TECHNICAL SESSION NO. 5:
CATV Antenna Design and Selection

Session Chairman:
Herbert Michels

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

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

ALBERT K. FOWLER

INTRODUCTION

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

FACTORS GOVERNING ANTENNA SELECTION

Some of the more important ones are:

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

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

PERFORMANCE CRITERIA

The most significant electrical performance criteria are:

gain
directivity
bandwidth

Other related factors are:

VSWR
side lobes
back radiation
noise generation

The most significant mechanical performance criteria are:

wind load
ice load
mounting provisions
ease of assembly
packaging configurations

Other factors are:

temperature
humidity
shock and vibration
appearance (aesthetic qualities)

Antenna Types

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

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

Beam Characteristics

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

CHART 1

Antenna	Characteristics
Yagi	Narrow Band Directive High Gain
Log Periodic	Broad Band Fairly Directive Moderate Gain
Parabolic	Narrow or Broad Band Extremely Directive Very High Gain
Corner Reflectors	Narrow Band Fairly Directive Good Gain
Dipole	Narrow or Broad Band Low Directivity
Zig-Zag Broadside	Narrow Band Directive High Gain
Helical	Broad Band Directive Good Gain
Dipole & Reflector	Narrow Band Low Directivity Low Gain
Array Antennas (Arrays of any of the above antenna types)	Narrow or Broad Depending on Basic Radiator Extremely Directive High Gain

