AD

7577-1-Q

TECHNICAL REPORT ECOM-01499-1

Azimuth and Elevation Direction Finder Study

Quarterly Report

By

D. L. SENGUPTA, J. E. FERRIS, R. W. LARSON
and T. M. SMITH

December 1965

7577-1-Q = RL-2159

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND FORT MONMOUTH , N.J.

CONTRACT DA 28-043-AMC-01499(E)
THE UNIVERSITY OF MICHIGAN
DEPARTMENT OF ELECTRICAL ENGINEERING
RADIATION LABORATORY
ANN ARBOR, MICHIGAN

Each transmittal of this document outside the Department of Defense must have prior approval of USAECOM, AMSEL-WL-S, Ft. Monmouth, N. J.

Technical Report ECOM-01499-1 December 1965

Azimuth and Elevation Direction Finder Study

First Quarterly Report
1 September through 30 November 1965

Report No. 1

Contract DA 28-043-AMC-01499(E)
DA Project 5A6 79191 D902 01 04

Prepared by

D. L. Sengupta, J. E. Ferris, R. W. Larson and T. M. Smith

The University of Michigan Radiation Laboratory
Department of Electrical Engineering
Ann Arbor, Michigan

For

United States Army Electronics Command, Fort Monmouth, N. J.

EACH TRANSMITTAL OF THIS DOCUMENT OUTSIDE THE DEPARTMENT OF DEFENSE MUST HAVE PRIOR APPROVAL OF USAECOM, AMSEL-WL, FT. MONMOUTH, N. J.

ABSTRACT

The results of theoretical analysis of the radiation patterns produced by a spherical antenna array are reported. Each antenna element is assumed to produce elliptically polarized radiation having a maximum along its axial direction. The case of circularly polarized antenna elements is considered in particular. The results reported herein are kept general so that they can be used when different parameters of the array are varied.

From the symmetry considerations of an icosahedron inscribed within a sphere, a special type of element distribution on the spherical surface is developed. This particular distribution is then used to compute numerically the pattern produced by a number of point sources placed on the spherical surface.

Results of experimental studies of the log conical spiral antennas are reported.

FOREWORD

This report was prepared by The University of Michigan Radiation Laboratory of the Department of Electrical Engineering under United States Army Electronics Command Contract No. DA 28-043-AMC-01499(E). This contract was initiated under United States Army Project No. 5A6 79191 D902 01 04 "Azimuth and Elevation Direction Finder Study". The work is administered under the direction of the Electronics Warfare Division, Advanced Techniques Branch at Fort Monmouth, New Jersey. Mr. S. Stiber is the Project Manager and Mr. E. Ivone is the Contract Monitor.

The material reported herein represents the results of the prelimination investigation into the study of the feasibility of designing a broadband circularly polarized direction finder antenna with hemispherical coverage.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I INTRODUCTION

This is the first report on a study to determine the possibility of developing a broadband VHF azimuth and elevation direction finder. The system is to employ an antenna array having circular polarization and hemispherical coverage. The desired frequency range is from .3 to 3 GHz. The investigation during this report period is divided into three broad parts: (1) theoretical analysis of the radiation patterns produced by a spherical antenna array, (2) choice of the element distribution and numerical computation procedure, and (3) experimental investigation of the properties of a possible antenna element.

The physical symmetry of a spherical surface suggests the possibility of using an antenna array where the individual elements are placed on the surface of a sphere. Theoretical analysis of the radiation pattern produced by such a spherical array is discussed in Section II. At the present time very little information is available on the radiation properties of a spherical antenna array. Harris and Shanks (1962) discussed a method of synthesizing optimum directional patterns from non-planar apertures. However, they dealt with only continuously illuminated apertures. Du and Tai (1964) reported the radiation patterns for four symmetrically located sources (dipoles or small apertures) on a perfectly conducting sphere. Our interest is to investigate the radiation patterns produced by a spherical array which consists of elliptically polarized (circularly polarized in particular) broadband antenna elements.

The findings of the study reported in Section II should provide information regarding the advantages and disadvantages of using a spherical structure for directional reception and/or transmission. The discussion of Section II is for an arbitrary distribution of antenna elements. The choice of a specific type of element distribution on a spherical surface is discussed in Section III. The choice of a definite type of element distribution should enable us to use the expressions developed in Section II for pattern calculations. The results of a preliminary numerical computation are also given in this section. Section IV gives the results of an experimental study of the characteristics of the antenna elements. Conical helix antennas are being studied for this purpose. The reasons for studying this particular type of antenna are that they are broadband and produce radiation patterns with circular or nearly circular polarization.

II SPHERICAL ARRAY ANALYSIS

This section reports the results of a preliminary theoretical analysis of the radiation patterns produced by a spherical antenna array. The results reported herein are kept general so that they may be used when different parameters of the array are varied.

2.1 Model of the Array

A pictorial representation of the antenna array is shown in Fig. 1a . The antenna elements are placed radially along the surface of a sphere of radius a . The distribution of the elements is kept arbitrary and the spherical surface is oriented with the z-axis of a rectangular coordinate system (x, y, z) as the polar axis. Each element is assumed to produce an elliptically polarized radiation having a maximum along its own axial direction. The antenna alements are phased such that the pattern produced by the array has a maximum along the direction $\theta=\theta_0$ and $\phi = \phi_0$. The feed system and the necessary phasing of the elements are not considered in the present discussion.

The position of a typical element at P' on the spherical surface is represented by the coordinates a, α_n and β_m as shown in Fig. 1b . The coordinates of a far field point P are R_0, θ and ϕ . The parameters α_n and β_m determine the distribution of the elements.

The expression for the radiation pattern produced by the array is obtained after combining the fields produced by the individual antenna elements at the far field point P. Before we can do this the polarization of the field produced by each element should be considered and expressed in such a form that all the fields may be superposed at the point P. This is done in the next section.

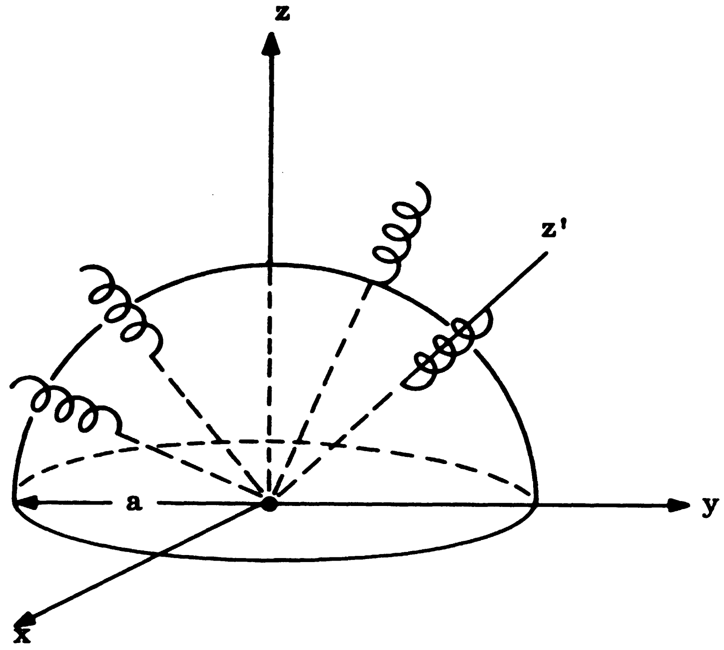

FIG. 1a: PICTORIAL REPRESENTATION OF SPHERICAL ANTENNA ARRAY

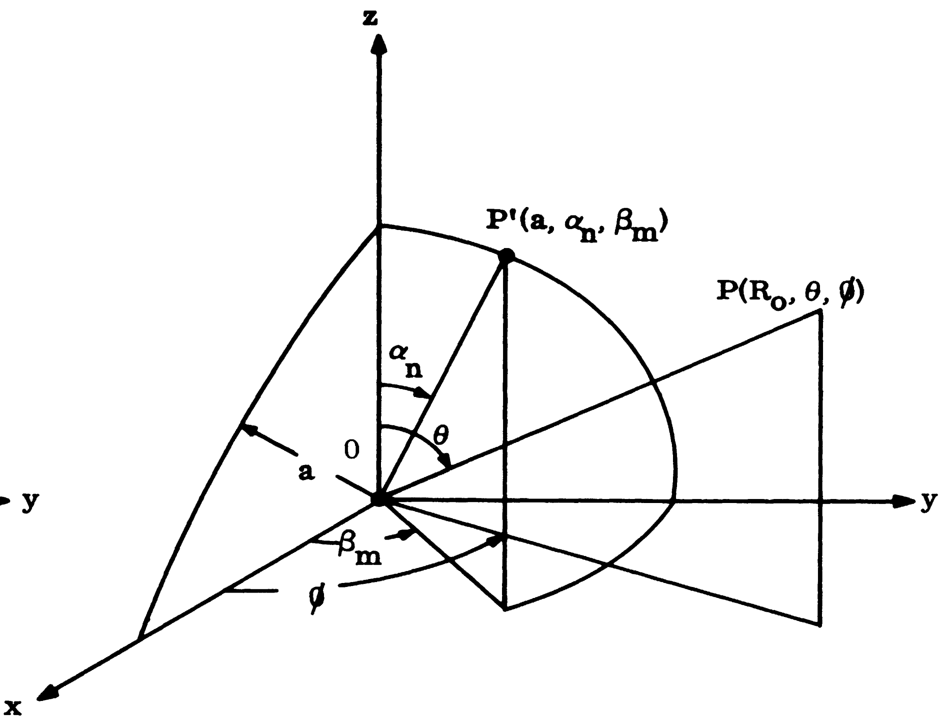

FIG. 1b: COORDINATES OF SOURCE AND FAR FIELD POINTS

2.2 Element Pattern Considerations

The field produced by a typical element at P' is at first expressed in a local coordinate system with origin at P' and the axis z' of the antenna element as the polar axis as shown in Fig. 2. The other two axes x', y' in this system are chosen such that x', y' and z' form an orthogonal system of Cartesian coordinates. The coordinates of the far field point P in the local system are R', θ' and ϕ'.

