptable return loss figure.

<u>CABLE LIFE</u>

Though there are many factors affecting cable life, aging of the conductors and the core has proved the most detrimental. The results of laboratory and field tests on the various flexible cable designs shows that moisture would affect the cable life especially at the high band frequencies. The effect of this aging was to cause an increase in attenuation and a decrease in shielding efficiency.

It was determined that the only completely effective practical vapor barrier was a metallic barrier such as that formed by a tubular outer conductor of copper or aluminum. It was further determined that this barrier has to be continuous all the way around, with no opening. Though this did take care of radial leakage, there was the additional problem that leakage at the connectors or taps would allow moisture to enter. This vapor would propagate the length of the cable if there were longitudinal paths.

To prevent longitudinal paths, new aluminum sheathed coaxial cable must be manufactured with adhesion to the center conductor and with compression of the dielectric under the outer conductor.

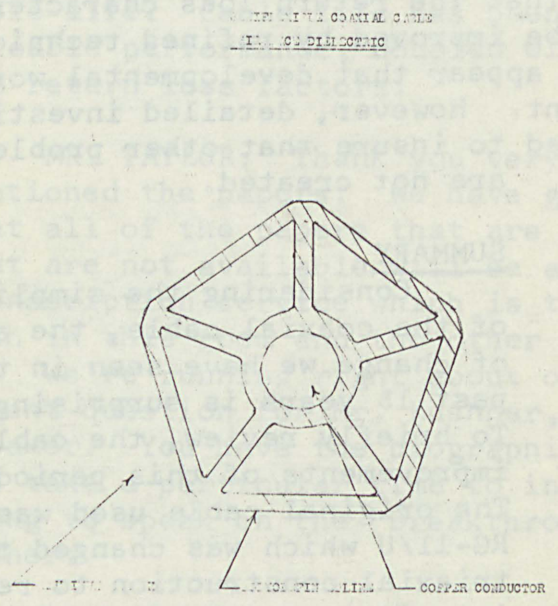


Figure 9

ATTENUATION REDUCTION

It would appear that future development will be in the area of improved dielectric material. Figure 4 shows the attenuation which could be achieved if improved foam polyethylenes were available. The attenuation which could be achieved with air dielectric cables is also shown in Figure 4. While the development of improved foam dielectrics appears feasible, it is questionable whether the use of air dielectric cable is practical.

In Figure 9 is an air dielectric cable which Times manufactures. Even though the center conductor is tightly covered with a layer of polyoelfin, and can in no way corrode, the attenuation of the cable is affected by moisture entry. To properly and dependably use this construction would require pressurizing the cable. While this is possible, the cost of pressurizing equipment, cost of special fittings and the increased maintenance problems, make the economic feasibility doubtful. Should the use of airspace cable be considered, it is worthwhile to note that corrosion of the center conductor is an irreversible process and that the center conductor should be protected.

IMPROVED RETURN LOSS RESPONSE

Our present evaluations indicate that the return loss characteristics of our present constructions can be improved by refined techniques and improved equipment. It would also appear that developmental work in new materials may lead to improvement. However, detailed investigation of such materials would be required to insure that other problems are not created.

SUMMARY

Considering the simplicity of the coaxial cable, the amount of change we have seen in the past 15 years is surprising. To briefly review, the cable improvements of this period: The original cable used was RG-11/U which was changed to a triaxial construction to reduce interference; the jacketing material was changed to eliminate contamination and increase cable life; this was followed by changing the dielectric to reduce attenuation, and next the outer conductor braid material to reduce cost. The most recent changes were to substitute a seamless aluminum outer conductor to prevent cable aging and to manufacture longer lengths to reduce installation costs.

We note that there have been significant reductions in attenuation coupled with reduction in cable costs which are indicated by the amplifier-spacing/cable cost Figure of Merit for Feeder Cable. We note also that there have been significant reductions in the Effective Cable Cost. Though materials are not presently available, it would appear that in the future a decrease in cable attenuation of approximately 10% will be realizable without significant cost increase. If an airspaced dielectric cable considered only 3% additional reduction in attenuation would be achieved.

It is questionable whether this additional increase in performance would be justified in light of additional equipment and maintenance costs.

It also appears feasible that return loss figures of 36 and 40 db may eventually be feasible. Present system requirements as established by major development groups in this field, have set a minimum return loss figure of 30 db for feeder and trunk cable, at the present time.

Because of the development of the aluminum sheathed coaxial cable with prevention of longitudinal vapor paths, it would appear that we have also approached optimum shielding efficiency and cable life. Cable life has been shown to be a very important factor in cable performance, coupled with the attenuation, cost, shielding and return loss factors.

MR. TAYLOR: Thank you very much, Mr. Kushner. Mr. Kushner mentioned the papers. We have gotten papers out of the boxes so that all of the papers that are available are here. Those papers that are not available will be available, however, through the transcription service which is taking down all of the presentations both in this room and the other room.

We're running right about on schedule. Unless somebody has an urgent question for Mr. Kushner, I would like to move on to the next speaker. You have the biographical sketch on your chairs so I will not take a particular time to introduce Dr. Theodore Hafner, who is going to speak on the "Breakthrough With Microwave by Wire". Dr. Hafner.

DR. THEODORE HAFNER (President, Surface Conduction, Inc.): I am somewhat embarrassed. I have to talk about something which is entirely different from what you have just seen. It is, in a way, fundamentally new. This has a certain advantage, but it also has a certain disadvantage. The disadvantage is in the difficulties of an explanation.

Now, if I may, I hope my predecessor here in speaking will forgive me if I use some of his figures. He's talking about improvements from 50 db per mile to 40 db per mile. And, I am going to speak about improvements from 40db per mile to 10 db per mile.

HISTORY AND THEORY

Wire or wireless. The surface wave, a third medium combining privacy of wire with the low loss of radiation. The surface wave, a fundamentally novel wave mode. Simple (though only theoretical) derivation of existence of surface wave; its low loss and wide applicability.

What is the G-Line? Where does it come from? Where does it go?

I am reminded of the famous Austrian General Radetzky. At one of the war games of the Austrian army, one of the participating army groups was commanded by an Archduke who was not too well known for his intelligence. After the battle, Radetzky surveyed the happenings increase the level in dbs, then you multiply the cross-mod by the number that is in the second column. But, again, as I said, there are many right ways of doing this thing and none is better than the other. Some are only more convenient. Thank You. (Applause)

MR. TAYLOR: Thank you, again, Dr. Shekel, very much. Maybe somebody will volunteer to be chairman of the Standards Committee. You can see the problems that arise in those deliberations.

Our next presentation will be on a subject that is somewhat new in this industry, Envelope Delay in CATV. Gaylord Rogeness from AMECO in Phoenix, Arizona, is our speaker, and his background, biographical sketch has been placed in your hands. Mr. Rogeness.

MR. GAYLORD ROGENESS: Thank you, Mr. Taylor. This morning I'm going to speak to you on the subject of Envelope Delay in CATV Systems.

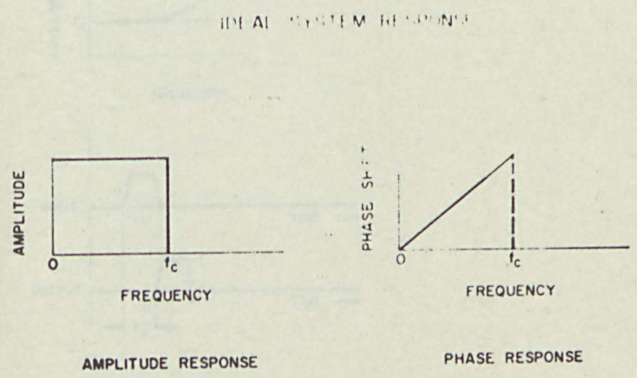
Comparison of pictures produced by off-the-air signals and signals that have been transmitted through long cascades indicate that the off-the-air signal produces a sharper, more crisp picture. This effect is also more noticeable on low band channels compared to the high band channels. The low band channels produce a picture that is somewhat more fuzzy.

These effects exist even though the amplifier cascade has been aligned for optimum amplitude response, the cross modulation is at a minimum level, and the signal-to-noise ratio is high. Envelope delay distortion is a quantity which can explain some of these effects. Until recently, CATV systems have been providing pictures in areas where TV reception has not existed or has been very poor. Hence, there was little need to consider the more subtle transmission system requirements. However, as CATV moves into areas where competition with off-the-air reception exists, and the transmission of good color pictures is required, the effects of envelope delay have to be considered.

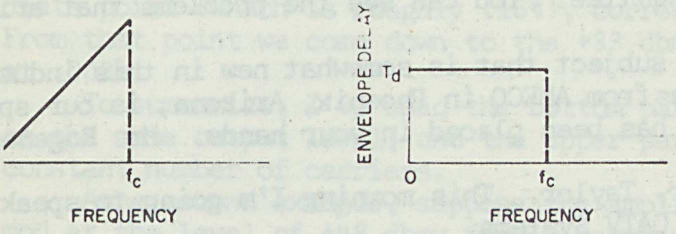
The objectives of my paper this morning are first to define envelope delay. Second, discuss the effects of envelope delay distortion of TV pictures. Third, discuss the sources of envelope delay, or where does envelope delay originate in the CATV transmission system? And finally, suggest possible measurement techniques and solutions to the problem of envelope delay distortion.

The CATV system receives a TV signal at an antenna and from this point has to transmit the TV picture signal to the home receiver through head-end equipment, cable and repeater amplifiers. Therefore, the transmission characteristics of this equipment should be as close to the ideal transmission characteristic as possible in order to provide the home receiver with the same picture quality that is received at the CATV antenna.

An ideal system has a flat amplitude response with respect to frequency and a phase shift characteristic that is linear. This is shown in FIGURE ONE. FIGURE TWO shows phase and delay characteristics of the ideal system. Envelope delay is defined as the rate of change of phase shift with respect to frequency. Or, in other words, envelope delay is the incremental slope of the phase shift curve versus frequency. In an ideal system the phase response is linear, so that the incremental slope of the phase response is constant. Hence, each frequency has the same value of envelope delay. It should also be noted that in an ideal system, time delay and envelope delay are equal.



IDEAL SYSTEM RESPONSE

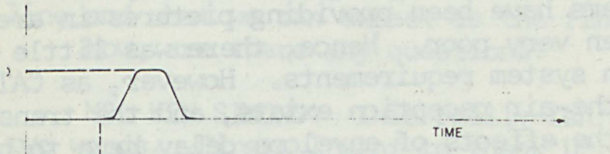


PHASE RESPONSE

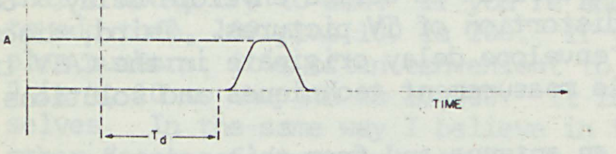
ENVELOPE DELAY RESPONS

A TV picture signal consists of a sum of pulses which in turn are the sum of many frequency components. When this signal is transmitted through an ideal transmission system, each frequency component experiences the same delay. As a result, the TV picture signal at the output of the transmission system is the same as that at the input but delayed in time. FIGURE 3A shows a pulse applied to the input of a CATV system. If the ideal characteristic of flat amplitude and linear phase over the band of frequencies being transmitted exists, the output will be a delayed replica of the input as shown in FIGURE 3B. The output pulse waveform will be exactly the same as the input pulse waveform and will occur at a later point in time.

The difference between envelope delay and time delay is shown in FIGURE FOUR. These quantities are compared at the frequency f_c. Time delay is the phase shift at this frequency divided by the frequency, whereas envelope delay is the slope of the phase response at the frequency f_c. Note that the magnitude of envelope delay is larger than the time delay magnitude.

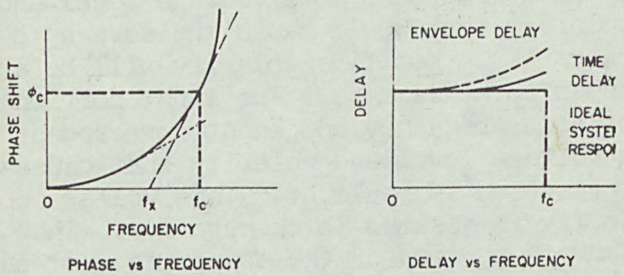


a) INPUT SIGNAL



b) OUTPUT SIGNAL IS DELAYED REPLICA OF INPUT SIGNAL

RELATION BETWEEN TIME DELAY AND ENVELOPE DELAY



PHASE vs FREQUENCY

DELAY vs FREQUENCY

$$\text{TIME DELAY} = \frac{\phi}{f_c}$$

$$\text{ENVELOPE DELAY} = \frac{\phi}{f_c - f_x}$$

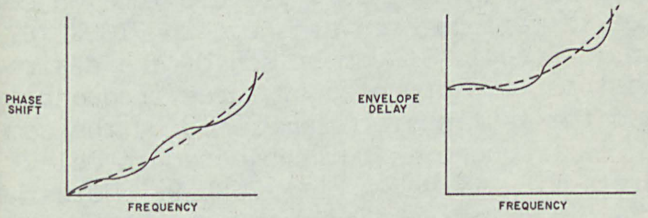
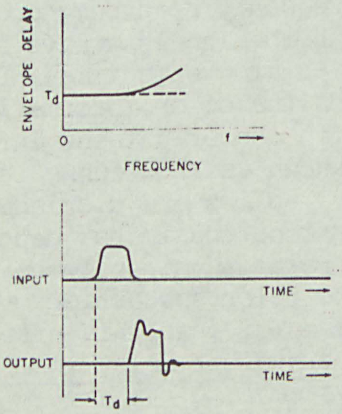


FIGURE 5. PHASE AND DELAY DEVIATION FROM LINEARITY. (NOTE THAT THE DOTTED LINE INDICATES THE SLOW DEVIATION FROM LINEARITY)



PULSE DISTORTION DUE TO NONUNIFORM ENVELOPE DELAY

FIGURE 4B shows a rough comparison of envelope delay and time delay over the frequency range of interest.

Specification of envelope delay deviation from a constant value is a means of restricting variations in the transmission system phase response. One of t the values of this specification lies in the fact that envelope delay is a measure of the rate of change of the phase response. Hence, not only is the magnitude of deviation from phase linearity defined, but also the rate at which the phase response deviates from linearity.

Phase distortion and therefore envelope delay distortion in a practical system can normally be characteriz-e by two descriptions. One is a gradual deviation from the linear phase characteristic, occurring over the major portion of the system passband. This distortion is important when comparing the transmission of color information with the luminance information through a system. The second type of distortion involves variation from linearity over small sections of the passband (See FIGURE 5). Both types of distortion must be considered in the design and operation of high fidelity pulse (or TV) transmission systems.

Effects of Delay Distortion

An envelope delay response common in practical systems is shown in FIGURE 6. The high frequency components are delayed by a greater amount than the low frequency components. A pulse applied to the transmission system with this delay response is shown in the center of figure 6. The resulting output is shown at the bottom of figure 6. Note that due to delay distortion, the pulse at the output now has both overshoot and undershoot. There are various types of delay distortion and each has effects on the fidelity of pulse transmission. I will not go into these this morning.

The next example which illustrates the effect of delay distortion involves the generation of a test pattern on a TV set.

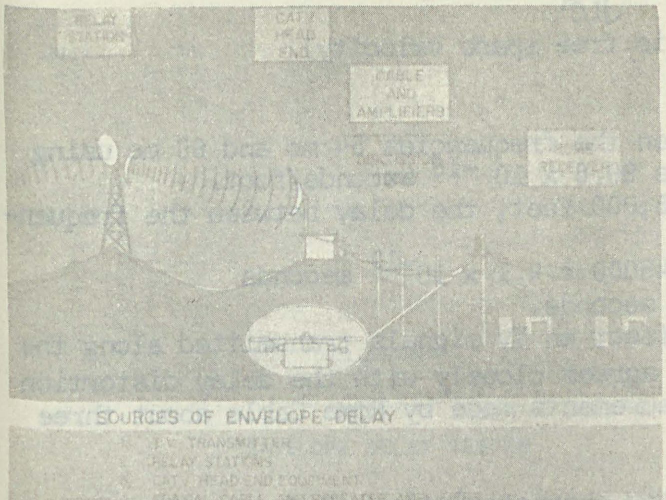
The bottom line of FIGURE 7 shows the desired test pattern. This test pattern is generated by the sum of three frequencies occurring in the time phase shown. The black portion of each frequency component shown corresponds to a voltage level and polarity that would cause the screen to be dark. A positive polarity will be assumed for this case. The light portion of each frequency component corresponds to a voltage level and polarity that causes the screen to be light. This voltage polarity is assumed to be negative. The darkest portion of the composite test pattern is then generated when all three positive voltages add at the same time. The dark gray is produced when only two positive voltages add. A completely white bar is produced when the negative voltages of all three frequency components add at the same time.

When all three frequency components are not delayed by the same amount during transmission to the TV picture tube, a composite test pattern as shown in FIGURE 8 could result. A comparison of the desired test pattern produced by three frequencies and the test pattern generated by the same three frequencies but subjected to delay distortion is shown in FIGURE 9. Note that the distorted pattern does resemble the desired pattern.

Consider next the effects of time delay distortion on a color picture. The color picture is composed of two main signals - the chrominance information which contains color information and the luminance signal which contains the brightness information. These signals are transmitted in different parts of the frequency spectrum, so it is important that both signals arrive at the TV picture tube at the same time. Due to delay distortion the color information may not coincide with the brightness information and an effect known as the "funny paper effect" occurs. Colors are displaced to the right or left of the image, depending upon the delay relationship between the picture carrier and color subcarrier. The red color is most sensitive to this effect.

Sources of Envelope Delay in a TV Transmission System

Sources of envelope delay in a TV trans-



mission system are depicted in FIGURE 10. A responsibility of the TV station is to transmit TV program material over the air. In so doing, the TV signal passes through equipment which have amplitude and phase characteristics that are frequency dependent.

Next a relay station may be necessary before the CATV system received the signal. This relay station is a second source of distortion in the system.

The CATV system consists of head end equipment, coaxial cable, and equalized amplifiers. Each of these three items is a potential source of distortion.

The signal finally arrives at the home receiver where it is processed and displayed. Many sources of amplitude and delay distortion exist in a TV set that is not properly aligned.

The FCC regulates the characteristics of the color TV signal being transmitted. The TV transmitter must have a prescribed envelope delay characteristic. This delay characteristic is specified to compensate for the delay distortion produced in the frequency selective circuits of the home receiver. The manufacturers of TV receivers use the specified delay characteristics of the transmitter to set design and manufacturing tolerances on their TV sets. Therefore, any picture transmission equipment placed between the TV transmitter and home receiver must be near perfect in order to minimize distortion.

Phase characteristics of the coaxial cable and equalized repeater amplifiers used in CATV systems will be discussed at some length today.

Phase Characteristic of Coaxial Cable

The transmission of energy along a coaxial cable is defined by the complex propagation constant. The propagation constant has a real and imaginary component. The real part describes attenuation along the cable and the imaginary component defines the phase shift constant of the coaxial cable. The propagation constant is

$$\gamma = \sqrt{(R+jwL)(G+jwC)} \quad (1)$$

For low loss cable, such as that used in the CATV industry, it is possible to simplify equation one and write the phase shift constant

$$\beta = \sqrt{LC}\left[1 + \frac{1}{8}\left(\frac{R}{WL}\right)^2\right] \quad \text{radians/unit length} \quad (2)$$

R, L., and C are the cable resistance, inductance, and capacitance per unit length and w is 2π times the frequency in cycles per second.

Remembering that envelope delay is the rate of change of phase shift with respect to frequency, the derivative of equation 2 yields the cable envelope delay.

$$T_E = \frac{dB}{dw} = \sqrt{LC}\left[1 - \frac{1}{8}\left(\frac{R}{WL}\right)^2\right] \quad \text{seconds/unit length} \quad (3)$$

Note that envelope delay is not constant with frequency because of the $\left(\frac{R}{WL}\right)^2$ term. However, the magnitude of this deviation from a constant value is small enough to have negligible effect. A numerical example will show this:

Constants taken from a cable manufacturer's data sheet for 75 ohm Alucel 1/2" coaxial cable are

Capacity $C = 16.5$ pf/foot

Velocity of Propagation $V_c = 0.82\ V_o = \frac{1}{\sqrt{LC}} = 7.87 \times 10^8$ ft/sec

Attenuation (V_o is free space velocity)

$\alpha = 0.006$ db/ft at 54 mc

$\alpha = 0.0065$ db/ft at 60 mc

The difference in envelope delay between the frequencies 54 mc and 60 mc using the cable constants listed and equation 3 is 90.6×10^{-18} seconds/foot.

For a 30 amplifier cascade extending 45,000 feet, the delay between the frequencer 54 mc and 60 mc is

$$T = 90.6 \times 10^{-18} \times 45000 = 4.1 \times 10^{-12} \text{ seconds}$$

$$T = 4.1 \text{ micro-micro seconds.}$$

This delay distortion has negligible effect on TV signals transmitted along the cable. This number of 4.1×10^{-12} seconds agrees closely with the delay distortion calculated from velocity of propagation measurements made by Rome Cable about three years ago.

Repeater Amplifier Delay Characteristics

The next problem is to describe the delay characteristics of the equalized repeater amplifier. A theoretical response for the equalized repeater amplifier was postulated for an 18db length of cable. The amplifier response was assumed maximally flat at both the low and high end. The high end roll off was assumed more steep than the low end because of the cut off characteristics of the transistors.

The transfer function of an equalized amplifier can be written:

$$\frac{e_{out}}{e_{in}} = \left[\frac{1 + j\frac{w}{w_1}}{1 + j\frac{w}{w_2}}\right]\left[\frac{\left(j\frac{w}{w_3}\right)^n}{\left(1 + j\frac{w}{w_3}\right)^n}\right]\left[\frac{1}{\left(1 + j\frac{w}{w_4}\right)^m}\right] \quad (4)$$

To calculate the envelope delay of this expression the phase response is first derived and is

$$\text{Phase} = \tan^{-1}\left(\frac{w}{w_1}\right) - \tan^{-1}\left(\frac{w}{w_2}\right) + 90^\circ = \tan^{-1}\left(\frac{w}{w_3}\right)^n - \tan^{-1}\left(\frac{w}{w_4}\right)^m \quad (5)$$

The envelope delay is the derivation of equation 5 with respect to w ($2\pi f$).

$$T = \frac{1}{f_1}\left[\frac{1}{1+\left(\frac{w}{w_1}\right)^2}\right] - \frac{1}{f_2}\left[\frac{1}{1+\left(\frac{w}{w_2}\right)^2}\right] - \frac{n}{f_3}\left[\frac{\left(\frac{w}{w_3}\right)^{n-1}}{1+\left(\frac{w}{w_3}\right)^{2n}}\right] - \frac{m}{f_4}\left[\frac{\left(\frac{w}{w_4}\right)^{m-1}}{1+\left(\frac{w}{w_4}\right)^{2m}}\right] \quad (6)$$

Phase, time delay, and envelope delay were calculated as a function of frequency using equation 5 and 6 are shown in FIGURE 11. The following values were used in the calculations:

$w = 2\pi f$

$w_1 = 2\pi \times 49.5 \times 10^6$ $n = 2$

$w_2 = 2\pi \times 334 \times 10^6$ $m = 4$

$w_3 = 2\pi \times 40 \times 10^6$

$w_4 = 2\pi \times 250 \times 10^6$

Note that envelope delay is not constant with frequency as is required for an ideal transmission system. Also note that channel 2 is more susceptible to response irregularities than channel 13 because it occupies a higher percentage bandwidth.

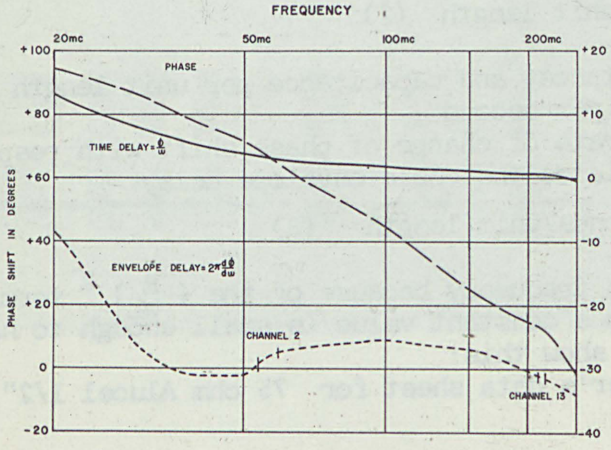
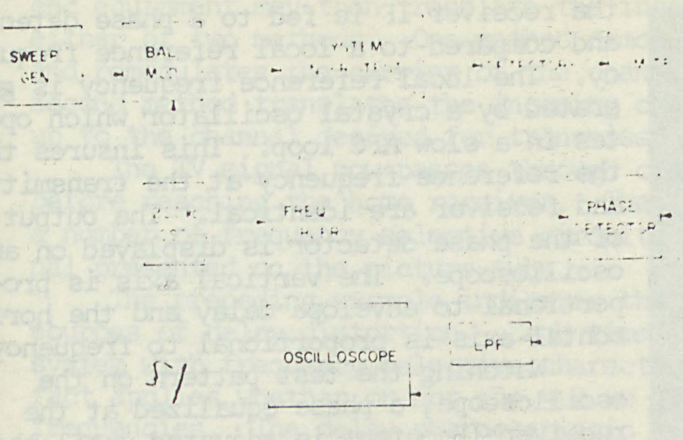


FIG. 11. CALCULATED PHASE AND DELAY RESPONSES



ENVELOPE DELAY TESTER

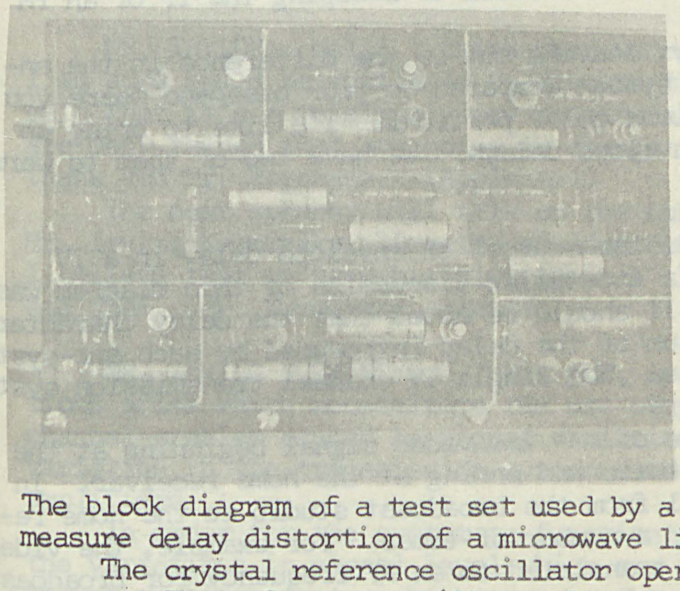
(6 mc bandwidth at 54 mc compared to 210 mc).

Envelope Delay Testing

A block diagram of a test set that measures envelope delay is shown in FIGURE 12. The 200kc reference oscillator output is applied to a frequency doubler and balanced modulator. The second input to the balanced modulator is a sweep generator. The output of the balanced modulator is two frequencies spaced at twice the reference oscillator frequency. These two signals are applied to the system under test and are swept across the frequency spectrum maintaining a constant spacing.

The test signals are detected at the output of the system under test and then passed through a limiter. The test signal at the output of the limiter is then compared in a phase detector with the output of the frequency doubler. Each of these signals is at the same frequency. However, the doubler output has a constant phase reference while the signal passed through the system under test is measuring the incremental slope of the system phase response. The output of the phase detector is a DC voltage proportional to the envelope delay of the system under test.

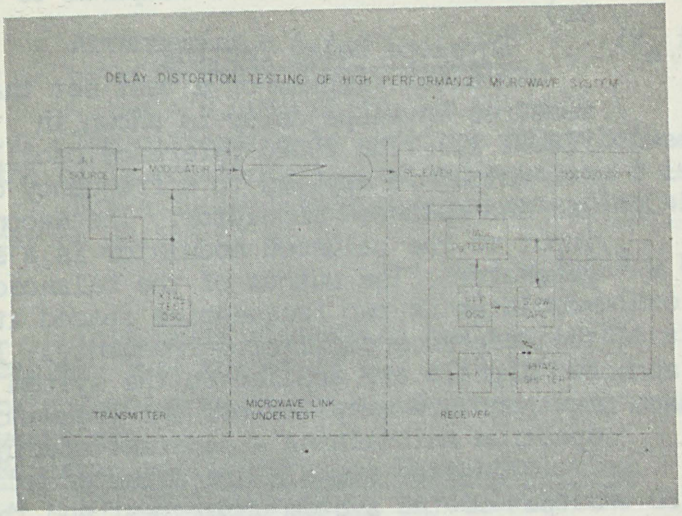
The oscilloscope displays envelope delay on the vertical axis and frequency on the horizontal axis. The vertical scale can be calibrated in terms of electrical degrees or directly in units of time (microseconds or nanoseconds). A frequency marker can be inserted into the test set for calibration of the horizontal scale.



An envelope delay test set was constructed by utilizing the principles described in the preceding three paragraphs. This test set is shown in FIGURE 13. Unfortunately, time did not permit the completion of many delay measurements before the convention. However, the envelope delay of a cascade of three AMECO ATM-70 amplifiers and 75 db (220mc) of coaxial cable was measured. The envelope delay characteristic was constant from 40 mc to about 90 mc and then began gradually sloping through the high band. The difference in delay across any high band channel was less than three nanoseconds (3×10^{-9} seconds).

The purpose of this next example is to point out that phase distortion, and hence delay distortion, can be measured and corrected in the field even though the transmitted and received signals are physically separated by large distances. The block diagram of a test set used by a manufacturer of microwave equipment to measure delay distortion of a microwave link is shown in FIGURE 14 (next page).

The crystal reference oscillator operates at about 500kc and modulates the RF source. The reference oscillator frequency is divided down to provide a sweep voltage to sweep the RF source through the passband of the transmission system. The swept RF signal is transmitted over the microwave link and is received at the remote



location of the receiver. The output of the receiver IF is fed to a phase detector and compared to a local reference frequency. The local reference frequency is generated by a crystal oscillator which operates in a slow AFC loop. This insures that the reference frequency at the transmitter and receiver are identical. The output of the phase detector is displayed on an oscilloscope. The vertical axis is proportional to envelope delay and the horizontal axis is proportional to frequency.

Watching the test pattern on the oscilloscope, a phase equalized at the receiver IF output is adjusted until the transmission system delay distortion is minimized.

Today I have defined envelope delay as the rate of change of the transmission system phase response. Some of the effects of delay distortion on the transmission of TV pictures were mentioned as a loss of crispness of the black and white signal and a funny paper effect on color pictures.

I believe that we must now develop test equipment to accurately measure the CATV system delay characteristics. After the delay characteristics have been measured, phase and/or delay equalizers can be designed to compensate for existing delay distortion. Thank you. (Applause)

MR. TAYLOR: Thank you very much. I think we would have time for one or two questions if somebody would like to. I see one here.

MR. WILLIAM CRUZ, (Collins Radio): I think it should be important at this point and time with your fine speech here to separate the distinction of envelope delay of your sweeping, the RF spectrum where cable activities -- it's all very proper, very correct. I agree with you completely. Your discussion of sweeping the IF of an FM or microwave system is also correct.

One other thing you are, sorry to say, leaving out is the difference in the envelope delay of your RF system or your IF system compared to your baseband where you are considering the envelope delay of various color portions. I'd like to bring up the point that they are quite different envelope delays. We have two of them to worry about. Thank you.

MR. ROGENESS: Referring to figure 10, the sources of envelope delay in a TV transmission system are shown pictorially. A detailed discussion of this diagram was not made because of the time limitation. It should be noted that the delay characteristic of a linear system is equal to the sum of the delay introduced by each sub-system contributing to the overall system response. The single TV channel transmission system delay characteristics are of importance here.

As an example, follow the transmission of a 4.2mc video signal beginning at the output of the TV camera at the broadcast studio and ending at the home receiver. In the transmission of this 4.2mc video signal from the broadcast studio to the home receiver, the video signal will be translated a number of times. For example, the video signal at the broadcast studio is mixed or translated to an RF frequency for broadcast. A microwave relay station may then receive this signal, translate it to IF frequencies and amplify it, and then mix back up to a microwave frequency for transmission at microwave. The next relay station may then translate the signal from microwave back to RF frequencies for re-transmission.

At this point a CATV system may receive the signal off the air. The CATV head-end equipment may then translate the incoming channel to a different channel by either of two methods. One method demodulates the incoming TV channel to baseband and remodulates the carrier of the channel to be transmitted over the cable. A second method translates the incoming channel down to IF frequencies and then back up to the channel desired for transmission over the cable.

The TV signal now passes through coaxial cable and equalized repeater amplifiers before reaching the home receiver. The TV signal in the home receiver passes through a number of frequency selective circuits before it is demodulated and the video signal presented on the picture tube.

The preceding example indicates that the 4.2 mc video signal is subjected to many sources of delay distortion. Each time it passes through a network or transmission system with frequency selective characteristics, delay distortion is possible. This fact applies whether or not the 4.2 mc TV signal is at video, IF, RF or microwave frequencies. The delay characteristic of the TV transmission path between TV camera and the TV picture tube in the home receiver is equal to the sum of the delay characteristics of each frequency selective network that the TV signal passes through.

The CATV system has control of the transmission characteristics of the head-end equipment and the cable system. Therefore, from a knowledge of the delay characteristics of the transmission systems external to the CATV system and a knowledge of the overall delay characteristic required to transmit an undistorted TV picture, the CATV system delay response can be specified.

MR. SABIN FLORESCU, from Carlsbad Cable Division: We were talking about envelope problems in the RF transmission systems, just the same way Bill Cruz said it. Our biggest problems are in the modulators. What do we do about them?

MR. ROGENESS: There are two types of phase distortion. One is differential phase which is a cross modulation of the color and luminance signals and is a function of the nonlinearity of the modulator; whereas envelope delay -- or the characteristics I was talking about were related to the phase response of the transmission system which are constant.

The delay response of head-end equipment between CATV antenna and coaxial cable must be constant with frequency in order to solve Mr. Florescu's problems.

MR. TAYLOR: Well, I think that we're running a little behind time. Mr. Rogeness I am sure would be available to discuss this question. I think it can also be safely said that it's a relatively new consideration in our industry and I am sure there are many things that are going to change in the future as a result of this discussion. Thank you Mr. Rogeness. (Applause)

The next speaker will talk on the subject of "Automatic Gain Control in CATV". Mr. Irving Kuzminsky, Director of Advanced Product Engineering of Entron, Inc. And, I believe that we have his biographical sketch to circulate if the pages will circulate them. Mr. Kuzminsky, please.

MR. IRVING KUZMINSKY: Thank you, Archer. In a CATV system, two types of situations arise which necessitate the use of gain control. One is a narrow-band single-channel problem caused by signal variations at the antenna. The other is a wide-band variation in the transmission system caused by changes in either the cable or the amplifiers.

In order for the system to function properly, it is necessary to first eliminate the variations in signal level which are normally encountered at receiving sites. Let us consider what might happen at the customer's receiver if this were not done.

Most present day CATV systems utilized adjacent-channel transmission as a means of most efficiently carrying the maximum number of channels at a minimum cost. However, as far as the receivers are concerned, the adjacent channels are potential sources of interference. This was the reason that, in the early days of CATV, some people thought that adjacent-channel systems would not work. In order for these systems to work properly, it is necessary to accurately control the levels of the signals with respect to each other so that the receiver is able to pick out the selected signal without objectionable interference from other signals.

Once the single-channel signals are combined onto a common line, random variations of these signals would be impossible to handle. This is because the gain of the trunk amplifiers is controlled on a wide-band basis. That is, the gain is varied in a coherent manner to all channels in the amplifier passband simultaneously. With random variation of each channel's signal, cross modulation and noise problems would be encountered in the trunkline system. With some signals going up, some going down, and others remaining constant, gain control would be impossible, and the problems generated are obvious. Thus, stabilization of the antenna signals is mandatory before the signals are inserted into the trunk system.

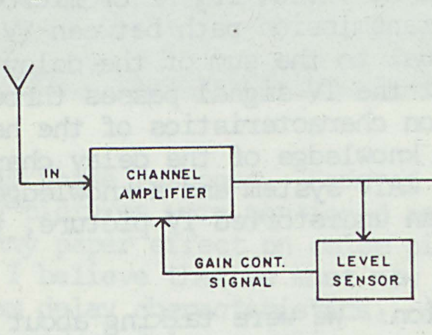


FIGURE I

FIGURE 1

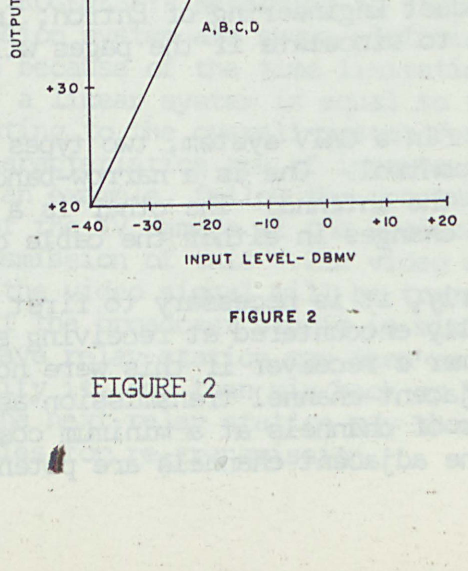


FIGURE 2

FIGURE 2

The variation in antenna signal level is usually handled by the method shown in FIGURE 1. The signal is amplified in a single-channel RF amplifier. The output signal is detected and provides a DC control signal which is indicative of the output signal level. This control signal is used to vary the operating point of the intermediate stages and, by this means, the gain of the amplifier so as to maintain the output at a nearly constant predetermined level.

