THE EFFECT OF FEED-LINE TAPER ON THE PERFORMANCE OF LOGARITHMICALLY PERIODIC DIPOLE AND V-TYPE ANTENNA STRUCTURES

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Master of Science in Electrical Engineering

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by
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ABSTRACT

A review of the basic ideas and theory of broadband logarithmically periodic antennas is briefly outlined. The development and construction of two types of logarithmically periodic dipole antennas is described. An experimental investigation of the effects of small-angle feed-line taper is made on the performance of the antennas. An analysis of the results is given over a 100 to 1200 megacycles per second frequency band.

PREFACE

This thesis is concerned with the practical development, operation, and characteristics of two types of logarithmically periodic dipole antennas. Antenna performance including input impedance, bandwidth, and radiation characteristics is investigated for small angle variations in the feed-line taper of the two antennas. The antennas investigated are a logarithmically periodic straight-dipole array and a logarithmically periodic V-dipole array. The latter is a modification of the straight-dipole array in which the dipole elements are bent to form a V-shaped structure.

The appendix of the thesis gives a detailed description of the antenna measurement techniques and includes the measurement data.

The author wishes to express his sincere thanks to Professor Ernest Bridges for the suggestion of the topic and for his helpful assistance. The financial support of the National Research Council under grant A-738 is also gratefully acknowledged.

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CHAPTER I

INTRODUCTION

An antenna is a transformer for converting guided electromagnetic waves into free-space waves. It provides the means of impedance matching between waves in free space and waves in a transmission line or waveguide. The antenna also directs the radiation in desired directions and suppresses it in other directions where it is not wanted.

The bandwidth of the antenna is the frequency range in which the observable characteristics such as the radiation pattern and input impedance have small variation. It is a relative term that can be made definite by specifying the degree of match within the band. Normally, this is done by specifying the maximum amount of reflected energy that can be sent back into the feed line from which it came, that is, by specifying the maximum reflection coefficient and/or the maximum standing-wave ratio at the antenna input.

Many investigations have been made on the theoretical and practical aspects of broadband antennas, but a breakthrough was made in 1957 with the introduction of the angle concept by Rumsey[1*] and the principle of logarithmic periodicity by Du Hamel and Isbell[2].

Rumsey focused on the idea that an antenna whose shape was specified entirely in terms of angles would have pattern and impedance characteristics independent of frequency.

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* The numeral denotes the reference number as listed in the bibliography.

This idea was used by Du Hamel to propose a pseudo frequency-independent antenna with electrical properties that repeat periodically with the logarithm of the frequency.

In 1958, at the University of Illinois, Isbell[3] found that the log-periodic principles could be applied to the design of a dipole array in which the pattern and impedance were essentially independent of frequency over a bandwidth governed by the size of the structure and the precision of construction. Isbell named these antennas log-periodic dipoles.

The new concepts stimulated much activity in the antenna field. Previously, antennas with broadband pattern and impedance characteristics implied a frequency range of perhaps two to one; now broadband performance over ranges as great as forty to one or more are possible.

In general, the frequency range or band over which the transformation between guided waves and free-space waves can be effected depends on the nature of the mismatch in the antenna. If the transformation has the nature of a gradually tapered line so that there is no sudden change, then the reflections are distributed over a distance of one or several wavelengths and have a chance to partly cancel because of phase differences.

The purpose of this thesis is to show the performance of two simply constructed log-periodic dipole antennas and investigate the effect of small angle variations in the feed-line taper of these antennas.

A brief theoretical background on log-periodic dipole antennas is given in chapter two, along with some practical aspects regarding the feed-line taper and construction details of the antennas. An analysis of the input impedance and radiation pattern measurements on the antennas is given in chapters three and four, respectively. The conclusions are presented in chapter five.

CHAPTER II

THEORETICAL DEVELOPMENT, ANTENNA CONSTRUCTION, AND FEED-LINE TAPER

Much has been written on the theoretical development of frequency independent antennas, but only a brief summary of the work done on logarithmically periodic antennas will be given here. The antenna construction details and remarks concerning the feed-line taper will also be given.

I. THEORETICAL DEVELOPMENT

Du Hamel and Isbell defined a logarithmically periodic antenna as "an antenna structure for which the electrical properties vary periodically with the logarithm of the frequency"[2]. They were able to show that the log-periodic antenna is a simple modification of an angular antenna. The modification causes a variation of the electrical properties with frequency, but the variation is sometimes very small, the result being a broadband antenna.

The original structures of Du Hamel and Isbell were obtained by a logarithmic transformation from the Z-plane to the W-plane according to the formula

$$Z = \ln W \qquad (2.1)$$

where W and Z are complex numbers. Letting $W = \rho e^{j\theta}$ and $Z = x + jy$, the equations defining the transformation are:

$$x + jy = \ln \rho e^{j\theta}$$

$$= \ln \rho + j\theta. \quad \text{.............................2.2}$$

Hence, $x = \ln \rho$, or $\rho = e^x$ 2.3

and $y = \theta$. 2.4

With this transformation, circles and radial lines in the W-plane are mapped into vertical and horizontal lines, respectively, in the Z-plane. An example of a log-periodic structure and its transformation is shown in figure 2.1, page 7.

The radii R_n, R_{n+1}, --- form a geometric progression where the geometric ratio is defined by

$$\tau = \frac{R_{n+1}}{R_n} \quad \text{.....................................2.5}$$

When the infinite structure is energized at the vertex, electrical properties at a frequency f will be repeated (except for a change in scale) at all other frequencies given by $\tau^n f$, where n is an integer. When plotted on a logarithmic scale, these frequencies are equally spaced with a period of $\ln \tau$; hence the name log-periodic structures.

Du Hamel and Isbell[2] found that the currents on the log-periodic structure decrease rapidly past the region where a tooth one-quarter wavelength long is positioned. This does away with the troublesome "end effect" produced in most types of antennas.

Isbell[4] found that if the lower part of the structure of figure 2.1, page 7, was bent about the horizontal axis, a unidirectional pattern pointing in the direction of the vertex could be obtained. The resulting structure is shown in figure 2.2. This structure has the property that

$$\frac{S_{n+1}}{S_n} = \frac{R_{n+1}}{R_n} = \tau, \qquad \text{.............................2.6}$$

where S_n is the length of the nth tooth element.

Isbell[3] suggested an array of conventional dipoles as a modification and practical application of the structure in figure 2.2. The resulting log-periodic dipole array is shown in figure 2.3, page 8.

Isbell found that in order to obtain radiation toward the small end and prevent excitation of the larger elements beyond the "active region", 180 degree phase shift must be added between adjacent elements as shown in figure 2.4, page 8. The "active region" of the antenna remains near the half wavelength element and as the frequency is increased it moves forward through the array.

When the dipole elements are connected to a balanced feeder the 180 degree phase reversal is produced by effectively twisting the feeder as shown in figure 2.5, page 9.

Another modified form of the structure of figure 2.2 is made up of an array of dipole elements bent to form a V-shaped structure as shown in figure 2.6, page 9. These antennas are called log-periodic V-dipole antennas.

The experimental investigations of Isbell[3] have shown that the log-periodic dipole structure is a linearly

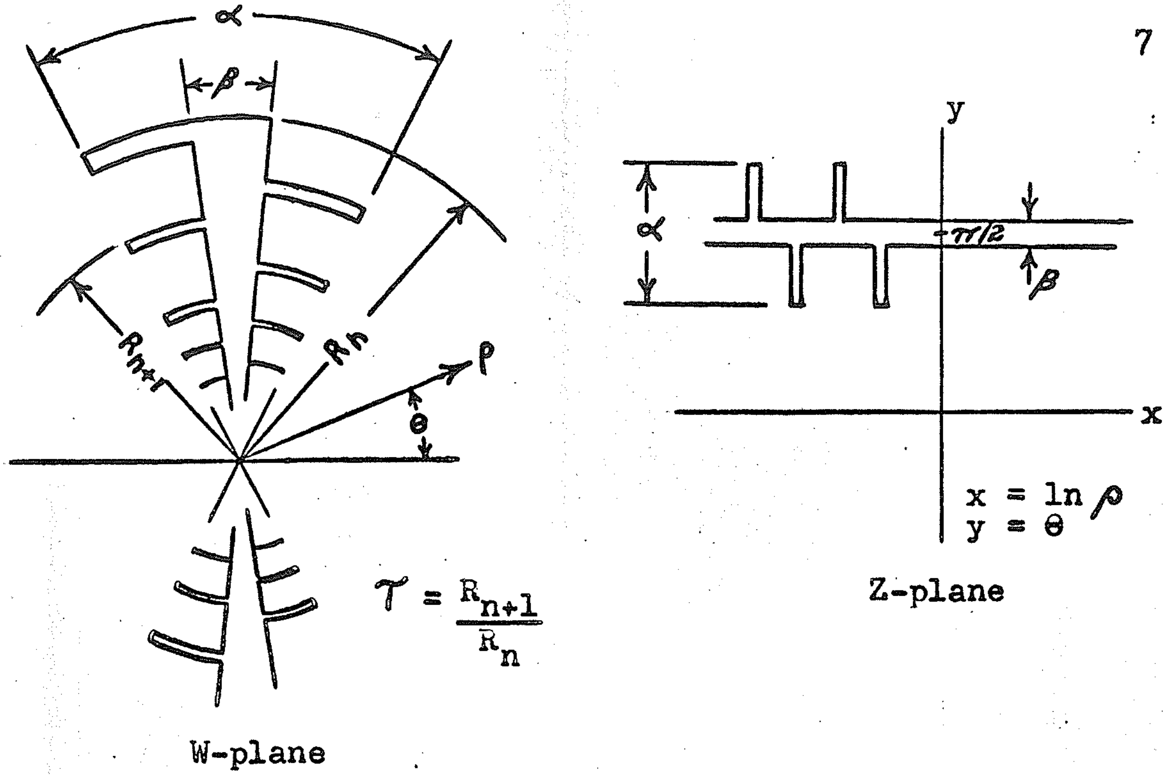


FIGURE 2.1

A LOGARITHMICALLY PERIODIC ANTENNA AND ITS TRANSFORMATION IN THE Z-PLANE .

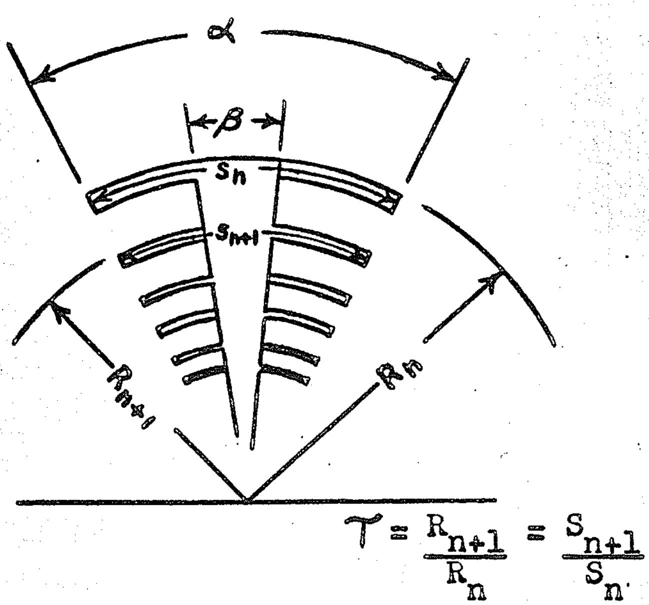
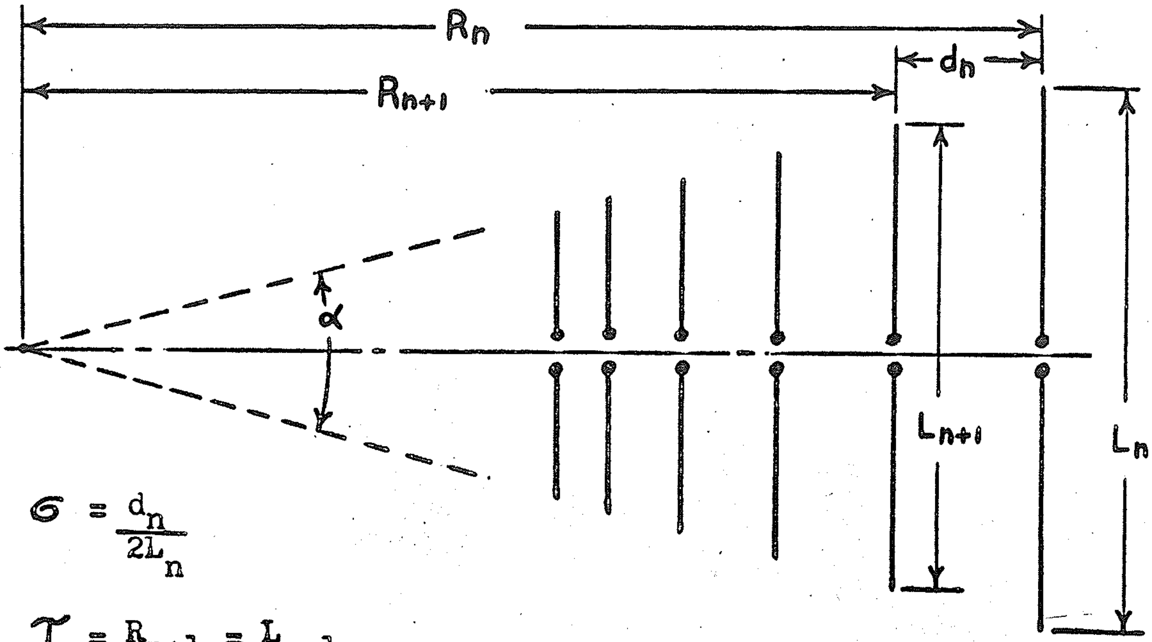


FIGURE 2.2

A LOG-PERIODIC ANTENNA BENT ABOUT THE HORIZONTAL AXIS



$$\sigma = \frac{d_n}{2L_n}$$

$$\tau = \frac{R_{n+1}}{R_n} = \frac{L_{n+1}}{L_n}$$

FIGURE 2.3

A LOG-PERIODIC DIPOLE ARRAY

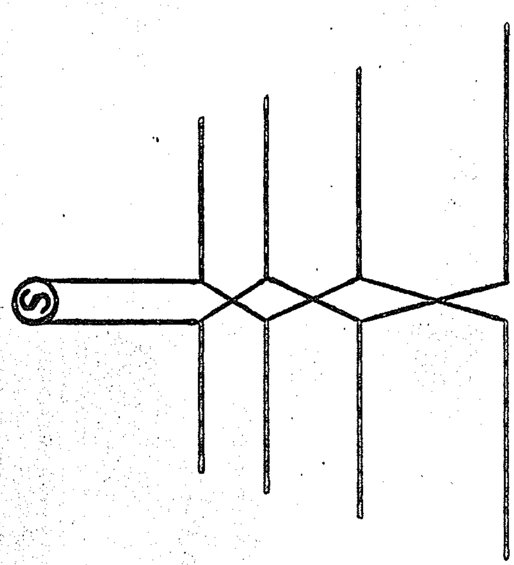


FIGURE 2.4

METHOD OF FEEDING THE LOG-PERIODIC DIPOLE ARRAY

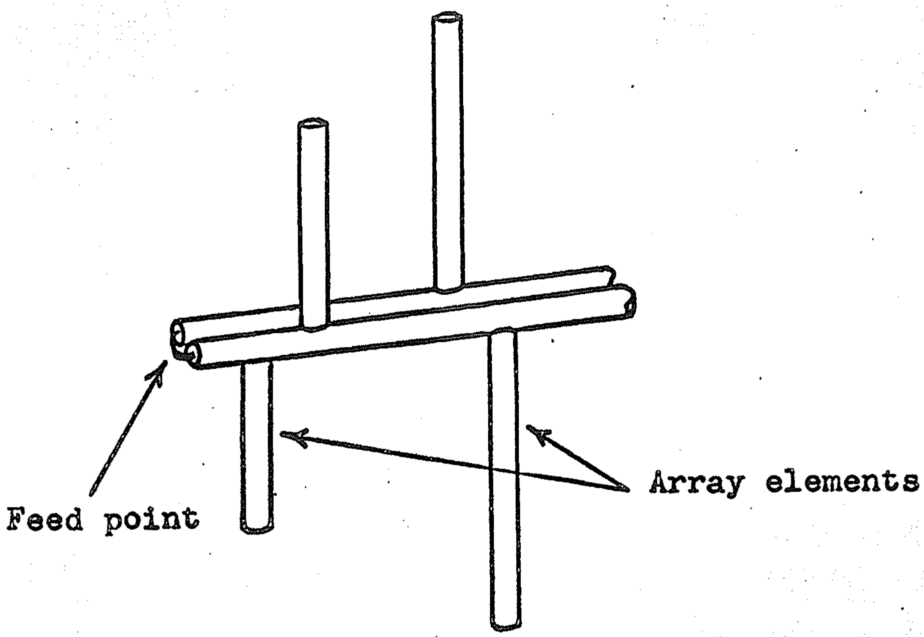


FIGURE 2.5

CONNECTION OF DIPOLE ELEMENTS TO
A BALANCED FEEDER

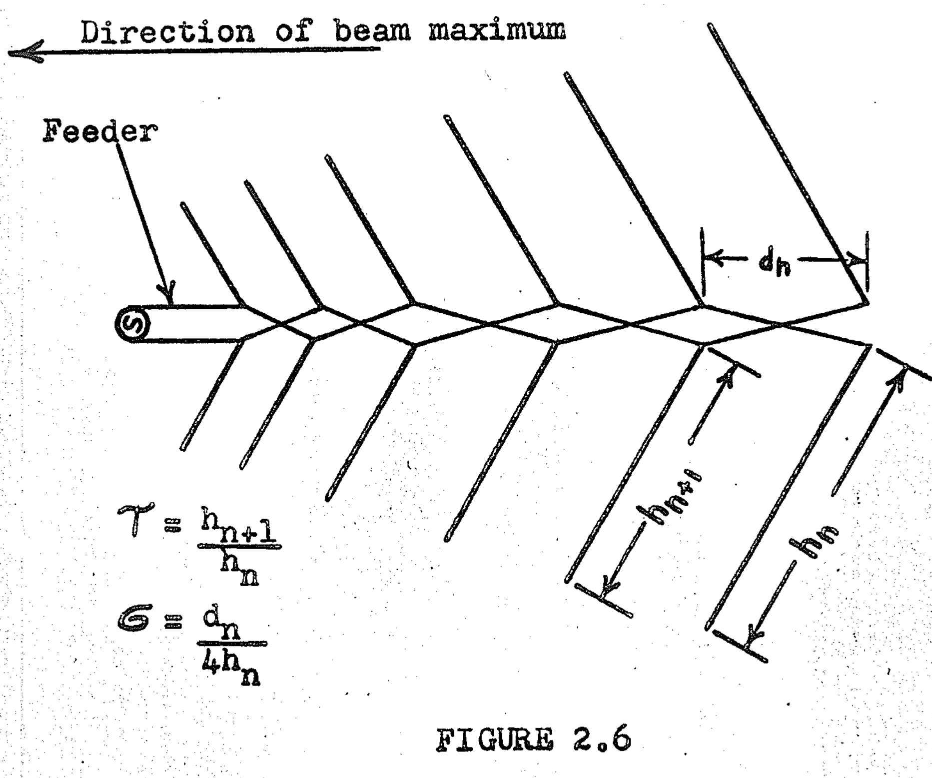


FIGURE 2.6

A LOG-PERIODIC V-DIPOLE ARRAY

polarized antenna of moderate gain. The pattern and input impedance were found to be almost independent of frequency over a bandwidth in which the size governed the low frequency limit and precision of construction governed the high frequency limit.

Du Hamel and Ore[5] have found that the impedance of the feed line plays a dominant role in determining the input impedance.

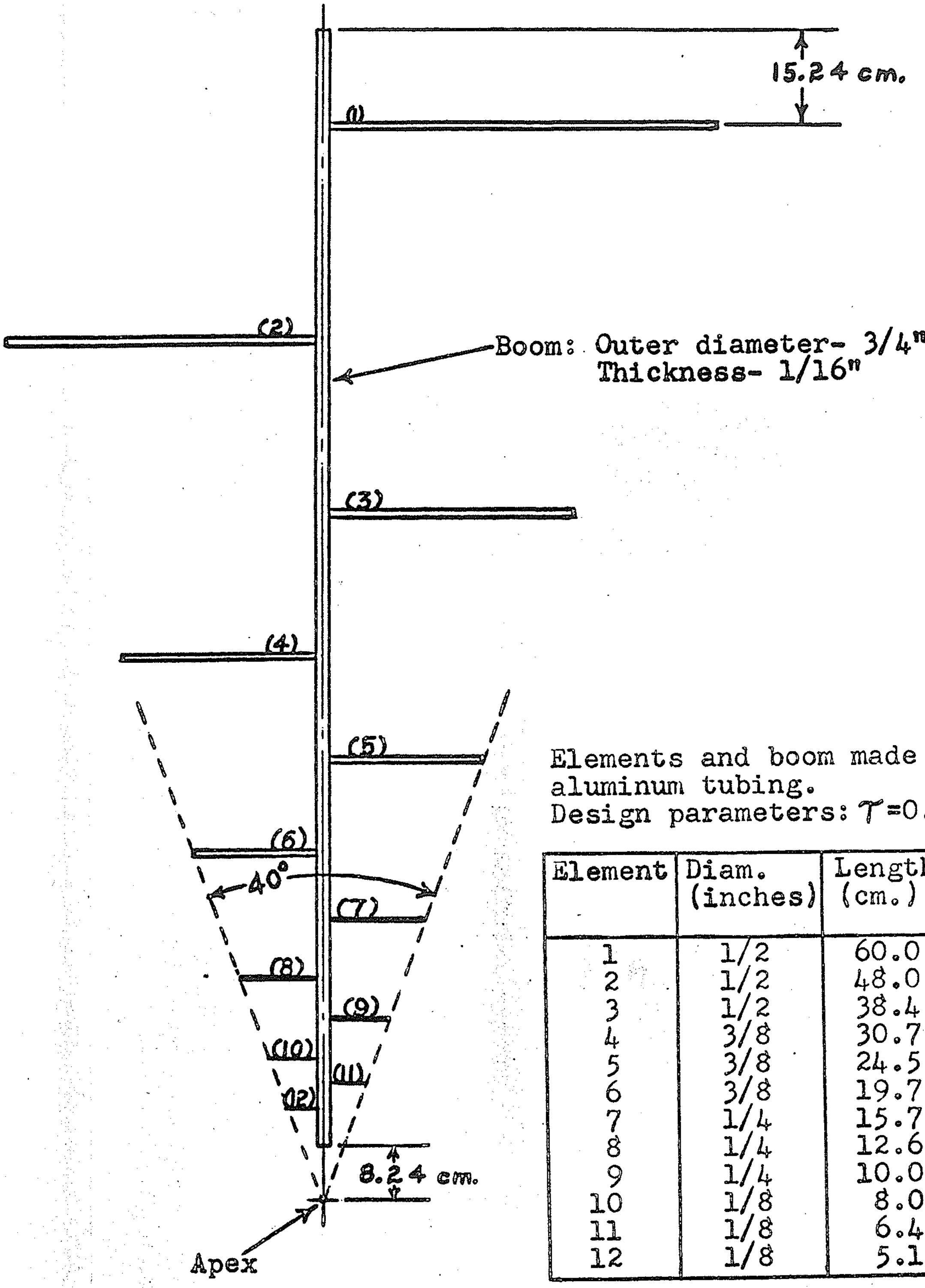
Bandwidths of ten to one have easily been obtained with log-periodic dipole antennas.

II. ANTENNA CONSTRUCTION

The main requirement for the design of a log-periodic dipole antenna is to know the frequency band over which the antenna is to operate. The antennas used in this experimental study were designed for a frequency range of approximately 200 to 1200 megacycles per second.

The working drawing of half the log-periodic straight-dipole structure is shown in figure 2.7. The other half is constructed in the same way except that each corresponding element is placed on the opposite side of the boom. Each half supports monopole elements; hence, when the two halves are combined, the conventional dipole elements are formed. The 180 degree phase reversal between adjacent elements also results.

The design parameters as well as the element diameters and lengths are given in figure 2.7.



Elements and boom made of aluminum tubing.
Design parameters: $\tau=0.80$, $\alpha=40°$.

Element	Diam. (inches)	Length (cm.)	Dist. from apex (cm.)
1	1/2	60.0	165.0
2	1/2	48.0	132.0
3	1/2	38.4	105.0
4	3/8	30.7	84.5
5	3/8	24.5	67.4
6	3/8	19.7	54.1
7	1/4	15.7	43.1
8	1/4	12.6	34.6
9	1/4	10.0	27.5
10	1/8	8.0	22.0
11	1/8	6.4	17.6
12	1/8	5.1	14.0

Scale: 1/10 full size

FIGURE 2.7

WORKING DRAWING OF HALF THE LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA STRUCTURE

The antenna is made of aluminum tubing and the elements are rigidly brazed to the boom. The two booms are held together by plexiglass dielectric and styrofoam supports.

Different size tubing was selected in order to keep the length-to-diameter ratio for all elements reasonably high and comparable.

The antenna is fed at the small end with twenty-one feet of RG-8A/U co-axial cable. The cable is run through the inside of one boom. The outer conductor is soldered to that boom and the inner conductor to the other boom. The separation of the two booms from center to center at the feed point is 1.5 inches. The boom tubing is 3/4 inches in diameter and 1/16 inches thick.

For the structure shown in figure 2.7, page 11, the longest dipole element has a resonant frequency of 125 megacycles per second. The shortest dipole element has a resonant frequency of 1456 megacycles per second. At the high frequencies, however, the feed-line dimensions become significant in terms of the wavelength; consequently, the high frequency limit of the antenna is lowered. At 1456 megacycles, for example, the feed-point separation is approximately one-fifth of a wavelength and the feed-line is approximately one-tenth of a wavelength in diameter.

The log-periodic V-dipole antenna is the same as the straight-dipole antenna in all respects except that the elements are bent 10 degrees toward the apex. The elements then form angles of 80 degrees with respect to the boom, rather than 90 degrees as before.

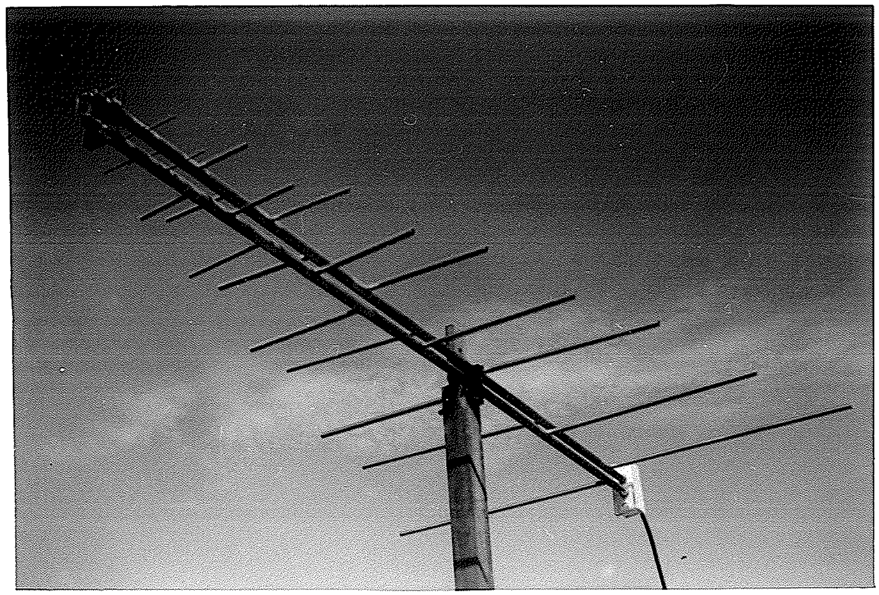


FIGURE 2.8

PHOTOGRAPH OF LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA

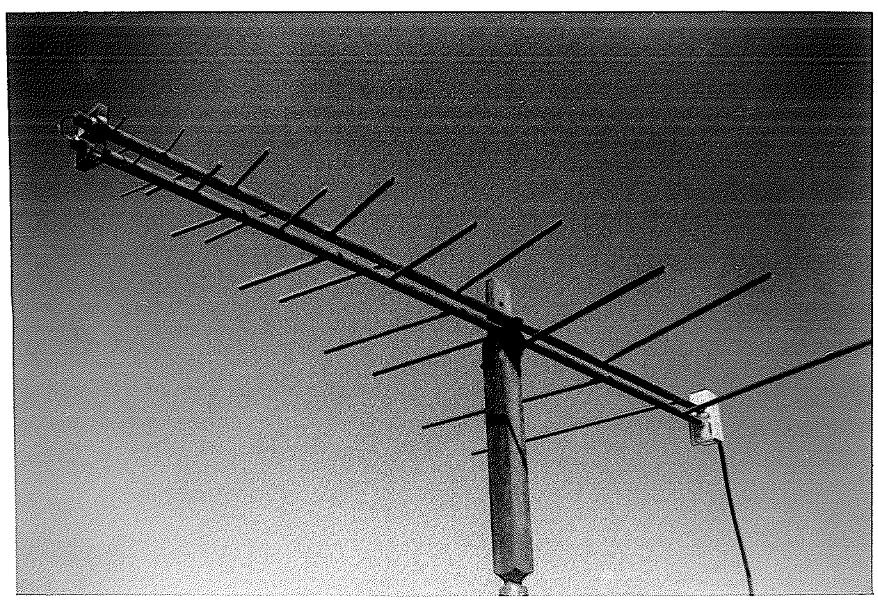


FIGURE 2.9

PHOTOGRAPH OF LOG-PERIODIC V-DIPOLE ANTENNA

It is evident that the two antennas are easily constructed and are quite rigid.

Photographs of the two antennas are shown in figures 2.8 and 2.9, page 13.

III. FEED-LINE TAPER

The feed line of each antenna was tapered by simply forming an angle between the two booms supporting the elements, as shown in figure 2.10. This angle is defined as the taper angle Ψ. The large and small end separations are defined as "a" and "b", respectively.

For purposes of construction and measurement, it was found more convenient to specify the end separation "b" instead of the angle Ψ. For all taper angles used, the feed end separation "a" was held at approximately 1.5 inches.

Antenna pattern and input impedance measurements were taken for taper angles ranging from zero to twenty degrees, the small angles being specified by "b" separations of 1.5, 2, 4, 6, and 8.75 inches. Table 2.1, page 15, gives the corresponding taper angles for the "b" end separations used on the antennas.

Figure 2.11, page 16, shows a photograph of the log-periodic straight-dipole antenna with a tapered feed-line. The end of the antenna is held for a particular "b" separation by a styrofoam support. Styrofoam has good dielectric properties and wave reflections resulting from its use are negligible. A laboratory test showed that the relative dielectric constant of styrofoam is less than 1.2.

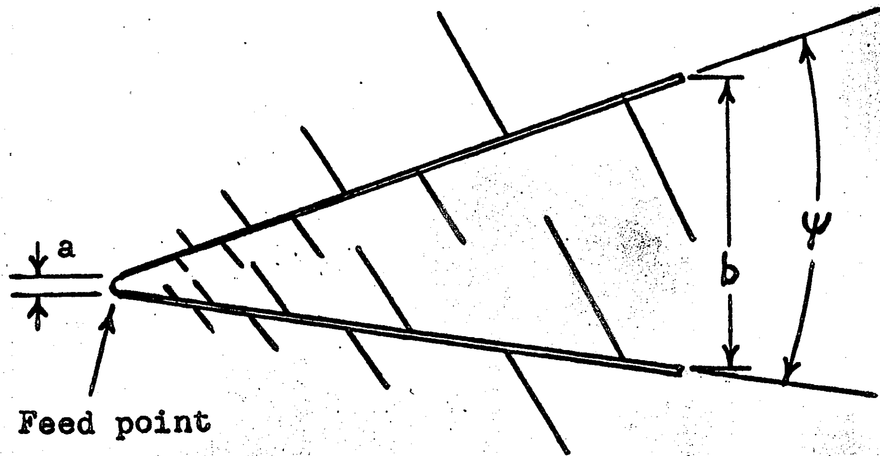


FIGURE 2.10

LOG-PERIODIC DIPOLE ANTENNA WITH TAPERED FEED

TABLE 2.1

END SEPARATIONS AND CORRESPONDING TAPER ANGLES USED ON ACTUAL ANTENNAS

Feed end separation "a" (inches)	Large end separation "b" (inches)	Taper angle ψ (degrees)
1.5	1.5	0.0
"	2.0	1.05
"	4.0	2.75
"	6.0	4.43
"	8.75	6.75
"	12.5	10.0
"	24.2	20.0

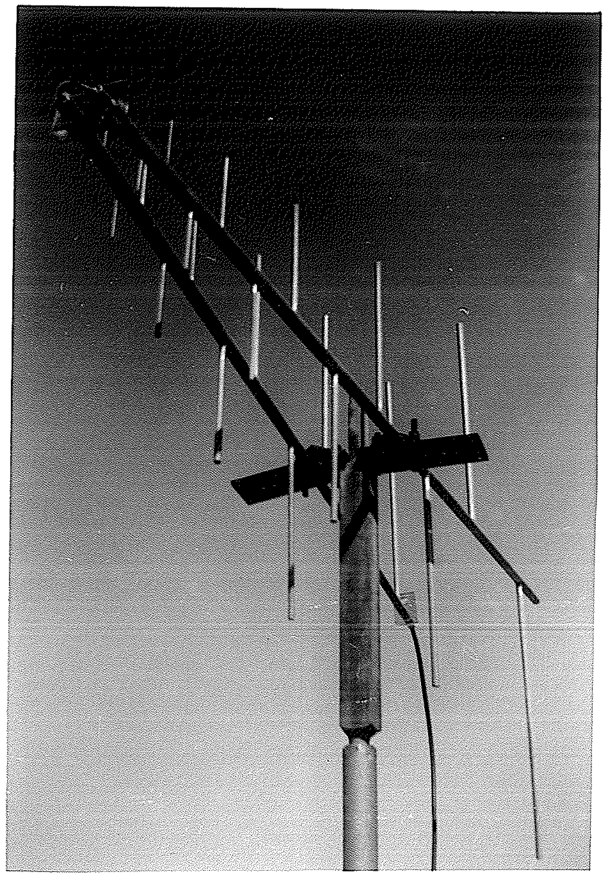


FIGURE 2.11

PHOTOGRAPH OF LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA WITH A TAPERED FEED

CHAPTER III

ANALYSIS OF THE INPUT IMPEDANCE MEASUREMENTS

This chapter deals with the input impedances that were measured on the log-periodic straight-dipole and V-dipole antennas. For purposes of clarity and analysis, the input impedances are presented in graphical form. A general discussion of the results is given. The measurement technique and experimental set-up, as well as the tabulated results, are given in Appendix A.

I. INTRODUCTION

The input impedance of an antenna is the impedance looking into the input terminals. It is the impedance presented to the line which feeds the antenna. The input impedance determines the degree of match to the feed line. If this impedance is the same as the characteristic impedance of the feed line, a perfect match results. Under these conditions, the antenna will radiate maximum power without reflecting any portion of it back into the feed line. Evidently, if the input impedance of an antenna can be varied, the problem of matching it to given feed lines is somewhat reduced. Achievement of a satisfactory match is normally specified by a maximum voltage standing-wave ratio (VSWR) or just maximum standing-wave ratio (SWR) on the feed line.

It was stated in the introductory chapter*, that antennas which have the nature of a transformation with a gradually tapered line have the advantage of producing minimum reflections. Furthermore, in a tapered transition, reflections are not critically dependent either on the exact transition length or on the exact wavelength of the transmitted waves. For the log-periodic dipole antennas used in our study, we were confronted with a convenient way of tapering the antennas by simply tapering the feed lines. As might be expected, tapering also introduces disadvantages, particularly for large taper angles, which may offset any matching improvement.

In this chapter, the graphical presentation of measured input impedances will show some potential variations of the impedances and also the effect of the tapered feed-lines.

II. RESULTS OF INPUT IMPEDANCE MEASUREMENTS

Antenna input measurements are commonly presented in two ways. In the first case, if the overall performance of the antenna is desired, the SWR over the operating frequency band is given. In the second case, if one is designing an antenna to match a feed line, the impedance at the input terminals is of interest.

The input impedance values obtained at each frequency may be connected to form an impedance-versus-frequency curve on a Smith Chart[6a]. The shape of this curve on a Smith Chart

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* See Chapter I, page 2, paragraph 3.

is a function of the characteristic impedance of the feed line. To avoid this dependance, it is sometimes desirable to plot the impedance values on a simple resistance (R)-versus-reactance (X) diagram, where the input impedance is $R + jX$.

R-X diagrams for the log-periodic straight-dipole and V-dipole antennas are given in figures 3.1 to 3.14. The diagrams are shown for various angles of feed-line taper. The amount of taper is designated by the end separation "b" or by the taper angle Ψ.

III. R-X DIAGRAM CALCULATIONS

It can be shown[6b] that lines of constant SWR are circles on the R-X diagram, centered on the R-axis and crossing the R-axis at Z_o/SWR and $Z_o x SWR$, where Z_o is the characteristic impedance of the transmission line. Letting the minimum and maximum R-axis intercepts be designated by R_{min} and R_{max}, respectively, we have the equations

$$R_{min} = Z_o/SWR \quad \text{.......................} 3.1$$

and

$$R_{max} = Z_o x SWR. \quad \text{.......................} 3.2$$

Solving the two equations for Z_o and the standing-wave ratio, we have

$$Z_o = \sqrt{R_{max} x R_{min}} \quad \text{.......................} 3.3$$

and

$$SWR = \sqrt{R_{max}/R_{min}}. \quad \text{.......................} 3.4$$

Suppose a constant SWR circle can be drawn on the R-X diagram to enclose all input impedance points taken at different frequencies. This circle then represents the maximum

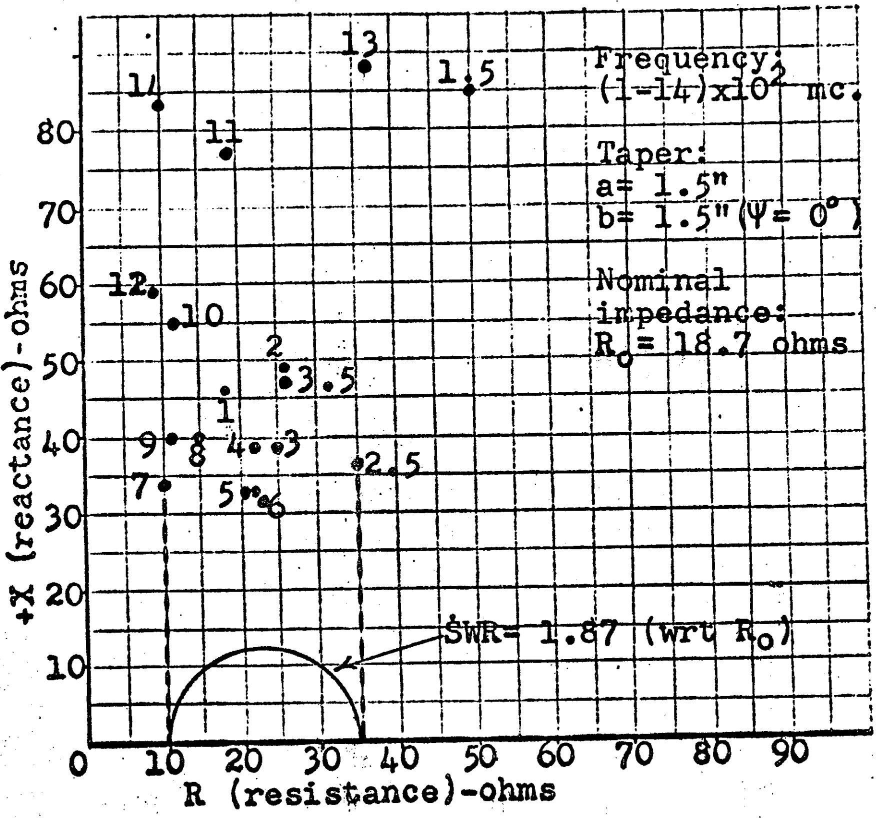

FIGURE 3.1

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA WITH NO TAPER

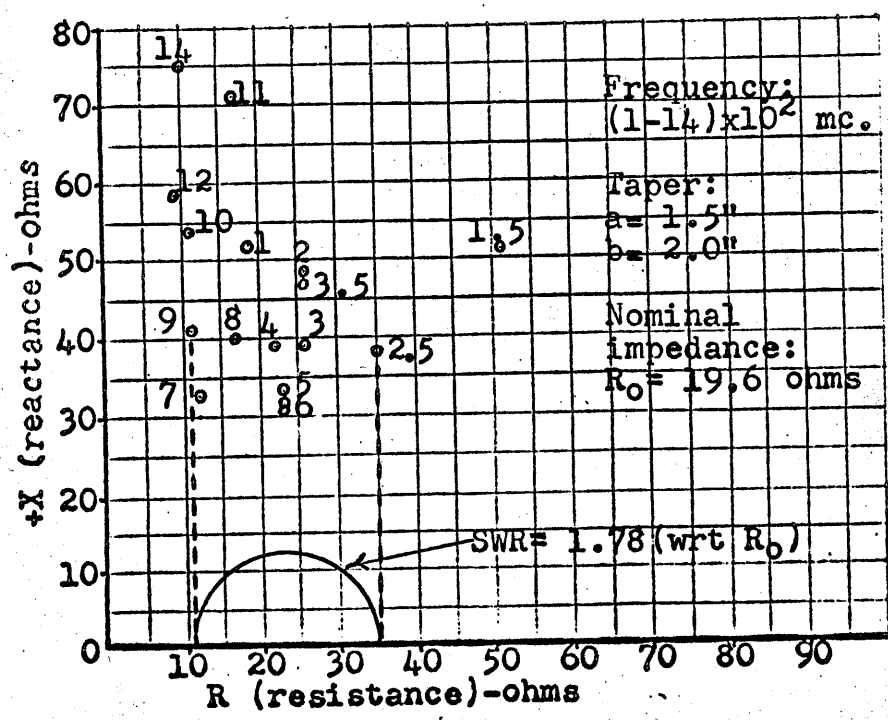

FIGURE 3.2

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA WITH END SEPARATION "b" OF 2.0"

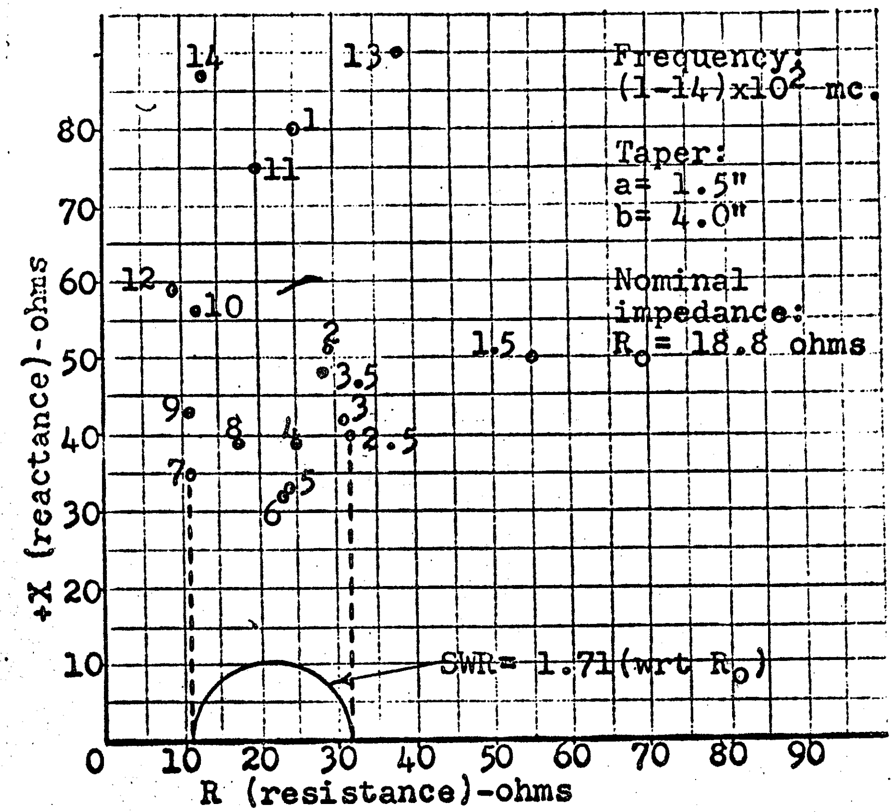

FIGURE 3.3

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA WITH END SEPARATION "b" OF 4.0"

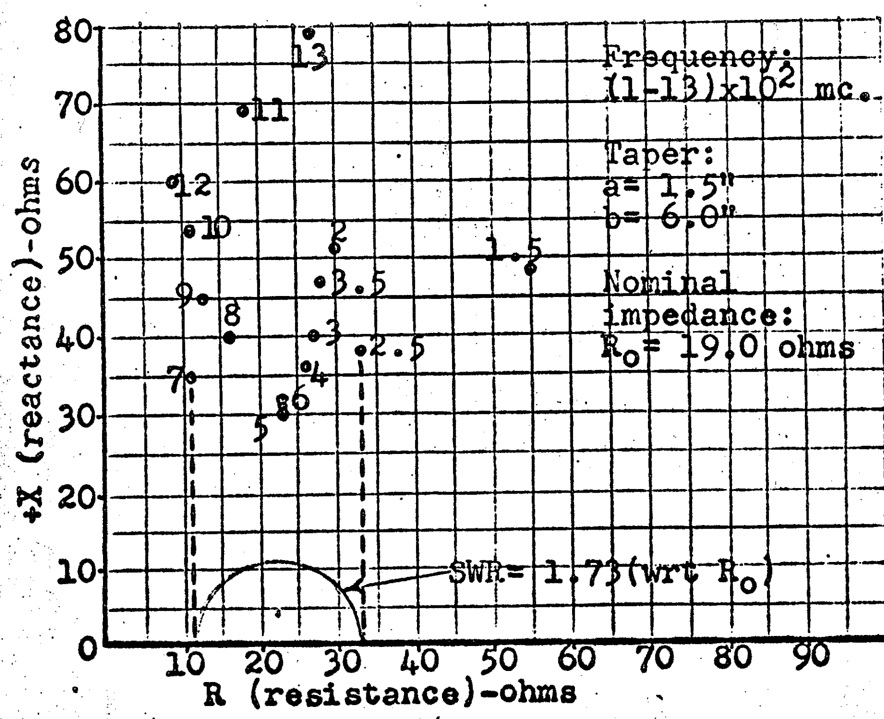

FIGURE 3.4

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA WITH END SEPARATION "b" OF 6.0"

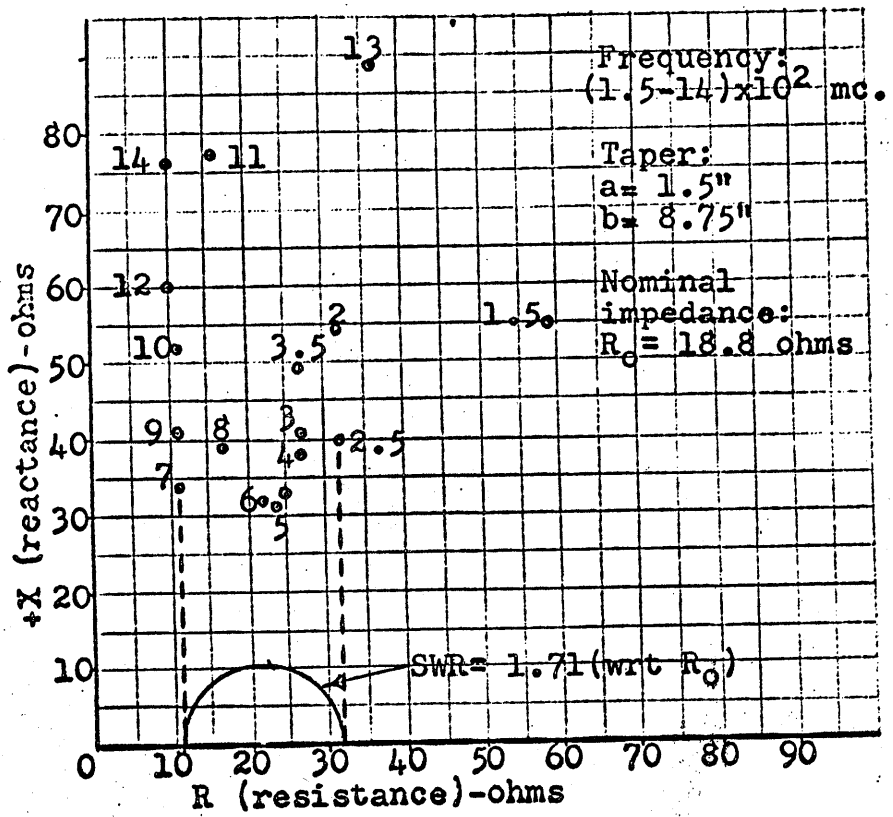

FIGURE 3.5

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA WITH END SEPARATION "b" OF 8.75"

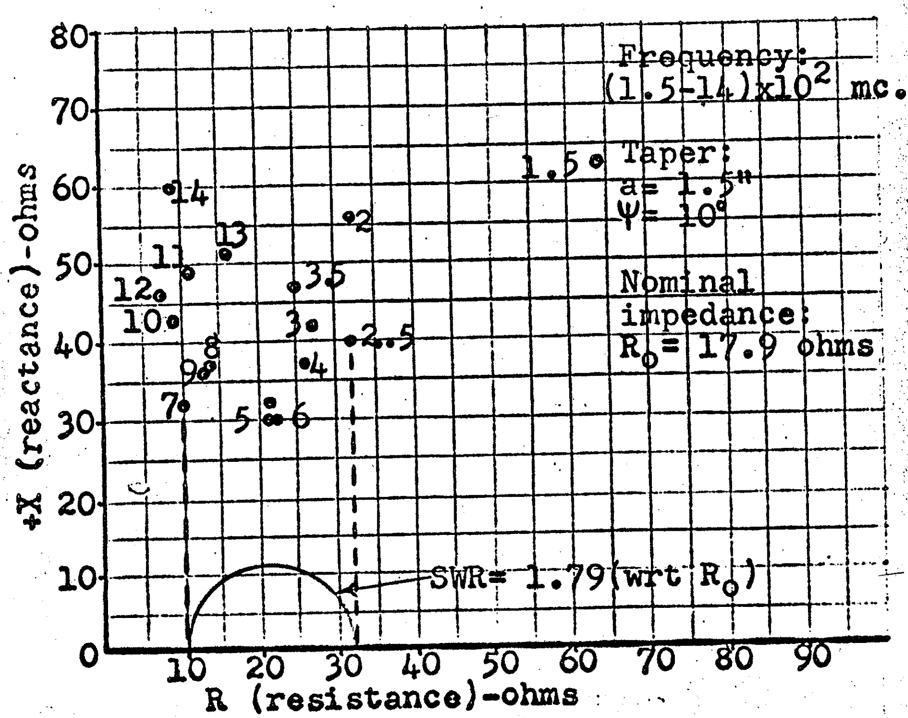

FIGURE 3.6

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA WITH TAPER ANGLE "Ψ" OF 10°

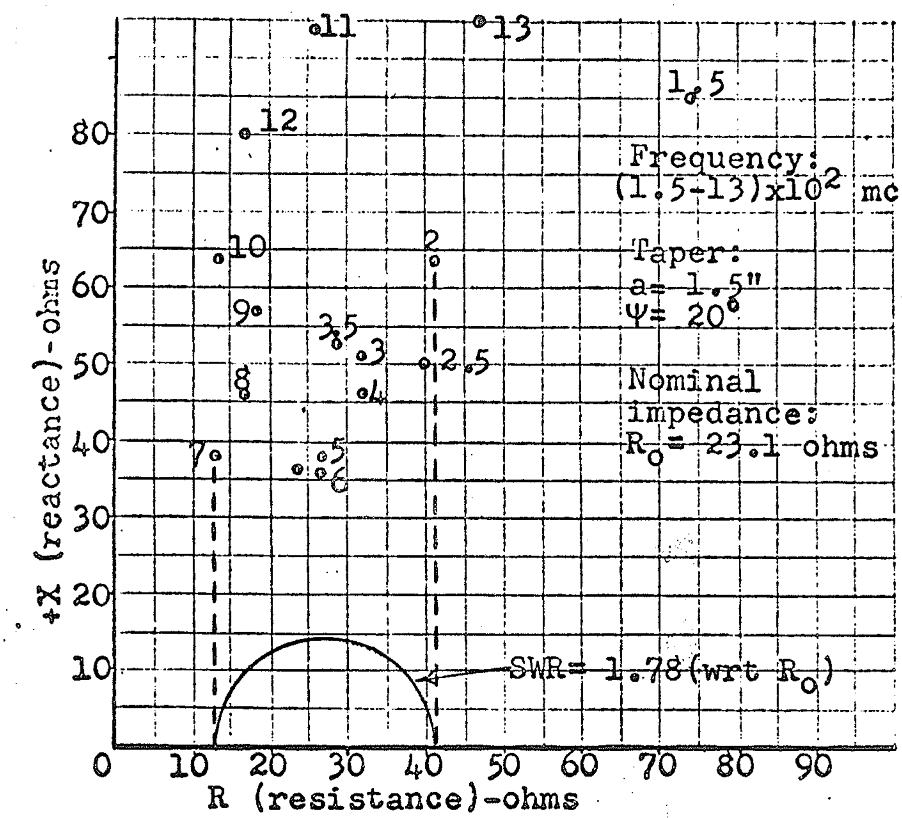

FIGURE 3.7

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA WITH TAPER ANGLE "Ψ" OF 20°