Assume that the far field of a single element is expressed as the field produced by a point source placed at P'. Since we are dealing with a single element now we shall represent the coordinates of P' as α, β instead of α_n, β_m. Thus the total electric field produced by a single element at the field point P can be written as follows:

$$\vec{E}_{\alpha\beta} = \hat{e}_{\theta'} E_{\theta'_{\alpha\beta}} + \hat{e}_{\phi'} E_{\phi'_{\alpha\beta}} = \left[\hat{e}_{\theta'} f_1(\theta',\phi') \frac{e^{i(\omega t - kR' - \psi_{\alpha\beta})}}{R'} \right.$$

$$\left. + \hat{e}_{\theta'} f_1(\theta',\phi') \frac{e^{i(\omega t - kR' - \delta - \psi_{\alpha\beta})}}{R'} \right] , \qquad (1)$$

where

$\hat{e}_{\theta'}$, $\hat{e}_{\phi'}$ are the unit vectors in the θ' and ϕ' directions,

$k = 2\pi/\lambda$ = propagation constant in the medium,

δ is the phase difference between the two components of the field

ω is the radian frequency of operation,

$\psi_{\alpha\beta}$ is the phase delay introduced into the element for beam steering purpose,

$f_1(\theta', \phi')$, $f_2(\theta', \phi')$ are the pattern factors of the two components of the element field.

In the above we have assumed that each antenna element does not produce any radial component of field. The field given by (1) is elliptically polarized. For circularly polarized field $f_1(\theta', \phi') = f_2(\theta', \phi')$ and $\delta = \pm \pi/2$.

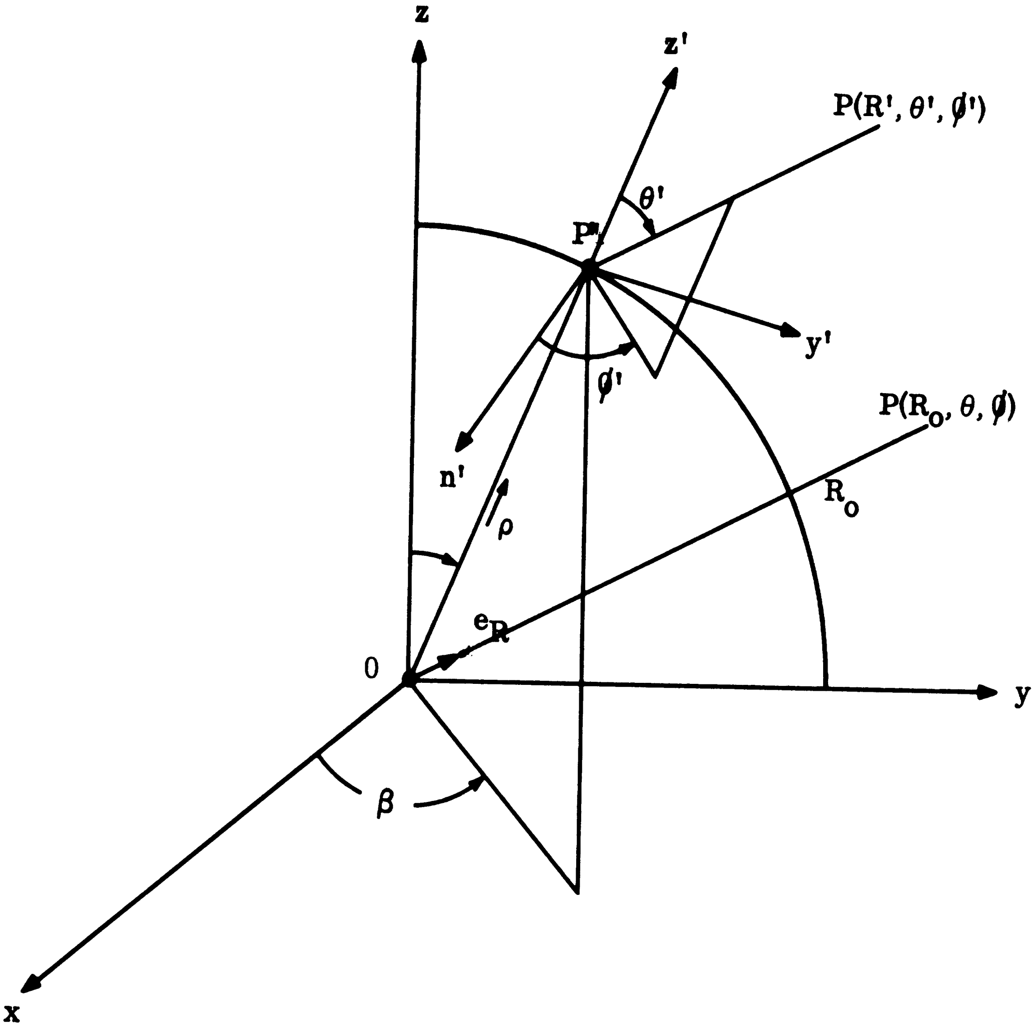

FIG. 2: LOCAL COORDINATE SYSTEM USED

After shifting the origin P' of the local coordinate system to the point O, eq. (1) can be written as

$$\bar{E}_{\alpha\beta} = \left[\hat{e}_{\theta'} f_1(\theta',\phi') + \hat{e}_{\phi'} f_2(\theta',\phi') e^{-i\delta}\right] e^{i(k\vec{\rho}\cdot\hat{e}_R - \psi_{\alpha\beta})} \cdot \frac{e^{i(\omega t - kR_o)}}{R_o} , \qquad (2)$$

where $\vec{\rho}$ is the vector OP' and $\hat{e}_R$ is the unit vector in the direction of the far field point expressed in the unprimed coordinate system. In obtaining (2) from (1) we have made the usual far field approximation. Note that the quantity $(\vec{\rho}\cdot\hat{e}_R)$ in (2) is given by

$$\frac{\vec{\rho}\cdot\hat{e}_R}{a} = \sin\alpha\sin\theta\cos(\phi-\beta) + \cos\alpha\cos\theta . \qquad (3)$$

We now wish to express (2) in terms of the coordinates θ and ϕ. For this we need the transformation relations given in the next section.

2.3 Coordinate Transformation Relations

The transformation relations for going from the primed to unprimed coordinates can be obtained by using the general method of orthogonal transformation of coordinates (Stratton, 1941). In general, θ', ϕ' can be expressed as

$$\left.\begin{aligned} \cos\theta' &= (\hat{e}_R\cdot\hat{e}_{z'}) \\ \cot\phi' &= \frac{(\hat{e}_R\cdot\hat{e}_{x'})}{(\hat{e}_R\cdot\hat{e}_{y'})} \end{aligned}\right\} , \qquad (4)$$

where $\hat{e}_{x'}$, $\hat{e}_{y'}$, $\hat{e}_{z'}$ are the unit vectors in the x', y' and z' directions, and

$$\hat{e}_R = \hat{e}_x \sin\theta\cos\phi + \hat{e}_y \sin\theta\sin\phi + \hat{e}_z\cos\theta , \qquad (5)$$

$\hat{e}_x$, $\hat{e}_y$ and $\hat{e}_z$ are the unit vectors in the x, y, z directions respectively. The unit vectors $\hat{e}_{x'}$, $\hat{e}_{y'}$, $\hat{e}_{z'}$ and $\hat{e}_x$, $\hat{e}_y$, $\hat{e}_z$ are related to each other by the following matrix equation:

$$\begin{bmatrix} \hat{e}_{x'} \\ \hat{e}_{y'} \\ \hat{e}_{z'} \end{bmatrix} = \tilde{A} \begin{bmatrix} \hat{e}_{x} \\ \hat{e}_{y} \\ \hat{e}_{z} \end{bmatrix} \tag{6}$$

where $\tilde{A}$ is a rotation matrix and is given by

$$\tilde{A} = \begin{bmatrix} \cos\alpha\cos\beta & \cos\alpha\sin\beta & -\sin\alpha \\ -\sin\beta & \cos\beta & 0 \\ \sin\alpha\cos\beta & \sin\alpha\sin\beta & \cos\alpha \end{bmatrix} . \tag{7}$$

After using equations (4) - (7) the following two relations are obtained,

$$\cos\theta' = \sin\alpha\sin\theta\cos(\phi-\beta)+\cos\alpha\cos\theta, \tag{8}$$

$$\cot\phi' = \frac{\cos\alpha\sin\theta\cos(\phi-\beta)-\sin\alpha\cos\theta}{\sin\theta\sin(\phi-\beta)} . \tag{9}$$

The transformations of the unit vectors $\hat{e}_{\theta'}$ and $\hat{e}_{\phi'}$ can be obtained now after equating the respective gradients of $\cos\theta'$ and $\cot\phi'$ in the two systems. It can be shown that they are given by

$$\hat{e}_{\theta'} = -\hat{e}_{\theta}\frac{\cos\theta\sin\alpha\cos(\phi-\beta)-\sin\theta\cos\alpha}{\sin\theta'} + \hat{e}_{\phi}\frac{\sin\alpha\sin(\phi-\beta)}{\sin\theta'} , \tag{10}$$

$$\hat{e}_{\phi'} = -\hat{e}_{\theta}\frac{\sin\alpha\sin(\phi-\beta)}{\sin\theta'} - \hat{e}_{\phi}\frac{\cos\theta\sin\alpha\cos(\phi-\beta)-\sin\theta\cos\alpha}{\sin\theta'} . \tag{11}$$

