Reflector modification of the Yagi antenna
by Thomas D Smith

A THESIS Submitted to the Graduate Faculty In partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering
Montana State University

Abstract:
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Since it is not a-wise practice to begin experimentation before giving some thought as to what the final result should be, a section entitled "theoretical analysis" is included to assist in the approach of other problems of a similar nature that may be encountered. A mathematical solution of the Corner reflector and Tagl antenna Is presented, however because of, its complexity, computations are not actually made. Another problem which has been modified but is similar to this has been solved by an indirect method.

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Thomas D. Smith

ABSTRACT

This thesis was undertaken to investigate the influence upon gain and horizontal directional characteristics caused by various reflectors when used in conjunction with the commercial Yagi antenna. An effort has been made to present the information in such a manner as to aid the reader in determining whether the addition of a reflector may be justifiable for a particular situation. Although maximum gain and a narrow beam are the desired characteristics that are sought, objectional effects are also noted.

A brief discussion of the fundamental theory of the Yagi antenna is given in the first part of the following material. Information on commercial construction of this antenna is presented along with a comparison of its advantages and disadvantages.

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INTRODUCTION

Within the past few years, Yagi antenna arrays have become increasingly important. Since this antenna is inexpensive and has relatively high gain and good directional characteristics, it plays a very important role in television reception in remote sections of the country. Until other carrier systems, such as relay or cable, dominate the country; the Yagi array will undoubtedly remain in wide usage.

Because of the present importance of this antenna, the author felt that an investigation of the Yagi for the purpose of improving its gain was highly justifiable. A corner reflector was chosen for the major portion of this work due to its simplicity of construction and gain advantages when used with a dipole antenna. By inductive reasoning, it was presumed that with the right adjustments, an improvement in gain would be acquired over the original Yagi, and yet the modified antenna would retain its primary advantages — namely a good field pattern, simplicity of design and construction, and low cost.

Although the Yagi antenna is not a recent invention, the mathematical computations of gain become extremely involved. Many authors compare experimentally obtained results, but tend to shy away from the mathematical solutions. Consequently literature on this aspect of the Yagi is quite limited.

During the following discussion the test antenna may be referred to as the source of the radiation field. This essential assumption may be made because the important characteristics, which are field pattern, gain, and impedance, are the same if the antenna is used for receiving or transmitting.

To eliminate a detailed discussion of the fundamental theory of radiation, it is assumed that the reader possesses a basic knowledge of wave propagations. Accepted abbreviations and symbols in Electrical Engineering are used in this text.

YAGI ARRAY

In microwave work, the most fundamental antenna is the half-wave dipole. It is a common antenna and has a very simple form which may be seen in Fig. 1(a). The dipole is made up of two quarter wave antennas placed end-to-end and fed in the middle in such a manner that the current simulates a sinusoidal distribution. Although the current does not necessarily conform exactly to facts, this is an essential assumption made by theorists. Nevertheless this error in calculations is not of significance and therefore may be neglected.

The resistance of this antenna is approximately seventy-three ohms and should be used in conjunction with a seventy-three ohm transmission line for the most efficient results. It is possible to match the impedance of this antenna with a line that contains a different impedance by utilizing shorted stubs though this procedure may become quite involved.[1]

When greater field directivity and higher gain are required than can be obtained from a single antenna, antenna arrays are often used. An antenna array is a system of similar antennas oriented in such a manner that the eminating electromagnetic waves tend to add or cancel one another in various directions. Consider a two-element array, each

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[1] J. D. Ryder, "Networks, Lines and Fields", Prentice-Hall, Inc., New York, 1950, p-267.

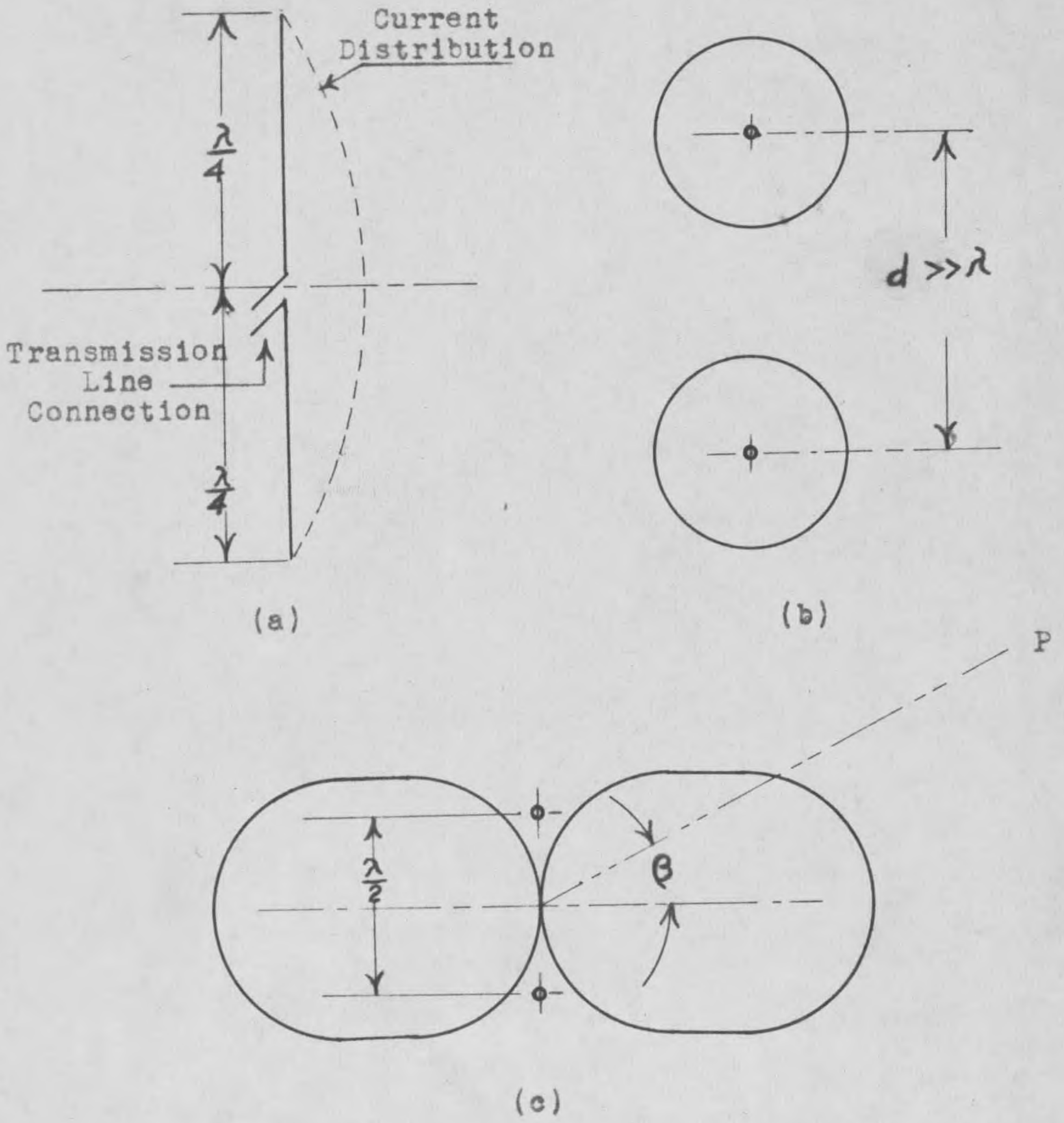


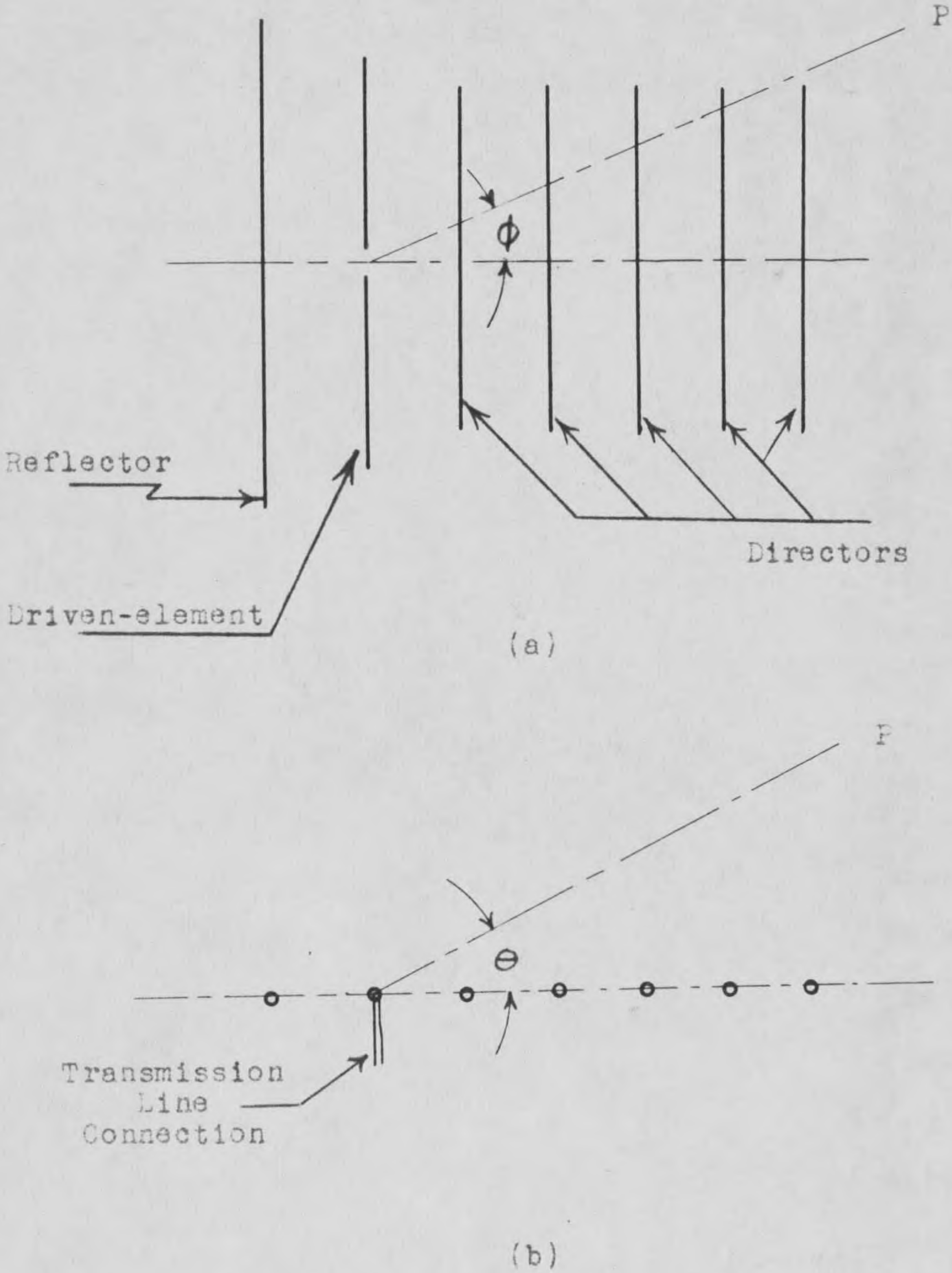
FIG. 1

(a) Top view of dipole antenna, (b) end view of the field intensity patterns of two dipoles separated by a distance much greater than a wavelength, and (c) end view of the field intensity pattern of two dipoles fed in phase and spaced a distance of one-half wavelength apart.

element being a half-wave dipole, in which both antennas when sufficiently separated produce an omnidirectional intensity pattern as shown in the end view of Fig. 1(b). When they are fed in phase and placed a distance of one-half wavelength apart, their combined radiation pattern acquires the form of a figure eight as is evident in Fig. 1(c). If the field intensity at a point "P" were measured when $\beta = 90^\circ$, the indication would be zero as the fields tend to cancel one another. But as β approaches 0°, the transmitted waves approach the same phasing and hence a maximum intensity occurs.