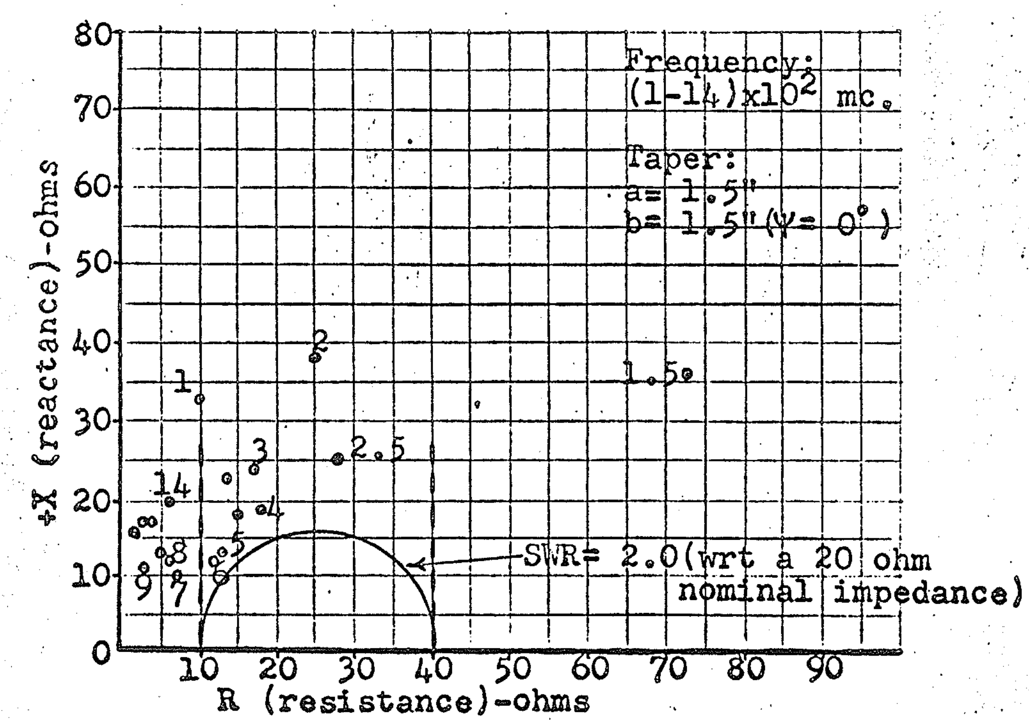

FIGURE 3.8
R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC V-DIPOLE ANTENNA WITH NO TAPER

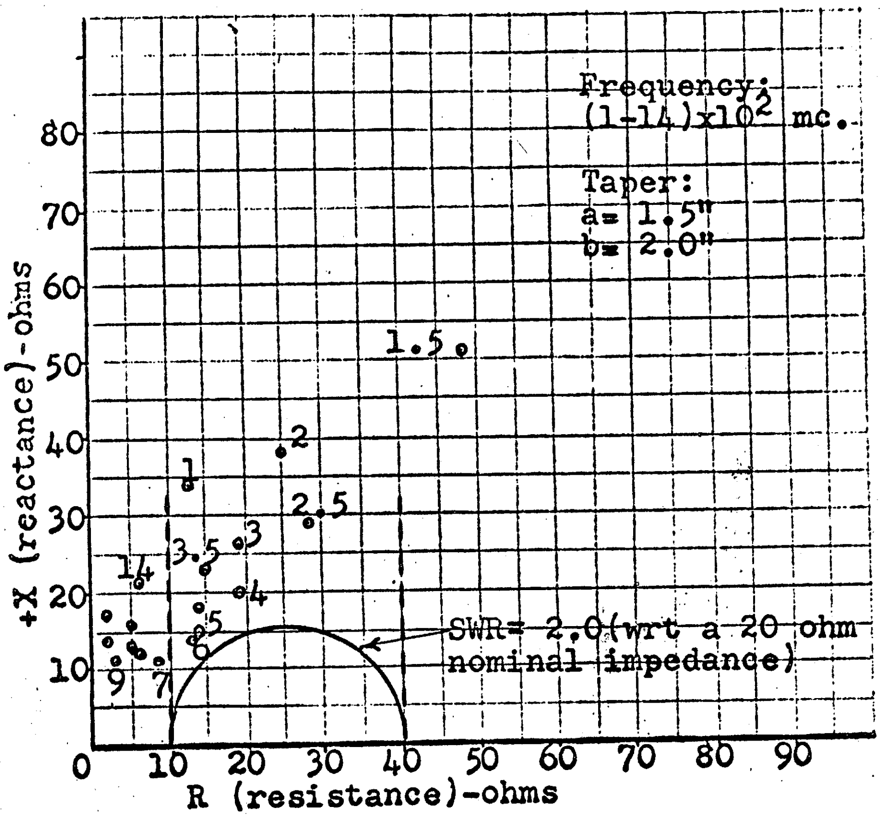

FIGURE 3.9

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC V-DIPOLE ANTENNA WITH END SEPARATION "b" OF 2.0"

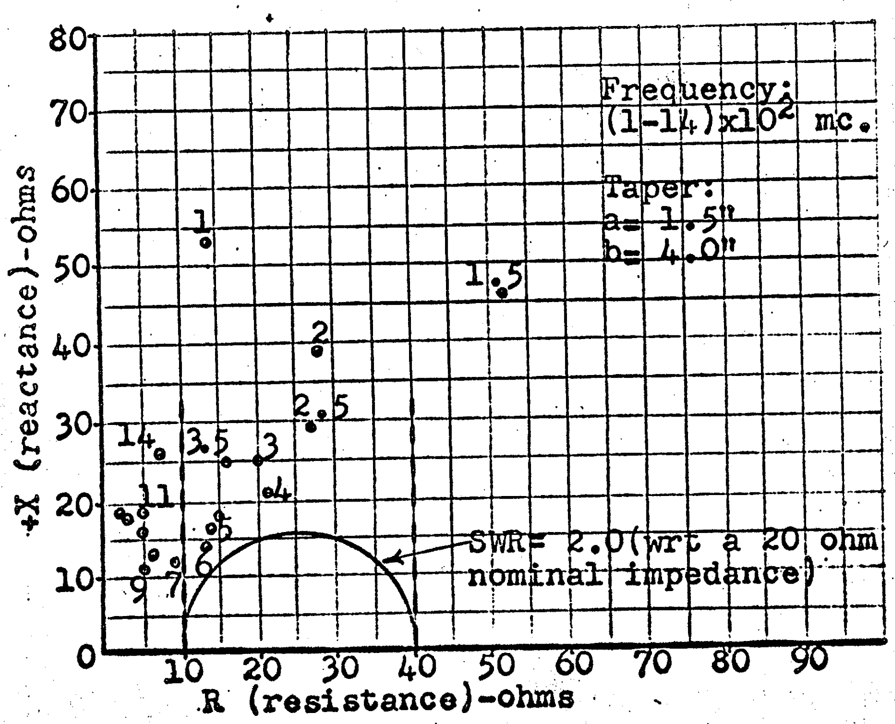

FIGURE 3.10

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC V-DIPOLE ANTENNA WITH END SEPARATION "b" OF 4.0"

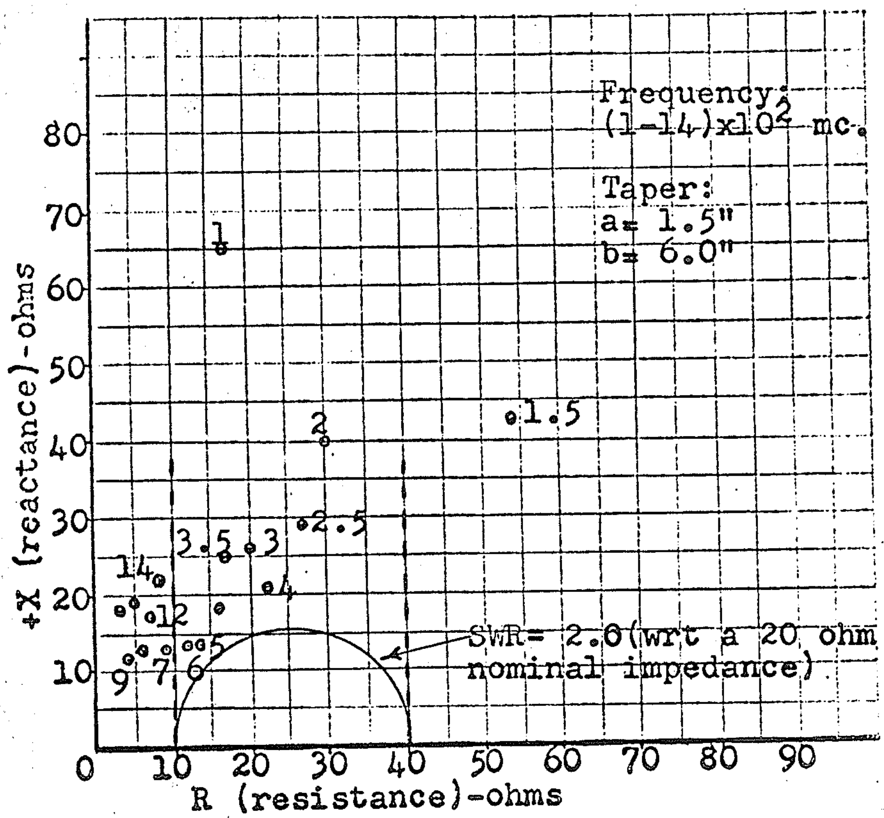

FIGURE 3.11

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC V-DIPOLE ANTENNA WITH END SEPARATION "b" OF 6.0"

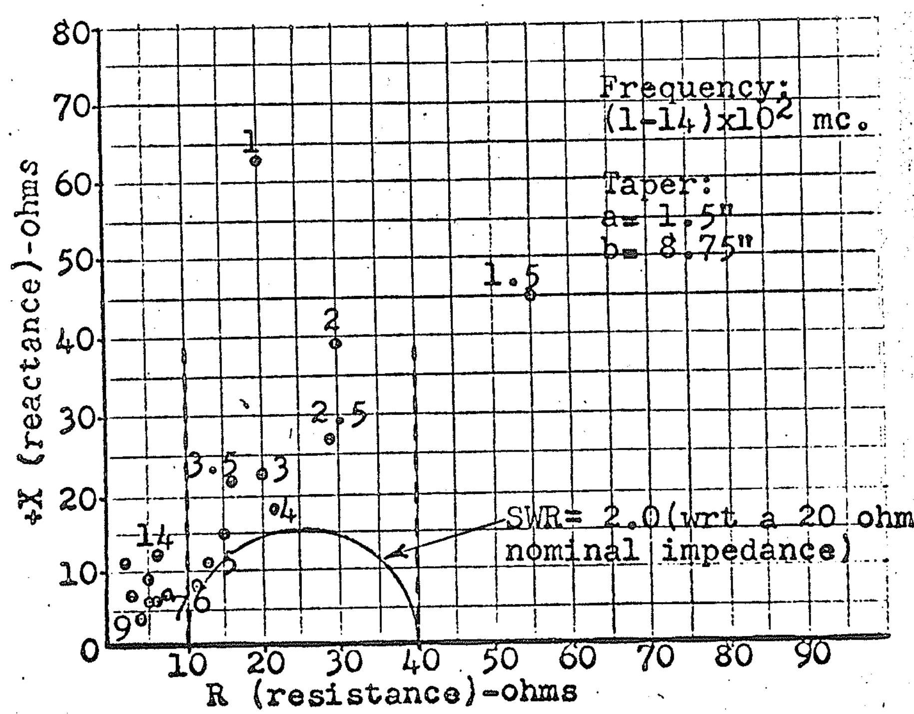

FIGURE 3.12

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC V-DIPOLE ANTENNA WITH END SEPARATION "b" OF 8.75"

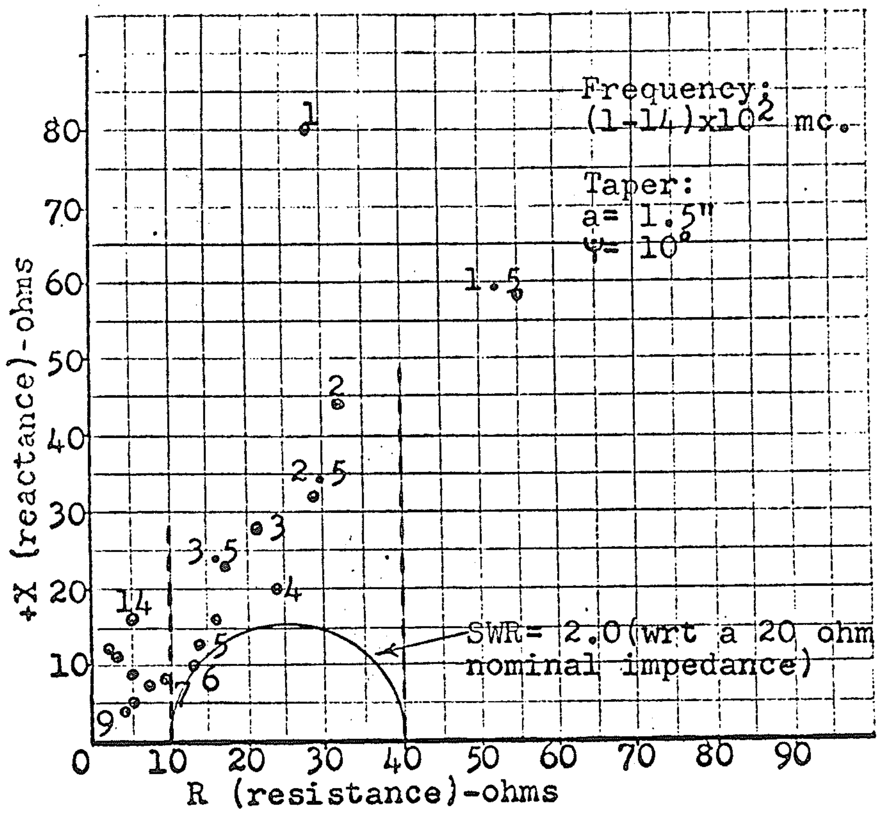

FIGURE 3.13

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC V-DIPOLE ANTENNA WITH TAPER ANGLE "ψ" OF 10°

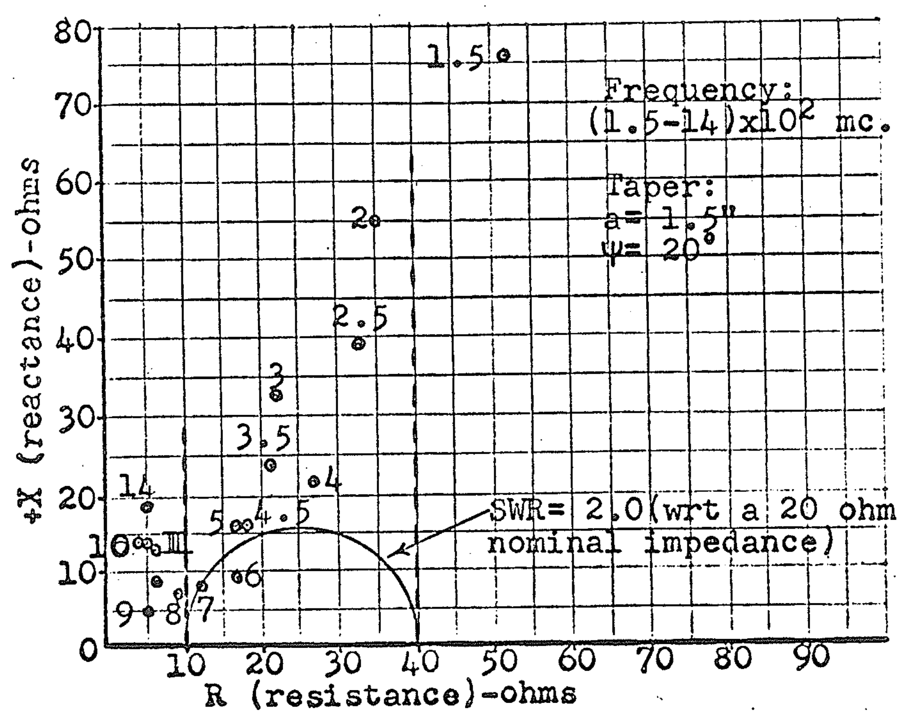

FIGURE 3.14

R-X DIAGRAM OF INPUT IMPEDANCES FOR THE LOG-PERIODIC V-DIPOLE ANTENNA WITH TAPER ANGLE "ψ" OF 20°

SWR over the entire band. The R-axis intercepts of the circle also provide us with a means of calculating a characteristic impedance, according to equation 3.3. This impedance value can be thought of as a mean resistance level for the specified band. It will be known as the nominal characteristic impedance, or the nominal impedance, and will be designated by R_o. Hence, from equation 3.3,

$$R_o = \sqrt{R_{max} \times R_{min}}. \quad \ldots\ldots\ldots\ldots 3.5$$

The SWR represented by the circle is the maximum SWR of the band, referred to the nominal impedance R_o.

DuHamel and Berry[7] stated that impedances of log-periodic antennas whose patterns exhibit a small variation over a period can be characterized by a characteristic impedance and an SWR with respect to that characteristic impedance. The impedance locus circles a point on the real axis once every one or one-half period depending on the type of array. One period corresponds to a change in frequency from f to τf.

The feed points of the antennas tested in this study have the form of a tapered loop. It was expected that this would add a series inductive reactance to the input impedance value and, consequently, shift the impedance points above the real axis on the R-X diagrams. It was also expected that this reactance would increase with increasing frequency. The R-X diagrams seem to verify these assumptions. The straight-dipole antenna (figure 3.1, page 20), for example, centered its input impedance points around an average inductive reactance of approximately forty ohms, rather than around the real R-axis, when considering frequencies from 200 to 900 megacycles per second.

The effect of the series inductive reactance produced by the input feed can best be shown on an input reactance (X)-versus-frequency plot. Such a plot is shown in figure 3.15 for the log-periodic straight-dipole antenna with no taper. The solid curve corresponds to the measured input reactance of the antenna and the straight-line represents the reactance of a constant inductance, which, in this case, is equal to 9.36×10^{-3} microhenries. If the straight-line reactance is attributed to the input-feed loop, then the actual antenna input reactance corresponds to the dashed curve obtained by subtracting the straight-line reactance from the measured values. The actual antenna input impedance is then predominantly centered around the real R-axis in the R-X diagram. The R-X diagram for the same antenna and corrected for the feed-line reactance is shown in figure 3.16, page 30.

In figure 3.15, it is interesting to note that, if the feed-line contributes a constant inductance, only the input impedance values at the higher frequencies are greatly affected. The high reactive components, which occurred at the low frequencies, remain in the corrected values of the input impedance. In other words,

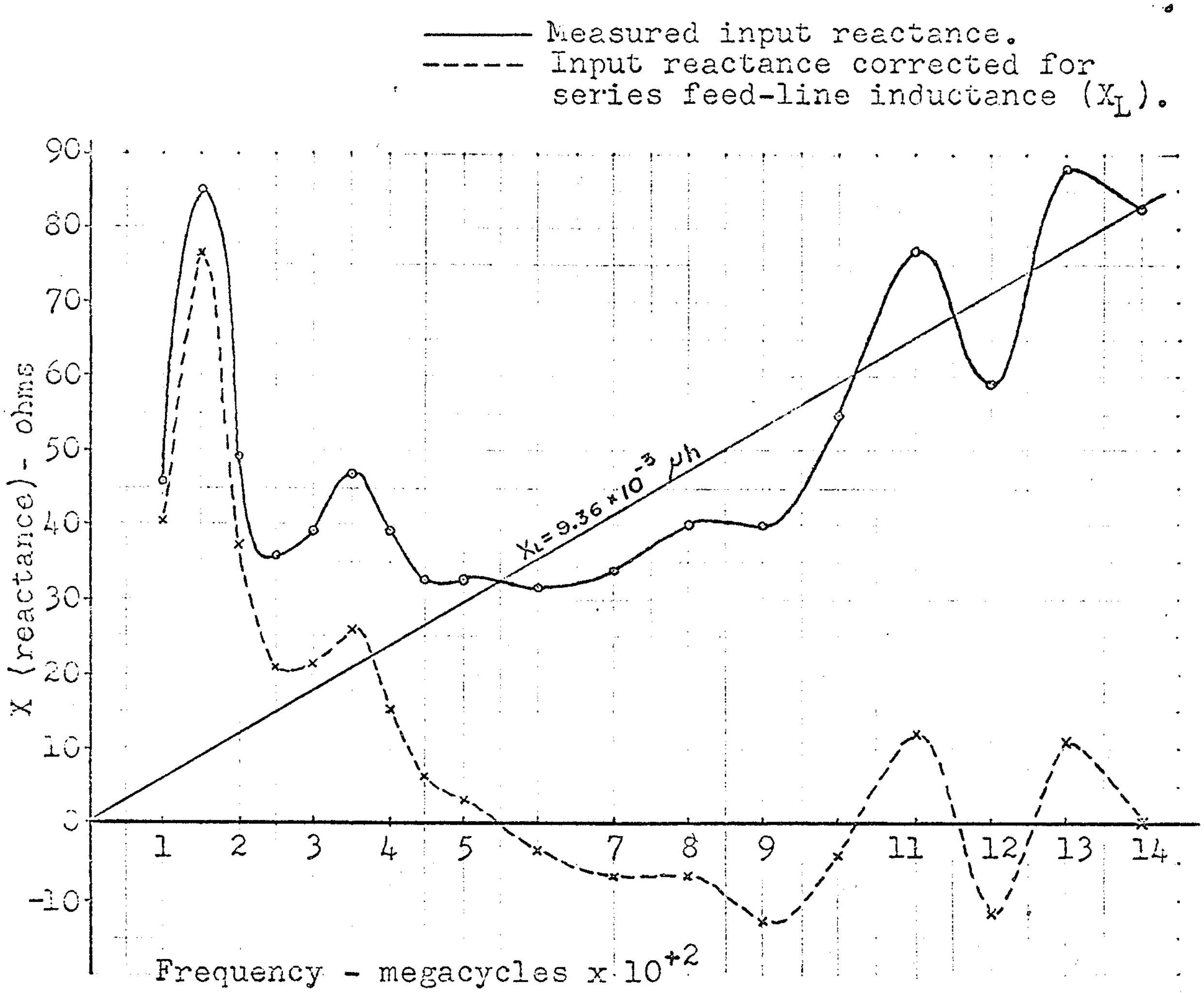

FIGURE 3.15

MEASURED INPUT REACTANCE AND ACTUAL INPUT REACTANCE VERSUS FREQUENCY FOR THE LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA WITH NO TAPER

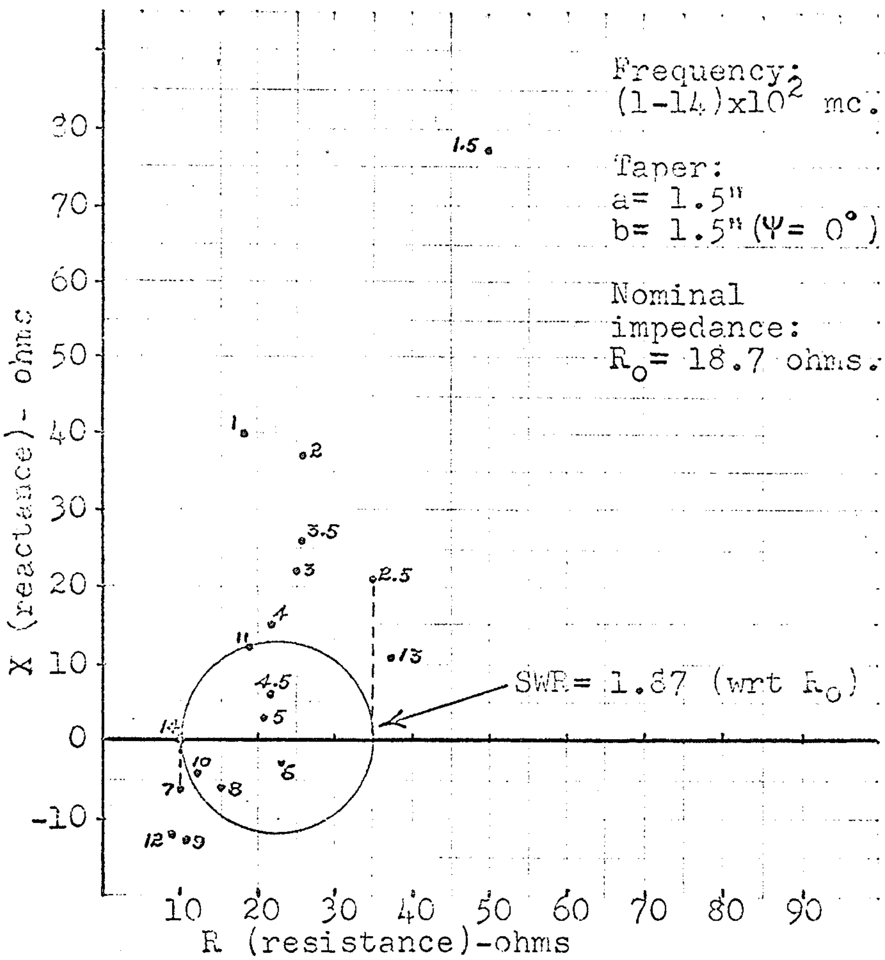

FIGURE 3.16

R-X DIAGRAM OF INPUT IMPEDANCES CORRECTED FOR FEED-LINE REACTANCE FOR THE LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA WITH NO TAPER the high reactive components at the lower frequencies are due mainly to the antenna itself and the high reactive components at the higher frequencies are due mainly to the input feed-line.

In practice, reactive components are undesirable since they usually increase mismatch when the antenna is connected to the feed line. Antenna designers have solved this problem by cancelling reactive effects with matching components or compensating networks[6c]. Compensation at a single frequency is a very simple problem; it becomes more difficult with increasing bandwidth due to larger variations of the reactance.

The reactive component introduced by the input feed is not really a fault of the antenna itself. It can vary greatly, depending on the type of input feed and the frequency used. Therefore, the input reactive component, although important in practical design, is not a fundamental characteristic of the antenna type. Furthermore, if we assume that compensation can, and will, be accomplished over the desired frequency band, the real part of the input impedance becomes the determining factor in characterizing the antenna by a nominal impedance. In view of this fact, we can shift the maximum and minimum real values, for the specified band, so that they lie on the R-axis. The nominal characteristic impedance R_o, can then be calculated from equation 3.5 and the standing-wave ratio, referred to R_o, can be found from equation 3.4. The value of R_o for the antenna will be changed only if the particular compensating network changes it.

The R-X diagrams for the log-periodic straight-dipole antenna (figures 3.1 to 3.7, pages 20 to 23) show the shift of the maximum and minimum resistance values for the approximate design band, the standing-wave ratio circles, and the corresponding nominal impedances. The R-X diagrams for the V-dipole antenna (figures 3.8 to 3.14, pages 23 to 26) show only the circles representing an SWR of 2.0 with respect to a 20 ohm characteristic impedance. This procedure will be justified in the next section.

IV. EFFECTS OF FEED-LINE TAPER

Let us first consider the effect of varying taper on the straight-dipole antenna. The R-X diagrams in figures 3.1 to 3.7, pages 20 to 23, all show high reactive components at the low and high frequency ranges. Moreover, these reactive components show greater variation with increased taper angles than the reactive components at the middle frequencies ranging from 200 to 900 megacycles. It is to be expected that parameter changes at high frequencies have a greater effect than at low frequencies because dimensions become more critical with respect to the wavelength. Since the antenna was designed for an approximate frequency band of 125 to 900 megacycles, the performance between these frequencies is the most important. The R-X diagrams show that the reactive components remain relatively constant over the 200 to 900 megacycle range. The resistance component at a given frequency increases slowly with increasing taper angles. For example, at 400 megacycles, the resistance component increases from 22 ohms at a taper angle of zero degrees to 32 ohms at twenty degrees. At 300 megacycles, the increase is from 25 to 32 ohms. This result would suggest that the nominal impedance should also increase with increasing taper angles. The nominal impedances and SWR's for the straight-dipole antenna are plotted against the taper angles in figure 3.17. The values were found from the R-X diagrams, for the 200 to 900 megacycle band.

Figure 3.17 shows that the nominal impedance stays relatively constant around 19 ohms for small taper angles up to about ten degrees. Actually, a slight decrease in R_o is noted at a ten degree taper. However, at twenty degrees, the nominal impedance rises to 23.1 ohms. We would expect a further increase for angles above twenty degrees. This is in agreement with the results obtained by DuHamel and Ore[5] for a trapezoidal tooth log-periodic antenna. They found the characteristic impedance to vary from 65 to 120 ohms over taper angles (Ψ) ranging from seven to sixty degrees. They did not, however, find the characteristic impedance for small angles below seven degrees. The trapezoidal tooth structure, although being more difficult to construct, is a slightly better approximation to the true log-periodic design than the dipole element structures used for our tests. Figure 3.17 also shows that the SWR remained fairly constant for taper angles up to twenty

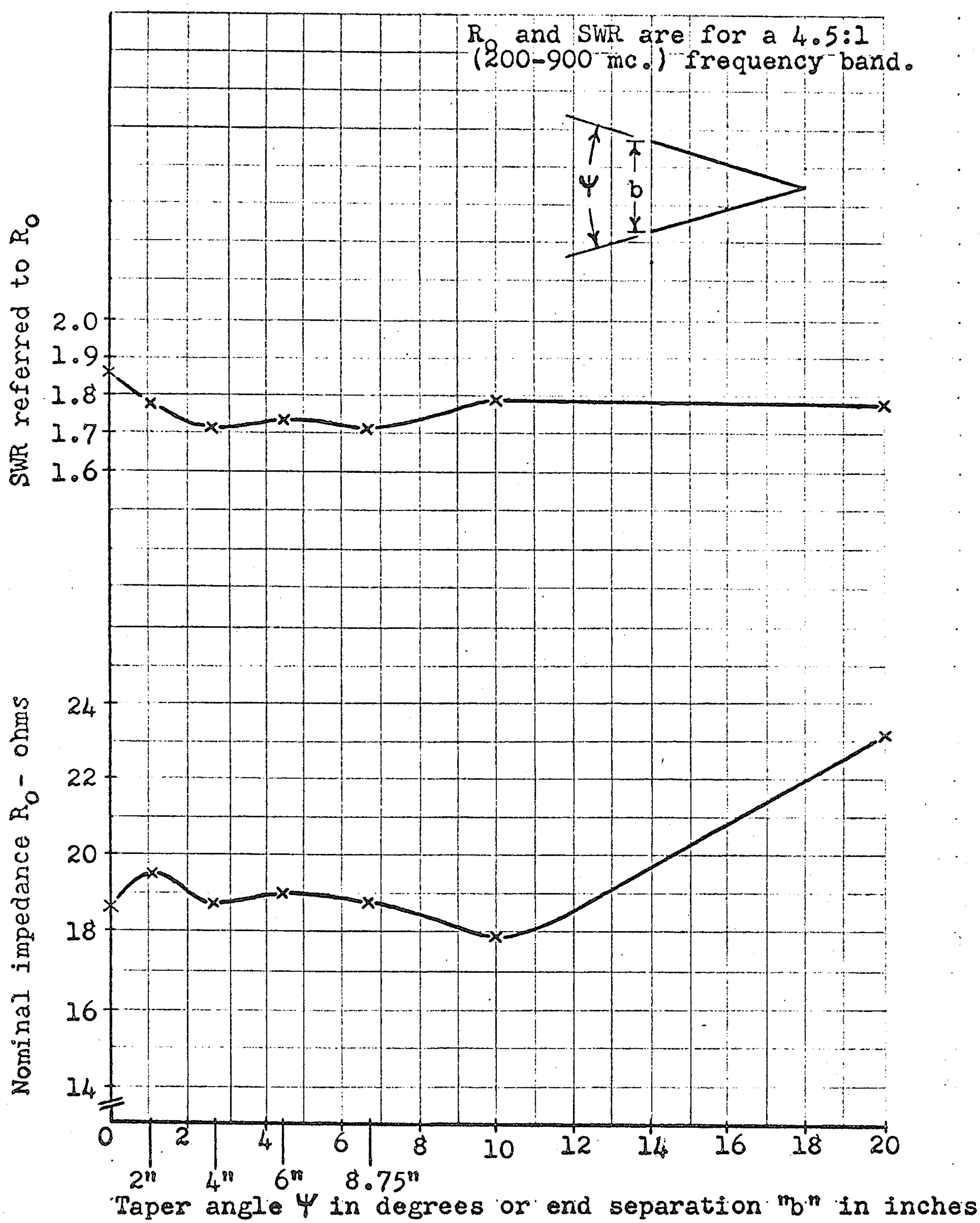

FIGURE 3.17

NOMINAL IMPEDANCE AND STANDING-WAVE RATIO VERSUS TAPER ANGLE FOR THE LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA degrees. Except at zero degrees, the SWR remained below 1.8 and above 1.7. Of course, this is the SWR, referred to the nominal impedance R_o, for a 4.5:1 (200 - 900 mc.) frequency band. For the trapezoidal tooth structure, DuHamel and Ore found the SWR to vary from 1.8 to 1.4 for taper angles from seven to sixty degrees. These SWR's, however, were obtained for a 10:1 (100 - 1000 mc.) frequency band.

Let us now consider the effect of varying taper on the V-dipole antenna. The R-X diagrams are shown in figures 3.8 to 3.14, pages 23 to 26. Unlike the straight-dipole antenna, the V-dipole antenna has a reactive component which, in general, decreases with increasing frequency. Also, the reactive components do not show large variations for increasing taper angles. Whereas the SWR's for the straight-dipole antenna are all below 1.9 for a 200 to 900 megacycle band, the SWR's for the V-dipole antenna are much higher for the same band. For example, the V-dipole antenna with a zero degree taper has an SWR greater than three. Apart from this, the nominal impedances for the band are as low as ten ohms. Unless low reactive components are a criterion for design, the V-dipole structure is inferior in performance as far as input characteristics are concerned.

An SWR of 2.0 is often specified as the maximum allowable in design. It is for this reason that circles representing an SWR of 2.0, with respect to a 20 ohm nominal impedance, were drawn on the V-dipole R-X diagrams. The 20 ohm nominal impedance was chosen because it agreed closely to the nominal impedances obtained for the straight-dipole antenna.

For the V-dipole antenna with no taper (figure 3.8, page 23), the SWR remains less than 2.0 for the approximate band from 200 to 650 megacycles. The R-X diagrams show that there is a slight improvement in bandwidths with increasing taper angles. At a taper angle of twenty degrees, the band extends from approximately 200 to 800 megacycles.

It is evident, from the results, that the straight-dipole antenna would provide a good match to a 20 ohm line over all the taper angles up to twenty degrees. It would produce an SWR of less than 1.9 for a 4.5:1 (200 - 900 mc.) frequency band. The V-dipole antenna would give an SWR of less than 2.0 for a maximum frequency band of 4:1 (200 - 800 mc.) at a taper angle of twenty degrees. The above SWR's, on a 20 ohm feed line, are based on the assumption that large reactive components would be cancelled by a compensating network. The lower SWR's and larger bandwidths indicate the superior input characteristics of the straight-dipole antenna.

V. DISCUSSION OF RESULTS

Enough data has been presented in the R-X diagrams to demonstrate the approximate behaviour of the input impedance as a function of continuous frequency values. The R-X diagrams for the log-periodic straight-dipole and V-dipole antennas are repeated in figures 3.18 and 3.19, respectively, for a zero degree taper angle. The impedance points have been connected

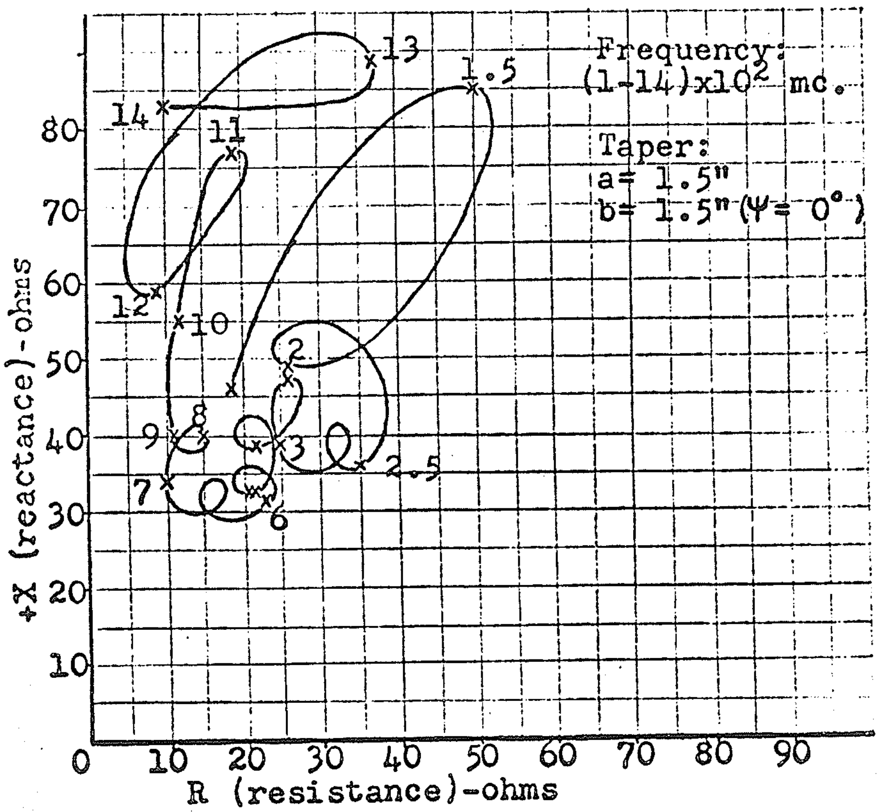

FIGURE 3.18

R-X DIAGRAM IMPEDANCE LOCUS FOR THE LOG-PERIODIC STRAIGHT-DIPOLE ANTENNA WITH NO TAPER

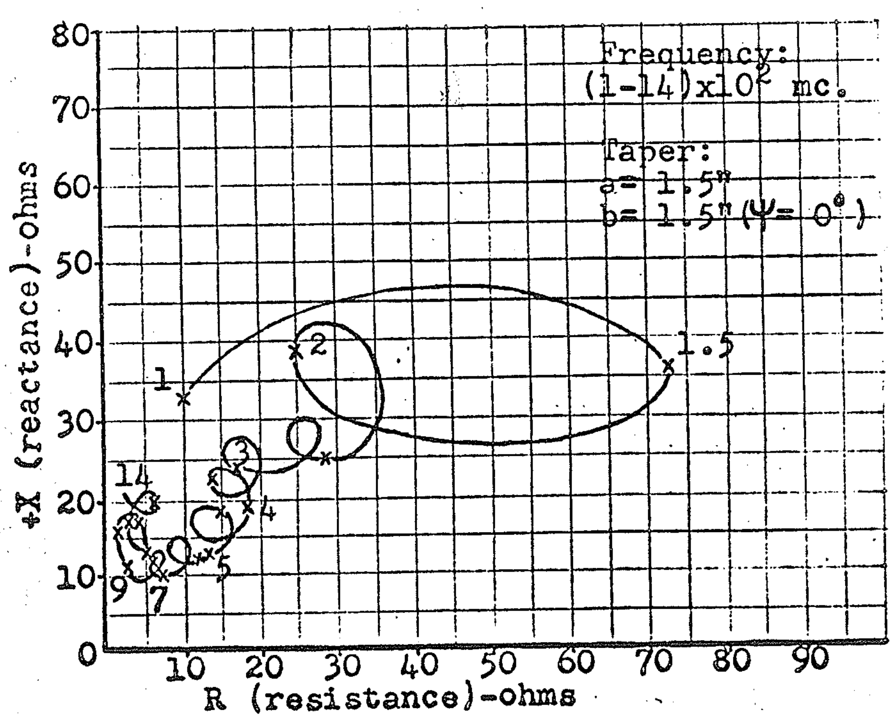

FIGURE 3.19

R-X DIAGRAM IMPEDANCE LOCUS FOR THE LOG-PERIODIC V-DIPOLE ANTENNA WITH NO TAPER to show the approximate impedance locus over the entire frequency range.

We have already attributed the large reactive components as being due to the introduction of series inductive reactance at the antenna feed point. We also stated earlier that the impedance locus should circle a point on the real axis once every one or one-half period. The loops formed by the impedance loci in figures 3.18 and 3.19, page 37, are these circled points shifted above the real R-axis by the series inductive reactance at the feed point. The changing position of these loops with frequency is a result of imperfect scaling of the antennas. As the frequency increased, the elements responsible for the radiation became larger in diameter with respect to the wavelength. Each time that the frequency was increased to the point where the next smaller set of dipole elements became activated (resonant), the impedance locus would shift to a lower resistance component value as shown in figures 3.18 and 3.19, page 37. DuHamel and Ore[5] received similar results with a log-periodic trapezoidal tooth structure, namely, that the input impedance decreased with increasing frequency.

By virtue of design, adjacent dipole elements have resonant frequencies of f and τf, where τ is equal to 0.8 for the straight-dipole and V-dipole antennas. In view of this, we expect a loop in the impedance locus every time the frequency varied from f to 0.8f, that is, every time the active region on the antennas shifted from one dipole set to another. The frequency range f to 0.8f corresponds to one period on these particular antennas. As closely as can be determined from the given points, figures 3.18 and 3.19, page 37, indicate that the impedance loci circle a point approximately every period. Mayes and Carrel[8] attributed deviation from periodicity as being due to the necessary truncation at the front of the antenna. This causes imperfect frequency scaling.

The loops in the impedance locus on an R-X diagram represent the impedance variation over a period. They are a frequency dependent shortcoming of the antenna design. The shifting of the loops over a number of periods is a frequency dependent shortcoming of the imperfect antenna construction. It is obvious from the R-X diagrams that these factors are what reduce the operational bandwidths of the log-periodic dipole antennas.

So far, we have been discussing the variation of the input impedance. We should consider the general impedance level. As might be expected, the input impedance magnitude is dependent on the characteristic impedance of the feeder from which the radiating elements obtain their energy. The feeder impedances of the test antennas are dependent on the spacing and size of the two booms making up the feeder. When the booms are not tapered, they can be likened to an air dielectric two-wire line for which

Ramo and Whinnery[9] have developed a characteristic impedance formula. The equation is given as

$$Z_o = 120 \cosh^{-1} (S/d) \text{ ohms}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

where S is the spacing between centers and d is the diameter of each line. The log-periodic straight-dipole and V-dipole antennas have booms of 3/4 inch diameters and have a center spacing of 1 1/2 inches with no taper. Substituting these values in equation 3.6, we get

$$Z_o = 120 \cosh^{-1} (2) = 157 \text{ ohms}.$$

This value is obviously much higher than the nominal impedance values of approximately 20 ohms obtained for the test antennas. It is also higher than any predicted value since the dipole elements attached to the booms would reduce the characteristic impedance. When the frequency corresponds to the resonant frequency of a dipole element, the input impedance of the antenna becomes dependent mainly on the driving point impedance of that resonant element. For a thin half-wavelength dipole, this value is only 73 ohms[10a]. The average length-to-diameter ratio of the dipole elements on the test antennas is approximately 50. According to King[12], the input resistance at resonance of these elements is around 68 ohms. We can only attribute the large difference between the predicted impedance and the nominal value of around 20 ohms as being due to imperfect antenna constructinn.

Nominal impedance levels from 55 to 100 ohms were obtained by Isbell[3] using a feeder with a characteristic impedance of 105 ohms. DuHamel and Isbell[2] assumed discrepancies between predicted and measured values as being due to the finite thickness and length of the elements.

The magnitude of the input impedances for log-periodic dipole antennas is also dependent on the design parameters τ and α. These parameters were fixed for the test antennas; τ had a value of 0.8 and α a value of forty degrees. Carrel[11] made an analysis of the log-periodic dipole antenna and found that the nominal impedance decreases with increasing τ and increasing α. He also derived an equation to determine the feeder characteristic impedance which would yield a given nominal impedance R_o. Unsurprisingly, this equation is a function of the dipole spacings, element thicknesses, and dipole driving point impedances.

In the preceeding section of this chapter, we found that small-angle taper variations did not make the antennas very flexible as far as the input characteristics were concerned. The effect of the taper variations on the radiating characteristics is a topic of discussion in chapter four.

CHAPTER IV

ANALYSIS OF THE RADIATION PATTERN MEASUREMENTS

Input impedances and standing-wave ratios are by no means the only factors to be considered in an antenna performance analysis. Of equal importance are the radiation properties of the antenna.

The radiation pattern measurement set-up, an explanation of the principal E and H-planes, and the measured patterns are given in Appendix C. Since a very large number of patterns were taken, only those which are sufficient to show the radiation characteristics are given in the appendix.

I. INTRODUCTION

The analysis or properties of radiation patterns is normally given in terms of the gain, directivity, beamwidths, side-lobe levels, and general beam shape. Except for unusual pattern shapes, the principal E and H-plane patterns[10b] are sufficient to show the radiation characteristics of an antenna.

The directivity or directive gain of an antenna is the ratio of the maximum to the average radiation intensity. It is usually given as the directivity over an isotropic source[10c]. An isotropic source is one which radiates equally in all directions and therefore has a directivity equal to one. Kraus derived an approximate formula[10d] for the directivity of a single-lobed pattern, based on the half-power beamwidths of the patterns in two planes at right angles. We can write this equation as

$$D = \frac{41,250}{B_e B_h}^{*}, \qquad \ldots\ldots 4.1$$

where B_e and B_h are the half-power beamwidths in degrees in the E and H-planes, respectively. The half-power beamwidth is the angle within which the electric field does not fall below 0.707 of its maximum value. The above formula is not exact because it does not take into account the exact shape of the beam and the minor lobes. Unless the beam is of unusual shape and when side-lobes are more than 10 db. down from the maximum, equation 4.1 gives a good estimate of the directivity. The directivity is often given in db., in which case ten times the logarithm to the base ten of the right side of equation 4.1 is found.

The strength of the side lobes or minor lobes is normally specified in db. below the main lobe. This is termed the front-to-back ratio in db.

II. EFFECTS OF FEED-LINE TAPER

The radiation patterns for the log-periodic straight-dipole and V-dipole antennas show that these structures radiate a single linearly-polarized lobe which is directed toward the apex of the array. The properties of these patterns may be characterized by the terms and definitions given in the introduction. The results of the calculations on the measured patterns are given in tables 4.1 and 4.2.

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* This equation is a further approximation to the one found by Kraus - $D = \frac{41,253}{B_e B_h}$.

TABLE 4.1

HALF-POWER BEAMWIDTHS, DIRECTIVE GAINS, AND FRONT-TO-BACK RATIOS FOR THE STRAIGHT-DIPOLE ANTENNA WITH VARIOUS FEED-LINE TAPER ANGLES

Frequency (mc)	Taper: end sep. b (in.)	Beamwidth * (degrees) E-plane	Beamwidth * (degrees) H-plane	Directivity D	Directivity db.	Front-to-back ** ratio in db. E-plane	Front-to-back ** ratio in db. H-plane
200	1.5	48	76	11.3	10.5	21.1	-
300	"	42	72	13.6	11.4	-	11.7
400		38	64	17.0	12.3	-	8.0
500		36	78	14.7	11.7	-	-
600		38	60	18.1	12.6	-	18.4
700		42	50	19.6	12.9	24.4	20.0
800		38	66	16.4	12.2	15.4	15.4
900		48	-	-	-	6.7	7.5
1000		40	42	24.6	13.9	-	-
1100		42	-	-	-	3.9	-
1200		-	-	-	-	9.4	14.9
200	2.0	52	86	9.2	9.7	14.4	-
400	"	40	66	15.6	11.9	-	11.7
600		38	74	14.7	11.7	-	14.9
800		42	64	15.4	11.9	14.4	14.9
900		-	-	-	-	-	5.5
1000		38	58	18.7	12.7	-	-
1200		-	-	-	-	9.9	14.9
200	4.0	52	92	8.6	9.4	14.4	-
400	"	42	66	14.9	11.7	-	12.8
600		38	46	23.6	13.7	-	16.5
800		44	66	14.2	11.5	14.9	19.2
900		-	-	-	-	-	10.4
1000		42	-	-	-	-	-
1200		-	-	-	-	8.9	15.4
200	6.0	60	92	7.5	8.7	9.9	-
400	"	48	70	12.3	10.9	-	15.9
600		38	52	20.9	13.2	-	17.1
800		44	68	13.8	11.4	-	20.0
900		-	-	-	-	-	10.8
1000		40	-	-	-	-	-
1200		-	-	-	-	9.9	16.5
200	8.75	56	94	7.8	8.9	16.5	-
400	"	50	74	11.1	10.5	-	-
600		38	54	20.1	13.0	-	19.2
800		46	70	12.8	11.1	-	23.1
900		-	-	-	-	-	12.8
1000		40	-	-	-	-	-
1200		-	-	-	-	9.4	16.5

* The blank spaces indicate pattern breakup.

** The blank spaces indicate that the back lobes are not measurable and the front-to-back ratio is greater than 20 db.

TABLE 4.2

HALF-POWER BEAMWIDTHS, DIRECTIVE GAINS, AND FRONT-TO-BACK RATIOS FOR THE V-DIPOLE ANTENNA WITH VARIOUS FEED-LINE TAPER ANGLES

Frequency (mc.)	Taper: end sep. b (in.)	Beamwidth * (degrees)		Directivity		Front-to-back ** ratio in db.	
		E-plane	H-plane	D	db.	E-plane	H-plane
200	1.5	56	88	8.4	9.2	11.7	-
300	"	48	80	10.7	10.3	-	16.5
400		46	66	13.6	11.3	-	14.9
500		36	82	14.0	11.5	21.1	-
600		42	54	18.2	12.6	-	20.0
700		40	44	23.4	13.7	20.0	17.7
800		48	76	11.3	10.5	20.0	20.0
900		-	-	-	-	8.6	7.3
1000		-	-	-	-	-	-
1100		-	-	-	-	7.1	14.0
1200		-	-	-	-	12.4	12.8
200	2.0	56	84	8.8	9.4	10.8	-
400	"	48	68	12.6	11.0	-	16.5
600		42	60	16.4	12.1	-	8.0
800		46	68	13.2	11.2	21.1	16.5
900		-	-	-	-	-	9.1
1000		-	-	-	-	-	-
1200		-	-	-	-	12.8	14.4
200	4.0	60	84	8.2	9.1	10.8	-
400	"	50	78	10.6	10.2	-	21.9
600		42	58	16.9	12.3	-	-
800		46	70	12.8	11.1	19.2	19.2
900		-	-	-	-	-	9.4
1000		-	-	-	-	-	5.4
1200		-	-	-	-	12.8	15.9
200	6.0	58	86	8.3	9.2	-	-
400	"	54	80	9.6	9.8	-	21.9
600		44	56	16.7	12.2	-	-
800		46	72	12.5	11.0	21.1	19.2
900		-	-	-	-	-	8.6
1000		-	-	-	-	-	3.6
1200		-	-	-	-	14.9	3.3
200	8.75	50	84	9.8	9.9	21.9	-
400	"	54	84	9.1	9.6	-	26.0
600		42	66	14.9	11.7	-	-
800		47	78	11.3	10.5	21.1	21.1
900		-	-	-	-	-	10.4
1000		-	-	-	-	-	-
1200		-	-	-	-	12.4	2.6

* The blank spaces indicate pattern breakup.