2.4 Field Components Produced by Each Element

We can now write the θ and ϕ components of the field produced at the point P by an element placed at the source point P' (a, α, β). Using (10) and (11) we can write the component fields as

$$E_{\theta_{\alpha\beta}} = -\left[\frac{\cos\theta\sin\alpha\cos(\phi-\beta)-\sin\theta\cos\alpha}{\sin\theta'}\,f_1(\theta',\phi')+\frac{\sin\alpha\sin(\phi-\beta)}{\sin\theta'}\,f_2(\theta',\phi')e^{-i\delta}\right]$$

$$\times\, e^{i(ka\cos\theta'-\psi_{\alpha\beta})}\ , \qquad (12)$$

$$E_{\phi_{\alpha\beta}} = \left[\frac{\sin\alpha\sin(\phi-\beta)}{\sin\theta'}\,f_1(\theta',\phi')-\frac{\cos\theta\sin\alpha\cos(\phi-\beta)-\sin\theta\cos\alpha}{\sin\theta'}\,f_2(\theta',\phi')e^{-i\delta}\right]$$

$$\times\, e^{i(ka\cos\theta'-\psi_{\alpha\beta})}\ . \qquad (13)$$

In (12) and (13) we have omitted the common factor $e^{i(\omega t-kR_0)}/R_0$. Equations (12) and (13) are very general. Let us now assume that the fields produced by the individual elements are circularly polarized so that we have $f_1(\theta',\phi')=f_2(\theta',\phi')=f(\theta',\phi')$ and $\delta=\pi/2$. Thus we can rewrite (12) and (13) as

$$E_{\theta_{\alpha\beta}} = -\left[\frac{\cos\theta\sin\alpha\cos(\phi-\beta)-\sin\theta\cos\alpha}{\sin\theta'}+\frac{\sin\alpha\sin(\phi-\beta)}{\sin\theta'}\,e^{-i\frac{\pi}{2}}\right]$$

$$\times\, f(\theta',\phi')e^{i(ka\cos\theta'-\psi_{\alpha\beta})}\ , \qquad (14)$$

$$E_{\phi_{\alpha\beta}} = \left[\frac{\sin\alpha\sin(\phi-\beta)}{\sin\theta'}-\frac{\cos\theta\sin\alpha\cos(\phi-\beta)-\sin\theta\cos\alpha}{\sin\theta'}\,e^{-i\frac{\pi}{2}}\right]$$

$$\times\, f(\theta',\phi')e^{i(ka\cos\theta'-\psi_{\alpha\beta})}\ . \qquad (15)$$

2.5 Radiation Pattern of the Spherical Array

The radiation pattern produced by the spherical array can now be obtained by superposing the similar component fields produced by the antenna elements. It is assumed that all the elements are excited uniformly in amplitude. At this stage we introduce the subscripts n and m to represent the position of an element, i.e. α_n and β_m instead of α, β used in the previous section. Thus the complete pattern expressions for the θ- and ϕ-components of the field produced by the array are given as

$$E_\theta(\theta,\phi)=\sum_{m,n}-\left[\frac{\cos\theta\sin\alpha_n\cos(\phi-\beta_m)-\sin\theta\cos\alpha_n}{\sin\theta'}+\frac{\sin\alpha_n\sin(\phi-\beta_m)}{\sin\theta'}e^{-i\frac{\pi}{2}}\right]$$

$$\times f(\theta',\phi')e^{i(ka\cos\theta'-\psi_{nm})}\ , \tag{16}$$

$$E_\phi(\theta,\phi)=\sum_{m,n}\left[\frac{\sin\alpha_n\sin(\phi-\beta_m)}{\sin\theta'}-\frac{\cos\theta\sin\alpha_n\cos(\phi-\beta_m)-\sin\theta\cos\alpha_n}{\sin\theta'}e^{-i\frac{\pi}{2}}\right]$$

$$\times\ f(\theta',\phi')e^{i(ka\cos\theta'-\psi_{nm})}\ , \tag{17}$$

where

$$\cos\theta'=\sin\alpha_n\sin\theta\cos(\phi-\beta_m)+\cos\alpha_n\cos\theta\ , \tag{18}$$

$$\sin\theta'=(1-\cos^2\theta')^{1/2}\ , \tag{19}$$

$\psi_{nm}=\psi_{\alpha_n\beta_m}$ = phase delay introduced into the element at the point a, α_n, β_m.

2.6 Some Special Cases

The patterns given by (16) and (17) are very general. In this section we discuss the following two special cases.

(a) Let us consider a spherical array in which all the antenna elements are oriented parallel to the z-axis. Thus the superposition of the fields can be done directly by using eq. (2). For circularly polarized antenna elements the radiation pattern can be shown to be given by

$$\vec{E}=\left[\hat{e}_\theta+\hat{e}_\phi e^{-i\frac{\pi}{2}}\right]f(\theta,\phi)\sum_{m,n}e^{i\left[ka\left\{\sin\alpha_n\sin\theta\cos(\phi-\beta_m)+\cos\alpha_n\cos\theta\right\}-\psi_{nm}\right]}\ . \tag{20}$$

In this case the principle of pattern multiplication can be applied directly and the last factor in eq. (20) may be looked upon as the space factor of the spherical array.

(b) Let the array consist of linearly polarized antenna elements, for example radially directed dipole elements. In this case we have $f_2(\theta', \phi')=0$ in eq. (2) and $f_1(\theta', \phi')=f_1(\theta')$ say. Under these conditions the terms involving $e^{-i\pi/2}$ in (16) and (17) will drop out and the following expressions are obtained for the field patterns:

$$E_\theta(\theta,\phi)=\sum_{m,n} -\frac{\cos\theta\sin\alpha_n\cos(\phi-\beta_m)-\sin\theta\cos\alpha_n}{\sin\theta'} f_1(\theta')e^{i(ka\cos\theta'-\psi_{nm})} , \tag{21}$$

$$E_\phi(\theta,\phi)=\sum_{m,n} \frac{\sin\alpha_n\sin(\phi-\beta_m)}{\sin\theta'} f_1(\theta')e^{i(ka\cos\theta'-\psi_{nm})} . \tag{22}$$

III ELEMENT DISTRIBUTION AND NUMERICAL COMPUTATION

In this section we outline the considerations leading to the choice of a specific type of element distribution and also give some results of preliminary numerical pattern calculation.

3.1 Element Distribution

The choice of the antenna element distribution on the spherical surface is governed by the criterion that in order to maintain a constant pattern during scanning the element distribution should appear practically the same from any far field observation point. A study of polyhedrons has led us to a better understanding of the problem. In particular we found the icosahedron to be advantageous for our requirements. The icosahedron is a three dimensional figure which has twenty faces, each face being an isosceles triangle . The antenna elements are placed at equidistant positions on the surface of the icosahedron. A sphere is circumscribed around the icosahedron and all the elements are brought to the surface of the sphere. By transferring the element positions from the icosahedron surface to the spherical surface part of the original symmetry is lost.

From a study of the icosahedron symmetry, the parameters α_n, β_{nm} (note we are using β_{nm} instead of β_m to express the dependence of β_m on the choice of n) can be approximated as:

$$\alpha_n = 90^o - n\ 15^o , \tag{23}$$

$$\beta_{nm} = \frac{72^o m}{6-|n|} , \tag{24}$$

where

n is an integer ranging from -6 to +6,

m is an integer ranging from 0 to values as high as 25 depending on n.

The 90^o shift in α_n as shown in (23) is introduced to take advantage of the symmetry which exists about the equator. In the computer program discussed later m is terminated whenever $\beta_{nm} > 360^o$. When n = 0 and n = ± 6, β_{nm} takes on the special values,

$$\beta_{0m} = \beta_{1m} \qquad \text{if } n = 0 , \tag{25}$$

$$\beta_{6m} = 0 \qquad \text{if} \left| n \right| = 6 . \tag{26}$$

Figure 3 gives the spatial distribution of elements as obtained from (23) and (24). It has 177 elements on the entire spherical surface.

It should be mentioned that the above is only one special type of element distribution. After studying other polyhedrons it may be found that a different distribution may be more useful in achieving our goals.