In the above section the array elements are both driven, that is, they are supplied with power by means of a transmission line. Directional arrays can also be constructed with the aid of elements in which currents are induced by the fields of a driven element. Such elements have no transmission line connection to the transmitter and are usually referred to as "parasitic elements".

A Japanese named Yagi reasoned that if parasitic elements could be made either to push against or to pull on the pattern of a driven antenna, a push-pull arrangement with greater gain and better beam qualities should be possible. He devised the Yagi array which consists of a driven antenna with a parasitic reflector and one or more parasitic directors. Such an antenna is represented in Fig. 2.



(a)

(b)

FIG. 2

(a) Top view and (b) end view of a seven element Yagi.

A Yagi array is the highest gain antenna of comparatively simple form and construction. One disadvantage of this antenna is that it has a relatively narrow bandwidth as compared to other conventional television antennas such as the fanned or conical antenna. Still gain is quite good on adjacent channels. Bandwidth can be increased by altering the dimensions, however not without sacrificing gain. Several Yagi arrays may be stacked one above the other on a single mast and cut and oriented for specific channels. With such an arrangement gain remains unchanged and the frequency response is unaffected for different channels. On the other hand if higher gain is desired, the Yagi may be conveniently stacked broadside. It has a good front-to-back ratio for rejection of co-channel interference, and can easily and efficiently eliminate reflections which cause ghost images on the television screen.

Without hesitance it may be said that the advantages of this antenna greatly outweigh the disadvantages.

CONSTRUCTION OF TEST YAGI

There are a number of arrangements that can be used in the design of a Yagi for good reception qualities. As far as practical use is concerned, each situation presents a different problem. In fact there are so many variables influencing results that definite answers are obscured. Height above ground, angle of signal arrival, space distribution pattern, and proximity of other objects are only a few of the conditions that effect the reception. Fig. 3 presents some of the spacings and dimensions that are commonly used.[1] The length of the driven-element is usually taken as $(1-0.05)\frac{\lambda}{2}$. This length is used because the effective length of a dipole antenna appears to be larger than it actually is.[2] From Fig. 3 it is seen that bandwidth is sacrificed for gain or vice-versa. If a wider bandwidth is desired, the directors can be made progressively smaller or spaced farther apart.

For the main test antenna used in the experimentation, a seven-element Yagi was constructed with the dimensions shown in Fig. 3(a) first being used. This antenna did not give the desired gain so the cut and try method of finding the correct lengths of the directors was performed. Each director was shortened and then another test made. Such a process was continued until a high gain was obtained. The miniature size of

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1. Noll and Mandl, "TV and FM Antenna Guide", The MacMillan Co., New York, 1951, p-258.
2. E. C. Jordan, "Electromagnetic Waves and Radiating Systems", Prentice-Hall Inc., New York, 1950, p-536.

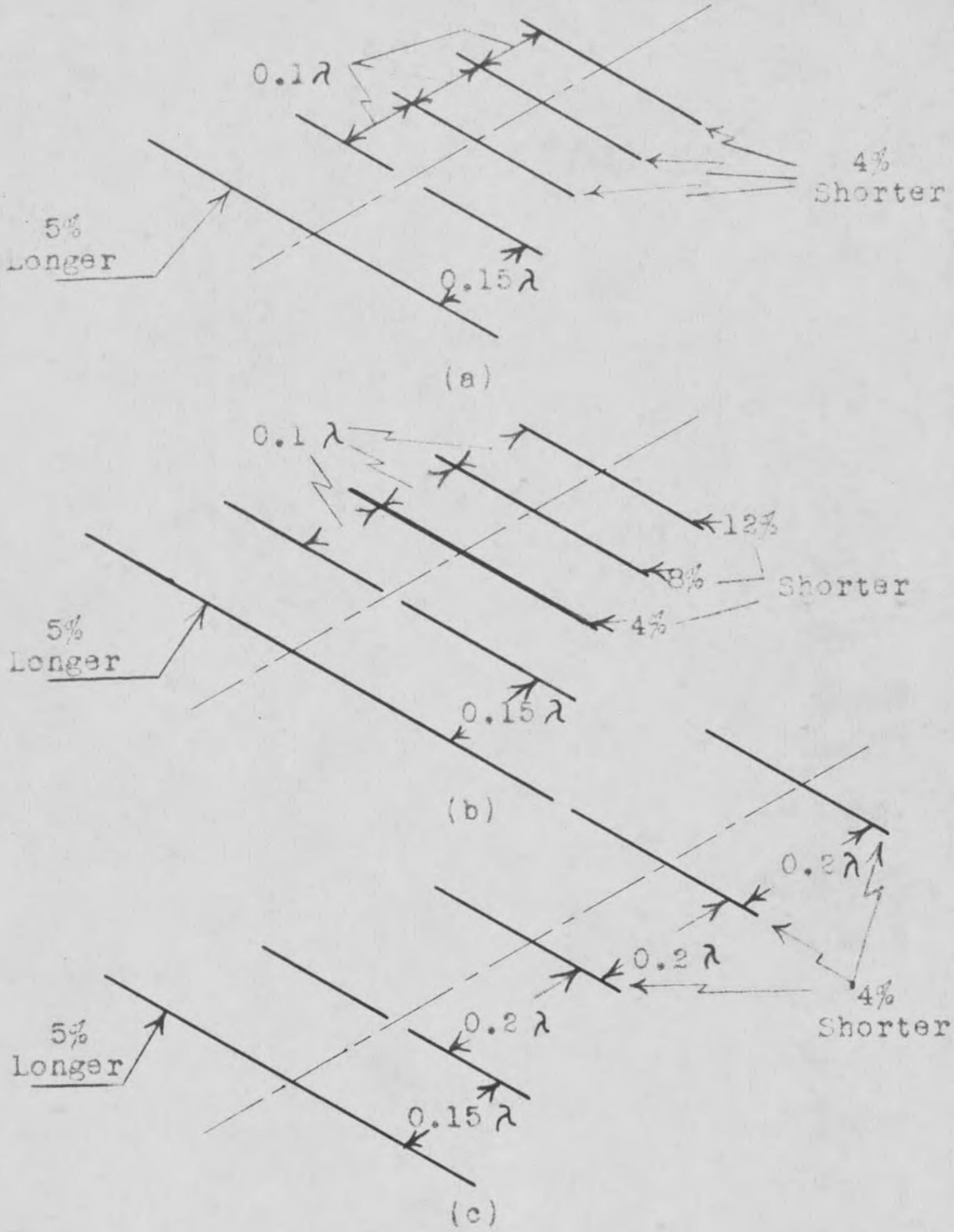
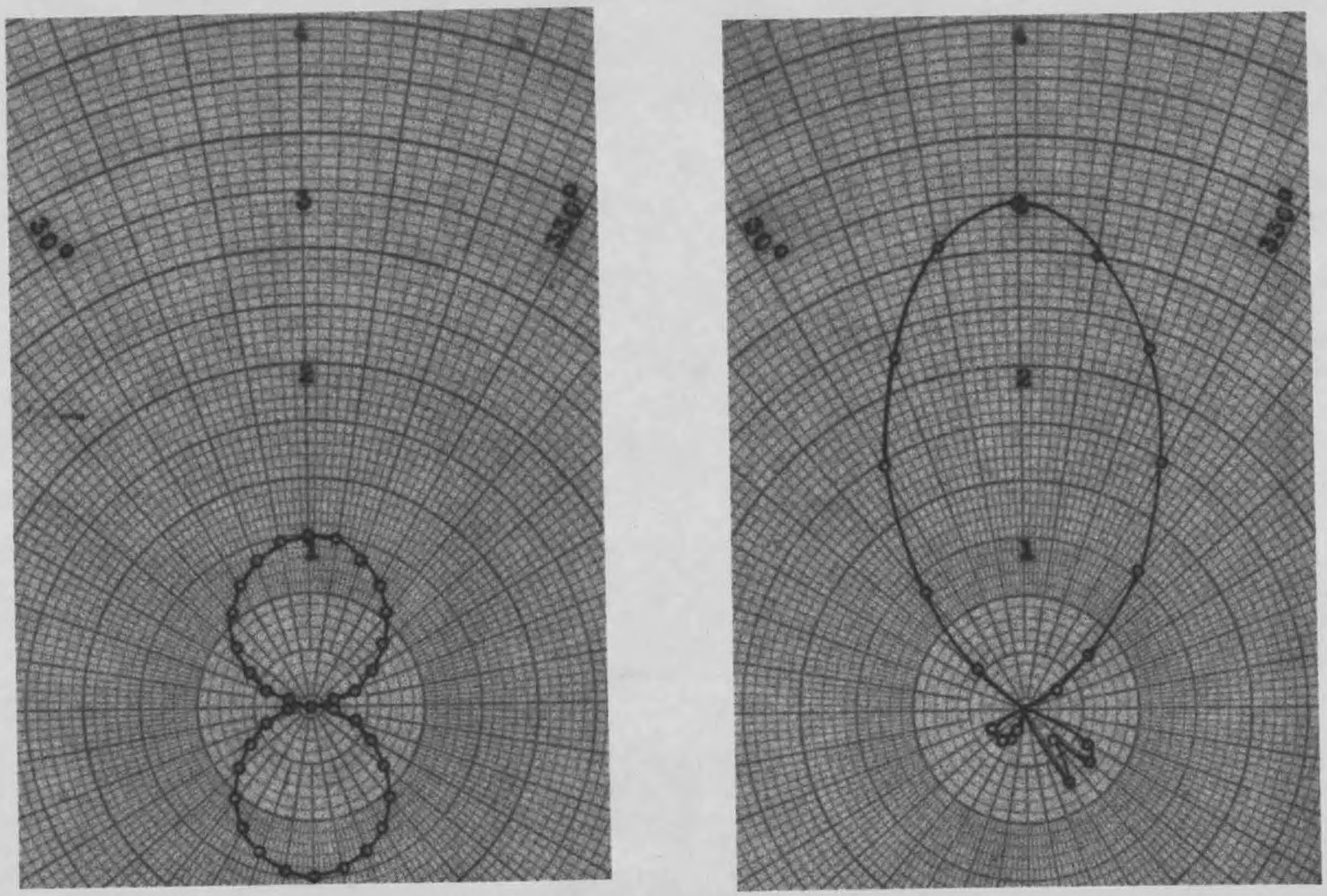


FIG. 3

Typical arrangements for commercial use with the following qualities: (a) high gain, narrow bandwidth, (b) less gain than above but greater bandwidth, (c) less gain but greater bandwidth. (Longer and shorter refer to the length of element with respect to the driven-element) the antenna models made it impossible for accurate measurements to be taken. After several attempts a test antenna was constructed that gave a gain of 9 db. Although this was not the maximum gain expected, it was the best out of all the trials. The field intensity of this antenna is compared to the half-wave dipole in Fig. 4.