** The blank spaces indicate that the back lobes are not measurable and the front-to-back ratio is greater than 20 db.

The half-power beamwidths, directive gains, and front-to-back ratios are given for both antenna structures with various taper angles. The amount of taper is designated by the end separation "b". The blank spaces in some of the columns indicate that the particular calculation was not applicable for that pattern due to multiple lobing or pattern breakup. Since we are interested in the maximum side-lobe levels over the frequency band, only the front-to-back ratios which are significant were calculated.

The patterns for the log-periodic structures were single lobed with low side-lobe levels for frequencies from 200 to 800 megacycles. At 900 megacycles, however, pattern breakup due to multiple lobing was observed. The beamwidths and directivities in tables 4.1 and 4.2 can be averaged over the frequency range from 200 to 800 megacycles for each separate taper condition. The resulting average values can be compared to show the effect of varying the feed-line taper.

The average E and H-plane beamwidths for the antennas are plotted as a function of the taper angle in figure 4.1. For the straight-dipole structure, both the E and H-plane beamwidths increased with increasing taper angles. For the V-dipole structure, the H-plane beamwidths also increased with increasing taper angles, but those in the E-plane remained relatively constant. The H-plane beamwidths for both structures were considerably higher than the E-plane beamwidths. It is interesting to note that the V-dipole

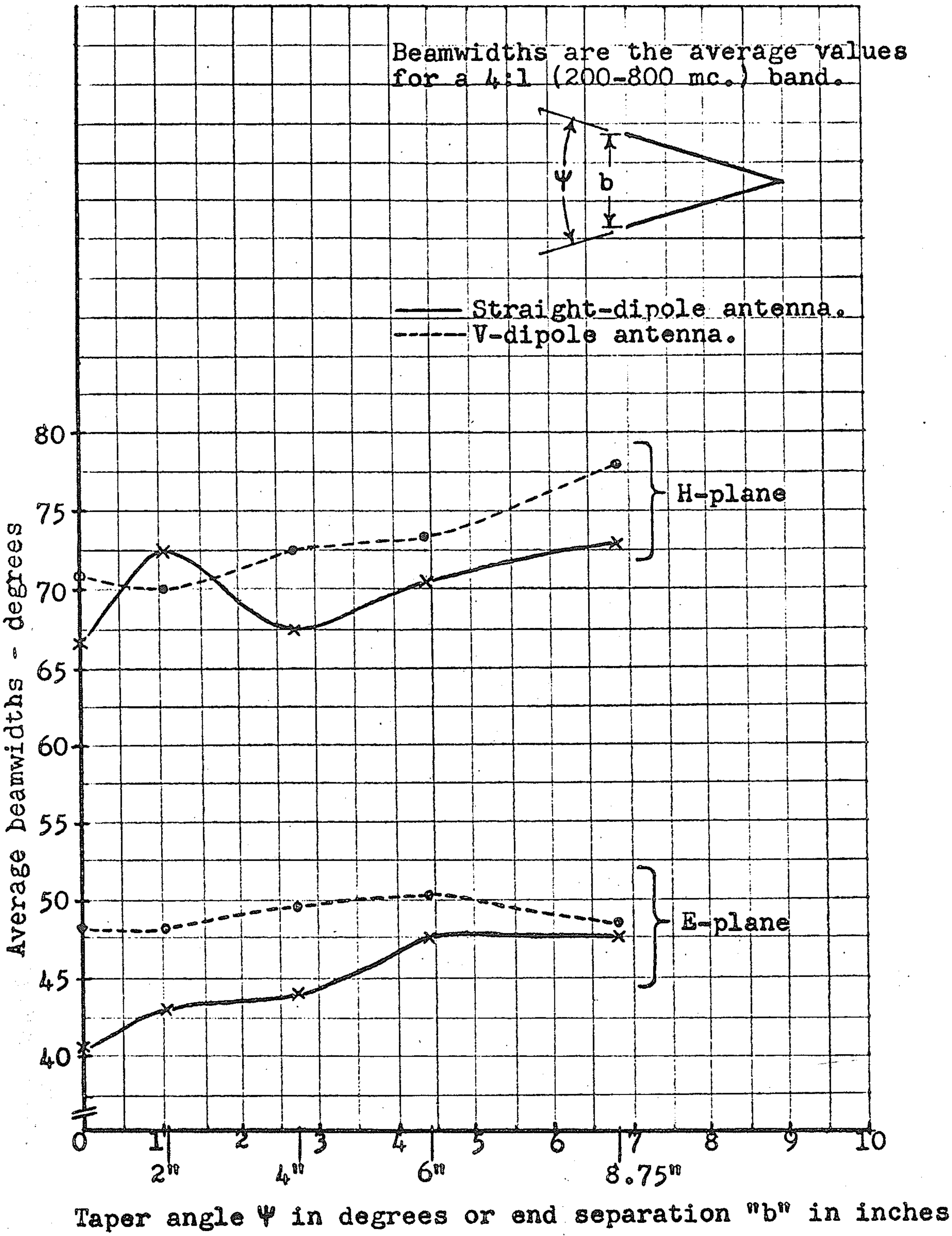

FIGURE 4.1

AVERAGE E AND H-PLANE BEAMWIDTHS AS A FUNCTION OF TAPER ANGLE FOR THE LOG-PERIODIC STRAIGHT-DIPOLE AND V-DIPOLE ANTENNAS structure has generally higher beamwidths than the straight-dipole structure.

The average directive gains in db. for the antennas are plotted as a function of the taper angle in figure 4.2. The figure shows that the directivity decreases with increasing taper angles. This decrease is to be expected because the directivity varies inversely as the beamwidth. The same inverse relation accounts for the fact that directivity is greater for the straight-dipole structure than for the V-dipole structure.

Let us compare our results with those found by DuHamel and Ore[5] for the wire trapezoidal-tooth structures. They found an average E-plane beamwidth of 67 degrees, an average H-plane beamwidth of 106 degrees, and an average front-to-back ratio of 15 db. They also found that the H-plane beamwidths decreased with an increase in taper angle Ψ and that the E-plane pattern was essentially independent of the Ψ-angle. Their results were obtained for Ψ-angles ranging from thirty to sixty degrees. The reverse was found to be true in our case for Ψ-angles below ten degrees; the E and H-plane beamwidths increased with an increase in taper angle. Over the 200 to 800 megacycle band of the straight-dipole structure, we obtained a minimum front-to-back ratio of 9.9 db. in the E-plane and 8.0 db. in the H-plane. The V-dipole structure had a minimum front-to-back ratio of 10.8 db. in the E-plane and 8.0 db. in the H-plane. The average front-to-back ratio

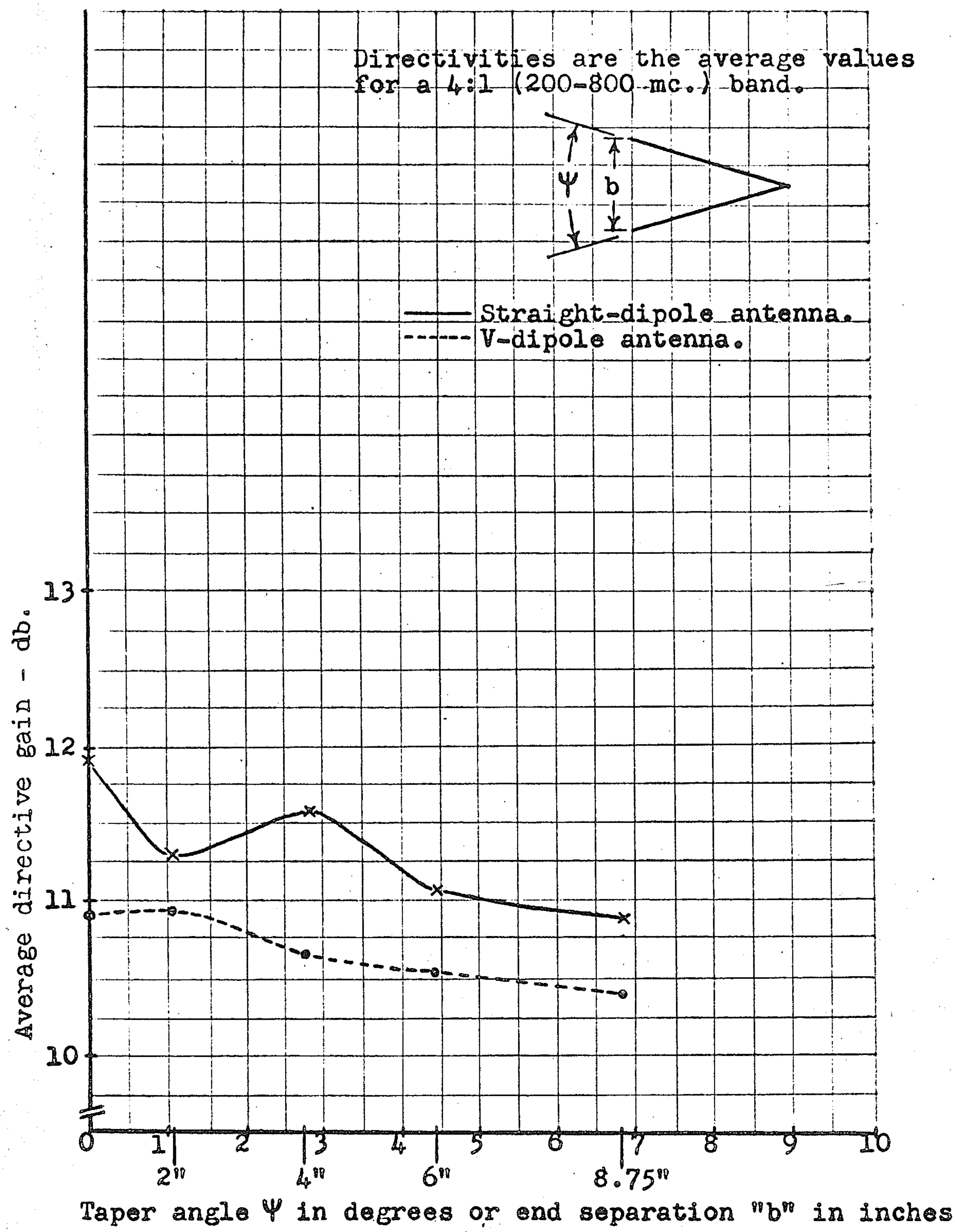

FIGURE 4.2

AVERAGE DIRECTIVITY AS A FUNCTION OF TAPER ANGLE FOR THE LOG-PERIODIC STRAIGHT-DIPOLE AND V-DIPOLE ANTENNAS for both structures over all the taper angles was better than 15 db.

III. DISCUSSION OF RESULTS

The variation of the directivity over the designed frequency band of a log-periodic antenna is a good measure of its frequency independent performance. Figure 4.3 shows the directivity as a function of frequency over a 4:1 (200 - 800 mc.) band for the test antennas with no taper. The straight-dipole structure had a maximum directivity variation of 8.3 or 2.4 db. For the V-dipole structure, the maximum variation was 15.0 or 4.5 db. These variations are very large and may be partly the result of the approximate method of calculation. The maximum directivity for both structures seems to occur near 700 megacycles.

We stated earlier that radiation pattern breakup was observed at 900 megacycles for both log-periodic structures. At this frequency multiple lobes appeared in the patterns. Pattern breakup may be caused by two factors. Firstly, if the frequency is increased to the point where the active region moves very close to the feed transition near the apex, pattern deterioration results. The second factor is a result of the dipole elements resonating in a three-half-wavelength mode. For example, at 900 megacycles the radiation may occur from the front elements on the antenna as well as from an element near the back operating in the three-half-wavelength

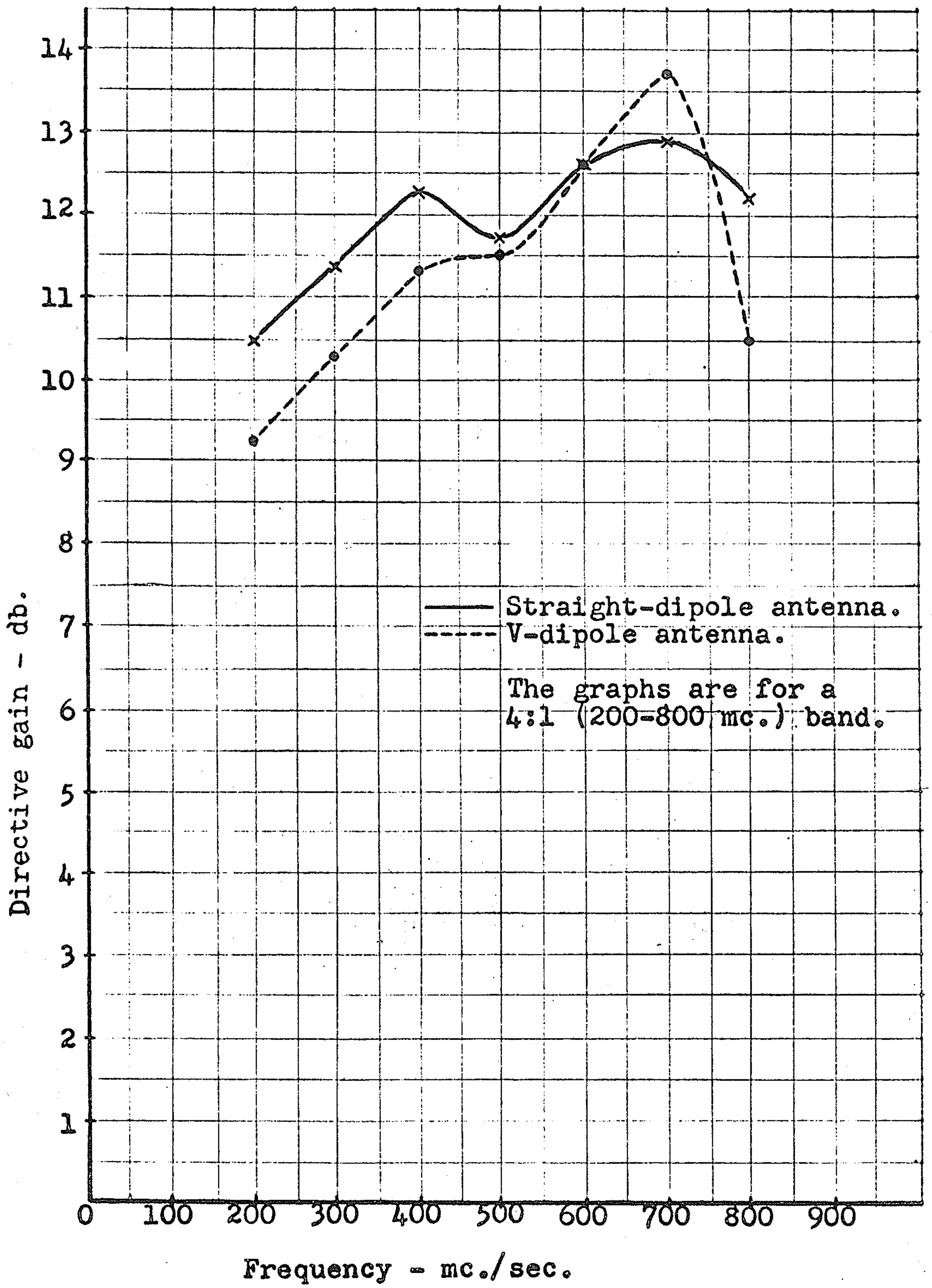

FIGURE 4.3

DIRECTIVITY AS A FUNCTION OF FREQUENCY FOR THE LOG-PERIODIC STRAIGHT-DIPOLE AND V-DIPOLE ANTENNAS WITH NO TAPER mode. The distance between the two active regions thus set up would cause lobing of the patterns. At 900 megacycles, an element equivalent in length to a half-wavelength at 300 megacycles would operate in the three-half-wavelength mode. A check of the design shows that our log-periodic structures support elements which are a half-wavelength long at 305.5 megacycles. These elements are undoubtedly the cause of the lobing at 900 megacycles.

The front-to-back ratios for the structures were found to be generally lower at 200 megacycles than at higher frequencies in the band. This is probably due to the active region approaching the length of the antenna at low frequencies. When this occurs, electrically speaking, the antenna no longer looks like an infinite structure.

The log-periodic straight-dipole and V-dipole structures were found to have directive gains greater than 10 db. and E and H-plane beamwidths of approximately 45 and 70 degrees, respectively, over a 4:1 bandwidth. The directivity of these antennas is surprisingly high. Isbell[3] obtained directive gains of 10 db. over a 2:1 bandwidth with the log-periodic dipole array. Mayes and Carrel[8] found average directive gains of about 8 db. over a 3:1 bandwidth. Carrel[11] also found that the gain of a log-periodic dipole antenna is determined primarily by the design parameters τ and α. The gain increases as τ increases and α decreases.

The variation of the feed-line taper on the dipole structures had generally more effect on the H-plane patterns than on the E-plane patterns. This was also true when considering side lobes. The beamwidths of all patterns increased with increasing taper angles except the E-plane beamwidths which remained relatively unchanged for the V-dipole antenna. However, a variation of the beamwidth in only one of the principal planes is sufficient to produce a variation in the antenna directive gain.

CHAPTER V

CONCLUSIONS

The log-periodic dipole antennas were found to have a characteristic radiation pattern which was single lobed and directed towards the apex of the array; they had an average nominal impedance of approximately twenty ohms, a directive gain greater than 10 db. over isotropic, and a standing-wave ratio referred to the nominal impedance of less than two for a bandwidth greater than four to one.

The results obtained for small feed-line taper angles showed that the standing-wave ratio did not seem to be strongly dependent on the nominal impedance R_o. Therefore it won't be strongly dependent on the feeder characteristic impedance. The nominal impedance remained relatively constant for small taper angles below ten degrees and increased with increasing taper angles above ten degrees. The antenna directivity was found to be a function of the taper angle; it decreased with an increase in taper angle. Although the decrease in directivity is a disadvantage, the taper angles did give an improvement in side-lobe levels at certain frequencies, particularily at 200 megacycles in the E-plane. An important observation from a comparison viewpoint was that for most log-periodic structures and for taper angles above ten degrees the directivity increases with increasing taper angles.

In comparing the straight-dipole and V-dipole structures, the most significant differences were the lower input reactive components and the lower directive gains of the V-structure for all taper angles.

It was concluded that frequency dependence of the characteristics was caused by two factors: (1) the particular log-periodic design, and (2) the imperfect antenna construction.

Enough data have been presented to provide information for practical design. Factors such as the pattern breakup at 900 megacycles and the front-to-back ratios become critical in practical applications. The small-angle taper variations provide a certain amount of independent control of input and radiation characteristics. However, for most applications one is usually interested in designing an antenna which exhibits maximum gain over a given frequency band compatible with limitations on the input impedance and standing-wave ratio.

The log-periodic dipole antenna, besides having comparable directive gain, offers considerable advantage over parasitic (i.e. Yagi)[10e] arrays in bandwidth and as a result is much less critical to adjust for proper operation.

It is obvious that in an experimental investigation of a broadband antenna one is confronted with the task of making hundreds of measurements. The data presented in this report were taken from over a thousand impedance measurements and hundreds of radiation pattern measurements. The emphasis is now on theoretical analysis. Carrel[11] has made an analysis of the log-periodic dipole antenna in terms of the known properties of dipoles. However, the straight-dipole and V-dipole structures are only two of many approximations to the true log-periodic design. The complexity and variations of log-periodic antennas makes a complete theoretical analysis an extremely difficult problem.

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BIBLIOGRAPHY

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APPENDIX

APPENDIX A

MEASUREMENT OF ANTENNA INPUT IMPEDANCE

The input impedance of the experimental log-periodic antennas is the impedance looking into the two wire feed line, rather than the impedance looking into the twenty foot eleven inch length of RG-8A/U co-axial cable feeding the antennas.

In order to measure the input impedance directly, a "dummy" line was employed with a special short at the end. The "dummy" line is identical to the co-axial lines feeding the antennas and is also twenty feet eleven inches in length. The special short refers to the cable terminated in a tapered loop with a flat plate providing the short. In other words, it is a short-circuited model of the actual cable to tubing transition used on the antennas. A photograph of the "dummy" line is shown in figure A.1.

Figure A.2 shows a block diagram of the input impedance measurement set-up.

The test antenna was placed on a mount on top of the Engineering Building and oriented in such a way so as to minimize interference from surrounding objects.

For each frequency, the "dummy" short-circuited line and the adjustable line was connected to the admittance meter. The line was adjusted for an odd multiple of a

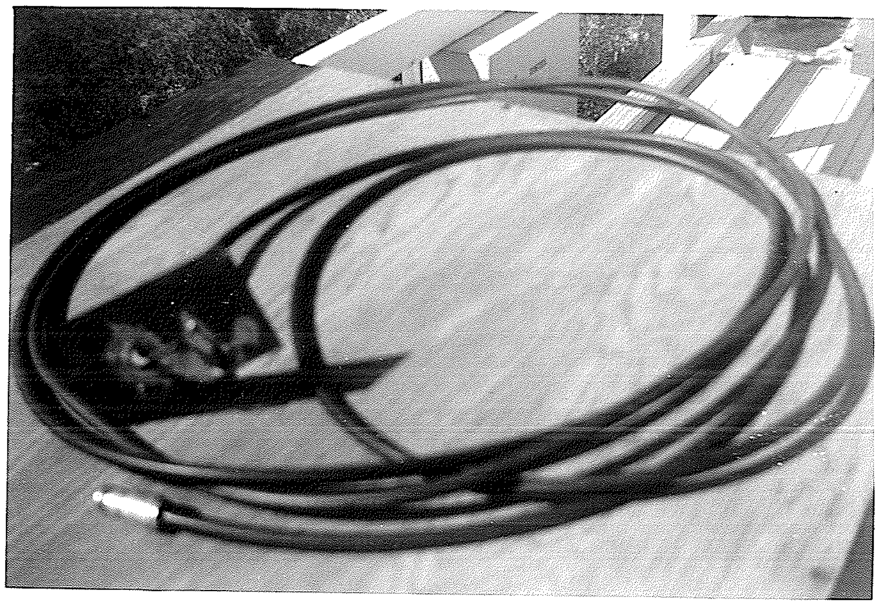
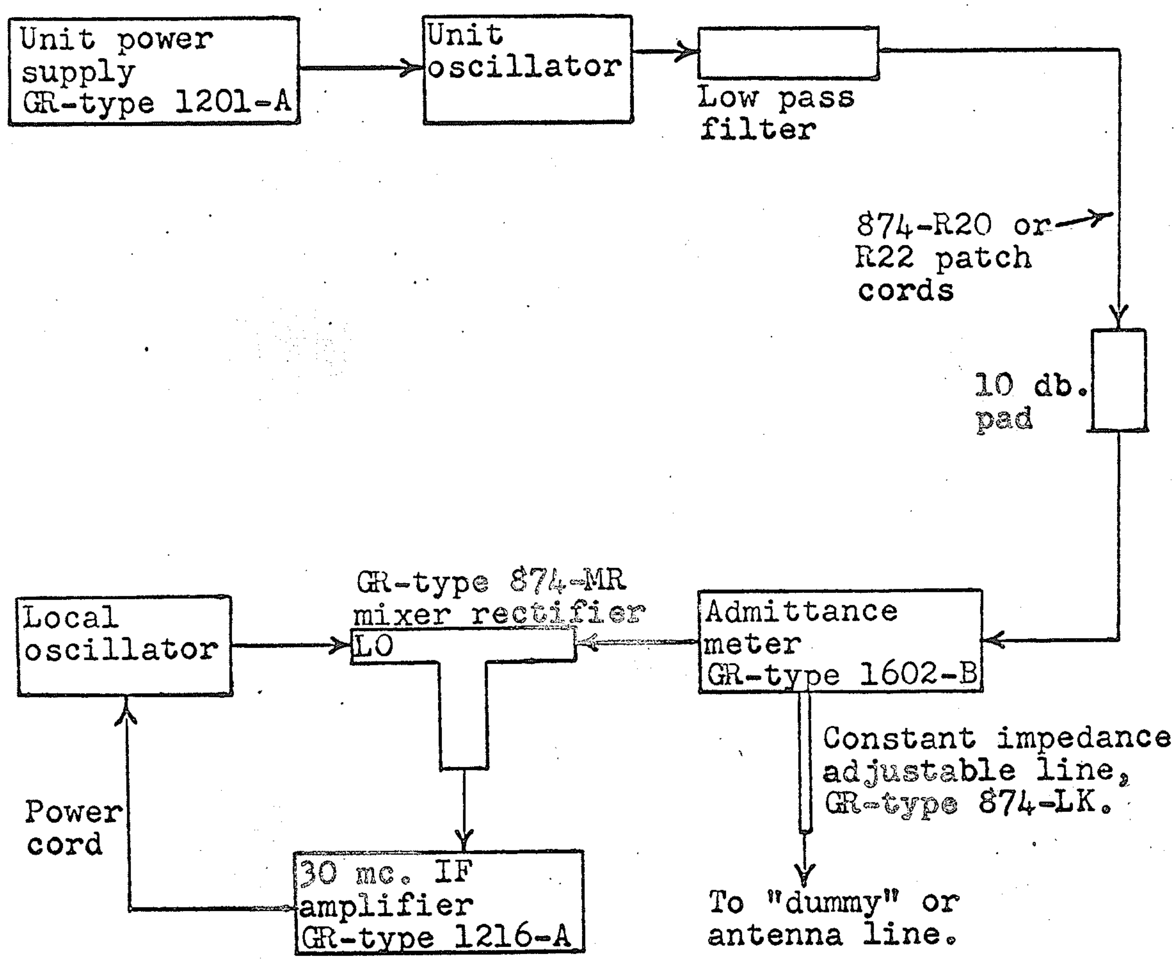


FIGURE A.1

PHOTOGRAPH OF THE SHORT-CIRCUITED MODEL OF THE ANTENNA FEED CABLE



<u>GR - UNIT OSCILLATORS</u>

Type 1215-B - 50 to 250 mc.
Type 1209-B - 250 to 920 mc.
Type 1218-A - 900 to 2000 mc.

FIGURE A.2

BLOCK DIAGRAM OF INPUT IMPEDANCE MEASUREMENT APPARATUS quarter wavelength. This was done by setting the meter to balance at the admittance of an open circuit (0 + j0) and the instrument balanced (a null on the I.F. amplifier) by adjusting the constant-impedance line. Due to the co-axial cable attenuation loss, it was necessary to adjust the conductance arm from the zero position to obtain a perfect null.

The "dummy" line was then removed and replaced by the antenna cable feed. The admittance meter was rebalanced by means of the arms. The meter readings multiplied by 2.5 were the series resistance and reactance of the antenna input uncorrected for line loss.

The 2.5 factor arises due to the quarter wavelength effective line length. The admittance seen by the admittance meter is

$$Y_m = Y_o^2 / Y_x \text{ millimhos,} \qquad \text{A.1}$$

where Y_o is the characteristic admittance of the line and Y_x is the unknown admittance. Therefore,

$$Y_m = Z_x / Z_o^2 \text{ millimhos,} \qquad \text{A.2}$$

where Z_o = 50 ohms. Hence,

$$Z_x = Y_m \text{ (millimhos)} \times 10^{-3} \times 50^2$$
$$= Y_m \text{ (millimhos)} \times 2.5 \text{ ohms.} \qquad \text{A.3}$$

The measured impedances were corrected for line loss by applying the loss in db.*, at each frequency, to a Smith Chart .

The characteristic impedance of RG-8A/U co-axial cable

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* The line loss in db. for the feed cable is given in Appendix B.

is 52 ohms. The admittance meter readings are based on a characteristic impedance of 50 ohms. This discrepancy causes a small error in the measured impedances. Because of the reduced accuracy, each impedance reading was taken as an average of two separate meter readings and the result taken to the nearest whole number. The accuracy of the admittance meter is $\pm 3\sqrt{M}$ percent, where M is the multiplying factor on the meter. The best accuracy that could be obtained for the impedance values was then ± 3 percent.

The results of the impedance measurements are given in table A.1 for the log-periodic straight-dipole antenna and in table A.2 for the log-periodic V-dipole antenna. The corrected input impedances are given for various feed-line tapers and frequencies ranging from 100 to 1600 megacycles per second. The feed-line taper is designated by the large end-spacing "b" or by the taper angle Ψ. The VSWR is the voltage standing-wave ratio on the feed cable of the antenna and is obtained from the corrected impedance point on the Smith Chart. It is the standing-wave ratio with respect to a 50 ohm line.

TABLE A.1

INPUT IMPEDANCES AND VOLTAGE STANDING WAVE RATIOS FOR LOGARITHMICALLY PERIODIC STRAIGHT-DIPOLE ANTENNA (LPD)

"b"-end spacing (inches)	Frequency (mc/sec.)	Input impedance (ohms)	VSWR	"b"-end spacing (inches)	Freq.	Input impedance (ohms)	VSWR
I.5 (ψ=0°)	I00	I8 +j 46	5.3	2.0	I00	I8 +j 52	6.0
"	I50	50 " 85	2.8	"	I50	5I " 5I	2.6
"	200	26 " 49	4.0	"	200	26 " 48	4.0
"	250	35 " 36	2.5	"	250	35 " 38	2.5
"	300	25 " 39	3.4	"	300	26 " 39	3.3
"	350	26 " 47	3.9	"	350	26 " 47	3.9
"	400	22 " 39	3.8	"	400	22 " 39	3.8
"	450	22 " 33	3.4	"	450	23 " 32	3.2
"	500	2I " 33	3.4	"	500	23 " 33	3.2
"	600	23 " 32	3.2	"	600	23 " 3I	3.2
"	700	I0 " 34	7.0	"	700	I2 " 33	6.2
"	800	I5 " 40	5.5	"	800	I7 " 40	5.0
"	900	II " 40	7.3	"	900	II " 4I	8.I
"	I000	I2 " 55	I0.0	"	I000	II " 54	9.8
"	II00	I9 " 77	9.0	"	II00	I7 " 7I	9.5
"	I200	9 " 59	I4.0	"	I200	9 " 58	I3.0
"	I300	37 " 88	6.I	"	I300	35 " 87	6.3
"	I400	I0 " 83	I8.0	"	I400	I0 " 75	I5.5
"	I500	35 " I28	I2.0	"	I500	25 " II2	I2.5
"	I600	0 " 94	∞	"	I600	0 " 86	∞

TABLE A.1(continued)

"b"-end spacing (inches)	Frequency (mc/sec.)	Input impedance (ohms)	VSWR	"b"-end spacing (inches)	Freq.	Input impedance (ohms)	VSWR
4.0	100	25 +j 80	7.3	6.0	100	29 +j 92	8.0
"	150	55 " 50	2.5	"	150	55 " 48	2.4
"	200	29 " 51	3.8	"	200	30 " 51	3.7
"	250	32 " 40	2.9	"	250	33 " 38	2.7
"	300	31 " 42	3.0	"	300	27 " 40	3.2
"	350	28 " 48	3.8	"	350	28 " 47	3.6
"	400	25 " 39	3.4	"	400	26 " 36	3.2
"	450	24 " 33	3.2	"	450	23 " 32	3.2
"	500	24 " 33	3.1	"	500	23 " 30	3.1
"	600	23 " 32	3.2	"	600	23 " 31	3.1
"	700	11 " 35	6.6	"	700	11 " 35	6.9
"	800	17 " 39	5.0	"	800	16 " 40	5.2
"	900	11 " 43	7.8	"	900	13 " 45	7.2
"	1000	12 " 56	9.8	"	1000	11 " 54	10.0
"	1100	20 " 75	8.3	"	1100	18 " 69	8.5
"	1200	9 " 59	13.0	"	1200	9 " 60	13.0
"	1300	38 " 90	6.2	"	1300	27 " 79	6.9
"	1400	13 " 87	16.0	"	1400	10 " 83	20.0
"	1500	36 " 130	11.5	"	1500	25 " 110	12.0
"	1600	0 " 106	∞	"	1600	0 " 91	∞

TABLE A.1 (continued)

"b"-end spacing (inches)	Frequency (mc/sec.)	Input impedance (ohms)	VSWR	"b"-end spacing (inches)	Freq.	Input impedance (ohms)	VSWR
8.75	I00	34 +j I04	8.5	12.5(10°)	I00	37 +j II4	9.0
"	I50	59 " 55	2.6	"	I50	64 " 63	3.0
"	200	32 " 54	3.8	"	200	32 " 56	3.9
"	250	32 " 40	2.8	"	250	32 " 40	2.8
"	300	27 " 4I	3.2	"	300	27 " 42	3.4
"	350	27 " 49	3.8	"	350	25 " 47	4.0
"	400	27 " 38	3.I	"	400	26 " 37	3.2
"	450	25 " 33	3.0	"	450	2I " 32	3.4
"	500	24 " 3I	3.0	"	500	2I " 30	3.2
"	600	22 " 32	3.2	"	600	22 " 30	3.I
"	700	II " 34	6.4	"	700	I0 " 32	6.7
"	800	I7 " 39	5.0	"	800	I4 " 37	5.7
"	900	II " 4I	7.8	"	900	I3 " 36	6.0
"	I000	II " 52	9.4	"	I000	9 " 43	I0.0
"	II00	I6 " 77	II.0	"	II00	II " 49	9.0
"	I200	I0 " 60	I2.0	"	I200	7 " 46	I3.0
"	I300	37 " 88	6.0	"	I300	I6 " 5I	6.7
"	I400	I0 " 76	I8.0	"	I400	9 " 60	I3.0
"	I500	2I " I00	I2.5	"	I500	I0 " 62	I2.0
"	I600	0 " 82	∞	"	I600	0 " 62	∞

TABLE A.1(continued)

"b"-end spacing (inches)	Frequency (mc/sec.)	Input impedance (ohms)	VSWR
24.2(20°)	I00	40 +j I22	9.5
"	I50	74 " 85	3.8
"	200	4I " 64	3.8
"	250	40 " 50	2.9
"	300	32 " 5I	3.6
"	350	29 " 53	4.0
"	400	32 " 46	3.2
"	450	24 " 36	3.4
"	500	27 " 38	3.I
"	600	27 " 36	3.0
"	700	I3 " 38	6.0
"	800	I7 " 46	5.7
"	900	I8 " 57	6.6
"	I000	I4 " 64	9.7
"	II00	26 " 94	9.I
"	I200	I7 " 80	II.5
"	I300	47 " 95	5.6
"	I400	I5 " I20	22.0
"	I500	62 " I60	I0.0
"	I600	0 " I97	∞

TABLE A.2

INPUT IMPEDANCES AND VOLTAGE STANDING WAVE RATIOS FOR LOGARITHMICALLY PERIODIC VEE-DIPOLE ANTENNA (LPVEE)

"b"-end spacing (inches)	Frequency (mc/sec.)	Input impedance (ohms)	VSWR	"b"-end spacing (inches)	Freq.	Input impedance (ohms)	VSWR
1.5(ψ=0°)	100	10 +j 33	7.0	2.0	100	13 +j 34	5.9
"	150	73 " 36	2.0	"	150	48 " 51	2.7
"	200	25 " 38	3.4	"	200	25 " 38	3.3
"	250	28 " 25	2.3	"	250	28 " 29	2.6
"	300	17 " 24	3.6	"	300	19 " 26	3.4
"	350	14 " 23	4.3	"	350	15 " 23	4.0
"	400	18 " 19	3.2	"	400	19 " 20	3.0
"	450	15 " 18	3.7	"	450	14 " 18	3.9
"	500	13 " 13	4.0	"	500	14 " 15	4.0
"	600	12 " 12	4.4	"	600	13 " 14	4.0
"	700	7 " 10	7.0	"	700	8 " 11	6.4
"	800	6 " 12	7.8	"	800	6 " 12	8.9
"	900	3 " 11	14.0	"	900	3 " 11	14.0
"	1000	2 " 16	23.0	"	1000	2 " 17	25.0
"	1100	4 " 17	13.0	"	1100	5 " 16	12.0
"	1200	5 " 13	10.5	"	1200	5 " 13	9.7
"	1300	3 " 17	20.0	"	1300	2 " 14	20.0
"	1400	6 " 20	9.3	"	1400	6 " 21	9.5
"	1500	2 " 18	23.0	"	1500	3 " 13	14.5
"	1600	2 " 10	20.0	"	1600	4 " 7	13.0

TABLE A.2(continued)

"b"-end spacing (inches)	Frequency (mc/sec.)	Input impedance (ohms)	VSWR	"b"-end spacing (inches)	Freq.	Input impedance (ohms)	VSWR
4.0	100	14 +j 53	7.6	6.0	100	17 +j 65	8.0
"	150	52 " 46	2.4	"	150	54 " 43	2.2
"	200	28 " 39	3.1	"	200	30 " 40	3.0
"	250	27 " 29	2.6	"	250	27 " 29	2.6
"	300	20 " 25	3.2	"	300	20 " 26	3.2
"	350	16 " 25	4.0	"	350	17 " 25	3.8
"	400	21 " 21	2.8	"	400	22 " 21	2.7
"	450	15 " 18	3.7	"	450	16 " 18	3.6
"	500	14 " 16	3.9	"	500	14 " 14	3.8
"	600	13 " 14	4.0	"	600	13 " 14	4.0
"	700	9 " 12	6.0	"	700	9 " 13	6.0
"	800	6 " 13	8.5	"	800	6 " 13	8.0
"	900	5 " 11	11.0	"	900	4 " 12	14.0
"	1000	2 " 19	24.0	"	1000	3 " 18	16.5
"	1100	5 " 19	11.5	"	1100	5 " 19	11.5
"	1200	5 " 16	9.6	"	1200	7 " 17	7.8
"	1300	3 " 18	15.0	"	1300	3 " 18	16.5
"	1400	7 " 26	9.1	"	1400	8 " 22	7.2
"	1500	4 " 18	14.5	"	1500	3 " 19	17.0
"	1600	3 " 13	17.0	"	1600	1 " 15	40.0

TABLE A.2(continued)

"b"-end spacing (inches)	Frequency (mc/sec.)	Input impedance (ohms)	VSWR	"b"-end spacing (inches)	Freq.	Input impedance (ohms)	VSWR
8.75	I00	20 +j 63	6.6	12.5(10°)	I00	28 +j 80	6.9
"	I50	55 " 45	2.3	"	I50	55 " 58	2.9
"	200	30 " 39	2.9	"	200	32 " 44	3.I
"	250	29 " 27	2.4	"	250	29 " 32	2.6
"	300	20 " 23	3.I	"	300	2I " 28	3.I
"	350	I6 " 22	3.7	"	350	I7 " 23	3.6
"	400	22 " I8	2.6	"	400	24 " 20	2.5
"	450	I5 " I5	3.5	"	450	I6 " I6	3.4
"	500	I3 " II	4.0	"	500	I4 " I3	3.8
"	600	II " 8	4.5	"	600	I3 " I0	3.8
"	700	7 " 7	6.5	"	700	9 " 8	5.6
"	800	6 " 6	8.8	"	800	7 " 7	7.2
"	900	4 " 4	I2.0	"	900	4 " 4	II.5
"	I000	2 " II	27.0	"	I000	2 " I2	20.0
"	II00	5 " 9	I0.0	"	II00	5 " 9	9.8
"	I200	5 " 6	9.I	"	I200	3 " II	I4.0
"	I300	3 " 7	I7.0	"	I300	5 " 5	I0.3
"	I400	6 " I2	8.5	"	I400	5 " I6	9.8
"	I500	3 " 4	I6.5	"	I500	4 " 4	II.0
"	I600	4 -j 2	I3.0	"	I600	4 " 2	II.3

TABLE A.2(continued)

"b"-end spacing (inches)	Frequency (mc/sec.)	Input impedance (ohms)	VSWR
24.2 (20°)	100	10 +j 111	30.0
"	150	52 " 76	4.0
"	200	35 " 55	3.6
"	250	33 " 39	2.7
"	300	22 " 33	3.3
"	350	21 " 24	3.0
"	400	27 " 22	2.3
"	450	18 " 16	3.2
"	500	17 " 16	3.3
"	600	17 " 9	3.0
"	700	12 " 8	4.3
"	800	9 " 7	5.6
"	900	5 " 5	9.0
"	1000	4 " 14	13.5
"	1100	6 " 13	8.9
"	1200	5 " 14	10.5
"	1300	6 " 9	8.5
"	1400	5 " 19	10.8
"	1500	4 " 10	12.5
"	1600	3 " 9	15.0

APPENDIX B

MEASUREMENT OF CABLE ATTENUATION

It was required to find the attenuation or line loss of the twenty foot eleven inch length of RG-8A/U co-axial cable attached to the input terminals of the log-periodic dipole antennas.

The impedance measurement set-up shown in figure A.2, page 62, was also used to measure the line loss.

For each frequency, the "dummy" short-circuited line (figure A.1, page 61) and the constant-impedance adjustable line was connected to the admittance meter. The line length was adjusted until the resonant condition was obtained, that is, zero reactance and some resistance greater than 50 ohms. Plotting this resistance on a Smith Chart, we obtained the line loss directly in db.

The results of the attenuation measurements are shown graphically in figure B.1. The results check closely with published values of attenuation and with values given in cable catalogues.

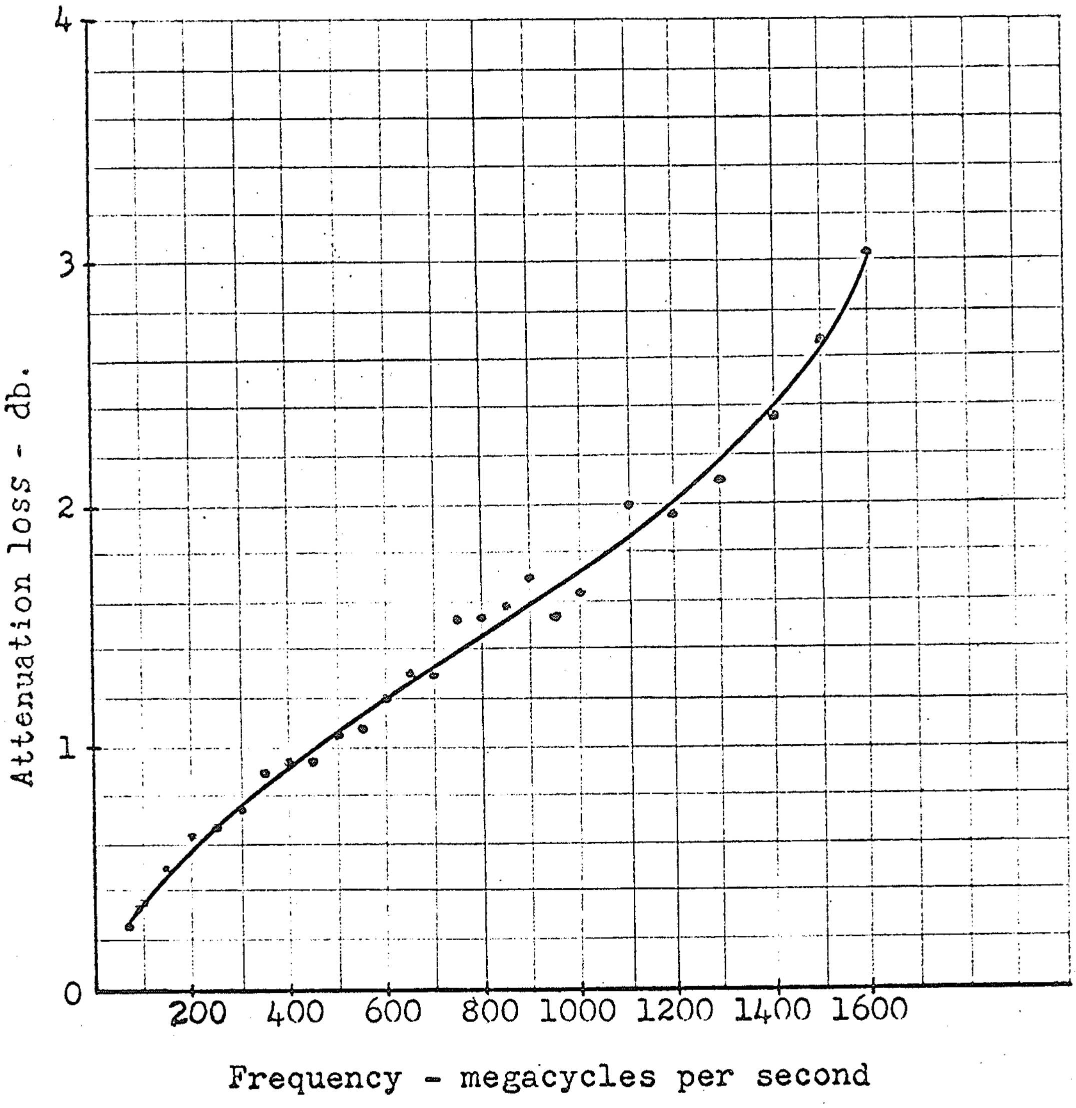


FIGURE B.1

ATTENUATION LOSS VERSUS FREQUENCY FOR 20'11" LENGTH OF RG-8A/U CO-AXIAL CABLE

APPENDIX C

MEASUREMENT OF ANTENNA FIELD-STRENGTH PATTERNS

The far-field patterns in the two principal planes were found for various feed-line tapers on the log-periodic antennas. The two principal planes are the E-plane and the H-plane as shown in figure C.1.

The antennas were linearly polarized in the E-plane.

A diagram of the transmitting and receiving system is shown in figure C.2. A block diagram of the measurement set-up is shown in figure C.3, page 77.

The log-periodic test antenna was used as the transmitting antenna and it was placed on the rotator as shown in figure C.2. A corner-reflector dipole antenna was used as the receiving antenna. The two antennas were placed about seventy feet apart on top of the Engineering Building so that reflections from surrounding objects were minimized. Screen reflectors were placed on the roof between the transmitting and receiving antennas to eliminate reflections to the receiving antenna.

For each pattern, the test antenna was rotated over 360 degrees and the field strength automatically recorded on the X-Y recorder. The angular position of the test antenna was indicated by a remote selsyn control. The selsyn movement also controlled the X-drive of the recorder by employing a circular rheostat as a voltage tap, the sliding contact

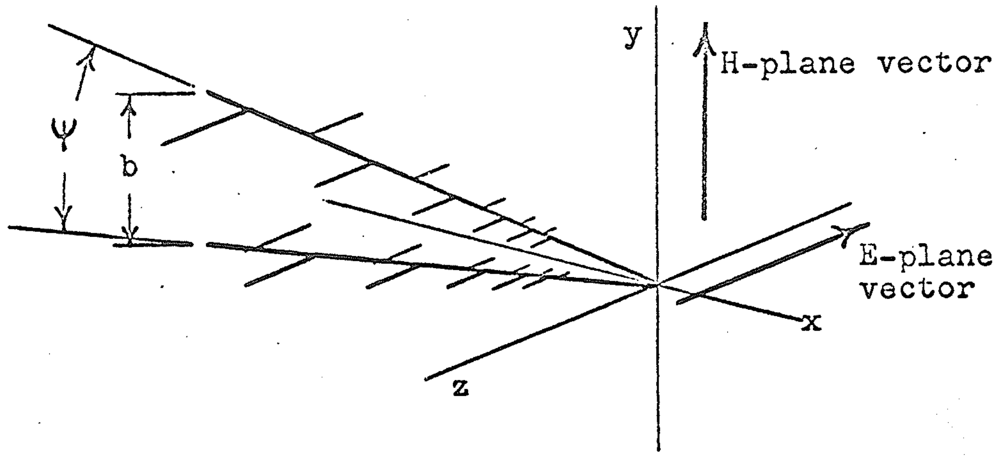


FIGURE C.1

ANTENNA ORIENTATION SHOWING THE
PRINCIPAL E AND H-PLANES

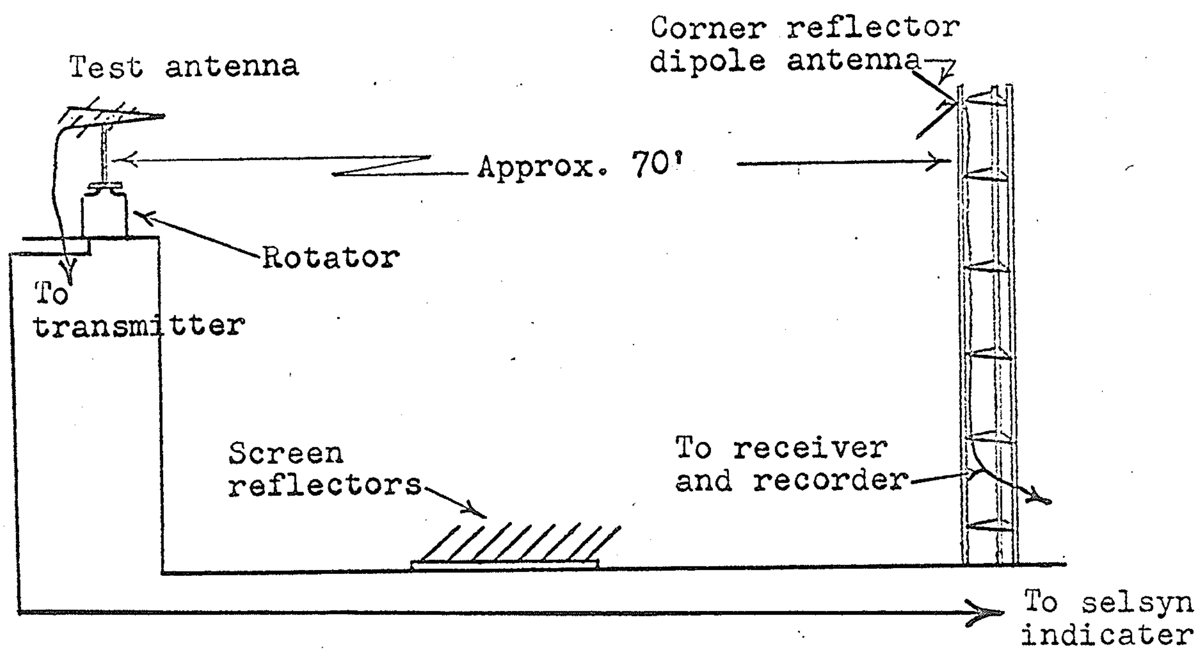


FIGURE C.2

ANTENNA TRANSMITTING AND RECEIVING SYSTEM
USED FOR PATTERN MEASUREMENTS

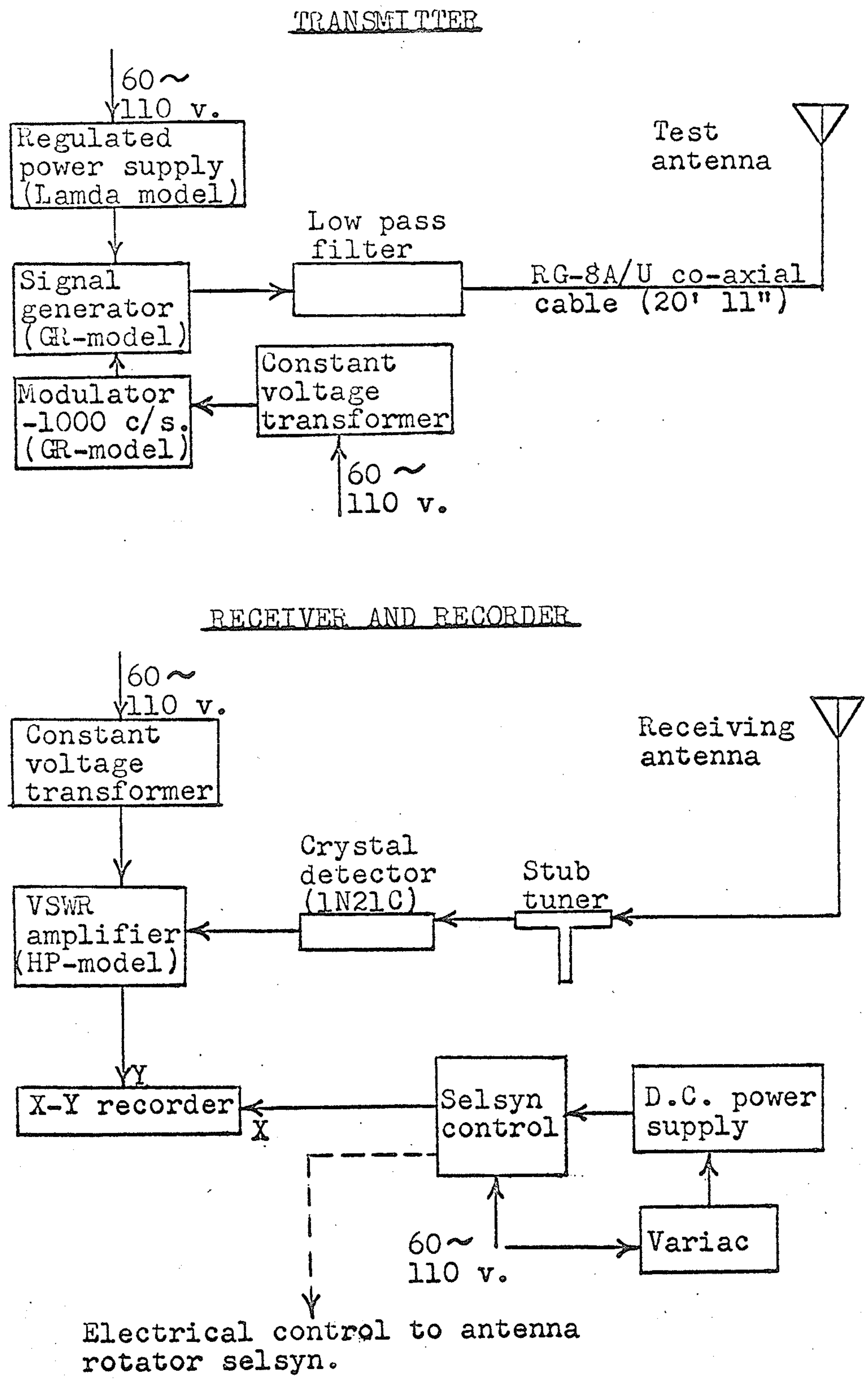


FIGURE C.3

BLOCK DIAGRAM OF ANTENNA PATTERN MEASUREMENT SET-UP being mechanically coupled to the selsyn shaft.