FIGURE 2 is a plot of the output level of a typical single-channel AGC amplifier. The amplifier being considered has a gain of 60 db. Curve A indicates that, with no AGC there is a linear relation between input and output except for high levels where the amplifier overloads. Curves B, C, and D show that, for small signals, the output follows the input. However, once the AGC threshold is exceeded, the output remains almost constant. Thus, for proper AGC operation, a minimum signal level is required depending on the setting of an output level control.

This is called "delayed AGC" because gain control is delayed until the threshold signal is reached. Curves B, C, and D represent different delays. The maximum allowable input level is determined by the overload characteristics of the amplifier.

Normally, the input and output stages are not varied, since varying the input stage affects noise figure and input match, and varying the output stage affects the overload level of this stage. Because of these noise and overload limitations, some other method should be used where large signal level variations exist.

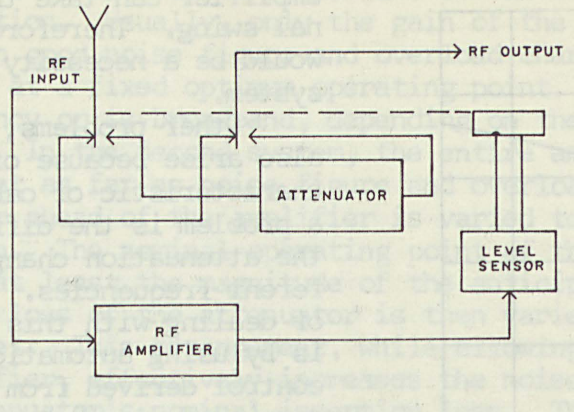


FIGURE 3

FIGURE 3

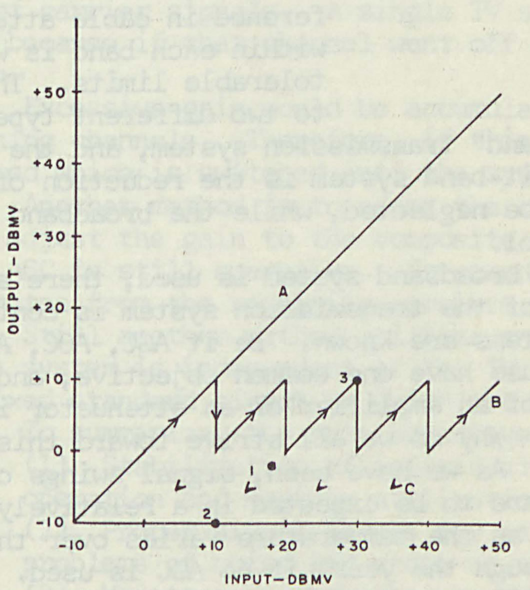


FIGURE 4

FIGURE 4

Consider the block diagram shown in FIGURE 3. The RF input signal is amplified and detected. When the detected signal exceeds a predetermined amplitude a delay is activated and an attenuator is inserted between the antenna and the head end equipment. When the signal decreases sufficiently, the attenuator is removed. A cascade of four such switchable attenuator sections--each section having 10 db attenuation-- effectively reduces a 60 db signal swing to 20 db. This smaller swing can then be handled by the AGC arrangement previously considered.

FIGURE 4 is a typical plot of output level vs. input level for a four-section controller. "A" is a plot of output level vs. input level with no compensation and, and, of course, the changes in output level follow the changes in input level. The output level vs. input level is shown by "B" for increasing, and by "C" for decreasing signal. At any given level, the input can vary over a 20 db range with no switching occurring. For example, at Point 1, with an input of 18 dbmv, two attenuators have been switched in so that the output is 18 - 20 or -2 dbmv. As long as the input signal level remains between +10 and 30 dbmv, no switching will occur, and operation will be along the joinging Points 2 and 3.

Once the signal levels at the head end are stabilized, the signals are ready to be inserted into the transmission system. Since the signals are stabilized, why is AGC necessary in the trunkline amplifiers? To answer this question, it is necessary to look at the entire trunkline system. While the signals may be stabilized at the input to the trunkline, they will still vary in the trunkline because of changes in cable attenuation with temperature variation and because of changes in amplifier gain. While the latter factor is a matter of conjecture, the change in cable attenuation is a well known fact and can be predicted.

If the last amplifier at the end of the longest trunk is capable of handling the largest signal swing expected then AGC is not required. FIGURE 5 (next page) shows the correction factor which must be applied to the 68° value of cable attenuation to obtain the attenuation at some other temperature.

We can see that the extreme temperature to which the cable may be subjected, attenuation correction factors are obtained of 1.06 at +120°F and 0.90 at -20°F. This means that for each 100 db of cable attenuation, there results an increase of 6 db at 120°F and a decrease of 10 db at -20°F.

A trunkline consisting of 1/2 inch foam dielectric aluminum jacketed cable may typically have an attenuation of 1.3 db per 100 feet at Channel 13 at 68°F. In a five mile line, this would amount to 340 db attenuation. However, at 120°F this would increase by 20.4 db, and at -20°F it would decrease by 34 db. No presently existing

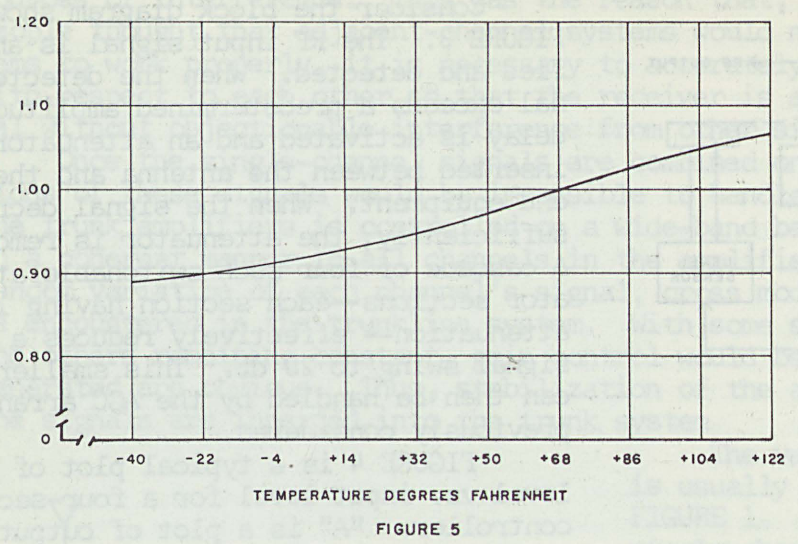


FIGURE 5

amplifier can take this signal swing. Therefore, AGC would be a necessity in this system.

Other problems, of course, also arise because of this characteristic of cable. Such a problem is the difference in the attenuation change at different frequencies. One way of dealing with this problem is by using automatic tilt control derived from two pilot carriers. Another way of dealing with the problem is to use thermal equalizers. A third way is to split the band so that the accumulated difference in cable attenuation within each band is within tolerable limits. This leads to two different types of transmission systems, the so-called "Split-Band" transmission system, and the broadband transmission system. The advantage of a split-band system is the reduction of change of tilt effects to the point where they may be neglected, while the broadband system must use some method of automatic tilt control.

Regardless of whether a split-band or a broadband system is used, there are still many methods in use today by which the gain of the transmission system is controlled. There are also many names by which these systems are known. Be it AGC, AOC, ALC, AVC, or A--you name it--C, all of the methods in use have one common objective, and that is to vary the gain or loss (in some cases) of an amplifier or an attenuator in an attempt to maintain a constant signal level. Why do we all strive toward this goal?

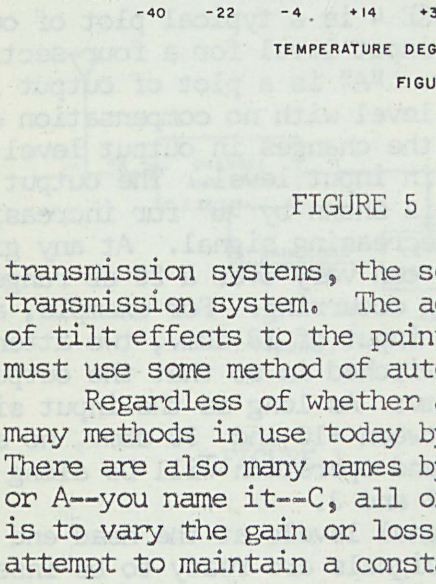


FIGURE 6

As we have seen, signal swings of 20 or 30 db are to be expected in a relatively short system as the temperature varies over the day and through the year, if no AGC is used. The use of AGC reduces maintenance problems by eliminating the need for periodic resetting of levels. Too, compensation for cable and equipment aging is provided to some extent. Let us look at some of the different methods that are used to achieve these goals.

Whether the transmission system is broadband or split-band, operation of the AGC circuits in either of these systems may be controlled by either TV signals or by pilot carrier signals. Also, either a single signal or a multiplicity of signals may be used for AGC purposes. Thus, many possible types of AGC systems exist. However, all of these methods are very similar in actual operation. FIGURE 6 is a block diagram which illustrates two methods which might be used with either TV signal or pilot carrier AGC systems.

In the first case, the amplifier is operated below its maximum gain capability

so as to be able to compensate for anticipated changes in input signal in either direction. Usually, only the gain of the intermediate stages are varied so as to maintain good noise figure and overload characteristics while the input and output stages are at a fixed optimum operating point. The detector is tuned either to a single frequency or is broadband, depending on the type of AGC system used.

In the second system, the entire amplifier is maintained at its optimum operating point as far as noise figure and overload characteristics are concerned. The attenuator ahead of the amplifier is varied to change the overall gain at the amplifier station. The nominal operating point of the attenuator must provide an insertion loss of at least the magnitude of the anticipated downward change in input signal level. The loss of the attenuator is then varied up or down to correct for changes in input level. This arrangement, while allowing optimum operation of each stage of the amplifier, effectively increases the noise figure of the amplifier by the amount of the attenuator's nominal insertion loss. The best solution may be a combination of the two methods. That is, place the attenuator at an intermediate point in the amplifier. This would allow optimum operation of the active elements in the amplifier and, at the same time, provide a good noise figure.

As stated previously, the AGC may be derived from either TV signals or from pilot carrier signals. A single TV signal cannot be used alone to activate the AGC because if that channel went off for any reason, all amplifiers would run wide open.

Excessive gain would be accumulated, and overload would soon occur on the remaining channels. Therefore, if this method is used, a standby oscillator is required which is switched into the system if the primary source goes off.

Another method is to sense the composite signals in the passband of the amplifier and adjust the gain to the composite level. With this method, if a station goes off, the AGC is still operative. No standby oscillator is required since the AGC circuit operates from the remaining carriers.

Still another mtthod utilizes only pilot carriers to drive the AGC circuits. This system is independent of the TV signal levels and has the advantage of providing a fixed standard signal to which the entire system may be referenced.

To summarize, the main advantages of AGC are:

(1) Stabilization of individual channel signals permits adjacent channel operation and maximum utilization of the transmission system.

(2) Proper signal levels may be maintained in the trunk, thereby avoiding problems of noise and cross modulation.

(3) Maintenance problems are reduced by eliminating the necessity to reset levels with changes in temperature.

Thank you. (Applause)

MR. TAYLOR: I think we can take time for one or two questions. Anybody have a question they want to ask Mr. Kuzminsky? One in the back of the room.

UNIDENTIFIED SPEAKER: This might be going back to this envelope delay problem, but I notice on the color set there was another image to the right and I've had this problem on black and white. I don't know what it is. Is it miss match?

MR. KUZMINSKY: Well, sounds like it.

UNIDENTIFIED SPEAKER: Miss match?

MR. KUZMINSKY: Yes.

MR. TAYLOR: Thank you. Thank you very much, Mr. Kuzminsky. (Applause)

Our next speaker is Mr. Robert Cowart, Vice President in Charge of Construction for Viking Company. And, he's going to talk on "System Reliability". I believe the

turn to new techniques so well adapted to his operations and that the G-Line should become for long distance what coaxial cable is for short distance wiring: a permanent instrument in CATV installations? This tool, in spite of its unorthodox suspension methods, is much closer to the wiring techniques of CATV than microwave towers.

The new technique could give Community and Pay Television relative independence not only from the FCC, but also from the old communication carriers in possession of established rights.

It has become a transmission medium in its own right, usually superior and frequently irreplaceable. It has also become more sophisticated.

The development of the G-Line parallels the development of modern solid-state technique. This also started around 1950 with the introduction of germanium diodes used at the outset only as detectors, but gradually penetrating the entire amplifier technique in the form of multi-electrode transistors.

What was once a single wire G-Line has now become a multi-conductor cable, adding to the surface wave, the conduction of high tension currents, the grounding for safety, and the capability of coupling in transit.

It can combine the functions of several components into a single unit having all these functions.

This is progress.

MR. TAYLOR: Thank you very much, Dr. Hafner, for a very interesting talk on a very interesting subject, which I have had some opportunity to fool with myself, as you said. I think that we had best move along. We started a half hour late because of the very remarkable performance we had at noontime and we have two very interesting and important papers to hear this afternoon.

Mr. Rudy Riley, President of Systems Engineering, Inc. is sponsored in this paper by Phelps-Dodge Electronics Products Company and he is speaking on "Just Twelve Inches Away". Mr. Riley.

MR. RUDY RILEY (President, Systems Engineering Inc.): A casual glance at a well-constructed CATV plant reveals the striking similarity to its neighbor, just 12 inches away. Since the beginning of our industry, telephone research, techniques and equipment have contributed immeasurably to the success of CATV.

Historically, the basic problems experienced by the telephone companies have proved to be common to all cabled communication networks.

This paper will discuss the two factors that effect the economics of a cable system most: Cable and its maintainence.

Cable

The advent of color television and all band transmission has created a demand for CATV cable with minimum frequency and delay distortion.* An air-insulated rigid coaxial cable meets these requirements. In this cable the center conductor is supported with a minimum number of carefully spaced, low-loss insulators. However, this type of construction is not practical for use in strand supported CATV systems.

Therefore, a semi-rigid cable using polyethylene, to uniformly support the center conductor, is generally used.

[* Subcommittee on Wire Communication of American Standards Association Sectional Committee on Electrical Definitions.
<u>Frequency Distortion</u> - Frequency distortion is that form of distortion in which the change is in the relative magnitudes of the different frequency components of a wave, provided that the change is not caused by non-linear distortion.
<u>Delay Distortion</u> - Delay distortion is that form of distortion which occurs when the phase angle of the transfer impedance with respect to two chosed pairs of terminals is not linear with frequency within a desired range, thus making the time of transmission or delay vary with frequency in that range.]

In order to reduce RF losses, the dielectric constant of the line is reduced by foaming the polyethylene or using a spiral ribbon of the material to support the center conductor. To satisfy the above mentioned criteria, extremely close manufacturing tolerances must be observed. Any anomalies in the supporting dielectric or the concentric cross section will cause wave reflections. These reflections give rise to delay distortion in the form of echoes, and, therefore, cause picture degradation.

Recent state-of-the-art breakthroughs in cable design promise to reduce the wave distortion products to an acceptable level.

One of these cables uses a thin helical membrane as the center support. Tests on several 1000 foot sections, using time domain reflectometry techniques, reveals that the departure from the normal characteristic impedance within the section does not exceed 1%. The attenuation is 6.6 dbmv per thousand feet at 216 megacycles and 70 degrees F.

By using the above described techniques, it is possible to determine the effect of bending radius and splices. Evaluation of these tests establishes the fact that the radius should be not less than 15 times the cable diameter and that splice VSWR should not exceed 1.04.

Future development of high quality cables will undoubtedly follow this trend toward the air dielectric configuration. Therefore, the thin supporting membranes will require new techniques for preventing excursions, with temperature, of the center conductor at cable junctions.

A new splice has been developed that requires no restrictive bends in the cable and exhibits a VSWR of 1.02. This splice is so designed that it might also serve as a bulkhead fitting for a hermetically sealed tap device.

In light of these recent developments, it is highly probable that future CATV systems will be pressurized.

Pressurization of Cable

Many of the older CATV systems used pressurized cable. This cable exhibited excellent electrical characteristics. However, its use was gradually discontinued because of several factors. The major factor was development of foam dielectric, aluminum sheathed, 75 ohm cable at a lower price. Other factors were:

A. Standard configuration had characteristic impedance of 70 ohms.
B. No satisfactory connectors were available.
C. Improper installation and maintenance.
D. An almost total misconception on the part of the installer and user concerning proper pressurization procedure.
E. Lack of industry standards.

As stated earlier in this paper, the need for cable with a return loss in excess of 36 db will probably dictate the return to this or a similar type. In addition, there are several compelling reasons why existing cables should be pressurized.

Why Pressurize Cable

Any pinhole or hairline crack that occurs in the sheath of a cable, regardless of its construction, becomes a potential source of trouble. The sheath openings may be categorized as follows:

Manufacturing Faults - These faults, while comparatively rare, do exist.

External - Caused by workmen, machines, ice, fire, rodents, etc.

Electrical - Due to lightning, corrosion, electrolysis, contact with wires, etc.

Moisture Entry

Moisture entering the cable by any means, either in the form of water or water vapor, will have a deleterious effect on system performance.

Water in cables can cause serious trouble. If water remains in the cable for long periods, electrolytic action or chemical corrosion may set in and eventually eat away the outer shield or affect the return loss of the cable. Water accumulating in the cable can freeze; as it turns into ice and expands, it can puncture the shield.

Moisture vapor can enter the cable by "cable breathing"; this is caused by temperature changes in non-pressurized cables. Air within such cables expands with rising temperatures, therefore building up a pressure. In the presence of any sheath opening, this pressure forces air out. Conversely, with falling temperatures, air in the cable contracts and draws additional air into the cable. Once inside the cable, the vapor tends to migrate freely and will travel considerable distances. This vapor will frequently precipitate out as free water under conditions of temperature change. Connectors are particularly susceptible to this water because there is usually some air space within the device.

Poly-sheathed, corrugated copper cable is susceptible to moisture entry because of its "tender" sheath and its low pneumatic resistance.

Positive Pressure

By maintaining a positive pressure within the cable, it is possible to prevent the entry of moisture. The cable will remain dry if the internal pressure exceeds the outside pressure; or in the case of buried cable, if the cable pressure exceeds the hydrostatic head of water exerted externally on the cable sheath.

Standard telephone procedure is to supply air to cable networks at pressures ranging from 5 to 10 psi. The usual practice is to feed dry air at a pressure of 10 psi into underground and buried cables and maintain them at 5 to 7 psi minimum pressures. These minimum figures are required to provide such cables with protection against the possible presence of hydrostatic heads of water in manholes, etc. Water exerts slightly less than 1/2 psi pressure for each foot of depth. A manhole 8 feet deep filled with water would develop 4 psi pressure on cables located near the bottom. Therefore, a minimum cable pressure of 4 psi would protect against moisture entry through a sheath break, but increasing the minimum pressure to 5/7 psi increases the interval after occurence of a leak before the pressure in the cable falls to a dangerously low level.

The normal procedure on aerial cables is to pressurize them at 7 psi unless they are very old and the sheath too weak to withstand this pressure. As noted previously, such cable is subject to rapid temperature changes, sometimes 50 to 60 degrees. Such variations can produce pressures within the cables varying from 1.5 to 2 psi from atmospheric due to cable breathing. Experience has shown that a minimum end point pressure of 2 psi will supply the required protection for the entire network and prevent cable breathing of aerial cables.

Pressurizing Techniques and Maintenance

Telephone cable is pressurized by admitting dry air from an air-drying machine into the cable at the central office. Contactors are installed at strategic points along the cable to provide alarm points for detecting leaks in the cable by the drop in the pressure which causes operation of the particular contactor in the vicinity of a leak.

The contactor operates to connect a resistor across a working cable pair. This resistor has no effect on dialing and transmission and the customer can use the circuit through the pair. The cable pairs associated with the connectors at different locations are periodically tested by the testboard personnel to detect operated connectors. An operated connector is indicated by a high resistance reading on the testboard meter.

It is possible to provide this alarm feature on CATV systems by diplexing a tone interrogator into coaxial cable. Operated contactors would be indicated by reed-type transponders. These transponders may also indicate amplifier levels. This method of detection is being used in a CATV system presently being constructed for Georgia TV Cable Co. in Athens, Georgia. There are several commercially available devices that can perform this operation. It is also possible to lash cable pairs with the coaxial system. Telephone companies will provide a similar service for approximately $3.00 per loop per month.

Alarm devices are supplemented by metering panels that measure air flow rates, delivered air humidity and pressure. The combination of these detection methods insures the continuity of plant operation.

When a leak is indicated, repairmen are dispatched to the approximate location. The actual break is located by a device which sprays a soap solution onto the cable. As the spray passes over the hole, the escaping air causes a foaming action that is visible from the ground.

Another type of leak detector that was recently developed makes use of an ultrasonic translator which picks up the sound of the air escaping from the holes in the sheath. These sounds are very high in frequency, in the 35,000 to 45,000 cycle range which are converted into audible sounds by the translator and heard in a headset receiver. A barium-titanate detector probe is used on a carriage arrangement to pick up the ultrasonic frequencies.

Removing Water from the Cable

When water has gained access through a sheath opening and causes trouble, there is no alternative but to remove it.

To remove water by evaporation merely by pumping dry nitrogen or dry air through the cable is impracticable because the cable section may contain a large quantity of water plus the fact that a large (224 cubic foot) cylinder of nitrogen or equivalent volume of dry air will only evaporate four or five tablespoons of water at 60 degrees F.

A method for removing water from cable has been developed utilizing acetone, a liquid which mixes completely with water in any proportion. A cable section containing water is flushed with acetone until the discharge liquid indicates a low water content. Then as much of the acetone as possible is forced out in liquid form and the remaining acetone is evaporated with nitrogen. Acetone has a low boiling point of 133 degrees F and, therefore, evaporates much more readily than water.

There are certain precautions, however, associated with the use of acetone. Since it is a volatile and combustible liquid comparable to gasoline, flames or sparks must be avoided. Prior to injecting acetone into the cable, nitrogen should be pumped into the section to purge the cable of oxygen, thereby minimizing the possibility of creating a combustible mixture of air and acetone.

Moreover, since acetone is a mild cracking agent to polyethylene, and since it will attack polyvinyl chloride, it is imperative that all acetone be removed from the cable section after the water is flushed out.

MR. TAYLOR: Thank you very much, Rudy. Our next speaker is talking on a very important problem. Mr. E. Mark Wolf, Assistant to the Vice-President of Engineering with the Rome Cable Division of ALCOA. Mr. Wolf.

MR. E. MARK WOLF (Assistant to the Vice-President of Engineering, Rome Calbe Division of ALCOA): Well, I think someone, and probably our good friend Mr. Taylor, deserves a high compliment for the efficiency of this setup. I have talked to a lot of people about underground cable, but this is the first time I've gone underground to do it. (Laughter) Maybe it's a good idea. But I guess we're here because we all have in

"TECHNICIANS' DAY"
THURSDAY MORNING - JULY 22, 1965

MR. ARCHER TAYLOR: We will open our Technician's Day Session. For several years NCTA has had a committee studying various aspects of Industry technical standards. This has proven to be a very difficult and very important job. It's, therefore, quite gratifying to me that this demonstration which you are about to see this morning could be produced under the sponsorship of the Standards Committee of NCTA. We have in our industry both in the manufacturer's design laboratories in the operation of systems a remarkable degree of technical confidence. A very large number of these engineers and technicians have participated in putting together this project to to demonstrate to you this morning.

I would like to present to you to tell you about the demonstration Mr. H. J. Schlafly. Mr. Schlafly is Senior Vice President of the Teleprompter Corporation, one of the multiple owners of CATV systems. He is formerly President of the Telepro Industries, Incorporated, served for six years as Director of Television Research for 30th Century Fox, was in the advance development laboratory of General Electric Company. He holds a BSEE at the University of Notre Dame and has done graduate work at Syracuse University. He is a Fellow of the Society of Motion Picture and Television Engineers and is a Senior Member of the Institute of Electronic and Electrical Engineers. Mr. Schlafly. (Applause)

MR. HUBERT SCHLAFLY: Thank you, Archer. The subject to this session is Measurement of Noise and Cross Modulation. I am representing the NCTA Ad Hoc Committee on Technical Standards and am appearing here in no other capacity.

Now, noise and cross modulation are at least two of the items in the life of a CATV operator that he could just as well do without. Most of us are familiar with noise. This is snow, dancing dots, picture grain or whatever you wish to call it. It spreads over the entire picture area, provides distraction to the viewer, then loss of picture detail and finally it curtains off the entire view.

Noise is random, it has no pattern, shape, form or period. It is unwanted signal, containing no intelligence which competes with the picture. We know a good deal about random noise (some call it thermal noise). We can see it, we understand it, we know how to measure it. I think that due to the shortness of time, with your permission, I will jump over any further remarks on random noise, and go into ar equally serious area of concern to us - unwanted signals.

This kind of picture interference, I call the "not-noise", or the "not-interference." It is <u>not</u> random, it is <u>not</u> easily understood, it is <u>not</u> easy to measure and after it is measured, the measurement is <u>not</u> easily interpreted. This is cross modulation.

Cross modulation is an unwanted byproduct of any amplifier that is less than perfect as a linear amplifying device. If the output signal at any operating level is not a constant multiplying factor of the input signal or is not a constant number of dbs added to the input level (for those of you who like to think in dbs), then, like the "Music Man" with 101 Trombones, "brother, you've got trouble in Central City".

Now, in order not to confuse us oldtimes who understand tubes but aren't so sure we understand transistors, let's refer to an amplifier as having a transfer characteristic. If this transfer characteristic is linear, everything is great. If it is nonlinear over the range that the designer choses to operate, you've got a whole beehive of possible signals that you never knew existed. If the transfer characteristic changes its slope over the used range, you have second order effects. You have second harmonics and second order beats. Thanks to luck and to the foresight of the original system engineers and to the understanding of the engineering staff of the Federal Communications Commission, VHF channels were selected so that second order effects do not bother us. They exist, but they don't fall into the frequency bands in which we work.

But, the rate at which the transfer characteristic changes slope produces third order effects and these do bother us. Now, amplifier gain and level enters into this picture, because although an equipment designer can find some portions of a transfer characteristic that is linear, the greater a portion of the transfer characteristic must be used the greater is the chance for nonlinearity. So the harder you drive an amplifier, the less linear it is likely to be and the greater will be these unwanted internally generated signals which we call cross modulation and intermodulation.

Low level amplifiers generally have good linearity and have very low levels of these unwanted modulation effects. High output level amplifiers, let's say in the range of 40 to 50 DBMV can have increasingly disturbing levels of this modulation. And, it increases rapidly with output level. A fairly accurate rule of thumb for a typical amplifier is that every 1 db of increase in output level produces about 2 db increase in the relative cross modulation interference.

Third order nonlinearity generates beats (beat frequencies or spurious signals) that do fall in portions of the spectrum that we use. These generated frequencies are referred to as:

Intermodulations $= 2f_a \pm f_b$

Third Harmonies $= 3f_a$

and Triple Beats $= f_a \pm f_b \pm f_c$

My analysis (which I don't guarantee to be without error) shows that only two video carriers, channels 3 and 4, have Third Harmonies which fall in an upper band channel.

Intermodulation products of the video carriers are confined to a reasonable number of frequencies in the TV channels (over half of which are avoided if adjacent channels are not used). Triple beats, which can occur almost anywhere, have not been analyzed by me on a statistical base.

Since the peak of sync has the greatest amplitude in TV signal, this unwanted vertical bar is noticed first. Of course, it's not that the video modulation of the unwanted channel isn't there, it's just that it's at a lower level and you don't see it. If the synchornizing frequencies of the two television signals on different channels are stable and constant, this vertical bar stands still in the picture. This may, in some cases, be less annoying than if they were not synchronous, in which case they do not stand still and you get the familiar windshield wiper effect. Cross modulation is hard to measure and since this annoyance is largely subjective, just as beauty is in the eye of the beholder, it is hard to evaluate. It is most easily seen on the blank screen. From here on we're going to work with an actual demonstration showing both broadcast picture and a closed circuit camera pick up of the oscilloscope display on this 8-foot wide screen by means of this TV projector.

There is a setup of equipment in the back room, intentionally in the back room, because we want to make no reference in this session to any particular philosophy or any particular manufacturer's methods or equipments. We have twelve picture input channels and we have a CW generator which can replace any one of the 12 pictures. All these signals are combined and fed to an input attenuator.

The output of that attenuator goes into the amplifier that's under test. The output of the amplifier goes to an output attenuator which cuts down the combined signal to a suitable level to put into a television receiver. In this case, the television receiver will be a TV projector and we'll put in on the large screen. As the input attenuation is decreased, meaning a higher drive signal, the amplifier will operate over a larger portion of its transfer characteristic and will show an increase in cross modulation effect. We adjust this output attenuator so that the level to the receiver is constant.

We also have a setup in the back room so that we can measure output level, not only the level of the CW carrier but also the AC modulation of that carrier, which in this case can only be cross modulation and we can view this on an oscilloscope.

This is a large screen view of the oscilloscope showing cross modulation as it is being measured right now in our back room set-up. Can someone tell me how many channels are on this picture? One? One channel. One interferring channel. Yes. This is one channel which is interferring with the CW carrier. The spike is the peak of the sync pulse. The signal in between those two spikes that you see is incidental video, but the item that's going to cause the trouble is that spike. Now, let's add an additional channel. A second channel of TV picture will be added to the amplifier at the input. Since the sync generators on the stations that we are using are non-synchronous, you will note that the additional interfering channel will drift through. If the picture that you add is synchronous, that spike will increase in size rather than give the drift thru effect. Now I will turn this projector over to the TV picture. That's cross modulation right there.

Although my raster isn't synced since we're running on CW signal rather than on a normal television picture, you can see those vertical bars. Let me turn over to another channel and get this thing tuned up a little bit. Remove one of the interfering channels. All right. Now, its stabilized somewhat.

Of course you are seeing cross modulation on a blank screen where it is much easier to see. If we put this onto a channel which had picture content you might not see it to this extent. But what you do see here is the interference that causes the trouble.

Now change the level of the amplifier. Reduce the output level of the amplifier, remove some of the output attenuation to bring the level back and see if we can observe the reduction in the cross modulation. This is 3 db less than you saw before and you can see that the interference signal (I've lost sync again, lost stability, there. That's better). is substantially less than you saw before and it would be less subjectively annoying on the picture.

Do you want to see a third interfering channel added? Put all of them on now and increase the output level so that we have an easier time seeing it. By increasing the output level of the amplifier we drive the amplifier harder. We use a greater portion of the transfer characteristic and we're getting into the change of gain and to the rate of change of gain which generates second and third harmonic effects. You're getting some beat here also.

We are intentionally overdriving this amplifier by a substantial amount just to accentuate the effect that you see here. Now I'll turn over to a picture channel. You can see the cross mod in the picture itself. Fairly stable here rather than the windshield wiper that many see as more objectionable. It's an amazing thing that the modulation of one picture can sit right on the other picture and modulate that carrier just as though it was an original part of its own signal.

Now, this isn't new. This isn't a new thing that the cable television people dreamed up. In fact, I have a textbook that I used in college (and that's a long time ago) on the table there, "Radio Engineering" by Terman. This book has 5 or 6 pages that give an excellent analysis of the problem of cross modulation.

Now, reduce the output level of the amplifier, gentlemen, by first 3 db and then 6 db and let's watch this reduction. Let's go 3 more. And, 3 more.

I want to remind you, again, that we have been intentionally overdriving this amplifier by terrific amount in order to accentuate the problem here. Bring it down to an acceptable level. Let me emphasize that word acceptable. Since it is a subjective problem, the value can differ. I must admit that we have not as yet agreed on exactly the proper means of test nor on a figure of db cross modulation must be down to be acceptable to the industry. That is the problem on which the NCTA Standards Committee is working.

Now, we have reduced the level of the output of the amplifier. We have removed a compensating amount of attenuation from the output line to the receiver and we have reduced the cross modulation by a substantial amount.

Let's go back to a CW picture showing cross mod and the drift through of sync signals. Those signals look synchronous to me there. Maybe they're flipping through so fast that I don't see them. Yes, now they do add. When they do come together, when they do become synchronous, those spikes add in height and of course you get a much worse condition temporarily. I haven't satisfied myself whether the larger signal is worse than the low frequency flip through.

In order to take a photograph of an additive cross modulation condition you may have to wait ten minutes to see it on the scope and when you did see it, it might last only a fraction of a second.

I just want to say that this demonstration has been a difficult one to put on. It has taken much equipment and has taken much time and thought. This was freely donated by several of the manufacturers who have not asked for, expect, nor will they get a plug, on this NCTA sponsored demonstration. I wish to compliment them and the industry. I have sat in many committees and I have fought for and seen fights for many standards. I have never been in an industry where I have seen as such a wonderful climate of cooperation or spirit of fighting for our common cause against the common enemy as I have in the NCTA. With the recognition that we must make our mark in a highly professional field that includes broadcasters, networks, telephone companies and others, this spirit of cooperation is vital. I do not see how our industry can help but flourish to new growth and success. Thank you. (Applause)

MR. TAYLOR: I would like to point out that we have in this room manufacturers, engineers and system engineers who have done a lot of work in this field. And, in addition to questions, if one of you has a contribution you'd like to make to this general area of discussion, we'd be delighted to spend a little time listening to it. There is a microphone there or right here. Yes, sir. Will you identify yourself?

MR. DICK PECK, WREX TV, Rockford, Illinois: The demonstration that you showed - presumedly the normal amplification of the amplifier itself was somewhere in the neighborhood of 30 to 40 db?

MR. SCHLAFLY: I would say that it's probably in that area.

MR. PECK: How far about that did you drive it?

MR. SCHLAFLY: Well, in this particular case, let's consider the rated output of the amplifier as 0 db and let me get an answer for you from the backroom here as to how far they went. I think a considerable amount. The answer is twelve to fifteen db above normal rated output. And, you recall a rule of thumb was that every increase of db and output level brings about 2 db increase in cross modulation. You know that we were running pretty high here.

MR. TOM MORRISSEY, Denver: I was just wondering if this was an all band or a split band amplifier and you might want to make a comment as to the effect that might have on it.

MR. SCHLAFLY: This is an all band amplifier. The number of channels that you use gives you that many more opportunities for cross modulation. If you have separation of the bands, you can substantially reduce some of the beat frequency or spurious signal annoyances.

In cross modulation, I'm under the impression, Tom, that it's just a matter of how many channels you're using, not necessarily whether they are high band or low band. Would you like to correct that?

MR. MORRISSEY: Well, if we have a true split band amplifier, of course, we have two separate channels, the signals are going through, and this is all I was suggesting, is that there are some of those in use.

MR. SCHLAFLY: Yes.

MR. MORRISSEY: Where the signals simply don't mix. There is no common modulation.

MR. SCHLAFLY: Correct.

MR. EARL QUALM, Long Island Cable Division: I notice that the interference with the vertical bar. Why was it colored white rather than black? Wasn't this a vertical sync bar? And, wasn't it in the black area?

MR. SCHLAFLY: This was a vertical sync bar. You notice that what video information you saw was negative. I think that in the mathematics analysis you come across that inversion of the cross mod. Is that correct, Ken? There is an inversion of sign in this modulation as against the normal modulation on the channel that it is influencing.

MR. JACK THREADGILD, Brady, Texas: You made measurements here with both the scope method and the TV receiver method and from the pictures you showed us, it looked like you could pick out your cross modulation better using raster on a TV set. Did you find this in all your experiements? In other words, which way can you detect it?

MR. SCHLAFLY: The most critical method is the white screen method, but you don't get numbers out of the white screen method. And I didn't metnion it, but the scope there was calibrated in percent of modulation, cross modulation interference, which could be readily read off if we had chosen to do that.

MR. THREADGILD: You can get a value, but the other one will tell you -- it will show up the problem quicker.

MR. SCHLAFLY: This is not an easy thing to measure and I think a good deal of thought is going to have to be given before we come up with an easy way of doing it or with a practical way of ding it in the field. Of course, the end result is the picture itself. And, this varies greater from viewer to viewer. It's like judging hi-fi. If it's your system, you think it's pretty good. (Laughter)

MR. TAYLOR: I'll take one more question. Then I think we'll get on with the program because we have a number of papers that are talking on the general subject of the problems in amplifiers. I see a hand back there?