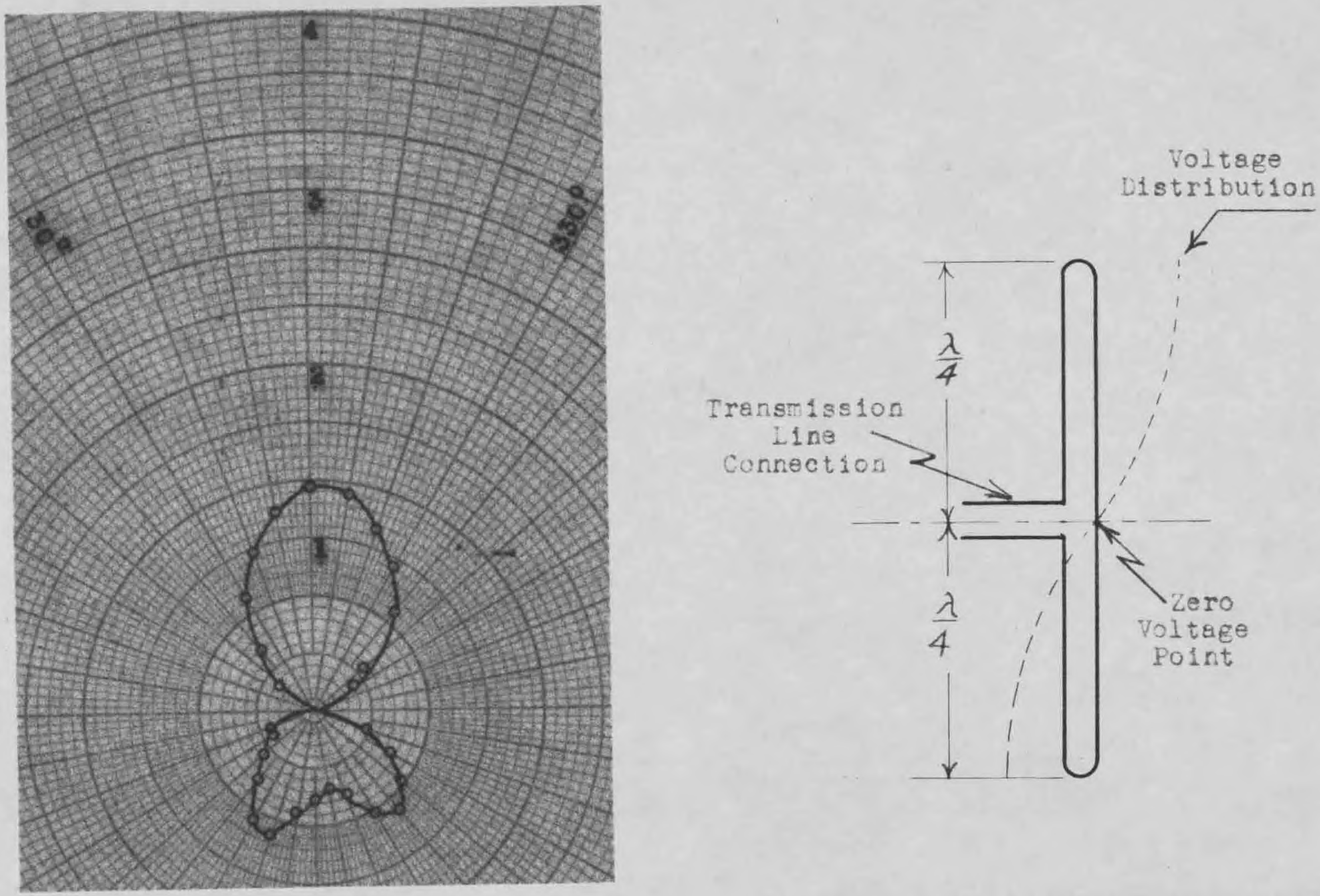
During the construction of the test Yagi, it was noticed that the directors of the arrays were necessarily cut shorter than the length of the driven-element minus 4%. Since this occured for all models, an attempt was made to determine the reason. Though much research was done, no literature could be found that gave an explanation. It is believed that the end fringe effect was increased because of the comparatively small models and high frequency used, thus causing the effective length of the elements to appear larger than their theoretical value.

A second test Yagi was built that consisted of a reflector, director, and driven-element. The spacing of the director was 0.15 wavelengths instead of the preceding 0.10, but the reflector spacing remained unchanged. Naturally it should be expected that gain of this latter antenna would be less than that of the preceding one assuming that both were cut fairly close to their maximum efficiency. Fig. 5(a) shows the field pattern of this antenna. A comparison may be made with the reference dipole of Fig. 4(a), and also with the seven-



(a) FIG. 4 (b)

Comparison of the field intensity patterns of (a) a dipole and (b) the seven-element test Yagi.



(a) FIG. 5 (b)

(a) Field intensity pattern of the three-element test Yagi, and (b) a folded dipole.

element Yagi of Fig. 4(b).

It is the usual practice to use a folded dipole for the driven-element rather than the plain dipole. A folded dipole consists of an equal lengthed element paralleled with the dipole. This antenna may be seen in Fig. 5(b). Field pattern and gain remain the same but the impedance is increased to 300 ohms. This permits an easier match to be made to transmission lines of high impedance, and when parasitic elements are added, the resulting impedance, although decreased, remains much greater than when a plain dipole is used. Similarly if another element were paralleled with the folded dipole, gain and pattern would remain unchanged and the impedance would be increased to approximately 660 ohms. Since the center of the paralleled element is at zero voltage, the mounting of this antenna is comparatively simple.

EXPERIMENTAL COMPONENTS

Experimental components needed in any radiation work are the transmitter, the receiver, and the antenna. This discussion will be subdivided into the following three topics:

a. Transmitter
b. Receiver
c. Antennas and Reflectors

Transmitter

A klystron oscillator was used as the transmitter. Since it was included in the equipment of the Electrical Engineering Department, it was quite easily obtained. Undoubtedly this was the most important factor in determining the type of transmitter to be employed.

Frequency of this klystron was very stable at 3,000 MC. Such a high frequency was a definite advantage because the antenna models required were miniature in size. When in operation it could be assured that it would cause no interference with frequencies of commercial communications, and more important, the tuned antenna would be relatively free from outside interference.

Power output of the klystron remained quite stable and was strong enough to be detected at great distances with a microammeter. To obtain a good radiation pattern and be certain that the radiation has only the two transverse components of a plain wave-front, namely E_t and H_t, the receiver must be a distance of several wavelengths away from the transmitter.

The complete transmitter and associated power equipment were mounted on a table that was highly mobile. This was an essential condition since all of the work was accomplished outside to eliminate reflections that would be produced within a closed room.

Fig. 6 is a photograph of the transmitting unit. The 30 inch parabolic dish at the right was used with the transmitting antenna to narrow the beam width and increase the signal intensity in the forward direction. An arrow indicates the klystron tube. On the bottom shelf of the table are two power supplies connected in series with an output of 1,150 volts.

Receiver

It was impossible to locate a field strength meter responsive to such a high frequency, consequently it was necessary to devise some method of determining relative reception strength. A very simple receiver was designed which included a microammeter, a germanium diode, matching stubs[1], and coaxial cable. The microammeter was a d-c meter with a range of 0 to 500 microamperes. A IN21 germanium diode was used as a detector for the circuit. Two purposes were served with the adjustable shorted stubs: 1) to match the impedance of the

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[1] Refere to footnote 1, page 7.

FIG. 6
TRANSMITTING UNIT

FIG. 7
RECEIVING UNIT

test antenna with the adjoining circuitry, and 2) to complete a d-c path for the meter when it was not completed by the antenna being used (i.e. the dipole). Fig. 7 is a photograph of the receiver, although the complete apparatus is not shown. The bottom is mounted on a stand that may be rotated around its vertical axis. A pointer located at the base of the shaft indicates the number of degrees of revolution.

Current in this system will not increase linearly with a linear increase in applied signal strength. In Fig. 20 of the appendix is a graph of voltage versus current for a typical germanium diode. Though the graph approaches a straight line, it actually continues to curve, therefore calibration of the system was necessary. This was easily accomplished by comparing an experimentally obtained curve with a curve of known values. When a half-wave dipole is rotated on its vertical axis in a horizontally polarized wave-front as in Fig. 8, the

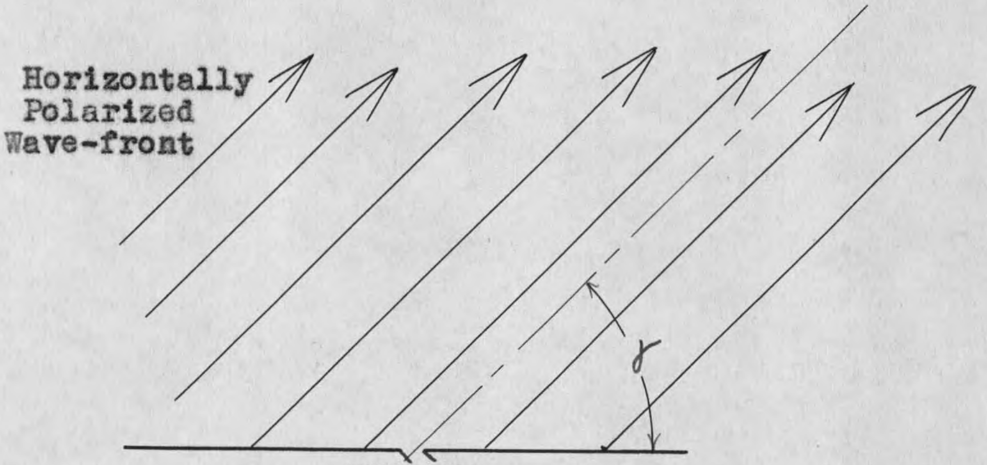

FIG. 8

Top view of dipole

intercepted signal will obey the equation[1]

$$I = \frac{k \cos\left(\frac{\lambda}{2}\cos\gamma\right)}{\sin\gamma} \qquad (1)$$

where "I" is the field intensity, "k" is a constant depending on the system, and "γ" is the angle of rotation.

This test was performed and the resulting curve compared with the calculated curve as in Fig. 19 of the appendix. All data obtained experimentally was corrected making use of the calibration chart.

Antennas and Reflectors

Two Yagi arrays, a seven-element (Fig. 9a) and a three-element (Fig. 9c), were used. The reflectors used were the corner reflector (Fig. 9b), the flat surface reflector (Fig. 9a), and the grid reflector (Fig. 9d). Since the transmitted frequency was so high, the actual size of the antenna models being inversely proportional to frequency were very small. To determine the length of an antenna needed for use with a specific frequency, it must be 5% shorter than a half-wave. Comparison of actual size is made with the antenna and reflector models in Fig. 9 by use of a six inch rule.

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[1] L. A. Ware, "Elements of Electromagnetic Waves", Pitman Publishing Corporation, New York and London, 1949, p-194.

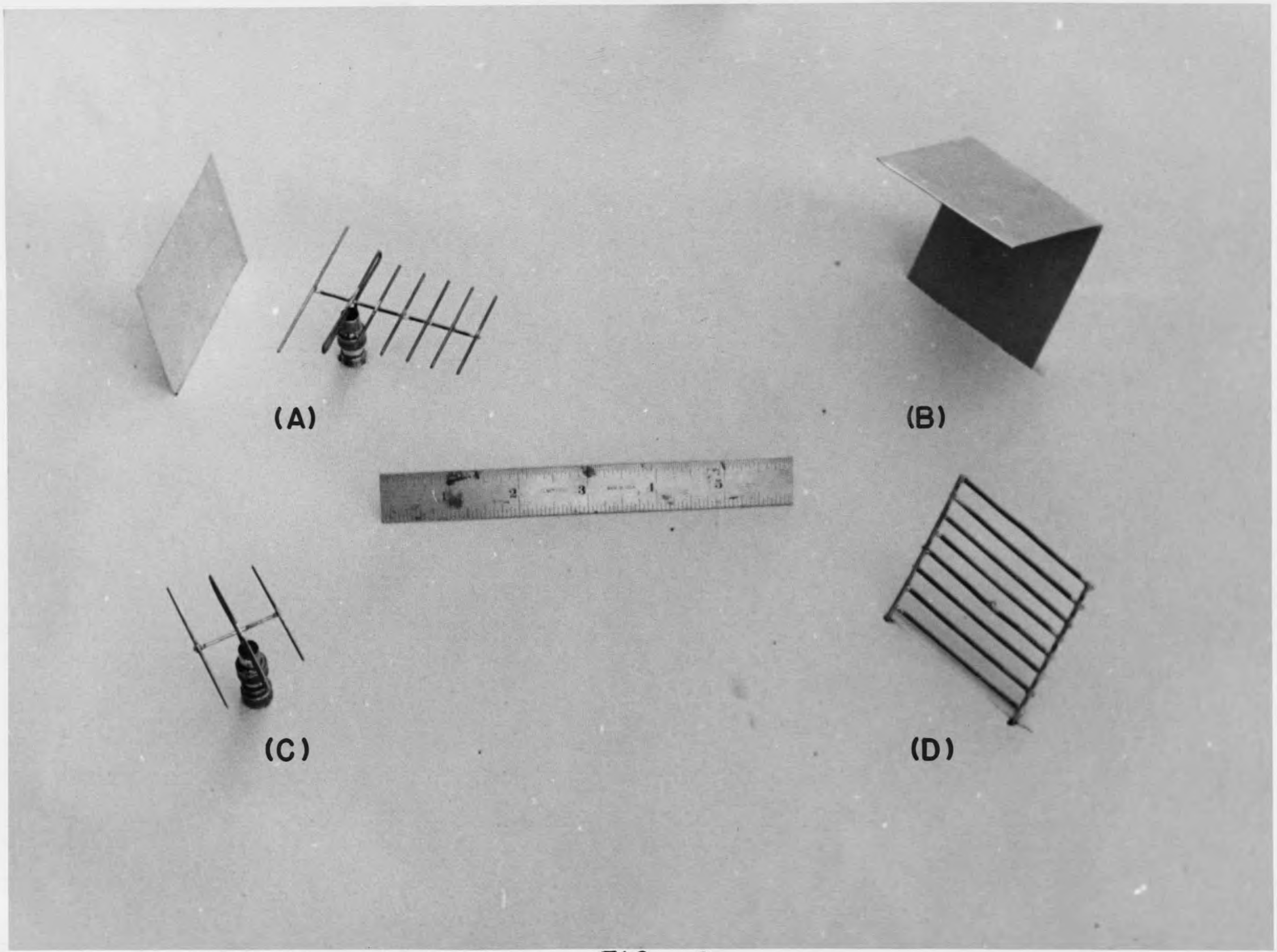

FIG. 9
TEST ANTENNAS AND REFLECTORS

THEORETICAL ANALYSIS

The purpose of this section is to analyse the problem and try to determine whether or not the desired results are possible. Otherwise much time could be wasted.