CHART 2

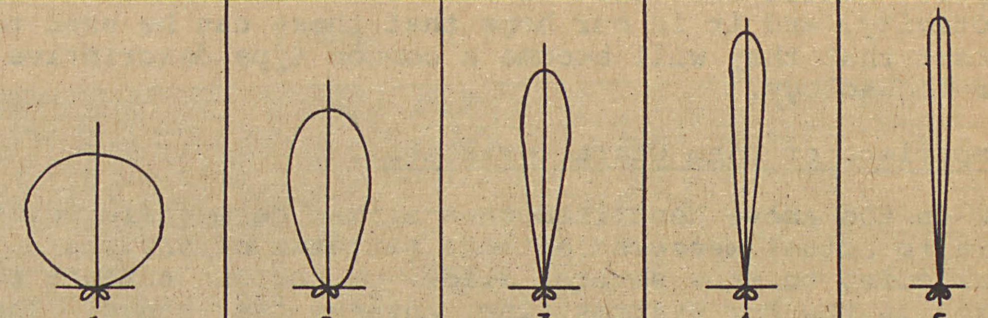
Narrow Band Antennas

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

Broad Band

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

CHART 3



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

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

Comparison of Beam Characteristics

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

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

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

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

ANTENNA PATTERNS OF YAGIS AND LOG PERIODIC ANTENNAS

FIGURES 1 TO 15

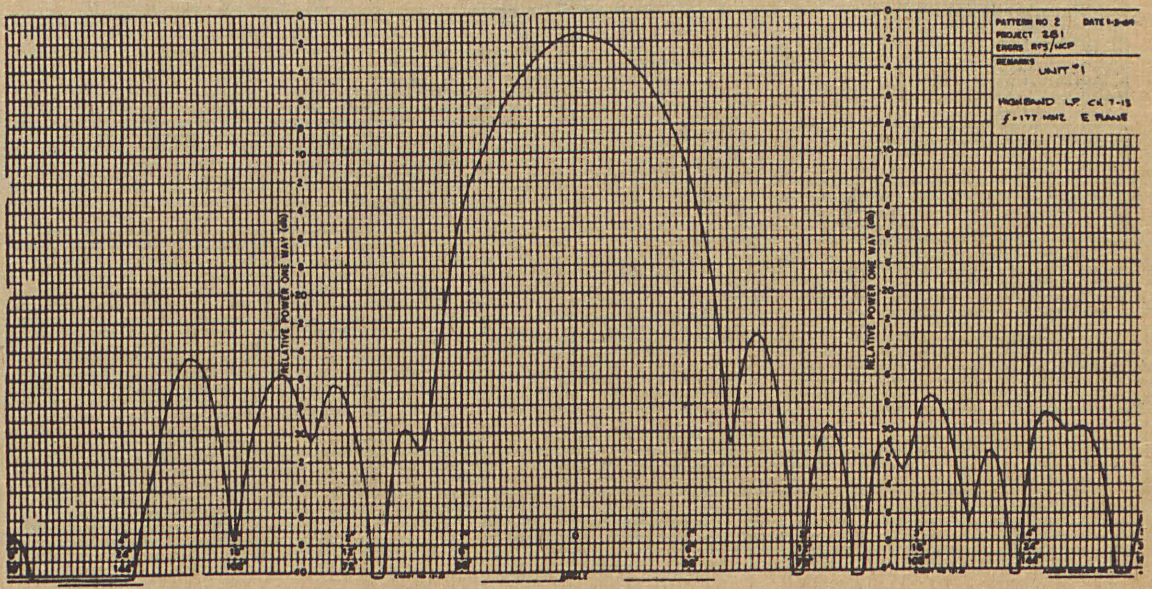


FIGURE 1

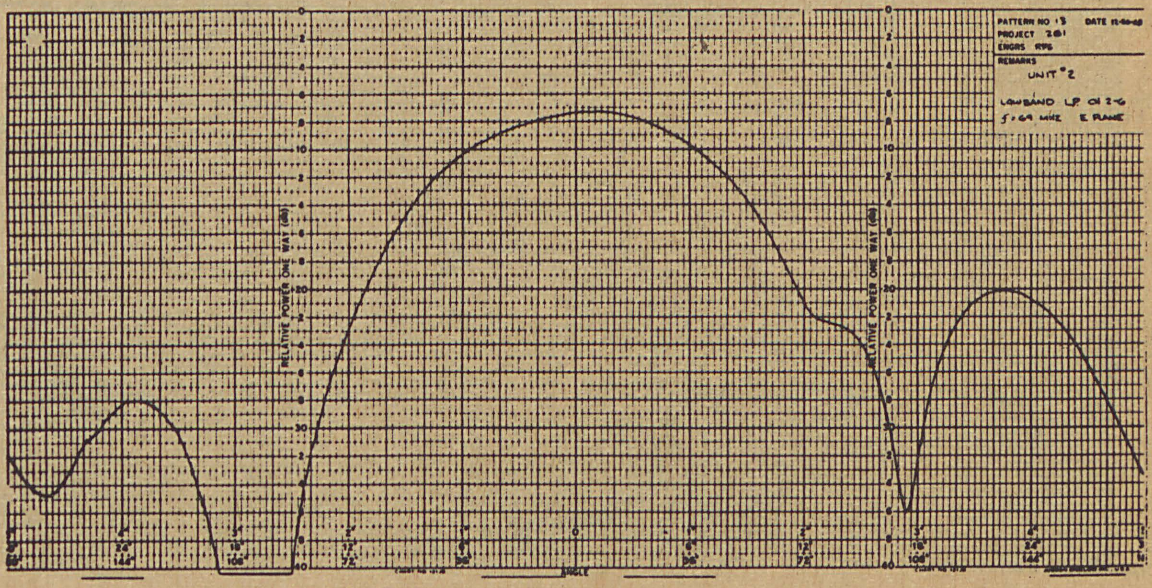


FIGURE 2

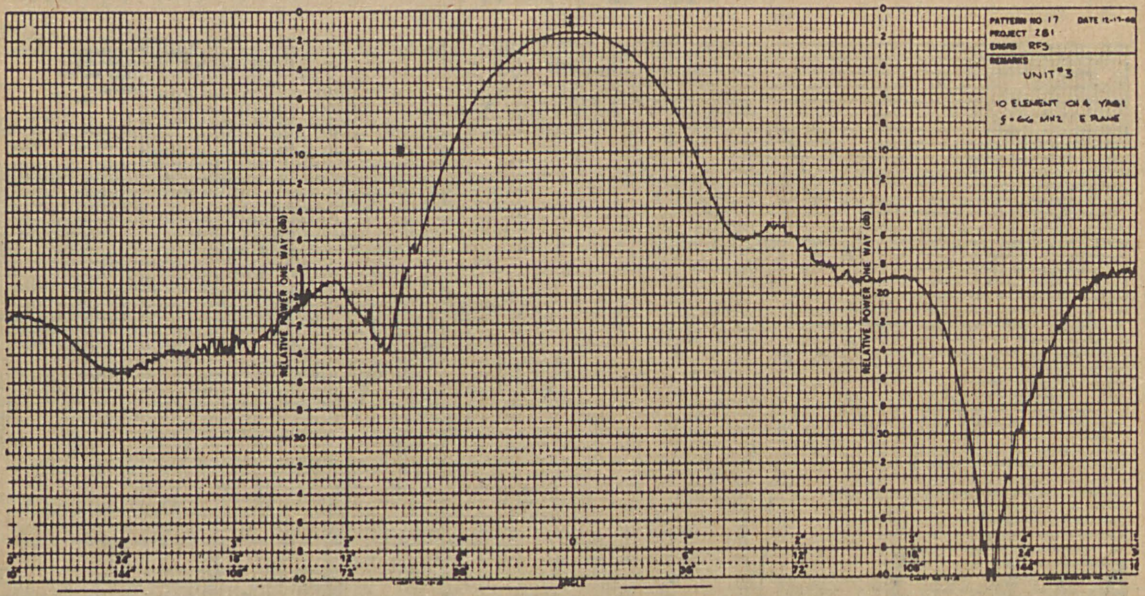


FIGURE 3

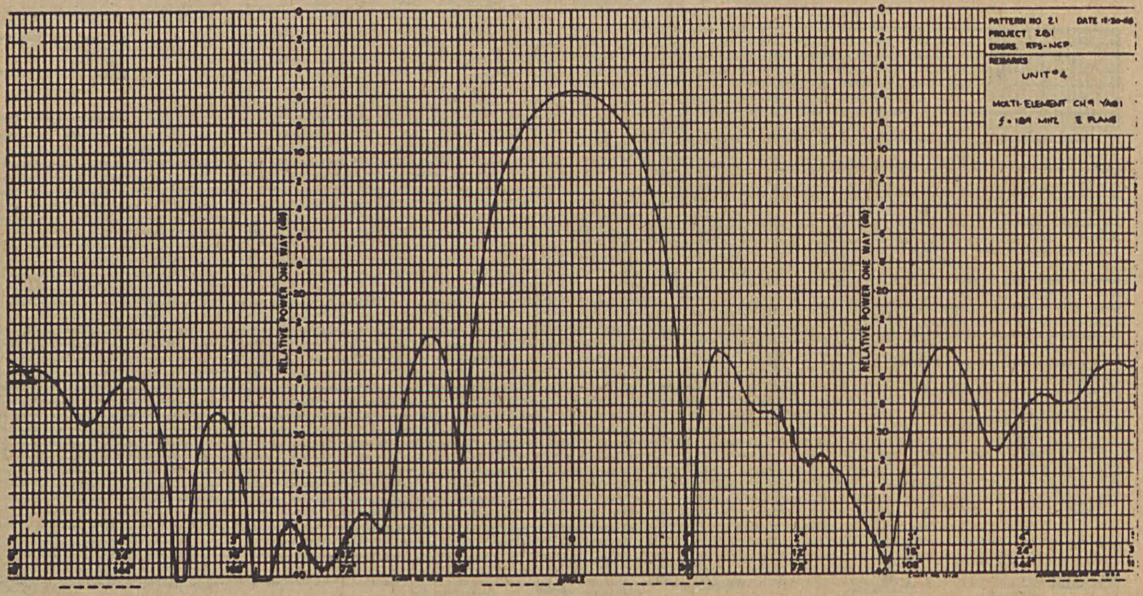


FIGURE 4

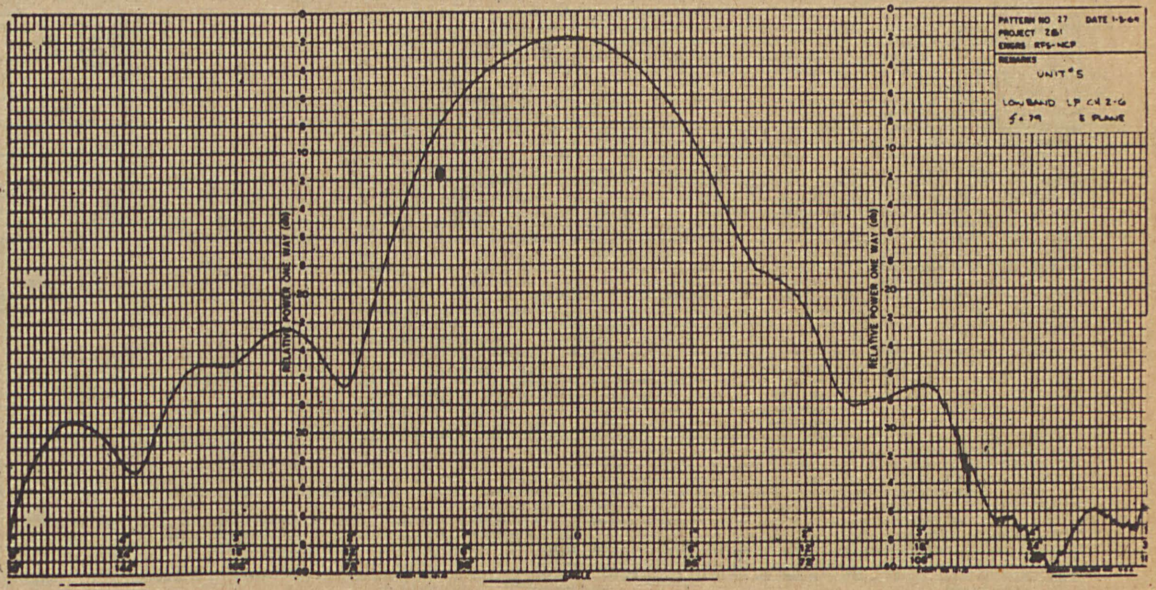


FIGURE 5

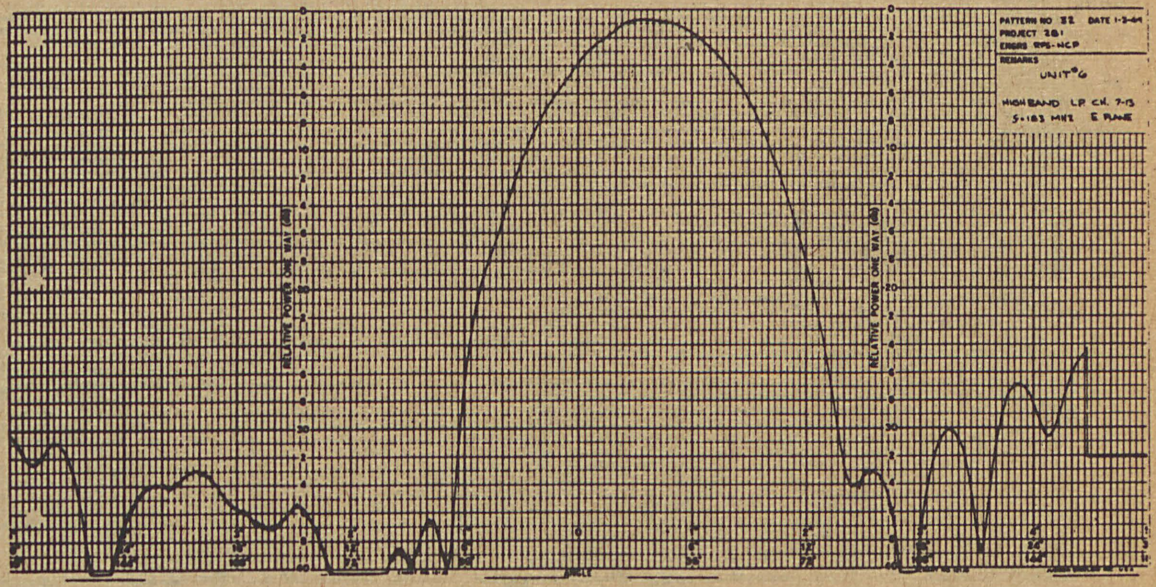


FIGURE 6

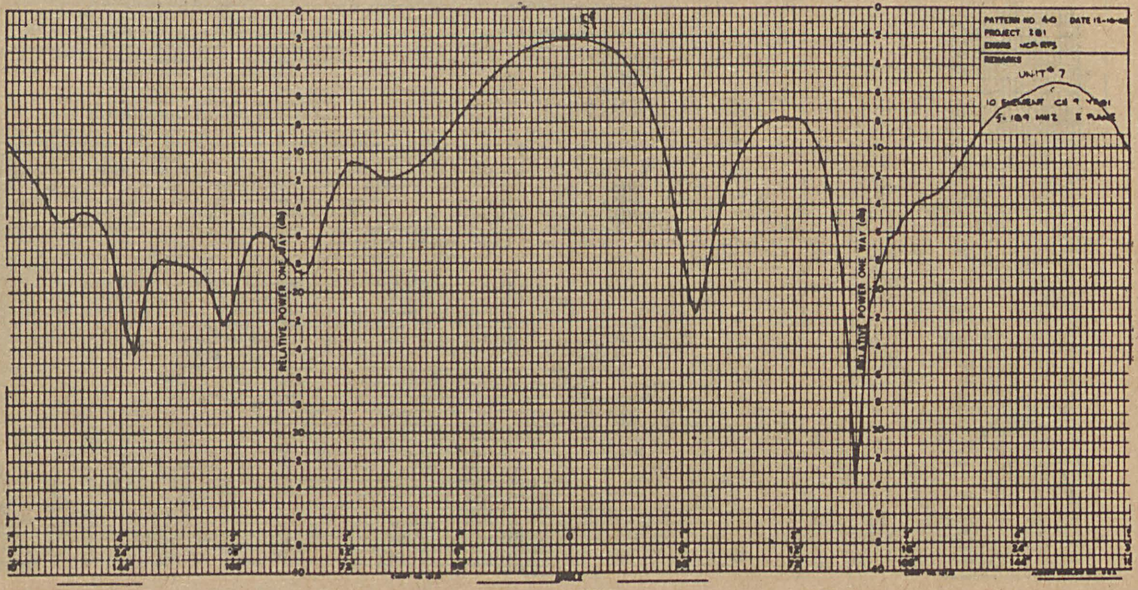


FIGURE 7

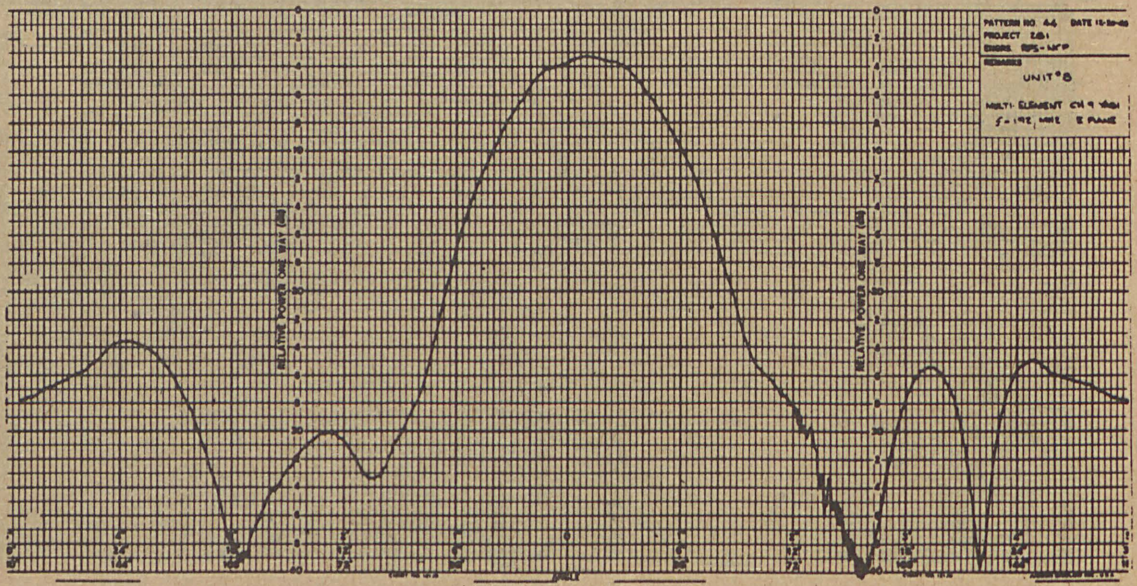


FIGURE 8

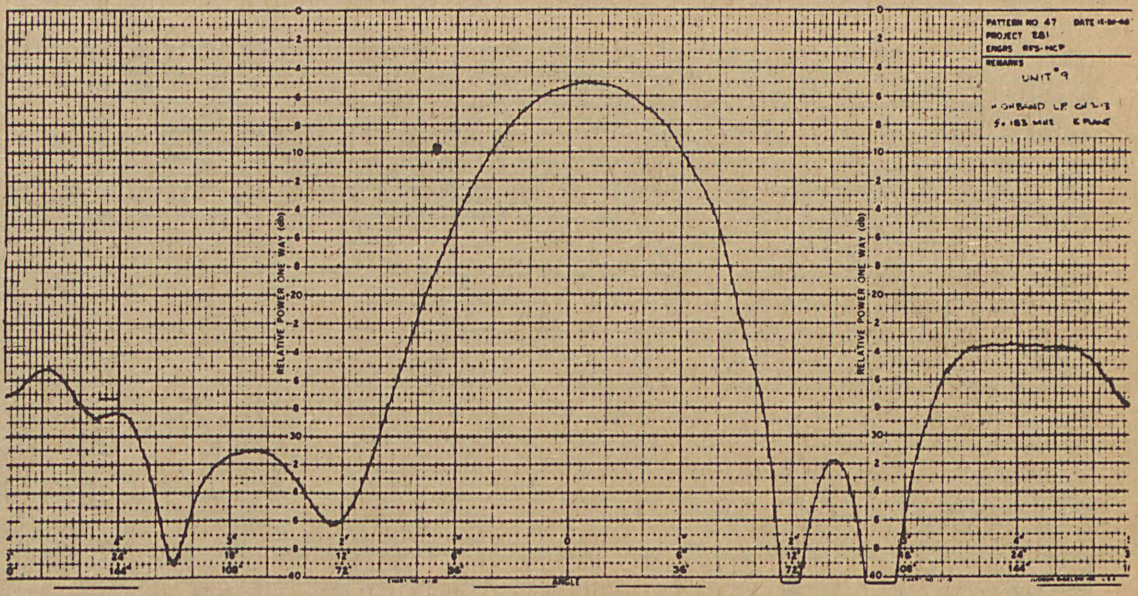


FIGURE 9

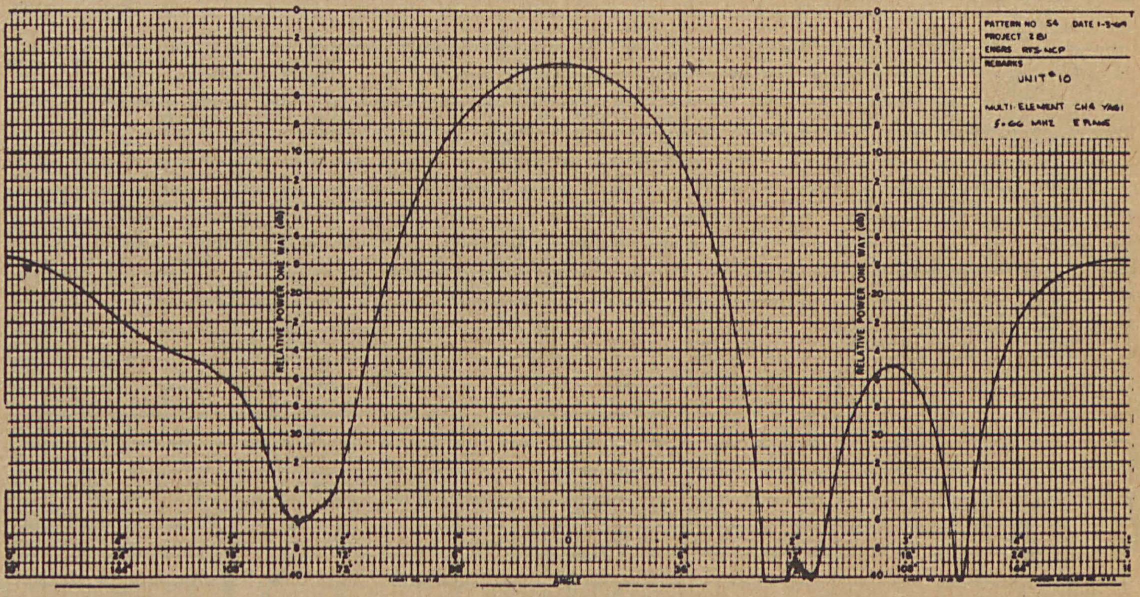


FIGURE 10

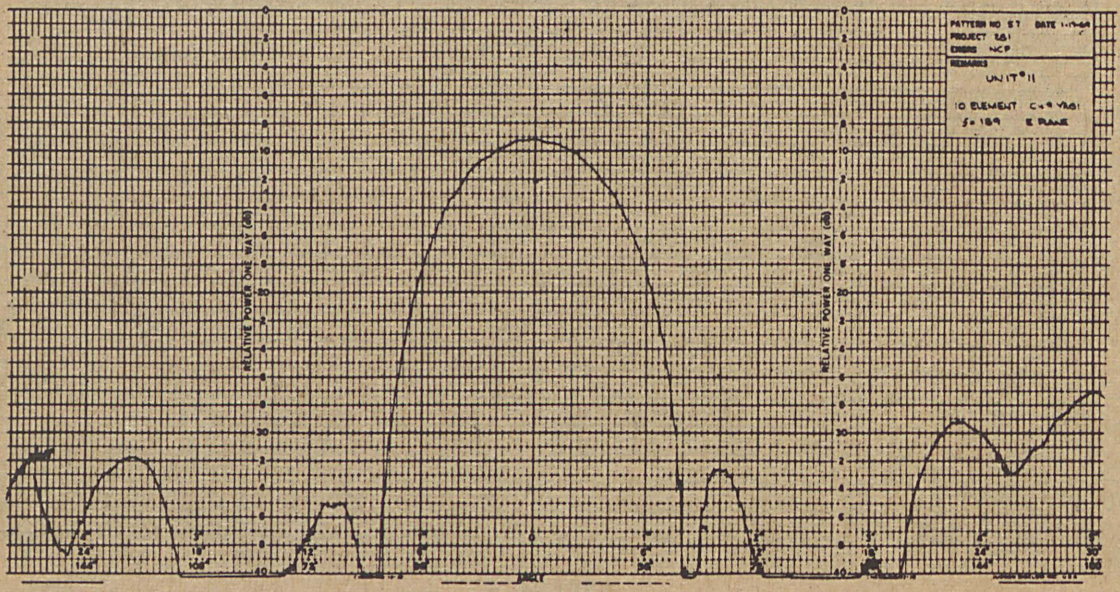


FIGURE 11

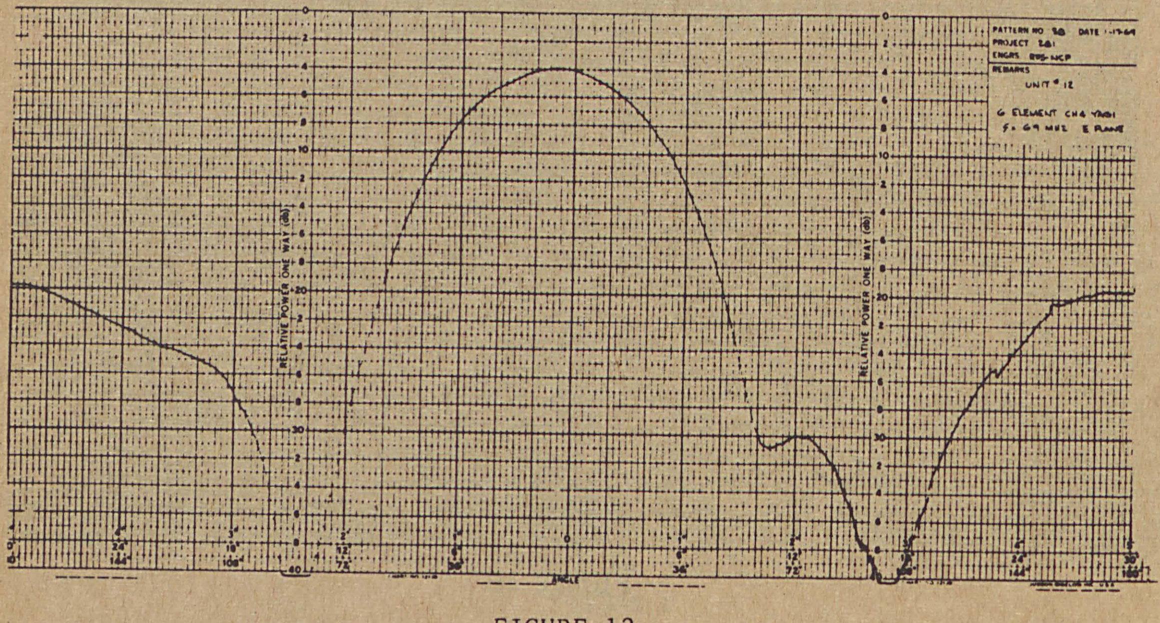


FIGURE 12

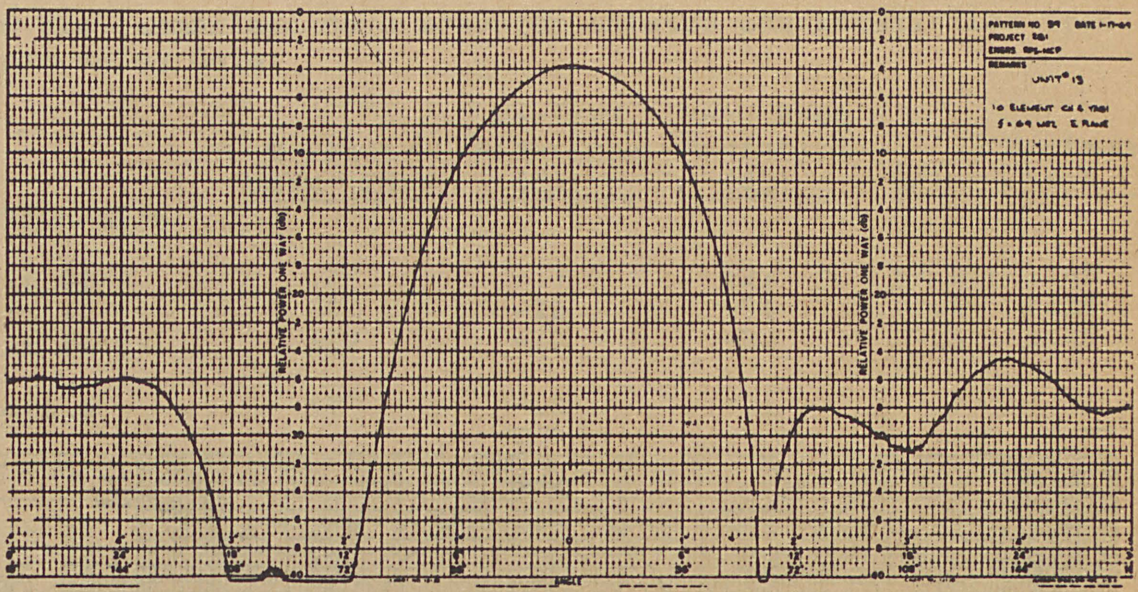


FIGURE 13

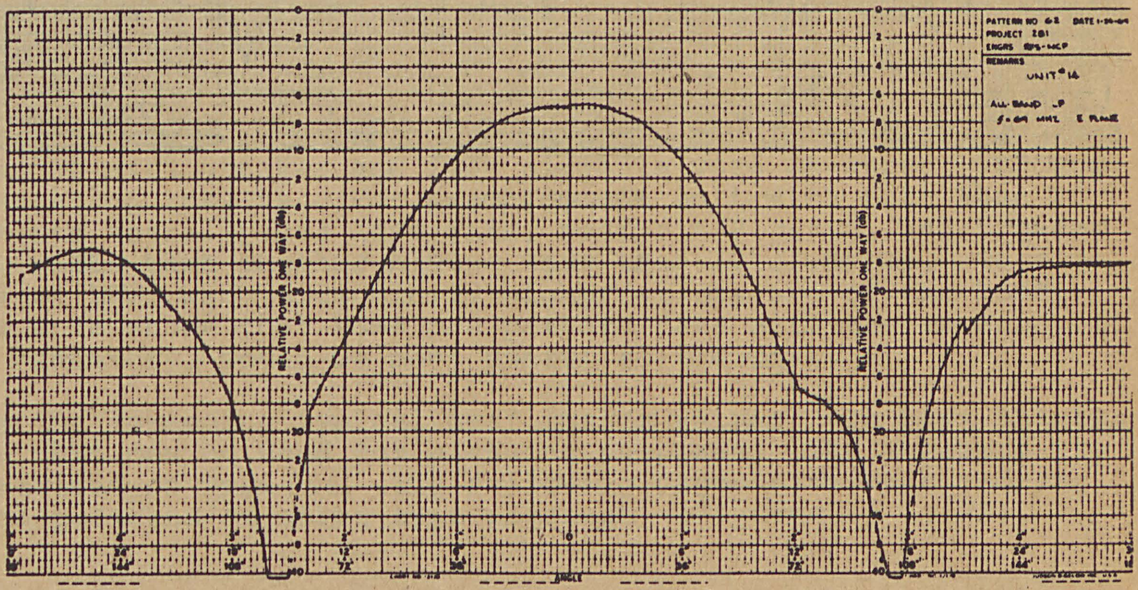


FIGURE 14

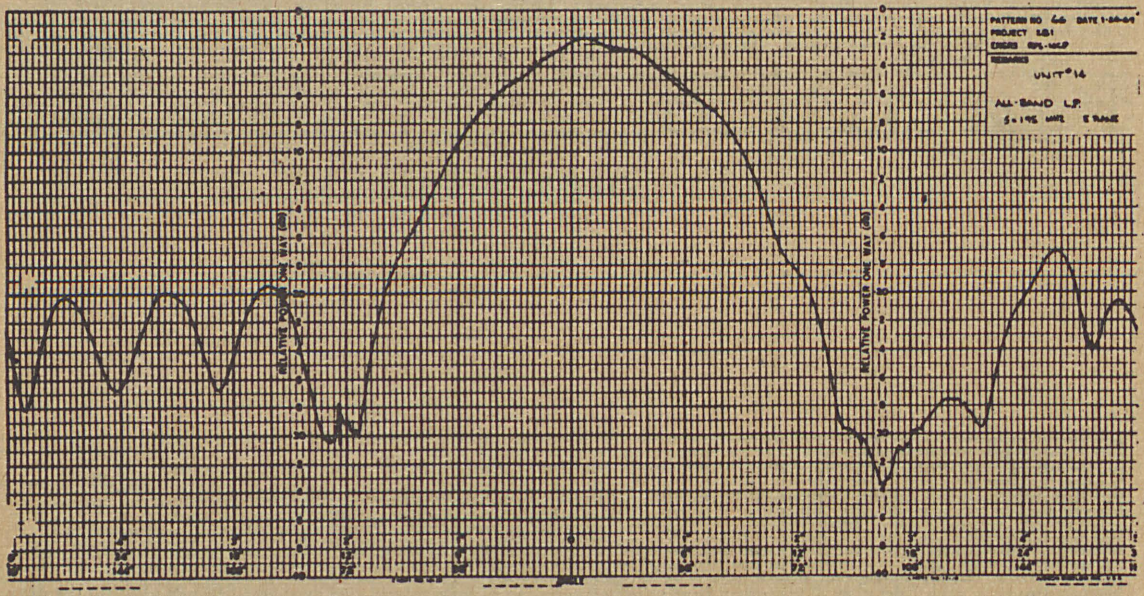

PATTERN NO 66
PROJECT
UNIT #14
ALL-BAND L.P.
RELATIVE POWER ONE WAY (DB)
RELATIVE POWER ONE WAY (DB)
ANGLE

FIGURE 15

Summary of Measured Antenna Characteristics

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