3.2 Pattern Representation

Let us consider the following expression,

$$A(\theta, \phi) = \sum_{m,n} e^{ika\,(\Delta_{nm} - \psi_{nm})} , \tag{27}$$

where

$$\Delta_{nm} = \sin\alpha_n \sin\theta \cos(\phi - \beta_{nm}) + \cos\alpha_n \cos\theta . \tag{28}$$

Equation (27) is the space factor of a number of point sources placed on the surface of a sphere of radius a and excited equally in amplitude. It may be looked upon as the space factor of an idealized spherical array as given in (20). In order that the pattern has a maximum along the direction $\theta = \theta_o$ and $\phi = \phi_o$ the required phase delay ψ_{nm} should be given by

$$\psi_{nm} = \sin\alpha_n \sin\theta_o \cos(\phi_o - \beta_{nm}) + \cos\alpha_n \cos\theta_o . \tag{29}$$

The pattern may be represented in many ways. In the present case we represent them in two planes. One of the planes is represented by

$$\phi = \phi o \quad , \qquad \theta = \theta_o + p\, 5^o \quad . \tag{30}$$

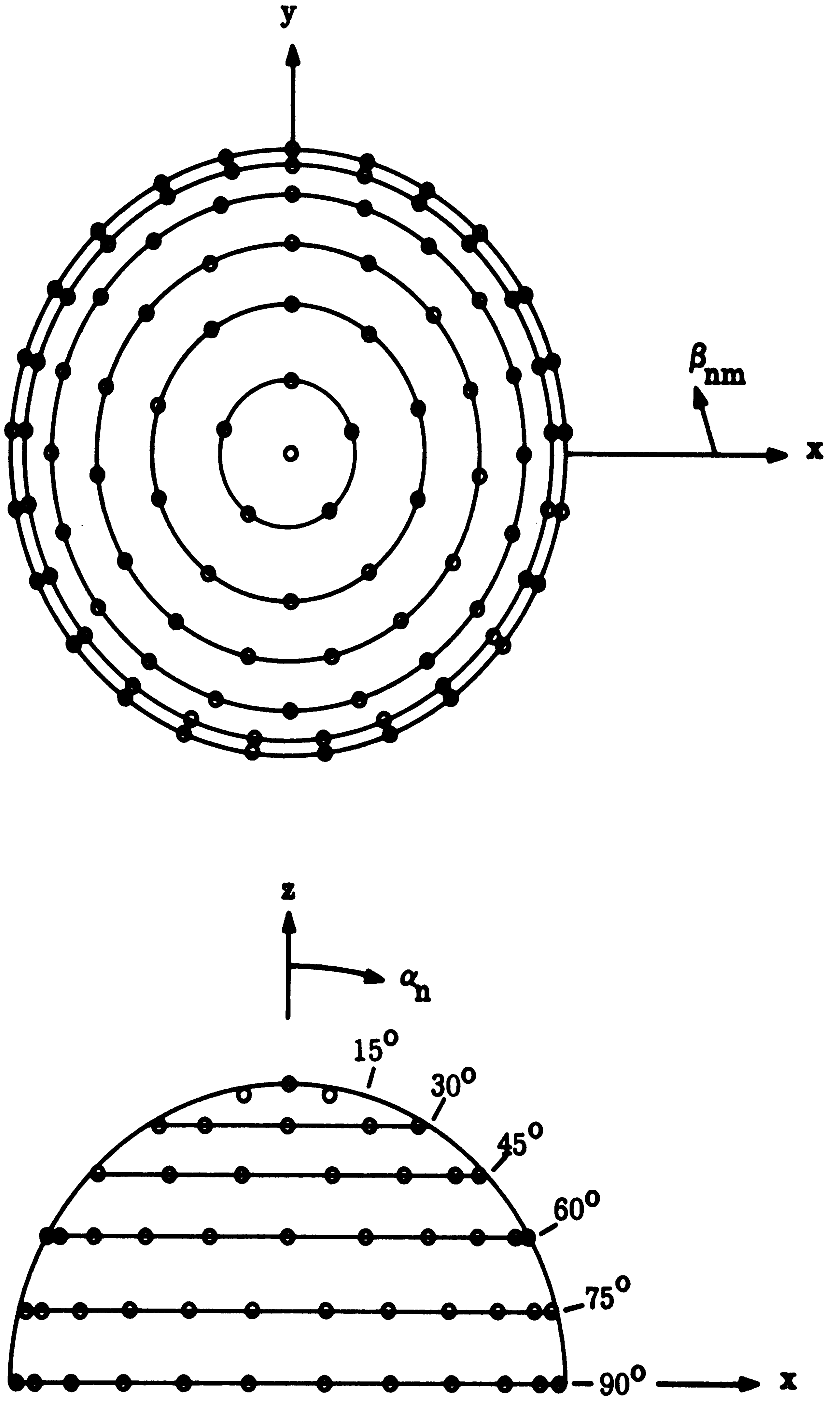

FIG. 3: ELEMENT DISTRIBUTION ON A HEMISPHERE

In this plane the pattern is represented as a function of θ at 5^o intervals.

An oblique plane which is orthogonal to the previous one, given by (30), may be represented by the following parameters.

$$\left.\begin{aligned} &\eta = p\,5^o\,,\ p = 0, 1, \dots\ 72 \\ &\theta = \cos^{-1}\left[\cos\eta\cos\theta_o\right] \\ &\phi = \phi + \sin^{-1}\left[\sin\eta/\sin\theta\right] \end{aligned}\right\} \quad . \tag{31}$$

In eq. (31) η is the angle measured around the oblique great circle from the point (θ_o, ϕ_o)

3.3 Sample Pattern Computation Procedure

For computational purposes we rewrite (27) in a slightly modified form:

$$S(\theta, \phi = \frac{A(\theta, \phi)}{A(\theta_o, \phi_o)} = \sum_{n,m} \delta_{nm}\, e^{ika(\Delta_{nm} - \psi_{nm})} \tag{32}$$

where

$$\delta_{nm} = \begin{cases} 1, & \text{if both } \psi_{nm} \geqslant 0 \text{ and } \Delta_{nm} \geqslant 0 \\ 0 & \text{otherwise} \end{cases} \quad . \tag{33}$$

The two conditions governing δ_{nm} have important physical meanings. If $-1 < \psi_{nm} < 1$ then all the elements on the sphere wouldbe active. In the present case $\psi_{nm} \geqslant 0$, i.e. only the hemispherical surface having θ_o, ϕ_o as the polar axis is active. The condition $\Delta_{n\,m} \geqslant 0$ prevents the elements from contributing to the field when they are in the shadow region with respect to the far field point P (R_o, θ, ϕ). In effect, we are assuming that the antenna elements are mounted on a totally absorbing sphere.

Under these special conditions (32) has been computed in the plane $\phi = 0^o$ for the case when $\theta_o = 0^o$, $\phi_o = 0^o$, a= 1.5λ and α_n, β_{nm} as given by (23) and (24). The total number of elements activated is 101. The power pattern is shown in Fig. 4. The detailed behavior of the pattern shown is currently under investigation. More realistic patterns will be computed by using the expressions given in Section II.

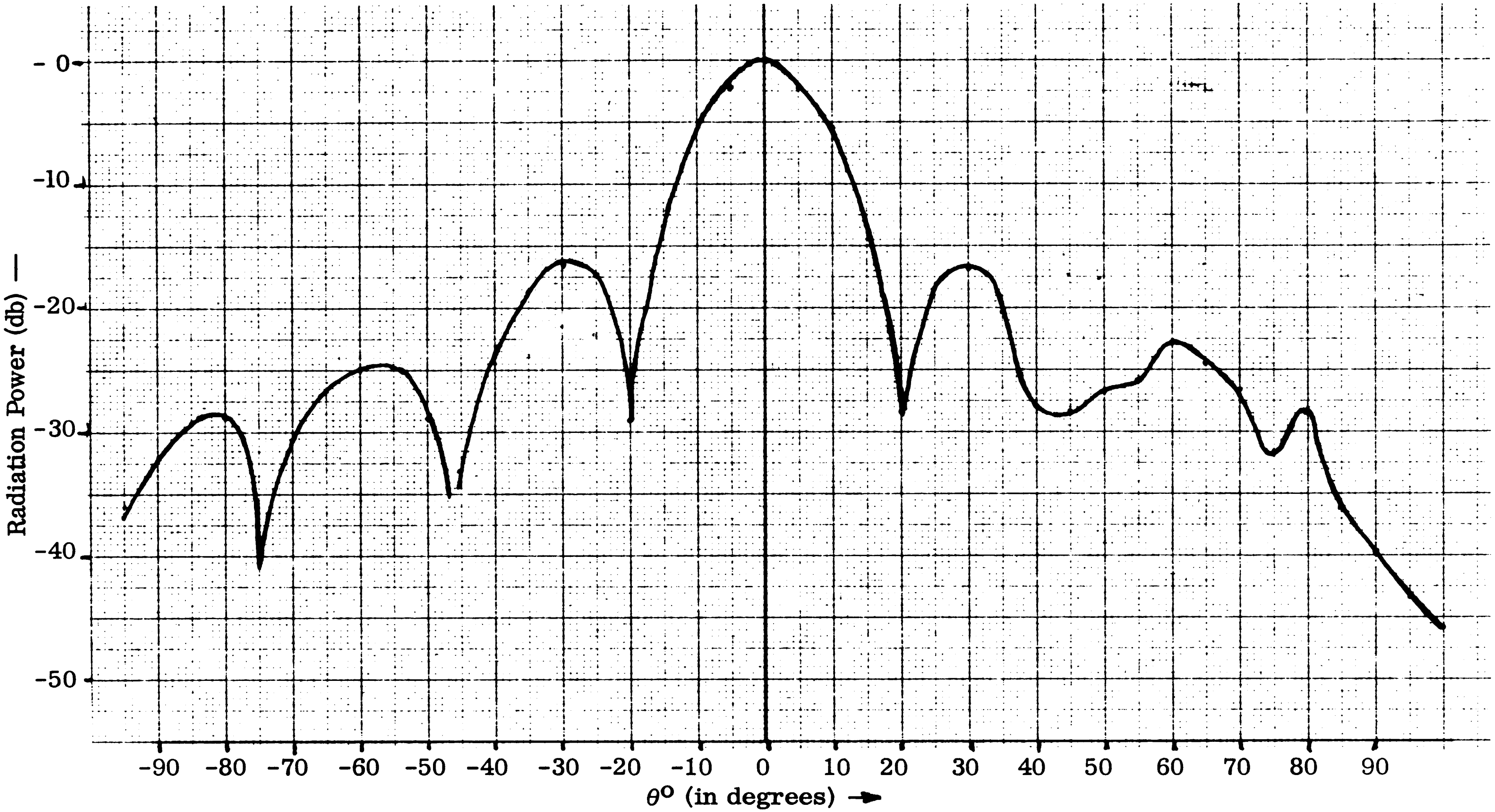

FIG. 4: PATTERN FOR POINT SOURCE DISTRIBUTION ON A HEMISPHERE
$\phi = 0$ (Polar cut), $a = 1.5\lambda$, 101 elements.