Let us first examine the function of the components of the Yagi array. When the wave-front strikes the first director, a current I_1 is induced in this element due to both the transverse wave components. This current will in turn set up a magnetic field around the element and re-radiate a second signal which may or may not be in phase with the original signal. Assuming the element is cut to the appropriate size that the phasing of the two approach each other, the resultant signal will be greater than either of its two component signals. Travelling to the second element the resultant wave will induce a current I_2 in that element, and a second re-radiated signal is created. Thus the signal that reaches the third element is composed of the original wave, the re-radiated signal from the first element, and the re-radiated signal from the second element. This process continues until the driven-element is reached at which point most of the signal will be absorbed. However, a part will pass this element and strike the reflector element. Because the latter has an inductive reactance, its phase will lag the phase of the oncoming signal and hence if the spacing is correct, the re-radiated signal from the reflector element will be in phase at the driven-element with the signal from the directors. If this be the case, maximum gain will occur. To achieve this condition, adjustment of the lengths and spacings of the parasitic elements must be quite exact.

To increase the gain without changing the dimensions or number of components of a given array, the field intensity must be increased at the receiver. Since we have no control over the transmitted signal, we must try to converge the approaching wave-front to a point. If the signals arrive in phase at this point, then the intensity will be greater than originally.

It is known that a simple method of converging a wave-front is by reflections from flat, conducting surfaces. Assuming no losses and the correct phasing, a single flat surface can be used to increase the intensity at a point by a factor of two. If two such surfaces are used and correctly positioned, the intensity will be increased by three. The reader should be reminded that when a wave strikes a surface, the reflected wave is 180° out of phase with the incident wave. This must be taken into account when setting up the reflectors.

When a Yagi is used as the antenna, the problem is not as simple as it previously appeared. It must be realized that if the reflecting surface is fairly large compared to the spacing of the elements in the array, the reflected wave will strike the parasitic elements also, causing a reaction with them. This secondary reaction may have an adverse effect on the original action of the Yagi. From this it is reasoned that with the right spacings and number of elements, a high gain will occur. Whether or not this situation will be present when a commercially constructed Yagi is used must be determined experimentally. If not, the trial and error method must be used to determine the correct dimensions of the original antenna.

A corner reflector consists of two flat, conducting surfaces with an antenna placed in the bisection of the angle formed by the intersection of these surfaces. This reflector was chosen because of its simplicity of construction and gain advantages when used with the dipole. An end view representation of the corner reflector mounted on a Yagi array is given in Fig. 10(a). "S" referes to the distance of the driven-element from the vertex of the angle. "η" is the angle of intersection of the two surfaces.

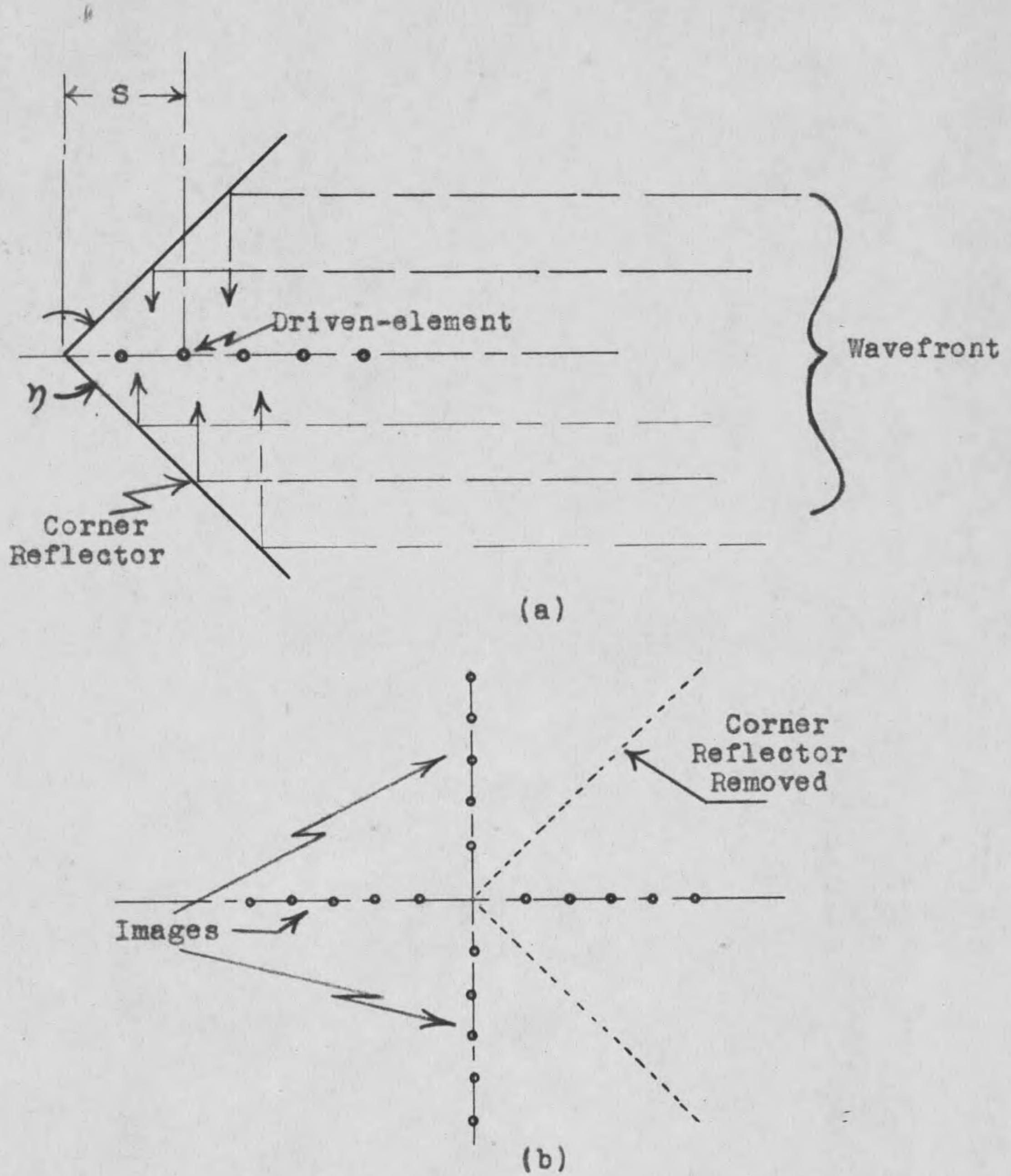

FIG. 10

(a) Yagi array with corner reflector , and (b) corner reflector replaced with the images of the actual array.

TEST PROCEDURE

All of the experimental work was performed on the east side of Ryan Laboratory. Having a relatively narrow beam width, the parabolic dish could be aimed so that its radiation would be in any direction chosen. The transmitting antenna was oriented in such a manner that objects which intercepted its path were well out of range, therefore if any undesirable reflections occured in the direction of the receiver, they could be neglected. Horizontal polarization was used.

The receiver was placed approximately one hundred feet from the transmitter in the path of radiation so that no objects were in the immediate vicinity. This distance is nearly equivalent to 300 wavelengths at the frequency of 3,000 MC. As mentioned before, this distance was used to insure that the wave-front contained only the transverse components. Also even though ground reflections could not be eliminated, their reaction at the receiver would not cause as great an error due to the angle of approach. Because the human body simulates a good reflector for short waves, it was necessary to remain relatively far away from the receiving antenna in such a position that the reflections would not interfere with the wave-front. A pair of field glasses were required to read the indicating meter.

First, the dipole was tested and recordings of relative field intensity made as it was rotated horizontally through an angle of 360° in 10° increments. The seven-element Yagi was then tested in a similar manner. Following this, the corner reflector was attached to the model and various values of "S" and "γ" were used. (See Fig. 10a) After each separate test was performed, it was rechecked at least twice, and also a reference check was recorded so that a comparison could be made. To show the disadvantages of using the same value of "S" for different values of "γ", two sets of readings were taken at each angle: 1) a constant distance of 0.25 wavelengths, and 2) a variable distance corresponding to maximum gain obtainable. Angle increments of 30° were taken with the corner reflector, the first being 180° or a flat surface.

Realizing that it was highly improbable that a mathematical solution of gain would be obtained for the above test, a three-element Yagi array was constructed. A small reflecting surface was positioned directly above the driven-element and oriented so that maximum signal was received with all reflections striking only this element. Gain was determined and a field pattern recorded. This antenna was then used with a 90° corner reflector.

Although field patterns were not plotted, the large flat sheet and the grid were used with both arrays to determine their reactions.

Data from all the test runs were averaged with their corresponding check and then corrected using the calibration chart before graphs were plotted.

MATHEMATICAL ANALYSIS

Whenever it is required to analyse an antenna that is placed near a flat conducting surface, the same results will be obtained if the reflector is removed and replaced with a suitably located image antenna.[1] For the case using a seven-element Yagi in a 90° corner reflector, there will appear three images. Thus the solution of such a problem would encounter a 28 element array positioned similar to the five-element array as shown in Fig. 10(b).

A multi-element array may be expressed in the following manner:[2]

$$E_{t1} = E_o\left[1 + k_1 e^{j\psi_1} + k_2 e^{j\psi_2} + \cdot\ \cdot\ \cdot\ + k_n e^{j\psi_n}\right] \quad (2)$$

where the symbols designate the following:

E_{t1} = total field intensity at a given point

E_o = field intensity due to driven-element

k_n = ratio of the n^{th} element current to the current in the driven-element

$\psi_n = \dfrac{2\pi d_n \cos\theta}{\lambda} + \alpha_n$

d_n = distance of the n^{th} element from the reference element or driven-element

θ_n = angle of declination from horizontal of the point in question

α_n = phase angle between the current of the n^{th} element and the reference element

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[1] E. C. Jordan, "Electromagnetic Waves and Radiating Systems," Prentice-Hall, Inc., New York, 1950, p-409.

[2] Same as above except p-398.