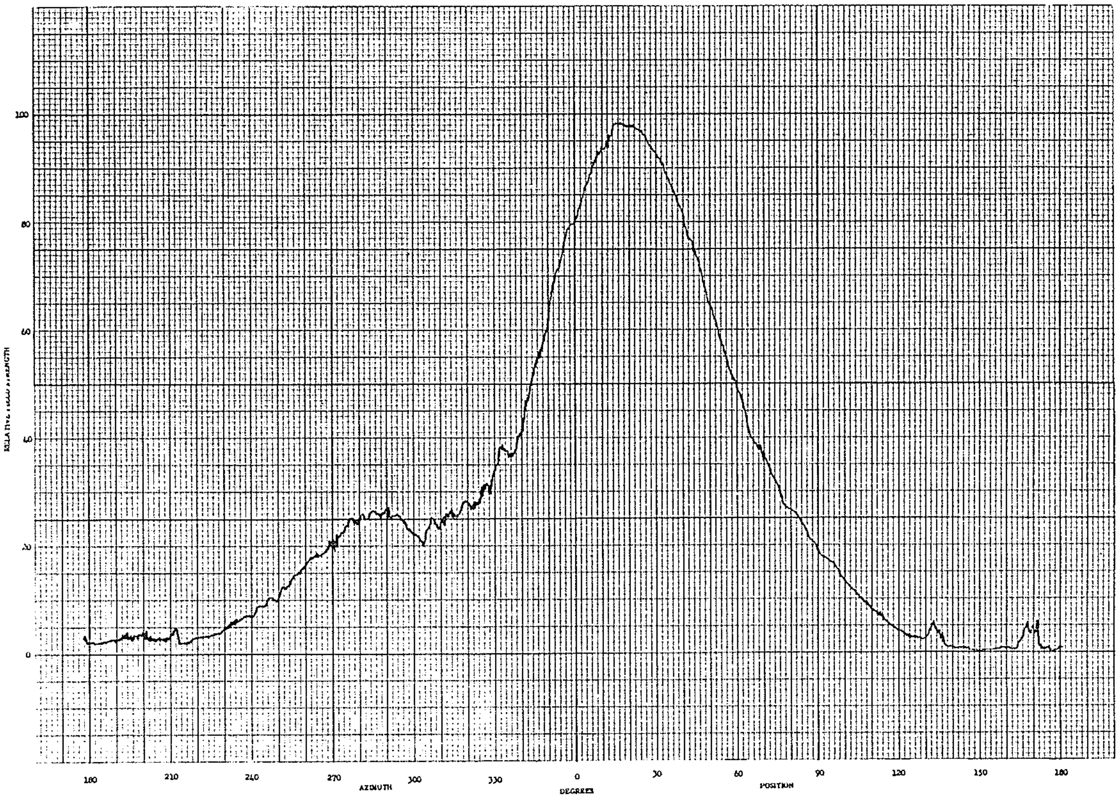
Regulated power supplies and constant-voltage transformers were used to stabilize the signals. Low-pass filters were used to eliminate the effects of harmonics. The resulting patterns were almost completely noise free.

A square-law crystal detector was used in the receiving circuit, the signal being fed into a standing-wave amplifier and then into the Y-drive of the recorder.

The E and H-plane patterns for the log-periodic straight-dipole and V-dipole antennas are shown on pages 79 to 121inclusive. Patterns were taken for frequencies ranging from 200 to 1200 megacycles per second. Because of the large number of patterns taken, only those which serve to show the antenna performance and changes thereof are shown here.

The feed-line taper is designated by the end separation "b" or by the taper angle Ψ. The zero degree position on the pattern recordings correspond to the direction of the beam maximum on the log-periodic antenna. In this position, the small or feed end of the test antenna was pointing directly at the receiving antenna.

The accuracy of the pattern measurement system was dependent mainly on the operation of the crystal detector in the square-law region and on its sensitivity to low signal strength. The angular position of the antenna could be indicated to within approximately two degrees.



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Vec

PATTERN NO. a=b=1.5"

FREQUENCY 200 mc.

PATTERN PLANE E

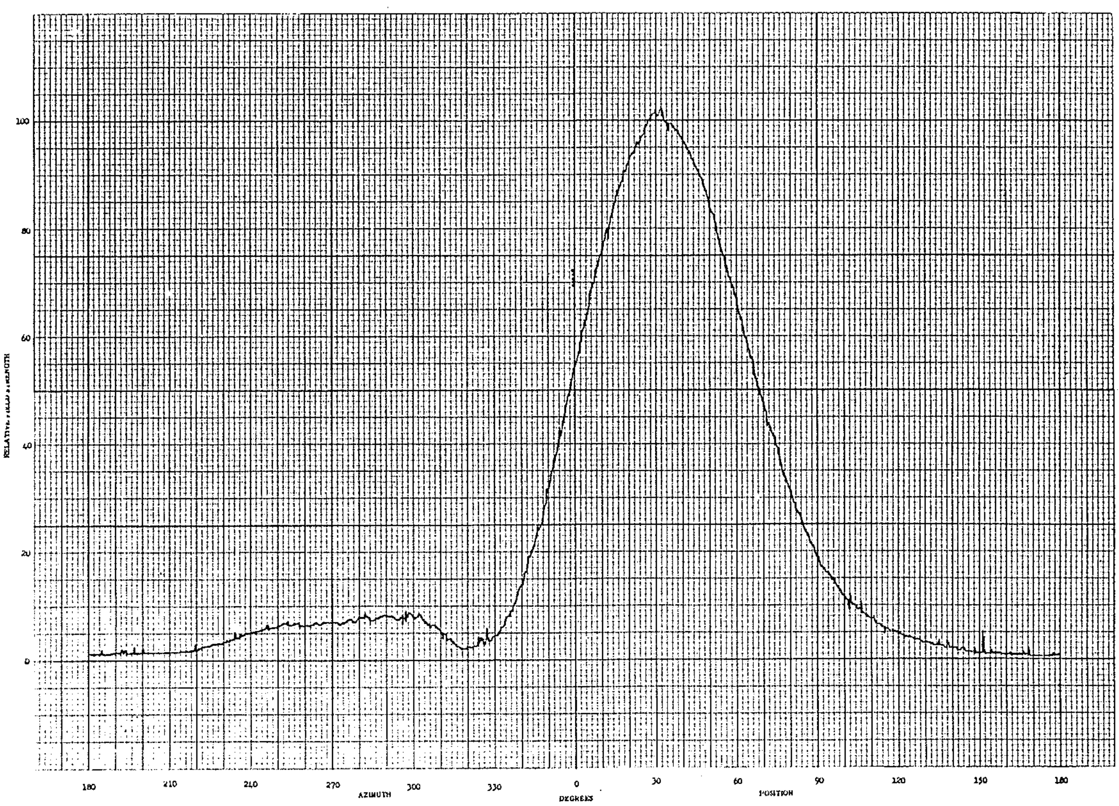
SCALE

VERTICAL

HORIZONTAL

NAME C.Y. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Dipole

PATTERN NO. a=b=1.5"

FREQUENCY 200 mc.

PATTERN PLANE E

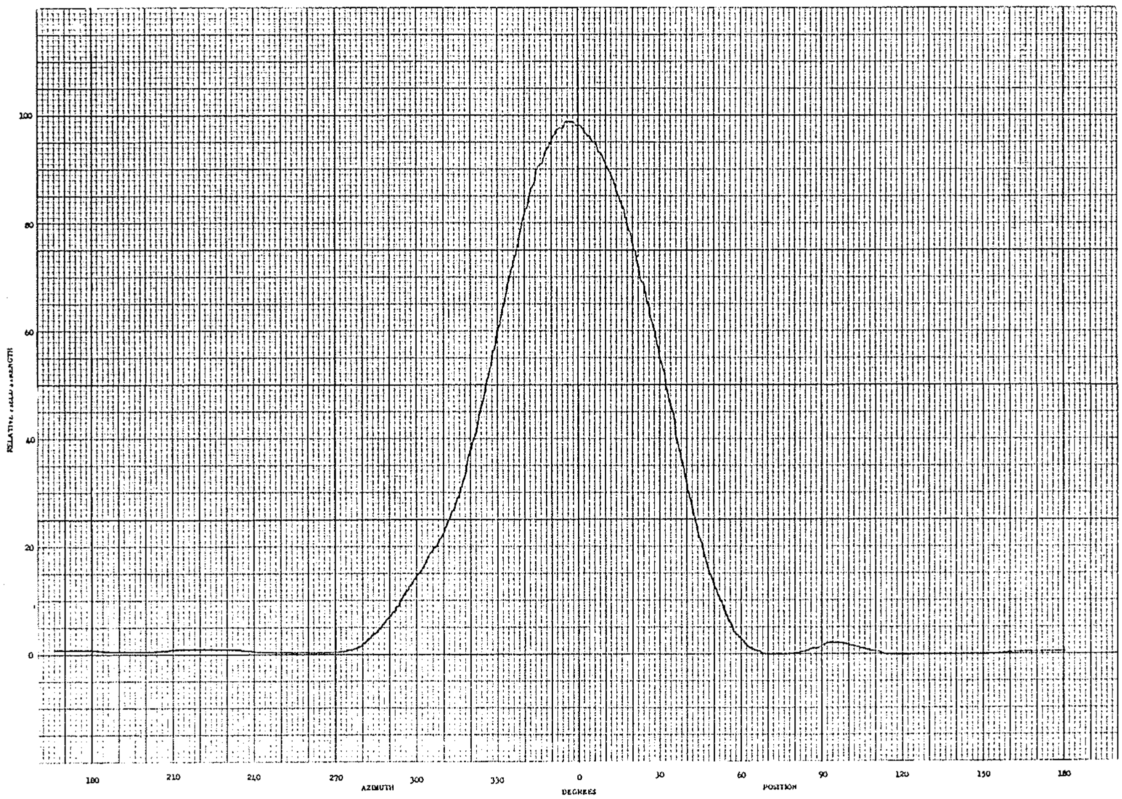
SCALE

VERTICAL

HORIZONTAL

NAME C.Y. Thio

DATE Nov. 12/63



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ANTENNA TYPE L.P. Vee

PATTERN NO. a = b = 1.5"

FREQUENCY 300 mc.

PATTERN PLANE E

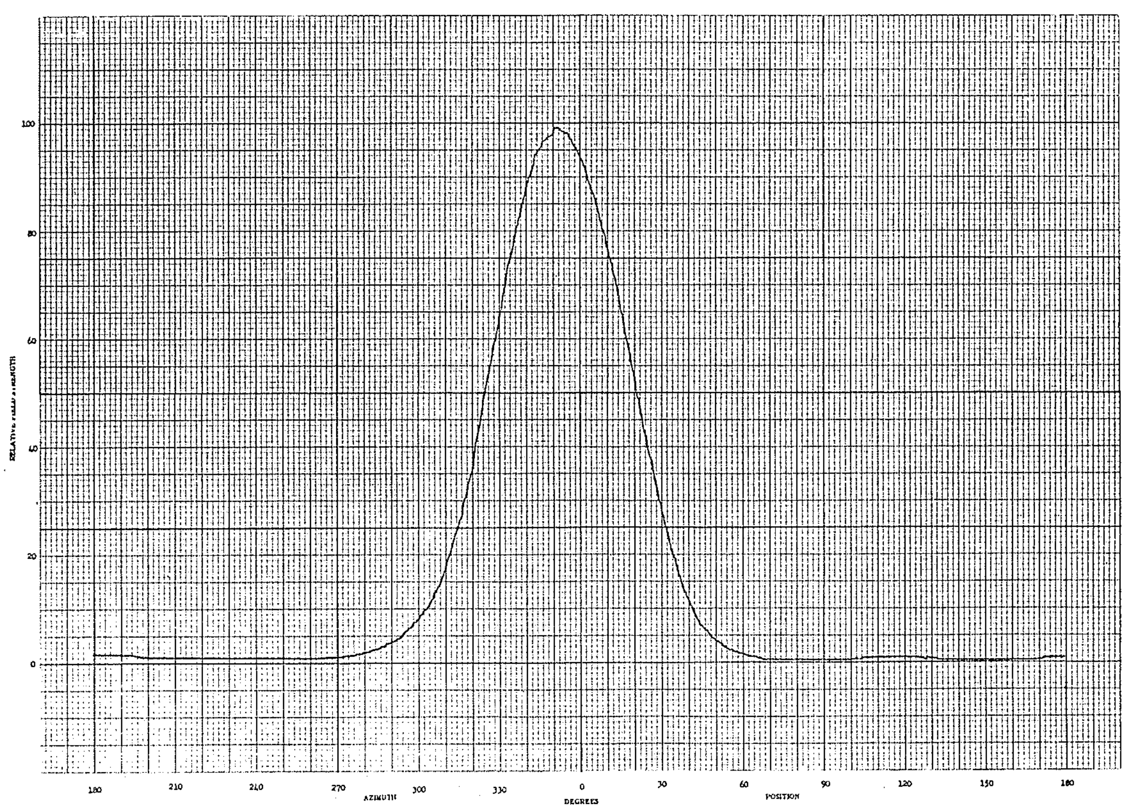
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Dipole

PATTERN NO. a = b = 1.5"

FREQUENCY 300 mc.

PATTERN PLANE E

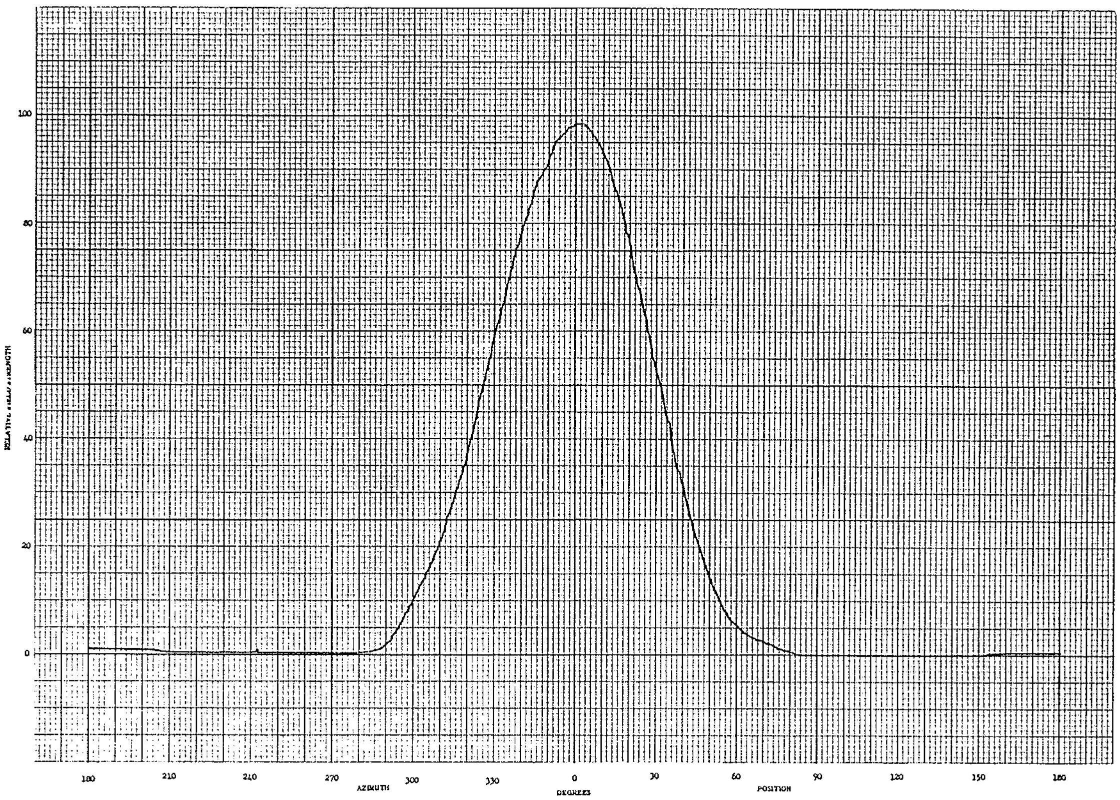
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



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OF
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ENGINEERING

ANTENNA TYPE
L.P. Vee

PATTERN NO.
a=b=1.5"

FREQUENCY
400 mc.

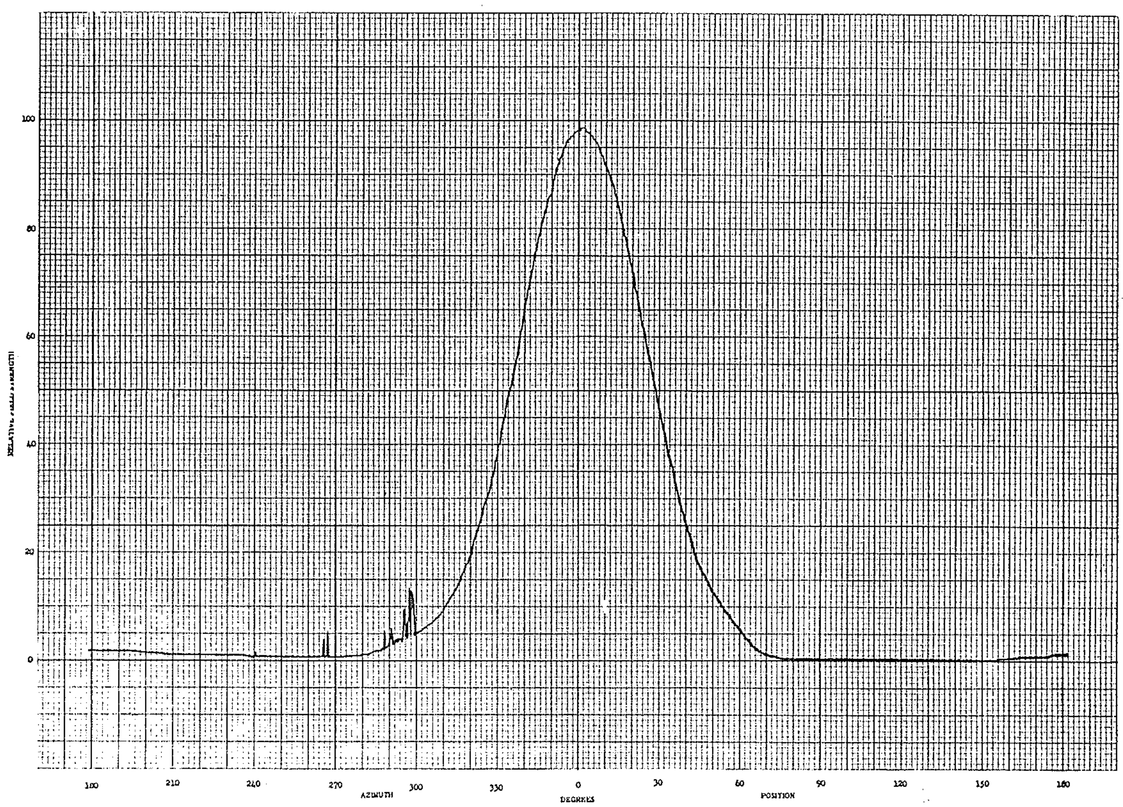
PATTERN PLANE
E

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



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OF
ELECTRICAL
ENGINEERING

ANTENNA TYPE
L.P. Dipole

PATTERN NO.
a=b=1.5"

FREQUENCY
400 mc.

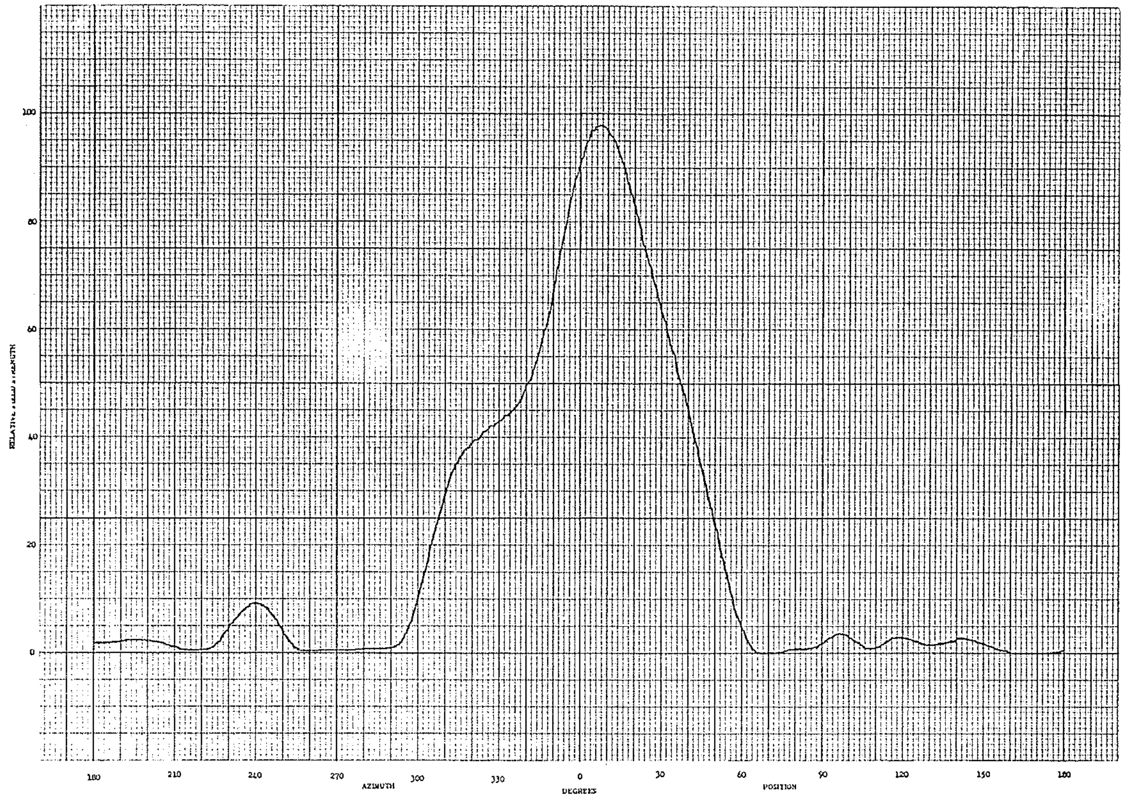
PATTERN PLANE
E

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



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DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Vee*

PATTERN NO. *α = b = 1.5"*

FREQUENCY *500 mc.*

PATTERN PLANE *E*

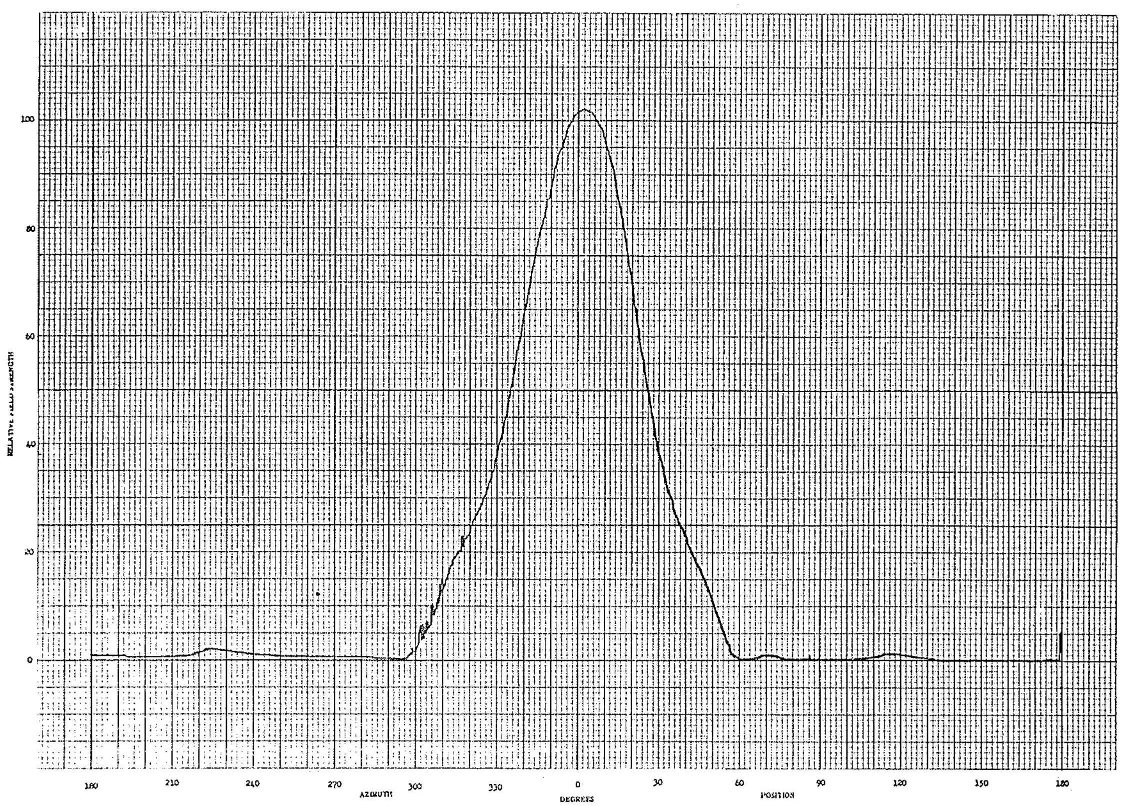
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Dipole*

PATTERN NO. *a = b = 1.5"*

FREQUENCY *500 mc.*

PATTERN PLANE *E*

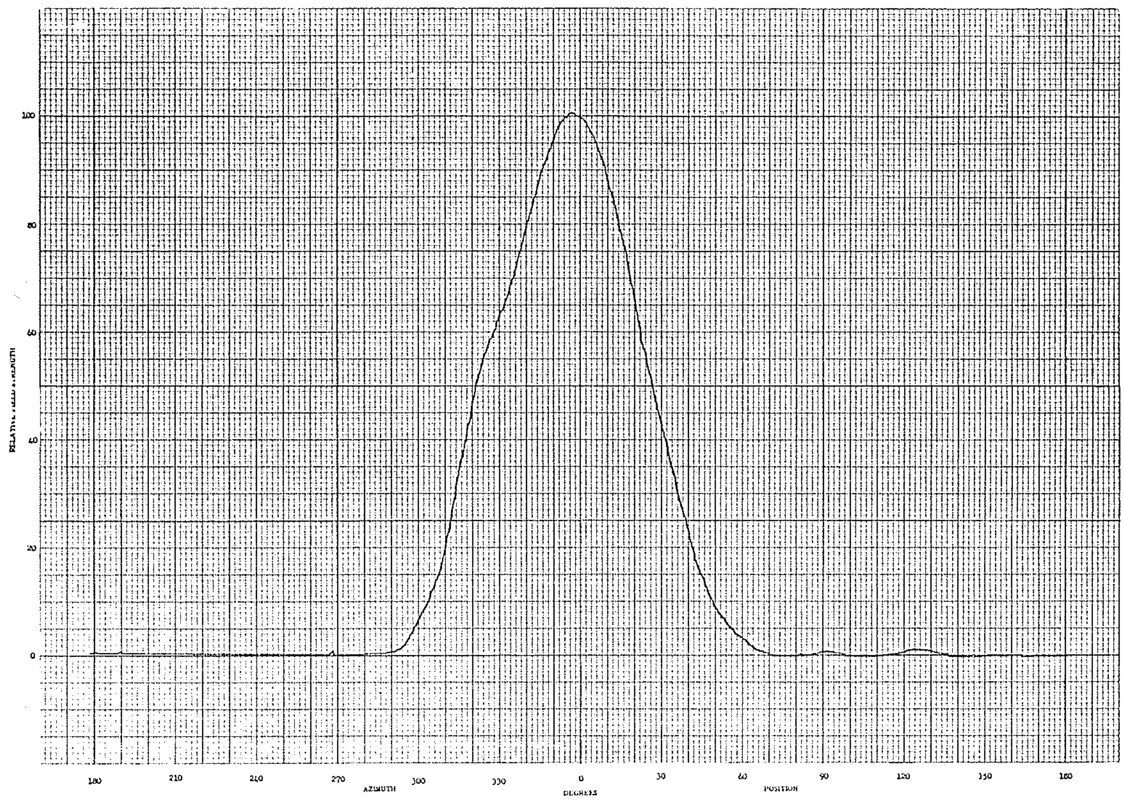
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



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OF
ELECTRICAL
ENGINEERING

ANTENNA TYPE
L.P. Vee

PATTERN NO.
a=b=1.5"

FREQUENCY
600 mc.

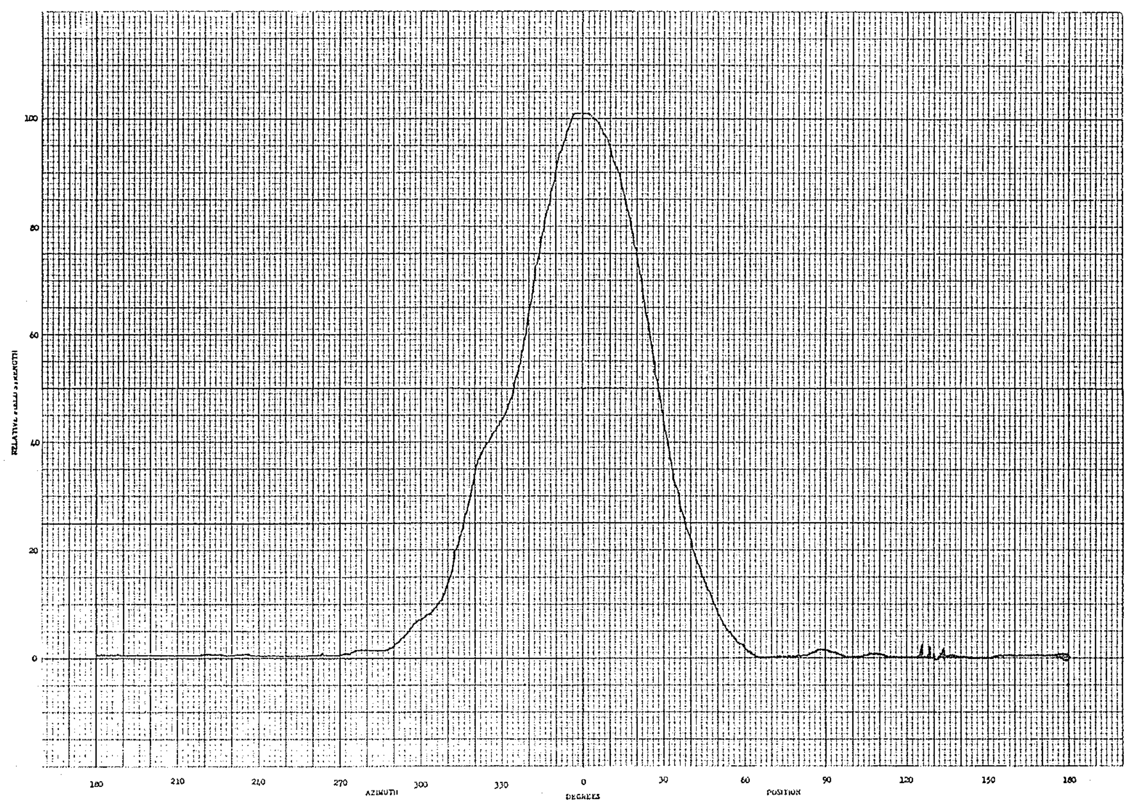
PATTERN PLANE
E

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



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OF
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ENGINEERING

ANTENNA TYPE
L.P. Dipole

PATTERN NO.
a=b=1.5"

FREQUENCY
600 mc.

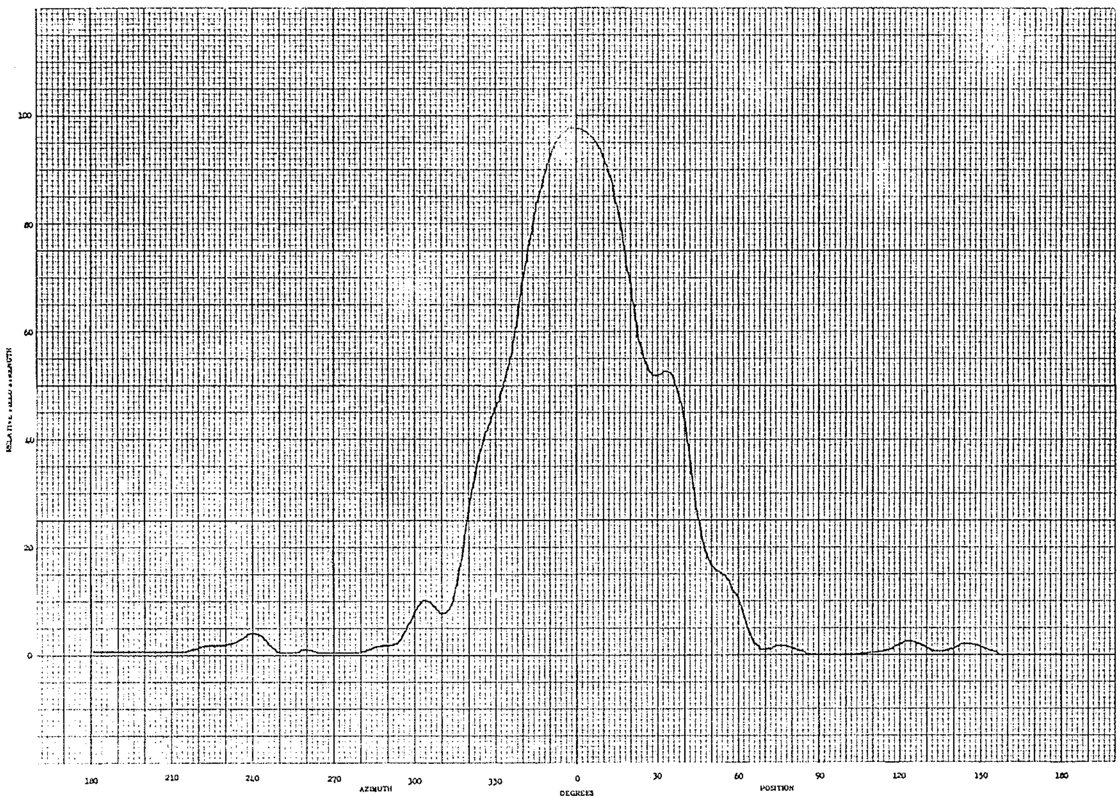
PATTERN PLANE
E

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L. P. Vee

PATTERN NO.: a=b=1.5"

FREQUENCY: 700 mc.

PATTERN PLANE: E

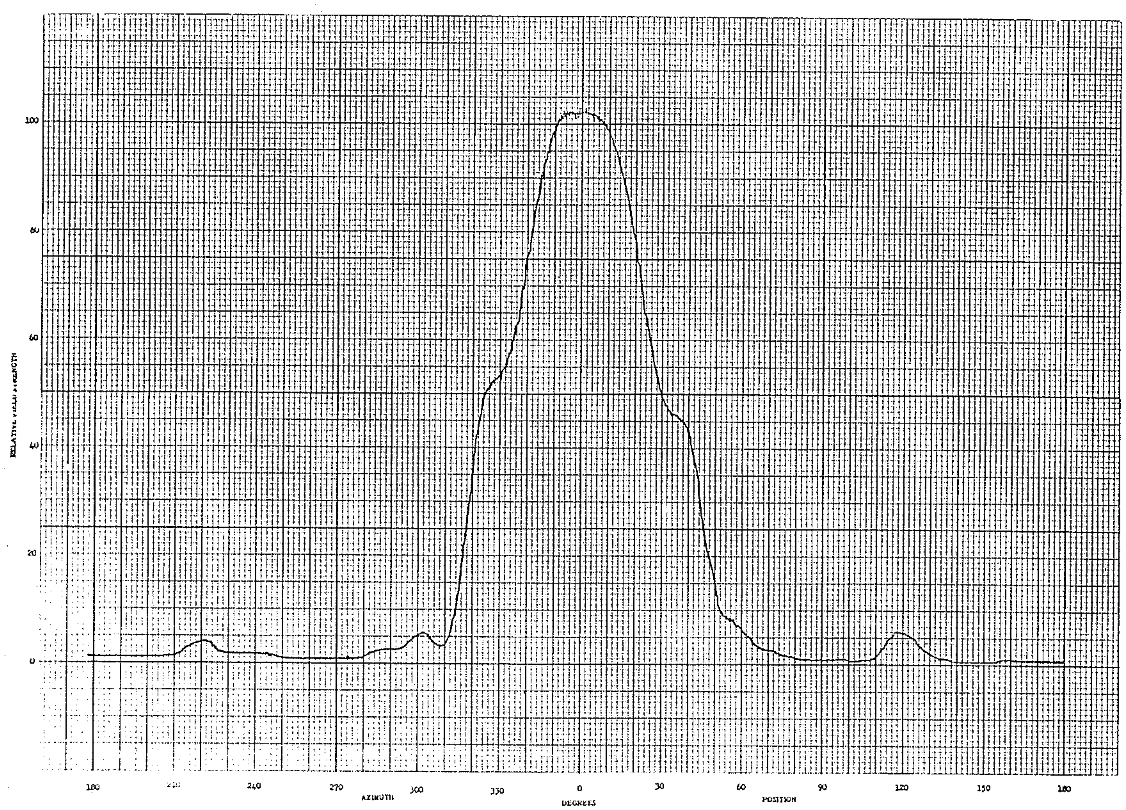
SCALE

VERTICAL:

HORIZONTAL:

NAME: C.V. Thio

DATE: Nov.12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L.P. Dipole

PATTERN NO.: a=b=1.5"

FREQUENCY: 700 mc.

PATTERN PLANE: E

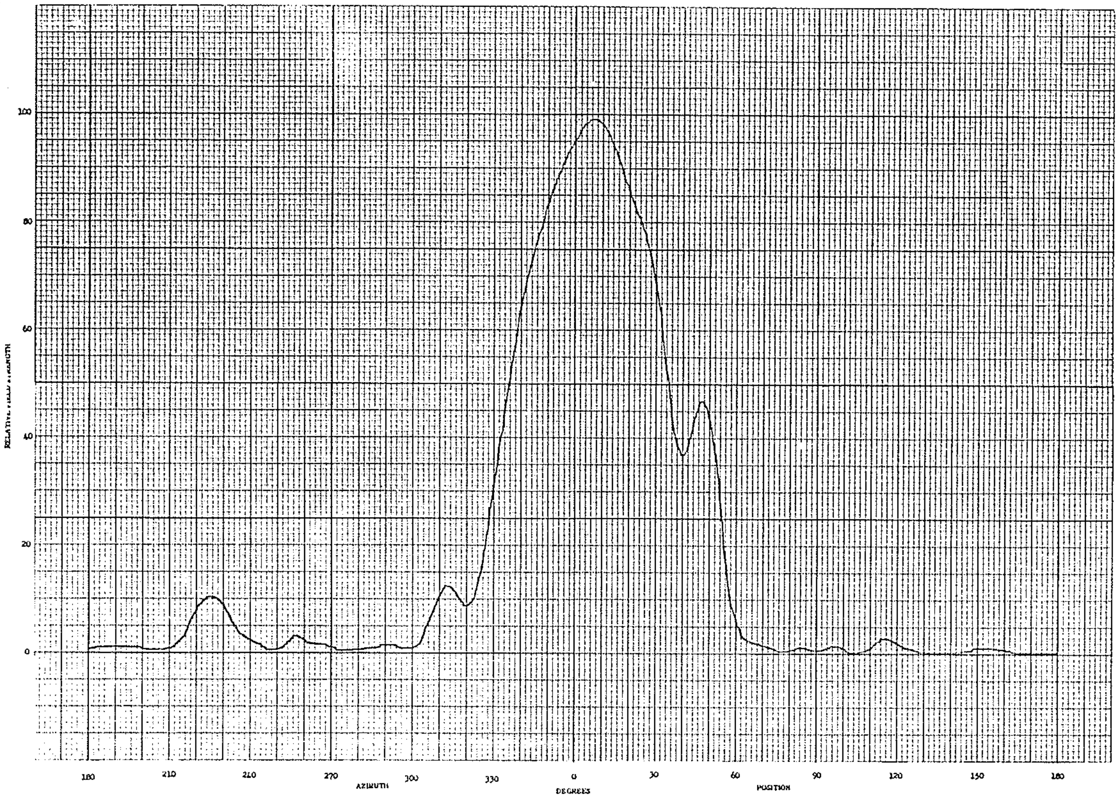
SCALE

VERTICAL:

HORIZONTAL:

NAME: C.V. Thio

DATE: Nov.12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Vee

PATTERN NO.
a=b=1.5"

FREQUENCY
800 mc.

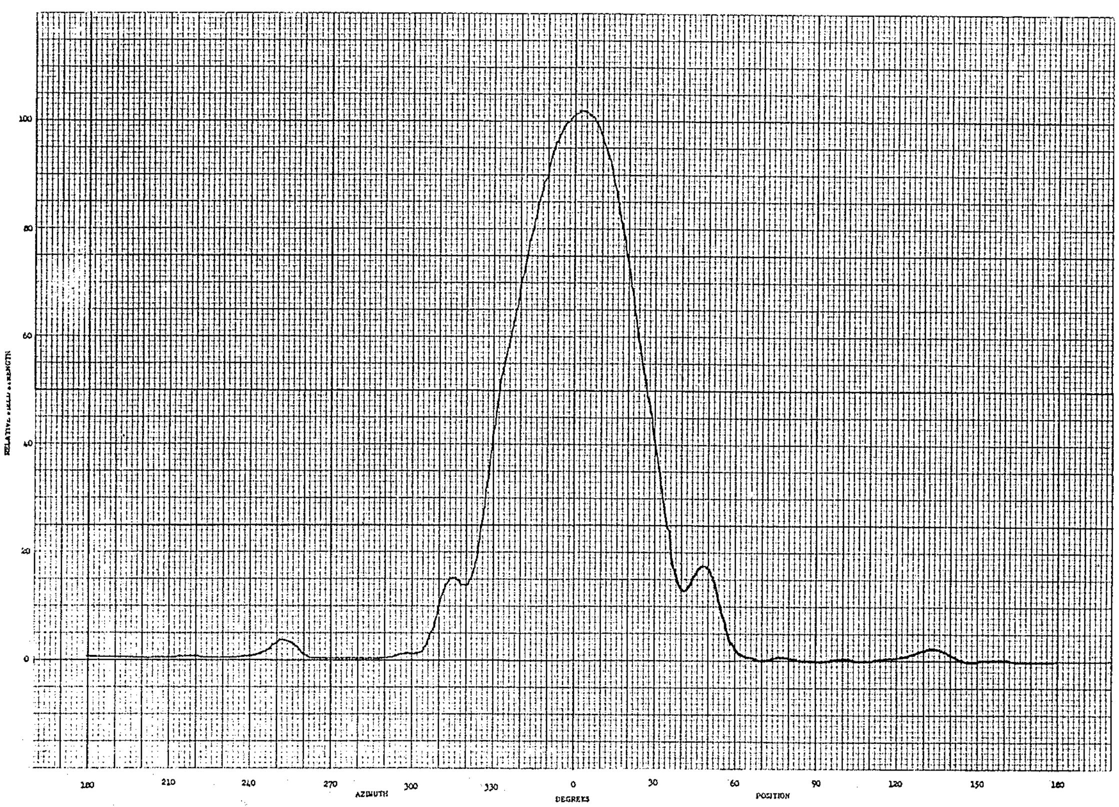
PATTERN PLANE
E

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Dipole

PATTERN NO.
a=b=1.5"

FREQUENCY
800 mc.

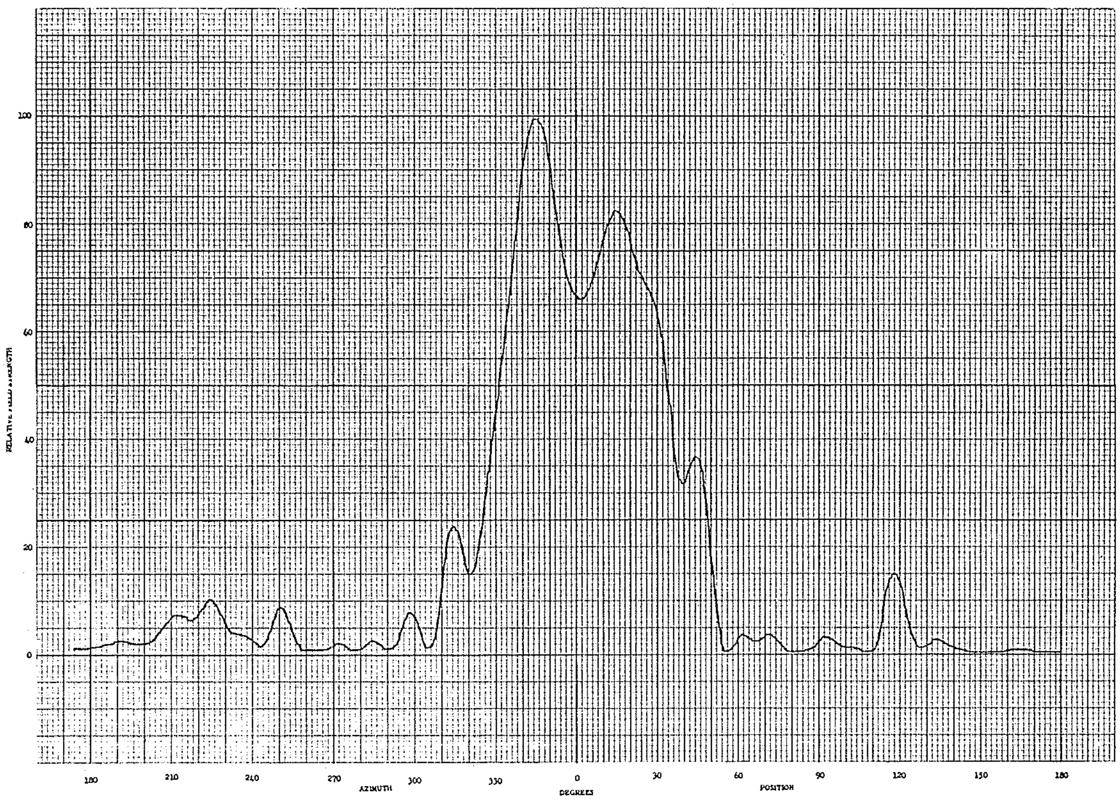
PATTERN PLANE
E

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L.P. Vee

PATTERN NO.: a=b=1.5"

FREQUENCY: 900 mc.

PATTERN PLANE: E

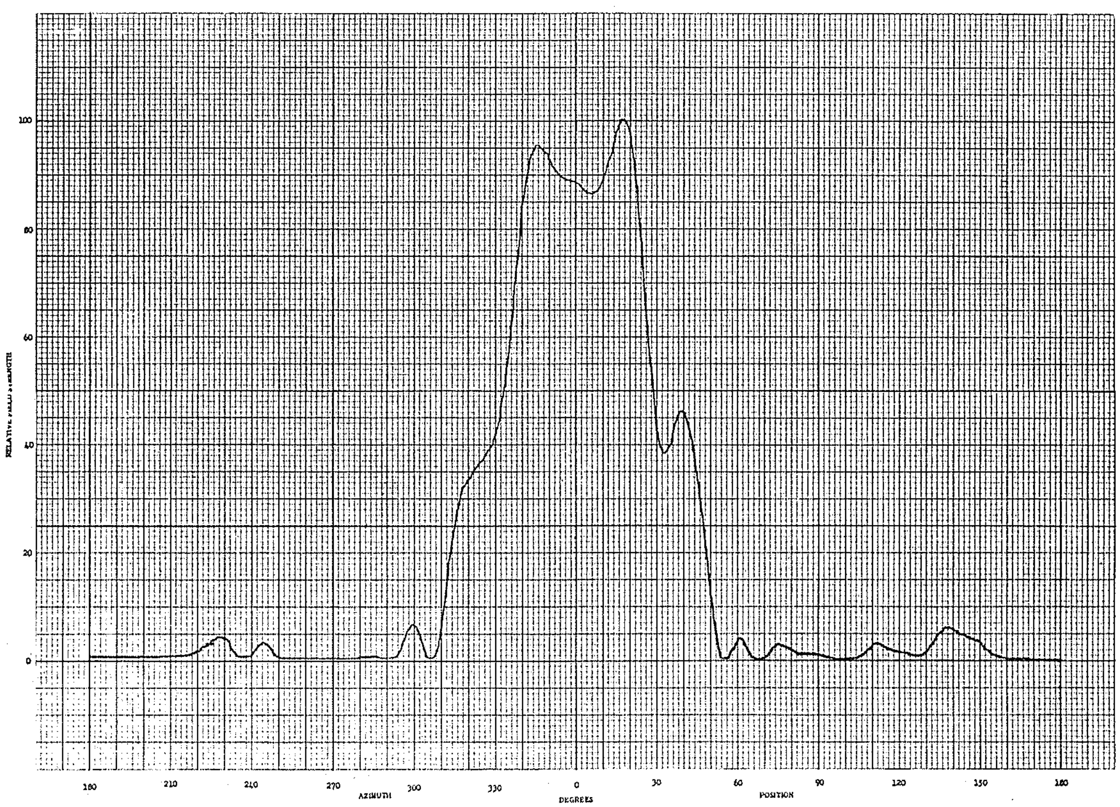
SCALE

VERTICAL:

HORIZONTAL:

NAME: C.V. Thio

DATE: Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L.P. Dipole

PATTERN NO.: a=b=1.5"

FREQUENCY: 900 mc.