MR. FORESCA, Cosbed Cable Division: To answer the gentlemen's question about the color of the sync bar. At one time I did some experiments on it. If you do change the cathode bias of the telebed that's involved in the intermodulation process, you will find that as you go with the bias on one side of the linear portion you will get one polarity sync pulse. As you go on the other side, you get a different polarity sync pulse.

MR. SCHLAFLY: Yes, I think that is correct.

MR. FORESCA: My question is that. To what extent the number of channels would affect the intermodulation level?

MR. SCHLAFLY: This is partially subjective, because it depends on where it lands. But if it synchronous it is an additive. I believe that it is an additive situation. Do any of you gentlemen care to comment on that?

MR. TAYLOR: This gentleman here has a question. Let's take one more.

UNIDENTIFIED SPEAKER: Mine is not a question. I just thought that maybe he might inform us as to how he set the CW signal on channel and then superimposed the other on the test?

MR. SCHLAFLY: As to how that was done?

UNIDENTIFIED SPEAKER: Just to tell us how you set this up?

MR. SCHLAFLY: There were 12 input channels and there was a CW generator. The input channel levels were set through those modulators and the CW level was set at the same level as the carriers that we had from off-the-air signal.

UNIDENTIFIED SPEAKER: But, when you set the CW signal in this test you showed, do you kill the other information on that channel?

MR. SCHLAFLY: Yes, sir. There was only the pure CW signal on that channel and it beat against the various signals of the television channels that were superimposed, mixed at the input to the amplifier. (Applause)

MR. TAYLOR: Again I want to thank Mr. Schlafly very, very much for coordinating this study on behalf of the Ad Hoc Standards Committee. And, again, I want to express the tremendous cooperation that has been given to this project by a number of manufacturers. We'll delay just a moment or two while the gear is removed to make possible some other visual aids.

I might say that many of the papers you will hear today are available in printed form and will be available on this table against the wall.

Our next speaker is Dr. Jacob Shekel of the Spencer-Kennedy Laboratory. You have his sketch here showing his background and I will not take further time to introduce him. Dr. Jacob Shekel. (Applause)

DR. JACOB SHEKEL: My talk will concern noise and cross-modulation from a few points of view. We all realize that noise and cross-modulation are the factors that ultimately limit the length of the system or the number of amplifiers that can be cascaded. But, I'm not sure that everybody here knows exactly how to estimate how many of the amplifiers can be cascaded and when that limit is reached; and how to do this before the system is built and before you find it out in effect. I want to separate the problem into three parts: First, how do we specify or measure or estimate the noise and cross-modulation of a single amplifier? Then, knowing that, how do we estimate the accumulation of noise and cross-modulation along the trunk line and distribution amplifiers? And, the third question, where do we stop? How far do we let it accumulate before we say this is as far as we go, because we cannot degrade the picture any further?

I am not going to discuss the third question. I am not going to give any numerical values on what should be the final noise or the final cross-modulation, because that is really up to the Standards Committee to set up. I don't think there is yet any complete agreement between the manufacturers or between the system users on the ultimate degradation that can be allowed. But I will describe what I hope is a very simple way of how to figure out from the specification of a single amplifier what the noise and cross-modulation of the total system are expected to be at the furthest point.

A simple way to estimate the noise at the end of the system, and one that I know is used quite extensively by system operators, is a simple measurement with a field-strength-meter. You measure the level of a certain channel at the furthest point of the line. Then you turn off the channel at the head-end and see what measurement you can read on the field-strength-meter. This measurement is due only to noise accumulated all along the system. You take the ratio of these two measurements--that is, the difference of the db readings--and this is what is called carrier-to-noise ratio in decibels.

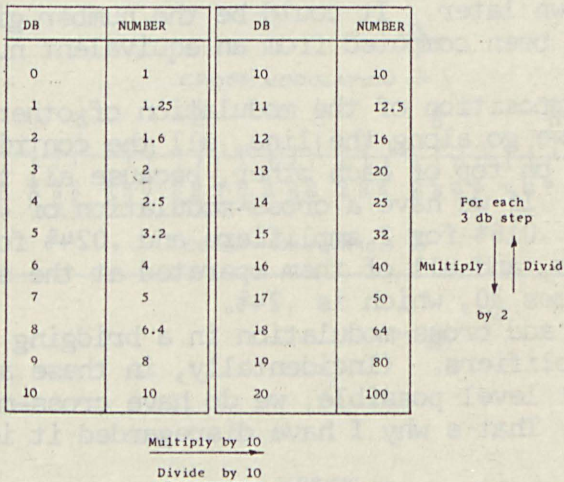
Now, since this is such a simple method to measure the carrier-to-noise ratio of the system, we can also define and specify tne amplifier the same way. Suppose we take a single amplifier of the kind that we're using in the trunk line, and connect the field-strength-meter at its output, terminate the input and read the meter. Let's take as an example that the field-strength-meter reads at a certain channel --28 dbmv. Then suppose that this amplifier is specified to be used at an output level of +33 dbmv. By subtracting the two numbers, remembering that one of them is negative, the carrier-to-noise ratio of a single amplifier appears to be the difference between 33 and minus 28, which is 61 decibels. This, I think, is the simplest way to measure and to estimate the carrier-to-noise ratio of a single amplifier, a measurement that every operator can do right in his own office or in the field.

Knowing the carrier-to-noise ratio of a single amplifier, what can I expect to be the carrier-to-noise ratio when I cascade any number of them? Or, an alternative question, how many can I cascade if I want the carrier-to-noise ratio to be at least (let's say) 45 db?

Now, here we have to go a little into a table of decibels. I want to show a very simple method that every one of us can follow to make up his own table of decibels without reference to any handbook or any slide rules. I think it's a very handy thing to know.

First, we have to realize that the noise is a random waveform, and if you take the noise contributions of the various amplifiers they are not coherent. If you project them on a scope there will be no similarities between the noise waveforms of the various amplifiers. When such waveforms are added, the power of the total wave is equal to the sum of the powers of the various contributions. That means that a noise of two amplifiers will be 3 db higher than the noise of a single amplifier, and the noise in a trunk of 10 amplifiers will be 10 db higher than that of a single amplifier.

These are the only two numbers that we have to remember, that "twice" is 3 db and "10 times" is 10 db. I am going to write down the column of dbs from 0 to 10. We know that 0 db is a ratio of 1, and every time we add 3 db we double the ratio. Twice is the same as 3 db. So 3 db would be 2, and 6 db is 4, and 9 db is 8, and 12 db is 16, 15 db is 32 and 18 db is 64. Now, we go the other way. 10db is 10 times. Going backwards, 3 db below that, 7 db would be 5 times, and 3 db below that, 4 db, would be 2.5, and 3 db below that would be 1.25. To complete the table we now go sideways, multiplying and dividing by 10.



DB	NUMBER	DB	NUMBER
0	1	10	10
1	1.25	11	12.5
2	1.6	12	16
3	2	13	20
4	2.5	14	25
5	3.2	15	32
6	4	16	40
7	5	17	50
8	6.4	18	64
9	8	19	80
10	10	20	100

Fig. 1

So, now we know how noise of various amplifiers will combine, or how the carrier-to-noise ratio will change along the line. In our example I have used the carrier-to-noise ratio of a single amplifier at 61 db. If I had two amplifiers they will be 3 db worse, or 58 db; and with 10 amplifiers, it will be 51 db.

Now, let's take the following question: If I start with a 61 db carrier-to-noise ratio of a single amplifier, how many can I cascade before I reach 45 db? The difference between 61 and 45 is 16. Going to the table, 16 means 40 amplifiers. So, 40 amplifiers of that type, operated at that level, will give a carrier-to-noise ration of 45 db. I can't say whether that is acceptable or not, but at least the system operator can go to the end of the system and measure the carrier-to-noise ratio, and if the reading is far from 45 db, then he knows right away that something must be wrong.

This is as far as we can estimate the carrier-to-noise ratio of a single amplifier and of a line with cascaded amplifiers. And, you will have noticed that I am trying here to specify the noise of the amplifier not by its noise figure, which is a certain measurement referred to the input, but by its noise output. First of all it is easier to estimate the output C/N ratio, and also it's a figure which is much easier to measure right in the field.

The second limitation on the system performance is the matter of cross-modulation. Now, of course, I'm not sure if we all know, after the previous demonstration, what exactly cross-modulation is. Maybe we know much more than we knew an hour ago. But, for the purpose of my talk it suffices that we can put a number to it. We say that an amplifier operated at a certain level with a given number of channels will have a certain amount of cross-modulation.

First of all, it is important that both the level and the number of carriers be specified, because the amount of cross-modulation changes with those two numbers, as it was demonstrated before. Also, the number which specified the cross-modulation can be given in two ways: It can be given in negative decibels (or "db down"), or it can be given as a percentage modulation. The meaning of the latter is that if we start with a CW carrier as our test signal, the modulation imposed by the other carriers will be a certain percentage.

The two specifications are equivalent to each other and there is a very simple way of passing from one to the other.

Let's look first at just the middle line of the nomogram on page 165, the one that is marked "cross-modulation". Here you see two scales, one in decibels and the other in percentage. For example, minus 40 db corresponds to 1%, minus 60 to .10% and minus 72 corresponds to .025%.

Now I would like to suggest that specifications be given in percentage rather than db, because then the way that cross-modulation accumulates along the trunk is very simply computed: You just multiply this number by the number of amplifiers. Let's take as an example that a trunk amplifier is specified to have .008% cross-modulation when operated at an output level of +33 dbmv with 12 channels. (How to get this number in the first place will be shown later. It could be the number given directly by the manufacturer, or it may have been computed from an equivalent number given by the manufacturer.)

The cross-modulation is really a superposition of the modulation of other channels onto the channel we are watching. And as we go along the line, all the contributions of all the amplifiers just add up in phase on top of each other, because all the channels progress along the line at the same speed. If we have a cross-modulation of .008% for one amplifier, we will have a cross-mod of .016% for 2 amplifiers and .024% for 3 amplifiers. Suppose we have 30 trunk amplifiers, and all of them operated at the same level, the total cross-modulation will be .008 times 30, which is .24%.

Now, this is only the trunk. We also add cross-modulation in a bridging amplifier, distribution amplifiers, line extension amplifiers. (Incidentally, in these amplifiers, since we try to operate them at the highest level possible, we do have cross-modulation, but we have almost no effect on the noise. That's why I have disregarded it in the first part of my talk).

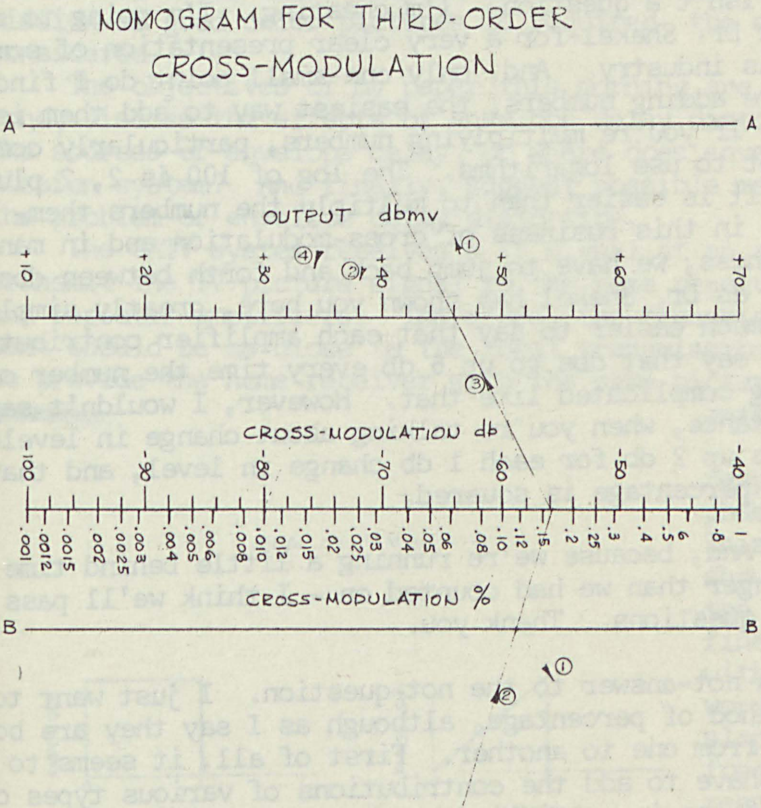
We have .24% accumulated along the trunk line. Suppose that now we start from here into a distribution amplifier, and let's take again as an example that it is specified to have .1% cross-modulation at +58 dbmv for 12-channel operation. If we operate it at this level, it will add .1% cross-mod. Again all the channels come to this amplifier at the same time, all together, so on top of the .24% from the trunk line we have to add .1% of the distribution amplifier and we end up with .34%.

If we have no further amplifiers in the line, we can expect the customer to have a cross-mod of .34%. Suppose that a customer is further along the line, where we have another line-extension amplifier. All we have to do again is to add the cross-modulation contributed by that amplifier. And, thus by a simple process of addition of the contributions of various amplifiers we can very easily estimate the cross-modulation of the pictures at the customer tap.

There is some difference between noise and cross-mod measurements, because the noise can easily be measured at the customer tap and you can compare this to the computed results; whereas, the cross-mod measurement is a little more complicated and the equipment is usually not such that can be taken to the customers' house or carried around in a truck. I hope that within a year or so maybe some of the manufacturers will come up with small kits to measure cross-modulation, when the Standard Committee will have decided on a method that is satisfactory to everybody.

Now, the only thing that remains in this method of estimating noise and ss-mod is how to find the cross-modulation of a single amplifier. In noise, it was simple. We just take an amplifier and measure it. We disregard the manufacturer's specs; we can check it every time.

On cross-mod we have to start from one number given by the manufacturer; and various manufacturers have various ways of specifying. For example, some manufacturers specify the level at which the cross-modulation for a number of channels is 57 db, while at least one other manufacturer specifies the level at which the cross-modulation is .05% when only two carriers are used in the test.



The nomogram shows a way of comparing these various specifications; and also a method to estimate what the cross-mod would be at the level that you actually use in the amplifier.

There are three scales on this nomogram: The middle scale is the cross-modulation that we discussed before. The upper scale is the output of the amplifier in dbmv, and the lower scale is the number of carriers used. This scale is really in two parts and we can use either of them, whichever is more convenient.

For a first example I'll start with an amplifier specified at .05% two carriers at +46 dbmv, and we want to know what would be the cross-modulation if you operated 12 carriers at +33 dbmv. First, we use the bottom part of the nomogram to find what is the effect of number of carriers. (Here I want to point out that the assumption on this nomogram is that the cross-modulation from various carriers will add incoherently. If we have many carriers that are on the same network that produce coherent sync pulses, the addition will be more severe than it is here.)

So, we join the point of "2 carriers," and .05% cross-modulation, find the intersection with line B, and then connect the "12-carrier" point through that intersection point up to the cross-modulation scale. This shows something around .16% (we don't really have to estimate this point exactly because this is only a partial answer).

Now, we go to the upper part of the nomogram and see what effect the level will have. We have now changed the number of carriers from 2 to 12. We take that intermediate point (which is roughly .16%), correct it to the +46 dbmv and go up to line A. From that point we come down to the +37 dbmv point and we end up on the cross-mod scale at .008%.

To summarize, I've used the bottom part to see the effect of number of carriers at the same output level; and the upper part for the effect of the output level at a constant number of carriers.

As a second example, suppose the amplifier is specified as having -57 db cross-mod at the level of +48 dbmv for 12 carriers. Here we don't have to change the number of carriers, and all we have to work with is the upper part of the nomogram. We connect the point at -57 db to the +48 dbmv, go up to line A. Now, suppose we are using the amplifier at a level of +37 dbmv, so we connect that point from scale A through the +37 and come up to .010% cross-modulation. This is the starting point for the computation of the trunk line.

Well, this is really all I wanted to show. How we estimate, or how we read the specification, or how we measure noise and cross-modulation with a single amplifier at the level we are going to work it, how the noise and cross-mod accumulate along the line and what we can expect as the final noise and cross-mod at the end of the line.

Now, are there any questions?

MR. KEN SIMONS: This really isn't a question. I'm cheating. I'm going to say two words. First, I want to thank Dr. Shekel for a very clear presentation of some facts that are long overdue in this industry. And, only one small point do I find that I would try to add. If you're adding numbers, the easiest way to add them is to add them, 100 plus 100 is 200. If you're multiplying numbers, particularly complex numbers, it's often convenient to use logarithms. The log of 100 is 2, 2 plus 2 is 4, 10 to the 4th is 10,000. It is easier than to multiply the numbers themselves. In the same way I believe in this business of cross-modulation and in many other facets of our community business, we have to jump back and forth between dbs and percent, and I believe we can, as Dr. Shekel has shown you here, greatly simplify the relationships involved. It's much easier to say that each amplifier contributed .1% cross-modulation than it is to say that dbs go up 6 db every time the number of amplifiers is doubled, or something complicated like that. However, I wouldn't say this worked all the time. For instance, when you're talking about change in levels, the amount of cross-modulation goes up 2 db for each 1 db change in level, and that's easier to say than to say that the percentage is squared.

MR. TAYLOR: Thank you, Ken. And, because we're running a little behind time - our demonstration took a little longer than we had counted on - I think we'll pass onto another paper without further questions. Thank you.

DR. SHEKEL: May I just give a not-answer to the not-question. I just want to defend in a couple of words the method of percentage, although as I say they are both equivalent and you can easily pass from one to another. First of all, it seems to me that percentage is easier when you have to add the contributions of various types of amplifiers. The cross-modulation of one is multiplied by the number of amplifiers in the trunk; and when you add the distribution amplifier, it is much easier using percentages.

As far as seeing the effect of output level on cross-modulation when it is in percent, one way would be using the nomogram, and the second way would be using the same table of dbs that I just invented 10 minutes ago. Because, you will check that if you increase the level in dbs, then you multiply the cross-mod by the number that is in the second column. But, again, as I said, there are many right ways of doing this thing and none is better than the other. Some are only more convenient. Thank You. (Applause)

MR. TAYLOR: Thank you, again, Dr. Shekel, very much. Maybe somebody will volunteer to be chairman of the Standards Committee. You can see the problems that arise in those deliberations.

Our next presentation will be on a subject that is somewhat new in this industry, Envelope Delay in CATV. Gaylord Rogeness from AMECO in Phoenix, Arizona, is our speaker, and his background, biographical sketch has been placed in your hands. Mr. Rogeness.

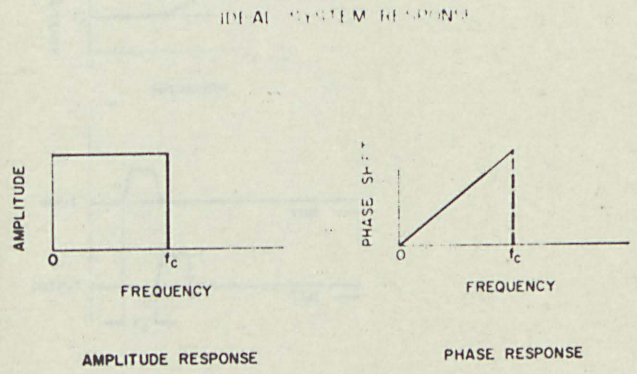
MR. GAYLORD ROGENESS: Thank you, Mr. Taylor. This morning I'm going to speak to you on the subject of Envelope Delay in CATV Systems.

Comparison of pictures produced by off-the-air signals and signals that have been transmitted through long cascades indicate that the off-the-air signal produces a sharper, more crisp picture. This effect is also more noticeable on low band channels compared to the high band channels. The low band channels produce a picture that is somewhat more fuzzy.

These effects exist even though the amplifier cascade has been aligned for optimum amplitude response, the cross modulation is at a minimum level, and the signal-to-noise ratio is high. Envelope delay distortion is a quantity which can explain some of these effects. Until recently, CATV systems have been providing pictures in areas where TV reception has not existed or has been very poor. Hence, there was little need to consider the more subtle transmission system requirements. However, as CATV moves into areas where competition with off-the-air reception exists, and the transmission of good color pictures is required, the effects of envelope delay have to be considered.

The objectives of my paper this morning are first to define envelope delay. Second, discuss the effects of envelope delay distortion of TV pictures. Third, discuss the sources of envelope delay, or where does envelope delay originate in the CATV transmission system? And finally, suggest possible measurement techniques and solutions to the problem of envelope delay distortion.

The CATV system receives a TV signal at an antenna and from this point has to transmit the TV picture signal to the home receiver through head-end equipment, cable and repeater amplifiers. Therefore, the transmission characteristics of this equipment should be as close to the ideal transmission characteristic as possible in order to provide the home receiver with the same picture quality that is received at the CATV antenna.

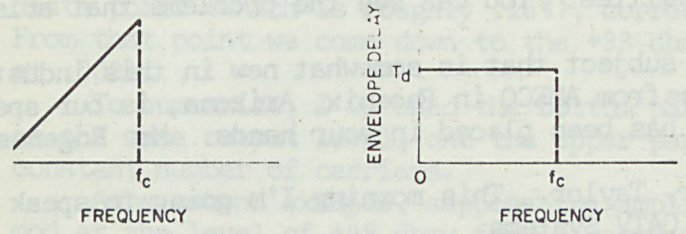


AMPLITUDE RESPONSE

PHASE RESPONSE

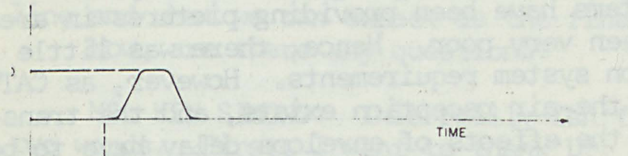
An ideal system has a flat amplitude response with respect to frequency and a phase shift characteristic that is linear. This is shown in FIGURE ONE. FIGURE TWO shows phase and delay characteristics of the ideal system. Envelope delay is defined as the rate of change of phase shift with respect to frequency. Or,in other words, envelope delay is the incremental slope of the phase shift curve versus frequency. In an ideal system the phase response is linear, so that the incremental slope of the phase response is constant. Hence, each frequency has the same value of envelope delay. It should also be noted that in an ideal system, time delay and envelope delay are equal.

IDEAL SYSTEM RESPONSE

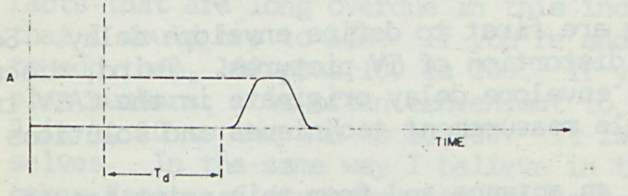


PHASE RESPONSE

ENVELOPE DELAY RESPONS



a) INPUT SIGNAL

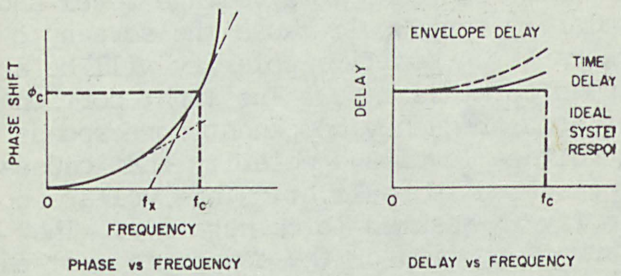


b) OUTPUT SIGNAL IS DELAYED REPLICA OF INPUT SIGNAL

A TV picture signal consists of a sum of pulses which in turn are the sum of many frequency components. When this signal is transmitted through an ideal transmission system, each frequency component experiences the same delay. As a result, the TV picture signal at the output of the transmission system is the same as that at the input but delayed in time. FIGURE 3A shows a pulse applied to the input of a CATV system. If the ideal characteristic of flat amplitude and linear phase over the band of frequencies being transmitted exists, the output will be a delayed replica of the input as shown in FIGURE 3B. The output pulse waveform will be exactly the same as the input pulse waveform and will occur at a later point in time.

The difference between envelope delay and time delay is shown in FIGURE FOUR. These quantities are compared at the frequency f_c. Time delay is the phase shift at this frequency divided by the frequency, whereas envelope delay is the slope of the phase response at the frequency f_c. Note that the magnitude of envelope delay is larger than the time delay magnitude.

RELATION BETWEEN TIME DELAY AND ENVELOPE DELAY



TIME DELAY = $\frac{\phi}{f_c}$

ENVELOPE DELAY = $\frac{\phi}{f_c - f_x}$

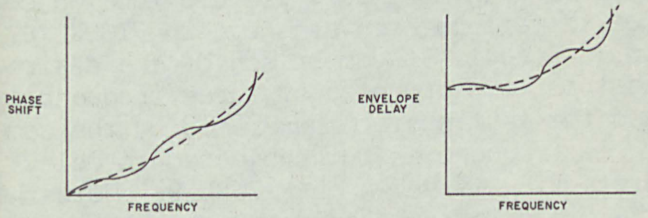
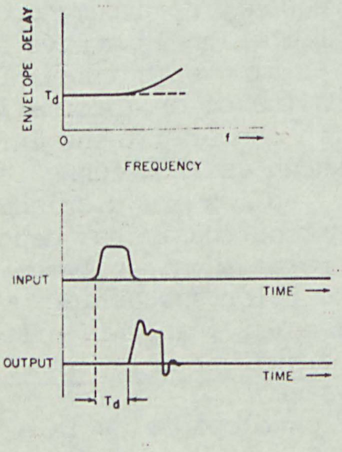


FIGURE 5. PHASE AND DELAY DEVIATION FROM LINEARITY. (NOTE THAT THE DOTTED LINE INDICATES THE SLOW DEVIATION FROM LINEARITY)



PULSE DISTORTION DUE TO NONUNIFORM ENVELOPE DELAY

FIGURE 4B shows a rough comparison of envelope delay and time delay over the frequency range of interest.

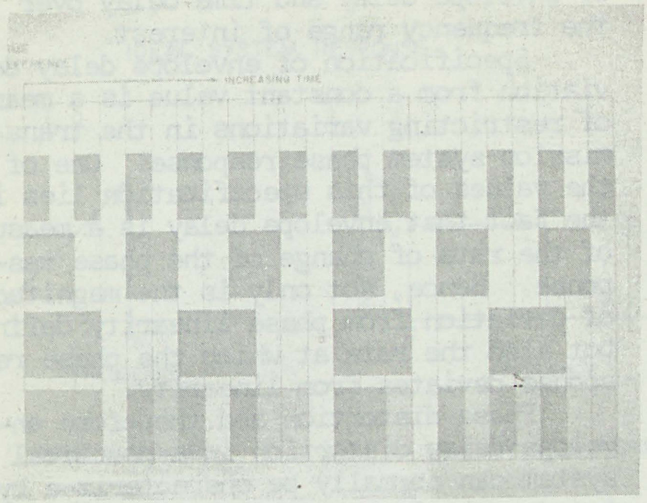
Specification of envelope delay deviation from a constant value is a means of restricting variations in the transmission system phase response. One of t the values of this specification lies in the fact that envelope delay is a measure of the rate of change of the phase response. Hence, not only is the magnitude of deviation from phase linearity defined, but also the rate at which the phase response deviates from linearity.

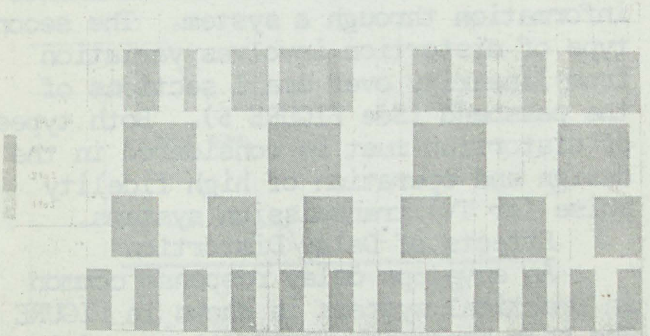
Phase distortion and therefore envelope delay distortion in a practical system can normally be characteriz-e by two descriptions. One is a gradual deviation from the linear phase characteristic, occurring over the major portion of the system passband. This distortion is important when comparing the transmission of color information with the luminance information through a system. The second type of distortion involves variation from linearity over small sections of the passband (See FIGURE 5). Both types of distortion must be considered in the design and operation of high fidelity pulse (or TV) transmission systems.

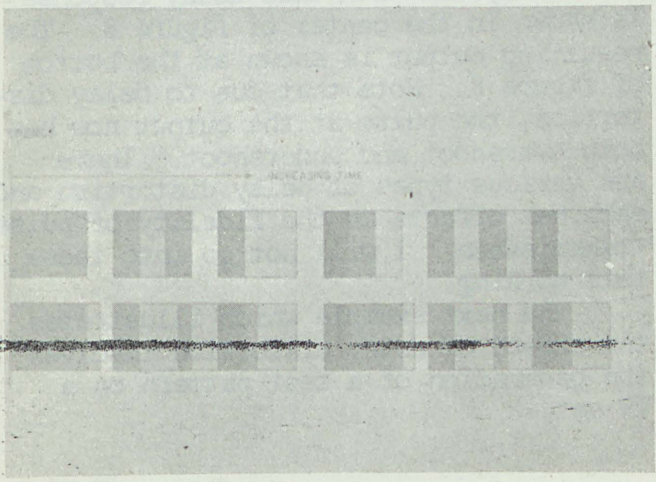
Effects of Delay Distortion

An envelope delay response common in practical systems is shown in FIGURE 6. The high frequency components are delayed by a greater amount than the low frequency components. A pulse applied to the transmission system with this delay response is shown in the center of figure 6. The resulting output is shown at the bottom of figure 6. Note that due to delay distortion, the pulse at the output now has both overshoot and undershoot. There are various types of delay distortion and each has effects on the fidelity of pulse transmission. I will not go into these this morning.

The next example which illustrates the effect of delay distortion involves the generation of a test pattern on a TV set.







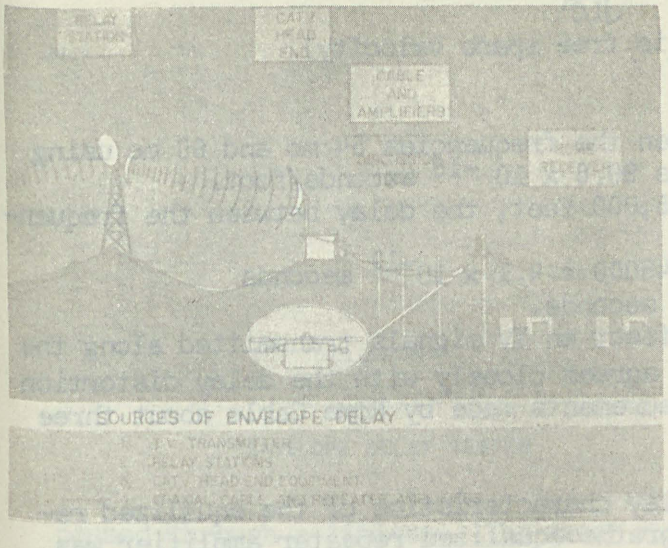
The bottom line of FIGURE 7 shows the desired test pattern. This test pattern is generated by the sum of three frequencies occurring in the time phase shown. The black portion of each frequency component shown corresponds to a voltage level and polarity that would cause the screen to be dark. A positive polarity will be assumed for this case. The light portion of each frequency component corresponds to a voltage level and polarity that causes the screen to be light. This voltage polarity is assumed to be negative. The darkest portion of the composite test pattern is then generated when all three positive voltages add at the same time. The dark gray is produced when only two positive voltages add. A completely white bar is produced when the negative voltages of all three frequency components add at the same time.

When all three frequency components are not delayed by the same amount during transmission to the TV picture tube, a composite test pattern as shown in FIGURE 8 could result. A comparison of the desired test pattern produced by three frequencies and the test pattern generated by the same three frequencies but subjected to delay distortion is shown in FIGURE 9. Note that the distorted pattern does resemble the desired pattern.

Consider next the effects of time delay distortion on a color picture. The color picture is composed of two main signals - the chrominance information which contains color information and the luminance signal which contains the brightness information. These signals are transmitted in different parts of the frequency spectrum, so it is important that both signals arrive at the TV picture tube at the same time. Due to delay distortion the color information may not coincide with the brightness information and an effect known as the "funny paper effect" occurs. Colors are displaced to the right or left of the image, depending upon the delay relationship between the picture carrier and color subcarrier. The red color is most sensitive to this effect.

Sources of Envelope Delay in a TV Transmission System

Sources of envelope delay in a TV trans-



mission system are depicted in FIGURE 10. A responsibility of the TV station is to transmit TV program material over the air. In so doing, the TV signal passes through equipment which have amplitude and phase characteristics that are frequency dependent.

Next a relay station may be necessary before the CATV system received the signal. This relay station is a second source of distortion in the system.

The CATV system consists of head end equipment, coaxial cable, and equalized amplifiers. Each of these three items is a potential source of distortion.

The signal finally arrives at the home receiver where it is processed and displayed. Many sources of amplitude and delay distortion exist in a TV set that is not properly aligned.

The FCC regulates the characteristics of the color TV signal being transmitted. The TV transmitter must have a prescribed envelope delay characteristic. This delay characteristic is specified to compensate for the delay distortion produced in the frequency selective circuits of the home receiver. The manufacturers of TV receivers use the specified delay characteristics of the transmitter to set design and manufacturing tolerances on their TV sets. Therefore, any picture transmission equipment placed between the TV transmitter and home receiver must be near perfect in order to minimize distortion.

Phase characteristics of the coaxial cable and equalized repeater amplifiers used in CATV systems will be discussed at some length today.

Phase Characteristic of Coaxial Cable

The transmission of energy along a coaxial cable is defined by the complex propagation constant. The propagation constant has a real and imaginary component. The real part describes attenuation along the cable and the imaginary component defines the phase shift constant of the coaxial cable. The propagation constant is

$$\gamma = \sqrt{(R+jwL)(G+jwC)} \quad (1)$$

For low loss cable, such as that used in the CATV industry, it is possible to simplify equation one and write the phase shift constant

$$\beta = \sqrt{LC}\left[1 + \frac{1}{8}\left(\frac{R}{WL}\right)^2\right] \quad \text{radians/unit length} \quad (2)$$

R, L., and C are the cable resistance, inductance, and capacitance per unit length and w is 2π times the frequency in cycles per second.

Remembering that envelope delay is the rate of change of phase shift with respect to frequency, the derivative of equation 2 yields the cable envelope delay.

$$T_E = \frac{dB}{dw} = \sqrt{LC}\left[1 - \frac{1}{8}\left(\frac{R}{WL}\right)^2\right] \quad \text{seconds/unit length} \quad (3)$$

Note that envelope delay is not constant with frequency because of the $(\frac{R}{WL})^2$ term. However, the magnitude of this deviation from a constant value is small enough to have negligible effect. A numerical example will show this:

Constants taken from a cable manufacturer's data sheet for 75 ohm Alucel 1/2" coaxial cable are

Capacity C = 16.5 pf/foot

Velocity of Propagation $V_c = 0.82\ V_o = \frac{1}{\sqrt{LC}} = 7.87 \times 10^8$ ft/sec

Attenuation (V_o is free space velocity)

$\alpha = 0.006$ db/ft at 54 mc

$\alpha = 0.0065$ db/ft at 60 mc

The difference in envelope delay between the frequencies 54 mc and 60 mc using the cable constants listed and equation 3 is 90.6×10^{-18} seconds/foot.

For a 30 amplifier cascade extending 45,000 feet, the delay between the frequencer 54 mc and 60 mc is

$$T = 90.6 \times 10^{-18} \times 45000 = 4.1 \times 10^{-12} \text{ seconds}$$

$$T = 4.1 \text{ micro-micro seconds.}$$

This delay distortion has negligible effect on TV signals transmitted along the cable. This number of 4.1×10^{-12} seconds agrees closely with the delay distortion calculated from velocity of propagation measurements made by Rome Cable about three years ago.

Repeater Amplifier Delay Characteristics

The next problem is to describe the delay characteristics of the equalized repeater amplifier. A theoretical response for the equalized repeater amplifier was postulated for an 18db length of cable. The amplifier response was assumed maximally flat at both the low and high end. The high end roll off was assumed more steep than the low end because of the cut off characteristics of the transistors.