The values of θ_n and d_n can be physically measured. When two or more antennas are used in an array, the driving-point impedance and hence the current in an antenna depends upon the self-impedance of that antenna and in addition upon the mutual impedance between that antenna and each of the rest. Therefore to determine k_n and α_n, a set of simultaneous equations must be used.

$$\begin{aligned} V_1 &= I_1 Z_{11} + I_2 Z_{12} + \cdot \quad \cdot \quad \cdot \quad \cdot + I_n Z_{1n} \\ V_2 &= I_1 Z_{12} + I_2 Z_{22} + \cdot \quad \cdot \quad \cdot \quad \cdot + I_n Z_{2n} \\ &\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ V_n &= I_1 Z_{1n} + I_2 Z_{2n} + \cdot \quad \cdot \quad \cdot \quad \cdot + I_n Z_{nn} \end{aligned} \qquad (3)$$

where

V_n = voltage across terminals of the nth antenna

I_n = current in the nth antenna

Z_{nn} = self-impedance of the nth antenna. (Determined from impedance charts)

Z_{2n} = mutual impedance between the nth and the 2nd antenna. (Also determined from charts)

Values derived from the above set of equations are substituted into equation (2) to find the total field intensity. From the solution of total intensity, the gain may be found as

$$G = \frac{E_{t1}}{E_o} \qquad (4)$$

For the case where n equals 28, the solution is a very tedious one and with "Z" a complex number, it becomes too involved to justify solving.

Data was also obtained using a three-element Yagi with a 1" X 2" flat reflector placed directly above the driven-element and oriented so that the reflections were only effecting this element. To solve for the gain, a set of mesh voltage equations must first be set up as follows:

$$\begin{aligned} V_1 &= I_1Z_{11} + I_2Z_{12} + I_3Z_{13} \\ 0 &= I_1Z_{21} + I_2Z_{22} + I_3Z_{23} \\ 0 &= I_1Z_{31} + I_2Z_{32} + I_3Z_{33} \end{aligned} \qquad (5)$$

Solving for the current ratios by simultaneous equations

$$\begin{aligned} \frac{I_2}{I_1} &= \frac{Z_{31}Z_{23} - Z_{21}Z_{33}}{Z_{22}Z_{33} - Z_{23}Z_{23}} \\ \frac{I_3}{I_1} &= \frac{Z_{21}Z_{23} - Z_{31}Z_{22}}{Z_{22}Z_{33} - Z_{23}Z_{23}} \end{aligned} \qquad (6)$$

From mutual- and self-impedance charts the impedances involved are found to be

$$\begin{aligned} Z_{12} &= 64 \angle{-6^\circ} \\ Z_{13} &= 64 \angle{-6^\circ} \\ Z_{23} &= 48 \angle{-44^\circ} \\ Z_{22} &= 56 \angle{-26.5^\circ} \\ Z_{33} &= 100 \angle{39^\circ} \end{aligned}$$

Substituting the known values in equation (2) we find

$$G = \left[1 + 1.05 \angle 261^\circ + 0.177 \angle 222.5^\circ \right] = 1.35 \angle -58^\circ$$

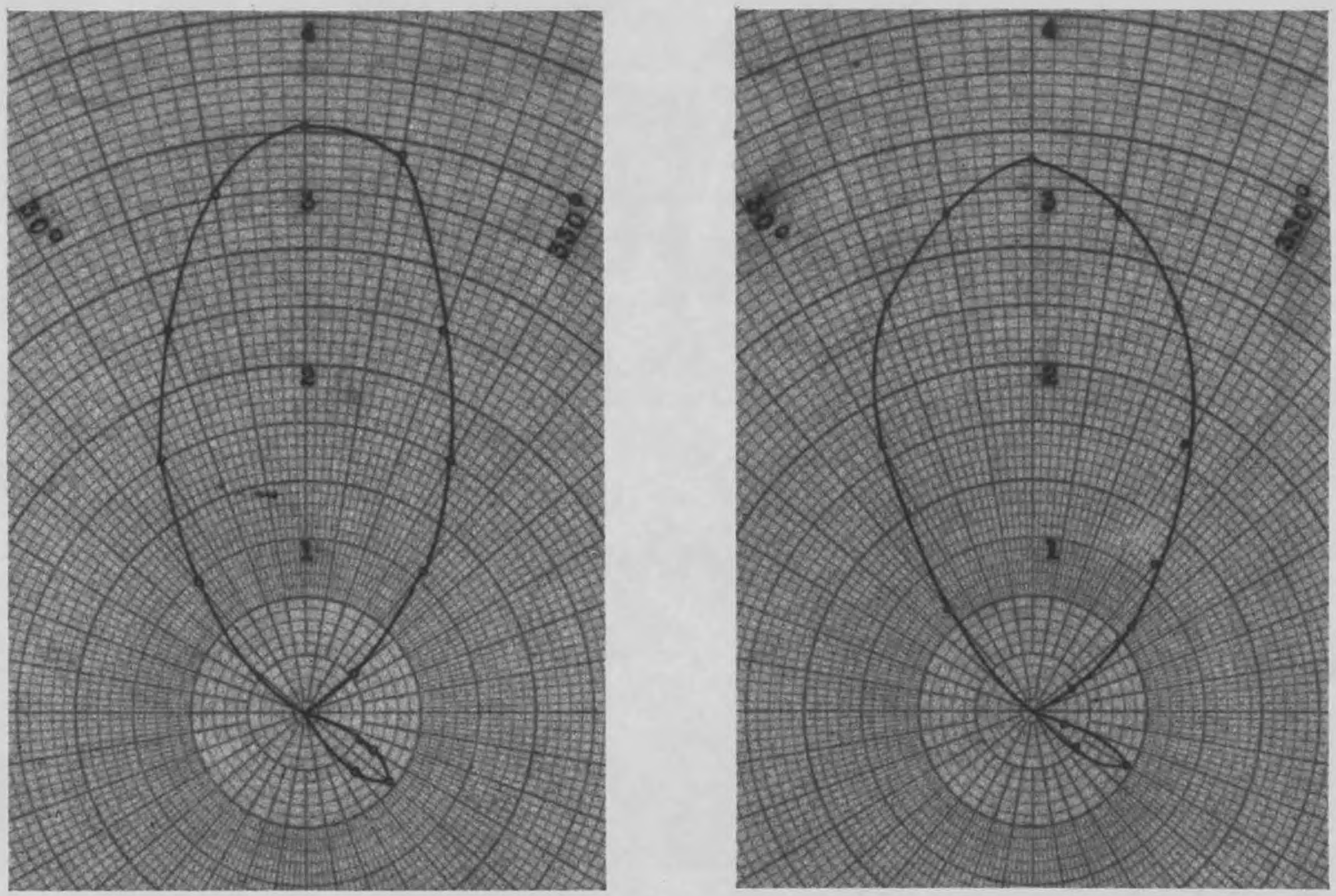
The gain of the three-element Yagi is 1.35 over the dipole. The angle has no significant meaning unless it is desired to increase the intensity. It would then be necessary to insure that the added field intensity was in phase with the original. Because the reflection from the above mentioned reflector reacts only with the driven-element and is adjusted for maximum reading, we may assume that the reflected wave is in phase with the principle wave when it reaches the Yagi. Therefore the intensity at the driven-element will be increased by unity, or the total intensity with this reflector will be 2.35.

EXPERIMENTAL RESULTS

Since it is easier to compare experimental results of antennas by use of field intensity patterns, the data obtained was plotted on polar coordinate paper. Gain is increased by compressing the field intensity pattern into a smaller area. Therefore a high gain would result if the field pattern were concentrated into one ray, however if there is more than a single ray eminating from the antenna, the gain may not be as great as anticipated. Although it would be desirable to determine all existing radiating rays, the engineering facilities did not permit such experimentation.

Figs. 11 through 16 represent the field intensities of the seven-element Yagi with the corner reflector. For each angle of the corner reflector, two readings (a constant distance and a variable distance) were recorded. Gain increase over the original Yagi is given in each case. Also the distance of the driven-element of the Yagi from the vertex of the reflector is given in wavelengths represented by "S". The angle of the reflector is "η". Fig. 17 is a graph of gain versus angle for the above results. This will give an overall comparison.

Fig. 18 is the result of using the corner reflector with an angle of 90° and also the flat surface reflector (1" X 2") in conjunction with the three-element Yagi.