IV EXPERIMENTAL STUDY OF CONICAL HELIX ANTENNAS

As mentioned in the introduction, conical helix antennas are chosen as elements for the spherical array. For this reason an experimental investigation has been undertaken to evaluate the VSWR and radiation pattern characteristics of such an antenna. The results of the investigation on one commercially available antenna are reported below.

4.1 VSWR Characteristics

The VSWR produced by the antenna has been measured by standard techniques over the frequency range of 0.25 to 3.0 GHz. The measured VSWR data are shown in Fig. 5.

4.2 Radiation Pattern Characteristics

The radiation patterns produced by the conical helix have been measured in the frequency range of 0.3 to 3.0 GHz in 200 MHz increments. The antenna was oriented in a fixed position and both E- and H-plane patterns have been recorded. Half-power beam widths for the two planes are shown as functions of frequency in Fig. 6. It can be seen from that figure that the half-power beam widths tend to vary from 65^o to 90^o in the E-plane and from 80^o to 125^o in the H-plane. The average half-power beam width for the E-plane is 80^o and that for the H-plane is 100^o.

The absolute gain of the antenna has been measured at frequencies of 1.5 and 3.0 GHz. For the measurement the method of substitution has been followed using a half-wave dipole as the standard antenna. Figure 7 shows the E-plane pattern of the unknown antenna and Fig. 8 shows that of the half-wave dipole at 1.5 GHz. From a comparison of the two and taking into account the mismatch losses, the gain of the conical helix at 1.5 GHz has been found to be approximately equal to the 8 db value reported by the manufacturer. Figures 9 and 10 show the E-plane patterns of the antenna and the half-wave dipoles at 3.0 GHz. From a comparison of the two, gain at 3.0 GHz was also found to be in agreement with the reported value.