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

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

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

PATTERNS OF 30 FT. ASTROSCAT PARABOLIC ANTENNA

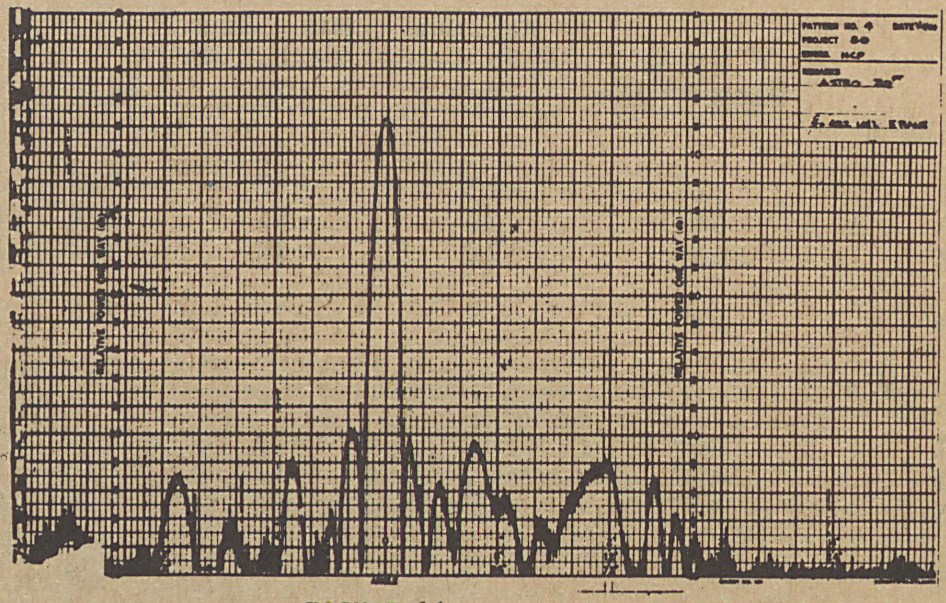


FIGURE 16

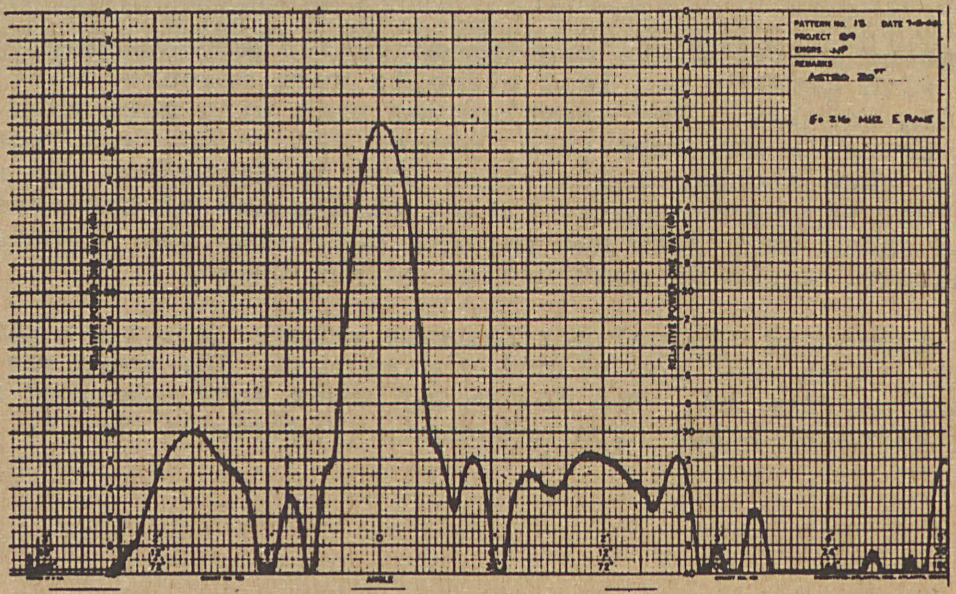


FIGURE 17

PATTERN OF ZIG-ZAG ANTENNA

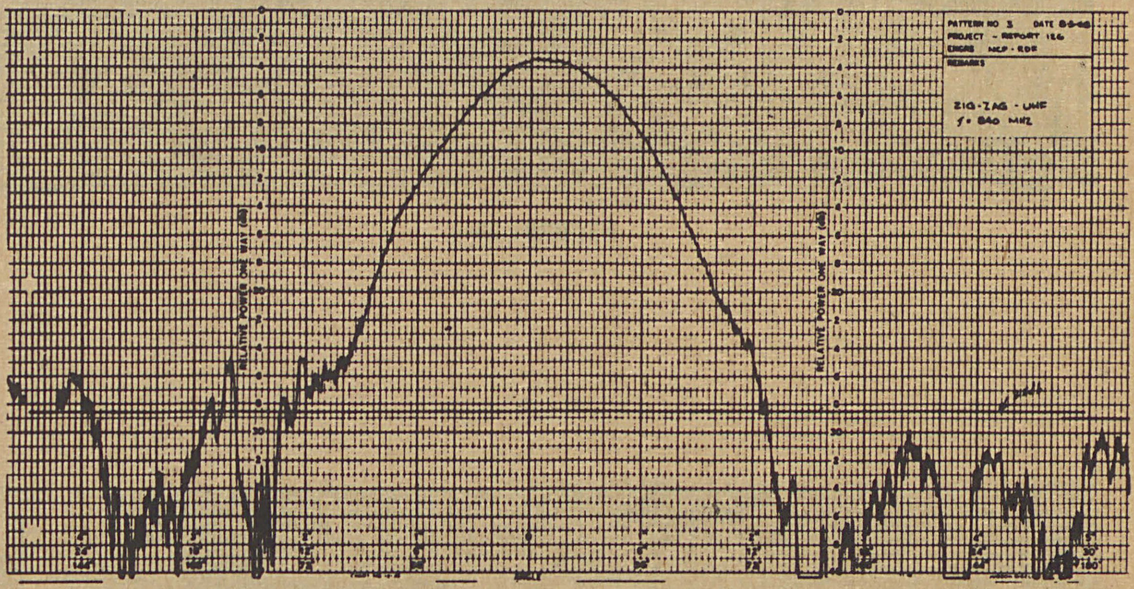


FIGURE 18

PATTERNS OF VHF CORNER REFLECTOR ANTENNA

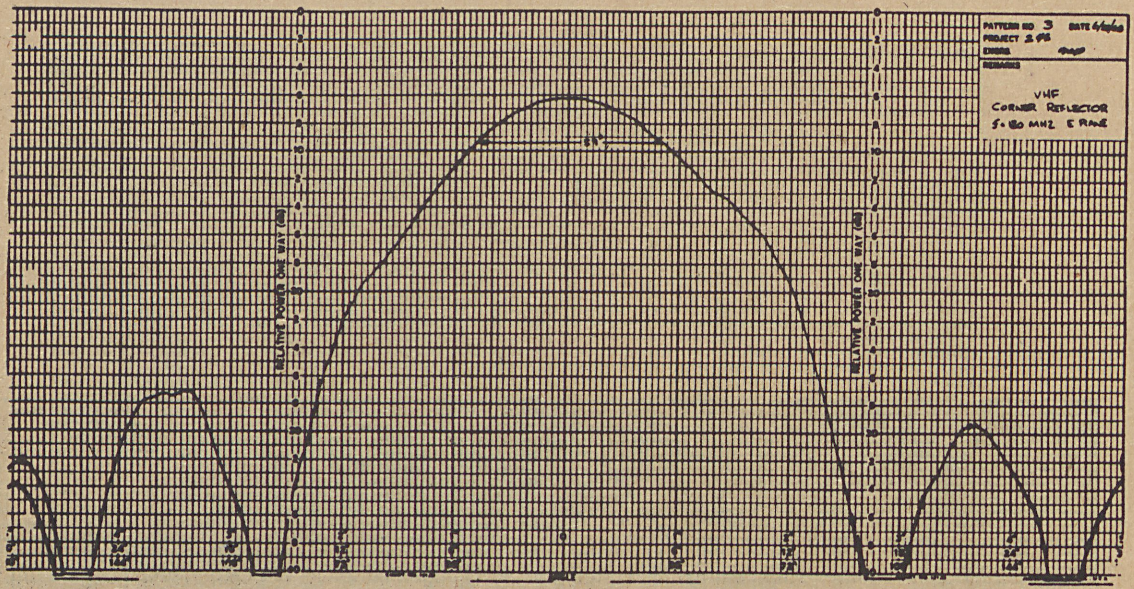


FIGURE 19

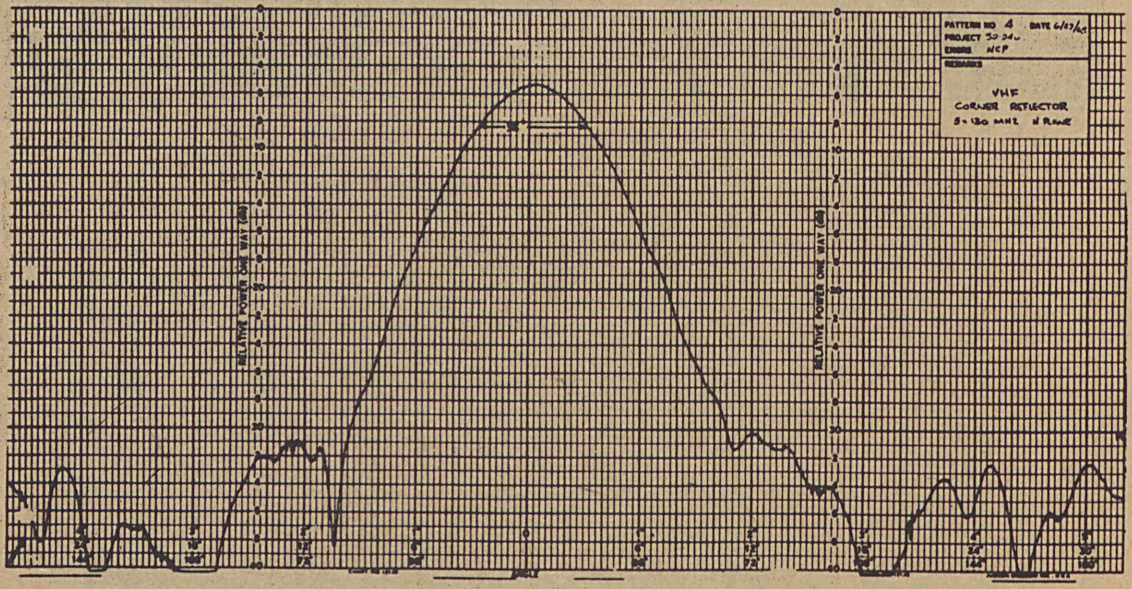


FIGURE 20

PATTERNS OF UHF CORNER REFLECTOR ANTENNA

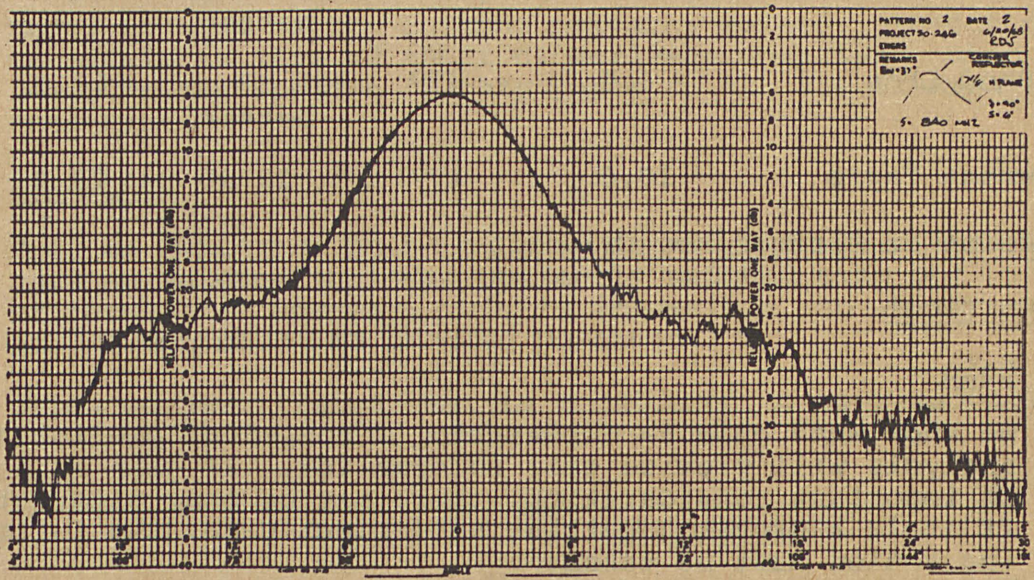


FIGURE 21

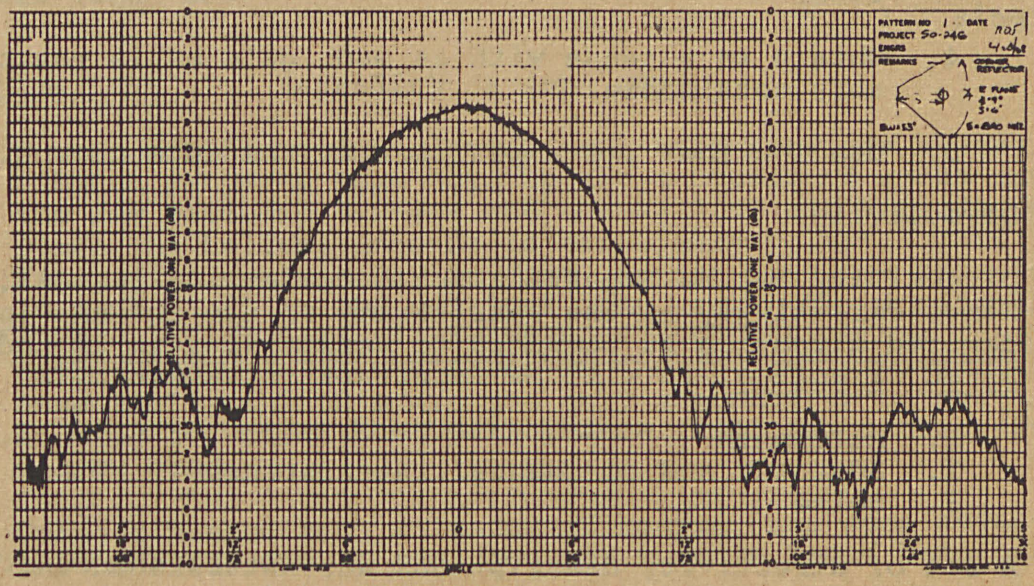


FIGURE 22

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

Discussion of Performance Criteria

Electrical

Gain

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

1. Minimize all line losses by selecting line with lower loss characteristics.

2. Use individual channel pickups to eliminate splitting losses.

3. Make site measurements to pick the best site location.

4. Obtain an antenna with as much gain as is reasonably obtainable.

5. Use low loss pre-amplifiers at the antenna end.

Directivity

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

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

A set of directivity descriptions was established in Chart No. 3. To effectively use directive antennas, the problem must be defined. Once it is defined, you may set about to obtain an antenna to do the job. If one is not available, a special array of antennas may be designed to solve the problem. In antenna requirements of this type, measured antenna patterns are highly recommended.