PATTERN PLANE: E

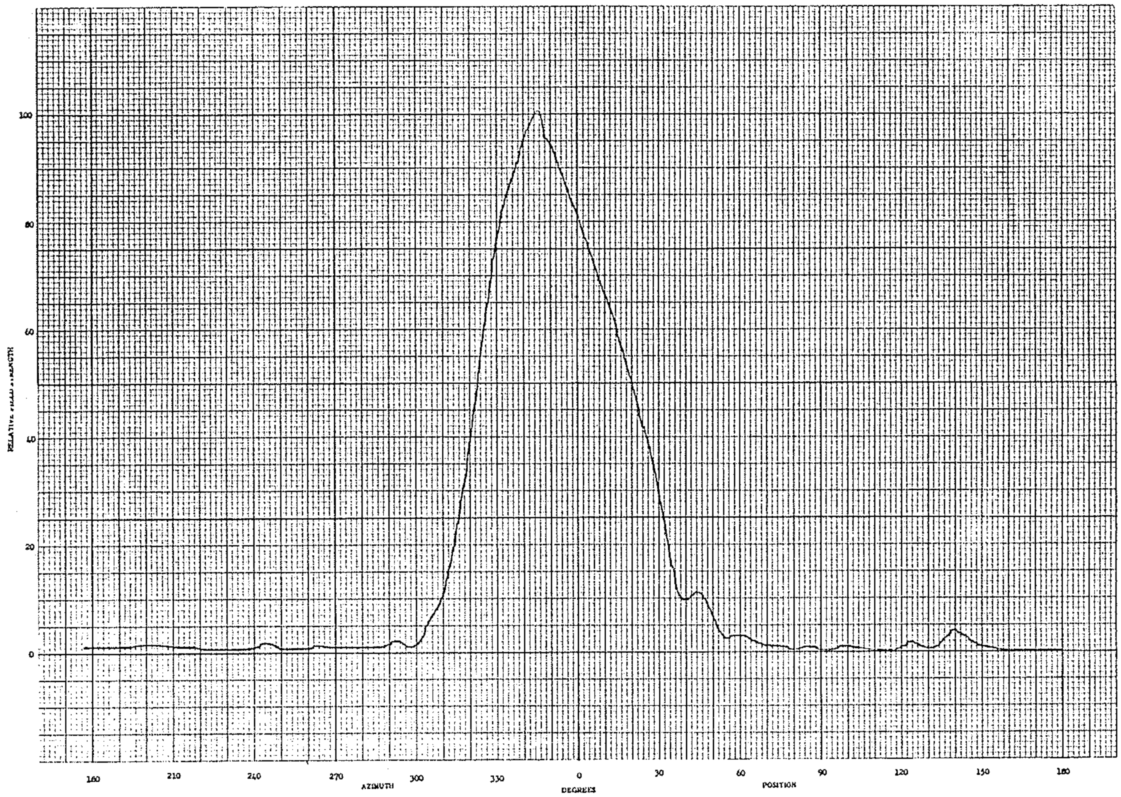
SCALE

VERTICAL:

HORIZONTAL:

NAME: C.V. Thio

DATE: Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Vee*

PATTERN NO. *a=b=1.5"*

FREQUENCY *1000 mc.*

PATTERN PLANE *E*

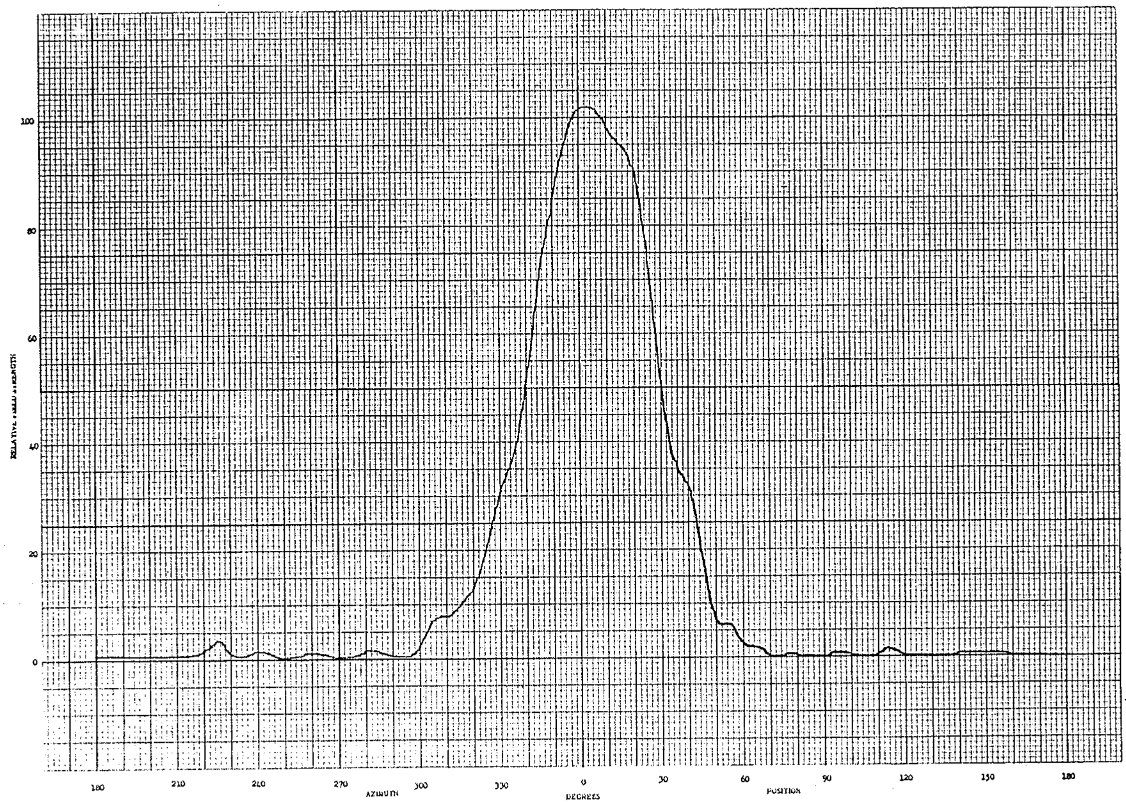
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



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DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Dipole*

PATTERN NO. *a=b=1.5"*

FREQUENCY *1000 mc.*

PATTERN PLANE *E*

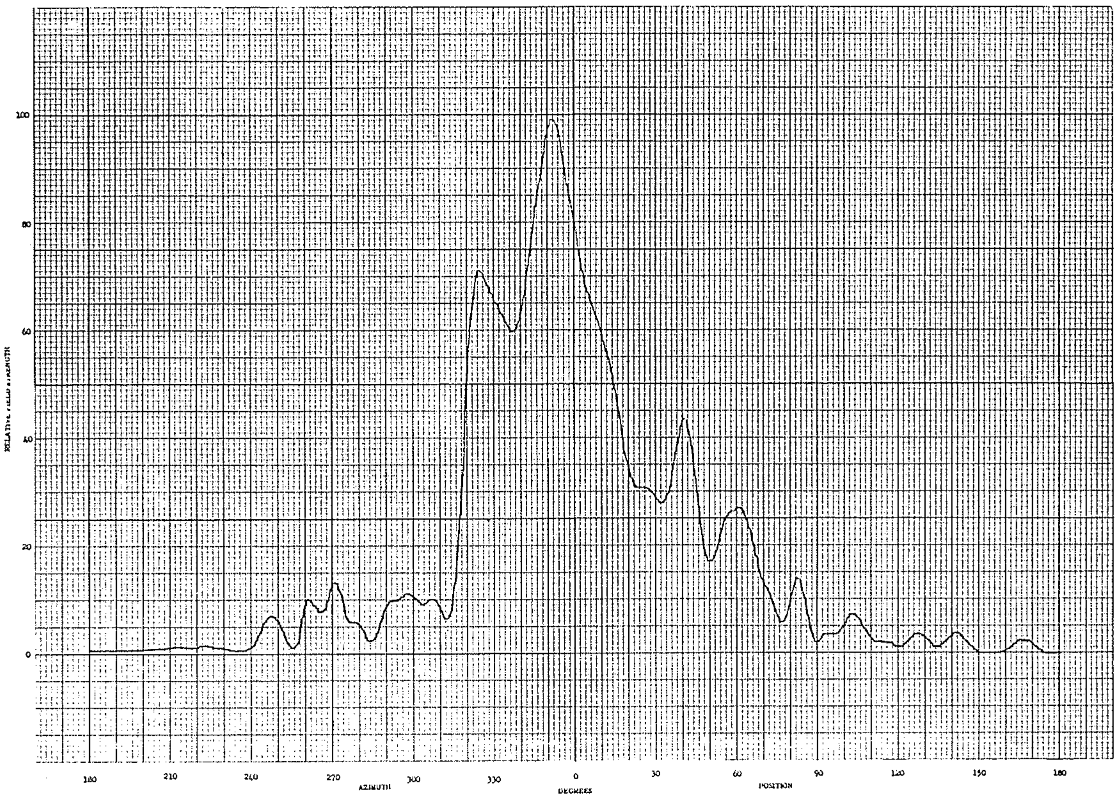
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



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DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Vee*

PATTERN NO. *a = b = 1.5"*

FREQUENCY *1100 mc.*

PATTERN PLANE *E*

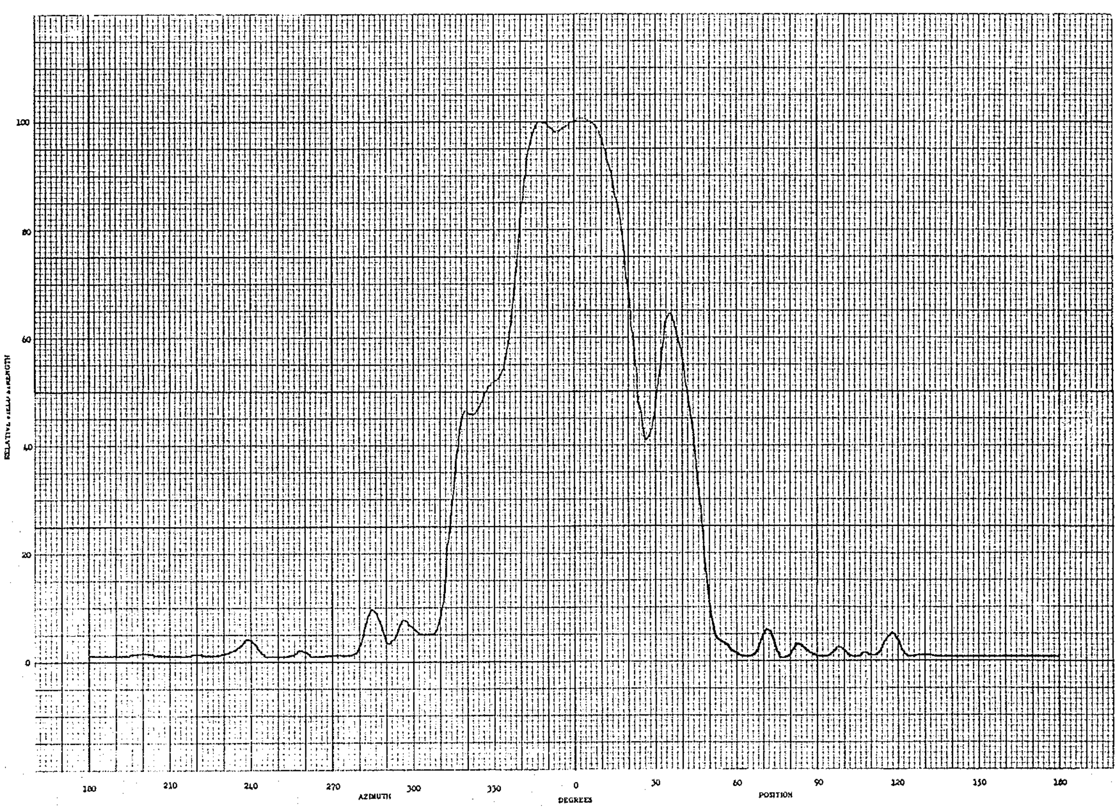
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Dipole*

PATTERN NO. *a = b = 1.5"*

FREQUENCY *1100 mc.*

PATTERN PLANE *E*

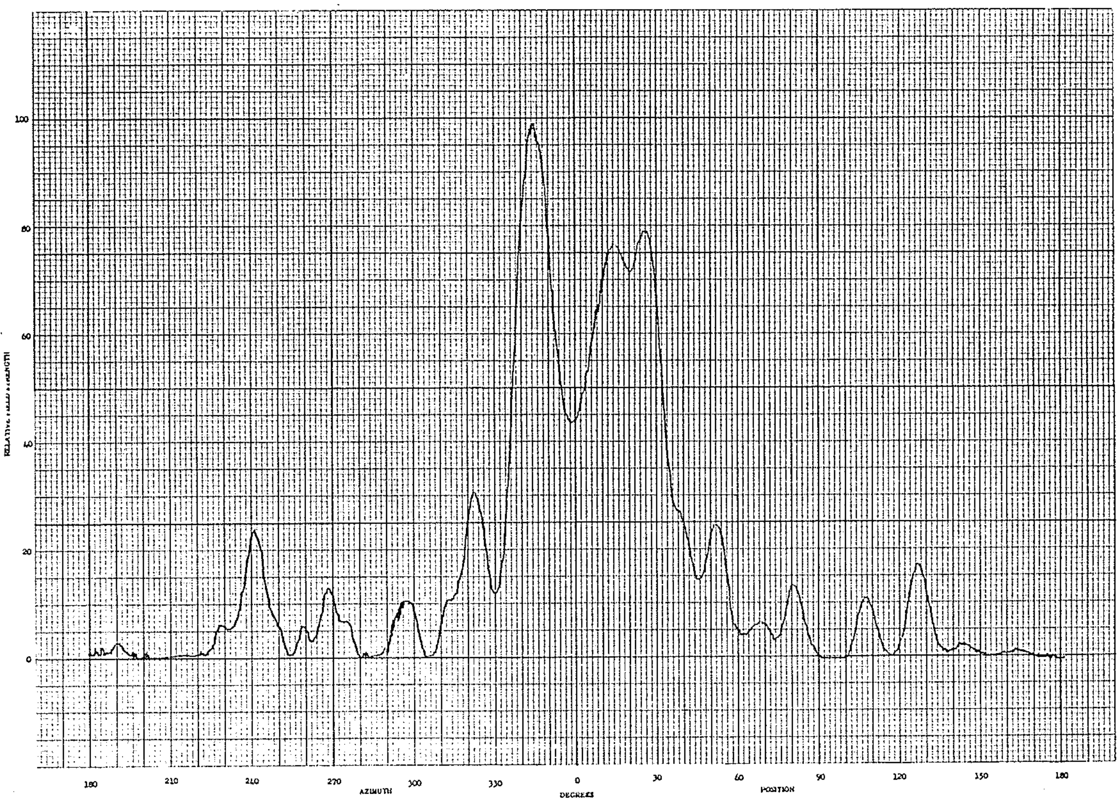
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Vee

PATTERN NO. a=b=1.5"

FREQUENCY 1200 mc.

PATTERN PLANE E

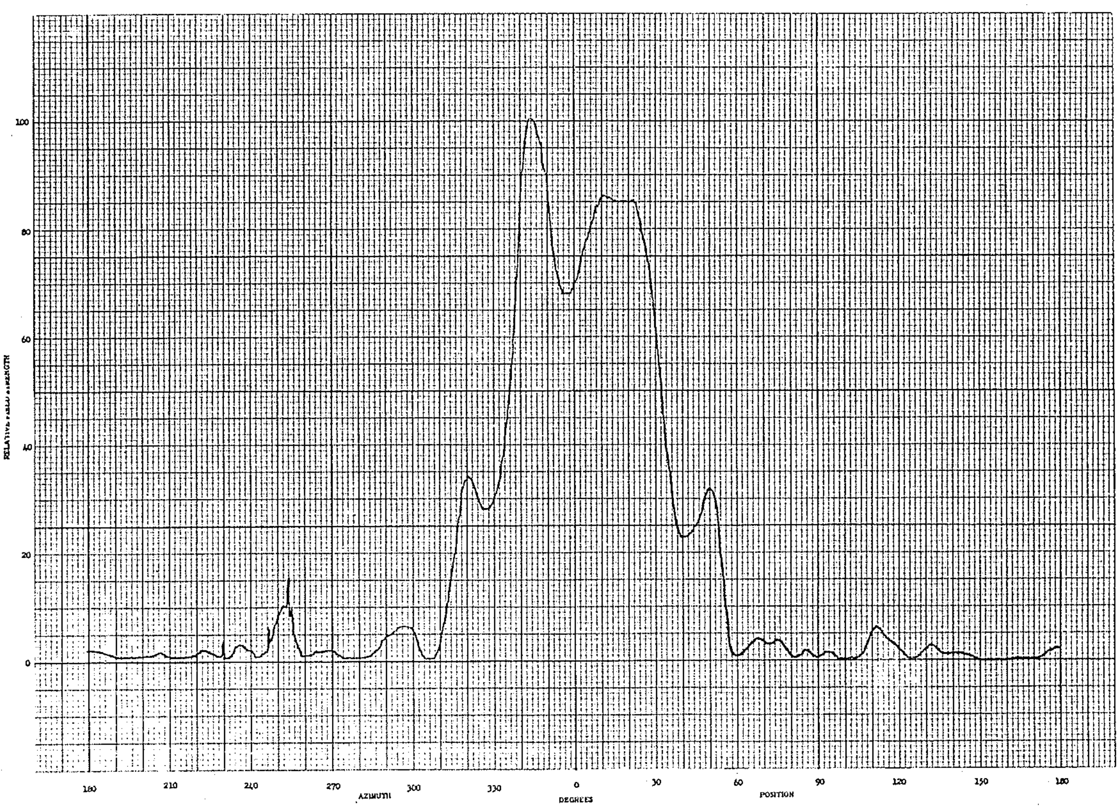
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov.12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Dipole

PATTERN NO. a=b=1.5"

FREQUENCY 1200 mc.

PATTERN PLANE E

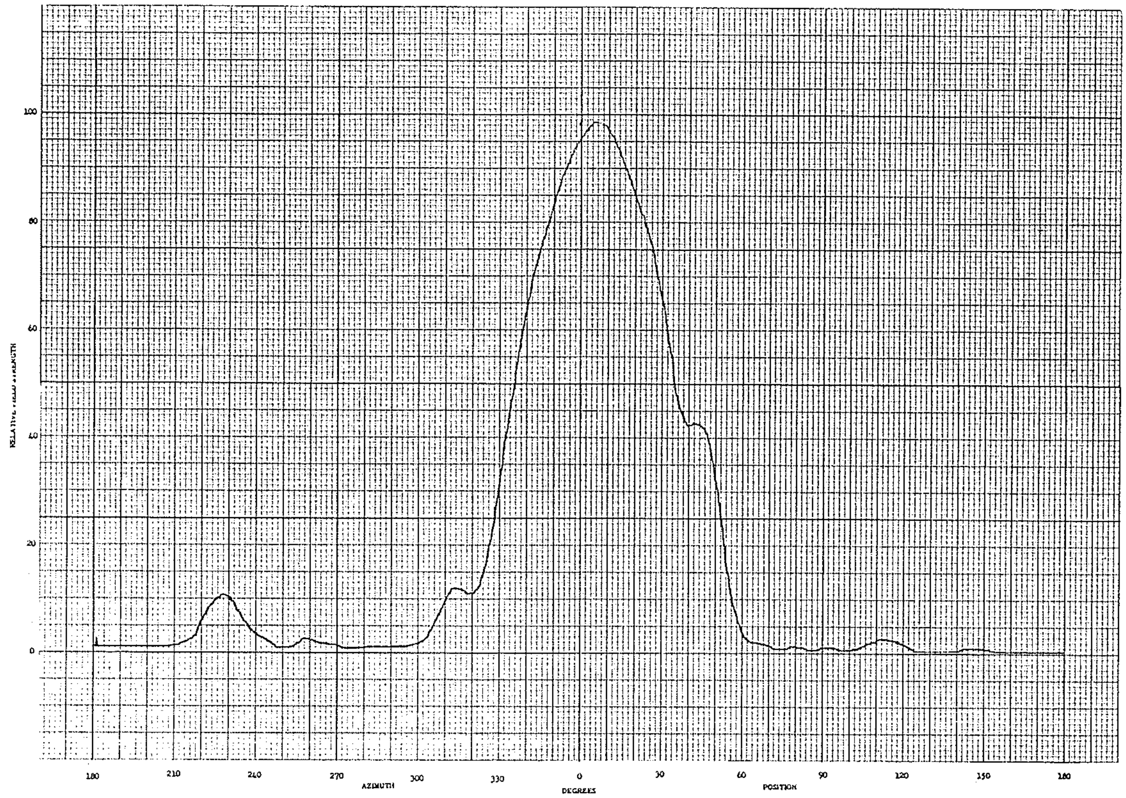
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov.12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: *L.P. Vee*

PATTERN NO.: *a=1.5", b=4.0"*

FREQUENCY: *800 mc.*

PATTERN PLANE: *E*

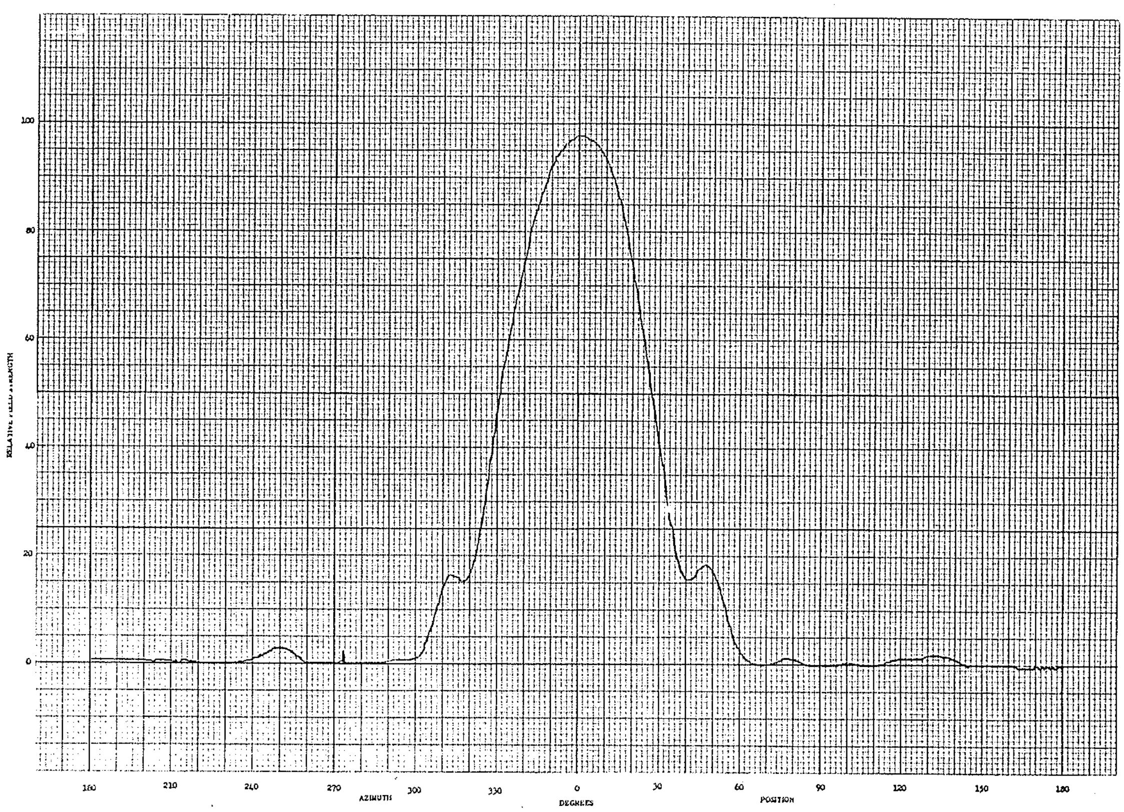
SCALE

VERTICAL

HORIZONTAL

NAME: *C.V. Thio*

DATE: *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: *L.P. Dipole*

PATTERN NO.: *a=1.5", b=4.0"*

FREQUENCY: *800 mc.*

PATTERN PLANE: *E*

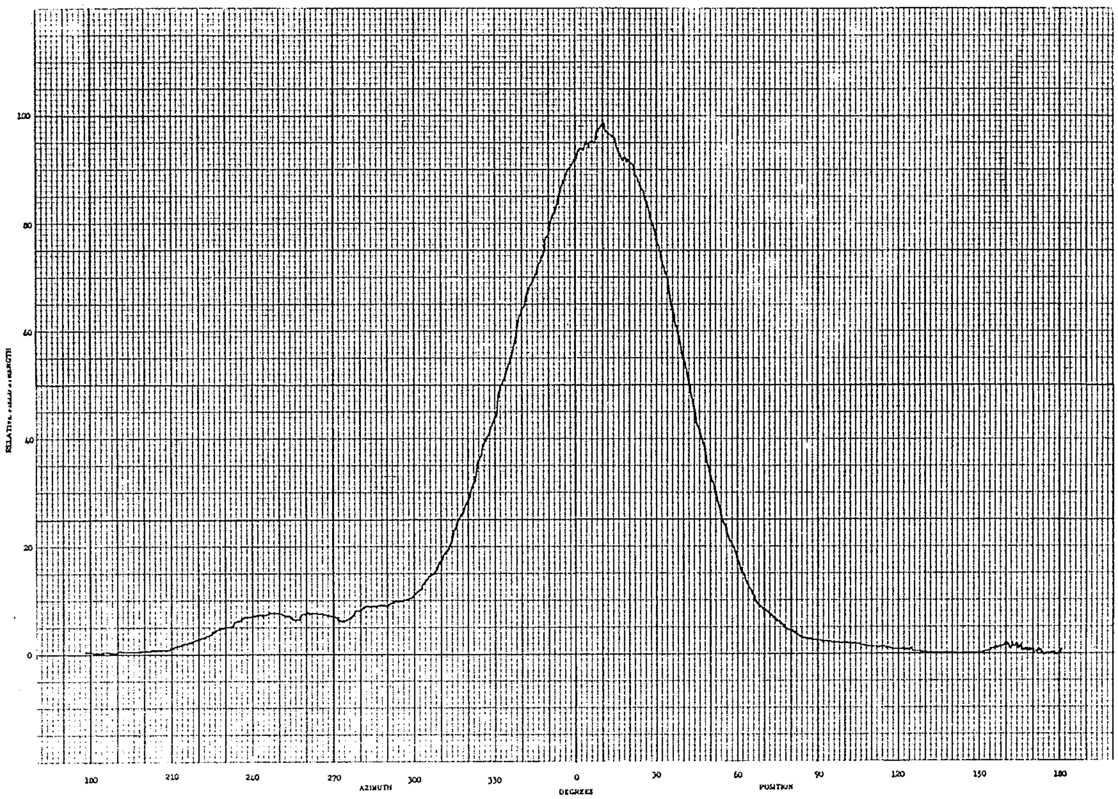
SCALE

VERTICAL

HORIZONTAL

NAME: *C.V. Thio*

DATE: *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L.P. Vee

PATTERN NO.: a=1.5", b=8.75"

FREQUENCY: 200 mc.

PATTERN PLANE: E

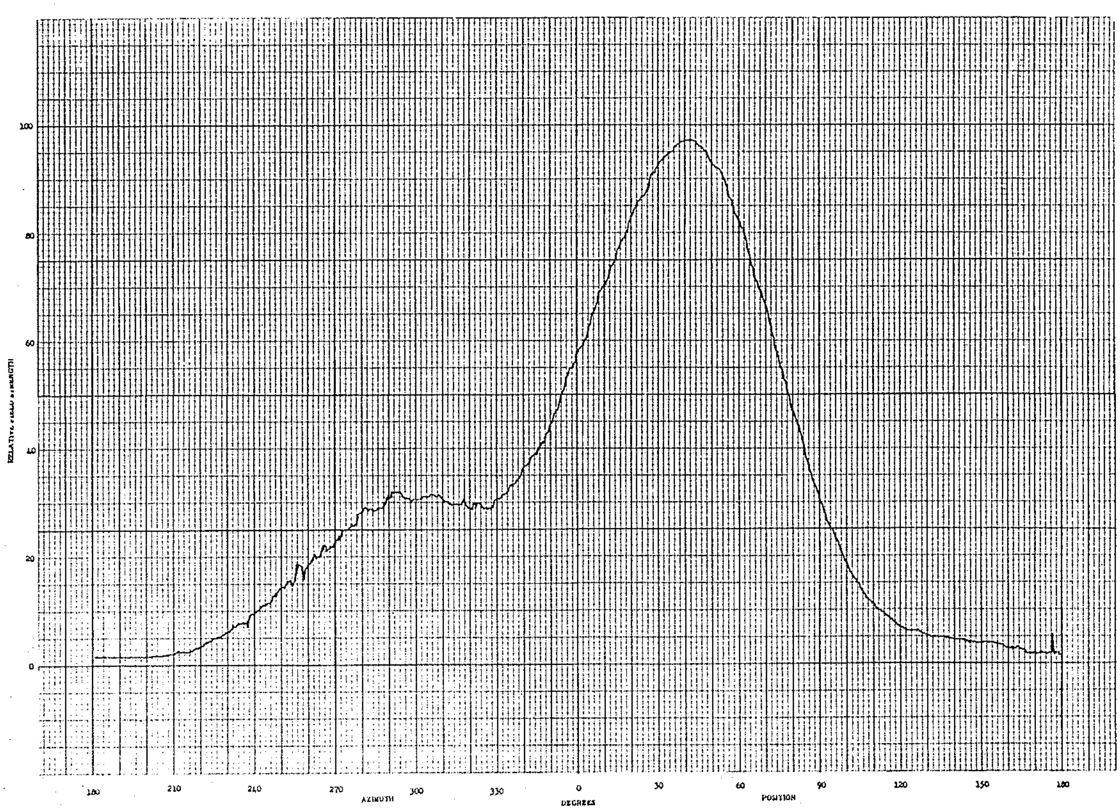
SCALE

VERTICAL

HORIZONTAL

NAME: C.Y. Thio

DATE: Nov. 12/63



THE UNIVERSITY OF MANITOBA

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ANTENNA TYPE: L.P. Dipole

PATTERN NO.: a=1.5", b=6.0"

FREQUENCY: 200 mc.

PATTERN PLANE: E

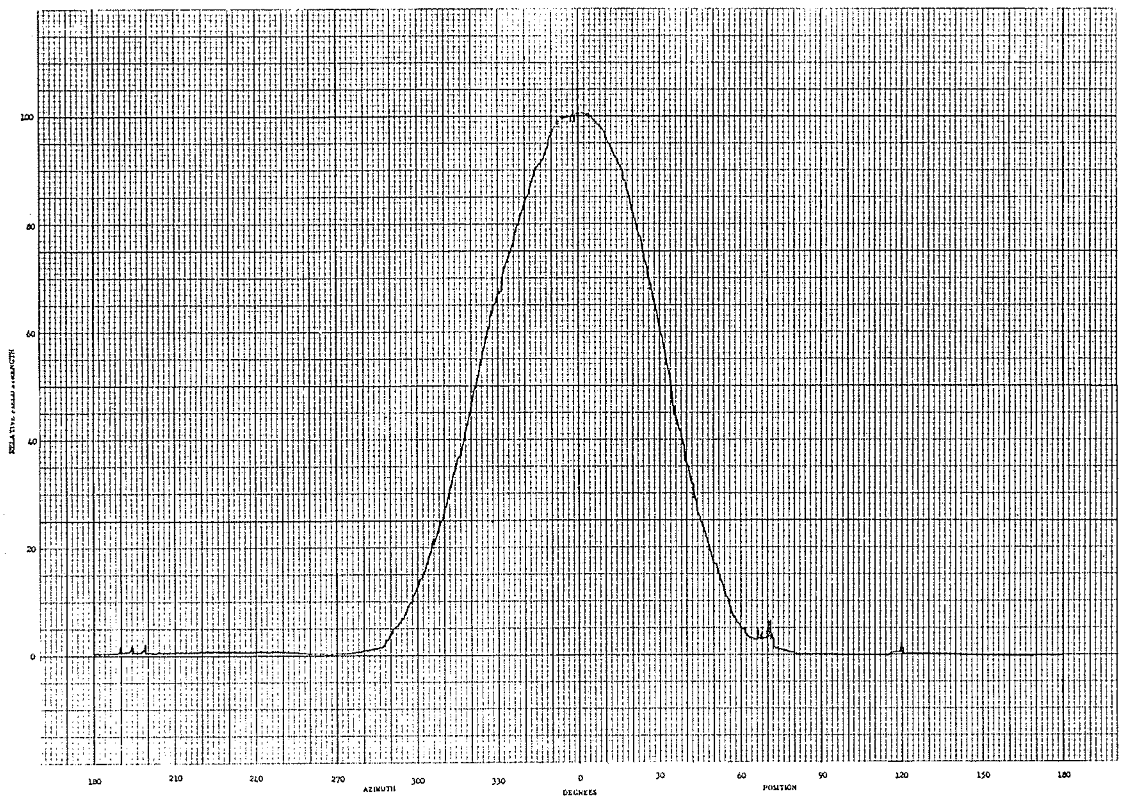
SCALE

VERTICAL

HORIZONTAL

NAME: C.Y. Thio

DATE: Nov. 12/63



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DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L. P. Vee*

PATTERN NO. *a=1.5", b=8.75"*

FREQUENCY *400 mc.*

PATTERN PLANE *E*

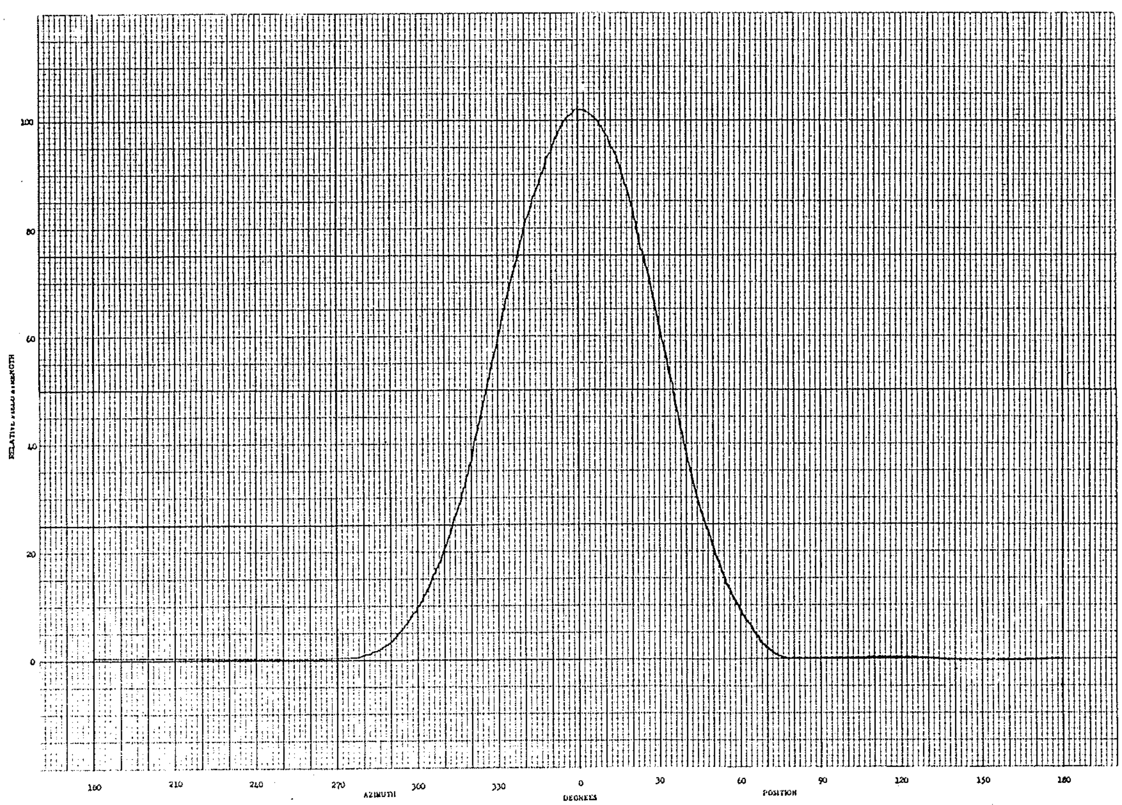
SCALE

VERTICAL

HORIZONTAL

NAME *C. V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L. P. Dipole*

PATTERN NO. *a=1.5", b=8.75"*

FREQUENCY *400 mc.*

PATTERN PLANE *E*

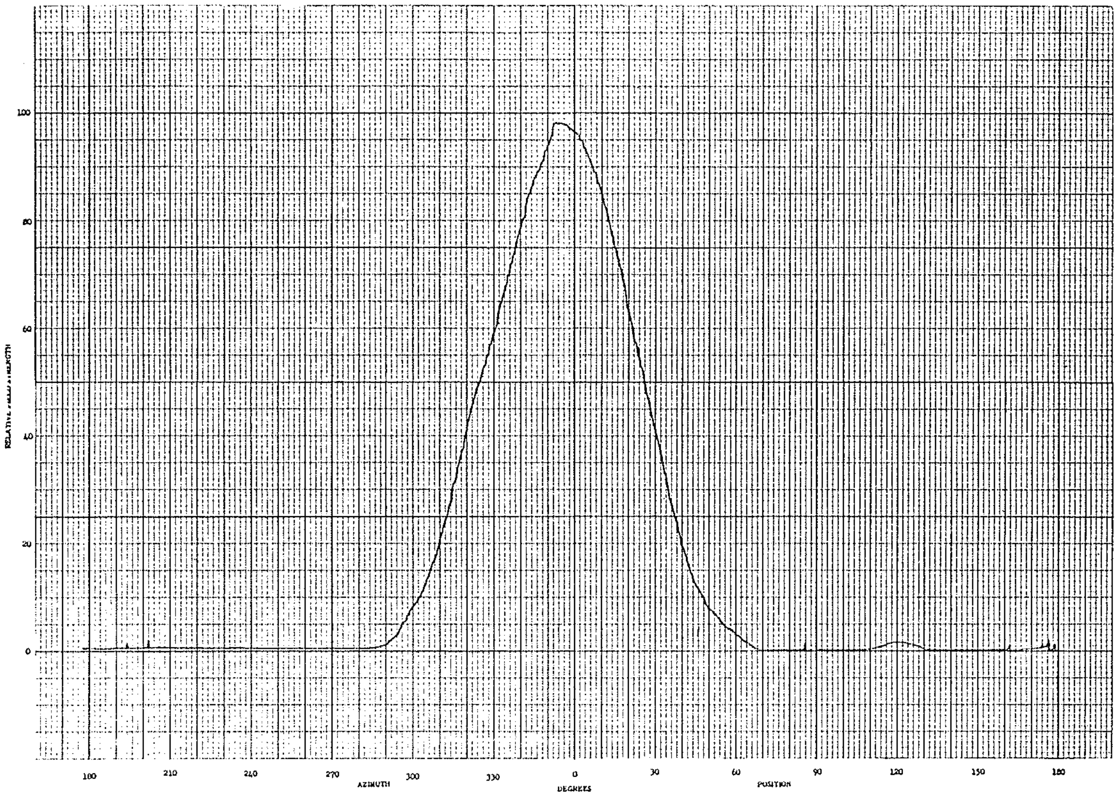
SCALE

VERTICAL

HORIZONTAL

NAME *C. V. Thio*

DATE *Nov. 12/63*



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DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Vee

PATTERN NO.
a=1.5", b=8.75"

FREQUENCY
600 mc.

PATTERN PLANE
E

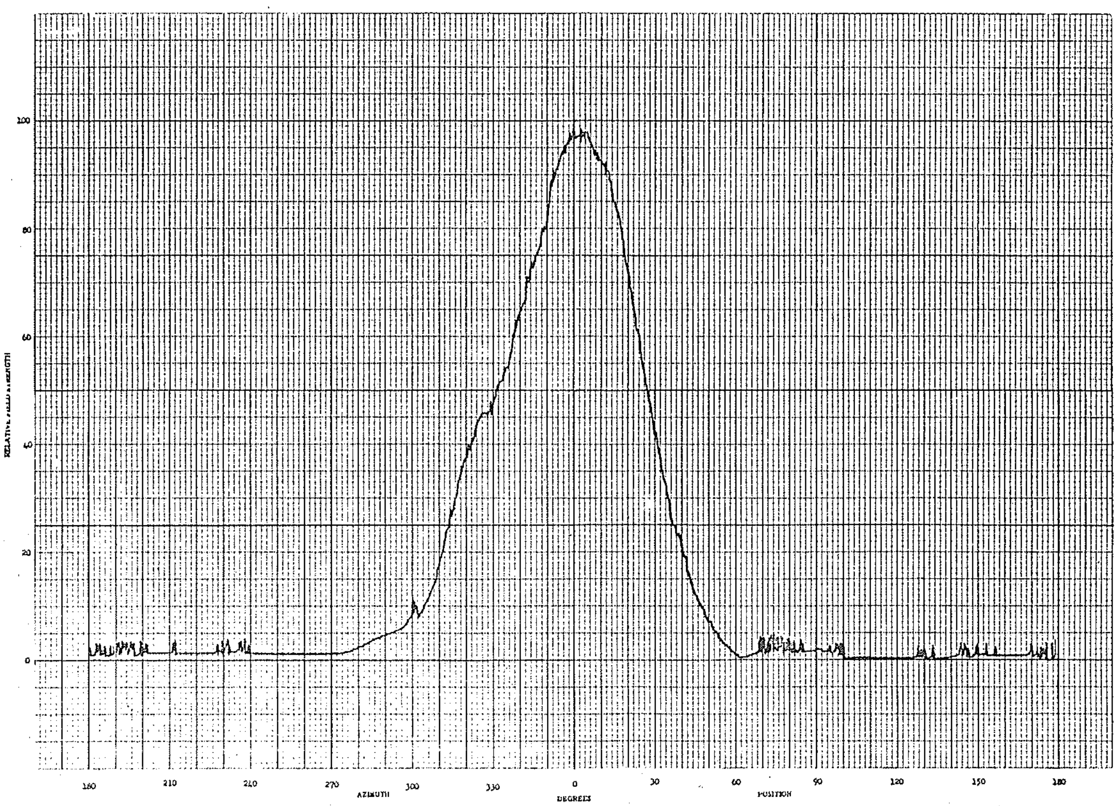
SCALE

VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Dipole

PATTERN NO.
a=1.5", b=8.75"

FREQUENCY
600 mc.

PATTERN PLANE
E

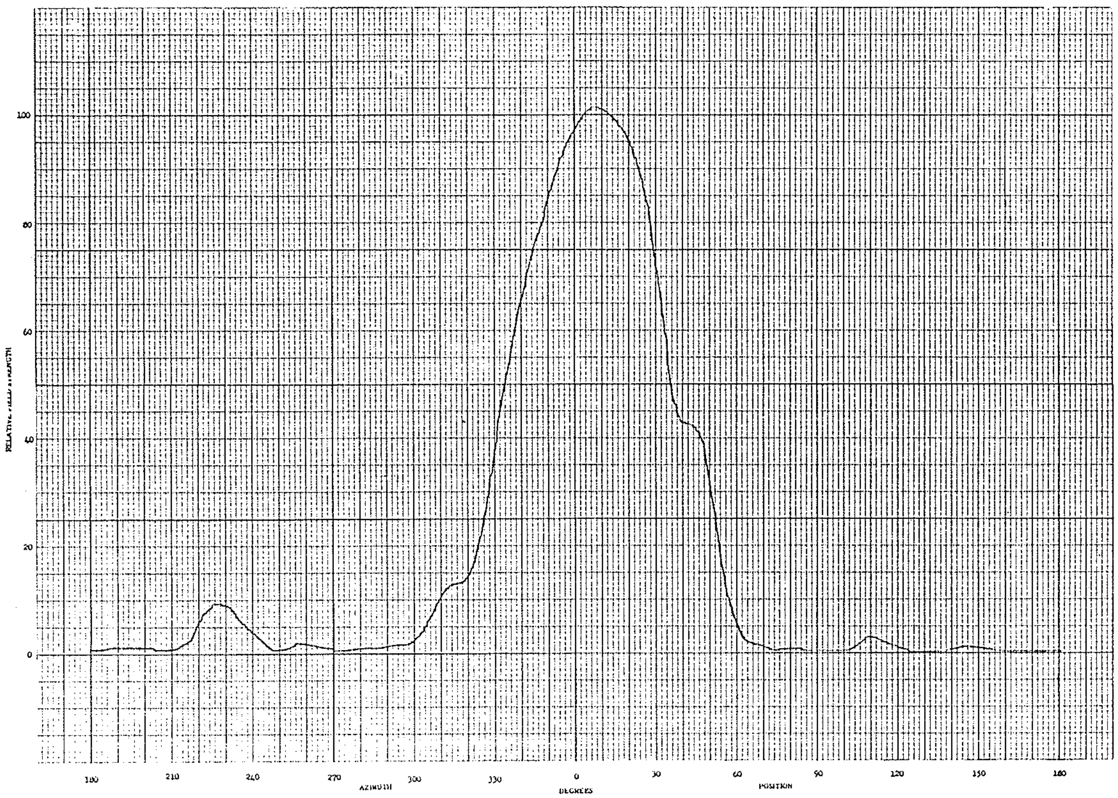
SCALE

VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Vee

PATTERN NO. a=1.5", b=8.75"

FREQUENCY 800 mc.

PATTERN PLANE E

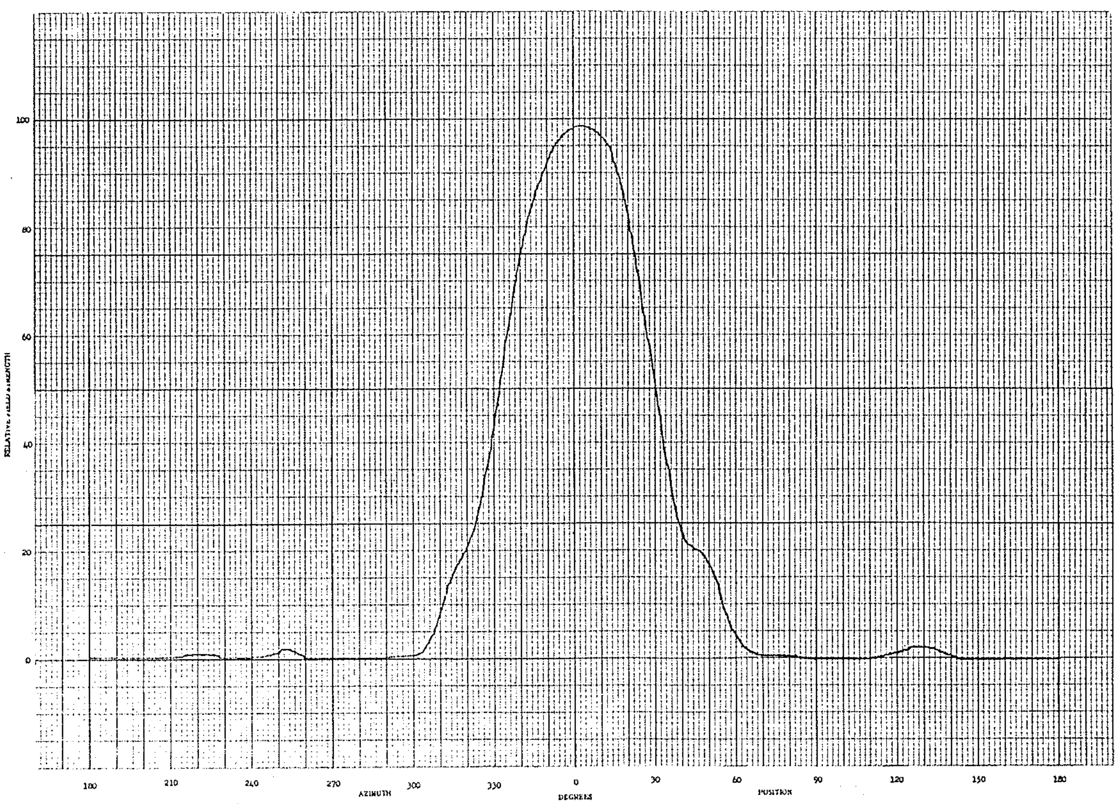
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Dipole

PATTERN NO. a=1.5", b=8.75"

FREQUENCY 800 mc.