The transfer function of an equalized amplifier can be written:

$$\frac{e_{out}}{e_{in}} = \left[\frac{1 + j\frac{w}{w_1}}{1 + j\frac{w}{w_2}}\right]\left[\frac{\left(j\frac{w}{w_3}\right)^n}{\left(1 + j\frac{w}{w_3}\right)^n}\right]\left[\frac{1}{\left(1 + j\frac{w}{w_4}\right)^m}\right] \qquad (4)$$

To calculate the envelope delay of this expression the phase response is first derived and is

$$\text{Phase} = \tan^{-1}\left(\frac{w}{w_1}\right) - \tan^{-1}\left(\frac{w}{w_2}\right) + 90° = \tan^{-1}\left(\frac{w}{w_3}\right)^n - \tan^{-1}\left(\frac{w}{w_4}\right)^m \qquad (5)$$

The envelope delay is the derivation of equation 5 with respect to w ($2\pi f$).

$$T = \frac{1}{f_1}\left[\frac{1}{1+\left(\frac{w}{w_1}\right)^2}\right] - \frac{1}{f_2}\left[\frac{1}{1+\left(\frac{w}{w_2}\right)^2}\right] - \frac{n}{f_3}\left[\frac{\left(\frac{w}{w_3}\right)^{n-1}}{1+\left(\frac{w}{w_3}\right)^{2n}}\right] - \frac{m}{f_4}\left[\frac{\left(\frac{w}{w_4}\right)^{m-1}}{1+\left(\frac{w}{w_4}\right)^{2m}}\right] \qquad (6)$$

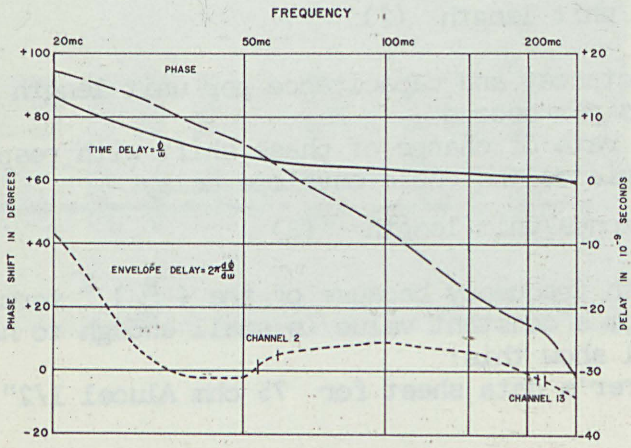
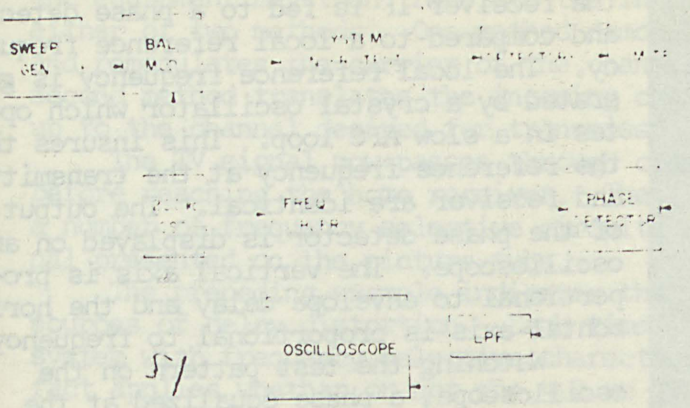


FIG. 11. CALCULATED PHASE AND DELAY RESPONSES

Phase, time delay, and envelope delay were calculated as a function of frequency using equation 5 and 6 are shown in FIGURE 11. The following values were used in the calculations:

$w = 2\pi f$	
$w_1 = 2\pi \times 49.5 \times 10^6$	$n = 2$
$w_2 = 2\pi \times 334 \times 10^6$	$m = 4$
$w_3 = 2\pi \times 40 \times 10^6$	
$w_4 = 2\pi \times 250 \times 10^6$	

Note that envelope delay is not constant with frequency as is required for an ideal transmission system. Also note that channel 2 is more susceptible to response irregularities than channel 13 because it occupies a higher percentage bandwidth.



ENVELOPE DELAY TESTER

(6 mc bandwidth at 54 mc compared to 210 mc).

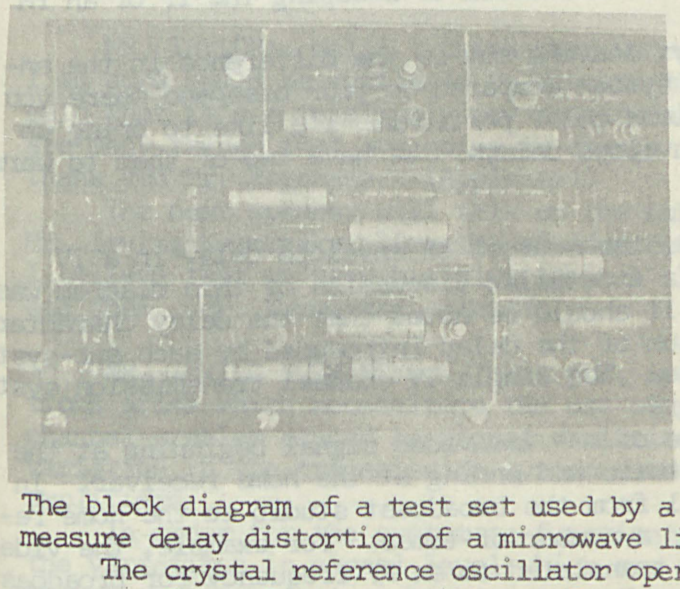
Envelope Delay Testing

A block diagram of a test set that measures envelope delay is shown in FIGURE 12. The 200kc reference oscillator output is applied to a frequency doubler and balanced modulator. The second input to the balanced modulator is a sweep generator. The output of the balanced modulator is two frequencies spaced at twice the reference oscillator frequency. These two signals are applied to the system under test and are swept across the frequency spectrum maintaining a constant spacing.

The test signals are detected at the output of the system under test and then passed through a limiter. The test signal at the output of the limiter is then compared in a phase detector with the output of the frequency doubler. Each of these signals is at the same frequency. However, the doubler output has a constant phase reference while the signal passed through the system under test is measuring the incremental slope of the system phase response. The output of the phase detector is a DC voltage proportional to the envelope delay of the system under test.

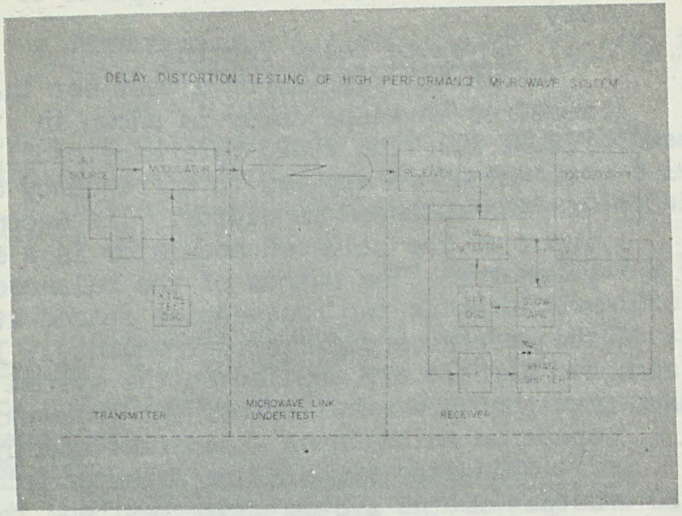
The oscilloscope displays envelope delay on the vertical axis and frequency on the horizontal axis. The vertical scale can be calibrated in terms of electrical degrees or directly in units of time (microseconds or nanoseconds). A frequency marker can be inserted into the test set for calibration of the horizontal scale.

An envelope delay test set was constructed by utilizing the principles described in the preceding three paragraphs. This test set is shown in FIGURE 13. Unfortunately, time did not permit the completion of many delay measurements before the convention. However, the envelope delay of a cascade of three AMECO ATM-70 amplifiers and 75 db (220mc) of coaxial cable was measured. The envelope delay characteristic was constant from 40 mc to about 90 mc and then began gradually sloping through the high band. The difference in delay across any high band channel was less than three nanoseconds (3×10^{-9} seconds).



The purpose of this next example is to point out that phase distortion, and hence delay distortion, can be measured and corrected in the field even though the transmitted and received signals are physically separated by large distances. The block diagram of a test set used by a manufacturer of microwave equipment to measure delay distortion of a microwave link is shown in FIGURE 14 (next page).

The crystal reference oscillator operates at about 500kc and modulates the RF source. The reference oscillator frequency is divided down to provide a sweep voltage to sweep the RF source through the passband of the transmission system. The swept RF signal is transmitted over the microwave link and is received at the remote



location of the receiver. The output of the receiver IF is fed to a phase detector and compared to a local reference frequency. The local reference frequency is generated by a crystal oscillator which operates in a slow AFC loop. This insures that the reference frequency at the transmitter and receiver are identical. The output of the phase detector is displayed on an oscilloscope. The vertical axis is proportional to envelope delay and the horizontal axis is proportional to frequency.

Watching the test pattern on the oscilloscope, a phase equalized at the receiver IF output is adjusted until the transmission system delay distortion is minimized.

Today I have defined envelope delay as the rate of change of the transmission system phase response. Some of the effects of delay distortion on the transmission of TV pictures were mentioned as a loss of crispness of the black and white signal and a funny paper effect on color pictures.

I believe that we must now develop test equipment to accurately measure the CATV system delay characteristics. After the delay characteristics have been measured, phase and/or delay equalizers can be designed to compensate for existing delay distortion. Thank you. (Applause)

MR. TAYLOR: Thank you very much. I think we would have time for one or two questions if somebody would like to. I see one here.

MR. WILLIAM CRUZ, (Collins Radio): I think it should be important at this point and time with your fine speech here to separate the distinction of envelope delay of your sweeping, the RF spectrum where cable activities -- it's all very proper, very correct. I agree with you completely. Your discussion of sweeping the IF of an FM or microwave system is also correct.

One other thing you are, sorry to say, leaving out is the difference in the envelope delay of your RF system or your IF system compared to your baseband where you are considering the envelope delay of various color portions. I'd like to bring up the point that they are quite different envelope delays. We have two of them to worry about. Thank you.

MR. ROGENESS: Referring to figure 10, the sources of envelope delay in a TV transmission system are shown pictorially. A detailed discussion of this diagram was not made because of the time limitation. It should be noted that the delay characteristic of a linear system is equal to the sum of the delay introduced by each sub-system contributing to the overall system response. The single TV channel transmission system delay characteristics are of importance here.

As an example, follow the transmission of a 4.2mc video signal beginning at the output of the TV camera at the broadcast studio and ending at the home receiver. In the transmission of this 4.2mc video signal from the broadcast studio to the home receiver, the video signal will be translated a number of times. For example, the video signal at the broadcast studio is mixed or translated to an RF frequency for broadcast. A microwave relay station may then receive this signal, translate it to IF frequencies and amplify it, and then mix back up to a microwave frequency for transmission at microwave. The next relay station may then translate the signal from microwave back to RF frequencies for re-transmission.

At this point a CATV system may receive the signal off the air. The CATV head-end equipment may then translate the incoming channel to a different channel by either of two methods. One method demodulates the incoming TV channel to baseband and remodulates the carrier of the channel to be transmitted over the cable. A second method translates the incoming channel down to IF frequencies and then back up to the channel desired for transmission over the cable.

The TV signal now passes through coaxial cable and equalized repeater amplifiers before reaching the home receiver. The TV signal in the home receiver passes through a number of frequency selective circuits before it is demodulated and the video signal presented on the picture tube.

The preceding example indicates that the 4.2 mc video signal is subjected to many sources of delay distortion. Each time it passes through a network or transmission system with frequency selective characteristics, delay distortion is possible. This fact applies whether or not the 4.2 mc TV signal is at video, IF, RF or microwave frequencies. The delay characteristic of the TV transmission path between TV camera and the TV picture tube in the home receiver is equal to the sum of the delay characteristics of each frequency selective network that the TV signal passes through.

The CATV system has control of the transmission characteristics of the head-end equipment and the cable system. Therefore, from a knowledge of the delay characteristics of the transmission systems external to the CATV system and a knowledge of the overall delay characteristic required to transmit an undistorted TV picture, the CATV system delay response can be specified.

MR. SABIN FLORESCU, from Carlsbad Cable Division: We were talking about envelope problems in the RF transmission systems, just the same way Bill Cruz said it. Our biggest problems are in the modulators. What do we do about them?

MR. ROGENESS: There are two types of phase distortion. One is differential phase which is a cross modulation of the color and luminance signals and is a function of the nonlinearity of the modulator; whereas envelope delay -- or the characteristics I was talking about were related to the phase response of the transmission system which are constant.

The delay response of head-end equipment between CATV antenna and coaxial cable must be constant with frequency in order to solve Mr. Florescu's problems.

MR. TAYLOR: Well, I think that we're running a little behind time. Mr. Rogeness I am sure would be available to discuss this question. I think it can also be safely said that it's a relatively new consideration in our industry and I am sure there are many things that are going to change in the future as a result of this discussion. Thank you Mr. Rogeness. (Applause)

The next speaker will talk on the subject of "Automatic Gain Control in CATV". Mr. Irving Kuzminsky, Director of Advanced Product Engineering of Entron, Inc. And, I believe that we have his biographical sketch to circulate if the pages will circulate them. Mr. Kuzminsky, please.

MR. IRVING KUZMINSKY: Thank you, Archer. In a CATV system, two types of situations arise which necessitate the use of gain control. One is a narrow-band single-channel problem caused by signal variations at the antenna. The other is a wide-band variation in the transmission system caused by changes in either the cable or the amplifiers.

In order for the system to function properly, it is necessary to first eliminate the variations in signal level which are normally encountered at receiving sites. Let us consider what might happen at the customer's receiver if this were not done.

Most present day CATV systems utilized adjacent-channel transmission as a means of most efficiently carrying the maximum number of channels at a minimum cost. However, as far as the receivers are concerned, the adjacent channels are potential sources of interference. This was the reason that, in the early days of CATV, some people thought that adjacent-channel systems would not work. In order for these systems to work properly, it is necessary to accurately control the levels of the signals with respect to each other so that the receiver is able to pick out the selected signal without objectionable interference from other signals.

Once the single-channel signals are combined onto a common line, random variations of these signals would be impossible to handle. This is because the gain of the trunk amplifiers is controlled on a wide-band basis. That is, the gain is varied in a coherent manner to all channels in the amplifier passband simultaneously. With random variation of each channel's signal, cross modulation and noise problems would be encountered in the trunkline system. With some signals going up, some going down, and others remaining constant, gain control would be impossible, and the problems generated are obvious. Thus, stabilization of the antenna signals is mandatory before the signals are inserted into the trunk system.

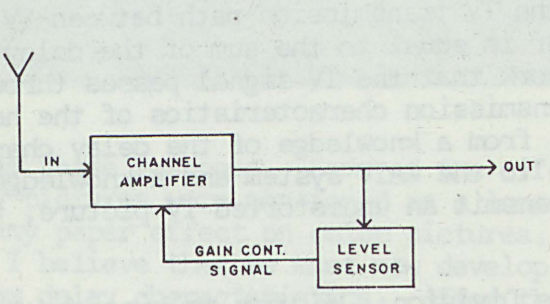


FIGURE I

FIGURE 1

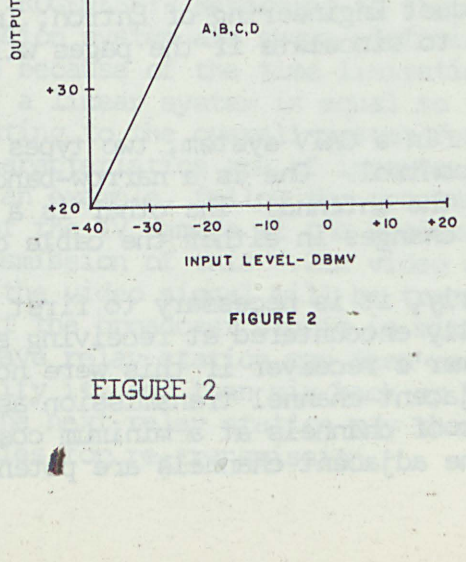


FIGURE 2

FIGURE 2

The variation in antenna signal level is usually handled by the method shown in FIGURE 1. The signal is amplified in a single-channel RF amplifier. The output signal is detected and provides a DC control signal which is indicative of the output signal level. This control signal is used to vary the operating point of the intermediate stages and, by this means, the gain of the amplifier so as to maintain the output at a nearly constant predetermined level.

FIGURE 2 is a plot of the output level of a typical single-channel AGC amplifier. The amplifier being considered has a gain of 60 db. Curve A indicates that, with no AGC there is a linear relation between input and output except for high levels where the amplifier overloads. Curves B, C, and D show that, for small signals, the output follows the input. However, once the AGC threshold is exceeded, the output remains almost constant. Thus, for proper AGC operation, a minimum signal level is required depending on the setting of an output level control.

This is called "delayed AGC" because gain control is delayed until the threshold signal is reached. Curves B, C, and D represent different delays. The maximum allowable input level is determined by the overload characteristics of the amplifier.

Normally, the input and output stages are not varied, since varying the input stage affects noise figure and input match, and varying the output stage affects the overload level of this stage. Because of these noise and overload limitations, some other method should be used where large signal level variations exist.

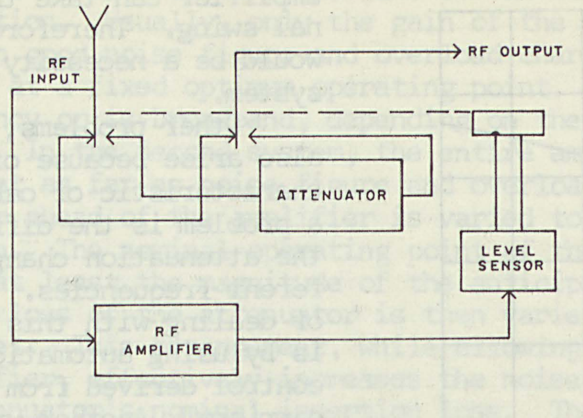


FIGURE 3

FIGURE 3

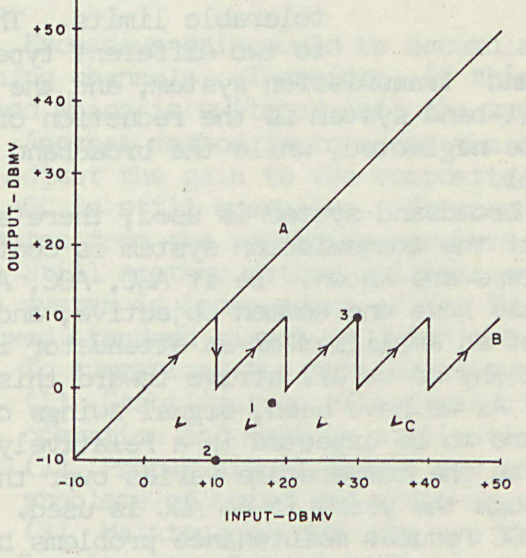


FIGURE 4

FIGURE 4

Consider the block diagram shown in FIGURE 3. The RF input signal is amplified and detected. When the detected signal exceeds a predetermined amplitude a delay is activated and an attenuator is inserted between the antenna and the head end equipment. When the signal decreases sufficiently, the attenuator is removed. A cascade of four such switchable attenuator sections--each section having 10 db attenuation-- effectively reduces a 60 db signal swing to 20 db. This smaller swing can then be handled by the AGC arrangement previously considered.

FIGURE 4 is a typical plot of output level vs. input level for a four-section controller. "A" is a plot of output level vs. input level with no compensation and, and, of course, the changes in output level follow the changes in input level. The output level vs. input level is shown by "B" for increasing, and by "C" for decreasing signal. At any given level, the input can vary over a 20 db range with no switching occurring. For example, at Point 1, with an input of 18 dbmv, two attenuators have been switched in so that the output is 18 - 20 or -2 dbmv. As long as the input signal level remains between +10 and 30 dbmv, no switching will occur, and operation will be along the joinging Points 2 and 3.

Once the signal levels at the head end are stabilized, the signals are ready to be inserted into the transmission system. Since the signals are stabilized, why is AGC necessary in the trunkline amplifiers? To answer this question, it is necessary to look at the entire trunkline system. While the signals may be stabilized at the input to the trunkline, they will still vary in the trunkline because of changes in cable attenuation with temperature variation and because of changes in amplifier gain. While the latter factor is a matter of conjecture, the change in cable attenuation is a well known fact and can be predicted.

If the last amplifier at the end of the longest trunk is capable of handling the largest signal swing expected then AGC is not required. FIGURE 5 (next page) shows the correction factor which must be applied to the 68° value of cable attenuation to obtain the attenuation at some other temperature.

We can see that the extreme temperature to which the cable may be subjected, attenuation correction factors are obtained of 1.06 at +120°F and 0.90 at -20°F. This means that for each 100 db of cable attenuation, there results an increase of 6 db at 120°F and a decrease of 10 db at -20°F.

A trunkline consisting of 1/2 inch foam dielectric aluminum jacketed cable may typically have an attenuation of 1.3 db per 100 feet at Channel 13 at 68°F. In a five mile line, this would amount to 340 db attenuation. However, at 120°F this would increase by 20.4 db, and at -20°F it would decrease by 34 db. No presently existing

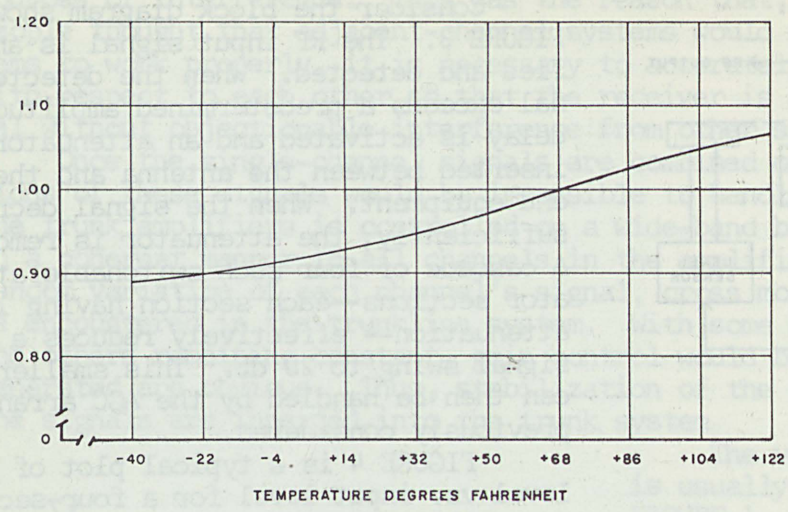


FIGURE 5

FIGURE 5

amplifier can take this signal swing. Therefore, AGC would be a necessity in this system.

Other problems, of course, also arise because of this characteristic of cable. Such a problem is the difference in the attenuation change at different frequencies. One way of dealing with this problem is by using automatic tilt control derived from two pilot carriers. Another way of dealing with the problem is to use thermal equalizers. A third way is to split the band so that the accumulated difference in cable attenuation within each band is within tolerable limits. This leads to two different types of transmission systems, the so-called "Split-Band" transmission system, and the broadband transmission system. The advantage of a split-band system is the reduction of change of tilt effects to the point where they may be neglected, while the broadband system must use some method of automatic tilt control.

Regardless of whether a split-band or a broadband system is used, there are still many methods in use today by which the gain of the transmission system is controlled. There are also many names by which these systems are known. Be it AGC, AOC, ALC, AVC, or A--you name it--C, all of the methods in use have one common objective, and that is to vary the gain or loss (in some cases) of an amplifier or an attenuator in an attempt to maintain a constant signal level. Why do we all strive toward this goal?

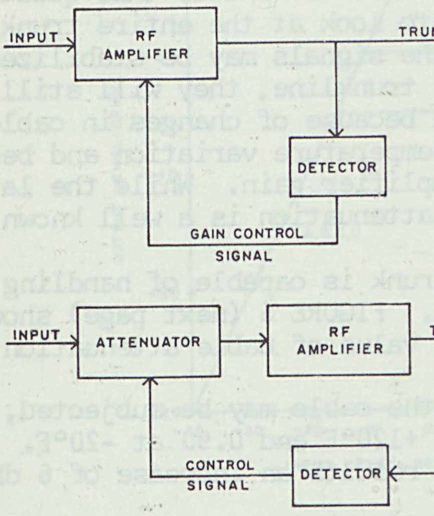


FIGURE 6

FIGURE 6

As we have seen, signal swings of 20 or 30 db are to be expected in a relatively short system as the temperature varies over the day and through the year, if no AGC is used. The use of AGC reduces maintenance problems by eliminating the need for periodic resetting of levels. Too, compensation for cable and equipment aging is provided to some extent. Let us look at some of the different methods that are used to achieve these goals.

Whether the transmission system is broadband or split-band, operation of the AGC circuits in either of these systems may be controlled by either TV signals or by pilot carrier signals. Also, either a single signal or a multiplicity of signals may be used for AGC purposes. Thus, many possible types of AGC systems exist. However, all of these methods are very similar in actual operation. FIGURE 6 is a block diagram which illustrates two methods which might be used with either TV signal or pilot carrier AGC systems.

In the first case, the amplifier is operated below its maximum gain capability

so as to be able to compensate for anticipated changes in input signal in either direction. Usually, only the gain of the intermediate stages are varied so as to maintain good noise figure and overload characteristics while the input and output stages are at a fixed optimum operating point. The detector is tuned either to a single frequency or is broadband, depending on the type of AGC system used.

In the second system, the entire amplifier is maintained at its optimum operating point as far as noise figure and overload characteristics are concerned. The attenuator ahead of the amplifier is varied to change the overall gain at the amplifier station. The nominal operating point of the attenuator must provide an insertion loss of at least the magnitude of the anticipated downward change in input signal level. The loss of the attenuator is then varied up or down to correct for changes in input level. This arrangement, while allowing optimum operation of each stage of the amplifier, effectively increases the noise figure of the amplifier by the amount of the attenuator's nominal insertion loss. The best solution may be a combination of the two methods. That is, place the attenuator at an intermediate point in the amplifier. This would allow optimum operation of the active elements in the amplifier and, at the same time, provide a good noise figure.

As stated previously, the AGC may be derived from either TV signals or from pilot carrier signals. A single TV signal cannot be used alone to activate the AGC because if that channel went off for any reason, all amplifiers would run wide open.

Excessive gain would be accumulated, and overload would soon occur on the remaining channels. Therefore, if this method is used, a standby oscillator is required which is switched into the system if the primary source goes off.

Another method is to sense the composite signals in the passband of the amplifier and adjust the gain to the composite level. With this method, if a station goes off, the AGC is still operative. No standby oscillator is required since the AGC circuit operates from the remaining carriers.

Still another mtthod utilizes only pilot carriers to drive the AGC circuits. This system is independent of the TV signal levels and has the advantage of providing a fixed standard signal to which the entire system may be referenced.

To summarize, the main advantages of AGC are:

(1) Stabilization of individual channel signals permits adjacent channel operation and maximum utilization of the transmission system.

(2) Proper signal levels may be maintained in the trunk, thereby avoiding problems of noise and cross modulation.

(3) Maintenance problems are reduced by eliminating the necessity to reset levels with changes in temperature.

Thank you. (Applause)

MR. TAYLOR: I think we can take time for one or two questions. Anybody have a question they want to ask Mr. Kuzminsky? One in the back of the room.

UNIDENTIFIED SPEAKER: This might be going back to this envelope delay problem, but I notice on the color set there was another image to the right and I've had this problem on black and white. I don't know what it is. Is it miss match?

MR. KUZMINSKY: Well, sounds like it.

UNIDENTIFIED SPEAKER: Miss match?

MR. KUZMINSKY: Yes.

MR. TAYLOR: Thank you. Thank you very much, Mr. Kuzminsky. (Applause)

Our next speaker is Mr. Robert Cowart, Vice President in Charge of Construction for Viking Company. And, he's going to talk on "System Reliability". I believe the

sketches will be circulated while he's talking. Mr. Robert Cowart.

MR. ROBERT COWART: I like in particular that ETA part, so I'll be very brief. I'd like to talk to you this morning briefly on system reliability.

These days we find outselves building more and more systems into areas that already have available to them strong high quality, highly reliable, local off-the-air signals. In order for a system to compete under these conditions, the system must be engineered in such a fashion that it could successfully compete in terms of the same quality, reliability and performance as these off-the-air signals. The preliminary determinants of quality are signal-to-noise ratio, cross modulation and ghosts. You are all familiar with these terms as a result of the industry schools which outline and detail methods of qualitative determination. I am sure that by now you are all familiar with these terms, with their method of determination and know of many ways in which to improve them. A fourth, extremely important, factor is reliability. A subject which has frequently been.ignored both in the past and at the present. My purpose today is to acquaint you with the basics of reliability and to point out to you some methods by which present system reliability can be improved.

Many studies have been made in the past both by military and commercial interests in the pursuit of those factors that control and influence reliability. In almost every case explored the most highly reliable system was the simplest system. I am sure you will all agree from your own experience that this is the case. The military answer for increased reliability is redundancy. This means having almost two complete sets of basic equipment, one ready to take over the function of the first, should it fail. The commercial solution to reliability is primarily by increasing the reliability of the components and increasing the size, weight and mass of the device. This is more or less the brute force approach.

In CATV, neither of these two standard approaches is really available to us because of the unusual demands we make of the device. In transistorized equipment we sacrifice virtually everything for the sake of a lower noise figure or increased output capability. We are pushing the upper limits of the State of the Art. We can't use redundancy because of cost. We can't use higher reliable components because high reliable, high performance transistors are not available yet. We must achieve our reliability in the method in which we construct our systems, and in the method in which we utilize the manufacture's product.

Most manufacturers today design equipment that is inherently reliable. In many, many cases that we have examined, we find that this inherent reliability of the device is lost in its application.

Reliability in electronics systems is generally considered to mean the length of time between events that render the system incapable of performing its designed function. In industry, exhaustive and extremely expensive studies are made to determine and assign quantitative values for the time between failure. This period is often referred to as mean time between failure or MTBF. In CATV these numbers are not available but the principle guiding the establishment of these numbers is available and it is with this principle that we will concern this discussion.

If all of the components of an electronics system are considered to be functionally in series and if the failure of any components in this series chain results in a system failure then the overall system reliability can be expressed by a very simple formula. This formula states that the overall system reliability, designated by the symbol "R", is equal to the reliability of each of the series components raised to the power of the number of those components that are in series.

$$R = r^n$$

Where r = mean reliability (probability function) of each component.
n = number of components in series.

This expression demonstrates something that you know intuitively to be true. In other words, the longer your trunk line in a system the greater the probability of failure of a component of the trunk. Conversely, the shorter the line tne less chance of failure. The formula also allows us to show mathematically that given two different amplifiers if twice as many amplifiers are used in a system of Type "A" as are Type "B" and Type "B" has half the reliability of Type "A" then the overall reliability of the system is exactly the same because there are twice as many pieces used but the reliability of each piece is twice as great. You intuitively know that the statement is correct.

The formula also shows that the high reliability system would have few parts and each part in itself should have the highest possible reliability. Towards accomplishing this end we customarily, in large systems, use extremely low loss trunk cable such as 3/4" aluminum and the highest possible db spacing between amplifiers because in our trunk system the highest reliability component is the cable; secondly, would undoubtedly be the connector; thirdly, the accessory items, splitters, directional couplers, etc.; and lastly with least reliability is the amplifier itself. Our major significant contribution to reliability of that trunk segment would be to decrease, by whatever means we could the cable loss, utilize wide amplifier spacing, etc., the number of amplifiers functionally in series. In our efforts to increase the reliability of that trunk segment we would attempt to reduce the total number of objects with lesser reliability than the cable to a minimum. This would mean we would reduce the number of splices, if possible, by care in our construction; we would reduce the number of splitters, directional couplers, equalizers and other objects inserted in the lines and try and make as much of the line as we could, sheer cable: Because, of course, the cable is the most highly reliable item of our components.

The same reasoning establishes a guide line in the design of equipment and has prompted most major manufacturers to abandon the practice of using splitters to generate inputs to associated distribution equipment and to instead build into the trunk amplifier chassis a fixed directional coupler to provide the input to distribution. When this is done we eliminate a jumper and several connectors that we used to use in the past to accomplish this. The same reasoning demands that in transistorized equipment the equipment should be mounted without equipment enclosures. That means not with the use of an equipment cabinet. When an equipment cabinet is used the signal must pass through a bulkhead connector, a mating connector internally in the cabinet, a jumper, and finally through another connector on the end of the jumper and into the amplifier chassis. The same thing is true on the output of the amplifier. When this is done there are five additional elements functionally in series with the signal between the two ends of the trunk cable. Although connectors have inherently high reliability, by removing the eight connector assemblies from the line and replacing them with two direct entry connectors, we have thus improved the reliability of each amplifier station four times. You intuitively know that the reliability of this configuration is far less than the direct entry type connector permanently mounted to the amplifier chassis.

In an operating system when you examine at the end of the year the maintenance that has been given to the system, you find some rather curious things. You find first of all that many of your system outages were not caused by any inherent failure of the amplifier itself. You find that they were caused by such unrelated things as power failures; by cars breaking off power poles; by trees falling across distribution and trunk cables; by the failure of fuses as a function of temperature; by lightning strikes; and by employee carelessness in leaving amplifiers disconnected, etc. Another important point that gains in significance as we move into the area of transistorized system construction with many, many, amplifiers dependant on a single power supply is that extreme caution should be used in selecting the location for the power supply. I am sure that you have all had an experience where a certain amplifier in your system continually caused you trouble because of failure of secondary voltage delivered by the power company. We have seen amplifiers installed and taking power from power company transformers already seriously over-loaded. Few of you have given any thought to requesting the power company to provide you with your own transformer, which need not be very large, to assure yourself of a non-interrupted source of power.

The cost is very low and the reward in terms of increased reliability is great. These things again point up the fact that in system design, a system should be engineered in such a fashion so that the absolute minimum of active elements of the system are in cascade. Ideally, as we have all discussed many times in the past, a system would be arranged in the manner of a wheel; with the center of the wheel the point of signal origination and of radial lines from the wheel hub to the outlying distribution areas. Although this is obviously impractical in most cases, an attempt to accomplish this type of construction can be made by the adoption and usage of extremely low loss master trunk cables as a backbone of the system. This new configuration will resemble somewhat the skeleton of a fish; with the master trunk cable being the backbone of the skeleton and distribution at right angles to this master trunk but in much, much smaller segments.

Many of you have suggested in the past that you accomplished a form of redundancy by paralleling master trunks perhaps several blocks or half a mile or so apart, but when you examine the situation existing in parallel trunk, you find that you have not accomplished your purpose because the basic law of system reliability catches up with you. Remember, it states that the reliability decreases exponentially in proportion to the number of active elements in cascade. By paralleling master trunk you are in effect doubling the number of elements in cascade. Now it is true that by the redundant parallel trunk method you do restrict the service fault to a smaller area, however, if the two or more trunk segments are exactly the same length, then the system reliability itself, on the basis of our definition of fault, is actually impaired by the same number of trunk lines existing.

In summary, let's recap the major points that we have established. A system gains RELIABILITY by SIMPLICITY. This means that when you make your new layouts, look at them carefully to determine if you have taken the shortest route, if you have arranged your construction to utilize a minimum of connectors and splices, see if your power feeds come from a reliable source and make sure that you are utilizing as fully as possible the reliability delivered to you by the manufacturers.

Thank you. (Applause)

MR. TAYLOR: I would open the floor to questions on any of the subjects we've been answering. Let's take any questions to Bob Cowart first, if you have them, however. Are there any questions on this Systems Reliability that you'd like to ask Bob Cowart? Well, if there are no questions specifically to Bob, they may arise later. I shut off a number of questions earlier, particularly on the subject of envelope delay. Ken Simons.

MR. SIMONS: Again, this isn't a question. I would like to take a few minutes if you don't mind to show you a little scheme that we have used for some years in our lab to measure group delay. You might call it Do-it-yourself-group-delay-measurement. It takes equipment that most of you will have in your service shop or lab and I think there's enough time to sketch it out. The accuracy is not of the highest order but perhaps we'll make up for that in the cheapness of the equipment used.

I should give a credit here. The very fine grease pencil I'm about to use is through the courtesy of VIKING.

Now, the basis of this method of group delay measurement is the constant delay of a long piece of cable. If you have a reel of cable and I'll represent it this way. That's a piece of cable. It's on a reel and you're looking at it in 4th dimension. The delay from here to here is constant, approximately constant as Mr. Rogeness told us. How we can use this constant delay thing to help us in measuring the delay error or the actual group delay of a piece of equipment? Well, we start over here with a sweep frequency generator. There are a good many reputable manufacturers - you can take your choice.

We split two ways with either a 6 db resistive splitter or a 3 db reactive splitter. We have now two outputs, one going here and one here. This one goes up to the cable and now over here we combine again. And, we do nothing here. We just put in a jumper, very simple. Over here we put a detector and we put it on the scope.

Now, because we have two pads here combining at this point, we have reinforcement at frequencies where the two signals are in phase. We have cancellation at frequencies where they are out of phase and net result: We have a pattern which is this one and if the cable is quite long it does it quite often. High frequency ripple pattern you might call it.

Because the delay of the cable is constant, the ripples occur at precisely spaced frequencies and a very simple relation exists at the frequency separation between adjacent minima and gives us the group delay.

The frequencies in microseconds and then we have microseconds. If the frequency is in megacycles, the time delay is in microseconds. The only limitation the method has -- it has two limitations. You want a good piece of cable that has a very uniform and impedance characteristic just so that various anomalies don't get in. The loss of the cable -- no -- the accuracy of balance. I left one item out of here. You have to put an attenuator in because the signal at this point is reduced by the loss of the cable, -- a low loss cable works better and you put in a certain amount of attenuation just so that the minima gets sharp, the nose are sharp.

Now, having very sharp nose, you can very precisely determine this frequency and take their difference and get the group delay. You first do this with just the cable and get a delay characteristic of the cable, which is approximately constant, surprisingly constant in practice, and then you put in whatever you want to measure here - system or amplifier. It adds delay to this lag and ripples become more closely spaced where the group delay is steep and space outward isn't. So you have a group delay characteristic, calculated and plotted on paper. And I don't think it costs anything providing you have all the equipment. (Applause)

MR. TAYLOR: Thank you, Ken. I see a question right here. Will you identify yourself, please?