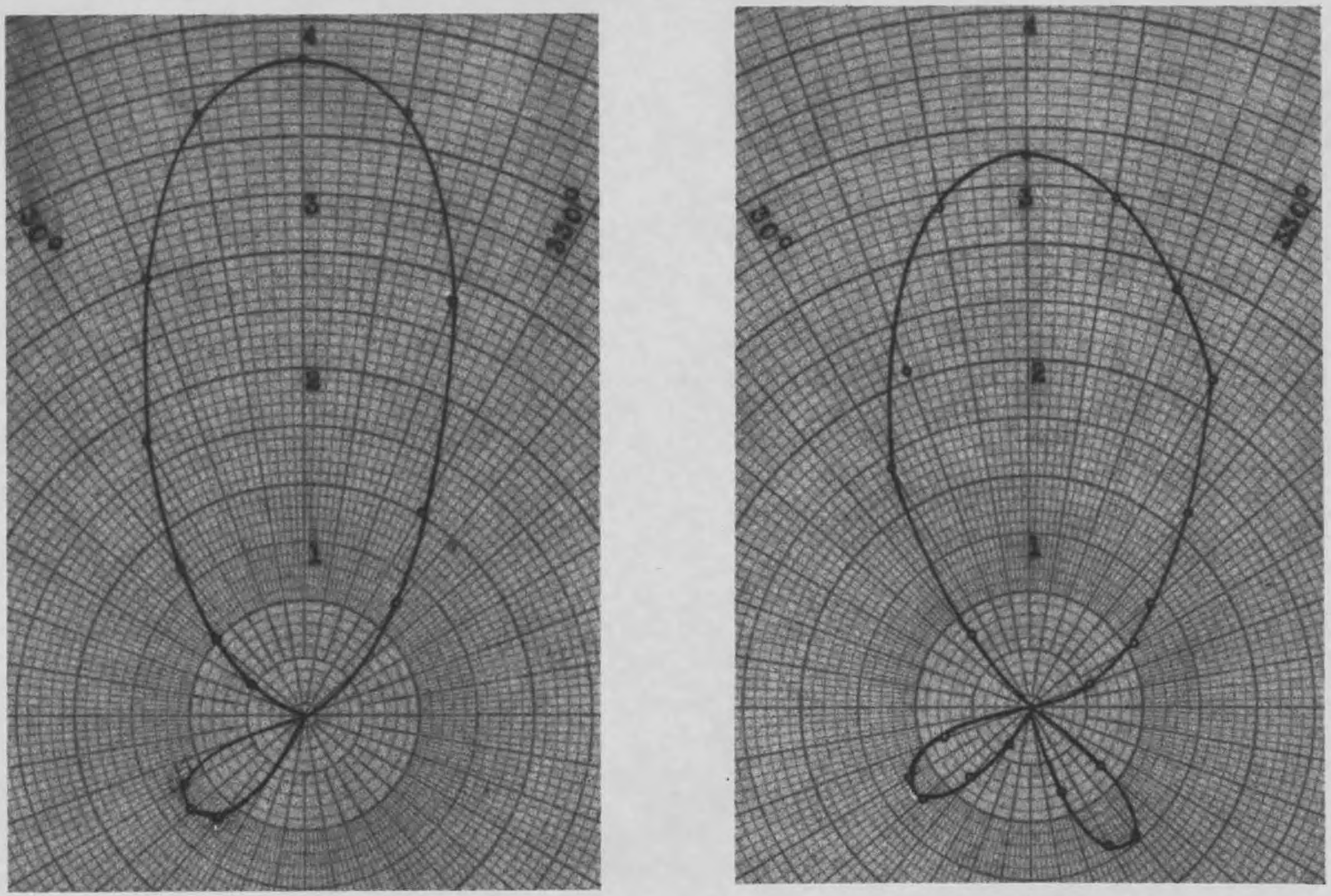


S = 0.15
G = 1.15

S = 0.25
G = 1.08

FIG. 11

$\eta = 180^\circ$

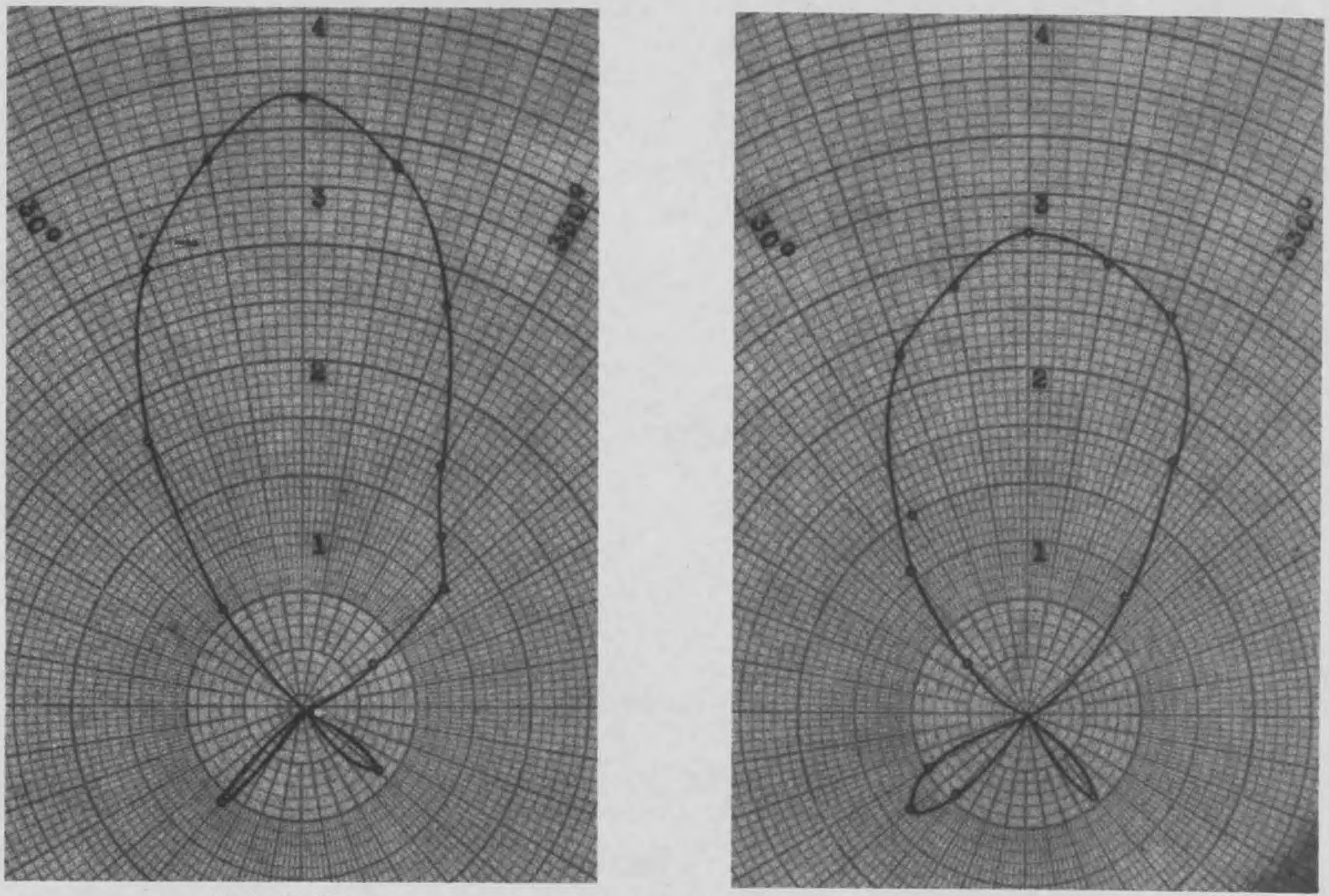


S = 0.15
G = 1.29

S = 0.25
G = 1.08

FIG. 12

$\eta = 150^\circ$

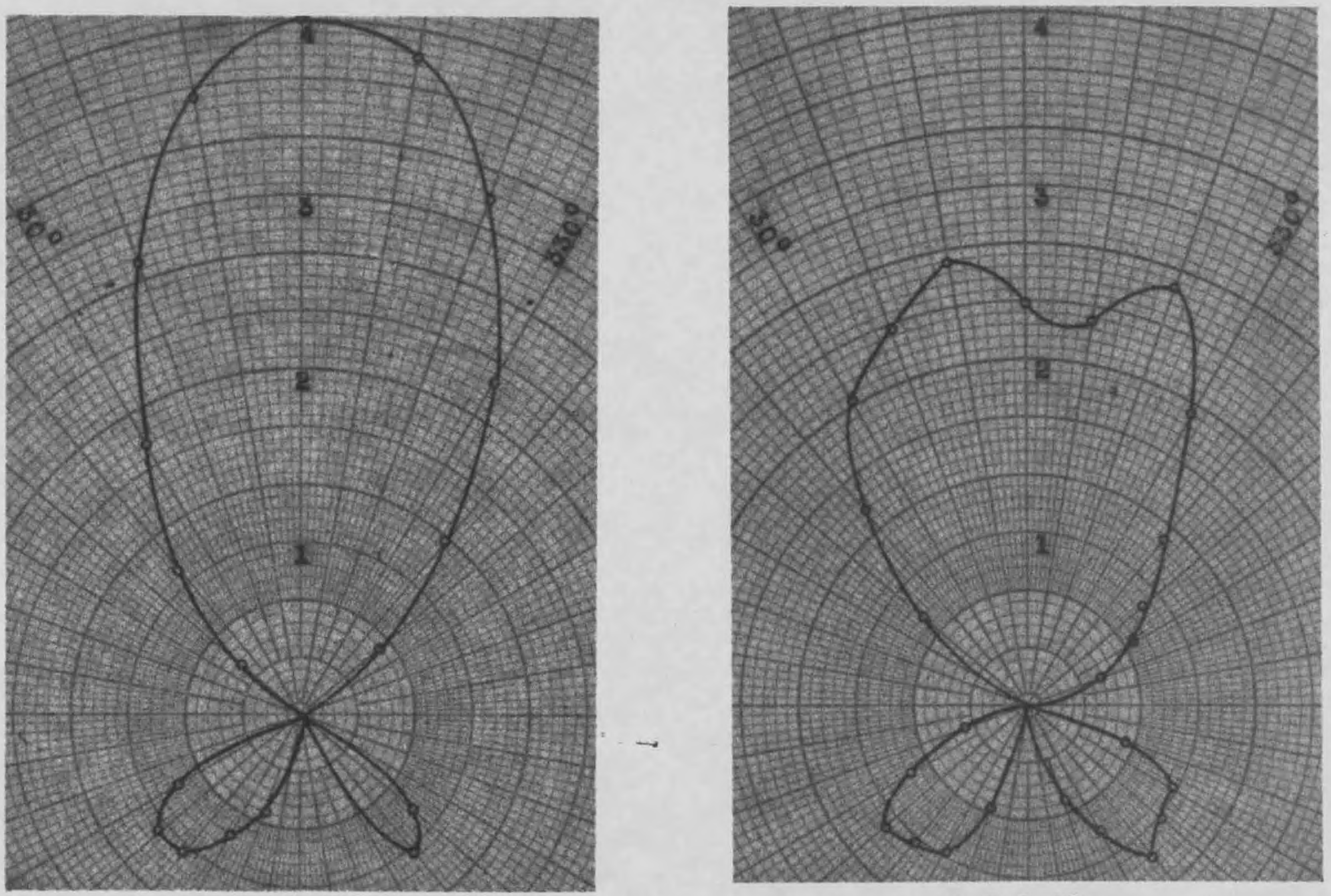


S = 0.59
G = 1.20

S = 0.25
G = 0.95

FIG. 13

$\eta = 120^\circ$

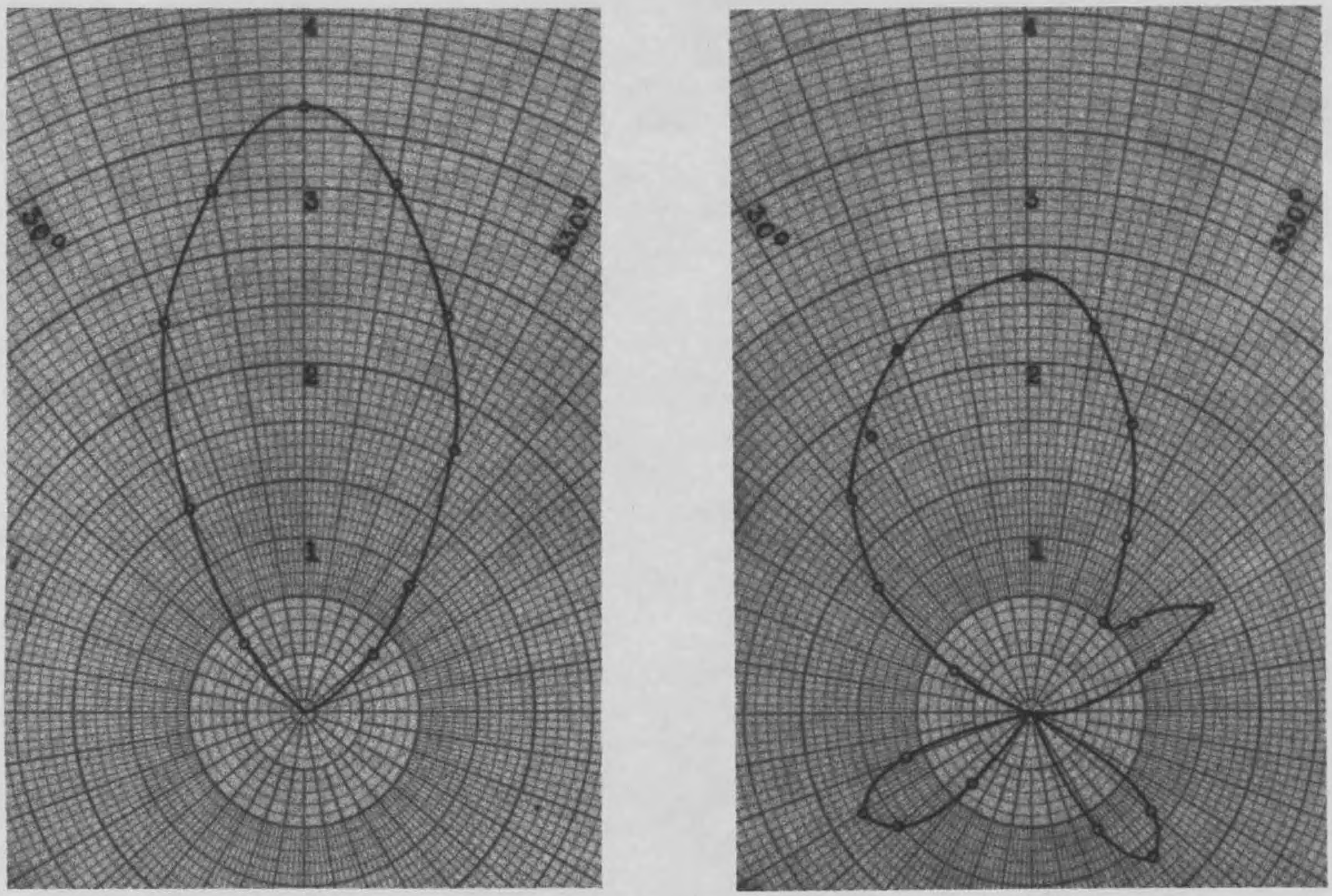


S = 0.50
G = 1.38

S = 0.25
G = 0.88

FIG. 14

η = 90°

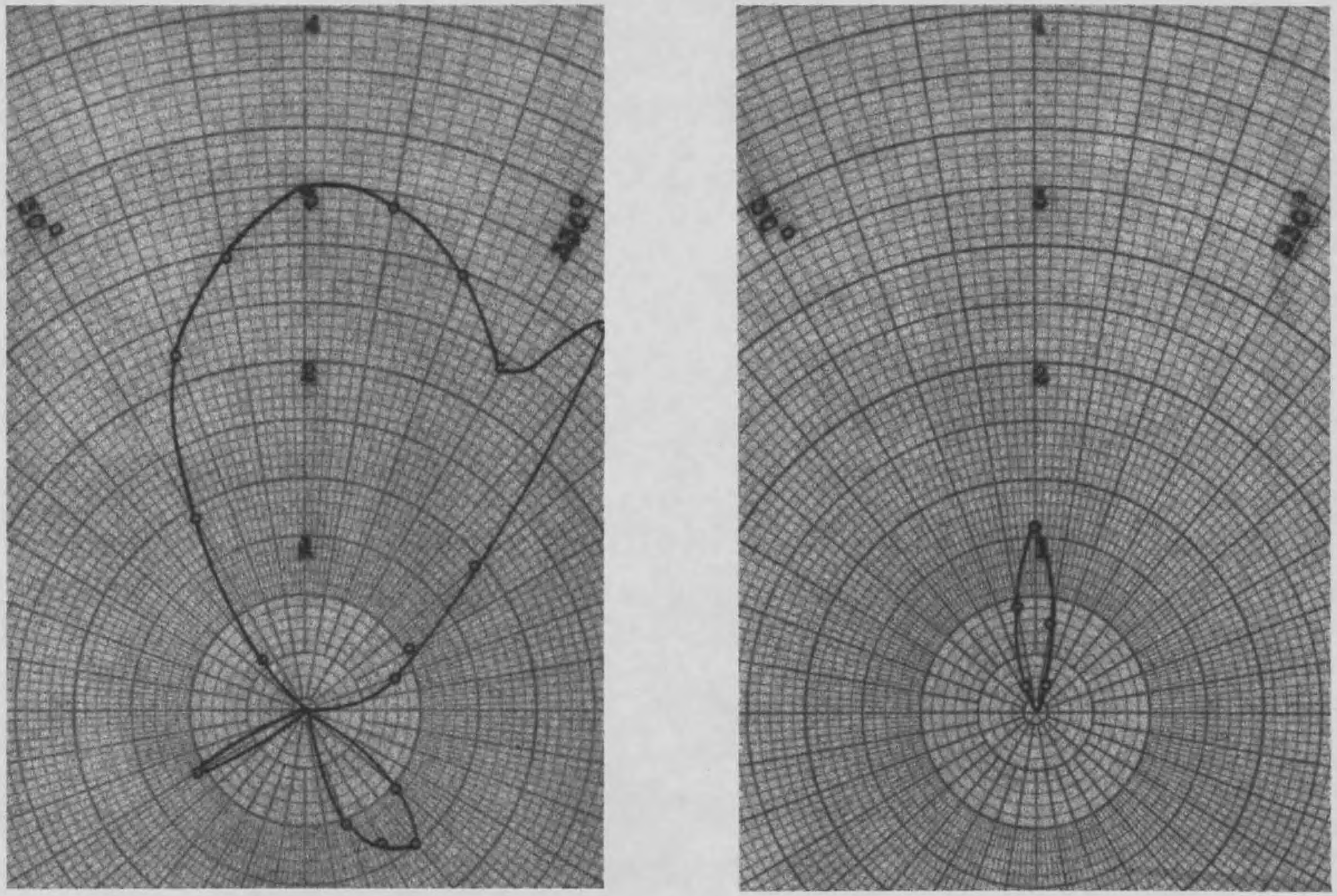


S = 0.34
G = 1.19

S = 0.25
G = 0.86

FIG. 15

$\eta = 60^{\circ}$



S = 0.56
G = 1.02

S = 0.25
G = 0.36

FIG. 16

η = 30°

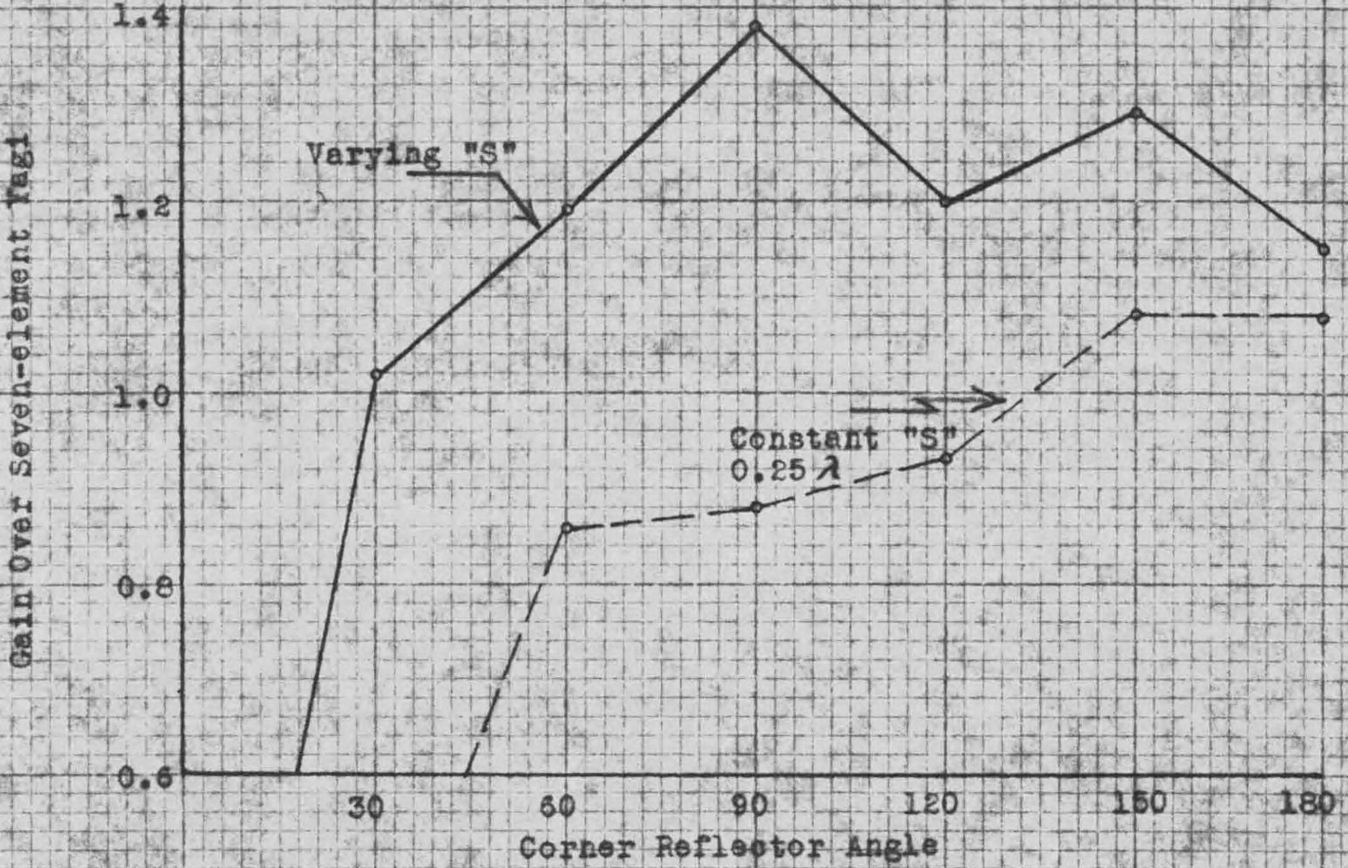
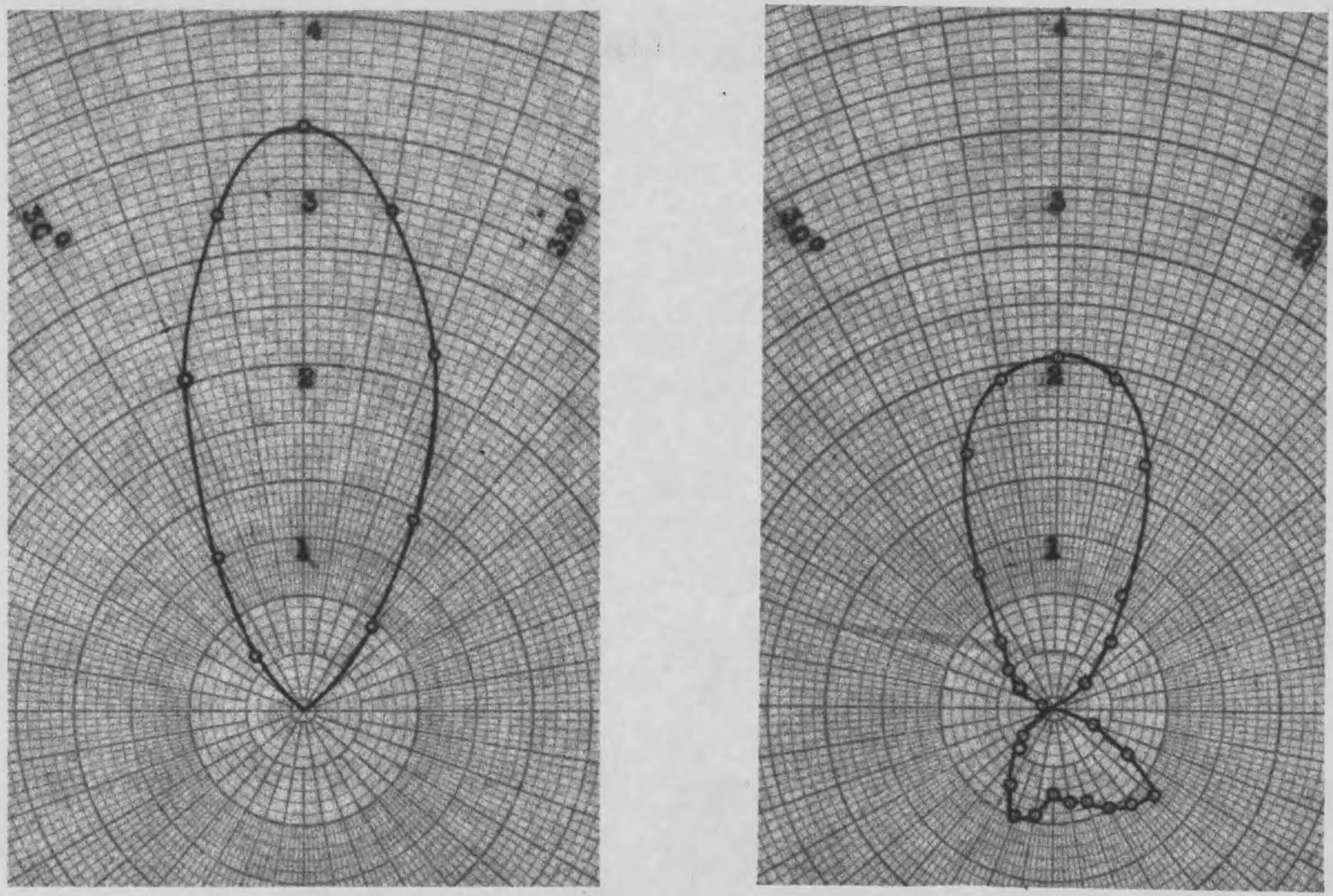


FIG. 17

Gain Versus Corner Reflector Angle for a varying and constant distance "S".



(a) G = 2.61

(b) G = 1.59

FIG. 18

Three-element Yagi array with (a) corner reflector, and (b) 1" X 2" flat surface reflector.

DISCUSSION OF RESULTS

The seven-element Yagi has an increase in gain of 2.9 over the reference dipole. A comparison of the two field patterns is made in Fig. 4. Although the Yagi has a slight amount of back lobe, the front-to-back ratio is great enough that it may be neglected. Beam width of this antenna is 45° as compared with 80° of the dipole. When the three-element Yagi was tested, it was found to have a gain of 1.29 greater than the dipole. Since the reason for a smaller gain of this antenna than the preceding seven-element array is obvious, an explanation is not deemed worthwhile. It is seen in Fig. 5 in which the field pattern of the three-element Yagi is plotted that the beam width of this antenna is 55°, however a rather large back lobe is present. This condition in certain cases will cancel the advantages of high gain and narrow beam, and therefore may be considered unsatisfactory at times.