PATTERN PLANE E

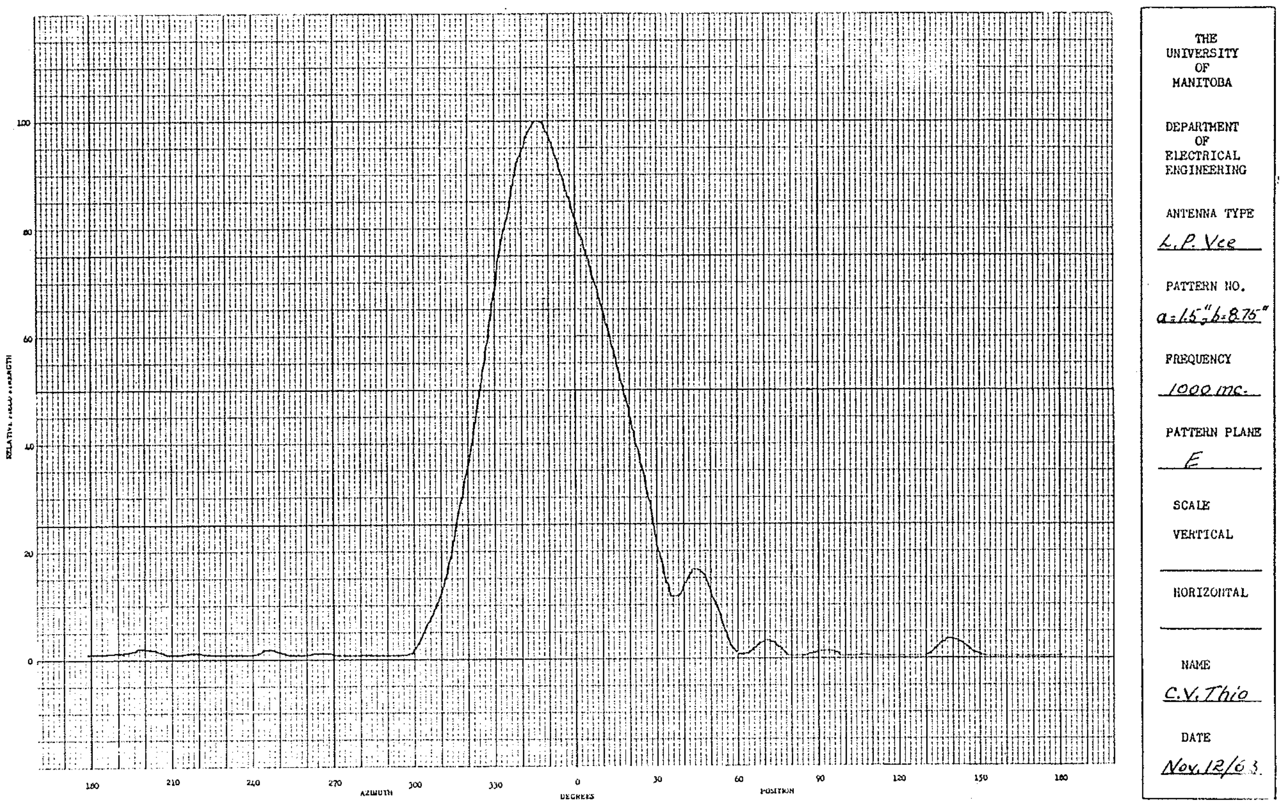
SCALE

VERTICAL

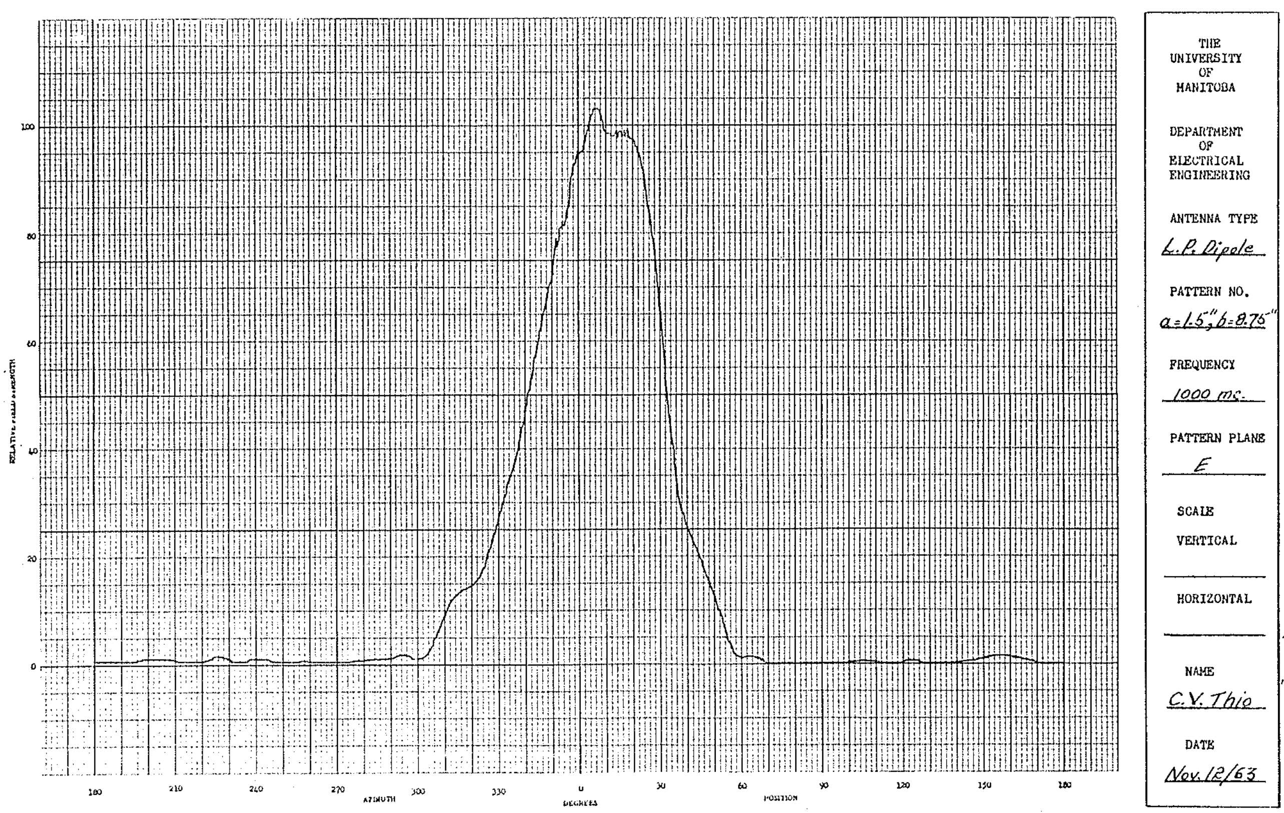
HORIZONTAL

NAME C.V. Thio

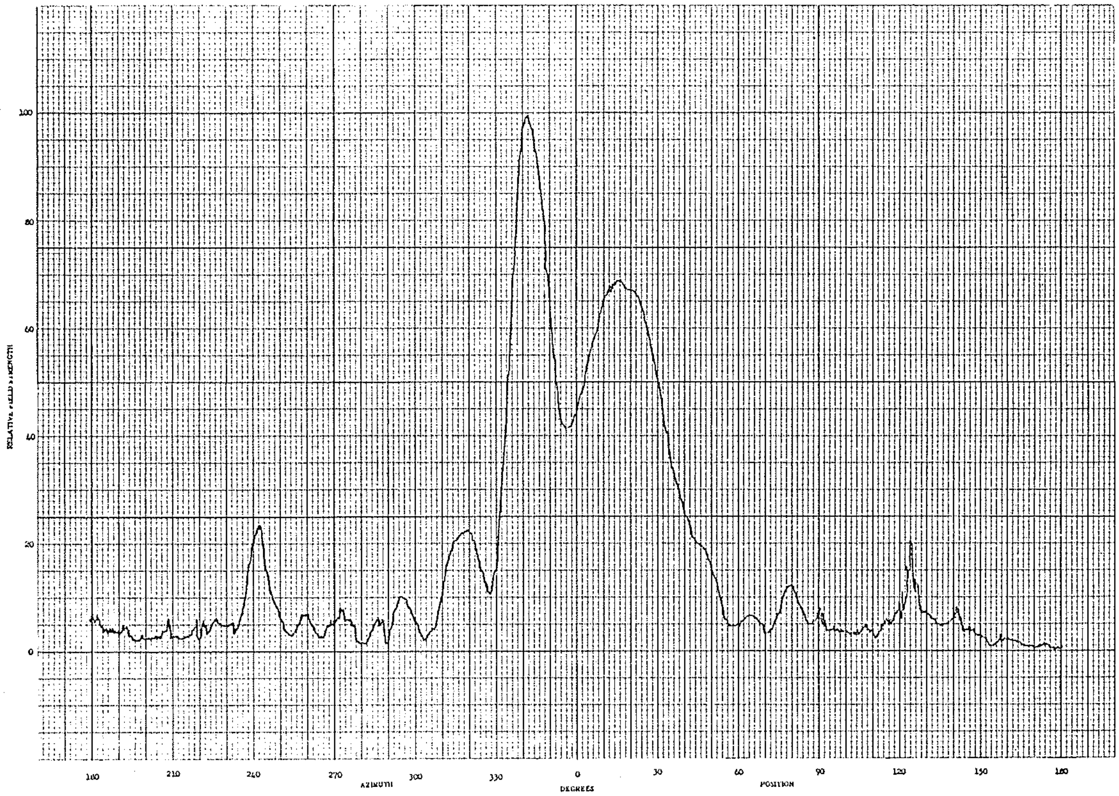
DATE Nov. 12/63



RELATIVE FIELD STRENGTH
100
80
60
40
20
0
180
210
240
270
300
330
0
30
60
90
120
150
180
AZIMUTH
DEGREES
POSITION
THE UNIVERSITY OF MANITOBA
DEPARTMENT OF ELECTRICAL ENGINEERING
ANTENNA TYPE
L.P. Vee
PATTERN NO.
a=1.5", b=8.75"
FREQUENCY
1000 mc.
PATTERN PLANE
E
SCALE
VERTICAL
HORIZONTAL
NAME
C.V. Thio
DATE
Nov. 12/63



RELATIVE FIELD STRENGTH
100
80
60
40
20
0
180
210
240
270
300
330
0
30
60
90
120
150
180
AZIMUTH
DEGREES
POSITION
THE UNIVERSITY OF MANITOBA
DEPARTMENT OF ELECTRICAL ENGINEERING
ANTENNA TYPE
L.P. Dipole
PATTERN NO.
a=1.5", b=8.75"
FREQUENCY
1000 mc.
PATTERN PLANE
E
SCALE
VERTICAL
HORIZONTAL
NAME
C.V. Thio
DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Vee*

PATTERN NO. *a=1.5″, b=8.75″*

FREQUENCY *1200 mc.*

PATTERN PLANE *E*

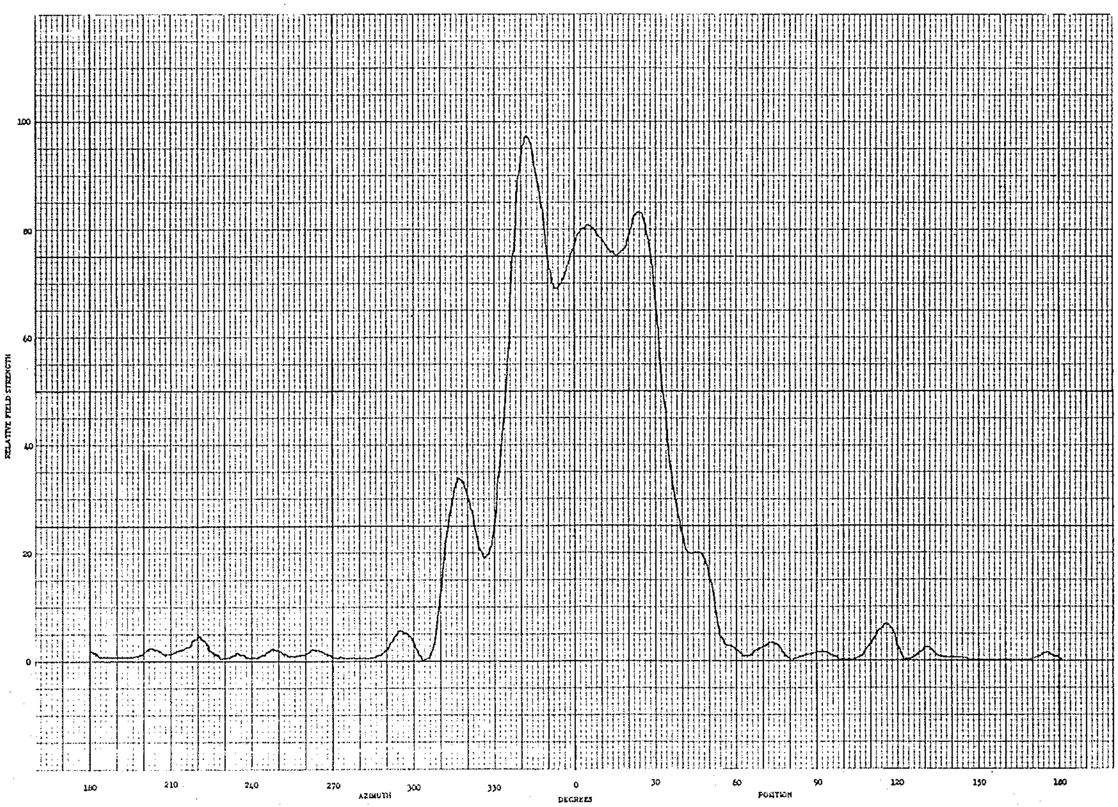
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Dipole*

PATTERN NO. *a=1.5″, b=8.75″*

FREQUENCY *1200 mc.*

PATTERN PLANE *E*

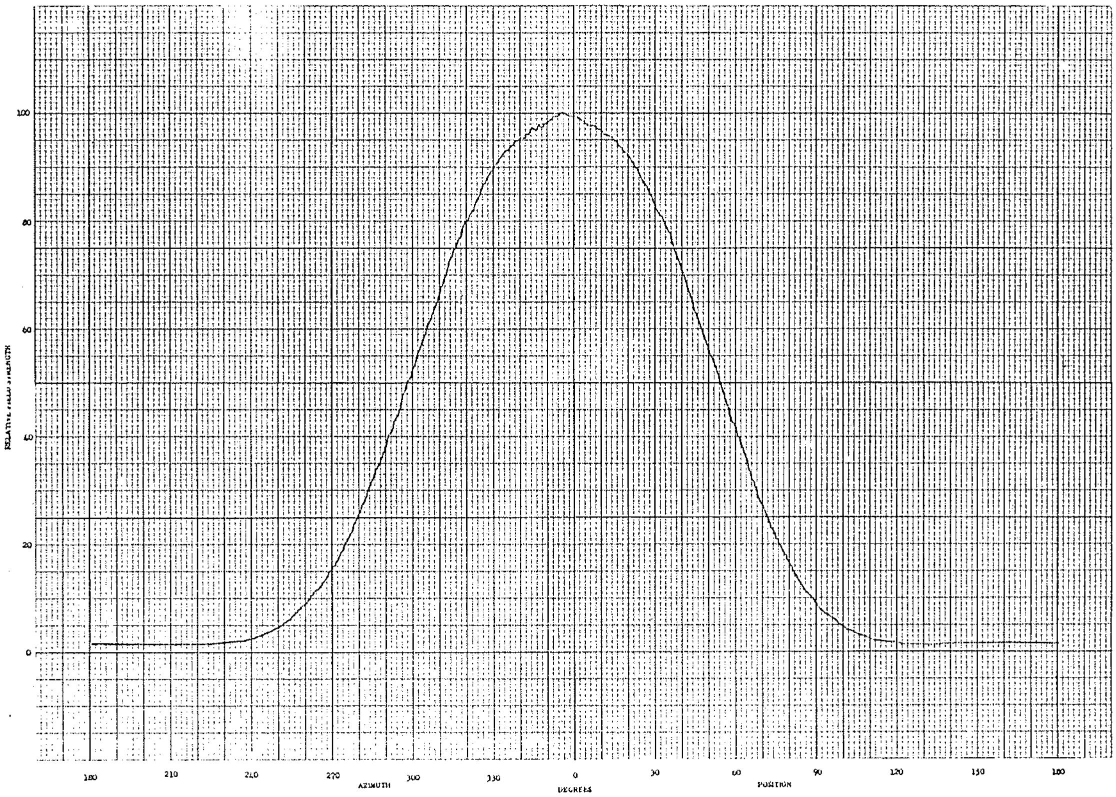
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L.P. Vee

PATTERN NO.: a=b=1.5"

FREQUENCY: 200 mc.

PATTERN PLANE: H

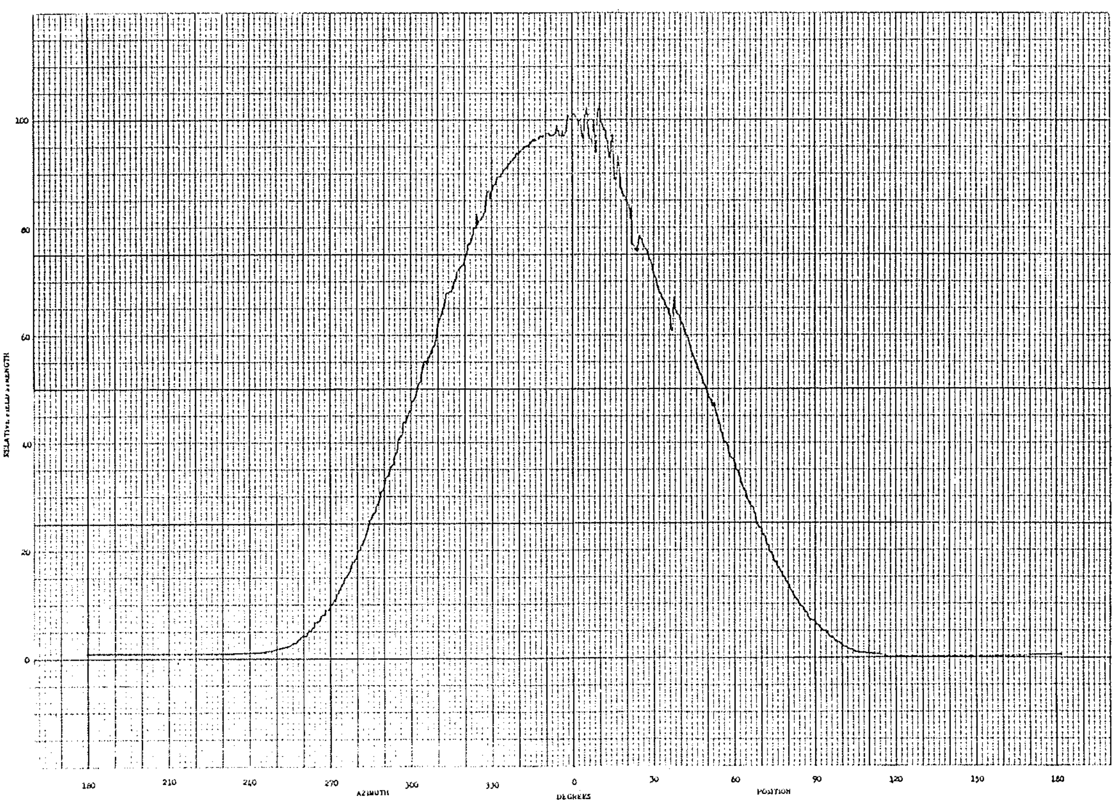
SCALE

VERTICAL

HORIZONTAL

NAME: C.V. Thio

DATE: Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L.P. Dipole

PATTERN NO.: a=b=1.5"

FREQUENCY: 200 mc.

PATTERN PLANE: H

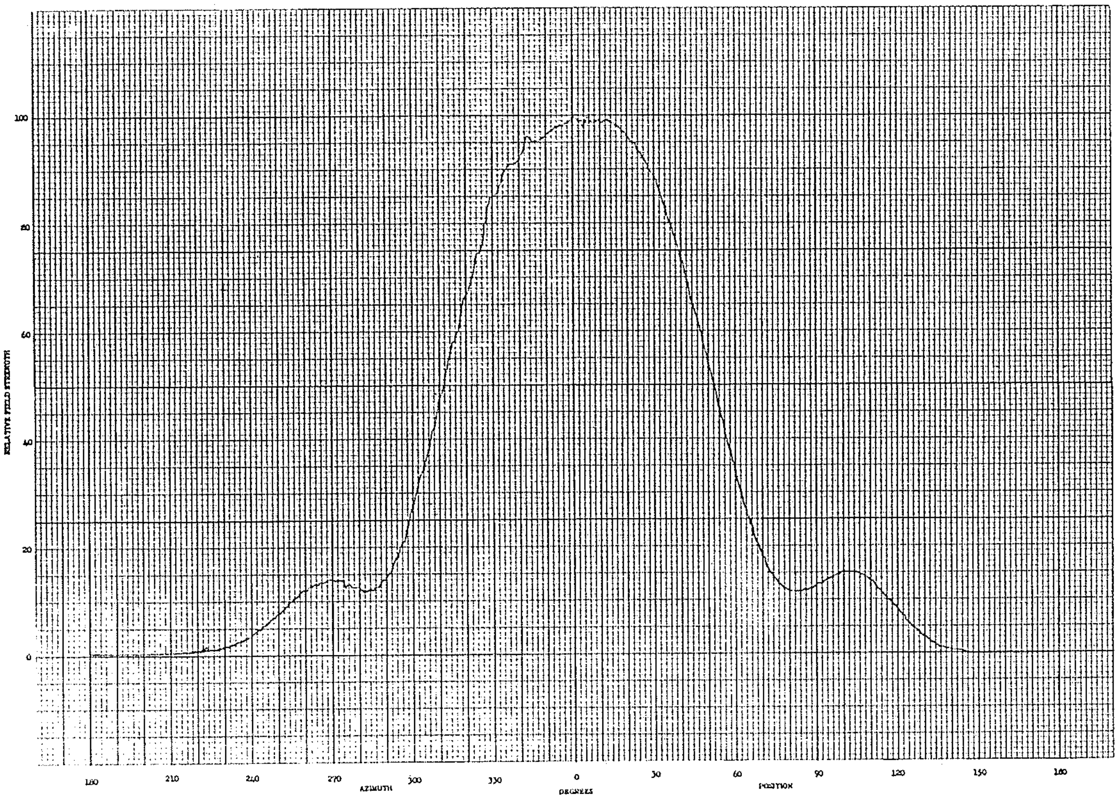
SCALE

VERTICAL

HORIZONTAL

NAME: C.V. Thio

DATE: Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Vee

PATTERN NO.
a=b=1.5"

FREQUENCY
300 mc.

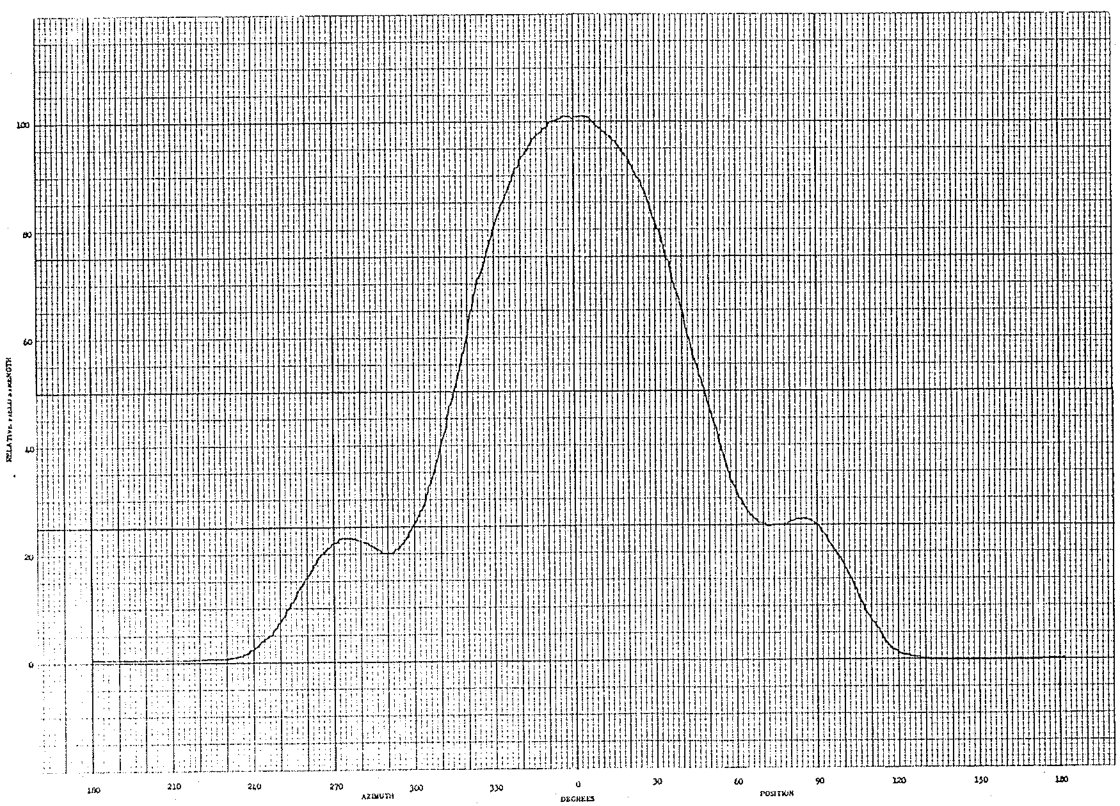
PATTERN PLANE
H

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Dipole

PATTERN NO.
a=b=1.5"

FREQUENCY
300 mc.

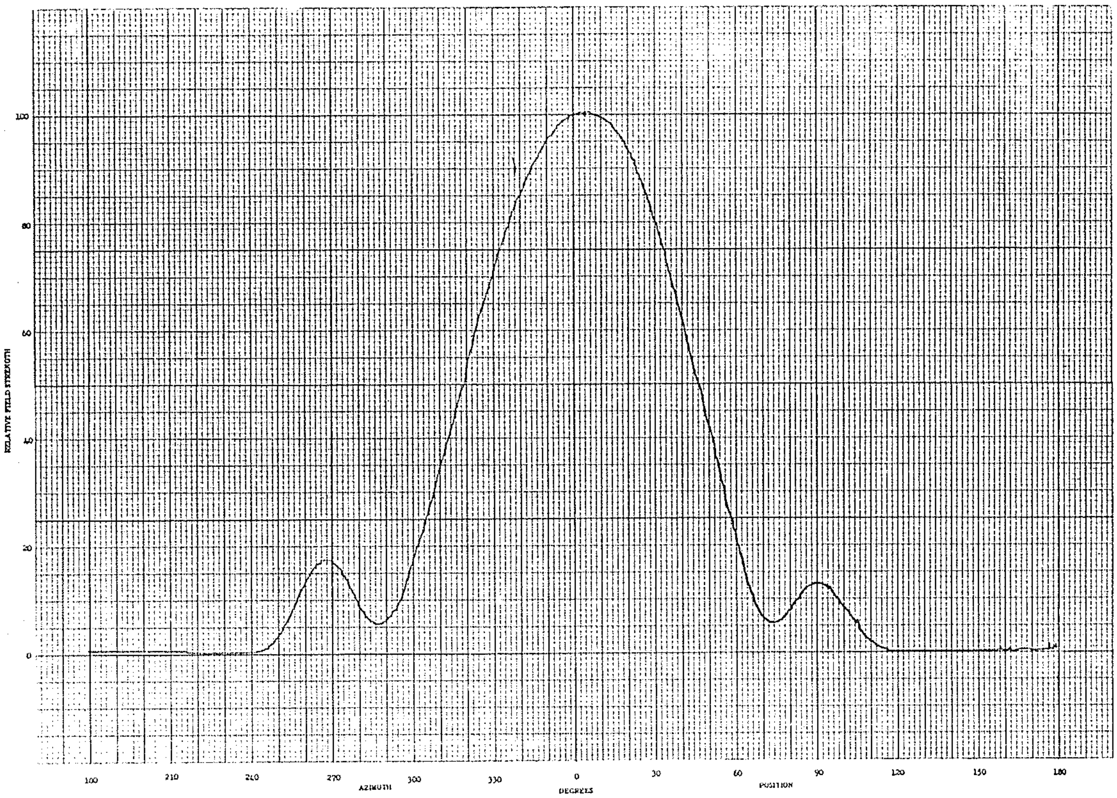
PATTERN PLANE
H

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Vee

PATTERN NO. a=b=1.5"

FREQUENCY 400 mc.

PATTERN PLANE H

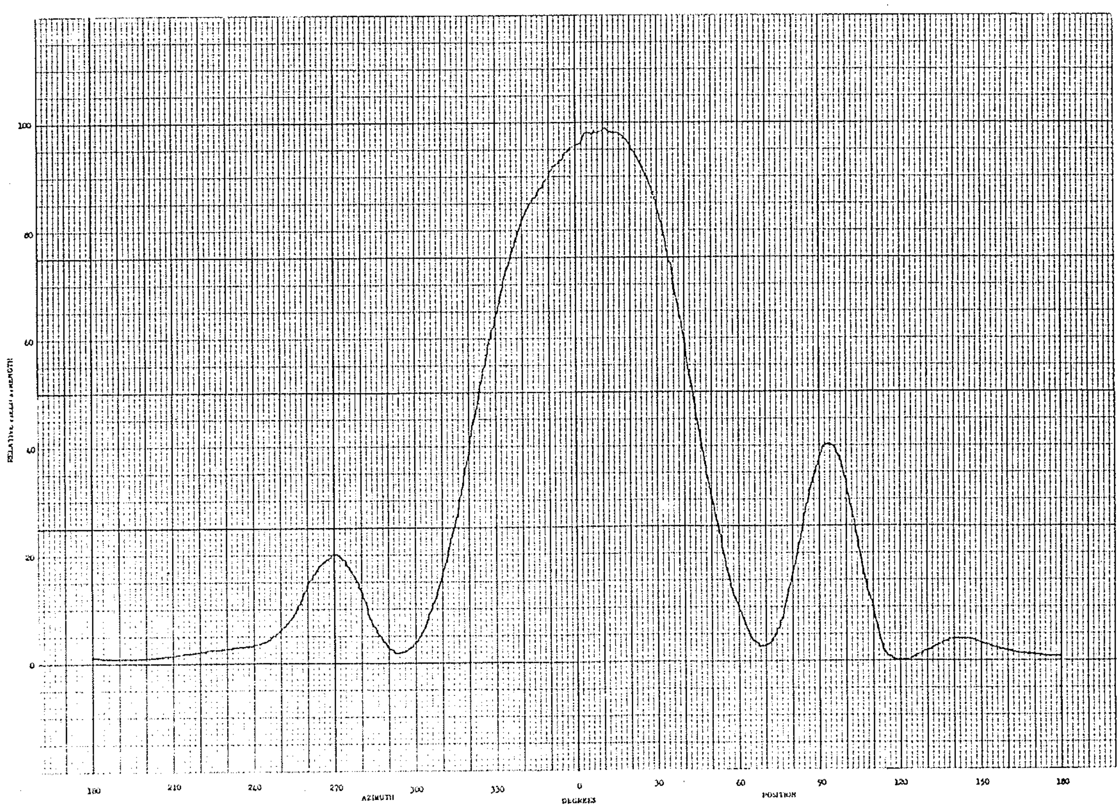
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Dipole

PATTERN NO. a=b=1.5"

FREQUENCY 400 mc.

PATTERN PLANE H

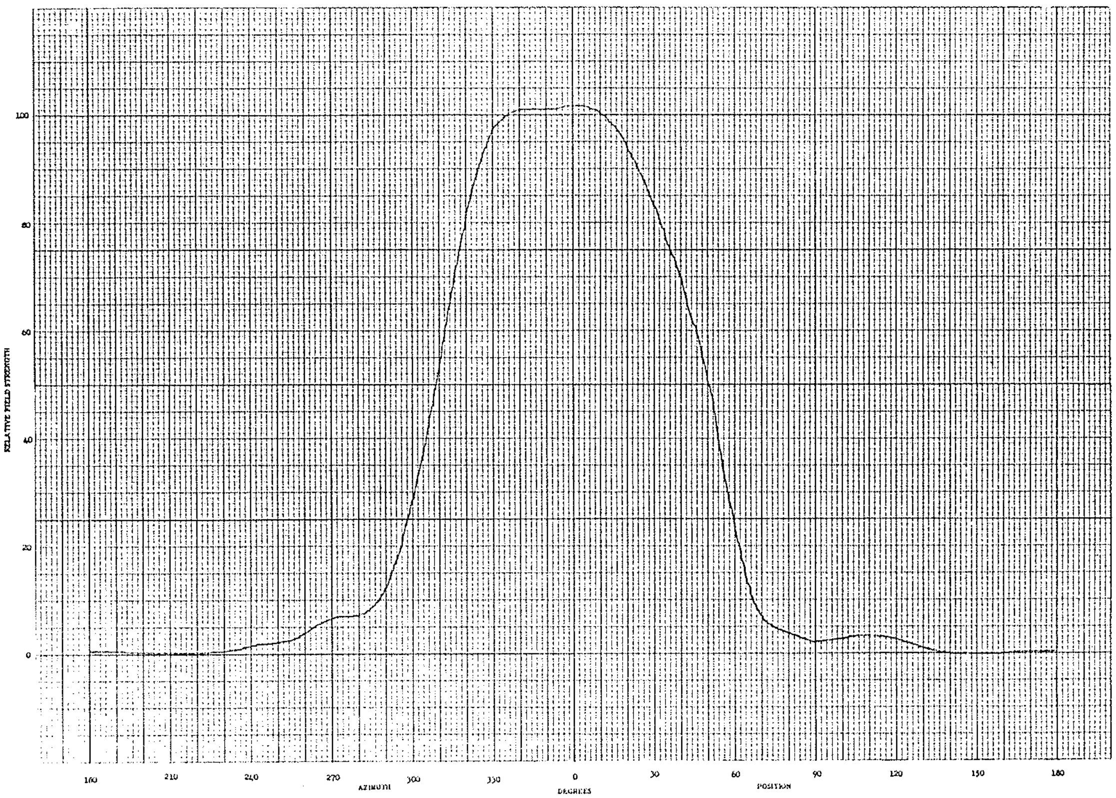
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L.P. Vee

PATTERN NO.: a=b=1.5"

FREQUENCY: 500 mc.

PATTERN PLANE: H

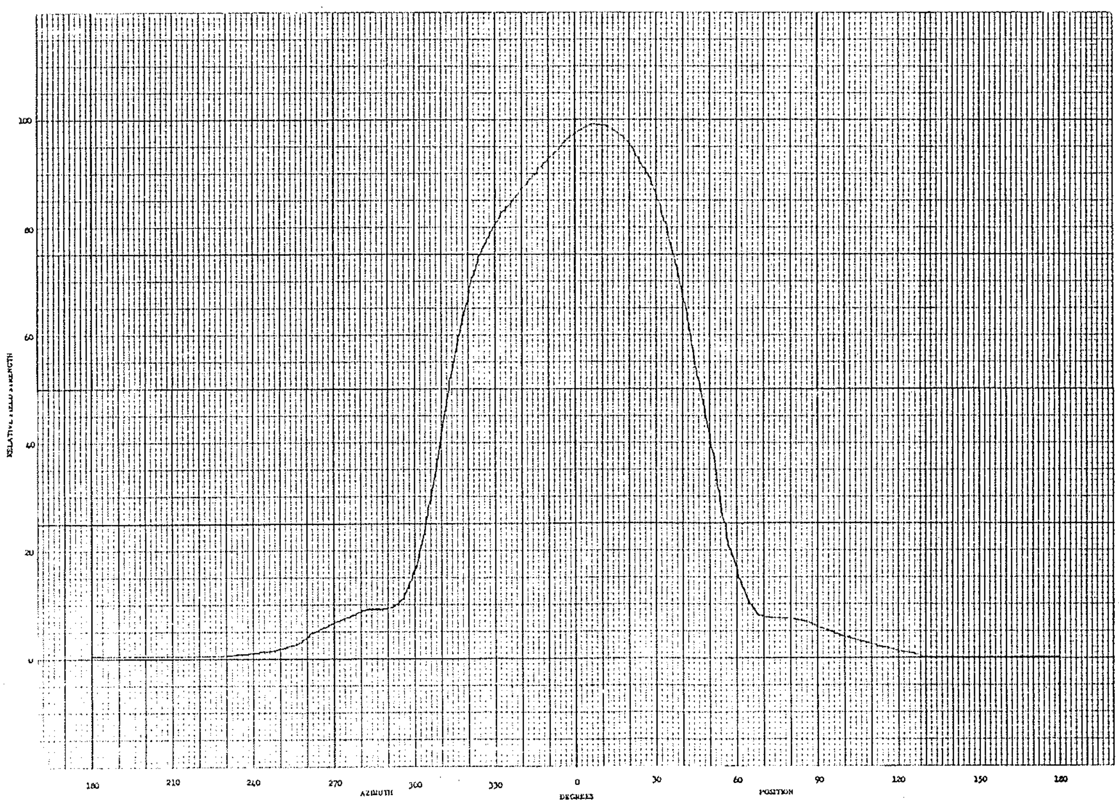
SCALE

VERTICAL: ____

HORIZONTAL: ____

NAME: C.V. Thio

DATE: Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L.P. Dipole

PATTERN NO.: a=b=1.5"

FREQUENCY: 500 mc.

PATTERN PLANE: H

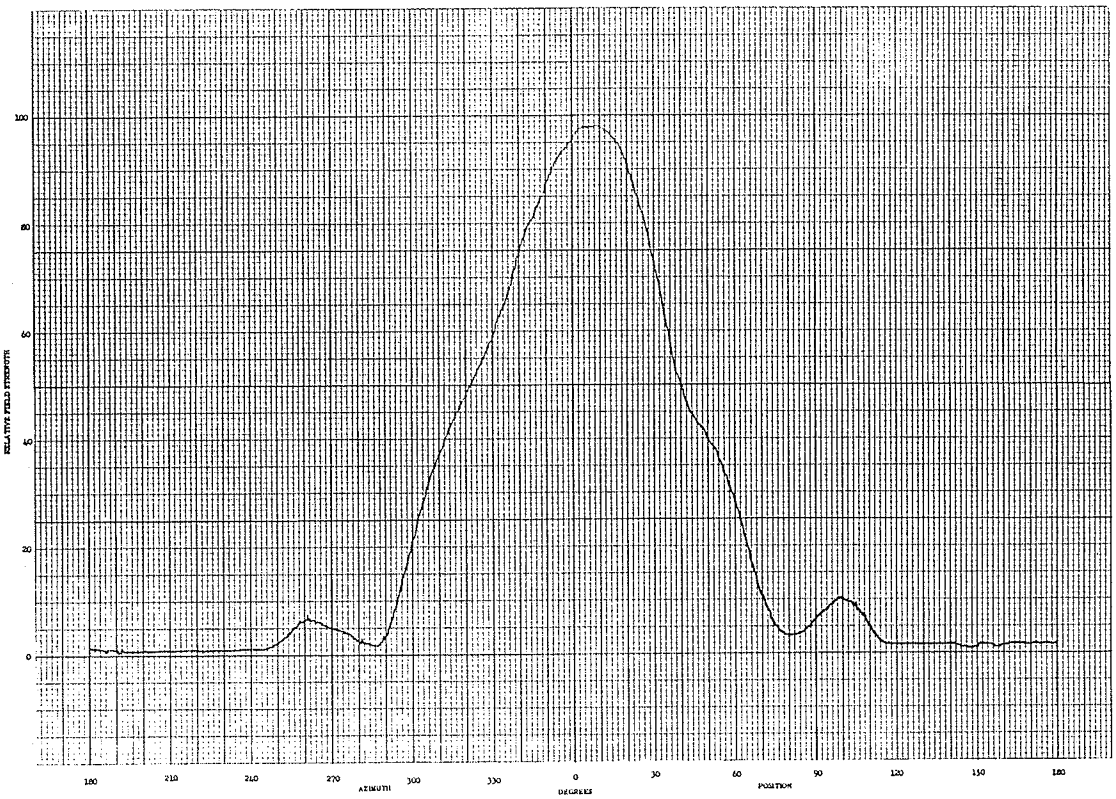
SCALE

VERTICAL: ____

HORIZONTAL: ____

NAME: C.V. Thio

DATE: Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Vee

PATTERN NO.
a = b = 1.5"

FREQUENCY
600 mc.

PATTERN PLANE
H

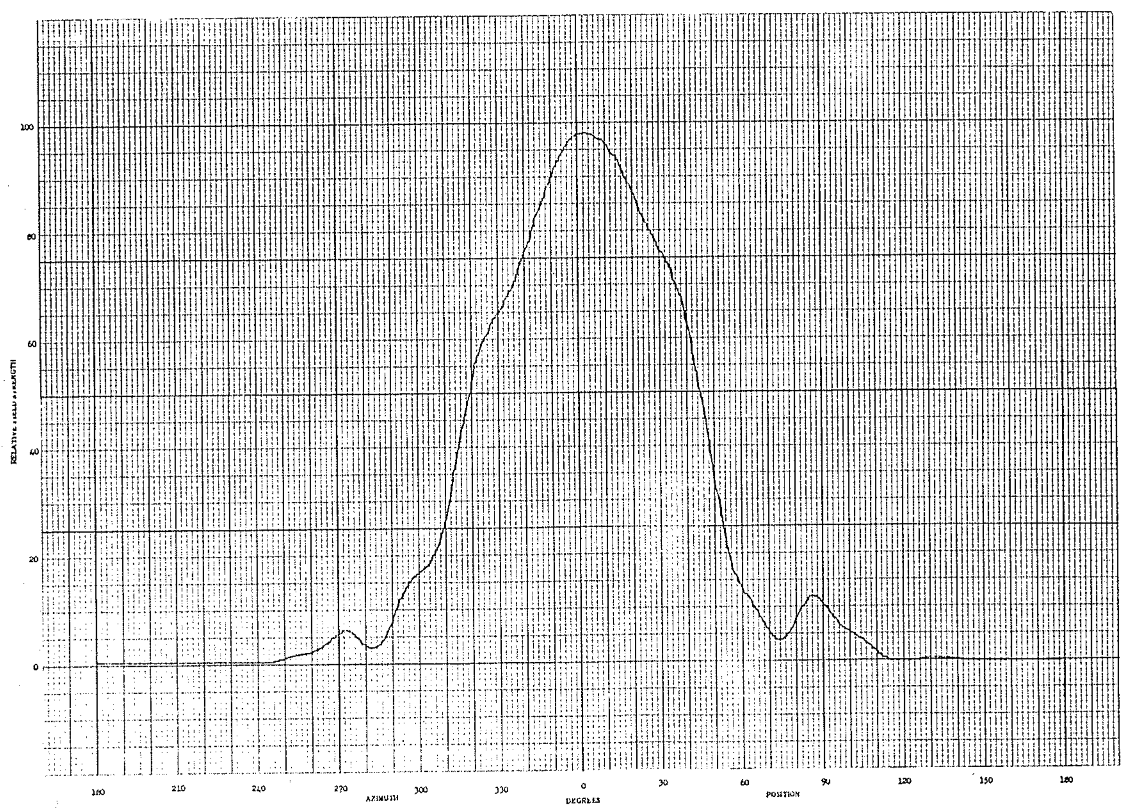
SCALE

VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Dipole

PATTERN NO.
a = b = 1.5"

FREQUENCY
600 mc.

PATTERN PLANE
H

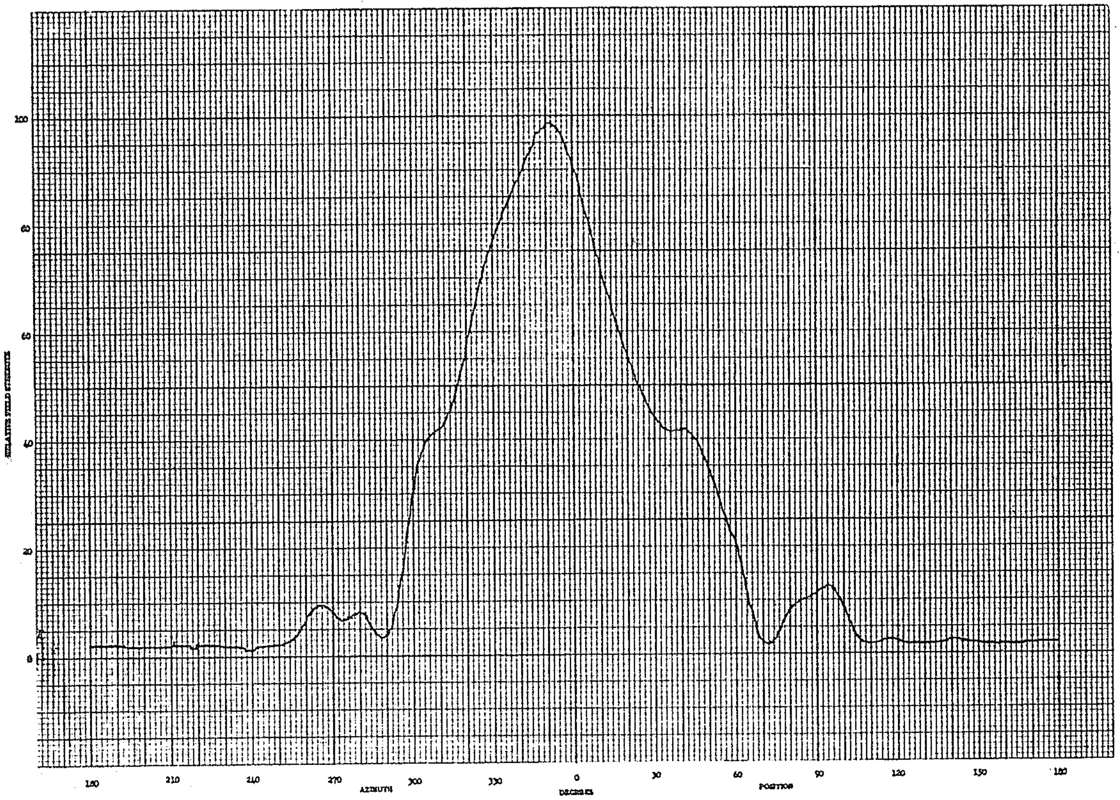
SCALE

VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Vee*

PATTERN NO. *a=b=1.5"*

FREQUENCY *700 mc.*

PATTERN PLANE *H*

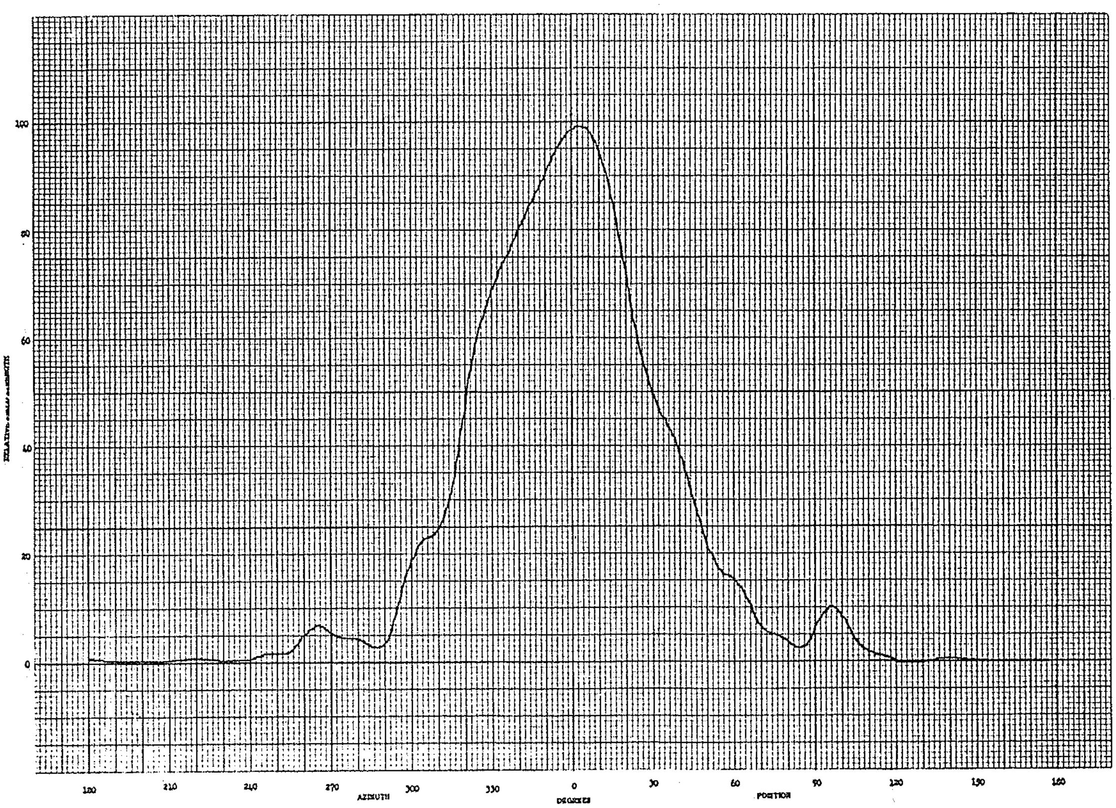
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Dipole*

PATTERN NO. *a=b=1.5"*

FREQUENCY *700 mc.*

PATTERN PLANE *H*

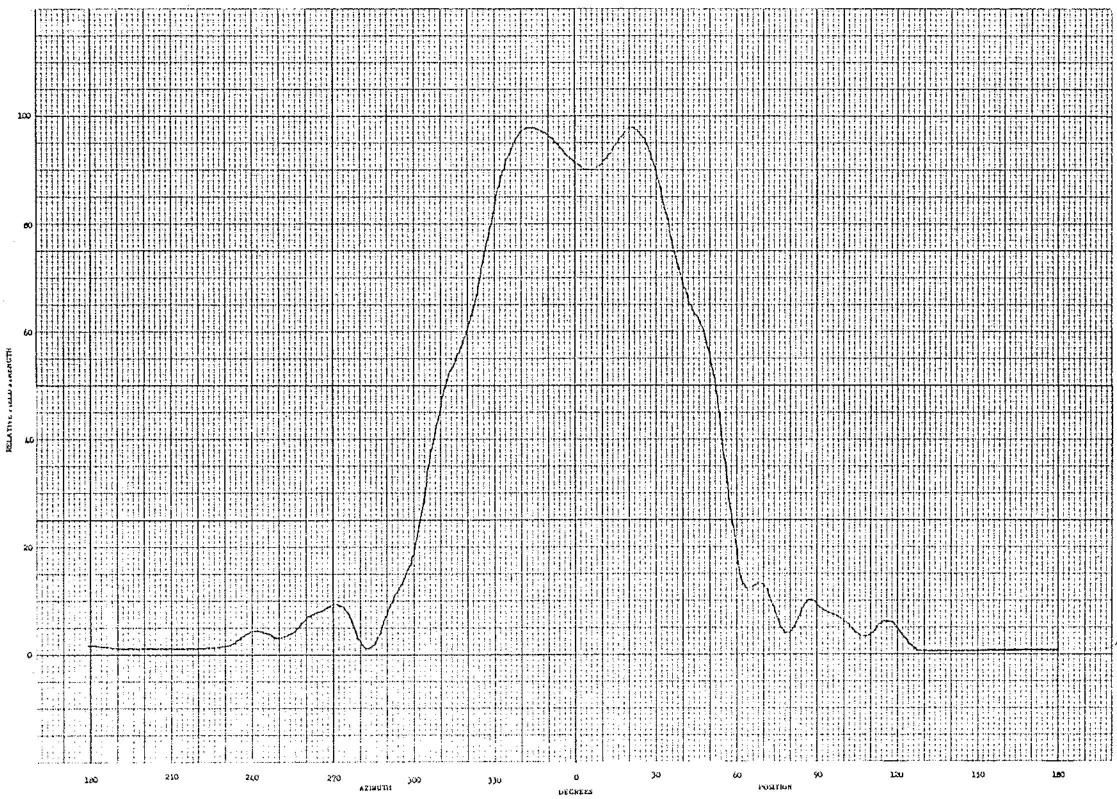
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L. P. Vee*

PATTERN NO. *a = b = 1.5"*

FREQUENCY *800 mc.*

PATTERN PLANE *H*

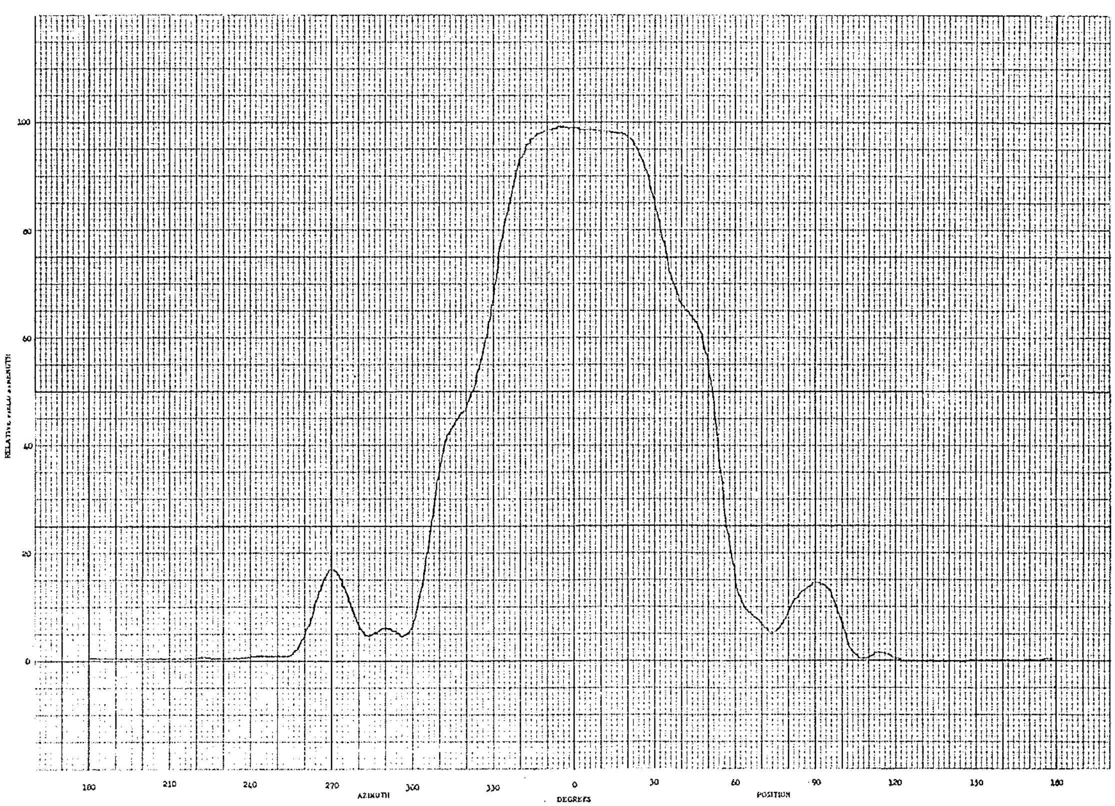
SCALE

VERTICAL

HORIZONTAL

NAME *C. V. Thio*

DATE *Nov. 12/65*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L. P. Dipole*

PATTERN NO. *a = b = 1.5"*

FREQUENCY *800 mc.*

PATTERN PLANE *H*

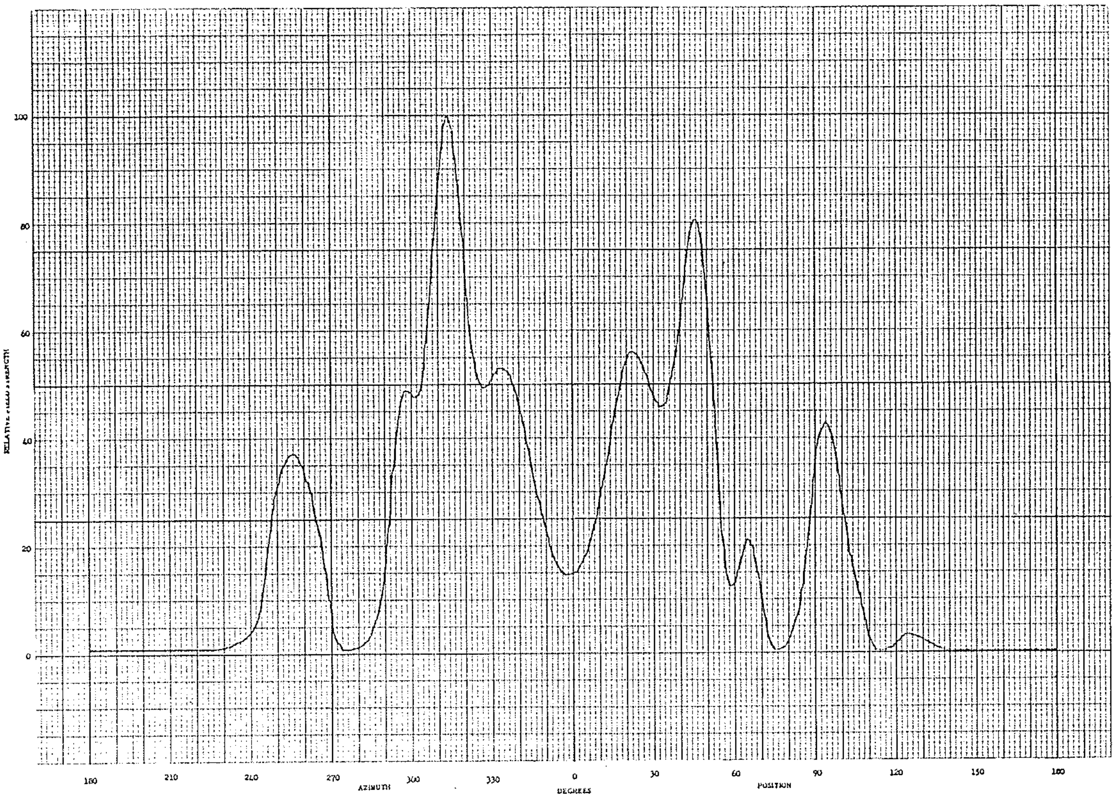
SCALE

VERTICAL

HORIZONTAL

NAME *C. V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Vee

PATTERN NO. a=b=1.5"

FREQUENCY 900 mc.