MR. DONALD LEVINSON, Wheeling, West Virginia: I would like to know whether anybody in the industry has been using the AT&T VIT signals and whether any work has been done in their field to evaluate our systems?

MR. TAYLOR: Does anybody care to respond on that? Will you identify yourself?

MR. BOB LEWIS, Dubuque, Ohio: The problem using these VIT Signals you end up taking tronoscope or scope for the time delay. I used it for checking microwave and I used it for taking times 24 scope. It is a good indication of color response. You can use it on the system. We've done this, but it takes a wide band detector, so there's problems in doing it but it is a good check.

MR. TAYLOR: Thank you. Anybody have further questions? Thank you all. Meeting is adjourned.

\- - - - - - -

MR. TAYLOR: This gentleman here has a question. Let's take one more.

UNIDENTIFIED SPEAKER: Mine is not a question. I just thought that maybe he might inform us as to how he set the CW signal on channel and then superimposed the other on the test?

MR. SCHLAFLY: As to how that was done?

UNIDENTIFIED SPEAKER: Just to tell us how you set this up?

MR. SCHLAFLY: There were 12 input channels and there was a CW generator. The input channel levels were set through those modulators and the CW level was set at the same level as the carriers that we had from off-the-air signal.

UNIDENTIFIED SPEAKER: But, when you set the CW signal in this test you showed, do you kill the other information on that channel?

MR. SCHLAFLY: Yes, sir. There was only the pure CW signal on that channel and it beat against the various signals of the television channels that were superimposed, mixed at the input to the amplifier. (Applause)

MR. TAYLOR: Again I want to thank Mr. Schlafly very, very much for coordinating this study on behalf of the Ad Hoc Standards Committee. And, again, I want to express the tremendous cooperation that has been given to this project by a number of manufacturers. We'll delay just a moment or two while the gear is removed to make possible some other visual aids.

I might say that many of the papers you will hear today are available in printed form and will be available on this table against the wall.

Our next speaker is Dr. Jacob Shekel of the Spencer-Kennedy Laboratory. You have his sketch here showing his background and I will not take further time to introduce him. Dr. Jacob Shekel. (Applause)

DR. JACOB SHEKEL: My talk will concern noise and cross-modulation from a few points of view. We all realize that noise and cross-modulation are the factors that ultimately limit the length of the system or the number of amplifiers that can be cascaded. But, I'm not sure that everybody here knows exactly how to estimate how many of the amplifiers can be cascaded and when that limit is reached; and how to do this before the system is built and before you find it out in effect. I want to separate the problem into three parts: First, how do we specify or measure or estimate the noise and cross-modulation of a single amplifier? Then, knowing that, how do we estimate the accumulation of noise and cross-modulation along the trunk line and distribution amplifiers? And, the third question, where do we stop? How far do we let it accumulate before we say this is as far as we go, because we cannot degrade the picture any further?

I am not going to discuss the third question. I am not going to give any numerical values on what should be the final noise or the final cross-modulation, because that is really up to the Standards Committee to set up. I don't think there is yet any complete agreement between the manufacturers or between the system users on the ultimate degradation that can be allowed. But I will describe what I hope is a very simple way of how to figure out from the specification of a single amplifier what the noise and cross-modulation of the total system are expected to be at the furthest point.

A simple way to estimate the noise at the end of the system, and one that I know is used quite extensively by system operators, is a simple measurement with a field-strength-meter. You measure the level of a certain channel at the furthest point of the line. Then you turn off the channel at the head-end and see what measurement you can read on the field-strength-meter. This measurement is due only to noise accumulated all along the system. You take the ratio of these two measurements--that is, the difference of the db readings--and this is what is called carrier-to-noise ratio in decibels.

Now, since this is such a simple method to measure the carrier-to-noise ratio of the system, we can also define and specify tne amplifier the same way. Suppose we take a single amplifier of the kind that we're using in the trunk line, and connect the field-strength-meter at its output, terminate the input and read the meter. Let's take as an example that the field-strength-meter reads at a certain channel --28 dbmv. Then suppose that this amplifier is specified to be used at an output level of +33 dbmv. By subtracting the two numbers, remembering that one of them is negative, the carrier-to-noise ratio of a single amplifier appears to be the difference between 33 and minus 28, which is 61 decibels. This, I think, is the simplest way to measure and to estimate the carrier-to-noise ratio of a single amplifier, a measurement that every operator can do right in his own office or in the field.

Knowing the carrier-to-noise ratio of a single amplifier, what can I expect to be the carrier-to-noise ratio when I cascade any number of them? Or, an alternative question, how many can I cascade if I want the carrier-to-noise ratio to be at least (let's say) 45 db?

Now, here we have to go a little into a table of decibels. I want to show a very simple method that every one of us can follow to make up his own table of decibels without reference to any handbook or any slide rules. I think it's a very handy thing to know.

First, we have to realize that the noise is a random waveform, and if you take the noise contributions of the various amplifiers they are not coherent. If you project them on a scope there will be no similarities between the noise waveforms of the various amplifiers. When such waveforms are added, the power of the total wave is equal to the sum of the powers of the various contributions. That means that a noise of two amplifiers will be 3 db higher than the noise of a single amplifier, and the noise in a trunk of 10 amplifiers will be 10 db higher than that of a single amplifier.

These are the only two numbers that we have to remember, that "twice" is 3 db and "10 times" is 10 db. I am going to write down the column of dbs from 0 to 10. We know that 0 db is a ratio of 1, and every time we add 3 db we double the ratio. Twice is the same as 3 db. So 3 db would be 2, and 6 db is 4, and 9 db is 8, and 12 db is 16, 15 db is 32 and 18 db is 64. Now, we go the other way. 10db is 10 times. Going backwards, 3 db below that, 7 db would be 5 times, and 3 db below that, 4 db, would be 2.5, and 3 db below that would be 1.25. To complete the table we now go sideways, multiplying and dividing by 10.

DB	NUMBER	DB	NUMBER
0	1	10	10
1	1.25	11	12.5
2	1.6	12	16
3	2	13	20
4	2.5	14	25
5	3.2	15	32
6	4	16	40
7	5	17	50
8	6.4	18	64
9	8	19	80
10	10	20	100

For each 3 db step

Multiply ↓ ↑ Divide

by 2

Multiply by 10 →

← Divide by 10

Fig. 1

So, now we know how noise of various amplifiers will combine, or how the carrier-to-noise ratio will change along the line. In our example I have used the carrier-to-noise ratio of a single amplifier at 61 db. If I had two amplifiers they will be 3 db worse, or 58 db; and with 10 amplifiers, it will be 51 db.

Now, let's take the following question: If I start with a 61 db carrier-to-noise ratio of a single amplifier, how many can I cascade before I reach 45 db? The difference between 61 and 45 is 16. Going to the table, 16 means 40 amplifiers. So, 40 amplifiers of that type, operated at that level, will give a carrier-to-noise ration of 45 db. I can't say whether that is acceptable or not, but at least the system operator can go to the end of the system and measure the carrier-to-noise ratio, and if the reading is far from 45 db, then he knows right away that something must be wrong.

This is as far as we can estimate the carrier-to-noise ratio of a single amplifier and of a line with cascaded amplifiers. And, you will have noticed that I am trying here to specify the noise of the amplifier not by its noise figure, which is a certain measurement referred to the input, but by its noise output. First of all it is easier to estimate the output C/N ratio, and also it's a figure which is much easier to measure right in the field.

The second limitation on the system performance is the matter of cross-modulation. Now, of course, I'm not sure if we all know, after the previous demonstration, what exactly cross-modulation is. Maybe we know much more than we knew an hour ago. But, for the purpose of my talk it suffices that we can put a number to it. We say that an amplifier operated at a certain level with a given number of channels will have a certain amount of cross-modulation.

First of all, it is important that both the level and the number of carriers be specified, because the amount of cross-modulation changes with those two numbers, as it was demonstrated before. Also, the number which specified the cross-modulation can be given in two ways: It can be given in negative decibels (or "db down"), or it can be given as a percentage modulation. The meaning of the latter is that if we start with a CW carrier as our test signal, the modulation imposed by the other carriers will be a certain percentage.

The two specifications are equivalent to each other and there is a very simple way of passing from one to the other.

Let's look first at just the middle line of the nomogram on page 165, the one that is marked "cross-modulation". Here you see two scales, one in decibels and the other in percentage. For example, minus 40 db corresponds to 1%, minus 60 to .10% and minus 72 corresponds to .025%.

Now I would like to suggest that specifications be given in percentage rather than db, because then the way that cross-modulation accumulates along the trunk is very simply computed: You just multiply this number by the number of amplifiers. Let's take as an example that a trunk amplifier is specified to have .008% cross-modulation when operated at an output level of +33 dbmv with 12 channels. (How to get this number in the first place will be shown later. It could be the number given directly by the manufacturer, or it may have been computed from an equivalent number given by the manufacturer.)

The cross-modulation is really a superposition of the modulation of other channels onto the channel we are watching. And as we go along the line, all the contributions of all the amplifiers just add up in phase on top of each other, because all the channels progress along the line at the same speed. If we have a cross-modulation of .008% for one amplifier, we will have a cross-mod of .016% for 2 amplifiers and .024% for 3 amplifiers. Suppose we have 30 trunk amplifiers, and all of them operated at the same level, the total cross-modulation will be .008 times 30, which is .24%.

Now, this is only the trunk. We also add cross-modulation in a bridging amplifier, distribution amplifiers, line extension amplifiers. (Incidentally, in these amplifiers, since we try to operate them at the highest level possible, we do have cross-modulation, but we have almost no effect on the noise. That's why I have disregarded it in the first part of my talk).

We have .24% accumulated along the trunk line. Suppose that now we start from here into a distribution amplifier, and let's take again as an example that it is specified to have .1% cross-modulation at +58 dbmv for 12-channel operation. If we operate it at this level, it will add .1% cross-mod. Again all the channels come to this amplifier at the same time, all together, so on top of the .24% from the trunk line we have to add .1% of the distribution amplifier and we end up with .34%.

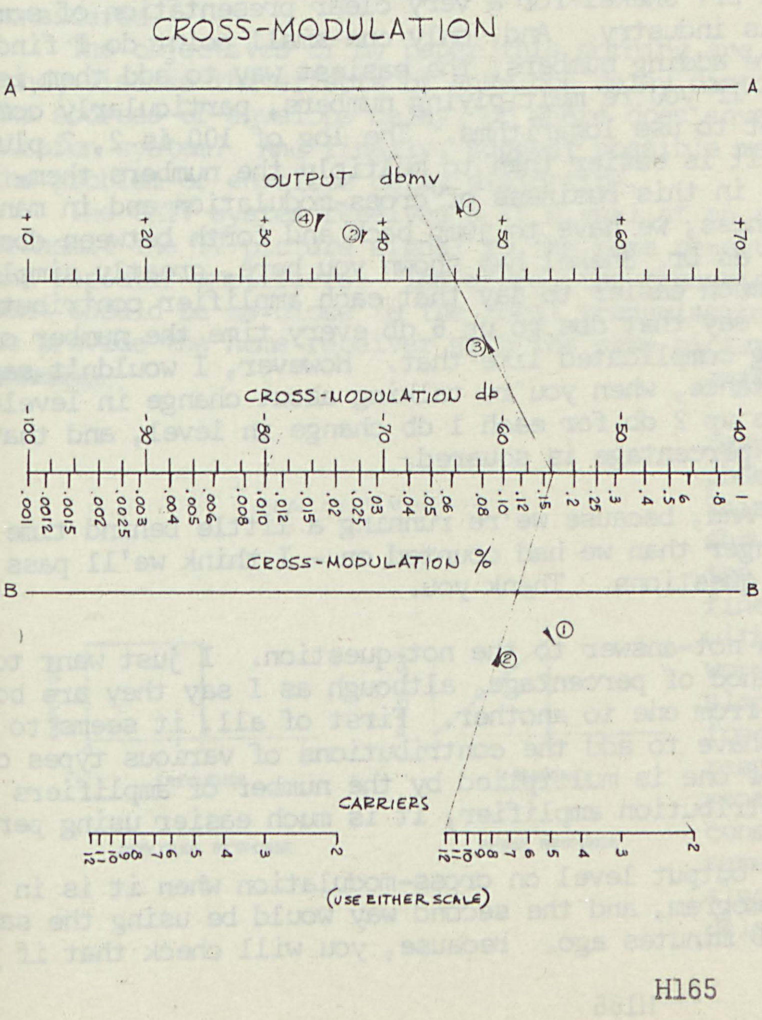
If we have no further amplifiers in the line, we can expect the customer to have a cross-mod of .34%. Suppose that a customer is further along the line, where we have another line-extension amplifier. All we have to do again is to add the cross-modulation contributed by that amplifier. And, thus by a simple process of addition of the contributions of various amplifiers we can very easily estimate the cross-modulation of the pictures at the customer tap.

There is some difference between noise and cross-mod measurements, because the noise can easily be measured at the customer tap and you can compare this to the computed results; whereas, the cross-mod measurement is a little more complicated and the equipment is usually not such that can be taken to the customers' house or carried around in a truck. I hope that within a year or so maybe some of the manufacturers will come up with small kits to measure cross-modulation, when the Standard Committee will have decided on a method that is satisfactory to everybody.

Now, the only thing that remains in this method of estimating noise and ss-mod is how to find the cross-modulation of a single amplifier. In noise, it was simple. We just take an amplifier and measure it. We disregard the manufacturer's specs; we can check it every time.

On cross-mod we have to start from one number given by the manufacturer; and various manufacturers have various ways of specifying. For example, some manufacturers specify the level at which the cross-modulation for a number of channels is 57 db, while at least one other manufacturer specifies the level at which the cross-modulation is .05% when only two carriers are used in the test.

NOMOGRAM FOR THIRD-ORDER CROSS-MODULATION



The nomogram shows a way of comparing these various specifications; and also a method to estimate what the cross-mod would be at the level that you actually use in the amplifier.

There are three scales on this nomogram: The middle scale is the cross-modulation that we discussed before. The upper scale is the output of the amplifier in dbmv, and the lower scale is the number of carriers used. This scale is really in two parts and we can use either of them, whichever is more convenient.

For a first example I'll start with an amplifier specified at .05% two carriers at +46 dbmv, and we want to know what would be the cross-modulation if you operated 12 carriers at +33 dbmv. First, we use the bottom part of the nomogram to find what is the effect of number of carriers. (Here I want to point out that the assumption on this nomogram is that the cross-modulation from various carriers will add incoherently. If we have many carriers that are on the same network that produce coherent sync pulses, the addition will be more severe than it is here.)

So, we join the point of "2 carriers," and .05% cross-modulation, find the intersection with line B, and then connect the "12-carrier" point through that intersection point up to the cross-modulation scale. This shows something around .16% (we don't really have to estimate this point exactly because this is only a partial answer).

Now, we go to the upper part of the nomogram and see what effect the level will have. We have now changed the number of carriers from 2 to 12. We take that intermediate point (which is roughly .16%), correct it to the +46 dbmv and go up to line A. From that point we come down to the +3? dbmv point and we end up on the cross-mod scale at .008%.

To summarize, I've used the bottom part to see the effect of number of carriers at the same output level; and the upper part for the effect of the output level at a constant number of carriers.

As a second example, suppose the amplifier is specified as having -57 db cross-mod at the level of +48 dbmv for 12 carriers. Here we don't have to change the number of carriers, and all we have to work with is the upper part of the nomogram. We connect the point at -57 db to the +48 dbmv, go up to line A. Now, suppose we are using the amplifier at a level of +37 dbmv, so we connect that point from scale A through the +37 and come up to .010% cross-modulation. This is the starting point for the computation of the trunk line.

Well, this is really all I wanted to show. How we estimate, or how we read the specification, or how we measure noise and cross-modulation with a single amplifier at the level we are going to work it, how the noise and cross-mod accumulate along the line and what we can expect as the final noise and cross-mod at the end of the line.

Now, are there any questions?

MR. KEN SIMONS: This really isn't a question. I'm cheating. I'm going to say two words. First, I want to thank Dr. Shekel for a very clear presentation of some facts that are long overdue in this industry. And, only one small point do I find that I would try to add. If you're adding numbers, the easiest way to add them is to add them, 100 plus 100 is 200. If you're multiplying numbers, particularly complex numbers, it's often convenient to use logarithms. The log of 100 is 2, 2 plus 2 is 4, 10 to the 4th is 10,000. It is easier than to multiply the numbers themselves. In the same way I believe in this business of cross-modulation and in many other facets of our community business, we have to jump back and forth between dbs and percent, and I believe we can, as Dr. Shekel has shown you here, greatly simplify the relationships involved. It's much easier to say that each amplifier contributed .1% cross-modulation than it is to say that dbs go up 6 db every time the number of amplifiers is doubled, or something complicated like that. However, I wouldn't say this worked all the time. For instance, when you're talking about change in levels, the amount of cross-modulation goes up 2 db for each 1 db change in level, and that's easier to say than to say that the percentage is squared.

MR. TAYLOR: Thank you, Ken. And, because we're running a little behind time - our demonstration took a little longer than we had counted on - I think we'll pass onto another paper without further questions. Thank you.

DR. SHEKEL: May I just give a not-answer to the not-question. I just want to defend in a couple of words the method of percentage, although as I say they are both equivalent and you can easily pass from one to another. First of all, it seems to me that percentage is easier when you have to add the contributions of various types of amplifiers. The cross-modulation of one is multiplied by the number of amplifiers in the trunk; and when you add the distribution amplifier, it is much easier using percentages.

As far as seeing the effect of output level on cross-modulation when it is in percent, one way would be using the nomogram, and the second way would be using the same table of dbs that I just invented 10 minutes ago. Because, you will check that if you

MR. KRUSE: With the load isolator, I believe, although I have not had any test in this direction, that the load isolator would absorb the reflected signal from the missmatch at the antenna and dissipate it. The result would generally be a change in amplitude response only. That is what I believe should happen. I'd be glad to discuss it further with anyone as far as perhaps some future testing in this direction.

MR. COOLEY: I thank you very much. Let's give him another hand, gentlemen. (Applause)

Our next subject on today's agenda is entitled, "Problems in Using Line Powered CATV Systems", and the gentleman that's going to provide that information is the Plant Manager for CAS Manufacturing Company in Irving, Texas; formerly served as production manager for Johnson Service Company, Electronics Division; also was production manager for Fishbach and Moore. A native of Dallas, he attended the University of Texas and Southern Methodist University and has nine years of management background. Gentlemen, Mr. Preston Spradlin is going to give us a little story on using line powered CATV equipment. Let's give him a hand as he comes up. (Applause)

MR. PRESTON SPRADLIN: Thank you very much, Mr. Cooley. I'd like to express my appreciation in being able to participate in this technician's session.

The title of my presentation is "Problems in Using Line Powered CATV Systems." Since the miracle of electronics, namely the transistor, enables us to use line powering but at the same time it creates problems, the question of why transistors for CATV should be answered first. May I have the first slide, please. (Illustrations next page)

I. <u>AC vs DC Line Powering</u> Line powering, the natural and economical way to power transistor amplifiers in cable systems, is in reality, a relatively simple matter and consequently, not too much thought has been devoted to this "life-line" of CATV. Yet, through experience, the majority of transistor failures and associated maintenance problems may be traced directly to problems in line powering.

CAS Manufacturing Company, as a result of several years of experience in line powering, has determined that adherance to the following procedures make possible maximum transistor performance.

The necessary power requirements of a conventional CATV system utilizing transistors is between 15 and 20 volts DC. In earlier systems, and as recently as 1960, CAS, like other manufacturers, used pure DC for line powering. This approach, being quite easily attainable, simplified standby systems and required little or no filtering networks in individual amplifiers.

The power supply was conventional and a wet cell could be used as a standby reserve.

Using pure DC, no problems were foreseen in the planning stage. However, in actual operation, continuous trouble caused by electrolysis and AC hum made it obvious to switch to AC line powering. A simple experiment demonstrating electrolysis is to fill a fitting with water and apply first AC and then DC and observe the action of each current. The application of DC builds up a carbon path and shorts the fitting or causes a high resistance leakage path. Even a small amount of moisture is sufficient to cause electrolysis when DC voltage is applied.

II. <u>Regulated vs Non-Regulated Supplies</u> In tube systems, constant voltage transformers became a necessity to prolong tube life and to furnish some degree of protection from lightning surges. In transistor systems, a constant voltage supply is normally built into each amplifier by using constant current transistor power supplies. Since this feature is inherent in transistor systems, the importance of having constant transofmrer voltage, although desirable, is not as important as in tube systems. Also, fast transients that may be destructive to transistors can pass readily through a regulated transformer diminishing afforded protection enjoyed so in tube amplifiers.

Basically, there are two types of constant current transformers - a sinusoidal and a normal harmonic. The sinusoidal type normally produces only a 3 percent harmonic

WHY TRANSISTORS FOR CATV?

1. Constant gain characteristics
2. Low power consumption
3. Feasibility of line powering
4. Compactness
5. Theoretically maintenance free

FIGURE 1

CAS TRANSISTORIZED TRUNK SYSTEM

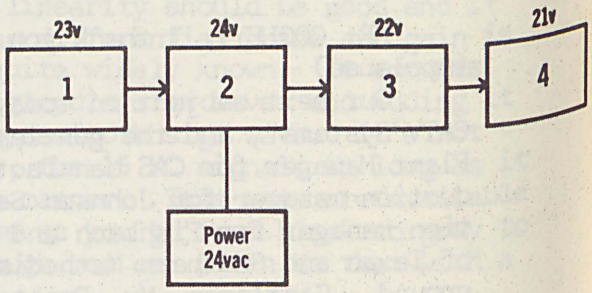


FIGURE 2

WAVE SHAPES BEFORE ADDING EXTENDER

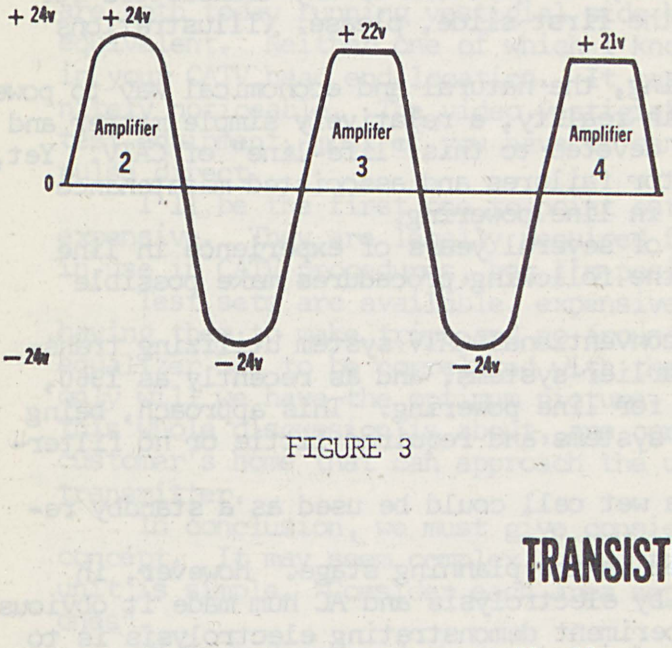


FIGURE 3

TRANSISTORIZED TRUNK SYSTEM

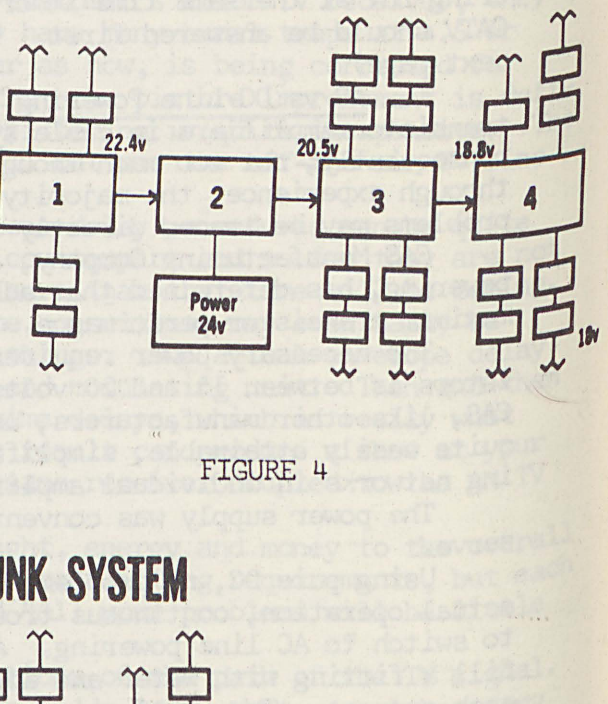


FIGURE 4

TRANSISTORIZED TRUNK SYSTEM

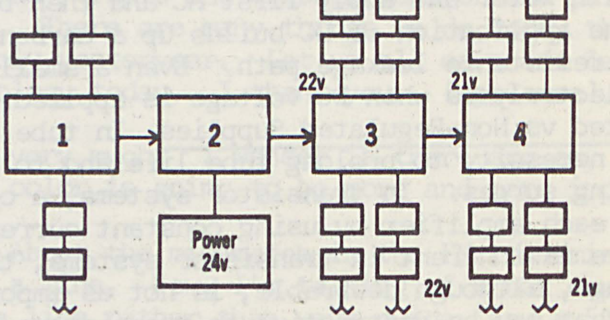


FIGURE 5

content and is particularly well suited for applications involving rectifiers and other equipment affected by harmonics in the supply voltage. Special electronic types which are sinusoidal are used for filament and plate regulation circuits. The normal harmonic type provides the same regulation, ± percent, and is a reliable voltage source for electrical loads such as filaments, relays, solenoids and other loads not affected by harmonics in the supply voltage. All types of transformers provide filaments with stabilized voltages which contribute greatly to reliable operation, longer life, thus reducing service costs. Another advantage of using a constant current transformer is the elimination of extra capacitors and chokes.

In a conventional transistor regulated supply, normally the base voltage of the transistor is held constant by a zener diode and since the voltage existing from the base to the emitter is inherently constant, a regulated supply is easily obtained. The physical size is such that an individual regulator may be conveniently placed in each amplifier.

Negative output voltages are obtained through the use of germanium power regulators and positive outputs by the use of silicon transistors. CAS currently is using both silicon and germanium power regulators. Silicon, although more expensive, offers greater protection against lightning surges. Obviously, line powered systems with transistor regulators offer many advantages over non-regulated systems. Consequently, the widespread use of transistor regulators is common.

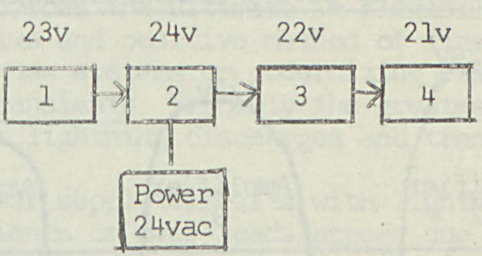
III. Half-Wave Line Powering In using a single center conductor for line powering, it is impossible to use other than a half-wave power supply without the use of bulky, inefficient isolation transofmrers. Therefore, all manufacturers, to our knowledge, use a half-wave rectifier to develop the necessary positive or negative supply voltage for the transistors.

Until recently, available power transistors have dictated the use of a negative supply. The half-wave rectifier, since it utilizes only one-half of the AC cycle, is necessarily only 50 percent efficient. Thus, a circuit requiring .5 amperes DC will require a source capability of approximately 1 ampere AC.

For reasons I will explain later, CAS decided to positively power the trunk system. This lends itself nicely to biasing the transistors, although a more expensive silicon transistor was required for power. An inherent bonus feature of the silicon power transistor is its ability to better withstand surges and etc. in the rectifying circuit.

Using a positive trunk system, CAS lays out 4 trunk amplifiers like this:

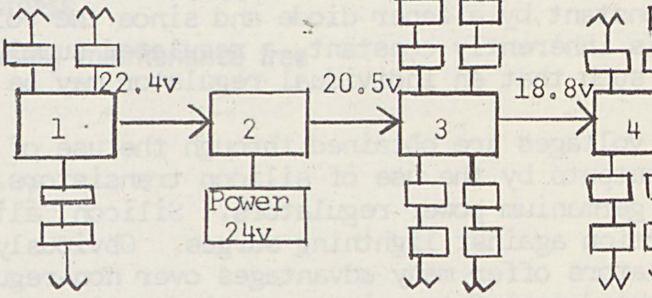
CAS TRANSISTORIZED TRUNK SYSTEM



For purposes of explanation, 24 VAC is depicted as the supply input. In actual practice, this voltage would be 28V nominal. 24 VAC input would be a minimum input due to general low primary voltage. Let's assume that the voltage is traveling from amplifier number 1 through amplifiers 2, 3, and 4, etc. The 24 VAC is fed into the system at amplifier 1 and forward to amplifiers 3 and 4. Let's further assume that each amplifier requires 1 amp, the initial starting voltage 24 VAC and one ohm resistance per length of cable between the amplifiers. With this assumption, amplifier 2 will be supplied 24 volts. The combined current of amplifiers number 3 and number 4 is 2 amps and by Ohm's Law E = IR or E drop = 2 amps X 1 ohm is (equal to 2 volts drop) the voltage at number 3 amplifier is 22 volts since the supply was 24. By use of the same formula, amplifier number 1 has 23 volts available. Amplifier number 4, due to the line resistance, has a further drop of 1 volt and therefore, the voltage at amplifier number 4 is 21 volts, the bare minimum.

Since amplifier number 4 has 21 volts available, it will operate. If extenders are added to the line as shown, we can obtain the following results:

TRANSISTORIZED TRUNK SYSTEM

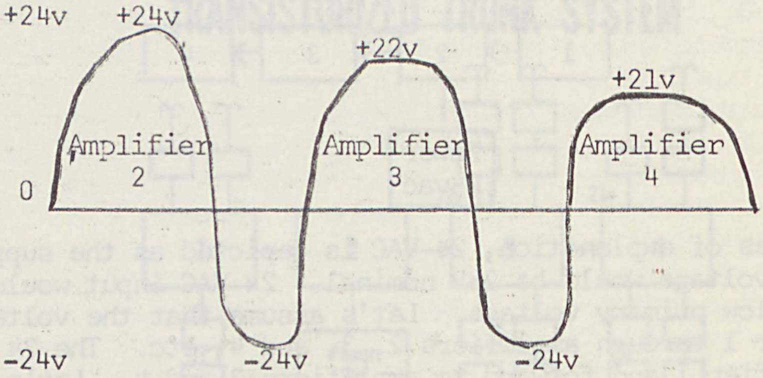


Assuming that each of the fifteen extenders added on #3 and #4, as shown, require .1 amp, the total current requirements for the extenders are 1.5 amp, the total current requirements for the extenders are 1.5 amps. By Ohm's Law, a 3.5 volt drop exists between the supply and amplifier #3 and a further drop of 1.7 volts exists between amplifiers #3 and #4 which results in the line voltage of 20.5 volts at amplifier #3 and 18.8 volts at amplifier #4. Keep in mind that each amplifier requires 1 amp. Now, note that the 18.8 volts at amplifier #4 is below the required voltage, and due to further drops in the extender lines, the last extender has a bare 18 volts from which to operate. The obvious answer in making this system work is to up the supply voltage from 24 to 33 or 34 volts. The disadvantages of this solution are:

1. The voltages exceed the safety limits specified by the National Electrical Safety Code.
2. The first amplifiers #1 and #2 have to dissipate more power, resulting in over heating, etc.

There is another solution --- Looking back to the AC supply, the output voltage appears like this before the extenders are added:

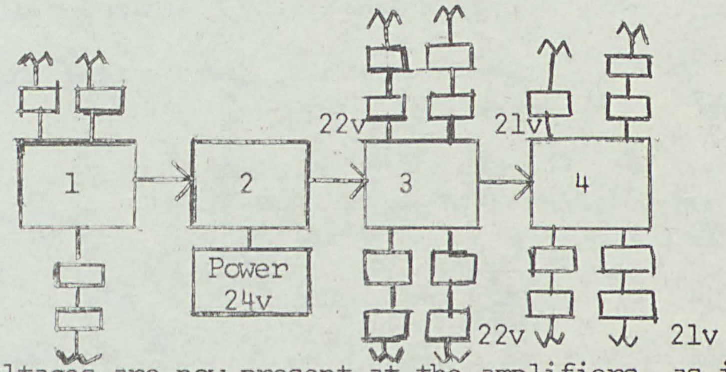
WAVE SHAPES BEFORE ADDING EXTENDERS



Note that the first cycle of the sine wave from the supply is symetrical. At amplifier #3, the positive half-cycle is clipped and appears on the scope as shown at a 22 volt level. The voltage at amplifier #4 is clipped further and is at a 21 volt level. Notice that the negative half-cycle remains symetrical and is at a higher amplitude than the positive half-cycle. At the level of 22 and 21 volts sufficient voltage is present for proper regulation and we have a workable system without the additional loading of the extenders.

IV. Positive and Negative Approach to Line Powering Suppose that the extenders are designed to operate on the negative half-cycle of the AC wave. Since additional loading will not be added to the positive half-cycle, the voltage on a combined trunk and feeder system will appear like this:

TRANSISTORIZED TRUNK SYSTEM



Proper supply voltages are now present at the amplifiers, as if there were no extenders present, and equally good voltages appear at the extenders. Ten extenders may be powered through each amplifier without loading the supply to a point where inadequate voltages would be present at the extenders.

By utilizing both halves of the AC wave, the following additional features become apparent:

1. We can accurately predict the number of trunk amplifiers per power supply as well as distances without regard to the number of extenders to be added either now or later.
2. The supply voltage level may be kept well within the limits prescribed by the National Safety Code. It is no longer necessary to boost the supply level beyond 30 volts to compensate for drops and to raise the low extender voltages. The lower voltage reduces the shock hazard.
3. Transients on both the positive and negative cycles are suppressed by the dampening effect of the transistor power supply loading.
4. Efficiency of the system now approaches 90 percent as opposed to 50 percent efficiency when using only one-half of the AC cycle.

AC line powering provides the ultimate in flexibility. The added advantage of utilizing both the negative and positive method of line powering should be strongly considered when planning new systems or modernizing existing ones.

V. Lightning and Transients Probably the greatest maintenance problems in CATV are the ever present lightning discharges and transients which can cause nightmares for servicemen.

CAS protects all power supply circuits with lightning arrestors and circuit breakers. When fast transients or over-loads appear due to the inherent time lag characteristics of breakers, they do not open the circuit. These transients must be absorbed by the amplifier system as they pass through power supply transformers, regulated or not. Each amplifier must be able to take a peak voltage on the order of 100 volts or more. By utilizing both the negative and positive cycles, we damp both and keep the transients to a minimum peak voltage. Power transistors with high peak voltage characteristics have become a must in each individual amplifier.

VI. Short Circuits in Line Powered Systems Accidental shorting of the CATV cables by technicians, installers, or equipment failures is commonplace. Naturally, the power transformers and associated equipment must be protected by fuses or some other means. It is very time consuming and frustrating for the technician to accidentally short the cable, causing him to have to climb down the pole and replace a fuse in some other remote location before finishing his job. This can very easily be prevented by the use of automatic overload relays which remake after the short is removed. No fuses are used in CAS line powered systems. Relays are used throughout.

In summarizing, for a successful line powered system with few maintenance problems we suggest the following:

1. Full use of both negative and positive cycles of the AC source.
2. Automatic overload protection for line powered shorts.
3. Adequate lightning arrestor usage and high peak voltage power transistors in each amplifier.

Thank you. (Applause) May I answer any questions you may have at this time?

QUESTION: When you're using regulated transformers and only using half the cycle does this disturb the regulation of the transformer?

MR. SPRADLIN: No, it does not. There are two types of constant current transformers. A sinusoidal type and a normal harmonic type. If you use the sinusoidal type, you wouldn't have any problem with regulation.

QUESTION: How about the normal harmonic type?

MR. SPRADLIN: The normal harmonic type does provide the same regulation as a s sinusoidal type, but normally you'd find the normal harmonic type used in filaments. relays and solenoids. Since the sinusoidal type normally produces only 3% harmonics you would use this one for power supply circuits. Each constant voltage transformer has different characteristics. You may find one that puts out a square wave works b better in some places and not as well in others. It depends strictly upon the load.

QUESTION: Does each amplifier that your company makes have a built in regulator and is it AC or DC powered?

MR. SPRADLIN: Yes. CAS Manufacturing Company has all transistor regulator supplies built into each individual amplifier. There is AC going into the amplifier proper. It is converted to DC by a regulated circuit inside each individual amplifier. The AC power continues down the cable until it is converted to DC to power each individual amplifier.

QUESTION: You said the amplifiers were AC powered but do you mean because it is halfwave rectified it is DCpowered?

MR. SPRADLIN: On the line proper, you have AC voltage but past the transistorized regulator direct current is used to power the transistors.

QUESTION: But you have DC current in the cable. You're on an alternating voltage system but a direct current system.

MR. SPRADLIN: No. Remember the AC for line powering is by-passed back into the cable for further line powering while the DC is blocked.

QUESTION: How do you block the DC from the next amplifier?

