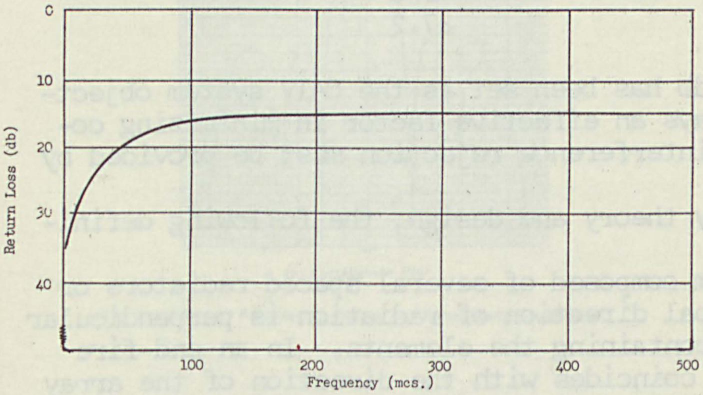
of the suckout is the primary feature distinguishing this type of discontinuity from the types discussed above.

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.

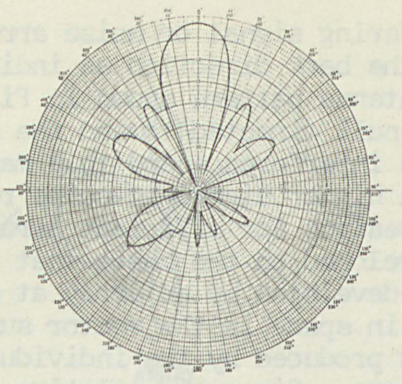
Gain--The ratio of the maximum radiation intensity in a given direction to the maximum radiation intensity produced in the same direction from a reference antenna with the same power input. Gain is frequently used as a figure of merit; it is closely associated with directivity, which in turn is dependent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

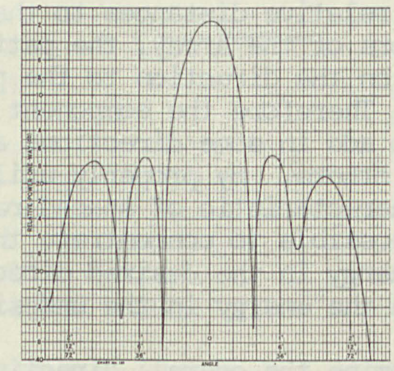
$$G_{iso} = G_{dipole} + 2.15 \text{ db},$$

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:

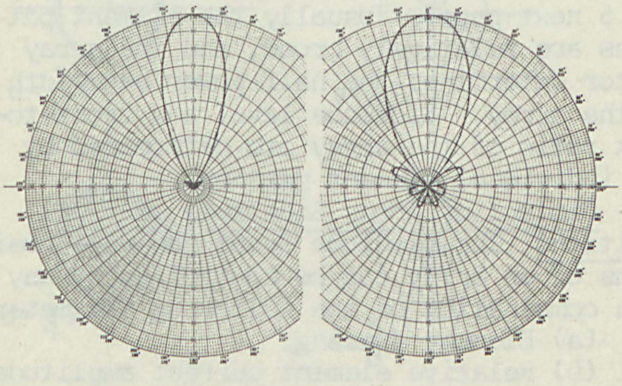


(a) Polar Plot

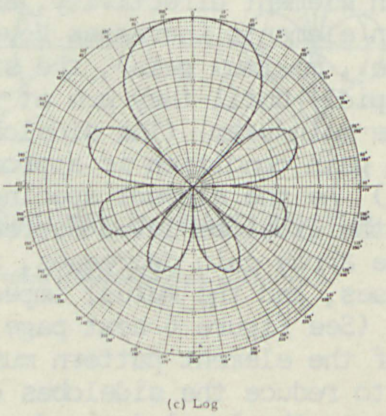


(b) Rectangular Plot

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

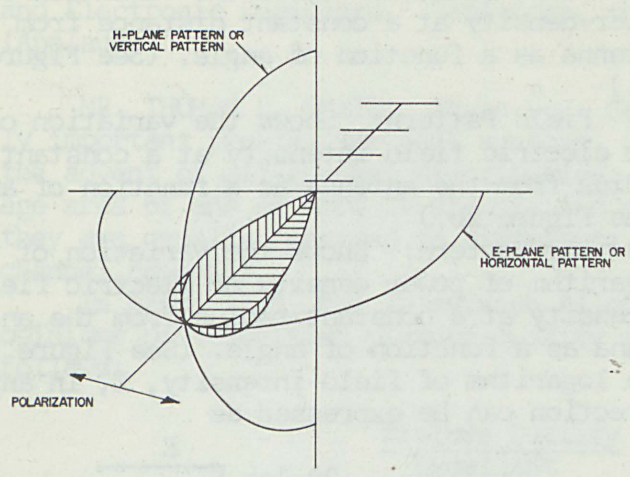
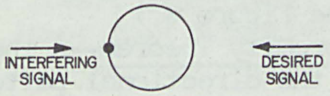
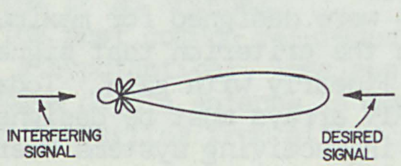


Fig. 3. Antenna Radiation Patterns, E- and H-Plane



(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).

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.

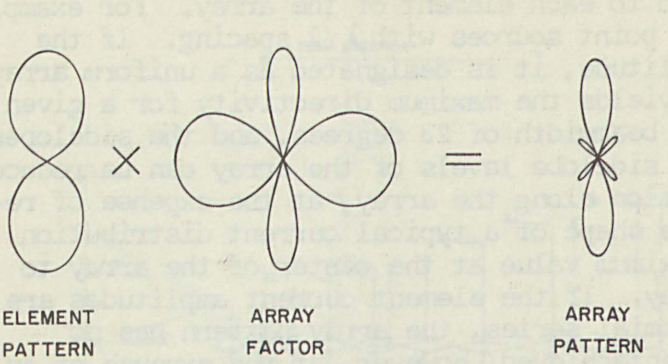


Fig. 5. Pattern Multiplication

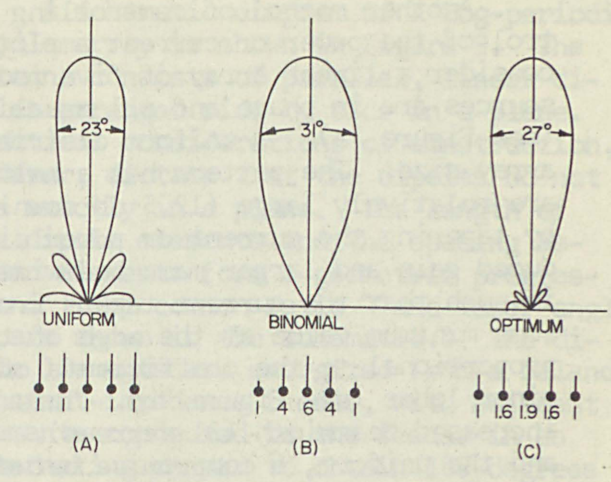


Fig. 7. Control of Sidelobe Level by Current Amplitude. Taken from Antennas, by J. D. Kraus (McGraw-Hill, 1950).