PATTERN PLANE H

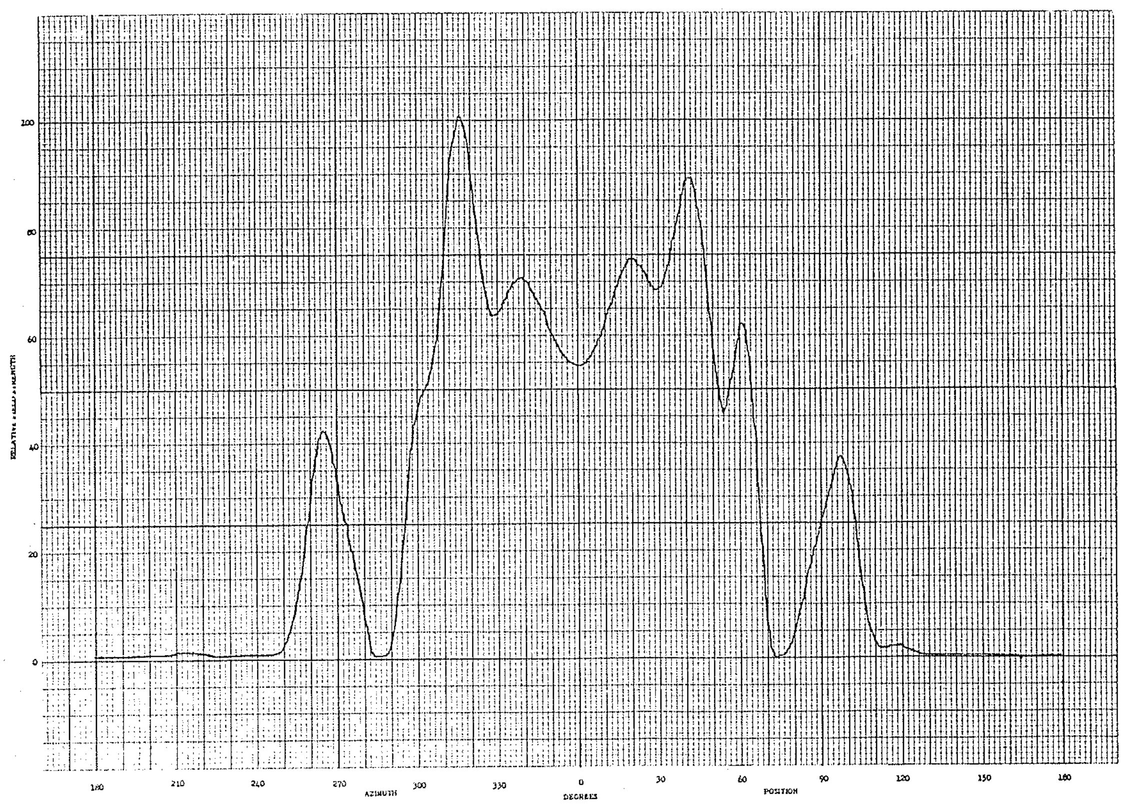
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Dipole

PATTERN NO. a=b=1.5"

FREQUENCY 900 mc.

PATTERN PLANE H

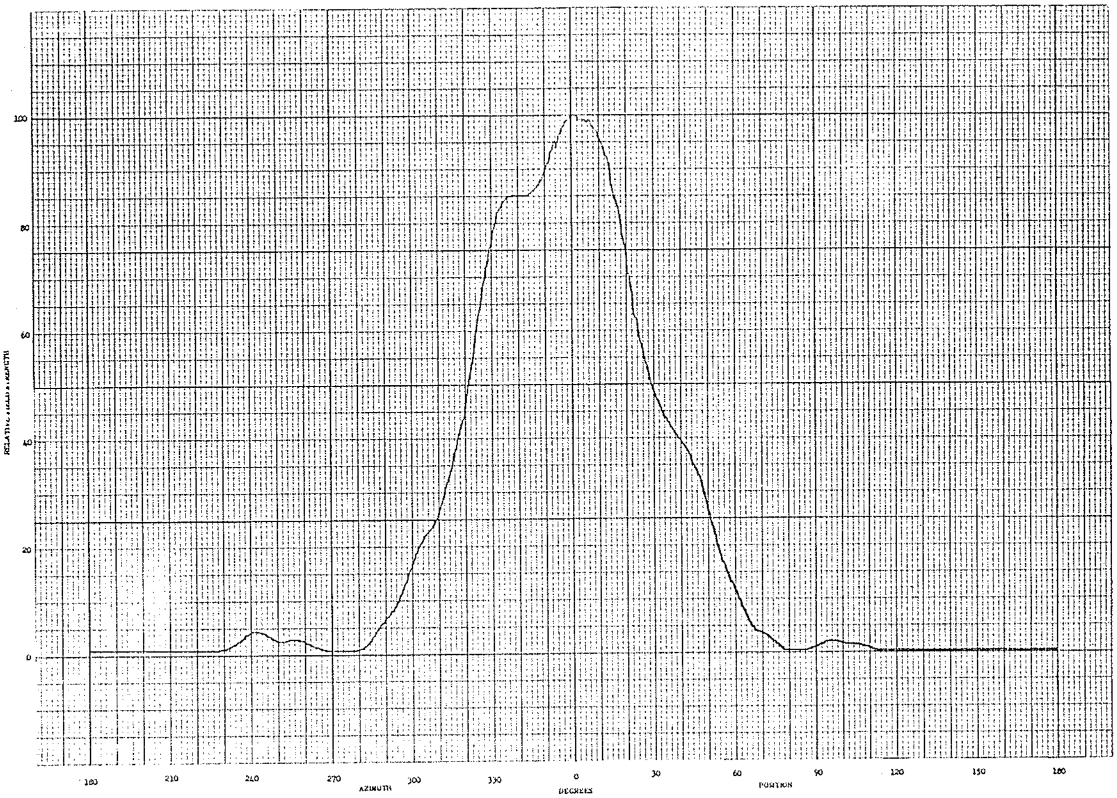
SCALE

VERTICAL

HORIZONTAL

NAME C.Y. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L.P. Vee

PATTERN NO.: a=b=1.5"

FREQUENCY: 1000 mc.

PATTERN PLANE: H

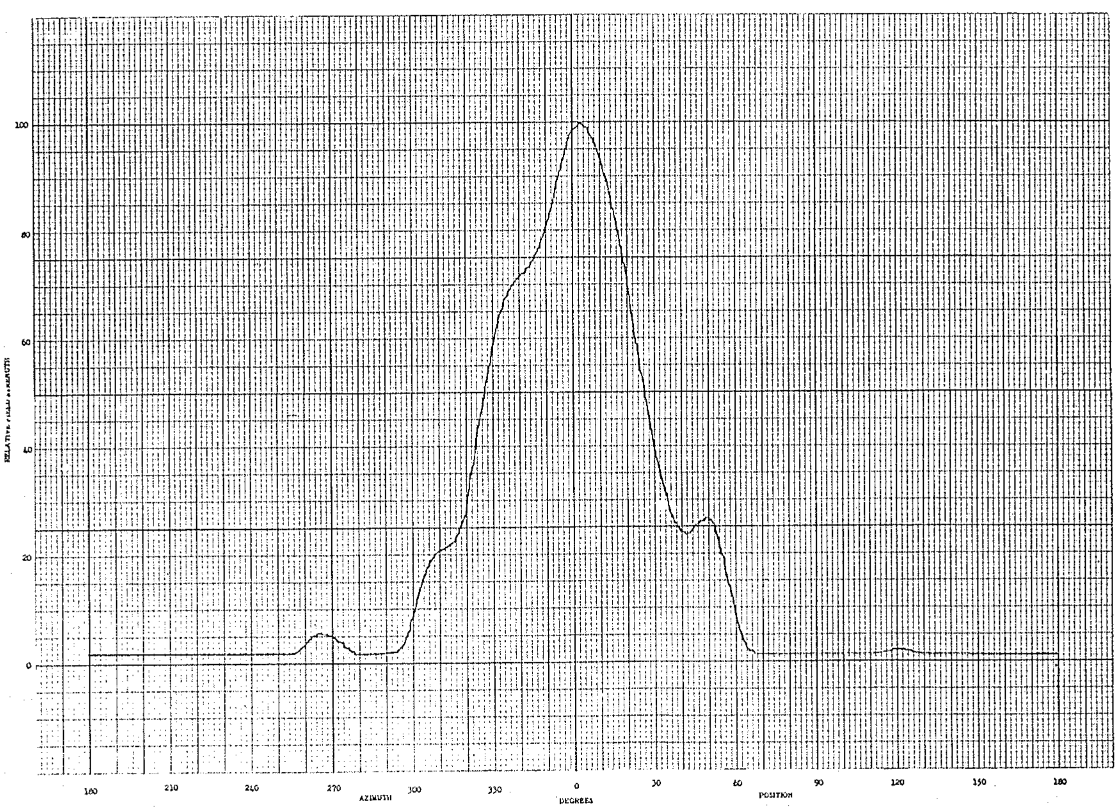
SCALE

VERTICAL:

HORIZONTAL:

NAME: C.V. Thio

DATE: Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L.P. Dipole

PATTERN NO.: a=b=1.5"

FREQUENCY: 1000 mc.

PATTERN PLANE: H

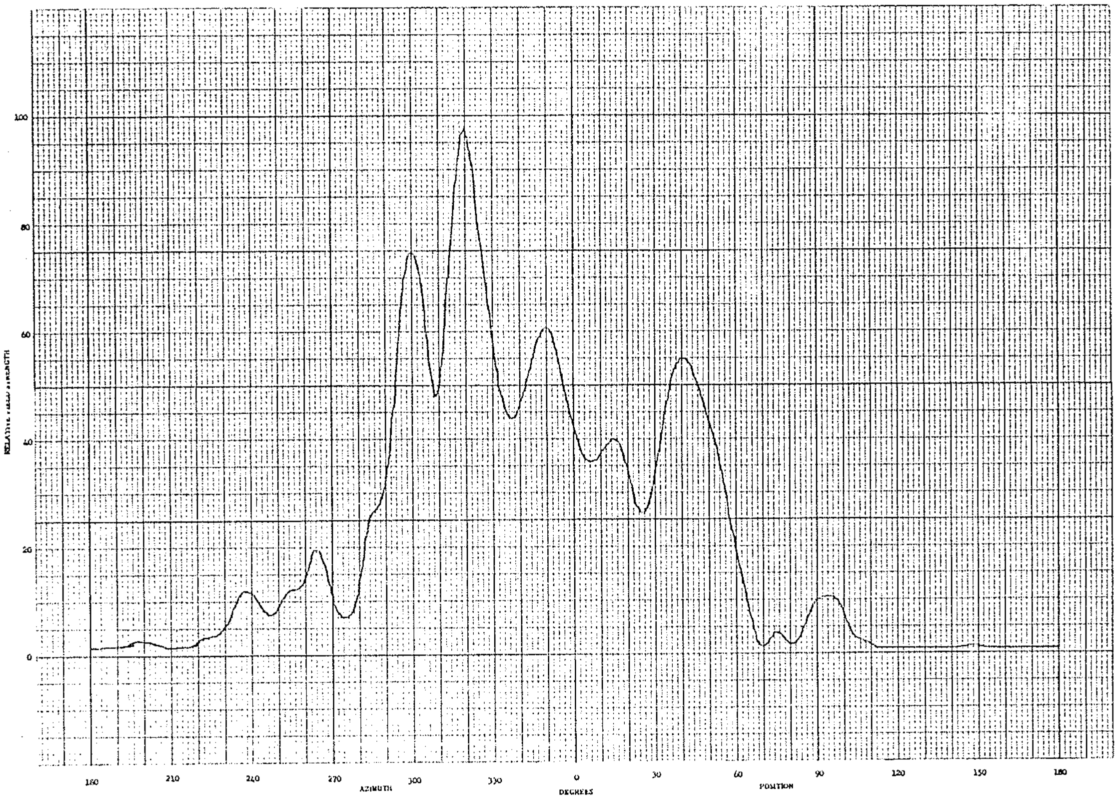
SCALE

VERTICAL:

HORIZONTAL:

NAME: C.V. Thio

DATE: Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Vee*

PATTERN NO. *a = b = 1.5"*

FREQUENCY *1100 mc.*

PATTERN PLANE *H*

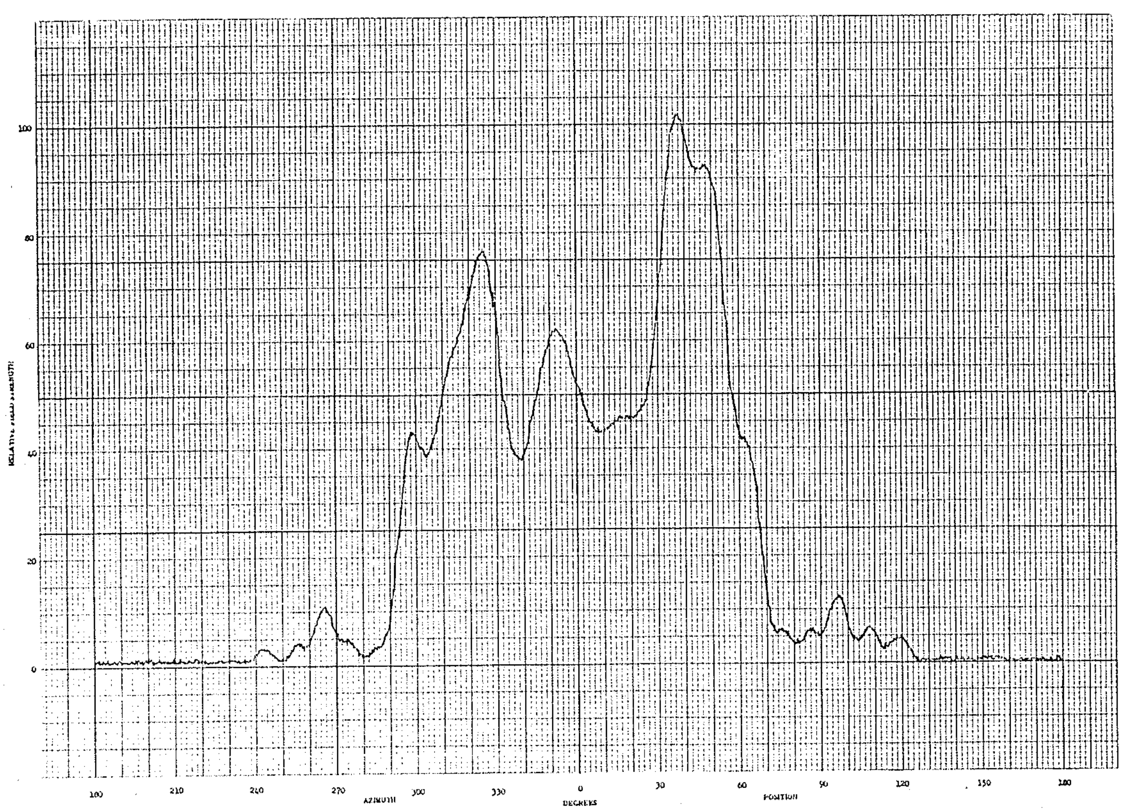
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Dipole*

PATTERN NO. *a = b = 1.5"*

FREQUENCY *1100 mc.*

PATTERN PLANE *H*

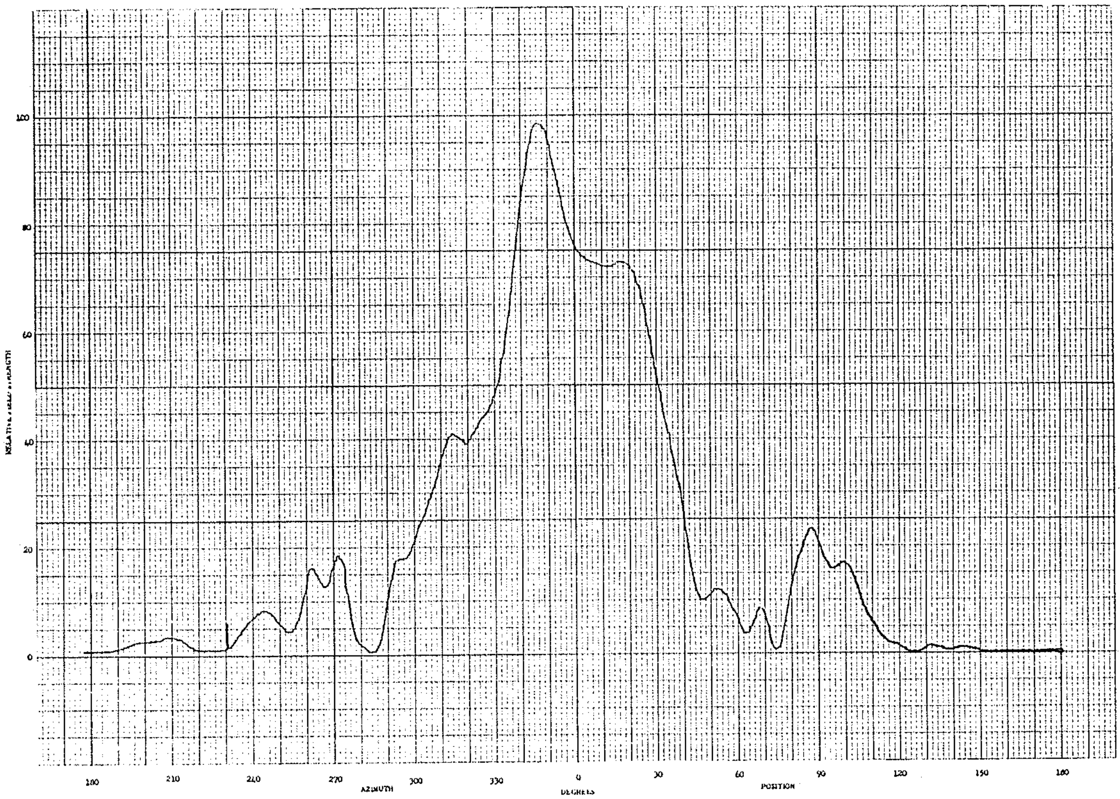
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Vee

PATTERN NO.
a=b=1.5"

FREQUENCY
1200 mc.

PATTERN PLANE
H

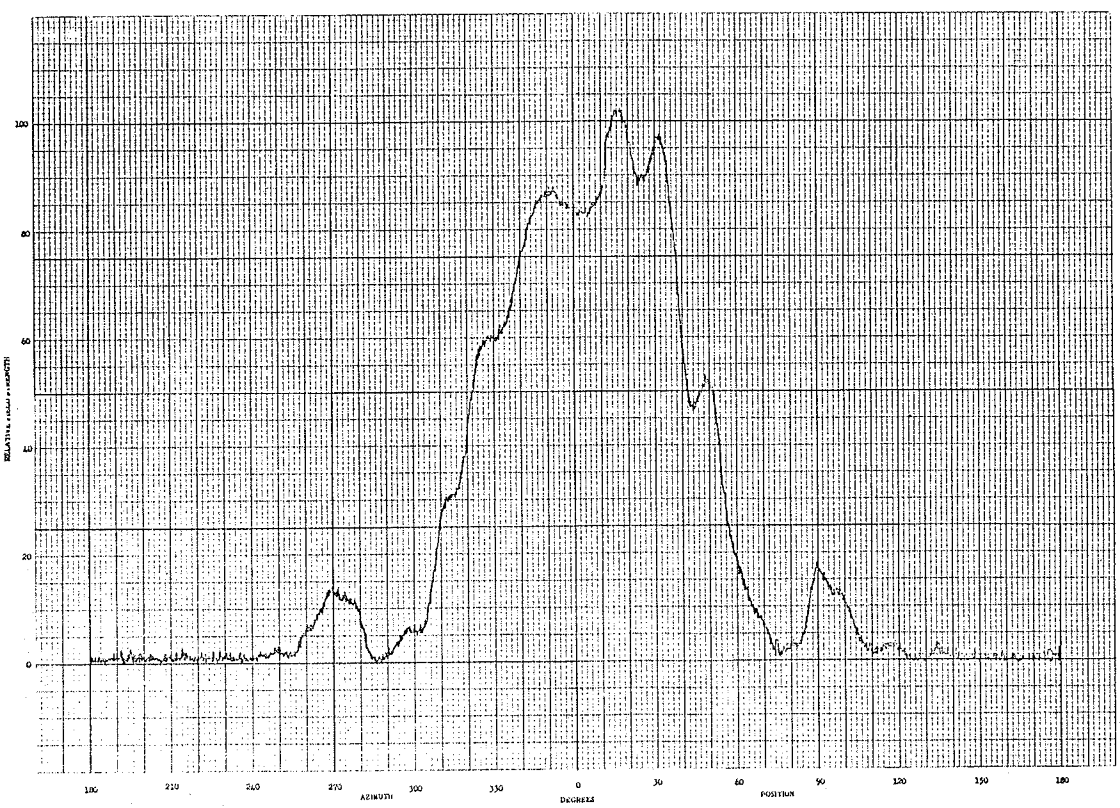
SCALE

VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Dipole

PATTERN NO.
a=1.5", b=1.5"

FREQUENCY
1200 mc.

PATTERN PLANE
H

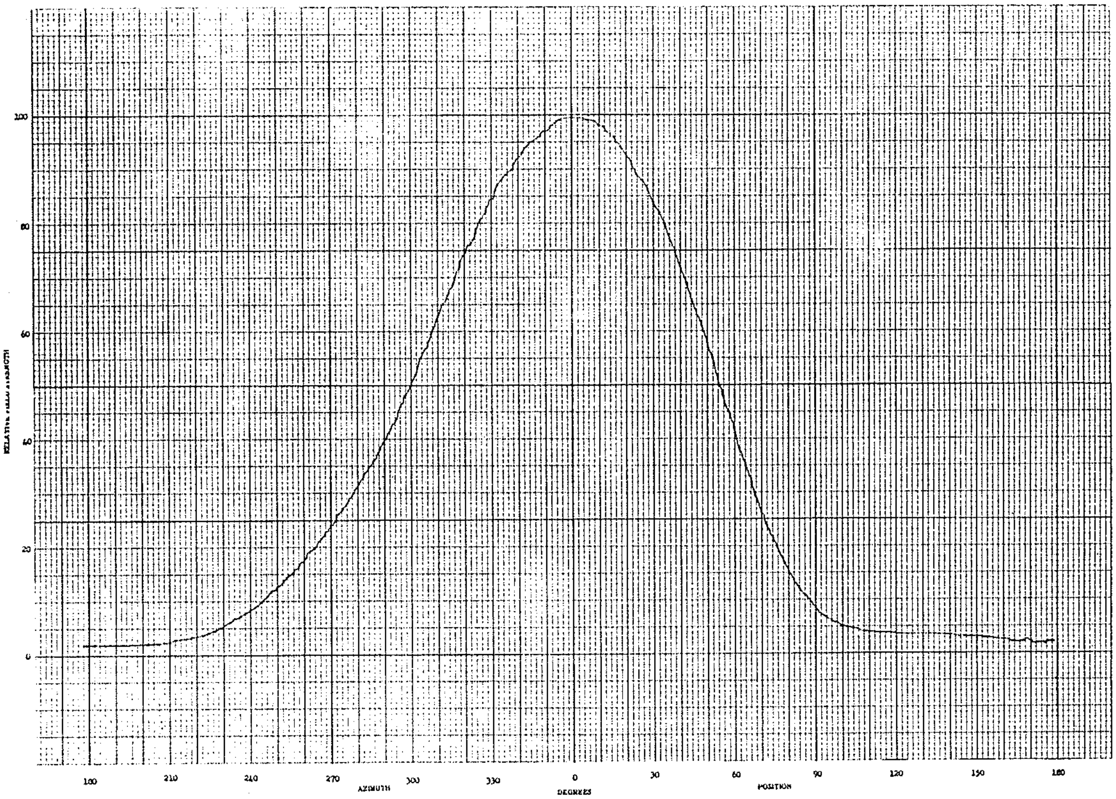
SCALE

VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L.P. Vee

PATTERN NO.: a=1.5", b=4.0"

FREQUENCY: 200 mc.

PATTERN PLANE: H

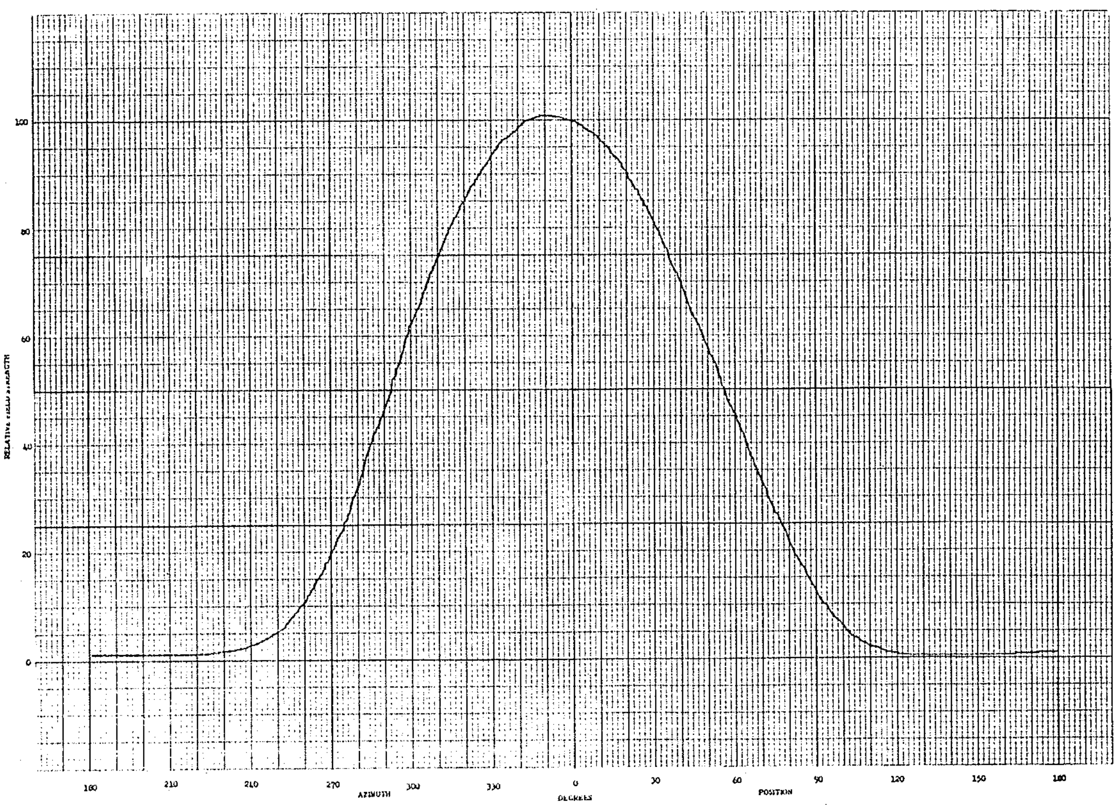
SCALE

VERTICAL

HORIZONTAL

NAME: C.V. Thio

DATE: Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE: L.P. Dipole

PATTERN NO.: a=1.5", b=4.0"

FREQUENCY: 200 mc.

PATTERN PLANE: H

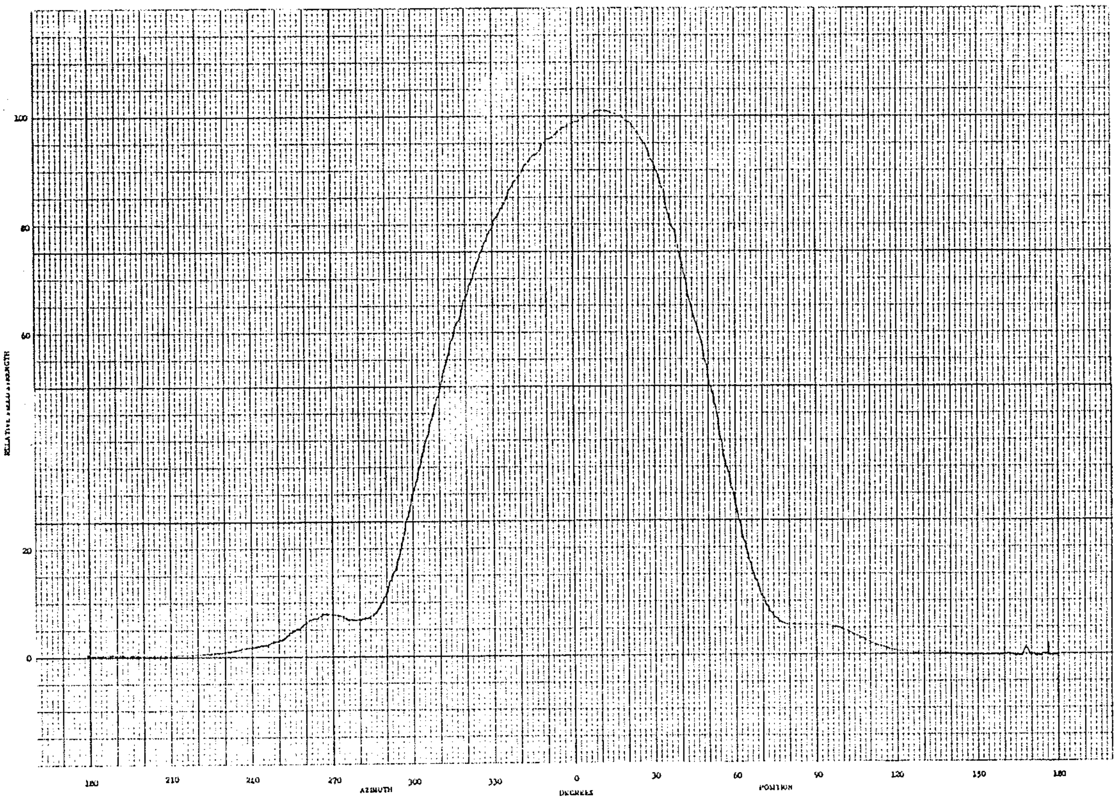
SCALE

VERTICAL

HORIZONTAL

NAME: C.V. Thio

DATE: Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Vee

PATTERN NO. a=1.5", b=4.0"

FREQUENCY 400 mc.

PATTERN PLANE H

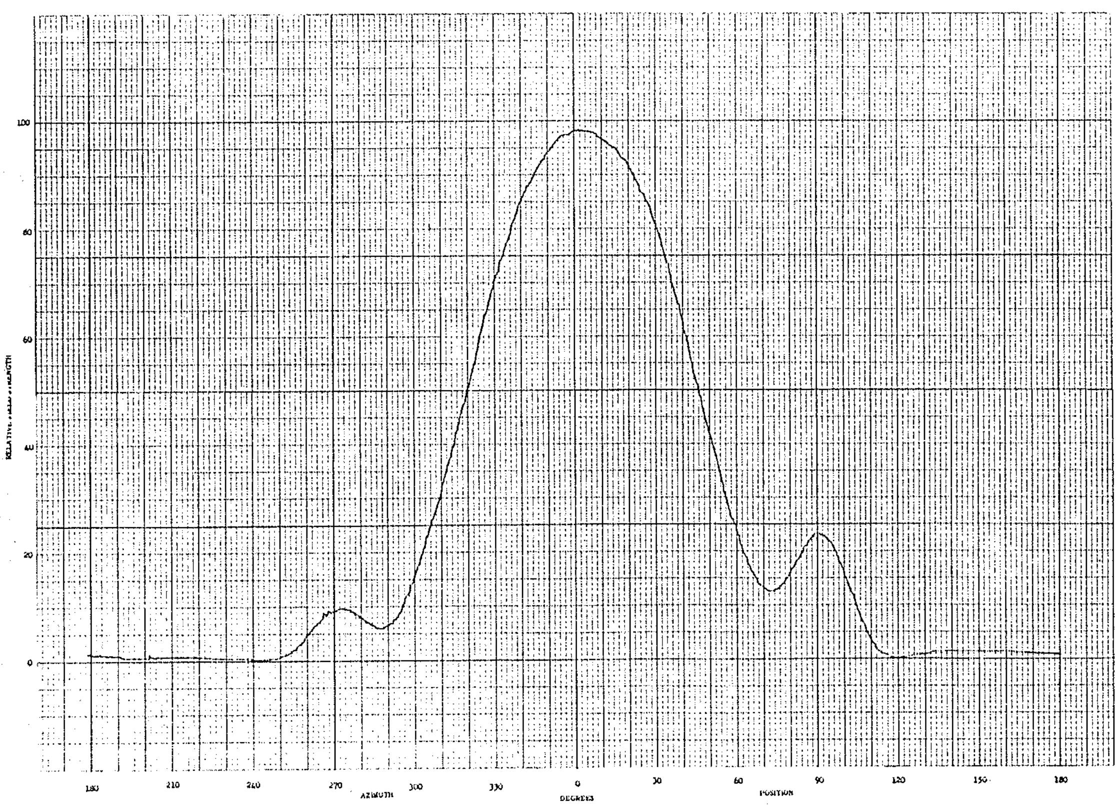
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Dipole

PATTERN NO. a=1.5", b=4.0"

FREQUENCY 400 mc.

PATTERN PLANE H

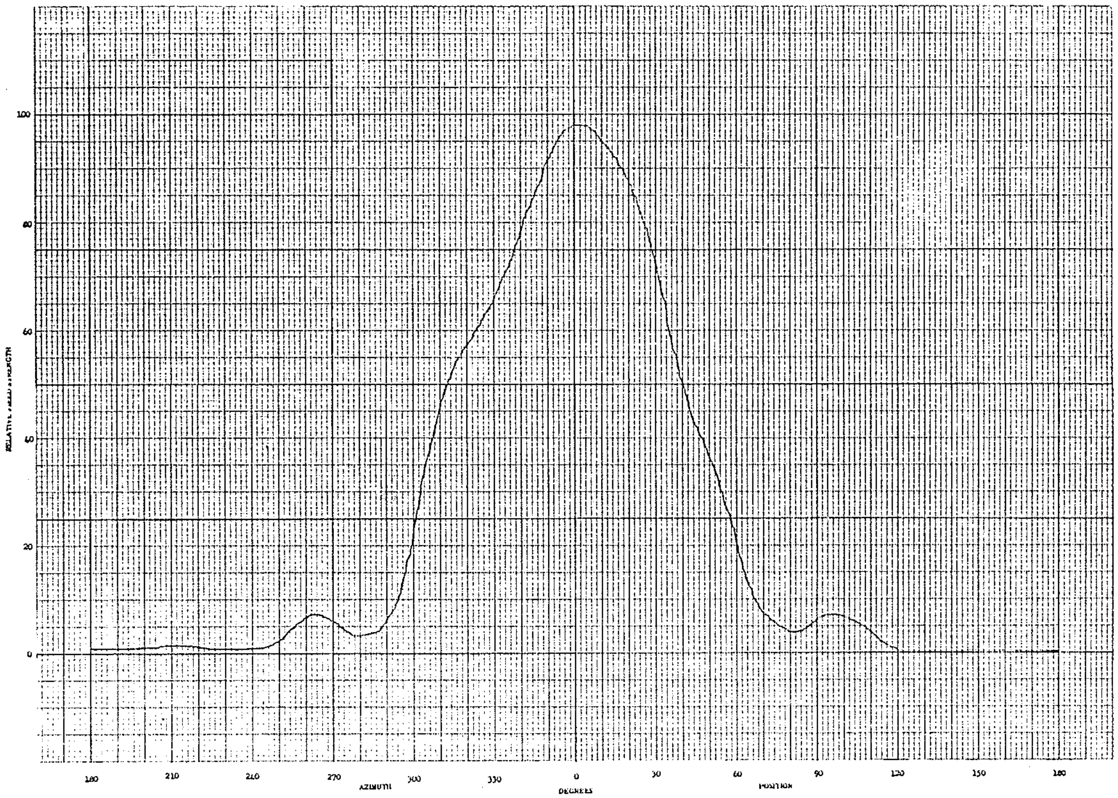
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Vee

PATTERN NO.
a=1.5", b=4.0"

FREQUENCY
600 mc.

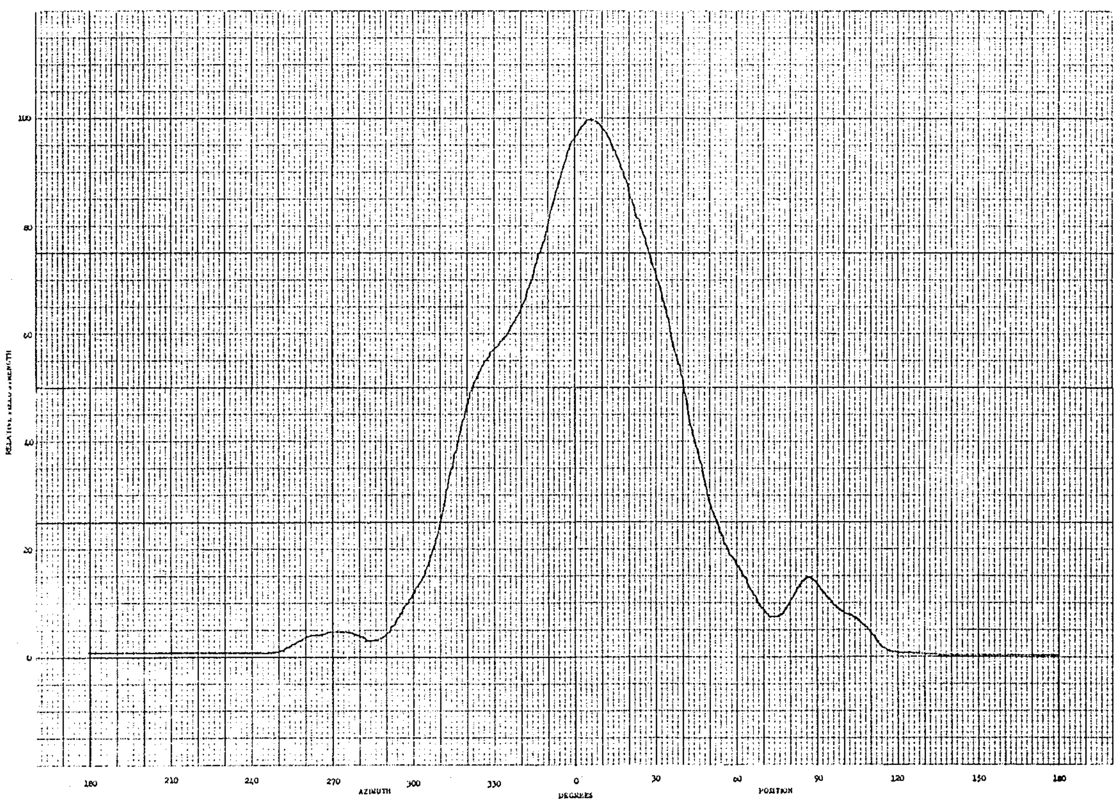
PATTERN PLANE
H

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Dipole

PATTERN NO.
a=1.5", b=4.0"

FREQUENCY
600 mc.

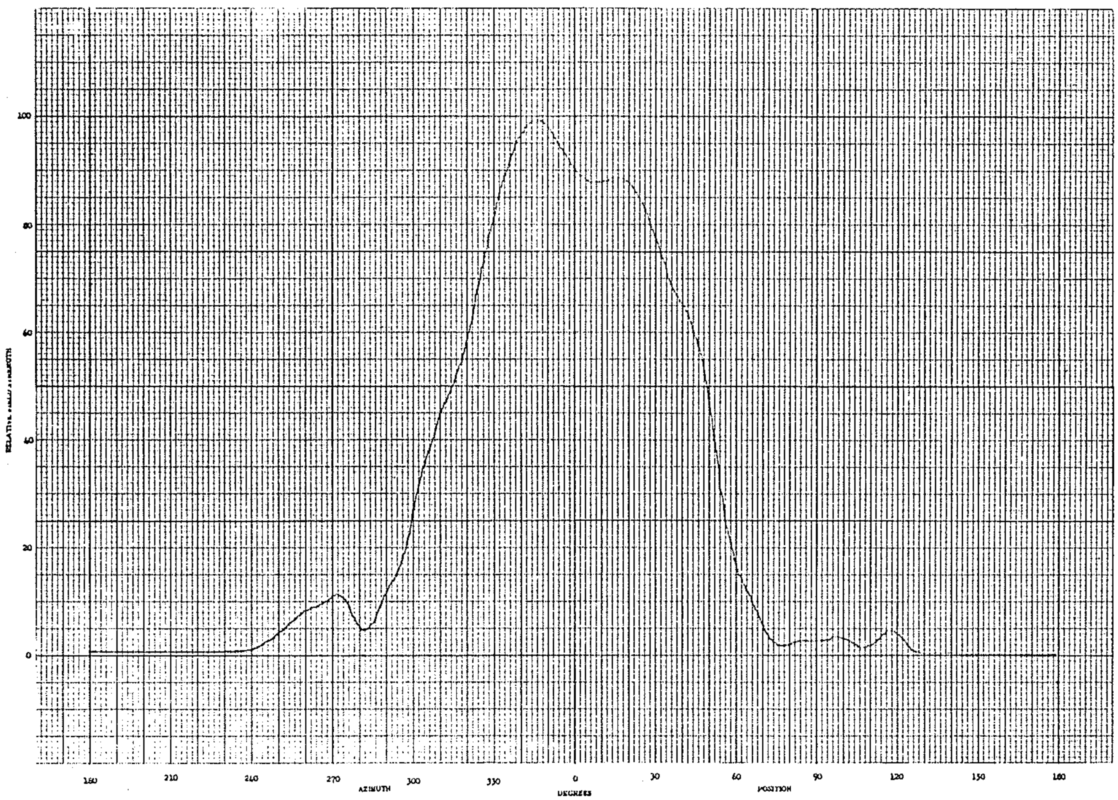
PATTERN PLANE
H

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L. P. Vee

PATTERN NO.
a = 1.5", b = 4.0"

FREQUENCY
800 mc.

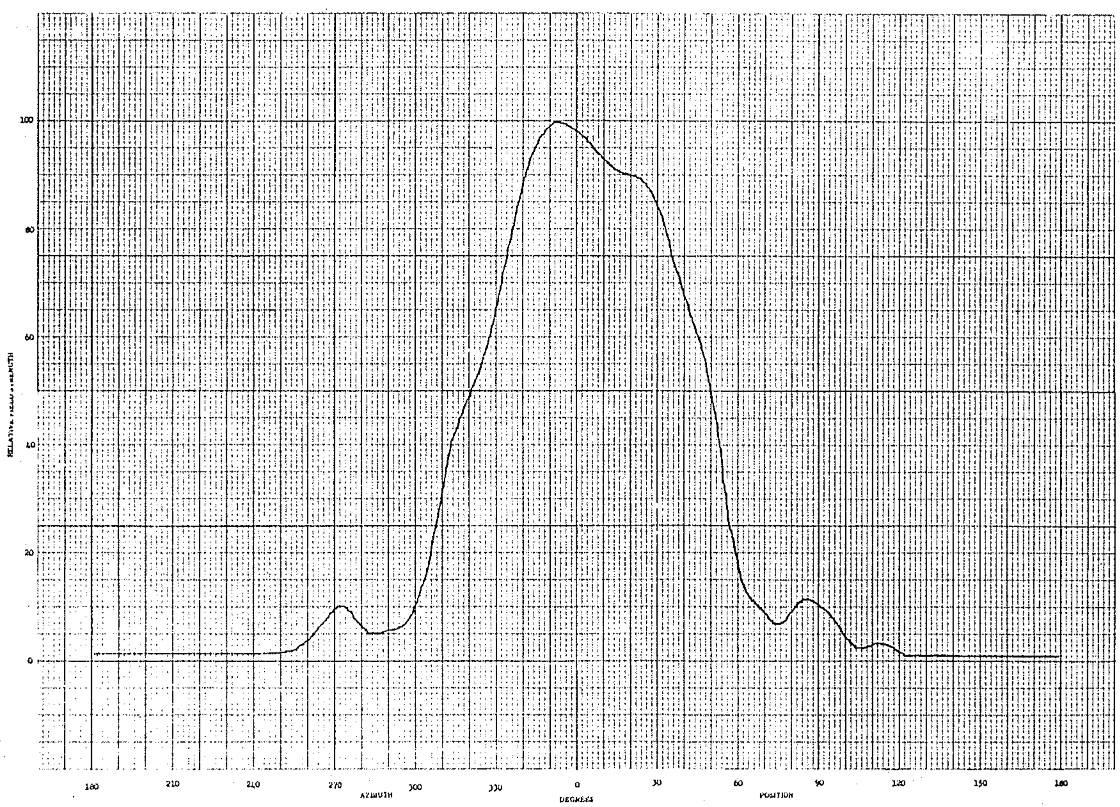
PATTERN PLANE
H

SCALE
VERTICAL

HORIZONTAL

NAME
C. V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L. P. Dipole

PATTERN NO.
a = 1.5", b = 4.0"

FREQUENCY
800 mc.

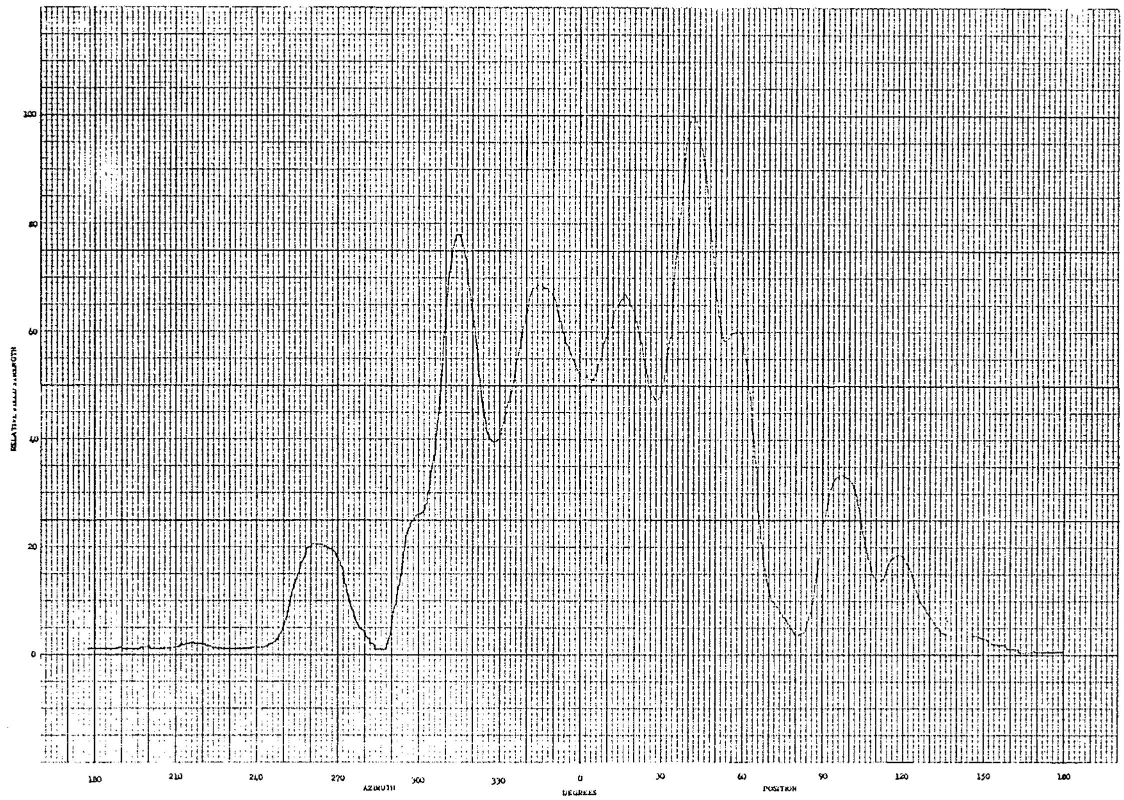
PATTERN PLANE
H

SCALE
VERTICAL

HORIZONTAL

NAME
C. V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Vee

PATTERN NO. a=1.5", b=4.0"

FREQUENCY 900 mc.

PATTERN PLANE H

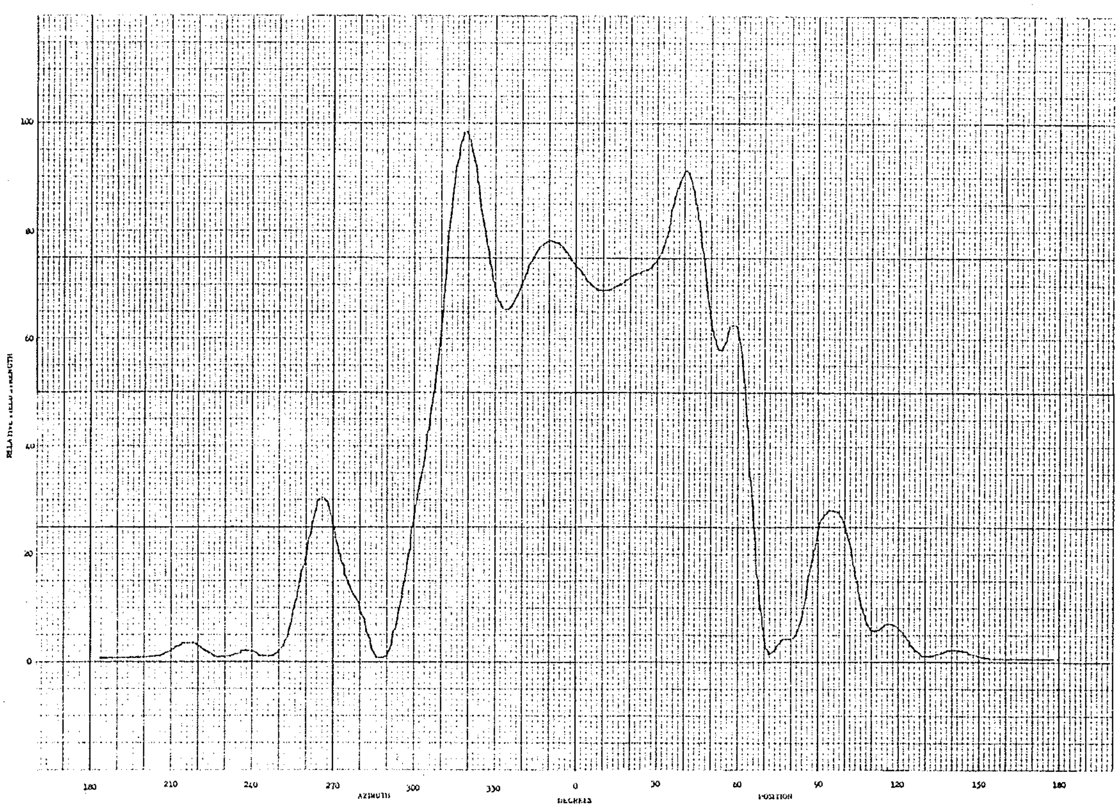
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Dipole

PATTERN NO. a=1.5", b=4.0"

FREQUENCY 900 mc.

PATTERN PLANE H

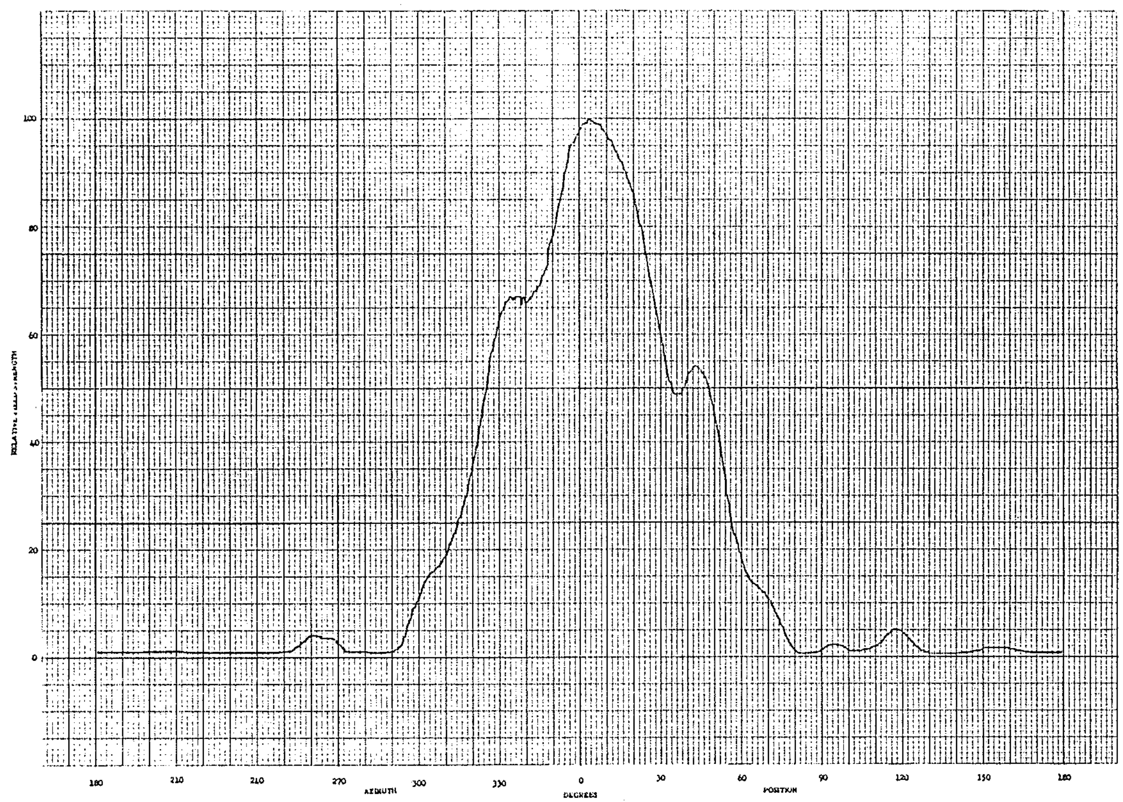
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Vee

PATTERN NO.
a=1.5", b=4.0"

FREQUENCY
1000 mc.