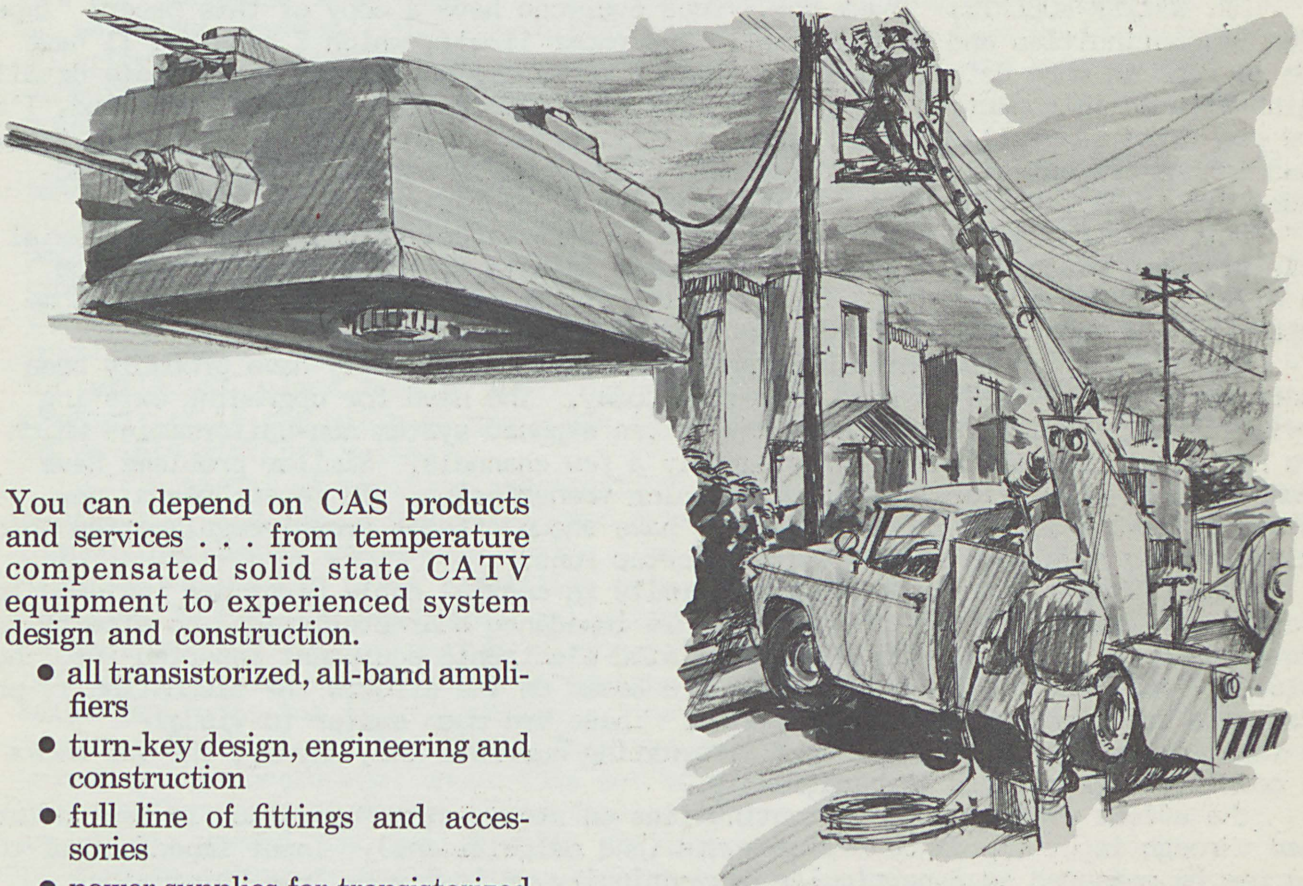
MR. SPRADLIN: We block the DC by means of capacitors.

QUESTION: Who manufactures a reliable resetting overloading relay?

MR. SPRADLIN: CAS Manufacturing Company is using a line of circuit breakers manufactured by Klixon which is a branch of Texas Instruments Supply Company in Dallas.

#

specify
CAS
for performance-proved CATV products and services!



You can depend on CAS products and services . . . from temperature compensated solid state CATV equipment to experienced system design and construction.

- all transistorized, all-band amplifiers
- turn-key design, engineering and construction
- full line of fittings and accessories
- power supplies for transistorized equipment
- live weather instrument packages
- ruggedized antennas
- aluminum and flexible coaxial cable
- TV and FM head-in systems

Write for CAS all-transistorized equipment brochure!

CAS MFG CO

P. O. BOX 47066 • DALLAS, TEXAS 75207

Klixon is a very good unit.

QUESTION: You stated that DC line powering caused electrolysis. You have further stated that there is DC in the amplifier. Why doesn't this cause electrolysis in the fittings?

MR. SPRADLIN: Since the DC component is blocked by capacitors it does not go through the fittings.

MR. COOLEY: Any more questions, gentlemen: Well, I thank you very much, Mr. Spradlin. (Applause)

The next paper is entitled, "The Effects of Coaxial Jumpers". Our speaker is the director of Research and Quality Control for Superior Cable Corporation. He was educated at Lenore Ryan College in Hickory, North Carolina. He has a BS degree, major in chemistry, physics and mathematics. He has 3 years in the United States Army in classified work on the Security Agency. Two years in the Shepherd Enterprises, Inc. as a chemist. Ten years in the Superior Cable Corporation as a technician, research and laboratory development engineer. He is presently Director of Research and Quality Control. Gentlemen, Mr. Walter Roberts. (Applause).

MR. WALTER ROBERTS: Thank you. Does everyone have a copy of this paper? "Impedence Discontinuities and CATV Cables". The paper itself, which I hope you'll have time to read in more detail later and which I won't try to discuss in complete detail, begins with an introduction of why uniformity in CATV systems is important. And, I'm sure you folks can tell me more reasons it's important than I can tell you. In fact, I was in the transmission line of business quite a while before I found out broadbanded didn't have anything to do with an all-girl orchestra.

But, in this little paper some of the factors affecting uniformity and coaxial cable plan are discussed. There is no attempt made to at least directly describe the effects of non-uniformities in associated electronic equipment, except for some graphs which I hope to show you on combined effects.

Demands for improvements in signal transmission uniformity have probably been experienced in every CATV system operating today. The need for upgrading existing service through additional channels has oftern exposed system non-uniformities which were not at all obvious while carrying only a few channels. Similar problems have become evident only after initiation of color transmission. In recent years, new systems involving longer cable trunk runs have shown effects from irregularities which would probably have gone undetected in shorter runs.

Some of the factors affecting uniformity in coaxial cable plant are reviewed in this paper. Except for the effects on cable impedance characteristics, no attempt is made to describe nonuniformities in associated electronic equipment inserted into the cable system. Most of the descriptions are based on the effects the discontinuity produces on a transient pulse along the line. These are much easier to visualize than in the case of steady-state alternating currents and, anyway, the two modes are completely correlated mathematically.

the effect of impedance discontinuities on steady-state operation is best determined through input impedance measurements (and calculations). Input impedance of the line may be measured at a particular discontinuity or it may be at a point along the cable remote from the location of the nonuniformities. The performance of the line, or its deviation from normal, is determined by the impedance it exhibits at a frequency or band of frequencies.

Also presented are charts showing relationships between cable impedance uniformity and attenuation uniformity. These are shown both for the case of discrete discontinuities and for the case of periodic, distributed discontinuities along the cable. These two sources do not result in equivalent impedance deviation attenuation relationships.

"

TRANSMISSION LINES

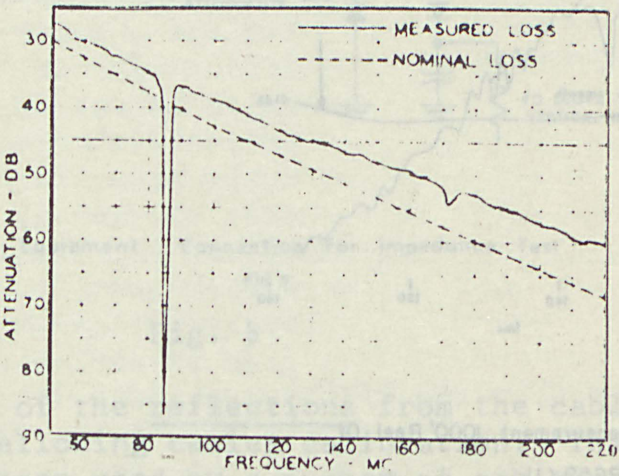
Thursday, July 22, 1965

MR. ARCHER S. TAYLOR, CHAIRMAN: Our first paper this morning is on the "Sweep Testing of Coaxial Cable" by Mr. Ken Simons of the Jerrold Corporation. Ken Simons graduated from the University of Pennsylvania in 1938. He's been in CATV since 1951. He helped design the 704-B field-strength meter, the UBC 26-B amplifier and the 900B sweep generator. He is formerly chief engineer of the Jerrold Corporation and is now Vice-President for Research and Development. Mr. Ken Simons. [Applause.]

MR. KEN SIMONS: Sweep testing is essential for coaxial cables used in ETV and CATV distribution systems. This article compares three basic methods: measurement of transmission loss, measurement of input impedance, and measurement of reflection coefficient.

The technical requirements for flexible coaxial cable were organized in Military Specification JAN-C-17, originally issued in 1944. This specification and its subsequent revisions spell out in detail the requirements for physical construction and a number of electrical parameters, including attenuation and dielectric strength of the cable. Regarding the characteristic impedance, JAN-C-17 specified the nominal impedance which was determined by a calculation involving the total measured capacitance of a reel of cable, and the delay factor measured on a short sample. For cables of relatively short lengths, this specification was adequate; but the advent of CATV systems, where TV signals are transmitted through many miles of cable, uncovered the need for an additional specification.

The problem first came to light in our organization about twelve years ago when one of our field engineers returned to the laboratory a reel of cable which, he claimed, would not pass TV channel 16.

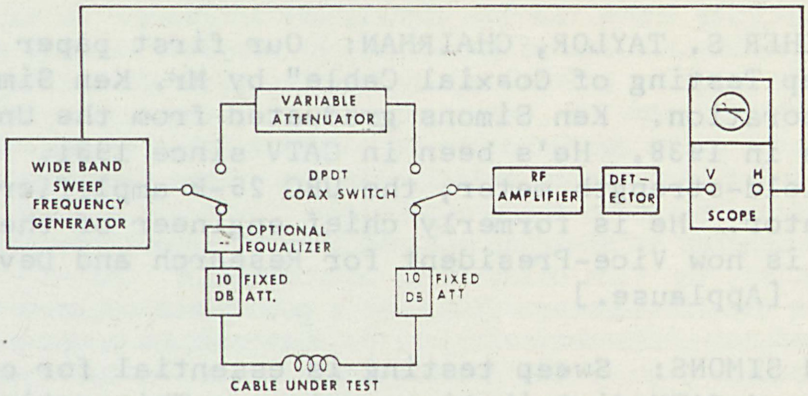


Loss versus frequency for 2,000 feet of defective RG11/U cable

FIG 1

Figure 1 shows the measured attenuation of this reel of cable, indicating an attenuation spike 50 db deep at 87 mc!

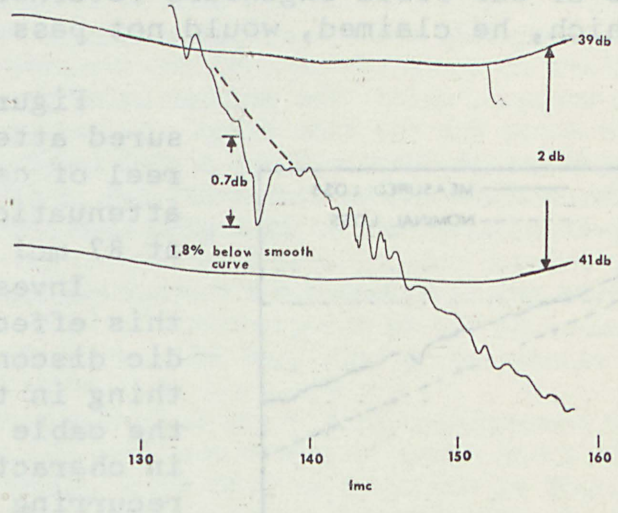
Investigation showed that this effect was due to periodic discontinuities. Something in the manufacture of the cable produced variations in characteristic impedance recurring at precisely spaced intervals throughout the length of the cable. Due to this precise spacing, many reflections, precisely phased at a certain frequency, arrived back at the input end



Equipment Connection For Transmission Test

FIG 2

Fig. 2

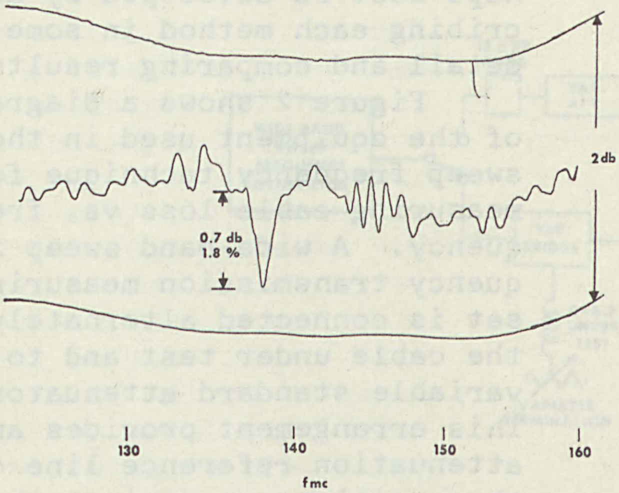


Transmission Measurement, 1000' Reel Of

RG59/U

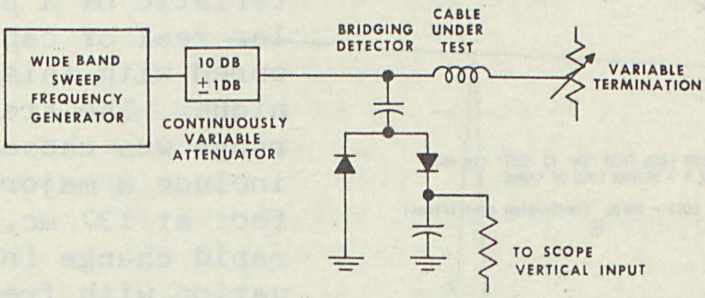
FIG 3

Fig. 3



Transmission Measurement 1000' Reel RG59/U
Equalized
FIG 4

Fig. 4



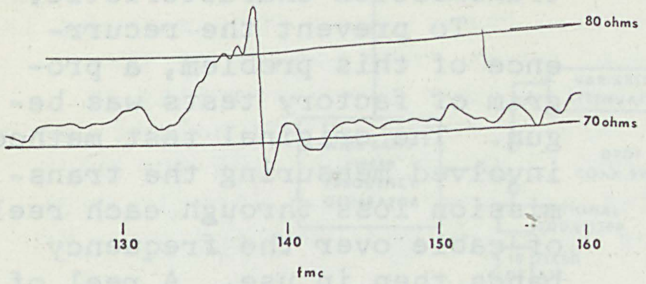
Equipment Connection For Impedance Test
FIG 5

Fig. 5

of the cable, causing this severe distortion of the transmission characteristic.

To prevent the recurrence of this problem, a program of factory tests was begun. The original test method involved measuring the transmission loss through each reel of cable over the frequency bands then in use. A reel of cable was rejected if the loss in these bands dipped more than 0.25 db below the smoothed attenuation characteristics.

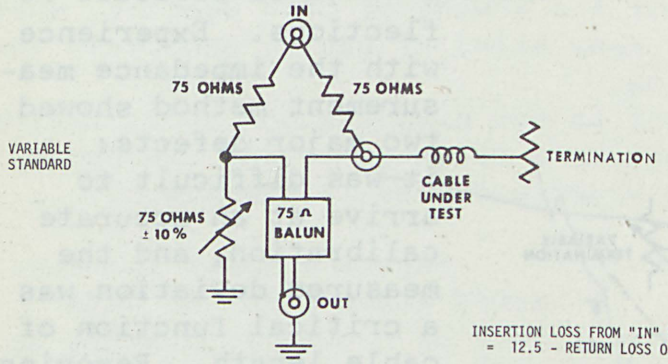
After this transmission loss measurement method had been used for several years, it became evident that a more sensitive test was needed. It was found that a measurement of the input impedance at each end of a reel of cable gave a more sensitive indication of the existence of periodic reflections. Experience with the impedance measurement method showed two major defects: it was difficult to arrive at an accurate calibration, and the measured deviation was a critical function of cable length. Removing two or three feet from the end of the cable would change the entire pattern. To overcome these defects, a test method was developed employing a bridge; this method allowed observation and measurement of the reflections from the cable end, eliminating uncertainity and allowing easier calibration. This reflection measurement method has been used by a number of cable manufacturers during the past five years and has provided a satisfactory way of controlling periodic defects.



Impedance Test On 1000' Sample Of RG59/U

FIG 6

Fig. 6



INSERTION LOSS FROM "IN" TO "OUT" (in db) = 12.5 - RETURN LOSS OF CABLE

RETURN LOSS = $20\mathrm{LOG}_{10}$ (reflection coefficient)

Variable Bridge For Cable Reflection Testing

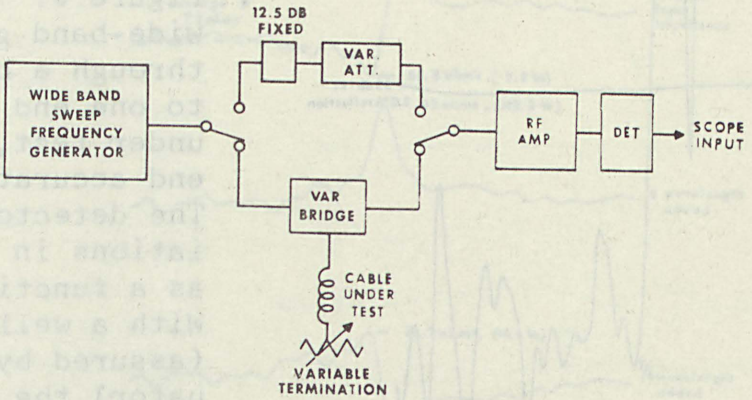
FIG 7

Fig. 7

The relative merits of the three methods of sweep frequency cable testing can perhaps best be developed by describing each method in some detail and comparing results.

Figure 2 shows a diagram of the equipment used in the sweep frequency technique for measuring cable loss vs. frequency. A wide-band sweep frequency transmission measuring set is connected alternately to the cable under test and to a variable standard attenuator. This arrangement provides an attenuation reference line on the oscilloscope against which the loss of the cable can be compared. For accurate measurement, it is essential that the cable face a well matched impedance at each end. 10-db fixed attenuators are used to establish this condition.

Figure 3 illustrates the loss characteristic of a particular reel of cable measured with this technique. The frequency range was chosen to include a major defect at 137 mc. The rapid change in attenuation with frequency makes accurate measurement of the dip at 137 mc difficult. The measurement is easier by inserting an equalizer in series with the cable so that the average loss is flat and the irregularity is more clearly displayed and measured, as shown in Figure 4. One of the defects of the transmission loss measurement method appears on this plot. With the high end-to-end attenuation present on this reel, the single shield allowed sufficient coupling to produce ripples in the frequency characteristic.

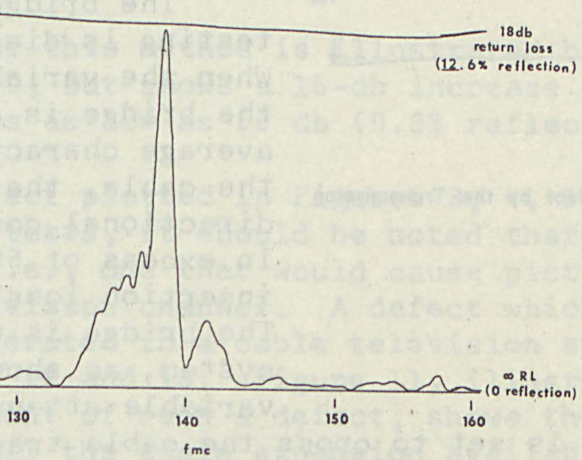


Equipment Connection For Reflection Test

FIG 8

Fig. 8

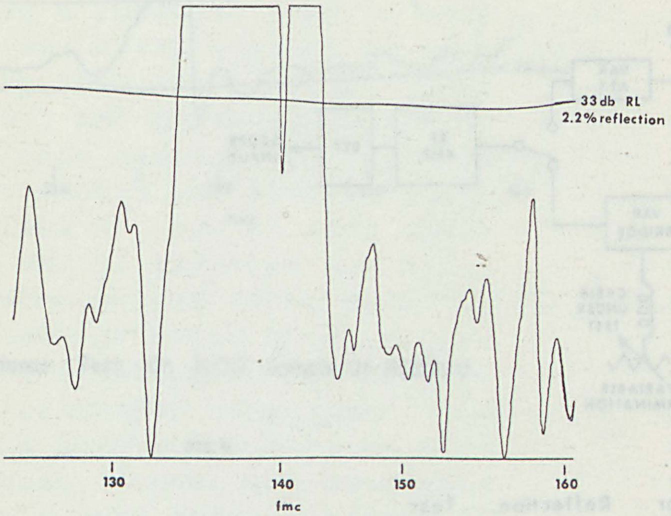
Fig. 10



Reflection Test On RG59/U Sample

FIG 9

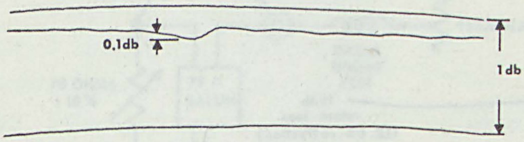
Fig. 9



Same as Fig. 9 with gain increased and reference changed.
FIG 10.

Fig. 10

A more sensitive test, free from this coupling problem, is obtained by using the technique diagrammed in Figure 5. The output of a wide-band generator is fed through a bridging detector to one end of the cable under test, with the other end accurately terminated. The detector measures variations in input voltage as a function of frequency. With a well-matched source (assured by the 10-db attenuator) the input voltage varies almost directly with the magnitude of the cable's input impedance. And impedance plot made by this technique for the same reel of cable is illustrated in Figure 6 (compare with Figure 4). Calibration was obtained by substituting a precise 75-ohm terminator for the cable end and varying the attenuator above and below 10 db by an amount corresponding to the indicated inpedance levels.

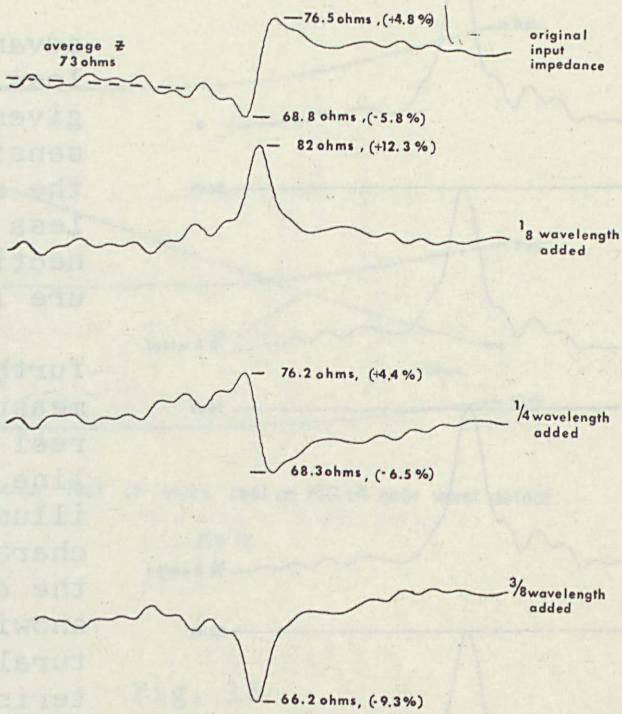


Measurement of a cable defect by the Transmission Method
FIG II

Fig. 11

The bridge used for reflection testing is diagrammed in Figure 7. When the variable standard arm of the bridge is adjusted to equal the average characteristic impedance of the cable, the bridge acts as a directional coupler with directivity in excess of 50 db and a constant insertion loss of about 12.5 db. The bridge is connected into a test system, as shown in Figure 8. The variable attenuator generates a reference trace which is set to cross the cable trace at peaks of the reflection characteristic. Since the measurement is made in dbs, the results are most conveniently expressed in these terms. The reflection coefficient expressed in db is the "return loss", and the return loss characteristic of cable, due to periodic variations in its structure, has become known as the "structural return loss".

Figure 9 illustrates a structural return loss plot with the characteristic of the same cable defect as shown on the curves in Figures 4 and



Same defect as FIG. II measured by the Impedance Method

FIG 12

Fig. 12

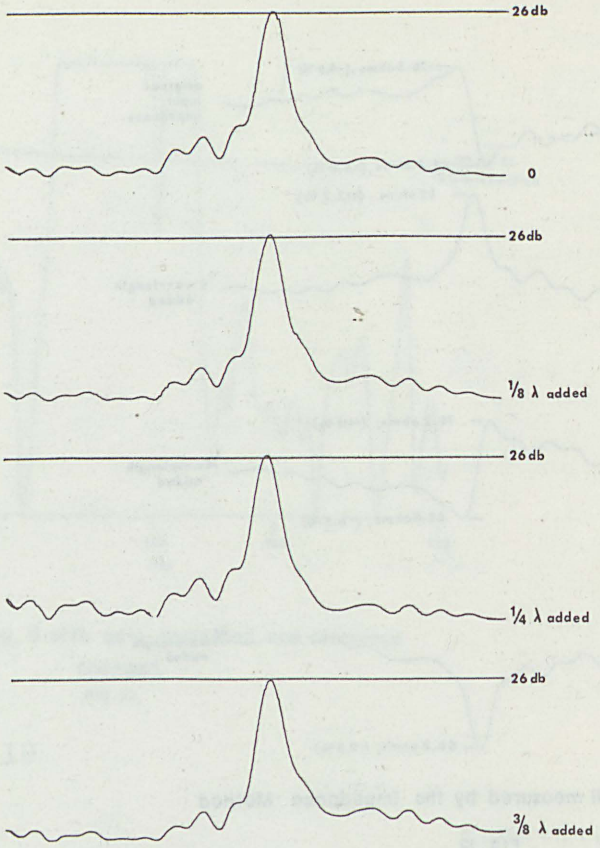
6. The sensitivity of this method is illustrated by Figure 10, which is similar to Figure 9, but shows a 15-db increase in sensitivity. Return loss variations as low as 50 db (0.3% reflection) can be clearly displayed.

Although the defect plotted in Figures 3, 4, 6 and 9 showed up clearly in all three tests, it should be noted that it was a particularly bad defect; i.e., one that would cause picture distortion if it fell within a television channel. A defect which is about the worst that can be tolerated in a cable television system is illustrated in Figures 11, 12 and 13. Figure 11, illustrating the transmission loss measurement of such a defect, shows the difficulty of this method: using all the scale expansion available, and equalizing the transmission characteristic, the 0.1-db variation is difficult to discern and impossible to measure accurately. Figure 12 shows a great improvement in sensitivity obtained by impedance measurement, but also illustrates the weakness of this method in that four different measurements were obtained, depending critically on small variations in the point at which the cable was connected to the detector. The reading on this particular defect varied from

4.4% to 12.3%, depending on the length of the connection.

Figure 13 shows the advantage of the return loss bridge method, which gives a high degree of sensitivity with essentially the same reading, regardless of the point of connection (compare with Figure 12).

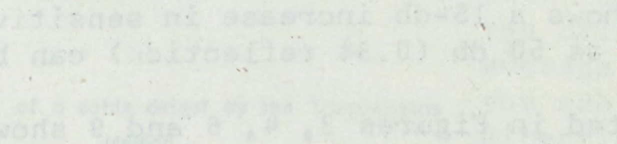
This comparison is further illustrated by measurements made on a reel of good CATV trunk line cable. Figure 14 illustrates the return loss characteristic taken over the entire TV spectrum, showing excellent structural return loss characteristics. Figures 15 and 16 show transmission loss measurements near the worst defect. Note that the transmission loss variation, at this point, can hardly be seen or measured by this method. Figure 17 illustrates an impedance test of this worst defect, and figures 18 and 19 show return loss tests in this same frequency range.



Same defect as FIGS 11 & 12 measured by the Reflection Method

FIG. 13

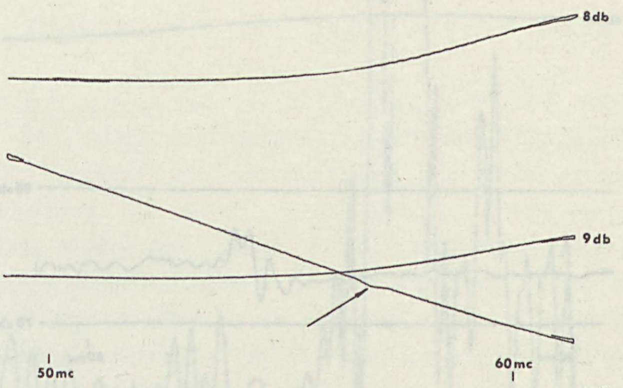
Fig. 13



Reflection Test On Sample Reel Of CATV Trunk Line Cable

FIG 14

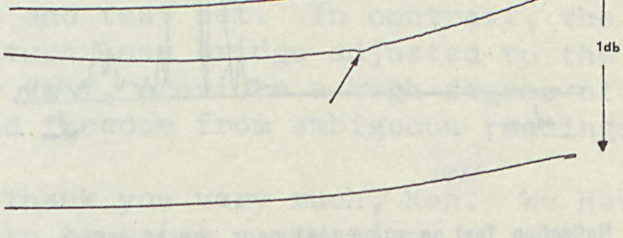
Fig. 14



Transmission Test on same reel as FIG. 14 near worst defect.

FIG 15

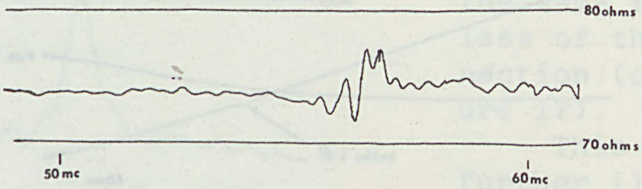
Fig. 15



Same as FIG. 15 except Transmission equalized.

FIG 16

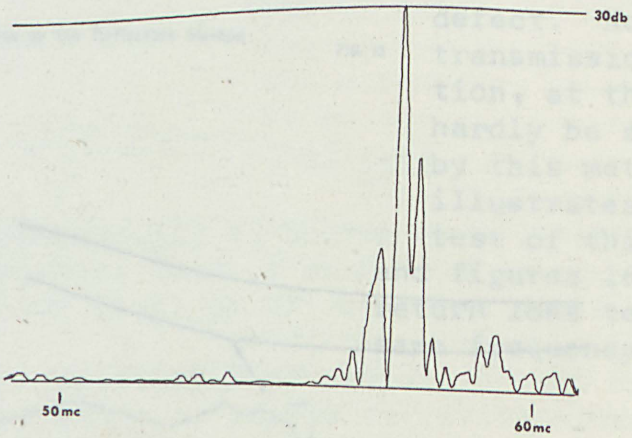
Fig. 16



Impedance Test on same reel as FIG 14 near worst defect.

FIG 17

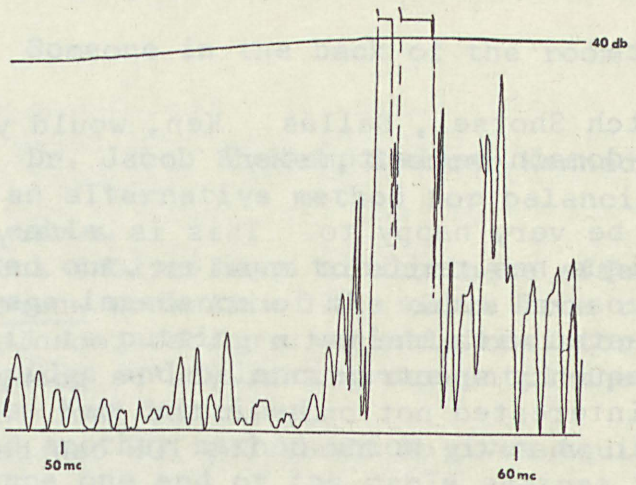
Fig. 17



Reflection Test on same reel near worst defect.

FIG. 18

Fig. 18



Same as FIG.18 except gain increased, reference shifted.

FIG.19

Fig. 19

In summary, three methods that have been used to determine the existence of electrical problems due to periodic discontinuities in cable have been described. The transmission measurement method suffers from low sensitivity and the need for equalization. The impedance measurement method presents difficulties in calibration and is ambiguous because of variations peculiar to the point of connection between cable and test set. In contrast, the reflection test method, using a return loss bridge adjusted to the average impedance of the cable under test, provides a high degree of sensitivity, ease of calibration, and freedom from ambiguous readings.

MR. TAYLOR: Thank you very much, Ken. We have a few minutes, if anyone would like to raise a question.

MR. EARL QUARR: Mr. Earl Quarr, Long Island Cable Division. Did I understand you correctly? Should you measure return loss from both ends of the cable?

MR. SIMONS: Very definitely, and I would say it's an encouraging sign if you measure the same from both ends. This says that particular reel probably has a uniform characteristic throughout. Generally, you should measure a reel from both ends and the characteristic should be good from both ends.

MR. QUARR: Thank you.

MR. TAYLOR: Dutch?

MR. SHOTSEL: Dutch Shotsel, Dallas. Ken, would you comment on the possibilities of time-domain reflectometry?

MR. SIMONS: I'd be very happy to. This is a very active subject. The time domain technique has terrific applications and is most helpful in the production of coaxial cable. It will show where the discontinuity occurs, as contrasted with the return loss technique which shows how it affects the frequency spectrum that you're going to use. Since a manufacturer is most interested not only in the fact that a given reel of cable is bad, but in what to do about it, TDR can be a terrifically useful tool.

There is one minor difficulty in the fact that the available TDR (and I may be doing somebody an injustice, but the only one I know about is the Hewlett-Packard) has a 50 ohm source impedance. You can work with this, but it introduces a small problem in the fact that you get multiple reflections. If there is an echo from the cable, it goes back to the 50 ohm source and is re-reflected. Since most of the discontinuities are small, this doesn't give much trouble. The Hewlett Packard engineers have told me they have a technique that they believe will be satisfactory in giving a matched 75 ohm source and with or without this improvement I believe the TDR is a tremendously useful tool.

MR. KUSHNER: Mr. Al Kushner, Times Wire. Ken, we've used your bridge, of course, in the factory, quite a bit and there's one thing we've noticed. If we first display on the scope 50 to 220 megacycles and measure a 30 db spike, and then reduce the sweep width so we're only looking at plus or minus ten mc, the reading will increase sometimes by as 2 db. Does this correspond with your results?

MR. SIMONS: It certainly does. The difficulty here is a simple one, and we do have a fairly effective correction for it. If you look at the RF signal that comes out of the bridge as an amplitude modulated one, the amplitude modulation has a very high percentage and the detector tends to exhibit peak clipping. In addition there is a problem with envelope frequency response. If you sweep past a ripple too fast, it is not displayed accurately and the correction which we found quite effective is to put a little high frequency boost in the audio output. It is adjusted by first spreading the pattern way out, getting a reading, then sweep maximum bandwidth and adjust the "boost" for the same reading.

MR. KUSHNER: There is one other thing. Since we've been working with 30 db cables we found that, when we get above 30 db return loss the TDR shows reflections of 60 to 70db down.

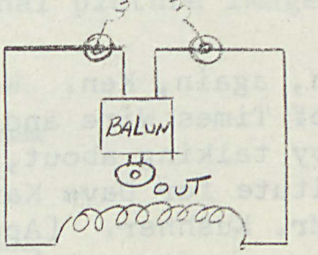
MR. SIMONS: TDR is most useful for isolated problems - lump discontinuities or for analyzing the nature of the periodicity as to whether it is a sinusoidal variation in diameter or whatever it may be.

MR. TAYLOR: Someone in the back of the room had his hand up. Dr. Shekel?

DR. SHEKEL: Dr. Jacob Shekel, Spencer Kennedy Labs. I just want to describe an alternative method for balancing out the average impedance of the cable.

As Ken pointed out, we have to eliminate effects due to variations in the average impedance of the cable from reel to reel. Now, one way of doing it is putting a variable resistor and capacitor on one side of the bridge and balancing out until the minima come down to the baseline, as Ken described.

We have found another method which gives equivalent results. In effect we balance one end of the cable against the other. For this you have to have a bridge allowing access to both connectors. Instead of building the standard impedance as part of the bridge, you have two outputs that you can balance against each other.



CABLE UNDER TEST

Now, this is the same basic bridge that Ken's been describing except that I have now two openings for two things to balance against each other. What we do in this case is to connect both ends of the cable to both ends of the bridge. The average impedance of the cable is likely to be the same at both ends since the cable was not especially made to taper from one end to the other. But the manufacturer tried to make it uniform, so the average impedance would balance out and wouldn't show on the output. If there is any mismatch in the connectors, there is one on each side of the bridge and their mismatches would balance out.