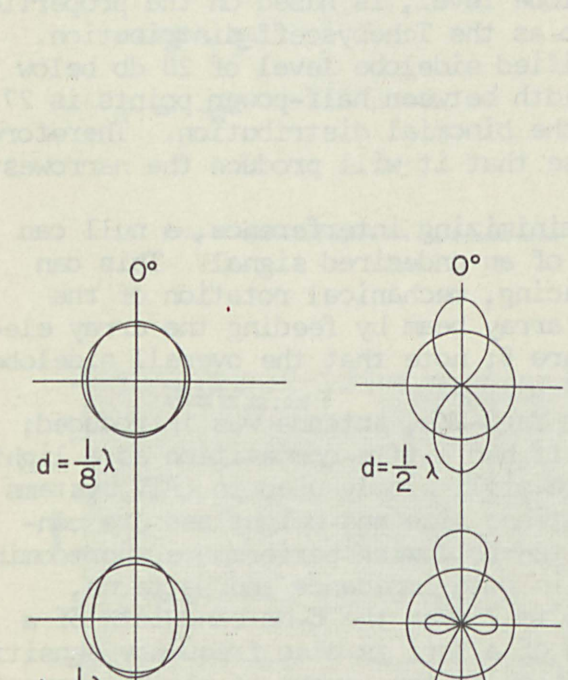
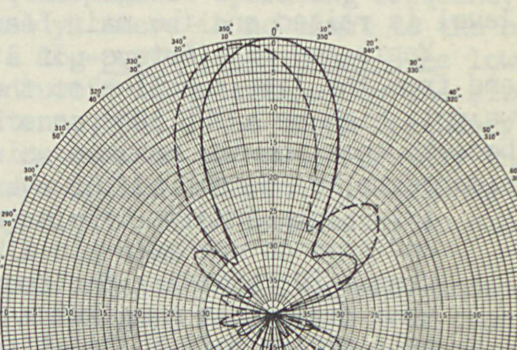


Fig. 6. Effects of Element Spacing on an Array Factor



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.

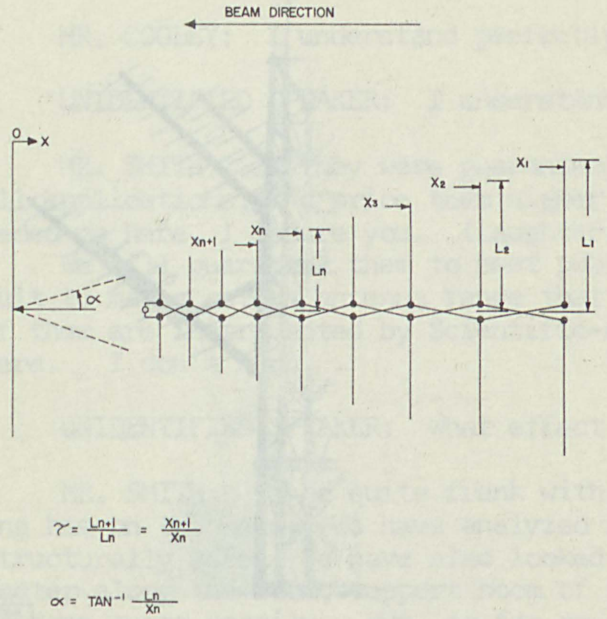


Fig. 9. Schematic Diagram of a Log-Periodic Array

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.

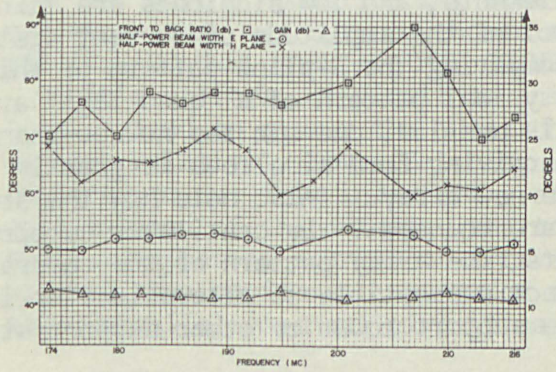


Fig. 10. Performance of Channel 7-13 Antenna

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.