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

Bandwidth

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

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

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

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

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

VSWR

Typical VSWR's are listed in the preceding paragraph.

Side Lobes

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

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

Back Radiation

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

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

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

Noise Generation

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

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

Mechanical

Windload

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

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

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

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

Ice Load

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

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

Mounting Provisions

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

Ease of Assembly

An important aspect of antenna design is the assembly process. For the simpler antennas, this usually does not represent much of a problem, and most manufacturers are submitting equipment which is readily assembled in the field. Some of the more sophisticated antennas may become a little complicated in their assembly; however, usually if the assembly instructions are followed to the letter, little difficulty will be encountered.

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

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

Packaging Configurations

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

Temperature

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

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

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

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

The Use of Antennas in Arrays

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

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

Array Fundamentals

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

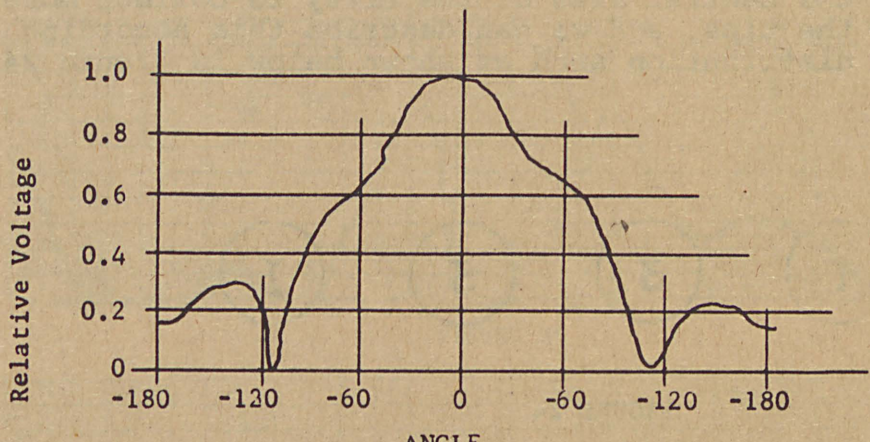


FIGURE 23

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

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

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

For a four element array:

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

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

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

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

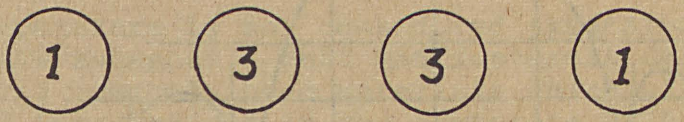


FIGURE 24

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

Array Illustration

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

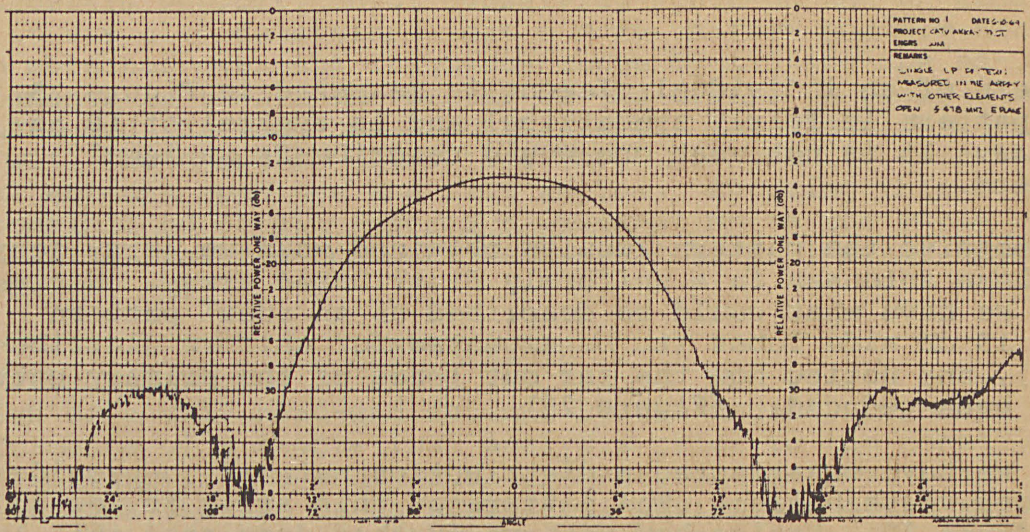


FIGURE 25

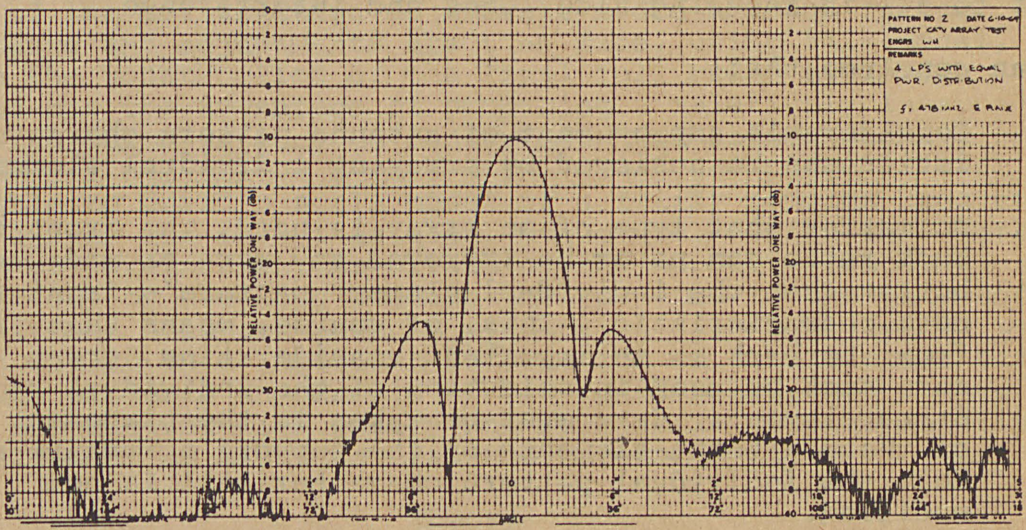


FIGURE 26

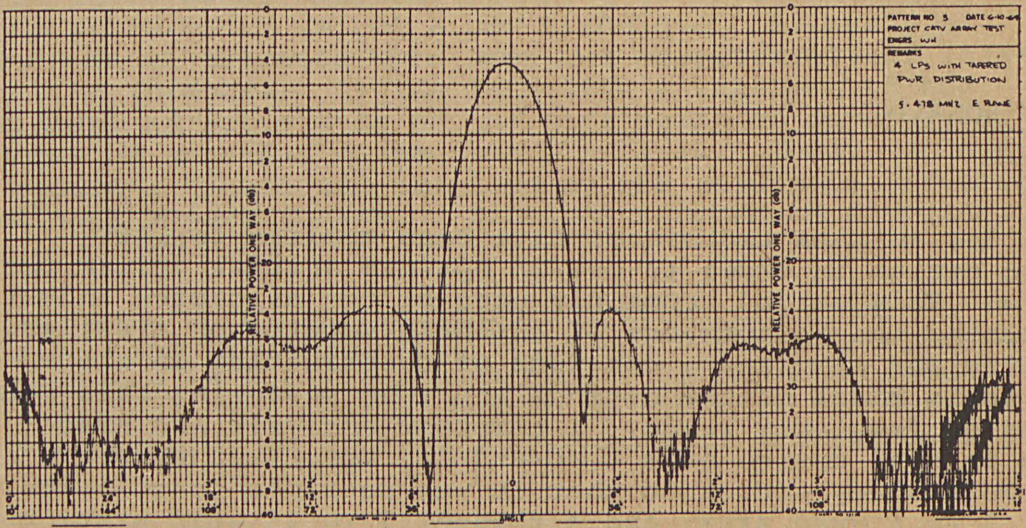


FIGURE 27

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

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

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

We can conclude that:

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

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

MARK H. RONALD

Summary

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

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

Introduction

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

Theory

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

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

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

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

where

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

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

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

Example

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

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

The element pattern in a principle plane is:

$$E = \text{Cos}^n\,\theta \qquad (3)$$

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

TABLE 1

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

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

$$E_a = \text{Cos}^n\,\theta \; (1 + \text{Cos}\,\Psi) \qquad (4)$$

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

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

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

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

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

where α is the tilt angle.