Now, if there is any chance that the attenuation is not enough and the signal may go in on one side and come out through the other side, and look as if it were a reflection, there is also a similar signal going the other way. And again, they will balance out. The only thing which is left is the random reflections which come from each end and because they are random, they are incoherent and they will not balance out. Moreover, each of them has the wave form of a noise. Thus we have, in effect, two noise wave forms that add up to give another noise wave form 3 db higher than each of them by itself. So when we make a measurement this way, all we have to do is subtract 3 db from the results and then we get the cable perfectly balanced against the best thing it could be balanced against, which is itself.

MR. TAYLOR: Did anybody have another question they would like to ask?

MR. SHIELD: Don Shield, Vancouver. Ken, I was wondering if you have come up with a practical limit to the length of cable for which your testing technique is useable? I know that 2000 feet is a typical length for a reel, but it seems to me that the length of the cable or the attenuation will have an effect on your results as well. Am I clear on that, or is that a confusing thing?

MR. SIMONS: The answer to that question is that the return loss method gives you a view into the first 500 to 1000 feet, depending on the loss of the cable. Of course, it doesn't matter how much longer than that it is, but you're not looking at the middle of the cable. You get a decidedly prejudiced view of each end of the cable and if the manufacturer, under the present circumstances, could make cable that was very good at both ends and bad in the middle and save money that way, I suppose you could get away with it. But it doesn't generally happen, if you have a cable that is good at both ends. All things being equal, it's apt to be good in the middle.

MR. TAYLOR: Thank you very much, again, Ken. We'll proceed onto the next paper by Mr. Allen Kushner of Times Wire and Cable, who is going to continue the discussion of cable by talking about, "Coaxial Cable Performance for CATV". This is a substitute for Dave Karrmann who was listed on the program. I introduce Mr. Kushner. [Applause]

MR. ALLEN M. KUSHNER (Times Wire & Cable, Division of The International Silver Company): Dave Karrmann was originally scheduled to write this paper. However, since the time we submitted his name he was taken off this particular project. I was assigned the job of writing the paper.

I watched with great interest Ken's paper because since I came with the Company my primary responsibility has been really to watch over the testing of cable. So I have seen some 300,000,000 feet of test reports reflecting basically what Ken has had on the board and it was quite interesting.

PURPOSE

The purpose of this paper is to discuss the characteristics of coaxial cable which are of major importance in CATV system performance. We shall attempt to accomplish this by showing how the cable affects system design and customer pciture quality. We also shall attempt to show the substantial improvements which have been made in cable design and manufacture in the past 15 years, and to discuss what remains to achieve the optimum cable design of the future. As a result of this

so as to be able to compensate for anticipated changes in input signal in either direction. Usually, only the gain of the intermediate stages are varied so as to maintain good noise figure and overload characteristics while the input and output stages are at a fixed optimum operating point. The detector is tuned either to a single frequency or is broadband, depending on the type of AGC system used.

In the second system, the entire amplifier is maintained at its optimum operating point as far as noise figure and overload characteristics are concerned. The attenuator ahead of the amplifier is varied to change the overall gain at the amplifier station. The nominal operating point of the attenuator must provide an insertion loss of at least the magnitude of the anticipated downward change in input signal level. The loss of the attenuator is then varied up or down to correct for changes in input level. This arrangement, while allowing optimum operation of each stage of the amplifier, effectively increases the noise figure of the amplifier by the amount of the attenuator's nominal insertion loss. The best solution may be a combination of the two methods. That is, place the attenuator at an intermediate point in the amplifier. This would allow optimum operation of the active elements in the amplifier and, at the same time, provide a good noise figure.

As stated previously, the AGC may be derived from either TV signals or from pilot carrier signals. A single TV signal cannot be used alone to activate the AGC because if that channel went off for any reason, all amplifiers would run wide open.

Excessive gain would be accumulated, and overload would soon occur on the remaining channels. Therefore, if this method is used, a standby oscillator is required which is switched into the system if the primary source goes off.

Another method is to sense the composite signals in the passband of the amplifier and adjust the gain to the composite level. With this method, if a station goes off, the AGC is still operative. No standby oscillator is required since the AGC circuit operates from the remaining carriers.

Still another mtthod utilizes only pilot carriers to drive the AGC circuits. This system is independent of the TV signal levels and has the advantage of providing a fixed standard signal to which the entire system may be referenced.

To summarize, the main advantages of AGC are:

(1) Stabilization of individual channel signals permits adjacent channel operation and maximum utilization of the transmission system.

(2) Proper signal levels may be maintained in the trunk, thereby avoiding problems of noise and cross modulation.

(3) Maintenance problems are reduced by eliminating the necessity to reset levels with changes in temperature.

Thank you. (Applause)

MR. TAYLOR: I think we can take time for one or two questions. Anybody have a question they want to ask Mr. Kuzminsky? One in the back of the room.

UNIDENTIFIED SPEAKER: This might be going back to this envelope delay problem, but I notice on the color set there was another image to the right and I've had this problem on black and white. I don't know what it is. Is it miss match?

MR. KUZMINSKY: Well, sounds like it.

UNIDENTIFIED SPEAKER: Miss match?

MR. KUZMINSKY: Yes.

MR. TAYLOR: Thank you. Thank you very much, Mr. Kuzminsky. (Applause)

Our next speaker is Mr. Robert Cowart, Vice President in Charge of Construction for Viking Company. And, he's going to talk on "System Reliability". I believe the

sketches will be circulated while he's talking. Mr. Robert Cowart.

MR. ROBERT COWART: I like in particular that ETA part, so I'll be very brief. I'd like to talk to you this morning briefly on system reliability.

These days we find outselves building more and more systems into areas that already have available to them strong high quality, highly reliable, local off-the-air signals. In order for a system to compete under these conditions, the system must be engineered in such a fashion that it could successfully compete in terms of the same quality, reliability and performance as these off-the-air signals. The preliminary determinants of quality are signal-to-noise ratio, cross modulation and ghosts. You are all familiar with these terms as a result of the industry schools which outline and detail methods of qualitative determination. I am sure that by now you are all familiar with these terms, with their method of determination and know of many ways in which to improve them. A fourth, extremely important, factor is reliability. A subject which has frequently been ignored both in the past and at the present. My purpose today is to acquaint you with the basics of reliability and to point out to you some methods by which present system reliability can be improved.

Many studies have been made in the past both by military and commercial interests in the pursuit of those factors that control and influence reliability. In almost every case explored the most highly reliable system was the simplest system. I am sure you will all agree from your own experience that this is the case. The military answer for increased reliability is redundancy. This means having almost two complete sets of basic equipment, one ready to take over the function of the first, should it fail. The commercial solution to reliability is primarily by increasing the reliability of the components and increasing the size, weight and mass of the device. This is more or less the brute force approach.

In CATV, neither of these two standard approaches is really available to us because of the unusual demands we make of the device. In transistorized equipment we sacrifice virtually everything for the sake of a lower noise figure or increased output capability. We are pushing the upper limits of the State of the Art. We can't use redundancy because of cost. We can't use higher reliable components because high reliable, high performance transistors are not available yet. We must achieve our reliability in the method in which we construct our systems, and in the method in which we utilize the manufacture's product.

Most manufacturers today design equipment that is inherently reliable. In many, many cases that we have examined, we find that this inherent reliability of the device is lost in its application.

Reliability in electronics systems is generally considered to mean the length of time between events that render the system incapable of performing its designed function. In industry, exhaustive and extremely expensive studies are made to determine and assign quantitative values for the time between failure. This period is often referred to as mean time between failure or MTBF. In CATV these numbers are not available but the principle guiding the establishment of these numbers is available and it is with this principle that we will concern this discussion.

If all of the components of an electronics system are considered to be functionally in series and if the failure of any components in this series chain results in a system failure then the overall system reliability can be expressed by a very simple formula. This formula states that the overall system reliability, designated by the symbol "R", is equal to the reliability of each of the series components raised to the power of the number of those components that are in series.

$$R = r^n$$

Where r = mean reliability (probability function) of each component.
n = number of components in series.

This expression demonstrates something that you know intuitively to be true. In other words, the longer your trunk line in a system the greater the probability of failure of a component of the trunk. Conversely, the shorter the line tne less chance of failure. The formula also allows us to show mathematically that given two different amplifiers if twice as many amplifiers are used in a system of Type "A" as are Type "B" and Type "B" has half the reliability of Type "A" then the overall reliability of the system is exactly the same because there are twice as many pieces used but the reliability of each piece is twice as great. You intuitively know that the statement is correct.

The formula also shows that the high reliability system would have few parts and each part in itself should have the highest possible reliability. Towards accomplishing this end we customarily, in large systems, use extremely low loss trunk cable such as 3/4" aluminum and the highest possible db spacing between amplifiers because in our trunk system the highest reliability component is the cable; secondly, would undoubtedly be the connector; thirdly, the accessory items, splitters, directional couplers, etc.; and lastly with least reliability is the amplifier itself. Our major significant contribution to reliability of that trunk segment would be to decrease, by whatever means we could the cable loss, utilize wide amplifier spacing, etc., the number of amplifiers functionally in series. In our efforts to increase the reliability of that trunk segment we would attempt to reduce the total number of objects with lesser reliability than the cable to a minimum. This would mean we would reduce the number of splices, if possible, by care in our construction; we would reduce the number of splitters, directional couplers, equalizers and other objects inserted in the lines and try and make as much of the line as we could, sheer cable: Because, of course, the cable is the most highly reliable item of our components.

The same reasoning establishes a guide line in the design of equipment and has prompted most major manufacturers to abandon the practice of using splitters to generate inputs to associated distribution equipment and to instead build into the trunk amplifier chassis a fixed directional coupler to provide the input to distribution. When this is done we eliminate a jumper and several connectors that we used to use in the past to accomplish this. The same reasoning demands that in transistorized equipment the equipment should be mounted without equipment enclosures. That means not with the use of an equipment cabinet. When an equipment cabinet is used the signal must pass through a bulkhead connector, a mating connector internally in the cabinet, a jumper, and finally through another connector on the end of the jumper and into the amplifier chassis. The same thing is true on the output of the amplifier. When this is done there are five additional elements functionally in series with the signal between the two ends of the trunk cable. Although connectors have inherently high reliability, by removing the eight connector assemblies from the line and replacing them with two direct entry connectors, we have thus improved the reliability of each amplifier station four times. You intuitively know that the reliability of this configuration is far less than the direct entry type connector permanently mounted to the amplifier chassis.

In an operating system when you examine at the end of the year the maintenance that has been given to the system, you find some rather curious things. You find first of all that many of your system outages were not caused by any inherent failure of the amplifier itself. You find that they were caused by such unrelated things as power failures; by cars breaking off power poles; by trees falling across distribution and trunk cables; by the failure of fuses as a function of temperature; by lightning strikes; and by employee carelessness in leaving amplifiers disconnected, etc. Another important point that gains in significance as we move into the area of transistorized system construction with many, many, amplifiers dependant on a single power supply is that extreme caution should be used in selecting the location for the power supply. I am sure that you have all had an experience where a certain amplifier in your system continually caused you trouble because of failure of secondary voltage delivered by the power company. We have seen amplifiers installed and taking power from power company transformers already seriously over-loaded. Few of you have given any thought to requesting the power company to provide you with your own transformer, which need not be very large, to assure yourself of a non-interrupted source of power.

The cost is very low and the reward in terms of increased reliability is great. These things again point up the fact that in system design, a system should be engineered in such a fashion so that the absolute minimum of active elements of the system are in cascade. Ideally, as we have all discussed many times in the past, a system would be arranged in the manner of a wheel; with the center of the wheel the point of signal origination and of radial lines from the wheel hub to the outlying distribution areas. Although this is obviously impractical in most cases, an attempt to accomplish this type of construction can be made by the adoption and usage of extremely low loss master trunk cables as a backbone of the system. This new configuration will resemble somewhat the skeleton of a fish; with the master trunk cable being the backbone of the skeleton and distribution at right angles to this master trunk but in much, much smaller segments.

Many of you have suggested in the past that you accomplished a form of redundancy by paralleling master trunks perhaps several blocks or half a mile or so apart, but when you examine the situation existing in parallel trunk, you find that you have not accomplished your purpose because the basic law of system reliability catches up with you. Remember, it states that the reliability decreases exponentially in proportion to the number of active elements in cascade. By paralleling master trunk you are in effect doubling the number of elements in cascade. Now it is true that by the redundant parallel trunk method you do restrict the service fault to a smaller area, however, if the two or more trunk segments are exactly the same length, then the system reliability itself, on the basis of our definition of fault, is actually impaired by the same number of trunk lines existing.

In summary, let's recap the major points that we have established. A system gains RELIABILITY by SIMPLICITY. This means that when you make your new layouts, look at them carefully to determine if you have taken the shortest route, if you have arranged your construction to utilize a minimum of connectors and splices, see if your power feeds come from a reliable source and make sure that you are utilizing as fully as possible the reliability delivered to you by the manufacturers.

Thank you. (Applause)

MR. TAYLOR: I would open the floor to questions on any of the subjects we've been answering. Let's take any questions to Bob Cowart first, if you have them, however. Are there any questions on this Systems Reliability that you'd like to ask Bob Cowart? Well, if there are no questions specifically to Bob, they may arise later. I shut off a number of questions earlier, particularly on the subject of envelope delay. Ken Simons.

MR. SIMONS: Again, this isn't a question. I would like to take a few minutes if you don't mind to show you a little scheme that we have used for some years in our lab to measure group delay. You might call it Do-it-yourself-group-delay-measurement. It takes equipment that most of you will have in your service shop or lab and I think there's enough time to sketch it out. The accuracy is not of the highest order but perhaps we'll make up for that in the cheapness of the equipment used.

I should give a credit here. The very fine grease pencil I'm about to use is through the courtesy of VIKING.

Now, the basis of this method of group delay measurement is the constant delay of a long piece of cable. If you have a reel of cable and I'll represent it this way. That's a piece of cable. It's on a reel and you're looking at it in 4th dimension. The delay from here to here is constant, approximately constant as Mr. Rogeness told us. How we can use this constant delay thing to help us in measuring the delay error or the actual group delay of a piece of equipment? Well, we start over here with a sweep frequency generator. There are a good many reputable manufacturers - you can take your choice.

We split two ways with either a 6 db resistive splitter or a 3 db reactive splitter. We have now two outputs, one going here and one here. This one goes up to the

SYSTEMS AND ANTENNAS
THURSDAY AFTERNOON - JULY 22, 1965

MR. CAYWOOD C. COOLEY: I hope you will give some consideration to the fact that I knew this about ten minutes ago and to the best of my ability I'll try to serve as your Moderator this afternoon.

Our first subject today is entitled, "Color TV--From Studio to Your Customer". And the gentleman that's going to deliver this is an engineer from the Collins Radio Corporation with more than 27 years of experience in radio communications, television, photography and optics. He is a member of the Society of Motion Picture and Television Engineers and he attended Wright Junior College, the Armour Institute, the Lewis Institute of Chicago, and the Bell Telephone School for War Training. I see he's got quite a bit of paraphenalia and slides and talks so I'm going to sit down and enjoy the program with you. We have half an hour and at about the 25 minute period interval, we will stop and hope we have an opportunity to attempt to answer your questions. Mr. W. P. Kruse. Am I saying it right, sir?

MR. W. P. KRUSE: You pronounce it right, but it's the wrong enunciation. Thank you, Mr. Cooley. The name is Kruse if you don't mind. Subject: "Color TV from Studio to Your Customer." First of all, in introduction, color TV is a permanent part of our economy at this day and age. The quantity of our programs is increasing monthly. We are not here to discuss the quality of programming. We're here to improve the transmission of the available techniques. At one end, our source of signal is the Color TV camera at the studio. On the other end, we have a customer looking at his color TV receiver. We and the broadcasters are between these two ends. The broadcaster will produce a program from any of the following switchable sources: 1) A local color TV camera, which may come from a live remote scene using FM microwave relay, coax cable or twisted shield repair. It may also come from a localized studio scene. It may come from film and slides. 2) The program may be coming from a video tape which does use FM record and play back techniques. The third source of our studio's program is network, of course. The program will get to that given studio via FM microwave relay, coaxial cable or occasionally twisted shield repair. Telephone company has these various methods in their longlines division.

A single building broadcasting plant could directly coax cable from the selected program to the AM TV transmitter system. In many places, there is no room for the transmitter tower and equipment in the downtown location. They would then have a multiple building plant that you would usually use an FM microwave STL. STL in this case is a Studio Transmitter Link between the studio and the AM transmitter site. I hope you will bear with me in my partial emphasis on the difference between the AM and th FM transmissions, because this is an important part of what I'm going to try and bring home to you people.

Our business is handling the signal between the off-the-air broadcast and the cable to our customer. It is our responsibility to add as little technical degradation as economically possible. We add many components to the system; however, you do have control over the off-the-air antenna location, the off-the-air AM receiver, the intervening microwave FM transmitter, its antenna, the following receiving antenna, the intervening microwave FM receiver. You then have your video back. It then goes into your cable-driving AM transmitter, your cable distributing amplifiers and cable to your customer's AM receiver. Already we have two FMs probably and two AMs before the customer gets to his picture.

The many conversions of the TV signal involve numerous possibilities of degraded reception. Our customers are becoming increasingly discerning as to picture quality. Our operating on the signal must be accomplished with great care. There are many factors involved. At times the signal must be predistorted to correct for later and inherent distortions in your customer's receiver.

In color television, as we are going to primarily emphasize this talk, we do have to be concerned with the over-all economic system, what the people are going to see in their homes in their color receivers. We do and will start with the very first item and that is, what can the eye see?

1. The human eye is capable of seeing large objects in full color. As the object viewed is decreased in size, the eye loses perception of greenish-yellow and blueist purple or magenta colors. Your eye continues to see small items in orange-red and blue-green or cyan color. Very small items are seen only in black and white. The exact amount of this color rendition of our eyes depends on individual persons, but there are generalized rules that are met and found quite widely in the various optical magazines and texts.

The above characteristics will, however, allow appreciable simplification of our color TV techniques. The size of the object at a given scanning distance is a given band width required out of that camera. If you can't see certain colors below a certain size, then you don't need band width for that color you can't see anyway.

2. We have a few terms to make sure we agree on our wording before we go on into the main portion of our text. The advent of television produced new meaning for some ordinary words and many new words. As an example, a grouping of words that apply to a subject follows: The following are in groups essentially meaning about the same thing. 1) Brightness, intensity, luminous perception of light, or we may even say the cathode ray tube current that produces that light they were going to look at. 2) Contrast, picture, video level are some of the terms we may use. The ratio between the maximum and minimum brightness in the picture. Often we'll say the video amplitude. Those factors are a group on the same subject. Item 3) Color may be called by tint, its hue and into electronics we'll say its color phase or color angle. The angle represents a specific hue as calculated by the TV color formula. 4) We have chroma or color gain or some receivers will mark it in for the customer to use and call it color brightness. These words essentially mean one in the same thing.

In this direction, a further explanation of chroma, color gain or color brightness, the physicist, the opticians will say saturation, purity of color, compared to gray or white. Black is the absence of color. The amplitude of the color information, or color gain. These in item 4 are all in the same direction.

The number of different terminologies for a given subject in these four listings here can lead to confusion unless we do agree upon what words you're going to call them. Unfortunately sometimes for variety we may go on and call them different names and make our speech try and sound a little bit better.

3. Now, the main part of the text. Color signal generation. The present US FCC standards follow the recommendations of much of the TV industry. The color band pass requirements are to provide full color to all images of large area. This corresponds to televized items producing a video spectrum response from DC to about 0.6 of a megacycle for full color. Objects that are smaller than given size that would produce a video spectrum higher frequency than 0.6 of a megacycle would then not be seen in certain colors. Green-yellow or purple color items are transmitted in black and white from 0.6 through 4.2 megacycles. Green-blue and orange-red color items are transmitted in black and white when a TV scan size is small enough to produce a video spectrum above 1.5 some megacycles. In other words, the band pass requirements are: 1) high definition black and white 0 to 4.2 megacycles; 2) Partial color. Green-blue and orange-red from 0 to 1.5 megacycles; 3) Full color including gree-yellow and purple-magenta, 0 to 0.6 megacycles. These three different band widths are in use in the broadcasting of our color in our present TV standards.

Means have been found for inserting the color information into the normal band width of the black and white signal. The camera outputs are various amplitudes of the harmonics of only the horizontal and vertical scanning frequencies. All the spaces between the horizontal frequency harmonics can be called the "Vast Wastelands of TV."

Clever engineers have found ways of using this space in the TV camera output spectrum. They placed a subcarrier at the 455th harmonic of one-half of your horizontal frequency, which for color is 15,734 cycles. This is between a 227th and 228th harmonic of the color, horizontal scanning rate. This odd value of horizontal frequency is due to the need for low visibility of the color subcarrier itself and also of the beat note between the color subcarrier and the sound inter-carrier spacing. The spacing between the color subcarrier and the sound intercarrier is 920,455 cycles or exactly 117 times half of 15,734. These numbers are fairly important. The signals are actually generated with these numbers in mind, so that the two beat notes, one from the color subcarrier itself, one from the color subcarrier beating against the aural intercarrier will both be of a very low visibility. They will average out in a normal viewing angle in a reasonably linear system.

The intercarrier spacing of 4.5 megacycles was maintained and the tolerance of the transmitter operation was tightened from plus and minus 4 KC to plus and minus 1 KC. Now, I say the intercarrier spacing, not the fundamental aural carrier frequency itself. The intercarrier is what really counts. That's where we're going to have a little problem in the color receiver with our 3.6 odd megacycles beating with the 4.5. Therefore, the 4.5 tolerance is tightened, but not locked together. It was found unnecessary.

All the preceding considerations produced a color subcarrier frequency of a nice long number. I know you've seen it in print. Let me tell you what it is once again. Three megacycles, 579 KC, 545 cycles. And, they try and maintain that within 10-11 cycles. There's an even tighter change of frequency, rate of change speck (specification) on it. This subcarrier is then modulated in amplitude and phase by the color camera signals. The blue-Purple or megenta colors amplitude modulate the subcarrier in an angular direction we will call Q. The green-yellow color amplitude modulates the same subcarrier near an angle we can call minus Q or 180 degrees away from the first set of colors. This Q signal has two sets of colors. They have been previously filtered down to zero, through 0.6 megacycles. The red-yellow colors amplitude modulate the same subcarrier near an angular direction we will call I. The green-blue cyan colors amplitude modulate subcarrier near an angle we call minus I. These two sets of colors, I and minus I, have previously been filtered to 0 through 1.5 megacycles. The output of the Q signal is 3.6 megacycles plus or minus .6, or 3 through 4.2 megacycles. The output of the I signal is 3.6 plus .6 minus 1.5 or 2.18 through 4.2. Any one color is seen at a given instance by our color camera. It will see red here, green there, yellow over there. So It's going to actually phase and amplitude modulate this subcarrier at a given direction depending upon what the color is. Any one color that is seen by the red, green or blue sensitive camera tubes is computed and band passed to be a single amplitude and one angle of a subcarrier.

The different colors seen by the camera will be another amplitude and another phase angle of the subcarrier. The various amounts of color purity or saturation produced proportional amplitudes of the subcarrier. The various tints or hues of color produced a computed angle of the subcarrier. A fixed phase reference color sinc burst is generated and added immediately after all horizontal sinc pulses. This burst is used to synchronize the color of the monitors in the studio, perhaps in your locations as well as your customer's receivers.

4. We have a factor which is rather important in color and this is called envelope delay. Envelope delay in AM broadcasting. The important concept here is that color is an amplitude and phase sensitive signal. It is added to the monochrome signal at 2.18 through 4.2 megacycles. The sound intercarrier and later subcarrier at 4.5 megacyles is perilously close to 3.6 and 4.2 megacycles. The AM receiver sound IF and video traps are generally narrow band, high Q tuned circuits. Their very action causes a serious delay in the passage of the 3 to 4.2 megacycle color and monochrome high frequency or small area components. Each and every AM TV receiver use these traps. Experts have found that the resulting delay curve is very consistent

in relation to trapping used in many different manufacturer's models of TV receivers.

The AM broadcaster is required to have a delay equalizer to predistort for this effect. The result is any AM transmitter and any AM receiver should therefore be compatible. This delay is often referred to as the funny paper affect.

The Sunday color comics are often printed out of register in any direction, being a low-cost color printing process. In TV, however, a color misregistration can be to the left or right only. The excellent paper this morning on envelope delay had a very good slide, showing a man in the boat with a color about half to an inch away from where it belonged compared to his brightness components.

Color to the left is caused by insufficient phase delay or a leading phase. To the right is excessive phase delay. This phase can be most sensitively measured with the concept of envelope delay.

Envelope delay is defined as the change of phase in degrees per change of frequency or the mathematicians will say DΘ/Df, the change of phase with relation to frequency.

Now, this frequency I'm referring to is that of the video; the microwave boys will say the base band or the telephone company may say base band. It will also, however, be including the AM side band of our AM transmitter and our AM receivers.

This delay of the envelope is that of the high frequency monochrome and all color components compared to the low frequency components. After all the low frequency components or the monochrome signal should be at the same TV screen location as the low frequency color components.

Commercial test equipment and finished design equalizers are available for envelope delay usage. Every color AM TV transmitter is required to correct for the color AM TV receiver's envelope delay. The receiver's envelope delay is caused by the sound trap for one and partially due to the vestigial side band transmission of the receiver and transmitter acting together.

Observable improvements are made when this correction is made. The main part I wanted to show is (this page of a paper which was available at our booth) is this chart saying, Overall envelope delays shown with AM transmitter powers.

Now, you see that across here we do have a straight line. This is the transmitter and receiver together properly compensated. Just for emphasis of the tolerances of the system, I included the dotted lines to show the AM transmitter tolerances of its filtering. Its filtering is supposedly from the camera terminals to an ideal demodulator off the transmitter's transmission lines.

We have a chart here in frequency in megacycles going as far as video is concerned from 0.2 megacyles, 1, 2.18, 3. At 2.18 our color starts. At 3, all of our colo is started, 3.58 is our color subcarrier and all over at 4.18 MC. Tolerance is tightened progressively through the exact part of subcarrier frequency.

We have the vertical components here of this chart in microseconds of envelope delay. It is given in time, in tenths of a microsecond and the existing AM transmitter broadcasting tolerance is plus and minus .1 microseconds from .2 megacycles up. Then the tolerance gets increasingly tighter as you get to the 3.58 MC color subcarrier where the tolerance is only plus or minus .05 microseconds or we can express that as plus and minus 50 nano-seconds.

A major item list for observing envelope delay includes a video sweep generator, envelope delay generator, a video envelope delay equalizer, a video vestigual side band filter, an AM transmitter with amplifier either set for VSP or a passive filter, your AM TV receiver, your envelope delay receiver and an oscilloscope.

5. Now, to go on, once we have used the AM transmitter's radiations into a head-end receiver, that head-end receiver has sound traps. We have then used up the correction; the straight line is now available to us at that head-end receiver. We pass it into the FM microwave, either STL or your CATV microwave. The video amplifiers in FM as well as AM that lead to modulation and those following demodulation are both equally susceptable to producing envelope delay. The microwave and IF band pass components can influence envelope delay in FM as well as AM; however, it is

easier to maintain an excellent phase versus frequency through 4.2 megacycles in an overall pass band that is nominally flat through 7 to 8 megacycles. It's the action of the traps at the aural intercarrier 4.5 that cause trouble in the 3 to 4 megacycle region.

There is no trapping of 4.5 in microwave equipment unless our customers do that on his own head end or terminal equipment. This lack of trapping at 4.5 megacycles precludes most phase shift at 4.2 megacycles. In general, the envelope delay will be negligible in the FM microwave.

6. Envelope delay in AM CATV. Your customers' AM receiver has sound traps at IF and at 4.5 in video amplifiers. It should be preceded by an envelope delay filter at the CATV AM transmitter or your name for it is a cable modulator.

7. We have spectrum conservation in our AM TV transmitters, AM receivers - therefore your customers' receivers - your head-end cable driving transmitters. In order to get your 6, 8, 10, 12 channels in some applications onto one cable, you are definitely using adjacent channel operation. You will, therefore, have to essentially adhere to the vestigial side band transmission that the broadcasters use. Their problems and your problems in that direction are one in the same.

Vestigial side bands. Vestigial means remnant or partial. The vestigial lower side band in the case of the AM broadcast TV transmitter has a flat response from carrier to .75 megacycles instead of 4.2. That's speaking of the lower side band. Using 200 KC as a zero db reference, the vestigial side band response is down 20 db at 1 1/4 megacycles on the low end instead of 4.75. Subtracting, 4.75 minus 1.75 you have a spectrum saving of 3 1/4 megacycles for every 5 megacycles channels in use. This saving of actual spectrum space has been in use for 15-20 years or better. You are using it.

The vestigial side band's amplitude response is accomplished at the carrier frequency. The attenuation may take place either by passive filters or the tuning of linear amplifiers. This carrier is transmitted without attenuation.

The solid line is that of the AM transmitter. The carrier sitting here at fv. The response goes out flat to three-quarters of a megacycle and then goes to better than 20 db down, 1 1/4 meg out. This is for the lower side band. The upper side band is still flat to 4.2 megacycles. The transmitter is used with a passive filter or tuning procedure. Your corresponding AM receiver then has its IF response running along the dotted line. Your visual carrier is 6 db down from the normal flat reception, ideally flat to 4.2 and sound traps at 4.5 megacycles.

This combination when all amplifiers and filters are properly aligned will give you a 100% modulation output that is level from 0 to 4.2 megacycles. It can be done. Your cable driving transmitter, its tuning, the normal -- I soouldn't say normal but the idealized and proper tuning of the receiver -- can produce an 0 to 4.2 meg flat video response.

8. AM VSB for CATV use. The cable modulator or CATV transmitter today is generally designed to be tuned to a VSB response. The CATV system will generally produce a better overall picture quality when a VSB or low frequency phase filter is used This is used before modulation. It is quite simple to check with a 100 KC square wave or a white window from a TV test generator and a decent scope, a receiver whose IF is tuned properly.

Adjust for optimum rectangular pulse. Another method if not a better way to check the vestigial side band filters, both video predistortion, RF per channel filtering, your receiver slopes, your receiver sound traps, is to use an overall envelope delay response. One commercial test set covers from a .5 to a 4.2 megacycles in one sweep. The AM broadcaster uses a 4.75 megacycle low pass filter. This keeps all his important side bands inside his 6 megacycle channel. It does interfere with the envelope delay but fortunately you are not required to have that filter, neither legally nor technically. The broadcaster has already mopped it up for you. A few exceptions may be for some of your adjacent channel duty.

9. The main portion of the discussion here is color differential phase and gain.

Amplitude linearity and phase linearity is a big factor here. I'm speaking of the phase and gain linearity of our video component as the picture goes from black through gray to white. The phase shall not change, because the phase is what tint our picture will be at any unit area. If a person walks around the studio from dark to light areas of studio lighting, we don't want their face to change color. This can happen if you have poor differential phase. The amplitude linearity should be good and it is called differential gain. The means for measuring differential phase and gain is basically a two-tone test and that has been coming quite widely known. It amounts to our color television procedures taking our 3.5 megacycle sign waves and adding it to a horizontal TV component, 15,750 cycle stairstep sawtooth sign wave. It's not real important what the wave is of the low frequency, the 15 KC signal, so long as it excursions from black to gray to white in some known manner. Test sets are available from several sources. To measure the change of phase as you go from black to gray to white and back, to measure the change of gain, although you can often do that with a scope directly.

10. Your customer's AM TV color receiver is the final end action. We do have to bring the result over to there. We're starting off with the AM transmitter in the broadcaster's equipment building. He has the filters in. Your head end receiver uses up all the filtering that he put in. Those problems do not exist in normal FM microwave either for the CATV operator or the STL connection from studio to transmitter. However, one point that I'm trying to bring across as a main factor in this paper is this. Your cable driving modulator and your home customer's color TV receiver, they are both today running vestigial side bands. They have many aural traps at 4.5 or equivalent. Neither one of which I know of, as far as now, is being corrected for in your CATV head end location. It can be shown that the picture improvement is definitely noticeable. The video vestigial side band filtering is quite inexpensive. The test equipment, most of you have or can actually all but use the off-the-air TV sinc pulse direct.

I'll be the first one to point out that envelope delay procedures can be quite expensive. They are legally required for your AM counterpart and so far they are not in use in CATV procedures, but I'm positive - I'm sure that that time will be coming.

Test sets are available, expensive, yes. Some consultants may eventually be having them to make trips and go around and check things. The actual envelope delay equalizer has to be correlated with the CATV head end modulating unit. Then and then only will we have the optimum picture. When all time delays, which is really what this whole discussion is about, are corrected, the result can produce a show at your customer's home that can approach the use of that same receiver coupled to the AM TV transmitter.

In conclusion, we must give considerable thought, energy and money to the overall concept. It may seem complex, have many apparently conflicting requirements, but each unit is simple. Consider each area separately and "All your problems will be little ones".

We have discussed the many trials and tribulations of the path of the TV signal. Our industry is progressing. There are many things we do today that were laboratory and mathematical concepts only yesteryear. Let us all earn and learn by experience and let's use today's technology today. I thank you. (Applause)

MR. COOLEY: Thank you very much. I wonder if there are any questions from the floor, gentlemen? I'm sure color is going to be more and more important. Yes, please.

UNIDENTIFIED SPEAKER: About the missmatch in the FM transmission between the microwave antenna and, say, a line. Now, I'm talking of a set down in the 2000 megacycle region where you use a line rather than wave guide, say a 50 ohm transmission line. Then, at the bottom you have a load isolator for say as much as 20 db load isolation, with the effect of the missmatch at the antenna. What, if any, what is the effect on the envelope delay?

MR. KRUSE: With the load isolator, I believe, although I have not had any test in this direction, that the load isolator would absorb the reflected signal from the missmatch at the antenna and dissipate it. The result would generally be a change in amplitude response only. That is what I believe should happen. I'd be glad to discuss it further with anyone as far as perhaps some future testing in this direction.

MR. COOLEY: I thank you very much. Let's give him another hand, gentlemen. (Applause)

Our next subject on today's agenda is entitled, "Problems in Using Line Powered CATV Systems", and the gentleman that's going to provide that information is the Plant Manager for CAS Manufacturing Company in Irving, Texas; formerly served as production manager for Johnson Service Company, Electronics Division; also was production manager for Fishbach and Moore. A native of Dallas, he attended the University of Texas and Southern Methodist University and has nine years of management background. Gentlemen, Mr. Preston Spradlin is going to give us a little story on using line powered CATV equipment. Let's give him a hand as he comes up. (Applause)

MR. PRESTON SPRADLIN: Thank you very much, Mr. Cooley. I'd like to express my appreciation in being able to participate in this technician's session.

The title of my presentation is "Problems in Using Line Powered CATV Systems." Since the miracle of electronics, namely the transistor, enables us to use line powering but at the same time it creates problems, the question of why transistors for CATV should be answered first. May I have the first slide, please. (Illustrations next page)

I. AC vs DC Line Powering Line powering, the natural and economical way to power transistor amplifiers in cable systems, is in reality, a relatively simple matter and consequently, not too much thought has been devoted to this "life-line" of CATV. Yet, through experience, the majority of transistor failures and associated maintenance problems may be traced directly to problems in line powering.

CAS Manufacturing Company, as a result of several years of experience in line powering, has determined that adherance to the following procedures make possible maximum transistor performance.

The necessary power requirements of a conventional CATV system utilizing transistors is between 15 and 20 volts DC. In earlier systems, and as recently as 1960, CAS, like other manufacturers, used pure DC for line powering. This approach, being quite easily attainable, simplified standby systems and required little or no filtering networks in individual amplifiers.

The power supply was conventional and a wet cell could be used as a standby reserve.

Using pure DC, no problems were foreseen in the planning stage. However, in actual operation, continuous trouble caused by electrolysis and AC hum made it obvious to switch to AC line powering. A simple experiment demonstrating electrolysis is to fill a fitting with water and apply first AC and then DC and observe the action of each current. The application of DC builds up a carbon path and shorts the fitting or causes a high resistance leakage path. Even a small amount of moisture is sufficient to cause electrolysis when DC voltage is applied.

II. Regulated vs Non-Regulated Supplies In tube systems, constant voltage transformers became a necessity to prolong tube life and to furnish some degree of protection from lightning surges. In transistor systems, a constant voltage supply is normally built into each amplifier by using constant current transistor power supplies. Since this feature is inherent in transistor systems, the importance of having constant transofmrer voltage, although desirable, is not as important as in tube systems. Also, fast transients that may be destructive to transistors can pass readily through a regulated transformer diminishing afforded protection enjoyed so in tube amplifiers.

Basically, there are two types of constant current transformers - a sinusoidal and a normal harmonic. The sinusoidal type normally produces only a 3 percent harmonic

Klixon is a very good unit.

QUESTION: You stated that DC line powering caused electrolysis. You have further stated that there is DC in the amplifier. Why doesn't this cause electrolysis in the fittings?

MR. SPRADLIN: Since the DC component is blocked by capacitors it does not go through the fittings.