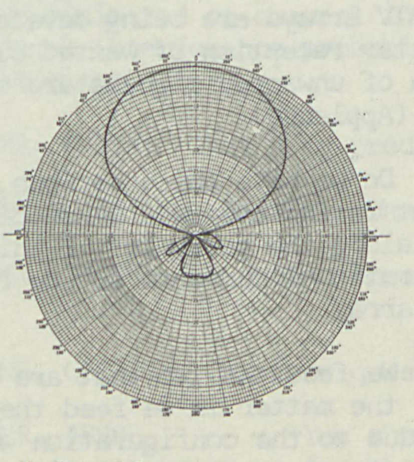


Fig. 11. Typical E-Plane Pattern of Channel 7-13 Antenna

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

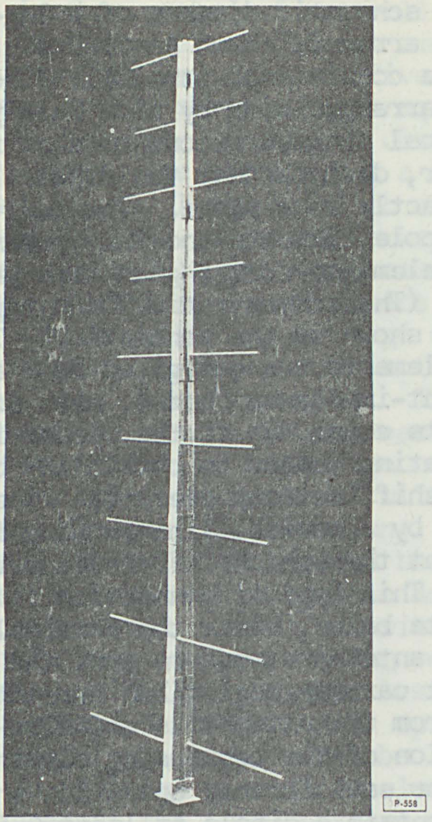
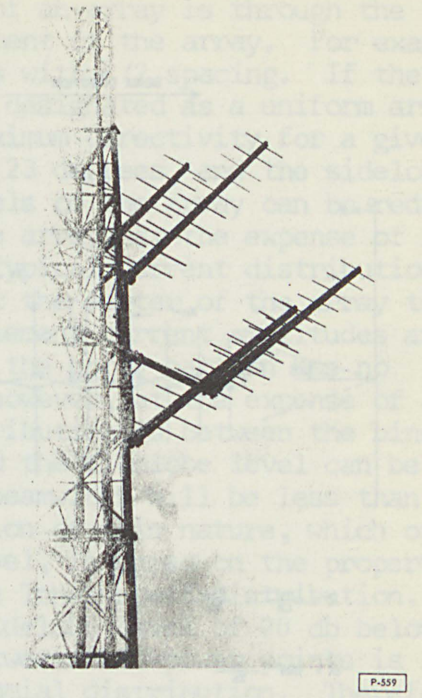


Fig. 12. Channel 7-13 Antenna



Quadrate Channeler Antenna, Installed on Tower

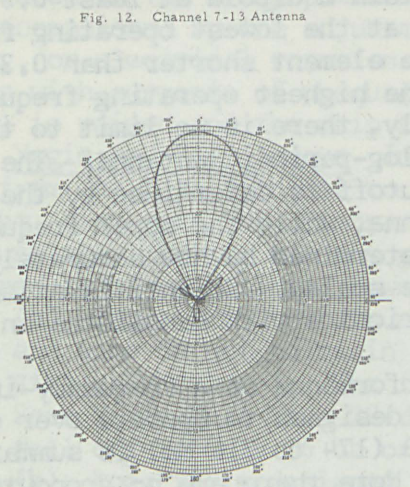


Fig. 14. Typical E-Plane Pattern of Quadrate Channeler

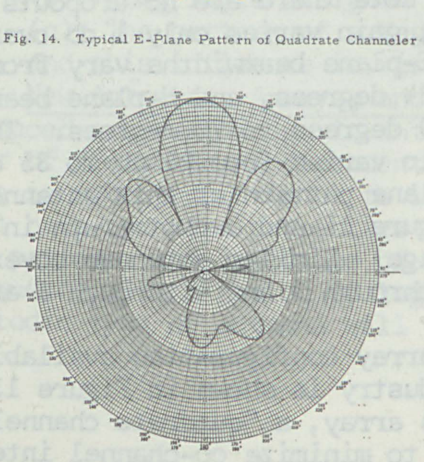


Fig. 15. Typical E-Plane Pattern of Quad-Yagi Array

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.)

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