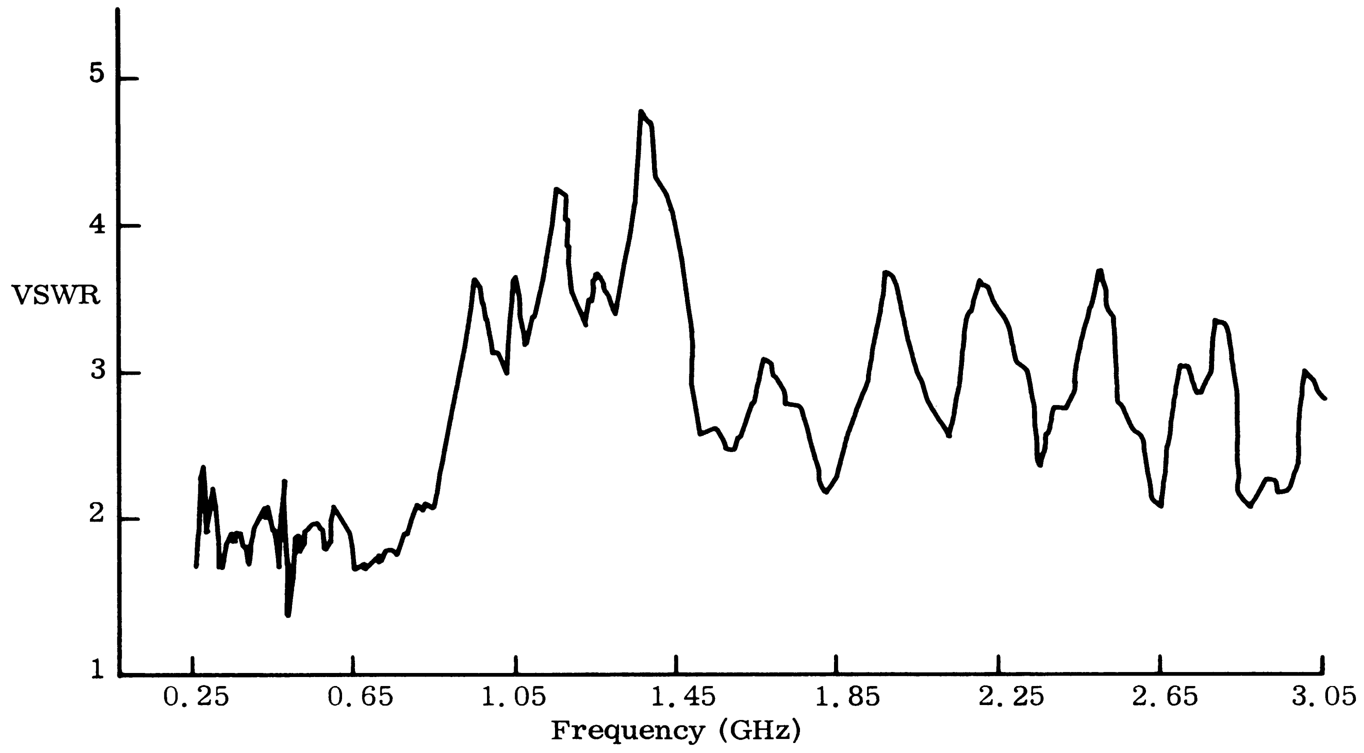

FIG. 5: CONICAL HELIX ANTENNA, VSWR VS FREQUENCY

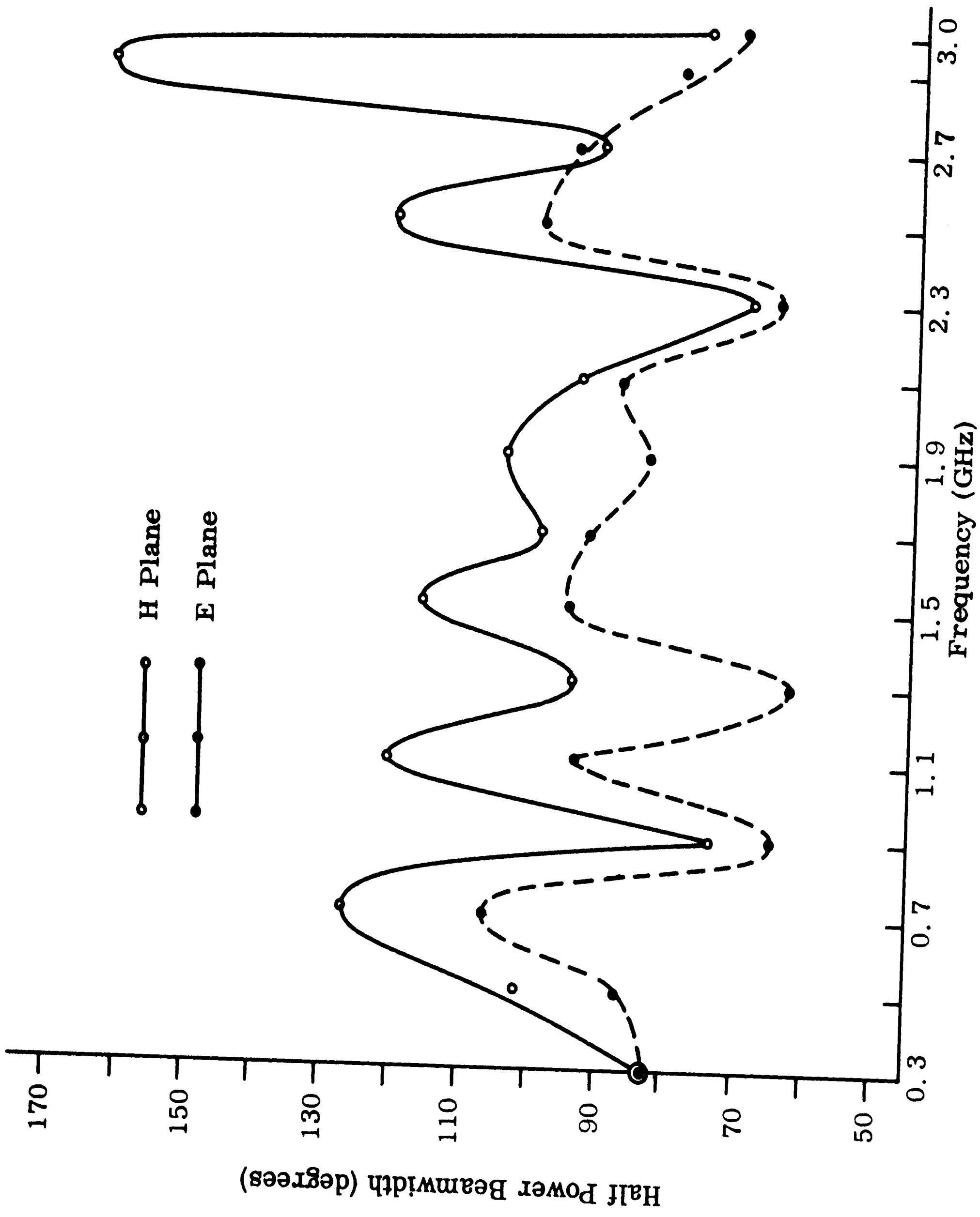

FIG. 6: CONICAL HELIX ANTENNA HALF-POWER BEAMWIDTH VS FREQUENCY

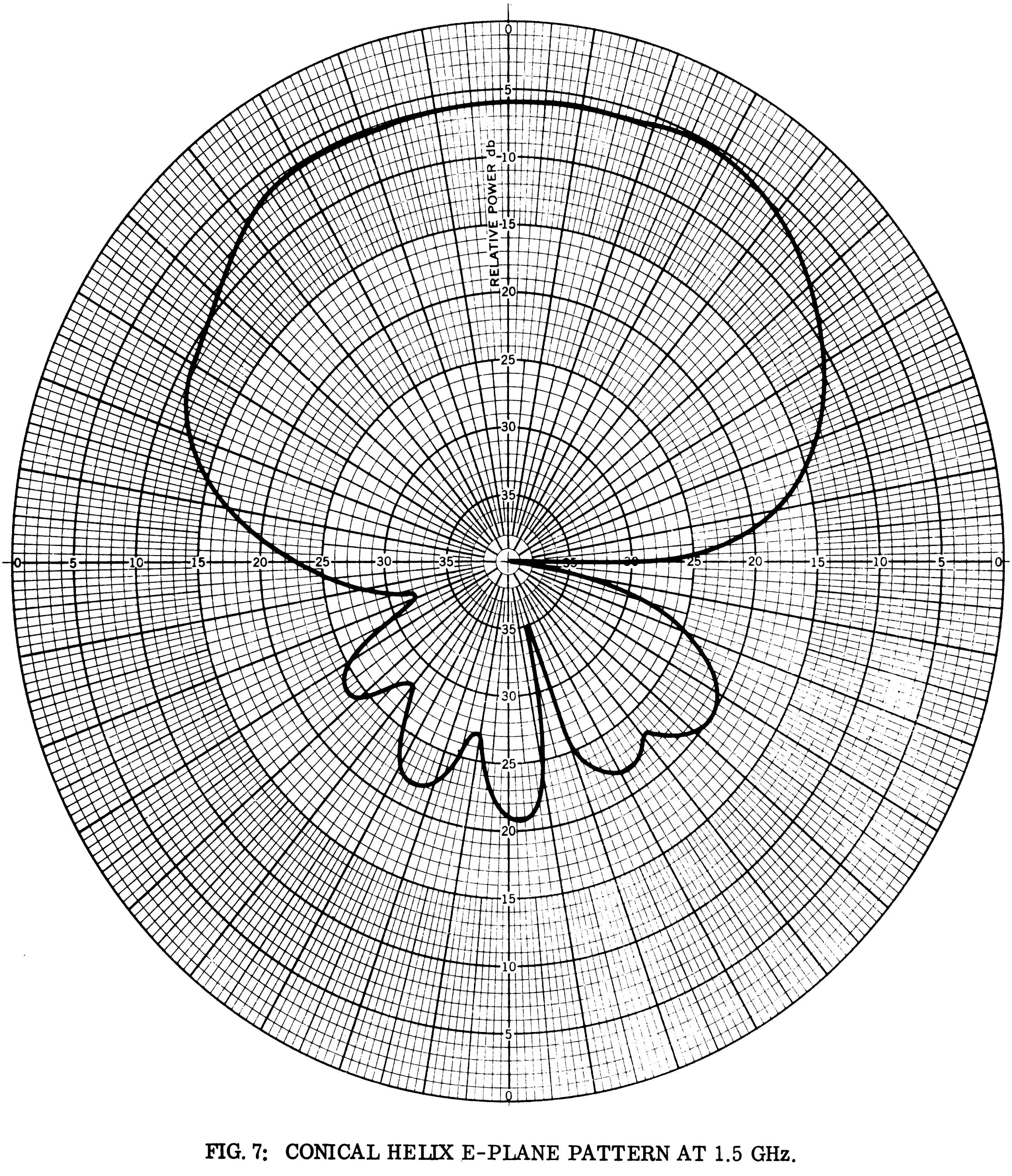

FIG. 7: CONICAL HELIX E-PLANE PATTERN AT 1.5 GHz.

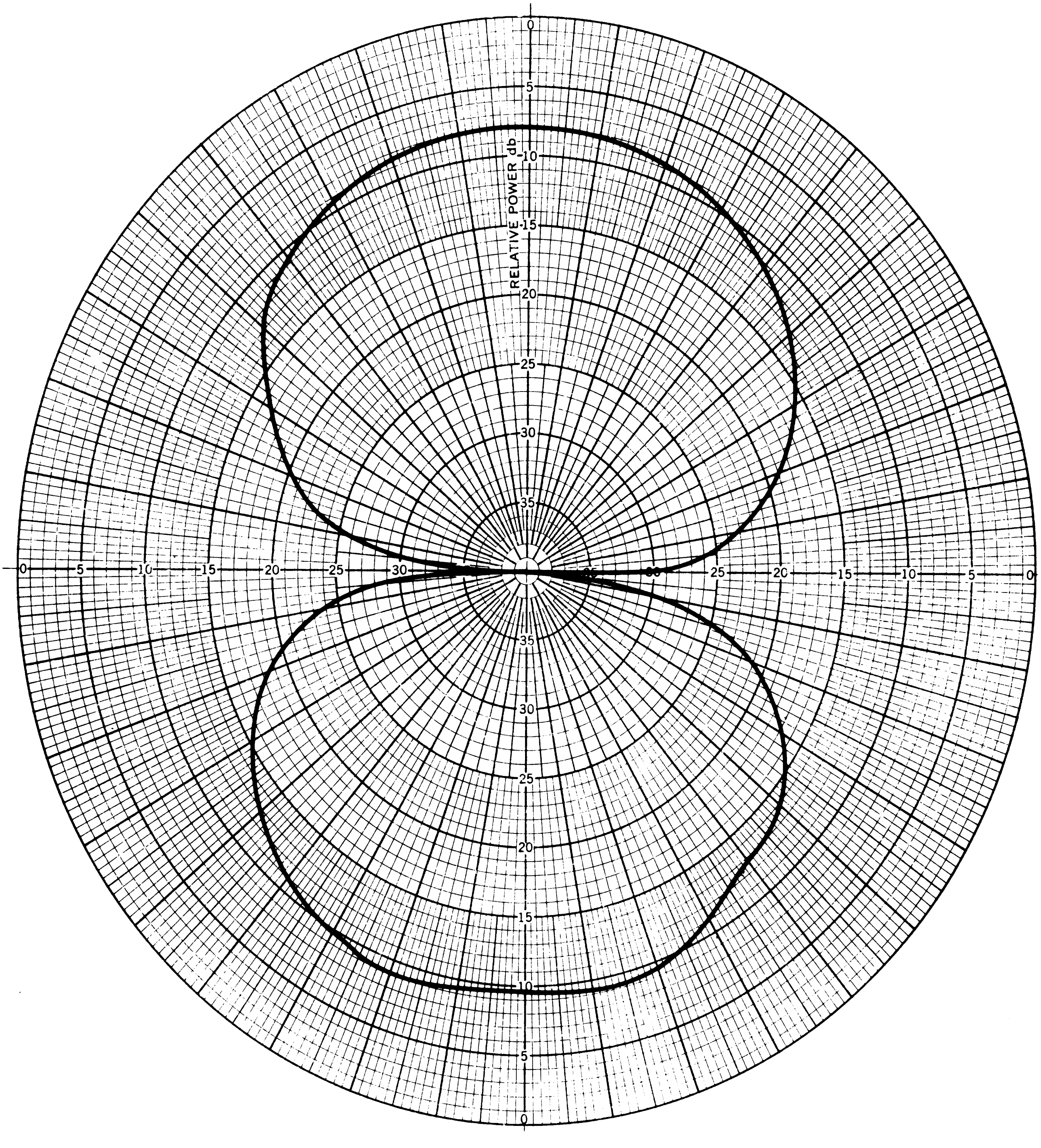

FIG. 8: HALF-WAVE DIPOLE E-PLANE PATTERN AT 1.5 GHz.