MR. COOLEY: Any more questions, gentlemen: Well, I thank you very much, Mr. Spradlin. (Applause)

The next paper is entitled, "The Effects of Coaxial Jumpers". Our speaker is the director of Research and Quality Control for Superior Cable Corporation. He was educated at Lenore Ryan College in Hickory, North Carolina. He has a BS degree, major in chemistry, physics and mathematics. He has 3 years in the United States Army in classified work on the Security Agency. Two years in the Shepherd Enterprises, Inc. as a chemist. Ten years in the Superior Cable Corporation as a technician, research and laboratory development engineer. He is presently Director of Research and Quality Control. Gentlemen, Mr. Walter Roberts. (Applause).

MR. WALTER ROBERTS: Thank you. Does everyone have a copy of this paper? "Impedence Discontinuities and CATV Cables". The paper itself, which I hope you'll have time to read in more detail later and which I won't try to discuss in complete detail, begins with an introduction of why uniformity in CATV systems is important. And, I'm sure you folks can tell me more reasons it's important than I can tell you. In fact, I was in the transmission line of business quite a while before I found out broadbanded didn't have anything to do with an all-girl orchestra.

But, in this little paper some of the factors affecting uniformity and coaxial cable plan are discussed. There is no attempt made to at least directly describe the effects of non-uniformities in associated electronic equipment, except for some graphs which I hope to show you on combined effects.

Demands for improvements in signal transmission uniformity have probably been experienced in every CATV system operating today. The need for upgrading existing service through additional channels has oftern exposed system non-uniformities which were not at all obvious while carrying only a few channels. Similar problems have become evident only after initiation of color transmission. In recent years, new systems involving longer cable trunk runs have shown effects from irregularities which would probably have gone undetected in shorter runs.

Some of the factors affecting uniformity in coaxial cable plant are reviewed in this paper. Except for the effects on cable impedance characteristics, no attempt is made to describe nonuniformities in associated electronic equipment inserted into the cable system. Most of the descriptions are based on the effects the discontinuity produces on a transient pulse along the line. These are much easier to visualize than in the case of steady-state alternating currents and, anyway, the two modes are completely correlated mathematically.

the effect of impedance discontinuities on steady-state operation is best determined through input impedance measurements (and calculations). Input impedance of the line may be measured at a particular discontinuity or it may be at a point along the cable remote from the location of the nonuniformities. The performance of the line, or its deviation from normal, is determined by the impedance it exhibits at a frequency or band of frequencies.

Also presented are charts showing relationships between cable impedance uniformity and attenuation uniformity. These are shown both for the case of discrete discontinuities and for the case of periodic, distributed discontinuities along the cable. These two sources do not result in equivalent impedance deviation attenuation relationships.

"

One of the most common source of discrete discontinuities in trunk cable results from the use of jumper cables, usually at amplifier locations. Actual test data showing effects on return loss and transmission uniformity are given for some typical jumper - amplifier combinations. Also displated are curves showing effects of moisture in connectors at these junctions and, particularly, the frequency dependence of these effects.

Single and Double Impedance Discontinuities Consider a "long" coaxial cable whose impedance is uniform along the length but which abruptly increases to a larger value at a single point, then remains uniform over the remainder of the length. The cable is "long" in both directions from the discontinuity.

Assume a positive polarity pulse is traveling at the velocity of propagation of the cable and suppose it passes through the junction into the larger impedance portion of the cable. At the junction some of the energy is reflected back toward the origin. Encountering an impedance increase at the junction, the reflected pulse is also of positive polarity and its shape is a replica of the pulse just as it encountered the junction. (The pulse shape may be distorted from its original shape but this is a result of attenuation and phase distortion while traveling from the point of origin along the cable.) The magnitude of the pulse is proportional to the impedance change . . for small impedance differences. In the extreme case of an increase in impedance (i.e., an open circuit) all of the energy is reflected.

If the pulse were traveling from the opposite direction and thus encountered n an impedance decrease, the only difference from the above case would be that the polarity of the reflected pulse would become reversed. In the extreme case of a short circuit, again all of the energy would be reflected but the voltage amplitude at that point would be zero.

Instead of one, imagine two discrete impedance increases separated a short distance from each other but otherwise located a long distance from either cable end.

Again, assume a positive pulse traveling from the smaller toward the greater impedance section of cable. A portion of the energy is reflected from the first junction without polarity reversal and an additional portion is similarly reflected from the second junction. If the transit time of the pulse between the two junctions (round trip) is small compared to the time duration of the pulse, then the amplitudes of the two reflected pulses tend to add together. As the separation between junctions increases (or if the width of the pulse is decreased), the two reflections tend to resolve into distinct pulses.

If a signal of positive and negative pulses alternating at a fixed frequency is applied to this cable, a special case arises where the pulse transit time between discontinuities is comparable to the time between successive pulses. When the junction separation and pulse repetition rate are such that a pulse returns to the first junction just as the next pulse reflection occurs (a quarter-wave section) the two reflections tend to subtract by virtue of their opposite polarity. If the distance between junctions were doubled (producing a half wave section), a reflected pulse would return to the first junction at the instant a reflection of like polarity had occurred at the first junction. Thus the amplitudes add to each other and produce a very pronounced effect under this set of circumstances.

Another form of double discontinuity occurs when an impedance increase is followed by a second junction at which the impedance decreases. Here polarity reversal of a pulse occurs at one junction and the two reflected pulses tend to cancel when the transit time between junctions is small compared to the pulse duration. As the separation between junctions increases, the time delay becomes sufficient that separate reflected pulses are resolved.

For a repetitive set of alternating pulses as described previously, the results applied to this case must be interchanged because of the polarity reversal; i.e., reinforcement of the reflections occurs for a quarter-wave section, subtraction occurs for a half-wave section.

One other variation of the double (increase-decrease) discontinuity which is of practical importance can arise when two short (compared to the pulse width) double discontinuities occur separated by a distance comparable to the quarter or half-wave sections already discussed. Two double discontinuities representing impedance increases (or decreases) affect repetitive alternating pulses much as in the case of the stairstep type discontinuity just discussed. Pairs of double discontinuities changing in opposite directions are similar to the double (increase-decrease) discontinuity. In such cases as these, the resultant reflected pulses are not replicas of the incident pulse shape.

Many combinations of these discontinuities can be conceived but the preceding illustrate some of the more common forms encountered. A simple rule for visualizing results of various combinations of discontinuities is to remember that phase reversal accompanies reflection from a decreasing impedance junction -- no reversal from an increasing impedance junction.

Input Impedance Deviations The input impedance of a line containing discontinuities can vary radically over even a narrow band of applied frequencies. In fact, measurement of input impedance deviations of cables provides one of the most sensitive known means of detecting discontinuities. The most common technique employs swept-frequency equipment and results are usually reported as return loss in decibels or as VSWR (See Table I). In practical work only the modulus of the input impedance deviation is determined.

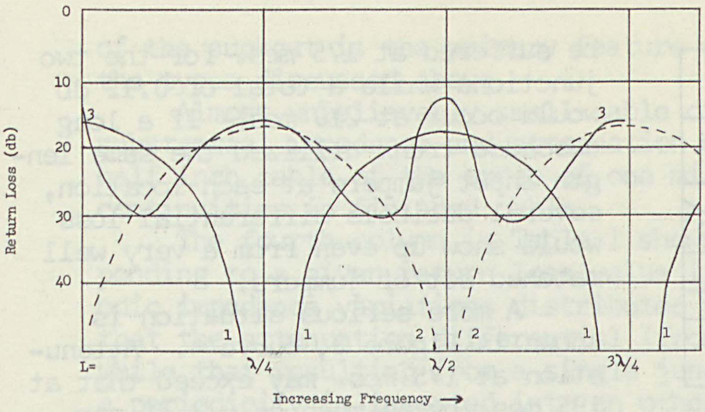
TABLE I

Return Loss (db)	VSWR	Reflection Coefficient	Attenuation Deviations Periodic (%)*	Attenuation Deviations Junction (db)
1	17.15	0.890	860	6.8
5	3.56	0.562	92	1.7
10	1.93	0.316	23	0.45
13	1.57	0.224	11	0.22
16	1.38	0.158	5.0	0.10
19	1.25	0.112	2.5	0.056
21	1.20	0.090	1.6	0.036
24	1.14	0.063	1.0	0.020
27	1.09	0.045	0.5	0.006
30	1.064	0.031	0.2	0.004
32	1.057	0.025	0.1	0.003

*At the "resonant" frequency of the cable periodicity.

A single impedance discontinuity along an otherwise uniform cable produces an input impedance deviation whose modulus is constant even though it contains non-constant real and imaginary components. Naturally the magnitude is a function of the size of the impedance step at the junction. But it is also a function of the distance between the junction and the point of measurement. If this distance is too great, the effect on input impedance is small even for large junction steps. The reflected energy is attenuated on the way back from the junction and therefore produces little effect at the point of measurement. This particular effect, incidentally, is responsible for one major limitation of the use of return loss measurements to determine cable uniformity -- the method is sensitive only to discontinuities located near the ends accessible for measurement.

Figure 1 (next page) shows impedance deviation (return loss) for several combinations of double discontinuities as measured from a point along the cable not too far away.



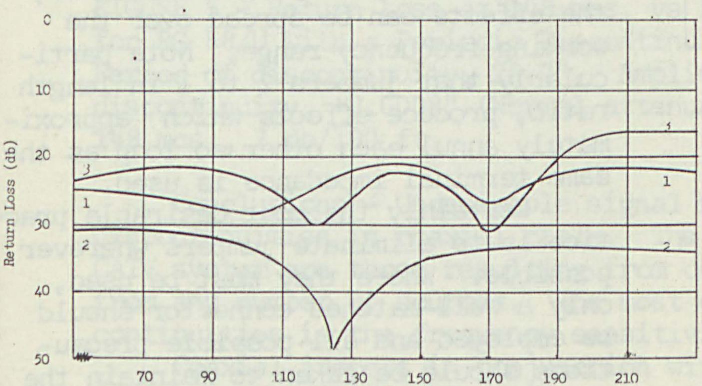
Increasing Frequency

FIGURE 1 - Calculated Return Loss vs Frequency of Various Double Discontinuity Cable Sections. (1) 90-ohm cable, 75-ohm section L, 60-ohm cable; (2) 90-ohm cable, 75-ohm section L, 90-ohm cable; (3) 125-ohm cable 75-ohm section L, 60-ohm cable.

Curve number 3 in Figure 1 is of special interest -- the magnitudes of the impedance steps are not equal. At no frequency does the impedance deviation become zero. Complex variants of such curves as this are the rule while idealistic curves such as numbers 1 and 2 are seldom encountered in system measurements. As in the cases described for alternating pulses, oppositely directed discontinuities result in interchanged input impedance deviations - compare curves 1 and 2.

Terminations at electronic devices may exhibit mismatches which act in conjunction with nearby discontinuities to produce double discontinuities generally showing characteristics of some of the pairs jus discussed. In the following section are presented details of just such effects.

Coaxial Jumper Cables - Though it is highly desirable to avoid the use of jumper cables in CATV systems, conditions arise where the practice cannot be avoided. However, the chances for creating a substantial double discontinuity are provided by the terminal equipment and conditions in the connector or splice. The use of an impedance matched connector avoids the more obvious source of mismatch at this junction but environmental conditions (such as the presence of water in the connector) can readily spoil the matched connection. Input and output terminals of typical amplifiers show substantial impedance deviations which also vary considerable over the working frequency range.



Frequency (mcs.)

FIGURE 2 - Return Loss vs Frequency - Amplifier Input with 18" Stub Cable. (1) Amplifier Input (SKL 222A), (2) Solid PE dielectric 75-ohm 18" jumper cable, (3) Ampl. Input incl. 18" jumper, with dry 75-ohm "N" connectors.

The combination of moist connectors and amplifier terminals can produce some startling effects. Figures 2 and 3 are drawn from data measured on actual jumper cable-amplifier combinations. The amplifier specifications indicate better than 20 db return loss, a fact which was substantiated by measurement. However results as poor as 17 db (Figure 2) were obtained with jumper cable-connector combinations which measured 32 db minimum before connecting to the amplifier input. As can be noted in Figure 3, extremely poor return loss values can result when the connector has been moistened.

The effects on an operating system can be better compared if the actual attenuation component resulting from a particular value of return loss is selected from Table I. For example, in Figure 2, a total of 0.026 db would be suffered at 175 mcs. for the two junctions while a total of 0.12 db would occur at 210 mcs. If a long cascaded trunk utilized the same length input jumpers at each location, several decibels differential loss would show up even from a very well matched set of jumpers.

A more serious situation is shown in Figure 3, curve 4. Attenuation at 175 mcs. may exceed that at 195 mcs. by as much as 0.2 db per output location. Six or eight decibels of differential attenuation could accue in a long run. Furthermore, transient dry and moist conditions can cause unpredictable and quickly changing differentials. Obviously this would represent an intolerable situation and most certainly the moisture must be eliminated.

If jumper cable lengths are to be limited to less than a quarter wave length, their utility is lost. A solid polyethylene dielectric jumper would be limited to less than about 8 inches at 210 mcs. Figure 4 illustrates one means of reducing the frequency sensitive results which would accrue with a large number of equal length jumpers. By deliberately varying the lengths, the effects can be spread over the working frequency range. Note particularly that jumpers 2 to 1 in length ratio, produce effects which approximately annul each other so long as the same terminal impedance is used.

Certainly the most desirable practice is to eliminate jumpers wherever possible. Where they must be used, only a well-matched connector should be employed and all possible precautions should be taken to maintain the connector dry and physically stable.

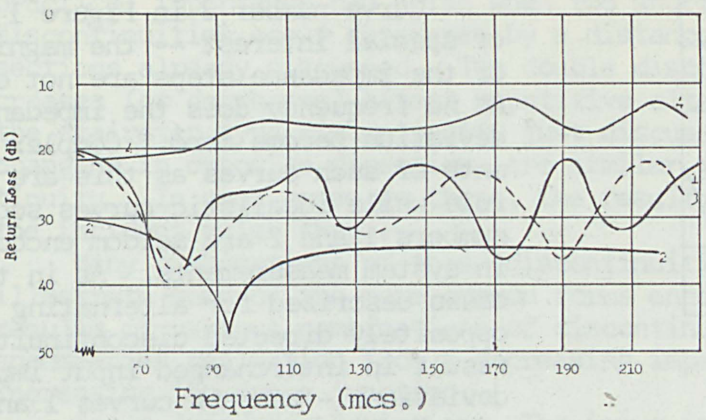


FIGURE 3 - Return Loss vs Frequency - Amplifier Output with 24" Jumper Cable. (1) Amplifier Output (SKL 222A), (2) Solid PE dielectric 75-ohm 24" jumper, (3) Ampl. Output incl. 24" jumper, with dry 75-ohm "N" connectors, (4) Same as (3) except connector moistened with water.

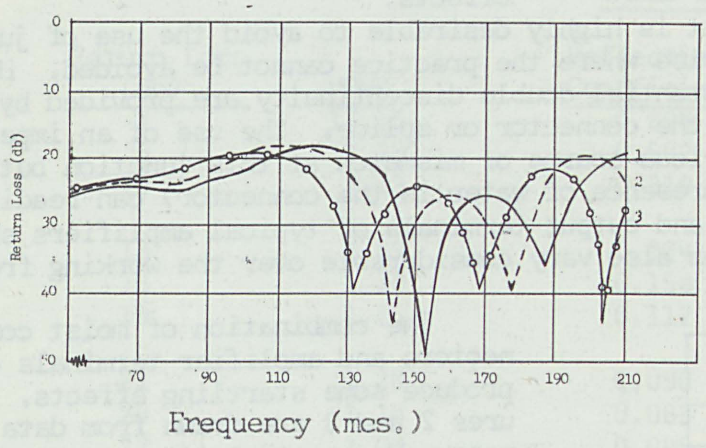


FIGURE 4 - Return Loss vs Frequency for Various Length Jumper Cables Connected Through Half-Step Equalizer (SKL 499) to Amplifier Input (SKL 222A) (1) 12" solid PE dielectric jumper cable, (2) 18" solid PE cable, (3) 24" solid PE cable.

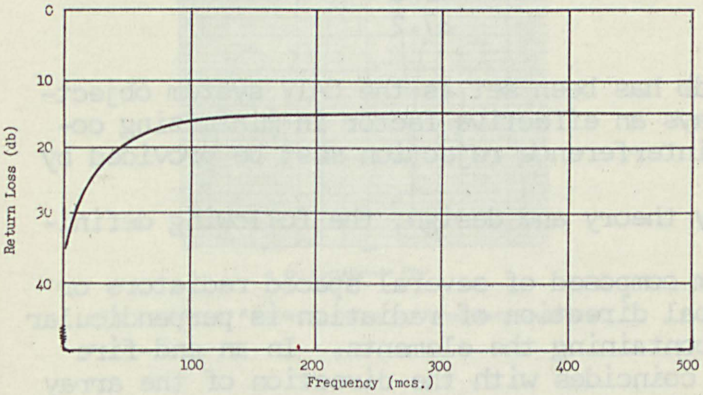
Cable Periodicities - An impedance change does not have to occur abruptly to produce a discontinuity and accompanying reflections. Smoothly changing cyclic variations in local impedance along cable lengths have plagued cable manufacturers at almost every stage of cable fabrication. The resulting effects on input impedance and transmission properties are, in principle, much as has already been described for discrete discontinuities. At a frequency for which the impedance variation period equals a half-wave section, the input impedance increases and a significant increase in attenuation occurs for extreme cases.

At the frequencies encountered in CATV systems, these discontinuities (or suckouts as commonly termed) occur over very narrow frequency ranges - in the order of a couple megacycles. The impedance variations, cycling every few feet, can repeat several hundred or thousand times throughout a cable length. In practice, the narrow band width of the suckout is the primary feature distinguishing this type of discontinuity from the types discussed above.

Almost unbelievably small cable diameter variations, if periodic, can cause a substantial impedance and attenuation discontinuity. Cable diameter variations in a half inch cable of the order of one mil (0.001") can cause intolerable impedance discontinuities in finished cable.

The fourth column in Table I shows the percent variation in attenuation corresponding to a given return loss value if the impedance deviation resulted from periodic impedance variations distributed uniformly along the length of the cable. Noticee that the attenuation differential (from normal) is proportional to the cable length while that resulting from a single junction is a fixed quantity. If a cable containing a periodicity is inserted into an otherwise uniform system, the distributed attenuation excess would occur and, in addition, junction reflections would occur at the terminal ends of the cable because of the mismatch in input impedance at that band of frequencies.

Figure 5 shows another trait exhibited by a cable with a periodic impedance discontinuity. The effective value of the return loss increases with cable length only over a limited length. This is natural because the attenuation of the reflected energy farther down the length prevents a substantial contribution to the energy reflected from points nearby. A single discontinuity located a reasonably short distance from a cable end can produce the same apparent return loss as would a set of small but periodic discontinuities. Yet, if these should persist, the small variations can accumulate a large attenuation discontinuity while the effect of the single discontinuity would have been negligible by comparison.



Length (feet)

FIGURE 5 - Return Loss at 148 mcs. vs Length for RG 58/U with a Periodic Discontinuity. Period of discontinuity, 26.7". Amplitude of discontinuity, ±0.0008" (Normal attenuation at 148 mcs., 7 db/100 ft.

Conclusions - Undesirable signal reflections occur from all sources of impedance discontinuities in coaxial cable. The most serious sources of reflections for the CATV system are those resulting from double discontinuities which, in turn, arise from any number of sources. The most objectionable problem created by double discontinuities is the frequency sensitivity of the input impedance.

Coaxial jumpers in conjunction with equipment terminal impedances can result in serious double discontinuities in trunk runs, particularly if all jumpers are of equal length. Staggered jumper lengths and well matched and protected connectors will alleviate problems of this source.

For a given input impedance deviation, periodic impedance variations in a cable can produce far more serious attenuation variations than would a single or double discontinuity.

Thank you. (Applause)

MR. COOLEY: Thank you, Mr. Roberts. The next subject on the agenda is "A New Antenna for CATV" and our speaker is a graduate of Mississippi State University with a BSEE. He did graduate work at Southern Methodist and worked for Ling Temco, All Products Company and Scientific Atlanta. He has published papers on a high gain space telemetering array and engineering report on a high frequency rotable log periodic operation.

When a leak is indicated, repairmen are dispatched to the approximate location. The actual break is located by a device which sprays a soap solution onto the cable. As the spray passes over the hole, the escaping air causes a foaming action that is visible from the ground.

Another type of leak detector that was recently developed makes use of an ultrasonic translator which picks up the sound of the air escaping from the holes in the sheath. These sounds are very high in frequency, in the 35,000 to 45,000 cycle range which are converted into audible sounds by the translator and heard in a headset receiver. A barium-titanate detector probe is used on a carriage arrangement to pick up the ultrasonic frequencies.

Removing Water from the Cable

When water has gained access through a sheath opening and causes trouble, there is no alternative but to remove it.

To remove water by evaporation merely by pumping dry nitrogen or dry air through the cable is impracticable because the cable section may contain a large quantity of water plus the fact that a large (224 cubic foot) cylinder of nitrogen or equivalent volume of dry air will only evaporate four or five tablespoons of water at 60 degrees F.

A method for removing water from cable has been developed utilizing acetone, a liquid which mixes completely with water in any proportion. A cable section containing water is flushed with acetone until the discharge liquid indicates a low water content. Then as much of the acetone as possible is forced out in liquid form and the remaining acetone is evaporated with nitrogen. Acetone has a low boiling point of 133 degrees F and, therefore, evaporates much more readily than water.

There are certain precautions, however, associated with the use of acetone. Since it is a volatile and combustible liquid comparable to gasoline, flames or sparks must be avoided. Prior to injecting acetone into the cable, nitrogen should be pumped into the section to purge the cable of oxygen, thereby minimizing the possibility of creating a combustible mixture of air and acetone.

Moreover, since acetone is a mild cracking agent to polyethylene, and since it will attack polyvinyl chloride, it is imperative that all acetone be removed from the cable section after the water is flushed out.

MR. TAYLOR: Thank you very much, Rudy. Our next speaker is talking on a very important problem. Mr. E. Mark Wolf, Assistant to the Vice-President of Engineering with the Rome Cable Division of ALCOA. Mr. Wolf.

MR. E. MARK WOLF (Assistant to the Vice-President of Engineering, Rome Calbe Division of ALCOA): Well, I think someone, and probably our good friend Mr. Taylor, deserves a high compliment for the efficiency of this setup. I have talked to a lot of people about underground cable, but this is the first time I've gone underground to do it. (Laughter) Maybe it's a good idea. But I guess we're here because we all have in common an interest in the problems of going underground with CATV; I think any list of problems probably has somewhere near the top the cost of such an installation and its reliability. These are both problems and important problems, but they should not be approached with fear and with worry, because we believe that underground CATV systems can be both reliable and economical.

We'll have a look here, a very short look, at some of the very extensive experience that exists, the background of engineering experience that exists, the background of engineering knowledge that goes with it in the manufacture and the use of underground power cable and underground telephone cable. And, I think we will see that much of this knowledge and experience is directly applicable to our problems in CATV.

In the CATV system construction field there are few subject which generate so much real concern as that of underground cable installation. Most of this concern centers around two areas; either fear that an underground system will prove unreliable and costly to maintain, or a conviction that initial cost will be unreasonably high. We do not believe that either of these worries is justified, and hope that by explaining to you our reasons we can help you to sleep a little better the next time the subject of going underground confronts you.

First of all, underground cable installation is not new. Power companies and telephone companies have been installing cable underground for many years. Thirty or forty years ago these installations were very costly, and some of them gave trouble. But in the past decade there have been remarkable changes in both cable design and installation techniques. Today, both cable cost and installation cost are drastically lower, and underground installations are giving very reliable and trouble-free service experience. Utilities are able and willing to cope with, and in some areas even to promote, complete underground systems.

It is worth examining the accumulated engineering knowledge and experience in putting power and telephone cables underground, since much of this knowledge and experience is directly applicable to CATV cables.

In St. Louis, Missouri, in April 1964, the Institute of Electrical and Electronics Engineers (IEEE) sponsored a three-day technical conference on Underground Residential Distribution. Over 30 technical papers were presented and discussed at this meeting, by engineers from power companies, telephone companies, cable manufacturers, transformer and accessory manufacturers. IEEE have bound these papers into a volume which can be purchased. This compilation records in detail the practices and experiences of the nation's leading utilities and manufacturers in providing underground power and communication services to residential neighborhoods. It is recommended to you as a reference book for underground techniques.

In applying this knowledge and experience to our own problems in putting CATV services underground, we should first examine the CATV cable itself to be certain that the construction used is adequate for the underground environment. We are talking about the modern low loss coaxial cable, with an inner copper conductor, foamed polyethylene dielectric, and an outer aluminum conductor (sheath).

Foamed polyethylene must not be exposed to the wet underground environment. This is true whether the cable is to be directly buried, or enclosed in conduit or duct. In this respect, foamed polyethylene is similar to the paper insulation long used in both telephone cables and power cables. These insulations must operate in a dry, stable environment, unaffected by external conditions other than temperature. This requirement is nicely met by enclosing the dielectric in a completely impervious seamless aluminum sheath. Aluminum has the necessary electrical and mechanical characteristics, and is more economical than other metals which might be chosen.

The remaining problem is a physical or chemical one, rather than electrical. We have the insulated inner conductor enclosed in a seamless metallic sheath, and thus isolated completely and permanently from external environmental affects, and have only the problem of protecting this sheath from unfriendly environments which might cause damaging corrosion. Practical and economical solutions to this problem exist and have been widely and successfully employed by others.

The protective covering over the aluminum sheath must perform several functions:

1. It must provide an impervious barrier between the sheath and the underground environment.
2. It must be heavy enough and tough enough to withstand handling incident to installation.
3. It must withstand widely varying soil conditions without deterioration.
4. It must withstand exposure to atmospheric conditions, sunlight and weather without degradation.

We know of no material better suited to fulfill these needs than a member of the polyethylene family. Fortunately, the polyethylenes are also more economical for such application than any other materials which might be considered as candidates at present. This may change in the future, since we are always evaluating promising new materials.

Polyethylene can provide the impervious barrier needed. The only requirement, other than freedom from holes, is that it be in intimate contact with the aluminum sheath. The polyethylene jacket must fit tightly so that there are no air pockets or voids between it and the sheath. The presence of an air pocket, under certain conditions, can permit the jacket to act as an osmotic membrane and pass moisture vapor, even though the polyethylene itself will not absorb moisture. Application of a tight-fitting jacket over the aluminum sheath is easily within the capability of modern manufacturing techniques.

Polyethylene is tough enough to withstand a reasonable amount of abuse in handling during installation. It should be handled with care and respect, but certainly not with any "kid glove" techniques. The object is to get the cable in place without any deep scrapes, cuts, or gouges in the jacket.

The thickness of the polyethylene jacket is determined by two factors. One is the ability of modern plastic extrusion equipment to reliably apply a homogeneous, continuous jacket, free from holes or other discontinuities. The purpose of the dielectric, or "spark" test on the jacket is to assure its freedom from such imperfections. This test is usually accomplished in the extrusion line by running the jacketed cable (with sheath grounded) through a charged electrode several feet long. The voltage on the electrode is selected so that if the jacket has holes or thin spots, an arc, or voltage breakdown will occur, and an alarm will be set off.

Diameter Over Aluminum Sheath Inches	Average Jacket Thickness Inches
0 - 0.750	0.050
0.751 - 1.500	0.065
1.501 - 2.250	0.080

Figure 1
Average Thickness of Thermoplastic Jacket over Aluminum Sheathed Cable From IPCEA S-61-402

Fig. 1

The other factor determining jacket thickness is the need to withstand "reasonable abuse" during installation and to withstand the moderate pressure or abrasion from ground movement during period of freezing and thawing, etc. Neither of these requirements is peculiar to CATV cable, and we can use the experience of power cable engineers in determining the proper and safe jacket thicknesses to be used. The Insulated Power Cable Engineers Association publish the most comprehensive wire and cable specifications which we have in this industry. They are highly regarded and widely used by public utilities; They reflect quite accurately the needs of cable users as well as the capabilities of cable producers. These standards specify the wall thicknesses to be used when a thermoplastic jacket is required over an aluminum sheath. The adequacy of these thicknesses is supported by extensive experience with heavy power cables, and we would be foolish not to profit by it.

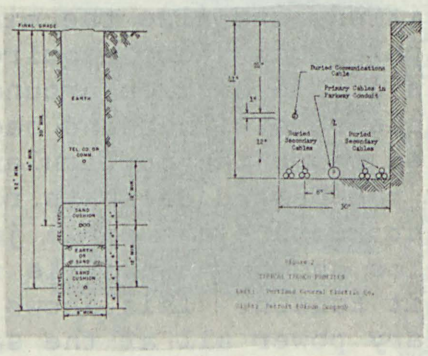


Figure 2
TYPICAL TRENCH PROFILES
Left: Portland General Electric Co.
Right: Detroit Edison Company

Fig. 2

IPCEA standards specify that thermoplastic jackets over aluminum sheathed cable shall have an average thickness not less than than shown in Figure 1.

The type of polyethylene used for this jacket is also important. Polyethylene is a family of materials. Members of the family are all identical chemically, but differ in molecular structure. In the early days of polyethylene the importance of these differences was not completely understood, and there were many cases of underground cable failure. Today the mechanism of these failures is well understood. We now have standard industry tests for environmental adequacy, and it is well known that what we call High Molecular Weight polyethylenes are completely reliable underground. It is interesting to note that this is the type polyethylene used on modern transoceanic telephone cables.

Polyethylene jackets should also contain proper black pigmentation to protect them from deterioration where exposed to sunlight. Such a cable, properly installed, will give many years of reliable and trouble-free underground service.

Now let's examine the meaning of "properly installed".

Here is where things can get a bit confused, because the term has several definitions, depending upon who is making the rules, and what part of the country we are talking about. We will discuss some of the practices in use by various utilities, and the reasons for them. If you become involved in, or are considering underground CATV system installation, you should first find out what the local rules and practices are. The local power company underground engineer is one good place to get this information. You are a customer of his, and he should have an interest in helping you. His background and experience is valuable, and for the most part, directly applicable to your problems.

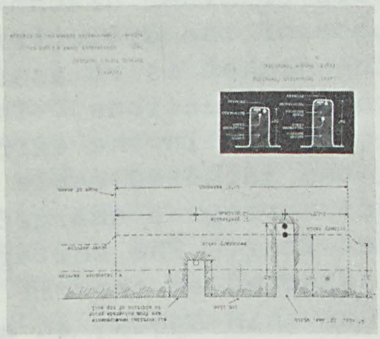


Fig. 3

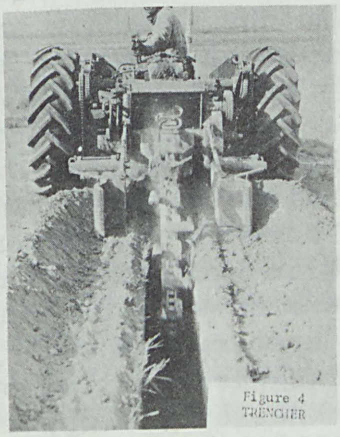


Fig. 4

Fig. 5

Let's look first at the trenching practices in use by several typical utilities.

Figure 2 shows the trench profile specified by Portland General Electric Co. (Oregon). It shows the use of a single trench for primary power, secondary power, and telephone cables, with each class of service at its own level. Note the 12" separation specified, and also the minimum below-grade stipulation. Also required in this instance is a sand cushion around each of the power cable runs. The sand backfill is specified where the particular terrain introduces the hazard of sharp rocks, etc., which might rupture the cable jacket.

Figure 2 also shows one profile required by Detroit Edison. This shows primary and secondary power all at the same level below grade, and again the 12" separation between power and telephone.

Figure 3 is the profile used by Mississippi Power & Light Co. It shows separate trenches for power and telephone cables.

And finally, Figure 3 also shows two profiles used by Commonwealth Edison Co. of Chicago. One shows the 12" separation between power and telephone cable, and the other shows the practice of random lay. In this case, all cables are placed in the trench in a random manner, with no separation between. This provides a substantial saving, since it permits backfilling in a single operation. Which of these practices, or variations of them, may be used will depend on what is permitted by local approving agencies. Random lay is rapidly gaining wide acceptance due to its obvious economy.

Fig. 6

Where the shared trench idea is not feasible, the practices are simpler. Preferably the cable should always be at least 24" below grade. 36" is even better. This largely avoids trouble from accidental dig-ins, from soil bacteria, and from frost heaving. The sand cushion is not necessary unless the terrain has sharp rocks. Trenching equipment comes in many sizes and shapes, as shown in Figures 4 - 7. Some of these are particularly interesting where installation must be made under established lawns or grades. Trenchers are available which open a slit less than 1" wide. Backfill is often not necessary, and the scar disappears in a short time. Also, the trench can follow an irregular path to avoid shrubbery or other obstructions. Depending on the locality, you may find trenching equipment is available locally, on a contract or rental basis. Your local power company is a good place to go for advice on this matter.

Obviously, trenching costs will vary widely, depending upon a number of things. Many power companies figure that under "normal" conditions they can trench and backfill for 30-35 cents per foot. This can run as low as 10 cents, but could also run higher under adverse conditions. The economic advantage of joint trench use is obvious.

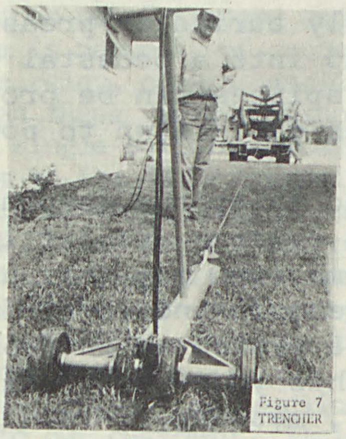


Fig. 7

In recent years there has been intense and increasing interest, for URD systems, in a preassembled cable in coilable plastic pipe. In this construction, the cable, installed in plastic pipe is delivered to the job-site in long lengths on reels, ready for installation. The pipe is made from another member of the polyethylene family, black high-density polyethylene. This material is tough, strong, abrasion resistant, and very economical compared to metallic pipe, or duct of other materials. Use of this system accomplishes several things:

1. It provides a hole in the ground for cable replacement, if ever needed.
2. It protects the cable from damage during installation.
3. It reduces the need for sand cushion in rocky terrain, or for protective planking under roadways.

4. It can provide for possible future expansion.

Fig. 8

At present there are no industry standards for preassembled cable in pipe, but work on such specifications is under way in an industry committee. In the meantime, individual manufacturers, working with power company engineers, have developed workable standards of their own. These standards define the properties and dimensions of the various sizes of pipe, the percent fill to be used in determining the proper pipe size, as well as the various cable constructions to be furnished. Figure 8 shows Rome Cable's publication describing this product and its use for power cable. Experience has provided simple rules for determining proper pipe size to be used with various cable sizes. A number of other manufacturers have similar publications describing their product. This construction should be equally attractive for CATV systems. The added protection given to the cable during installation is a distinct advantage, and in many cases makes installation easier and faster. The built-in hole in the ground can be extremely valuable, particularly where system expansion or cable replacement would otherwise dig up established lawns or rear lot line shrubbery plantings. The added cost for one cable preassembled in pipe would probably be about 8-12 cents per foot. If you choose to buy the pipe and pull it in yourself, you can save about 5 cents of this. One very important principle to remember is that the cable used, whether directly buried or preassembled in pipe, should be suitable for exposure to the underground environment. Whether directly buried or preassembled in pipe, cable terminations should be stubbed up into a pedestal which can be sealed from moisture. Straight-through splices can be protected for direct burial using materials and procedures well known to power and telephone cable manufacturers and users.

An increasing number of power companies and telephone companies are coming to the conclusion that underground cable systems are little, if any more costly, than aerial installations. Some even say that underground is cheaper. They are finding that maintenance and servicing costs are significantly less because the cable is in a protected environment, unaffected by storms, accidents, etc. Add to this your additional savings from elimination of pole rentals, pole hardware, messenger, lashing wire, etc., the economics of underground CATV would not appear to be discouraging. In fact, it may well be almost a stand-off with overhead, without even considering the reduced maintenance and servicing costs. [Applause.]

MR. TAYLOR: Thank you very much, Mark Wolf, for a very interesting talk. This concludes the formal presentations. Thank you very much for coming.

ISBN 0-940272-01-6; 0-940272-08-3; 0-940272-10-5; 0-940272-11-3; 0-940272-12-1; 0-940272-14-8; 0-940272-15-6; 0-940272-16-4; 0-940272-18-0; 0-940272-19-9; 0-940272-20-2; 0-940272-21-0; 0-940272-22-9; 0-940272-23-7; 0-940272-24-5; 0-940272-25-3; 0-940272-26-1; 0-940272-27-X; 0-940272-28-8; 0-940272-29-6; 0-940272-32-6; 0-940272-33-4; 0-940272-34-2; 0-940272-35-0; 0-940272-36-9; 0-940272-37-7; 0-940272-38-5; 0-940272-39-3; 0-940272-40-7; 0-940272-41-5; 0-940272-42-3; 0-940272-43-1; 0-940272-44-X; 0-940272-45-8; 0-940272-46-6; 0-940272-47-4; 0-940272-48-2; 0-940272-49-0; 0-940272-50-4; 0-940272-51-2; 0-940272-52-0; 0-940272-53-9; 0-940272-54-7