Because it is assumed that the reader is capable of studying the graphs and determining which situation is the best for any specific case, a detailed discussion of each angle and distance used with the corner reflector will be omitted, however outstanding points will be considered. Unless otherwise stated, the following discussion will refere to the seven-element Yagi.

The greatest increase of gain utilizing the 90° corner reflector and seven-element Yagi was 1.58 over the original array, a total gain over the dipole of 4. Beam width at this setting is 40°. Although this is a fairly directive beam, it is not the best that was acquired. When S = 0.25 wavelengths was used at this angle, the main front lobe was distorted. (See Fig. 14)

Fig. 15 compares the two settings used at 60°. When S = 0.34 wavelengths, the beam angle was decreased to 35°, and though maximum gain was not produced, such a narrow beam width may be more advantageous in areas which contain considerable interference. Another advantage seen here is that no back lobes are present. Using a distance of S = 0.25 wavelengths, the pattern was greatly distorted. Distortion may be caused by several conditions some of them being: 1) non-symetrical element lengths, 2) reflector not perfectly aligned with the antenna, 3) reactions caused by the reflector upon parasitic elements of the antenna, etc. It was difficult to obtain perfect settings at all times even though a finely graduated rule was used.

When an angle of 30° and the constant distance were used, a great decrease in gain was noted. Maximum gain for this particular angle was only 1.02 greater than the Yagi as can be seen in Fig. 16. No logical situation would ever require this set-up.

The other three angles, 180°, 150°, and 120°, produced a fair amount of gain over the Yagi, though nothing spectacular was noted. In Fig. 17 a better comparison may be made between angles and distances of the corner reflector.

Since only a maximum increase of 1.38 in gain over the seven-element Yagi was procured from the above tests, a three-element Yagi of different dimensions was constructed. When this antenna was used with the 90° corner reflector (this reflector angle was chosen because it produced greatest gain previously) gain increased by a factor of 2.61. Beam width of this antenna can be seen to be 54° in Fig. 18(a). This result is far superior to that formerly obtained.

A flat surface (1" X 2") was oriented above the three-element Yagi for a maximum gain increase of 1.59. Although gain and field directivity were highly satisfactory, this small surface did not eliminate the back lobe of the Yagi. A comparison of Fig. 18(b) and Fig. 5(a) shows that the back lobes are only slightly affected. This experimental gain (2.61) compares very favorably with the calculated gain (2.35), a difference of 11% being small when all possibilities for errors are considered.

The large flat reflector produced good gains, but not comparable to the three-element Yagi and the corner reflector. Difficulties may be encountered in the mounting of such a reflector, therefore data was not recorded because it would be impractical to use. The grid reflector, Fig. 9(d) also produced good gains, but usually slightly less than the solid surface reflector. A grid reflector could be used to greatly reduce wind resistance and still maintain a desired signal gain.

Most of the back lobes could have been eliminated by increasing the width of the reflector. This would undoubtedly introduce secondary lobes in the forward radiation pattern, which if not extremely large would not be too objectionable. The permissable increase of width will necessarily be determined by the situation at hand.

SUMMARY AND CONCLUSIONS

Greatest increase in gain over the original test antennas was obtained from the three-element Yagi with the corner reflector. Although this did not produce the greatest gain over the dipole, the implication received is that if adjustments are made on a multi-element Yagi, a very great gain would be acquired. Naturally it is much easier to adjust a few elements than several so the "law of diminishing returns" prevails. The experimentor must therefore make a compromise between gain desired, and time and work involved. Whether or not the time consuming process of the cut and try method would be justified depends on the particular situation for which the antenna is to be used. Undoubtedly the question arrises about the wind resistance of a solid flat surface. This may be aleviated by utilizing a grid type corner reflector which will approximate the same results as a solid reflector if the elements are placed fairly close in terms of wavelengths.

Conclusions deduced from this work may be summed up as follows:

1. A corner reflector may be used to increase the gain of a Yagi, however to achieve maximum gain, a commercially designed Yagi must be readjusted.
2. Whether or not the addition of a reflector is justified must be determined by the influencing factors of each separate situation.
3. A flat sheet will give fairly good gains without

readjustments being necessary, and to reduce wind resistance, a grid type surface may be used.

4. Mathematics involved in solving a Yagi array problem becomes too complicated to be profitable when a corner reflector is used. Trial and error method excels.

It is realized that the work contained in this thesis has made only a slight indentation on the problem of reflector modifications of the Yagi antenna. However it is hoped that it will enlighten those who may be inquisitive about this subject and wish to do further experimentation.

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APPENDIX

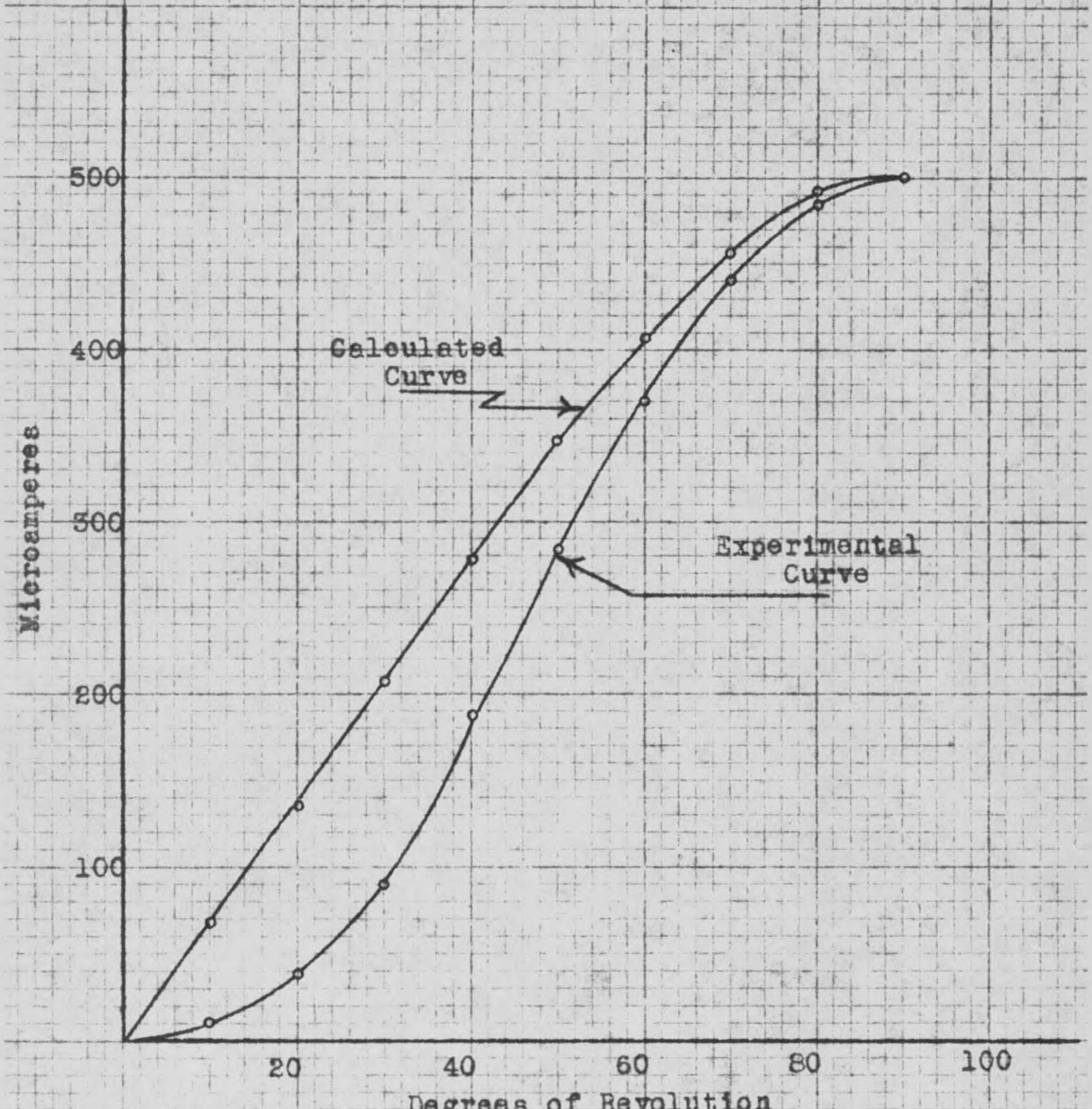

FIG. 19

Calibration Chart

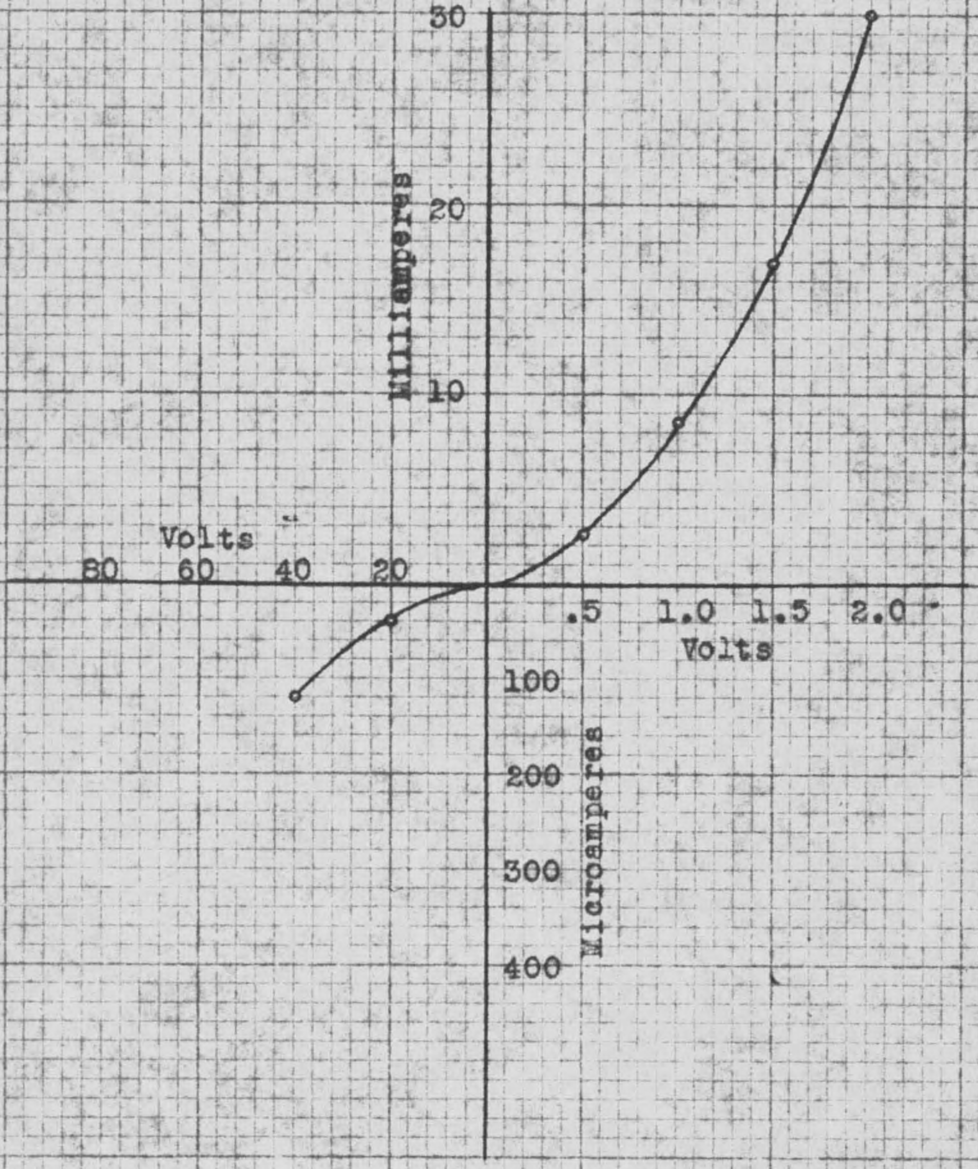

FIG. 20

Germanium Diode
Characteristic Curve