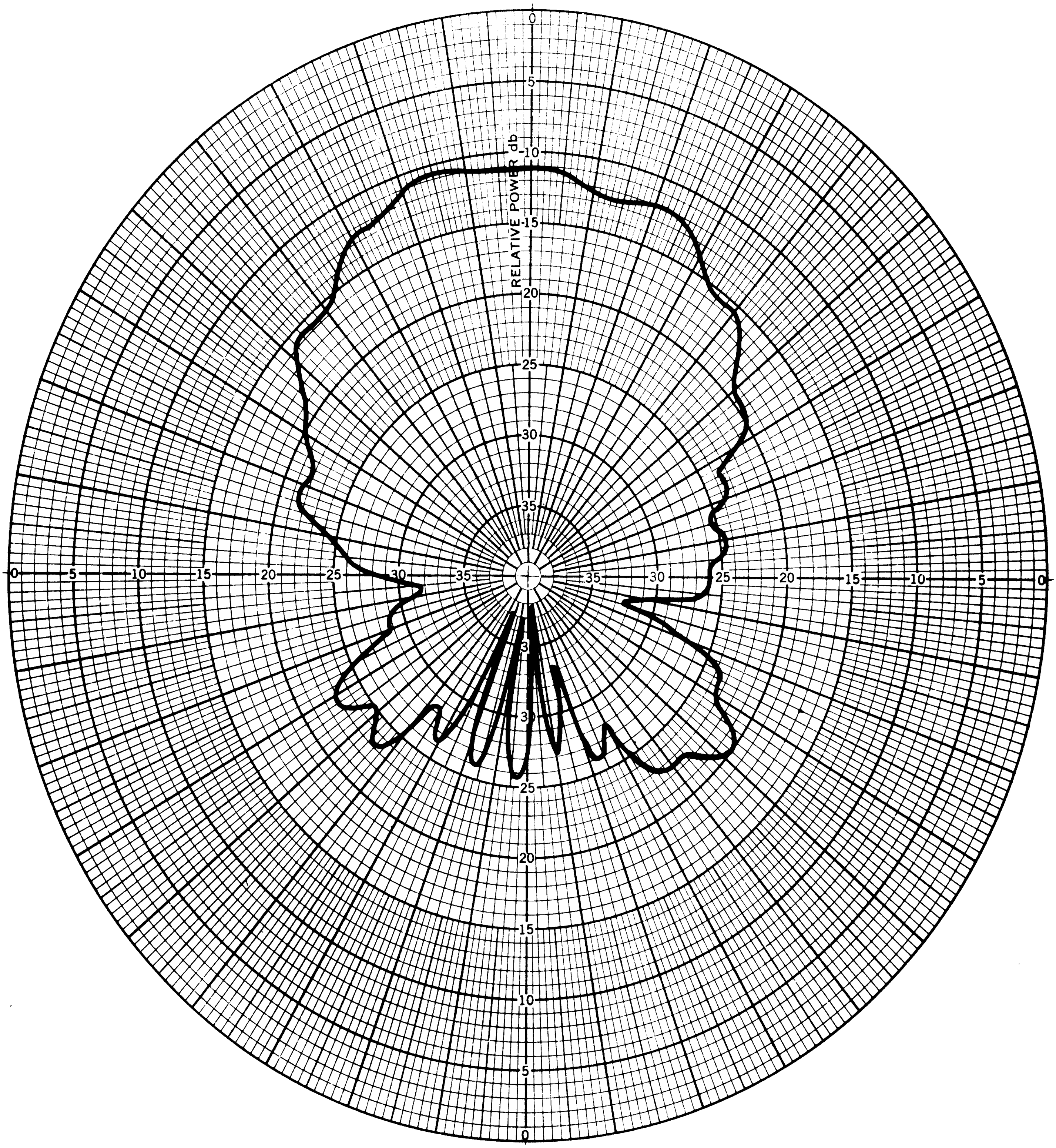

FIG. 9: CONICAL HELIX E-PLANE PATTERN AT 3 GHz.

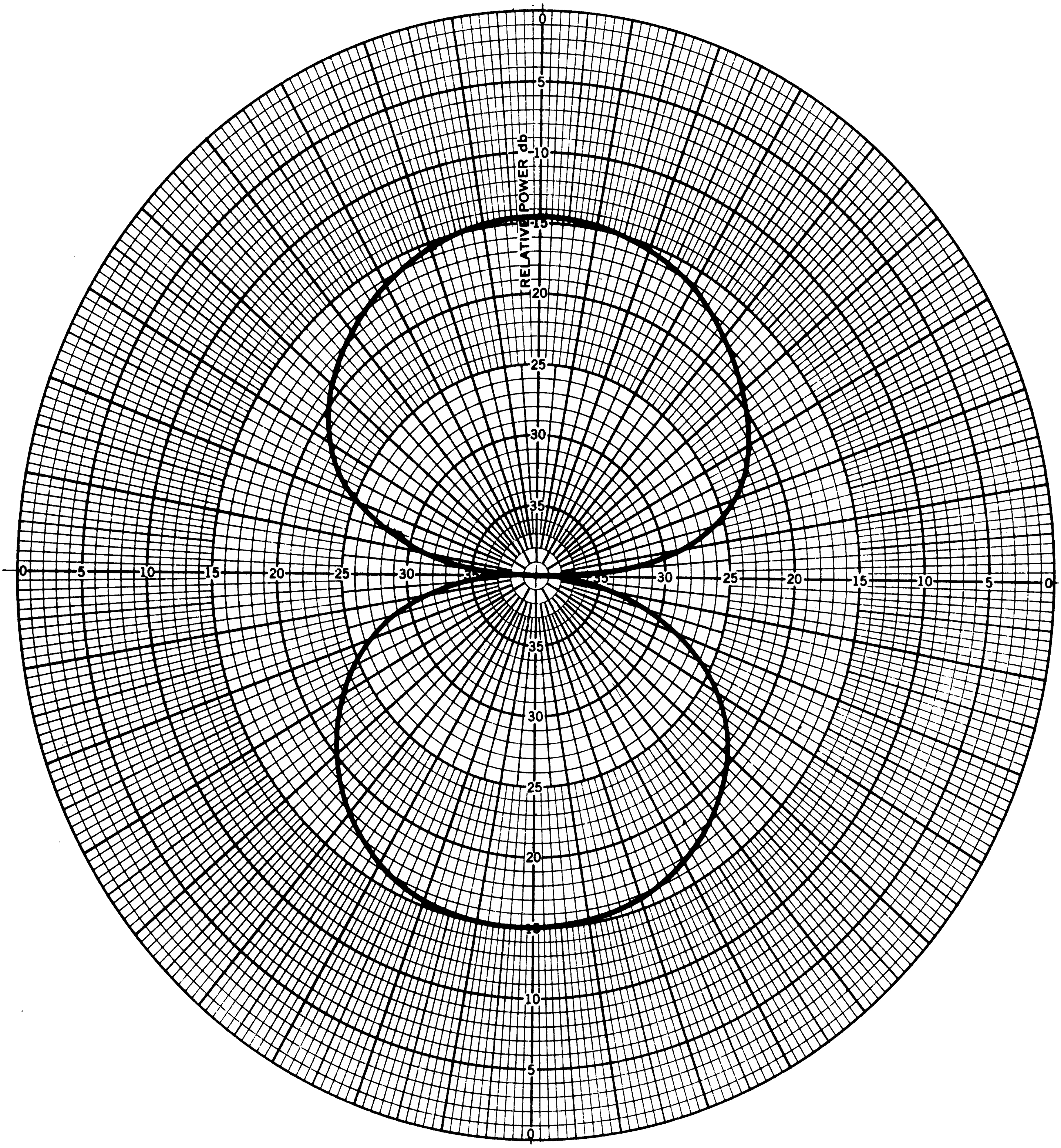

FIG. 10: HALF-WAVE DIPOLE E-PLANE PATTERN AT 3 GHz.

V REFERENCES

Du, Li-jen and C. T. Tai (15 December 1964), "Radiation Patterns of Four Symmetrically Located Sources on a Perfectly Conducting Sphere," The Ohio State University Research Foundation Report No. 1691-10.

Harris, J. H. and H. E. Shanks (May 1962), "A Method for Synthesis of Optimum Directional Patterns from Nonplanar Apertures," IRE Trans., AP-10, No. 3, pp. 228-236.

Stratton, J. A. (1941), Electromagnetic Theory, McGraw-Hill Book Company, Inc., pp. 59-64.

Copies

Commander
Aeronautical Systems Division
Wright-Patterson AFB, Ohio 45433
Attn: AVWE-3 (Mr. E.M. Turner) 1

Commander
A. F. Cambridge Research Laboratory
L.G. Hanscom Field
Bedford, Massachusetts 01731
Attn: CRD (Mr. C.J. Sletten) 1

Commander
Rome Air Development Center
Griffiss AFB, New York 13442
Attn: EMATA (Mr. C.L. Pankiewicz) 1

NASA Goddard Space Flight Center
Greenbelt, Maryland
Attn: Mr. P.A. Lantz, Code 525 1

USAEL Liaison Officer
Rome Air Development Center
Attn: RAOL
Griffiss Air Force Base, New York 13442 1

Director
National Security Agency
Fort G.G. Meade, Maryland, 20755
Attn: R31 (Mr. J.B. Norvell) 1

Naval Research Laboratory
Attn: Dr. R.J. Adams, Code 5330
Washington, D.C. 20390 1

Chief, Bureau of Ships
Department of the Navy
Main Navy Building
Washington, D.C. 20360
Attn: Mr. R. Fratila Code 362A 1

	Copies
Commanding General US Army Electronics Command Attn: AMSEL-HL-R Fort Monmouth, NJ 07703	1
Commander U.S. Navy Electronics Laboratory Attn: Mr. B.I. Small, Code 3220C San Diego, California, 92152	1
Commanding General U.S. Army Security Agency Arlington Hall Station Arlington, Virginia 22207 Attn: IALOG/ESE (Mr. C. Craig)	1
Commanding General U.S. Army Electronics Command Attn: AMSEL-NL-R Fort Monmouth, New Jersey, 07703	1
Defense Documentation Center Attn: DDC-IRE Cameron Station Building 5 Alexandria, Virginia 22314	20
Office of Assistant Secretary of Defense (R and E) Attn: Technical Library Rm 3E1065 Washington D C 20301	1
Defense Intelligence Agency Attn: DIARD Washington, D. C. 20301	1
Bureau of Ships Technical Library Attn: Code 312 Main Navy Building, Room 1528 Washington D. C. 20325	1
Director, U. S. Naval Research Laboratory Attn: Code 2027 Washington D. C. 20390	1

	Copies
Commanding Officer and Director U. S. Navy Electronics Laboratory ATTN: Library San Diego, California 92101	1
AFSC S and T Liaison Officer (RTSND) U S Naval Air Development Center Johnsville Warminster, Pennsylvania 18974	1
Systems Engineering Group SEPIR Wright-Patterson AFB, Ohio 45433	1
Electronic Systems Division AFSC Scientific and Technical Info Div (ESTI) L G Hanscom Field Bedford, Massachusetts 01731	2
Air Force Cambridge Research Laboratories ATTN: CRXL-R L. G. Hanscom Field Bedford, Massachusetts 01731	2
NASA Representative Scientific and Technical Information Facility P. O. Box 5700 Bethesda, Maryland 20014	1
Commanding General U. S. Army Electronics Command ATTN: AMSEL-WL-S Fort Monmouth, New Jersey 07703	5
U. S. Army Electronics Command EW-MET Commodity Attn: AMSEL-EW, Management Office Fort Monmouth, New Jersey 07703	1
U. S. Army Electronics Command ATTN: AMSEL-MR 225 South 18th Street Philadelphia Pennsylvania 19103	1