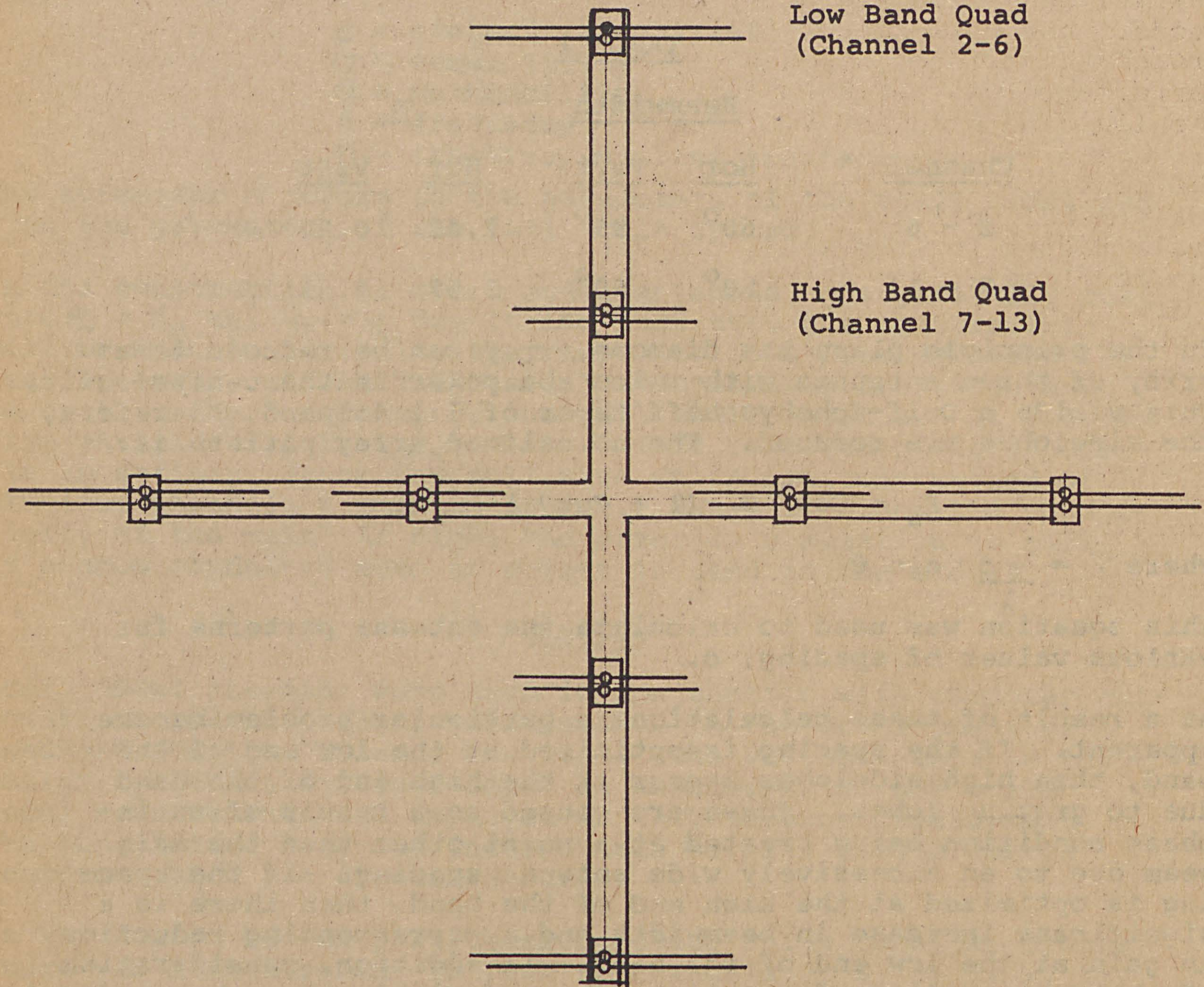


FIGURE 1: Dual Quad Configuration

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

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

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

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

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

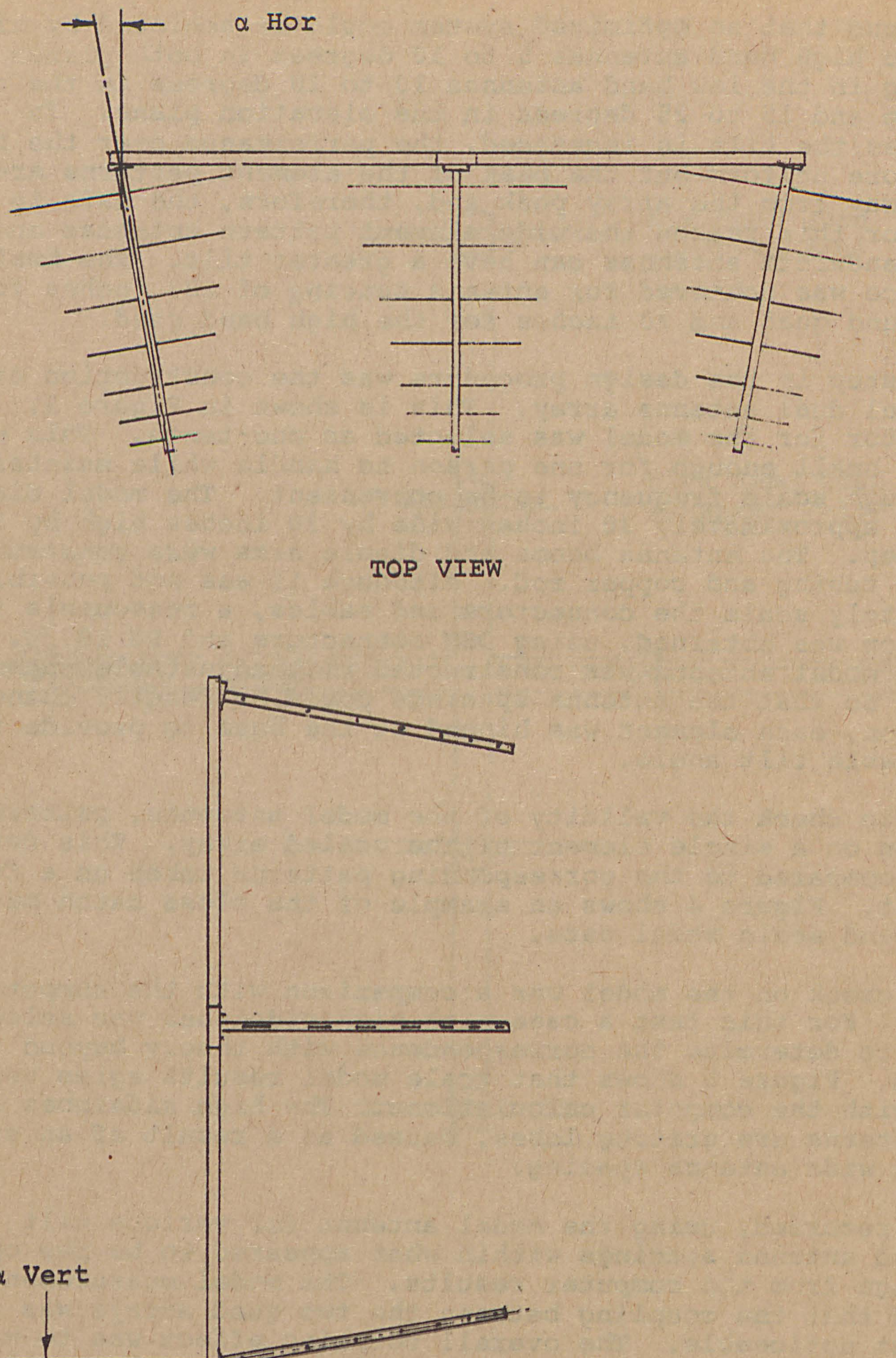


FIGURE 2: Quad Array Showing Tilt Angle

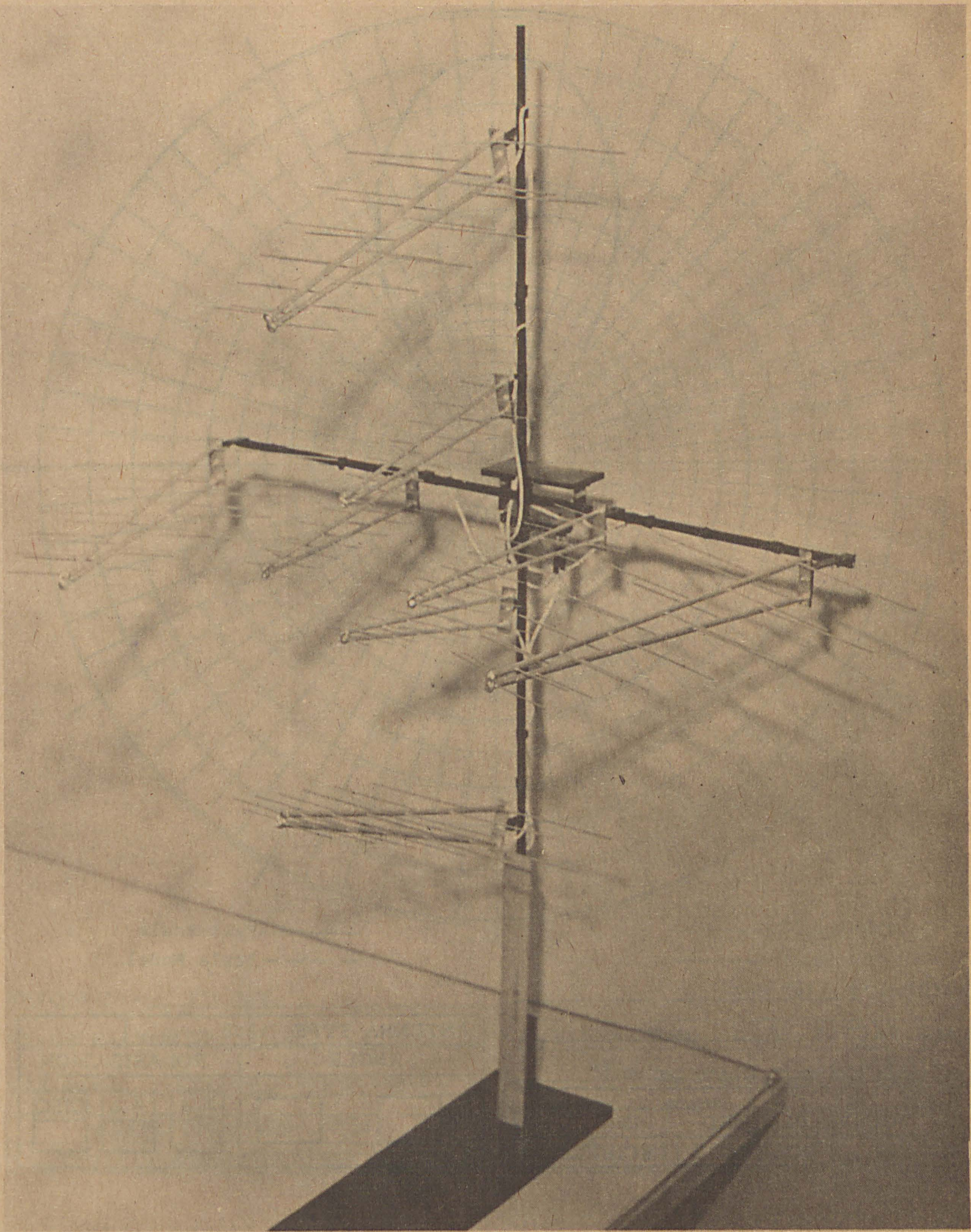


FIGURE 3: Scale Model Antenna

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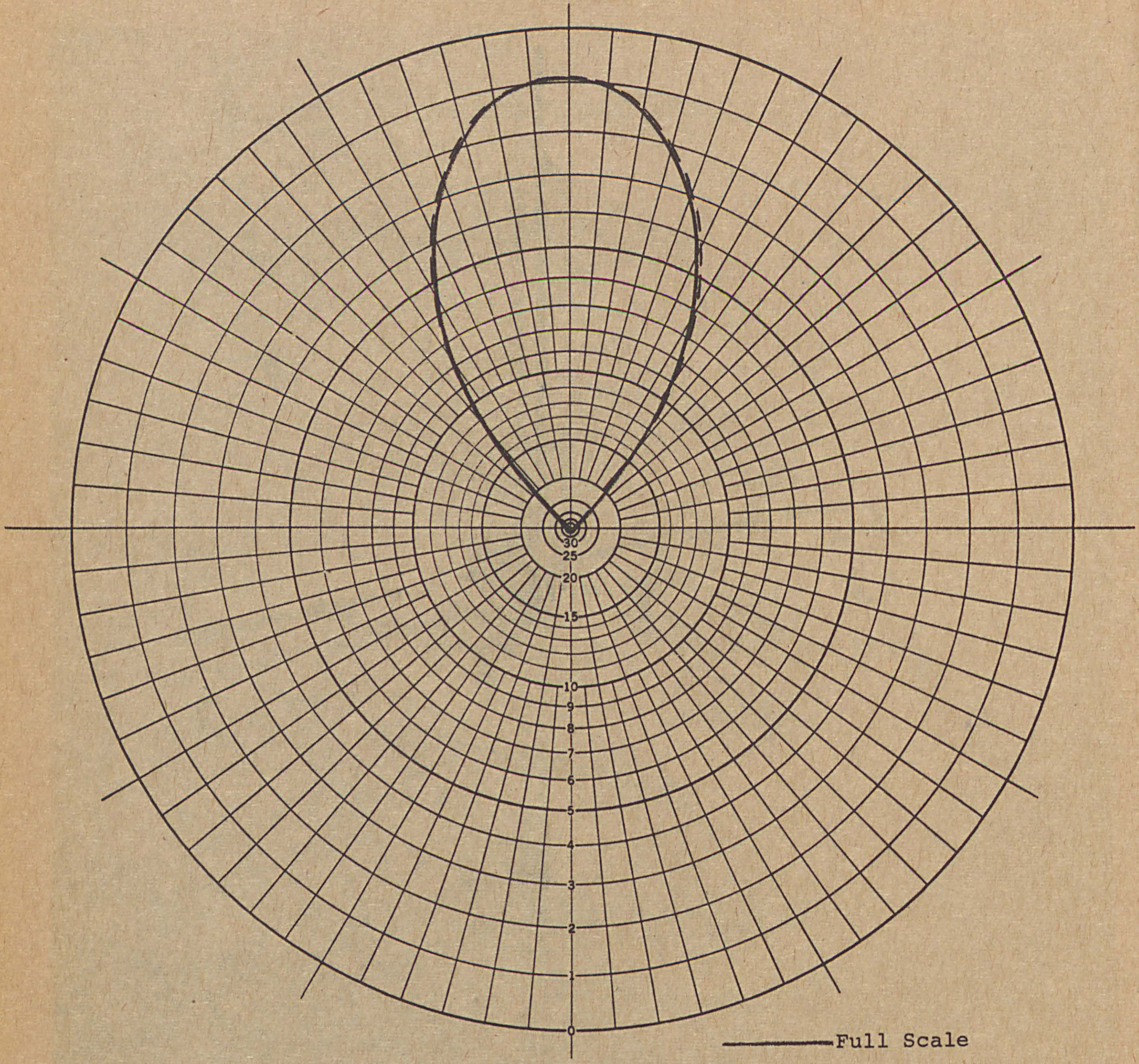
FIGURE 4



FREQUENCY 189 MHz

SCALE FACTOR 10

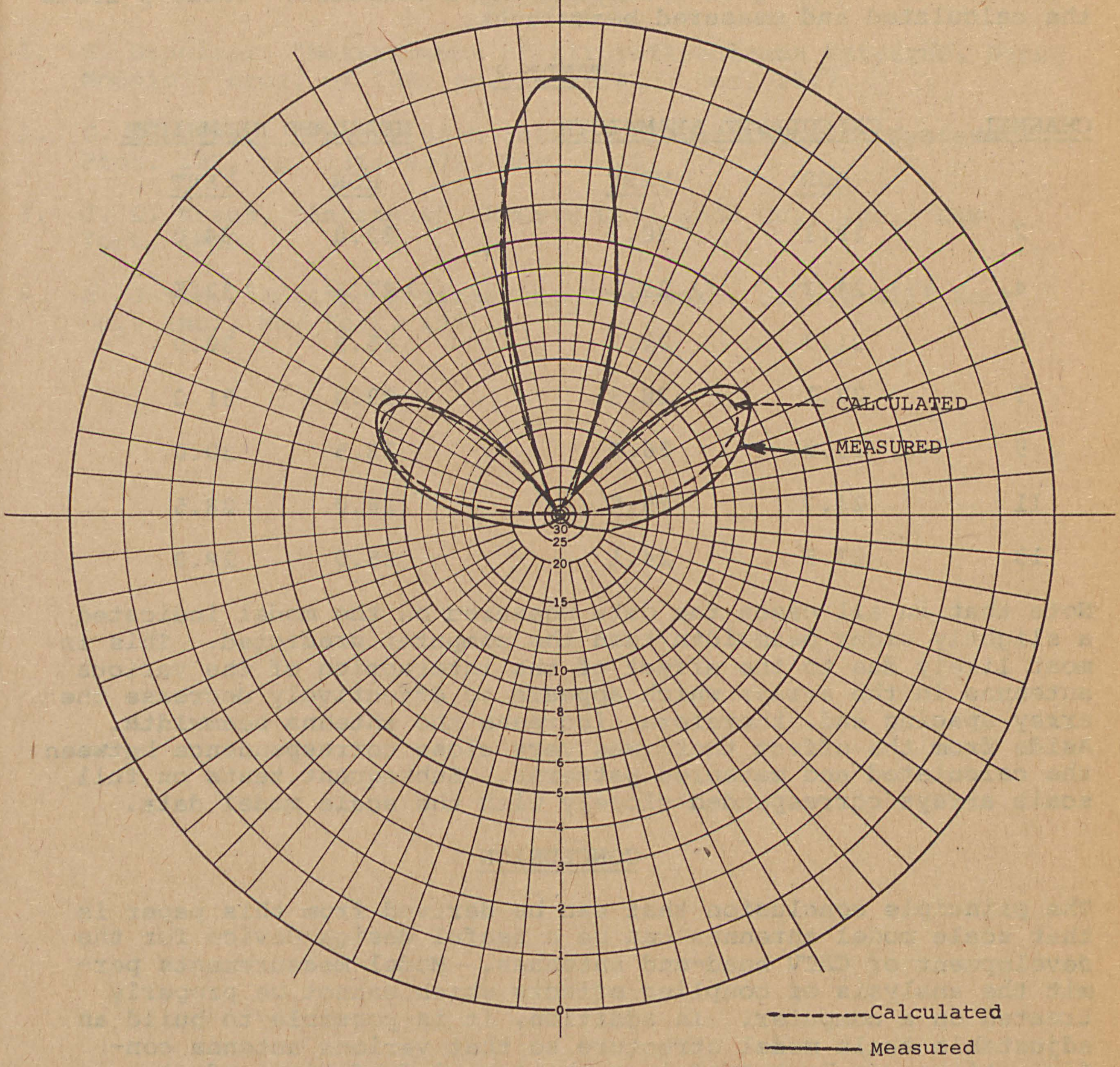
REMARKS azimuth plane pattern

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

ANTENNA TYPE 1300				
ANGLE		POLARIZATION		
Eϕ:	Eθ:	E ϕ	E θ	CIRC

ELTECH LABORATORIES, Inc.

FIGURE 5



FREQUENCY 850 MHz

SCALE FACTOR 10

REMARKS elevation plane pattern

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

ANTENNA TYPE 1100				
ANGLE		POLARIZATION		
Eϕ:	Eθ:	E ϕ	E θ	CIRC

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

TABLE 2

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

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

CONCLUSION

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

REFERENCES

1. G. Sinclair, "Measurement of Aircraft-Antenna Patterns, Using Models", Proc. of IRE, pp. 1451-1462, Dec. 1947.

2. G. Sinclair, "Theory of Models of Electromagnetic Systems", Proc. IRE, pp. 1364-1370, Nov. 1948.

3. J. D. Kraus, "Antennas", McGraw Hill Book Co., Inc., New York, 1950.

4. H. Jasik, "Antenna Engineering Handbook", McGraw Hill Book Co., Inc., New York, 1961.