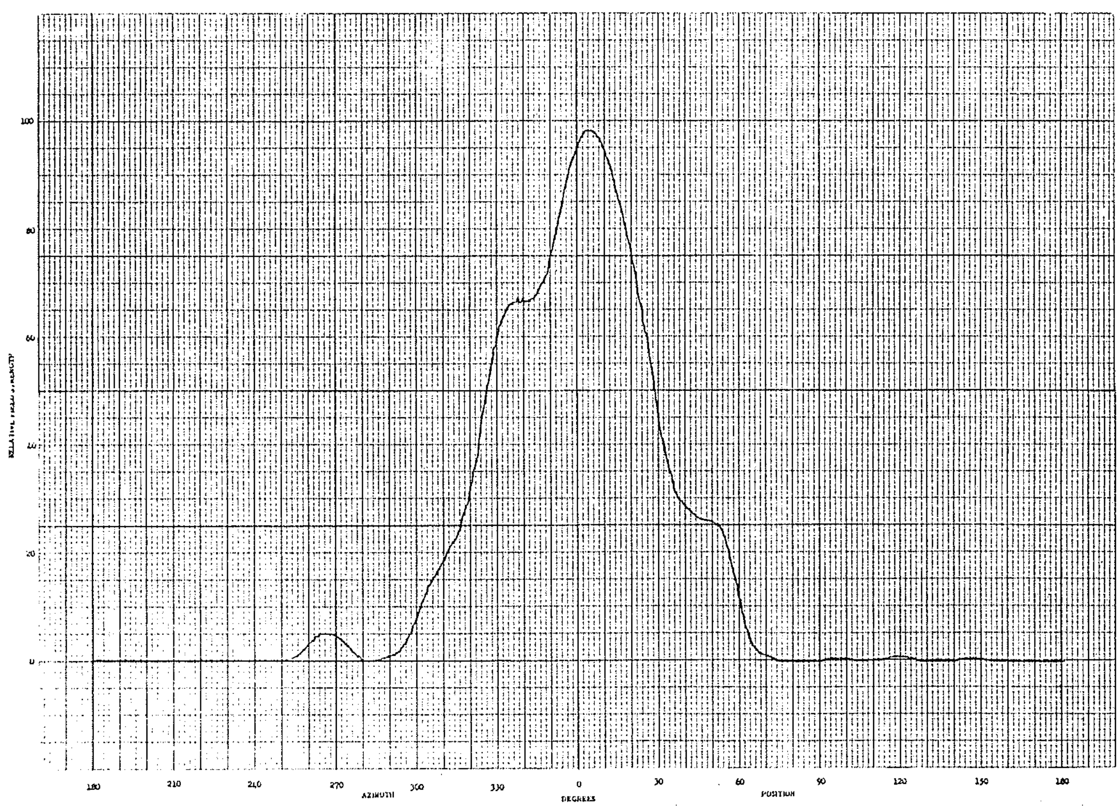
PATTERN PLANE
H

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Dipole

PATTERN NO.
a=1.5", b=4.0"

FREQUENCY
1000 mc.

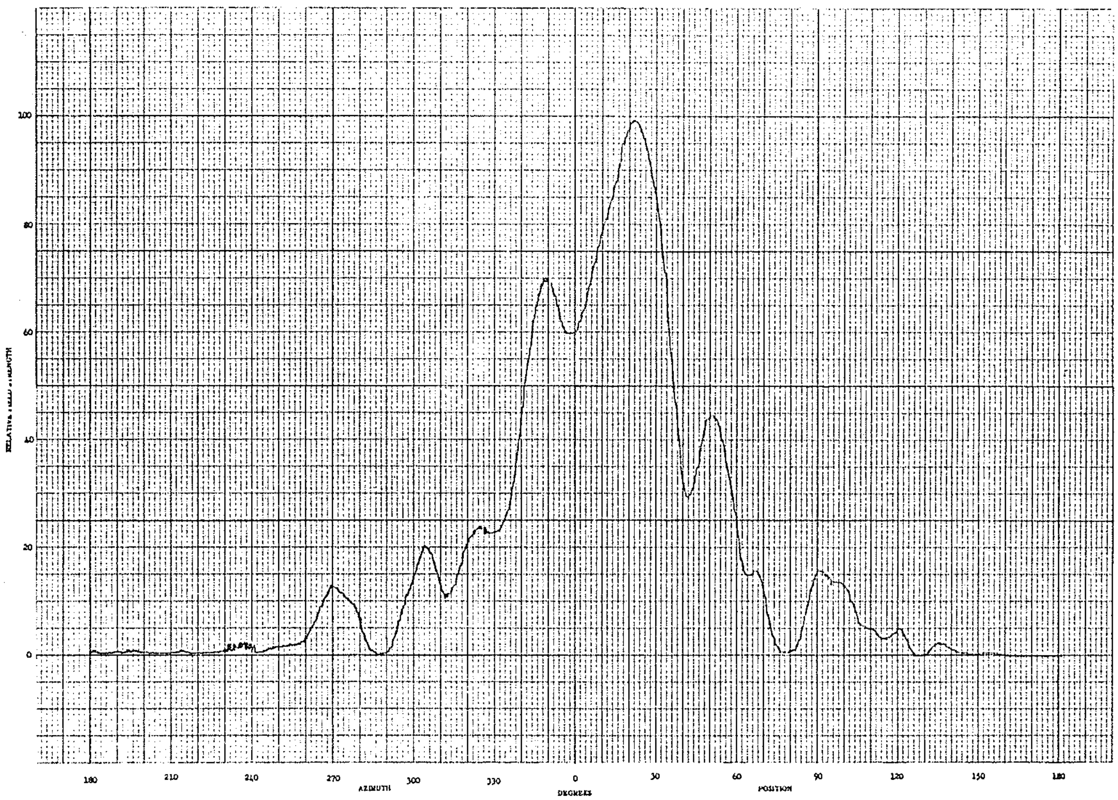
PATTERN PLANE
H

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Vee*

PATTERN NO. *a=1.5", b=4.0"*

FREQUENCY *1200 mc.*

PATTERN PLANE *H*

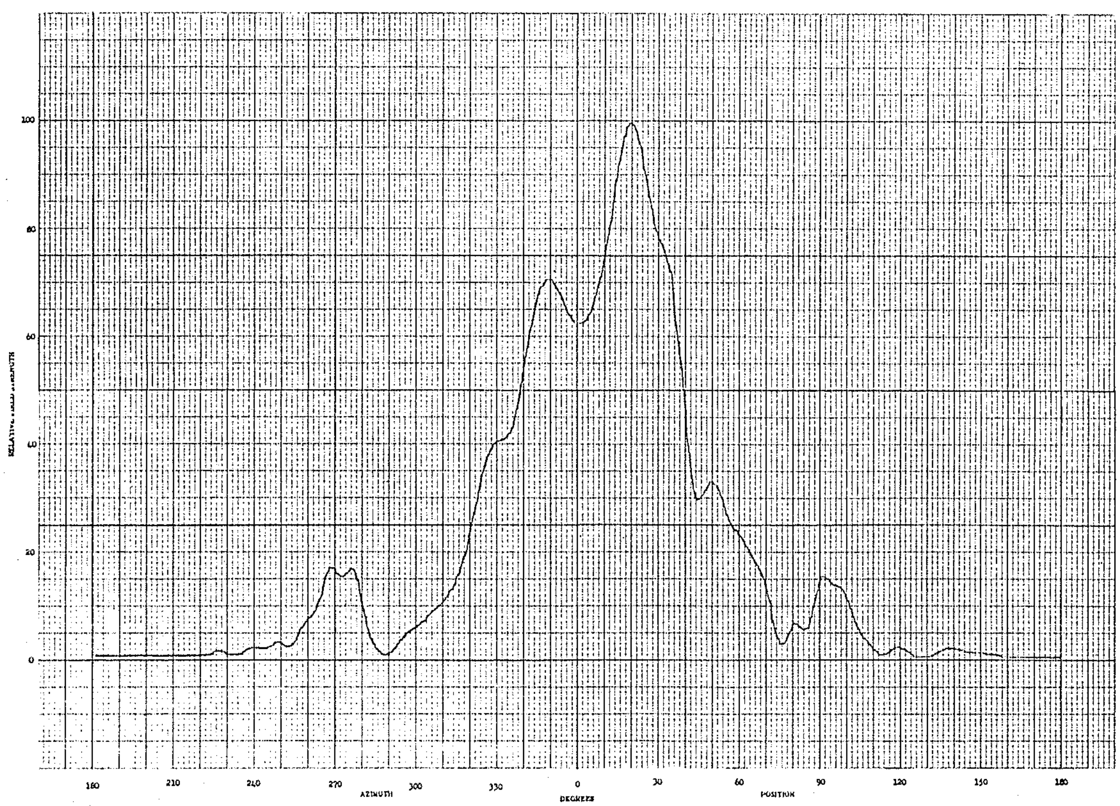
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Dipole*

PATTERN NO. *a=1.5", b=4.0"*

FREQUENCY *1200 mc.*

PATTERN PLANE *H*

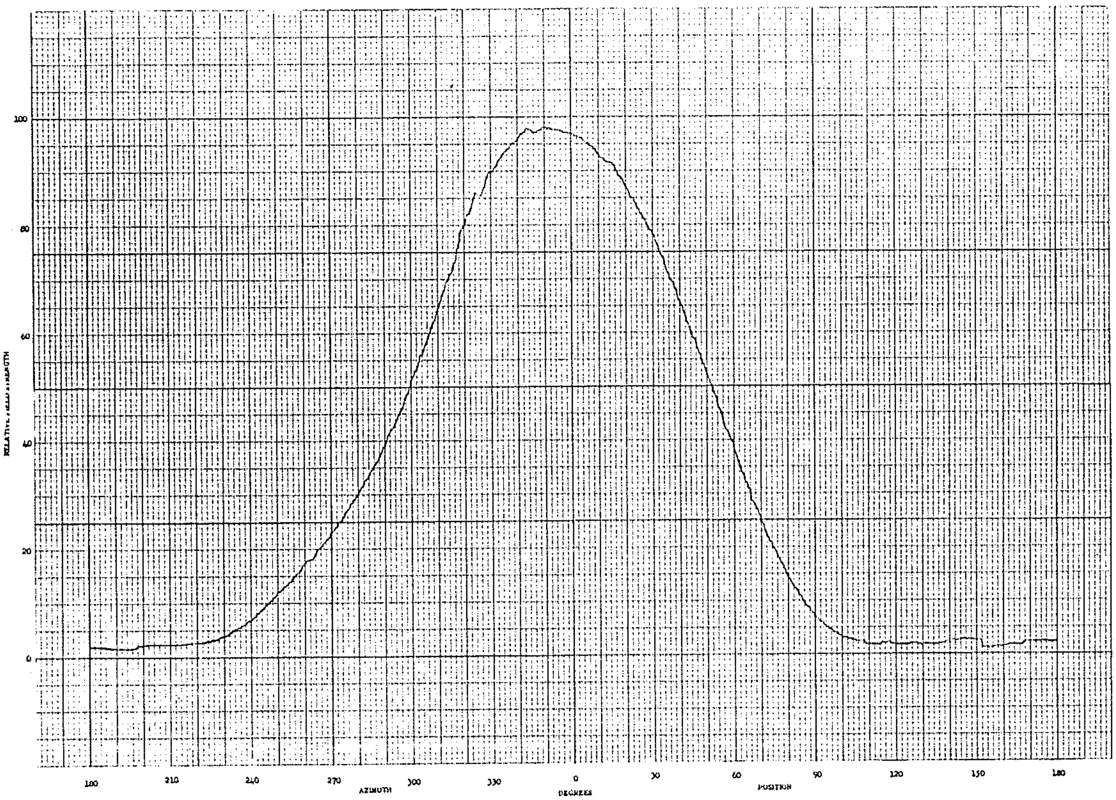
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Vee

PATTERN NO. a=1.5", b=8.75"

FREQUENCY 200 mc.

PATTERN PLANE H

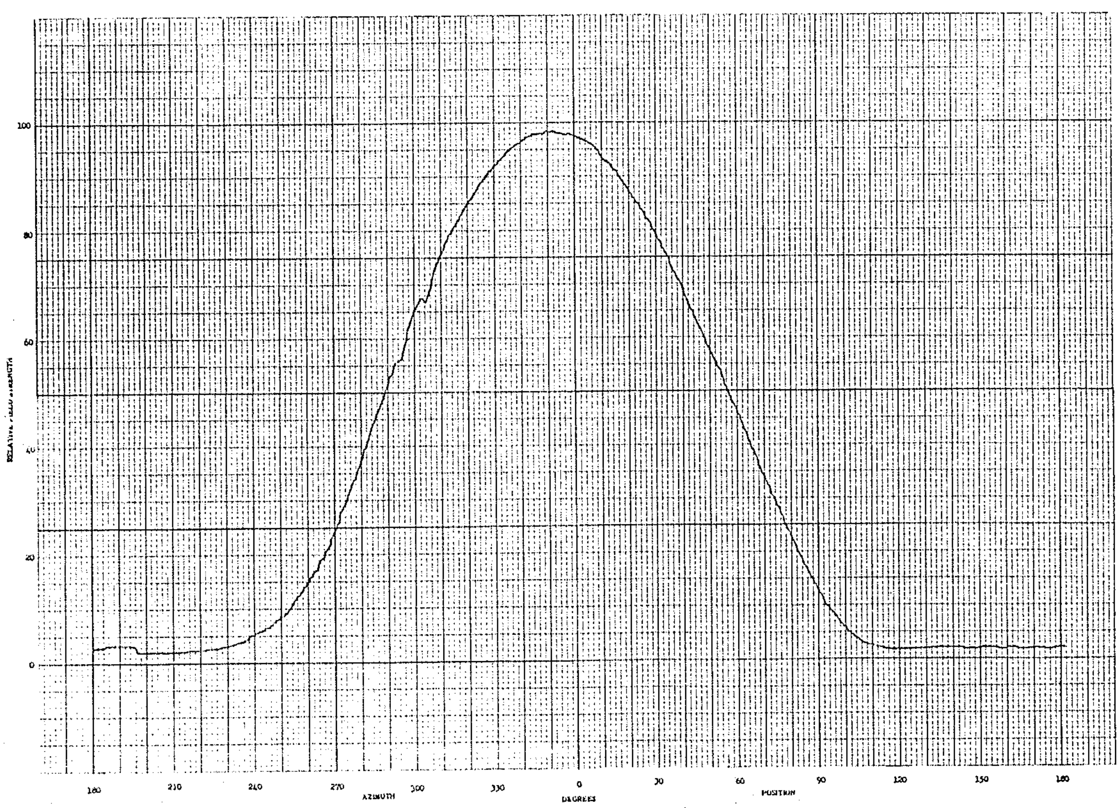
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Dipole

PATTERN NO. a=1.5", b=8.75"

FREQUENCY 200 mc.

PATTERN PLANE H

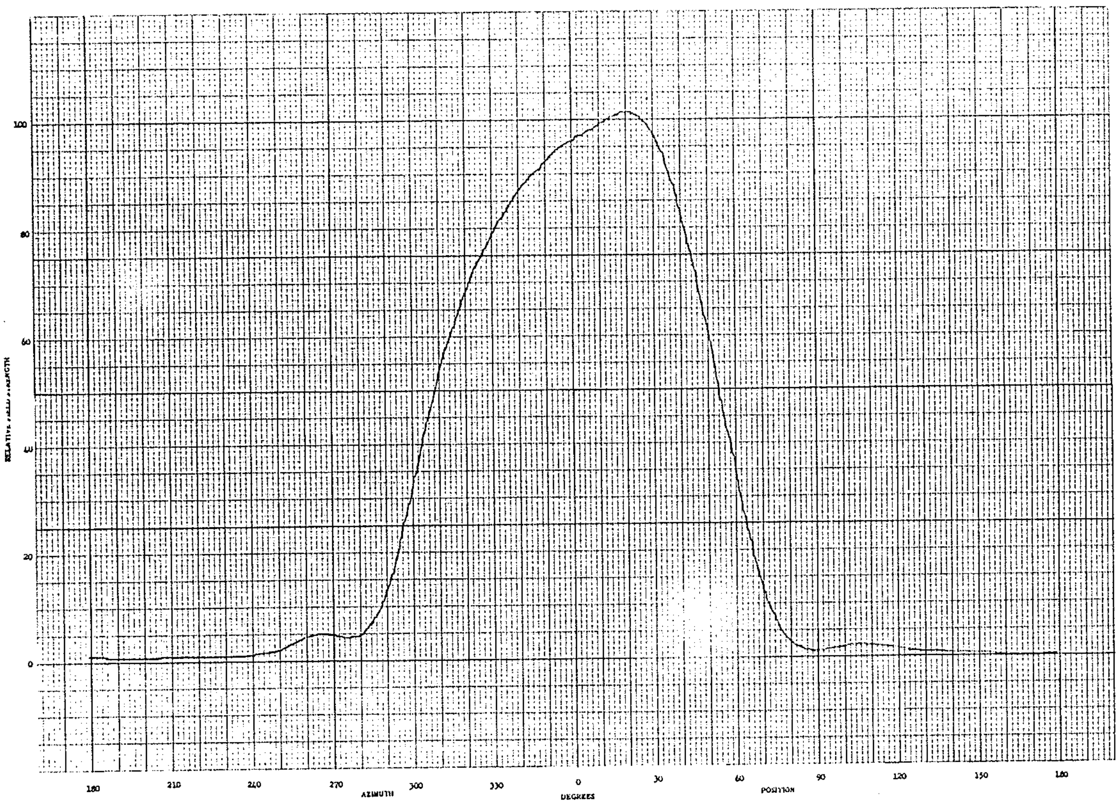
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Vee*

PATTERN NO. *a=1.5", b=8.75"*

FREQUENCY *400 mc.*

PATTERN PLANE *H*

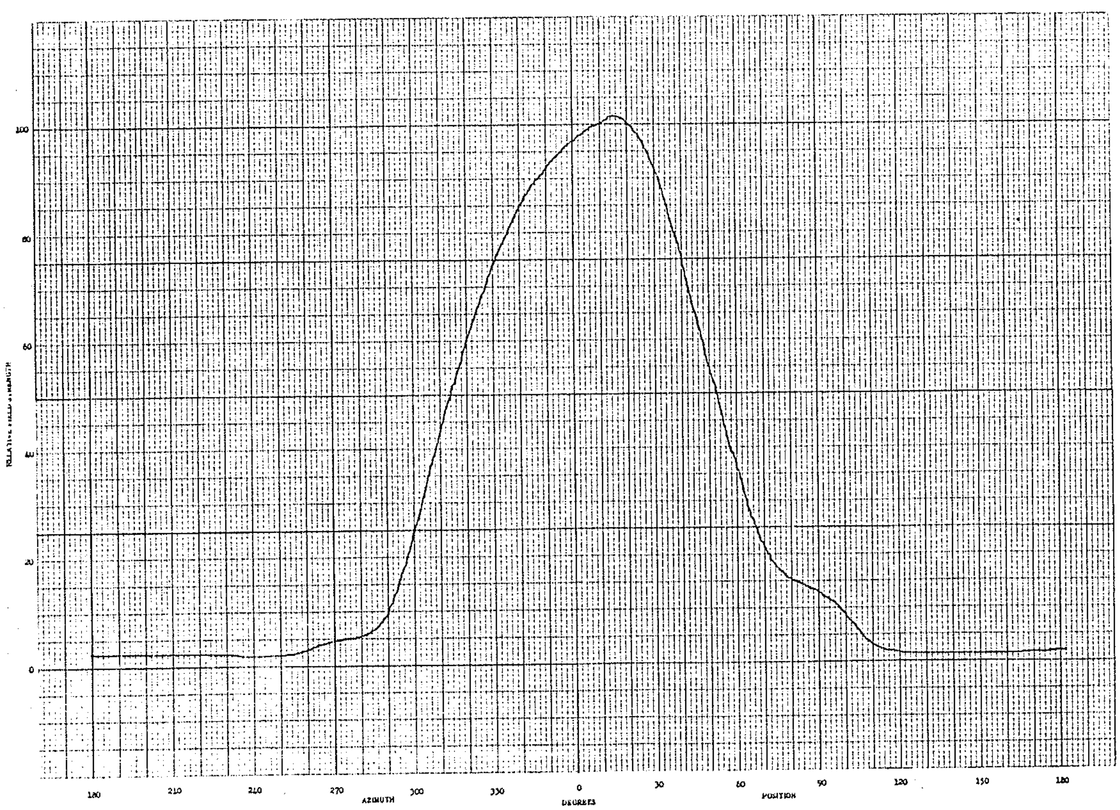
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE *L.P. Dipole*

PATTERN NO. *a=1.5", b=8.75"*

FREQUENCY *400 mc.*

PATTERN PLANE *H*

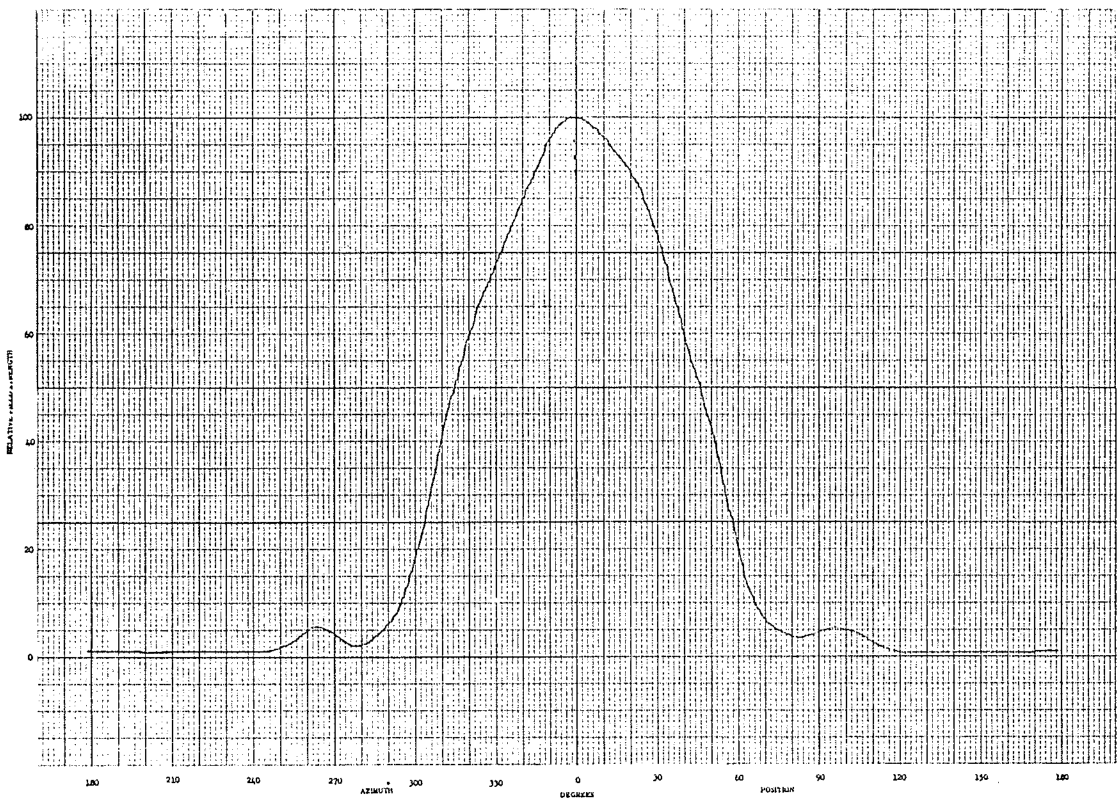
SCALE

VERTICAL

HORIZONTAL

NAME *C.V. Thio*

DATE *Nov. 12/63*



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Vee

PATTERN NO.
a = 1.5", b = 8.75"

FREQUENCY
600 mc.

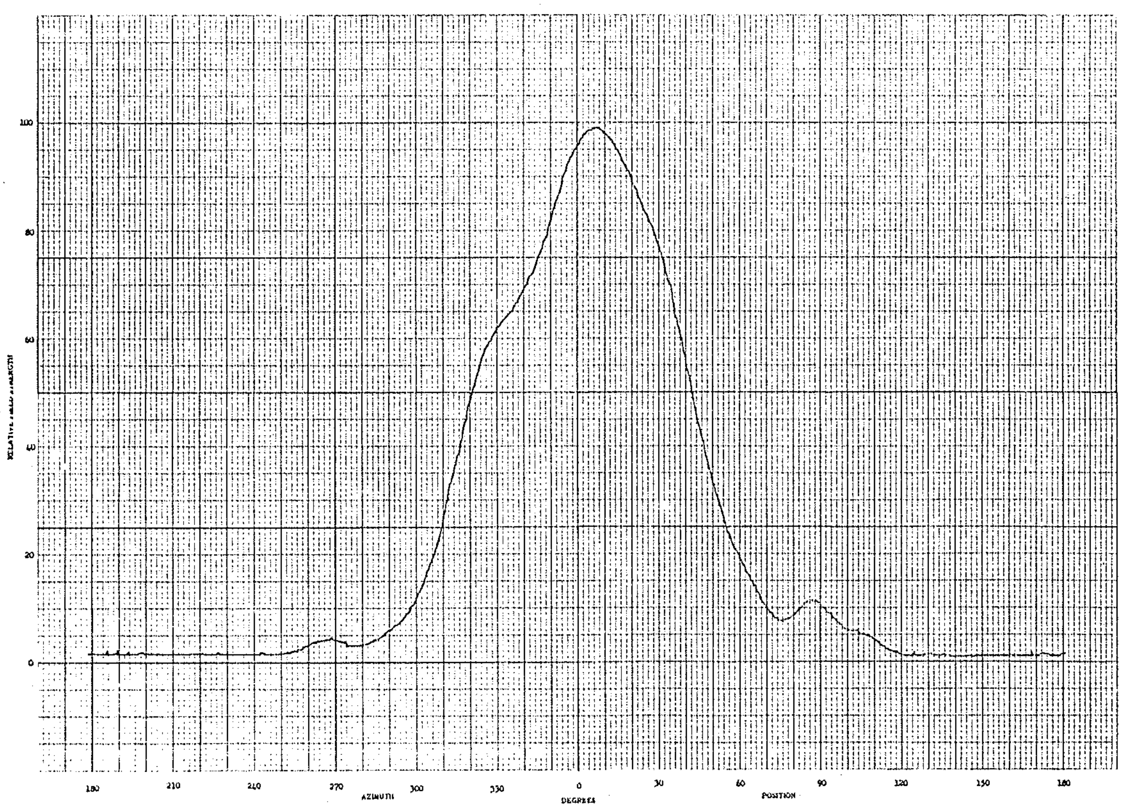
PATTERN PLANE
H

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L. P. Dipole

PATTERN NO.
a = 1.5", b = 8.75"

FREQUENCY
600 mc.

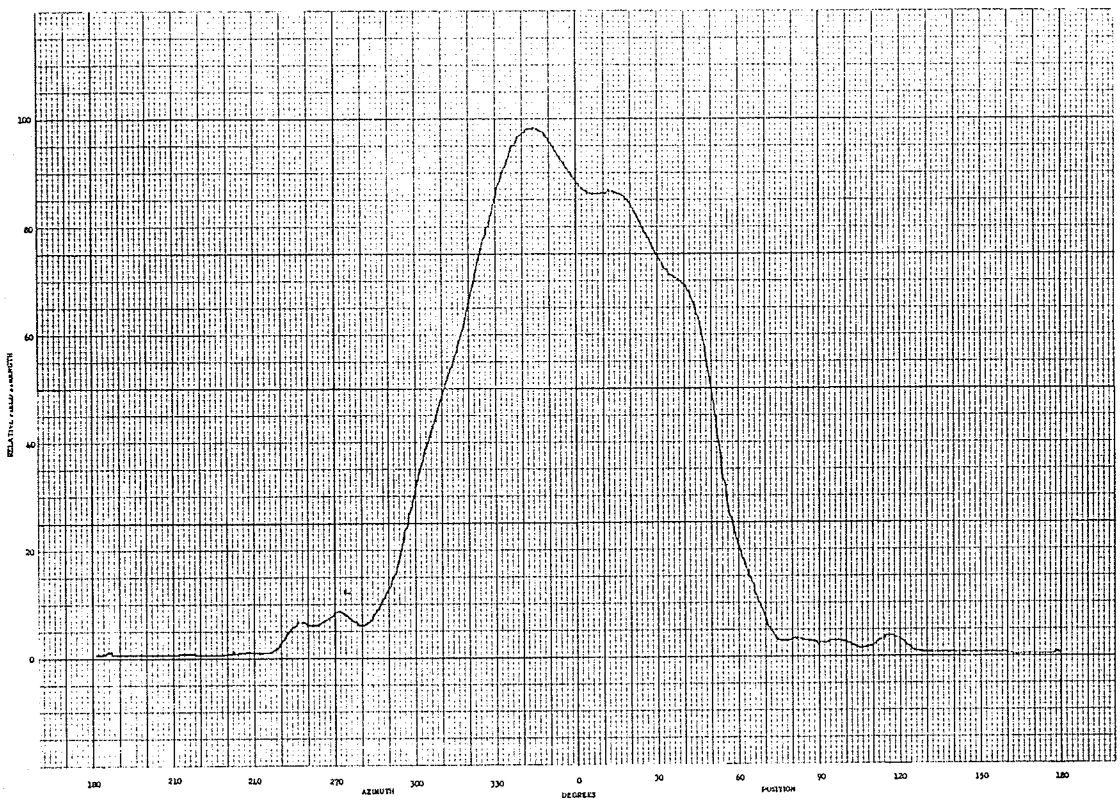
PATTERN PLANE
H

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Vee

PATTERN NO.
a=1.5", b=8.75"

FREQUENCY
800 mc.

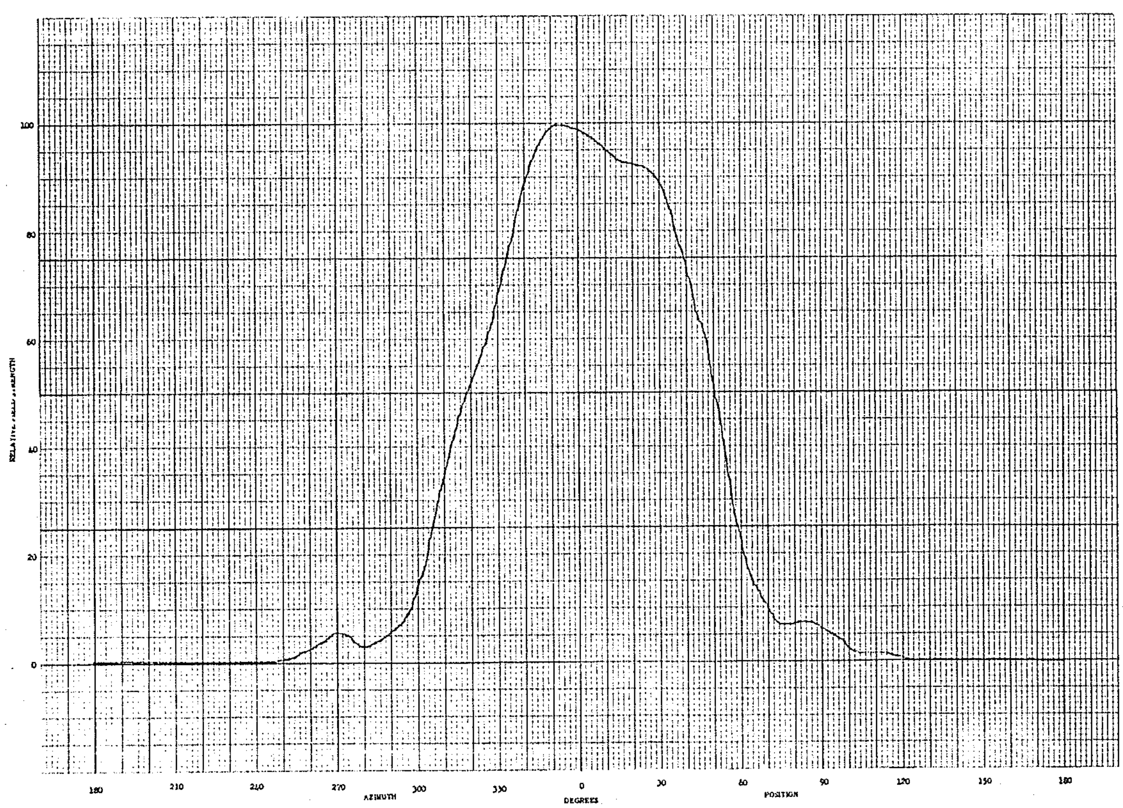
PATTERN PLANE
H

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE
L.P. Dipole

PATTERN NO.
a=1.5", b=8.75"

FREQUENCY
800 mc.

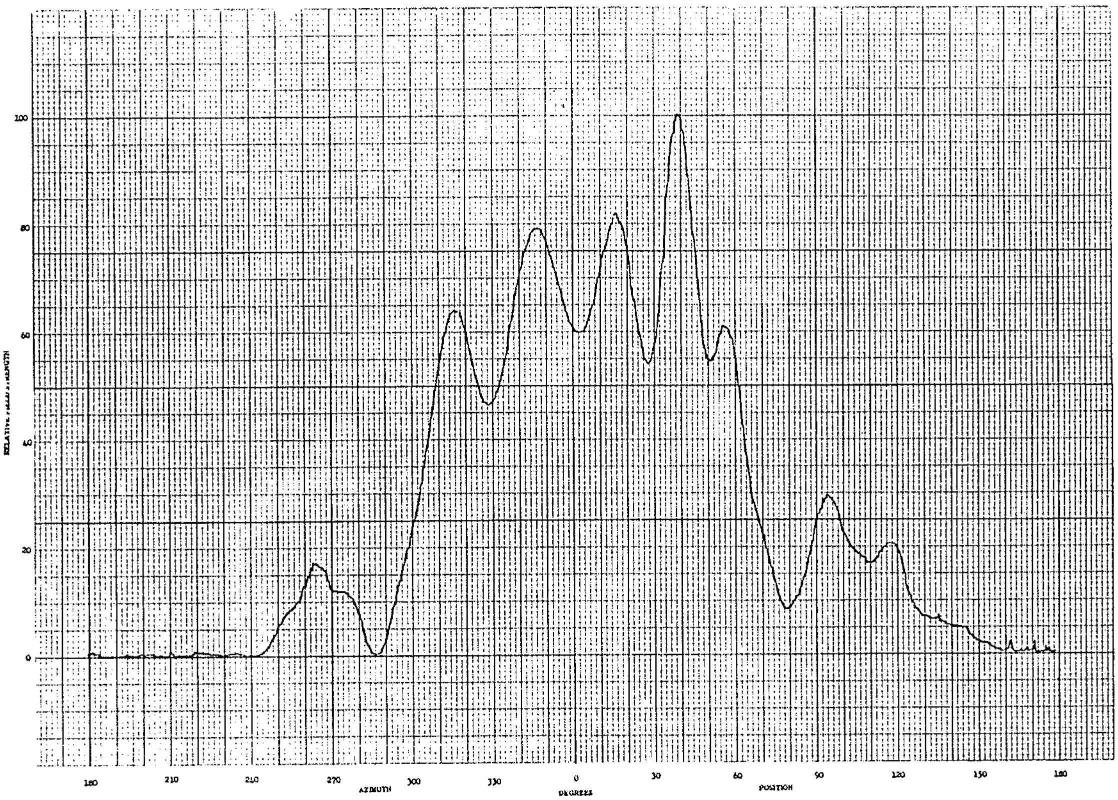
PATTERN PLANE
H

SCALE
VERTICAL

HORIZONTAL

NAME
C.V. Thio

DATE
Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Vee

PATTERN NO. a=1.5", b=8.75"

FREQUENCY 900 mc.

PATTERN PLANE H

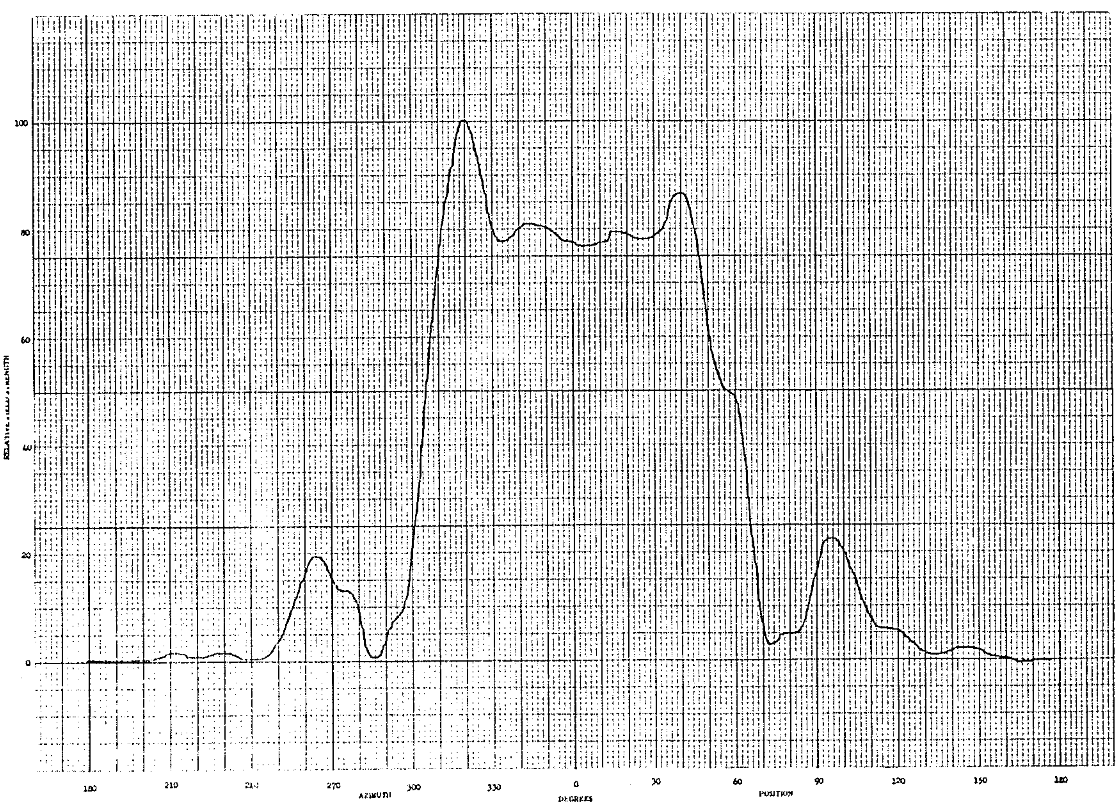
SCALE

VERTICAL

HORIZONTAL

NAME C.Y. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Dipole

PATTERN NO. a=1.5", b=8.75"

FREQUENCY 900 mc.

PATTERN PLANE H

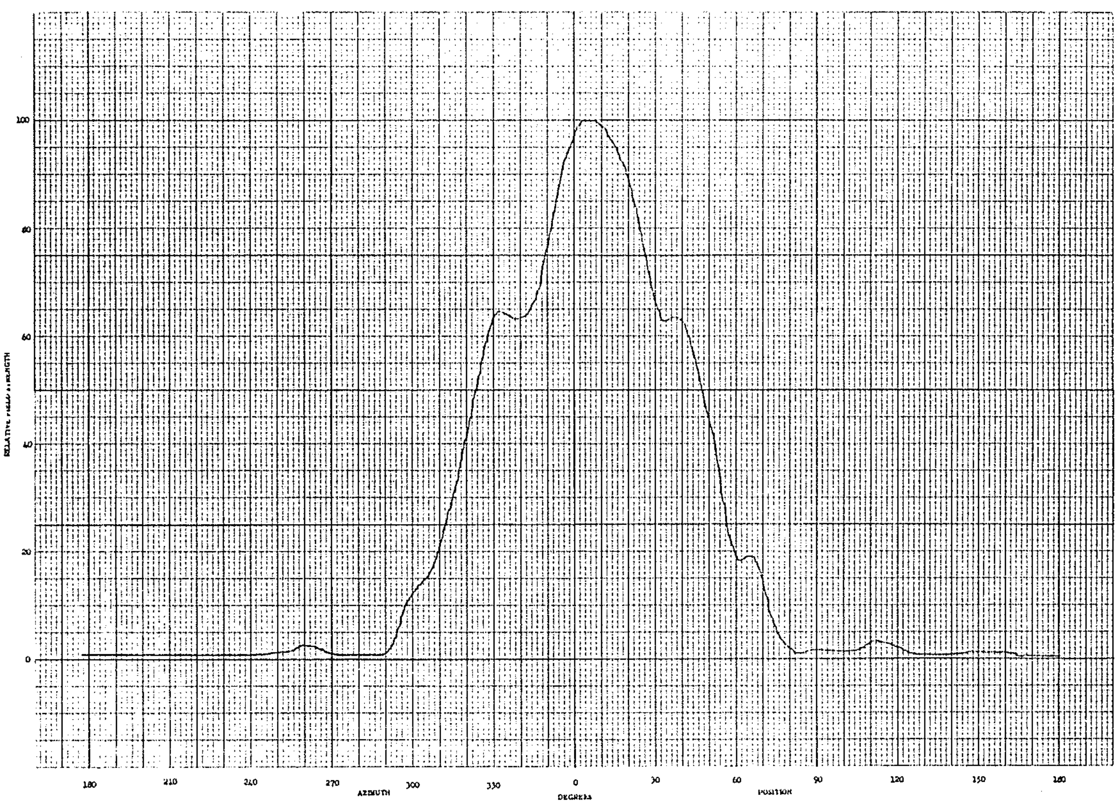
SCALE

VERTICAL

HORIZONTAL

NAME C.Y. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Vee

PATTERN NO. a=1.5", b=.875"

FREQUENCY 1000 mc.

PATTERN PLANE H

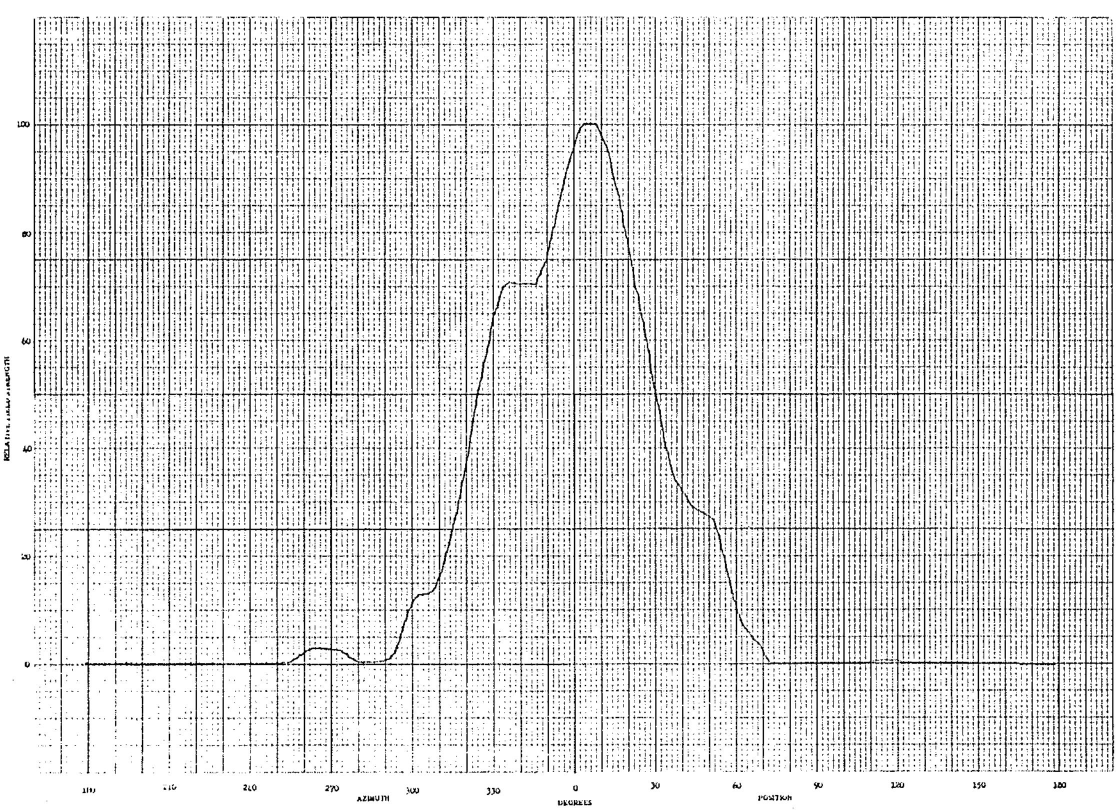
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Dipole

PATTERN NO. a=1.5", b=.875"

FREQUENCY 1000 mc.

PATTERN PLANE H

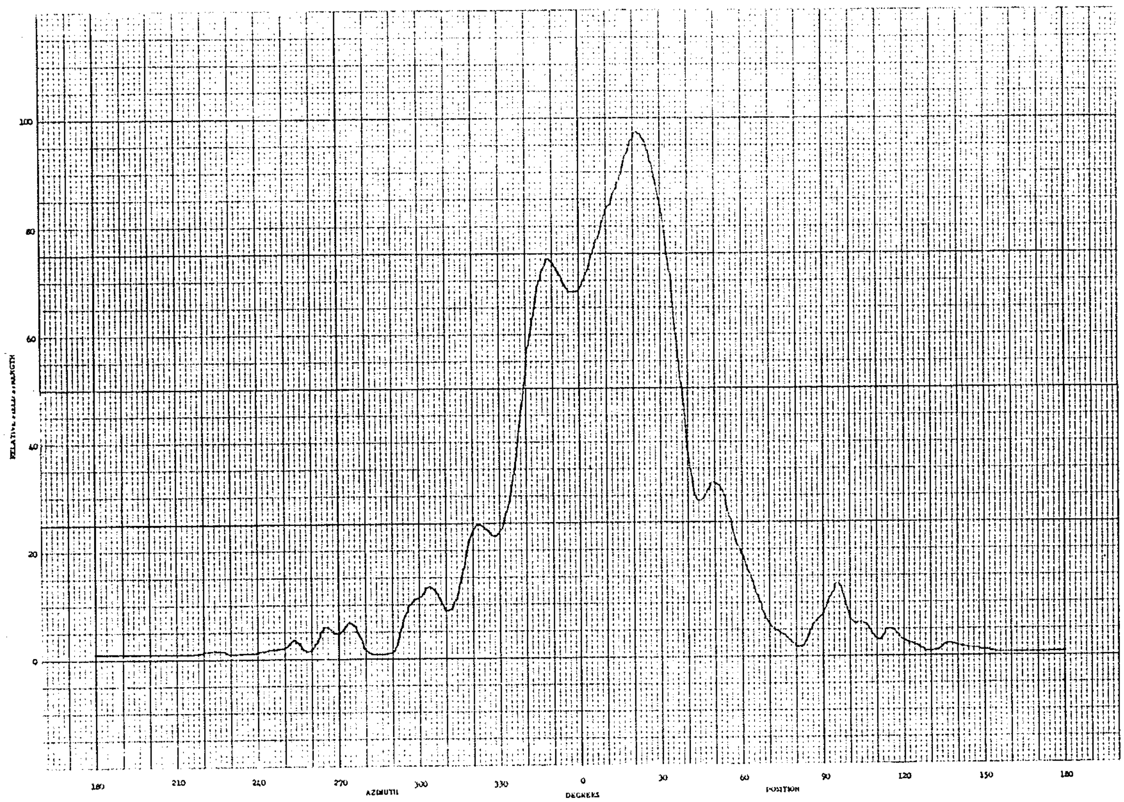
SCALE

VERTICAL

HORIZONTAL

NAME C.V. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Vee

PATTERN NO. a=1.5", b=8.75"

FREQUENCY 1200 mc.

PATTERN PLANE H

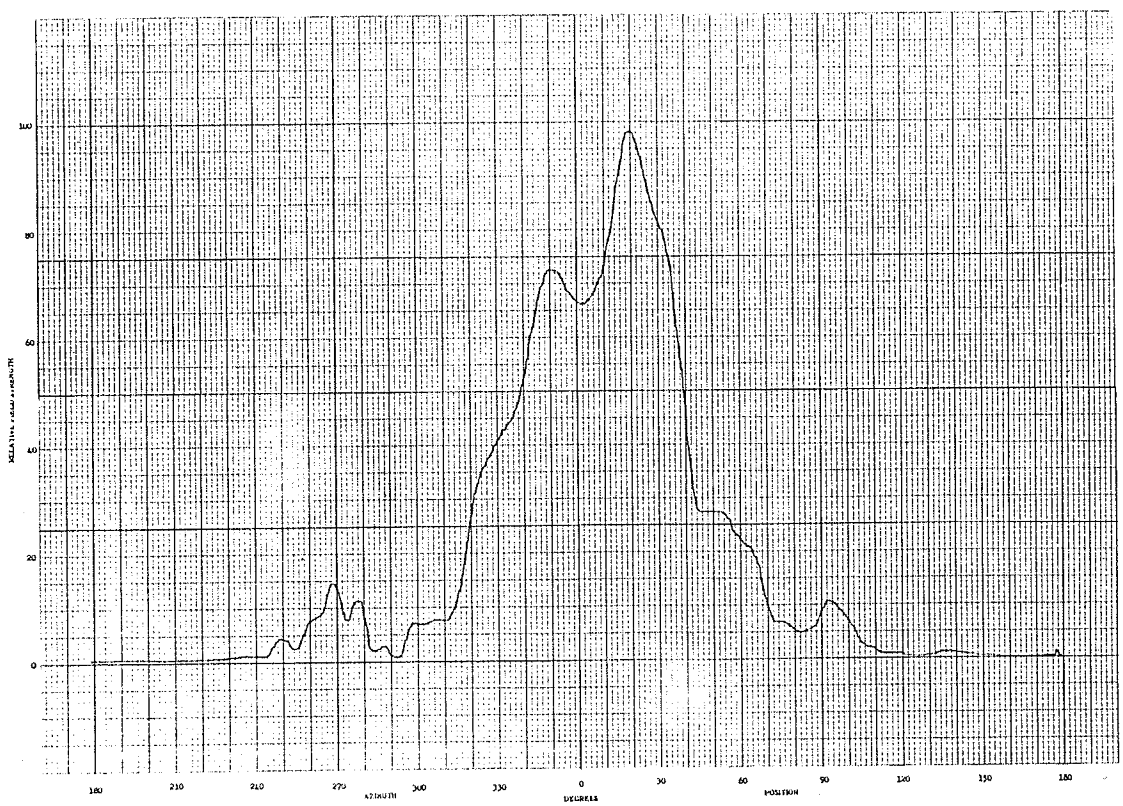
SCALE

VERTICAL

HORIZONTAL

NAME C.Y. Thio

DATE Nov. 12/63



THE UNIVERSITY OF MANITOBA

DEPARTMENT OF ELECTRICAL ENGINEERING

ANTENNA TYPE L.P. Dipole

PATTERN NO. a=1.5", b=8.75"

FREQUENCY 1200 mc.

PATTERN PLANE H

SCALE

VERTICAL

HORIZONTAL

NAME C.Y. Thio

DATE Nov. 12/63