	Copies
U. S. Army Electronics Command Attn: AMSEL-IO-T Fort Monmouth, New Jersey 07703	1
U. S. Army Electronics Command ATTN: AMSEL-XL-D Fort Monmouth, New Jersey 07703	1
U. S. Army Electronics Command ATTN: AMSEL-RD-MAT Fort Monmouth, New Jersey 07703	1
U. S. Army Electronics Command ATTN: AMSEL-RD-MAF Fort Monmouth, New Jersey 07703	1
U. S Army Electronics Command ATTN: AMSEL-RD-LNA Fort Monmouth, New Jersey 07703	1
U. S. Army Electronics Command ATTN: AMSEL-RD-LNR Fort Monmouth, New Jersey 07703	1
U. S Army Electronics Command R and D Activity ATTN: Commanding Officer White Sands Missile Range, New Mexico 88002	1
U. S. Army Electronics Command ATTN: Chief, Mountain View Office Electronic Warfare Laboratory P. O. Box 205 Mountain View, California 94042	1
U S. Army Electronics Command ATTN: Chief, Intelligence Materiel Development Office Electronic Warfare Laboratory Fort Holabird, Maryland 21219	1
U S. Army Electronics Command Liaison Officer, ASDL-9 Aeronautical Systems Division Wright-Patterson AFB, Ohio 45433	1

		Copies
U. S. Army Electronics Command Liaison Officer, EMPL Rome Air Development Center Griffiss AFB, New York 13442		1
U. S. National Bureau of Standards Boulder Laboratories ATTN: Library Boulder, Colorado 80301		1
	Total	63

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
The University of Michigan Radiation Laboratory
Dept. of Electrical Engineering, Ann Arbor, Michigan.

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. REPORT TITLE
AZIMUTH AND ELEVATION DIRECTION FINDER STUDY (U)

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
First Quarterly Report, 1 Sept. Through 30 Nov 1965.

5. AUTHOR(S) *(Last name, first name, initial)*
Sengupta, Dipak L.; Ferris, Joseph E.; Larson, Ronal W.; Smith, Thomas M.

6. REPORT DATE December 65	7a. TOTAL NO. OF PAGES 25	7b. NO. OF REFS 3

8a. CONTRACT OR GRANT NO.
DA 28-043-AMC-01499(E)
b. PROJECT NO.
5A6 79191 D902
c. Task No. 01
d. Sub-Task No. 04

9a. ORIGINATOR'S REPORT NUMBER(S)
Report No. 1.

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
7577-1-Q

10. AVAILABILITY/LIMITATION NOTICES
Each transmittal of this document outside the Department of Defense must have prior approval of USAECOM, AMSEL-WL-S, Fort Monmouth, New Jersey.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
United States Army Electronics Command
AMSEL-WL-S
Fort Monmouth, New Jersey. 07703

13. ABSTRACT

This report describes the general mathematical equations used for the theoretical analysis of the radiation patterns produced by a spherical antenna array, the choice of the element distribution, and the experimental investigation of the properties of a possible antenna element of an azimuth and Elevation Direction Finder in the frequency range from .3 to 3 GHz. Each antenna element is assumed to produce circularly polarized radiation having a maximum along its axial direction. The results reported herein are kept general so that they can be used when different parameters of the array are varied.

From the symmetry considerations of an icosahedron inscribed within a sphere a special type of element distribution on the spherical surface is developed. This particular distribution is then used to compute numerically the pattern produced by a number of point sources placed on the spherical surface.

Results of experimental studies of a log conical spiral antennas are reported.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. AZIMUTH AND ELEVATION DIRECTION FINDER						
2. SPHERICAL ARRAY						
3. CIRCULAR POLARIZATION						
4. LOG CONICAL SPIRAL						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
______________________________ ."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
______________________________ ."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
______________________________ ."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, *or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

I IDENTIFICATION OF PERSONNEL

Name	Title	Approx. Man Hours
Ferris, Joseph E	Associate Research Engineer	32
Hiatt, Ralph E.	Head, Radiation Laboratory	8
Hok, Gunnar	Professor, Electrical Engineering	48
Larson, Ronal W	Research Associate, Engineering	48
Sengupta, Dipak L	Associate Research Engineer	248
Smith, Thomas M	Research Associate, Engineering	208

Supporting services (e. g., secretaries, technicians,) are not included.

Biographies

FERRIS, JOSEPH E

Associate Research Engineer

He received a B. E. E. from George Washington University in 1961. Prior to that, he was a radar maintenance chief in the United States Army. During the period 1955 - 1961, he worked at Melpar, Inc., on a wide variety of problems in applied engineering in antenna design and microwave propagation. He conducted a phase error analysis of a large aperture microwave parabolic torus reflector; analyzed the feeds for a Luneberg lens to optimize the gain over the frequency range, 1000 - 10, 000 MHz; conducted a company-sponsored study of artificial dielectric-surface-wave antennas; designed and developed spiral, log-periodic, ridged horns, broadband dipoles, polyrods and associated antenna components to operate at various frequencies in the100 - 30, 000 MHz range. At the Bendix Systems Division (1961 - 1962) he developed communication and telemetry antennas intended for space application; conducted a radiation hazards program to determine the effects of electromagnetic radiation on electro-explosive devices; designed circularly polarized omnidirectional antennas for satellite communication systems. He studied problems typical of those encountered in making RFI measurements in a shielded room and designed a broadband antenna for use in these measurements. He joined the Radiation Laboratory in June 1963 and since that time has participated in and directed studies on RFI interference and on antennas. He is a member of the Institute of Electrical and Electronics Engeineers, Professional Groups on Antennas and Propagation, Electromagnetic Compatibility, and Microwave Theory and Techniques. He is presently the Chairman of the Southeastern Michigan Section of the Military Electronics Group of IEEE.

HIATT, RALPH E.

Head, Radiation Laboratory
Research Physicist

He received an M.A. in Physics from Indiana University(1939) and took additional post-graduate work in mathematics at Boston University. Prior to joining the Radiation Laboratory of The University of Michigan he was Chief of the Antenna Laboratory at Air Force Cambridge Research Center. During World War II he was Chief of the Ipswich Antenna Field Station of the Radiation Laboratory of Massachusetts Institute of Technology. He supervised and personally carried out experimental and theoretical research in the fields of radiation and scattering, ground-based antennas, airborne antennas, and waveguide components. He joined the Radiation Laboratory of The University of Michigan Department of Electrical Engineering in July 1958 as Associate Head and became Head of the Laboratory in November 1961. He was appointed Lecturer in Electrical Engineering in November 1962. He was President of the AFCRC Branch of the Research Society of America (1957-1958). He is listed in American Men of Science and holds memberships in the American Physical Society, Institute of Electrical and Electronics Engineers(Senior Member), Administrative Committee of the Professional Group on Antennas and Propagation of IEEE, Commission VI of URSI (International Scientific Radio Union), American Association for Advancement of Science, Eta Kappa Nu and Sigma Xi.

HOK, GUNNAR

Professor of Electrical Engineering

He received the degree of Electrical Engineering from the Royal Institute of Technology at Stockholm (1962). He was an Exchange Fellow of the American - Scandinavian Foundation at Cruft Laboratory, Harvard University (1931-1932). Professor Hok's technical experience is as follows: Radio Engineer, Stockholm Navy Yard (1926-1927), Assistant to the Chief Engineer, Marine Department, Radio Bureau of the Swedish Telegraph Board, Stockholm (1927-1933), Instructor in Electrical Engineering, Royal Institute of Technology, Stockholm on a part-time basis (1929-1930 and 1932-1936), Development Engineer, Geotechnical Corp., Cambridge Mass (1941), Instructor in Electrical Engineering, New York University (1941-1943), Research Associate, Radio Research Laboratory, Harvard University (1943-1946), Research Physicist, Wesleyan University, Middletown, Conn. (1946-1948). He joined The University of Michigan in 1948 as a Lecturer and Research Engineer, and is now a Professor of Electrical Engineering. He holds memberships in the American Physical Society , Institute of Electrical and Electronics Engineers (Fellow), Sigma Xi and Eta Kappa Nu.

LARSON, RONAL W.

Research Associate Engineer

He received an A. B. (Mathematics) and B. S. (Electrical Engineering) from the University of Michigan (1956). He received the M. S. (Electrical Engineering) from The University of Michigan (1957). During 1956-1957, he held a Westinghouse fellowship. He was engaged in microwave tube research in the Electron Physics Laboratory of The University of Michigan from 1956 - 1960 and specialized in crossed-field interaction. He is a Teaching Assistant and part-time lecturer in the Electrical Engineering Department. He joined the Radiation Laboratory in February 1961. His primary interest is in the plasma imbedded antenna. He holds memberships in The Institute of Electrical and Electronics Engineers, Phi Eta Sigma, Eta Kappa Nu, Tau Beta Pi, Phi Beta Kappa, Phi Kappa Phi, and Sigma Xi.

SENGUPTA, DIPAK L.

Associate Research Engineer

He received a B. Sc in Physics and an M. Sc. in Radio Physics in 1952 from Calcutta University. He received his Ph. D. in Electrical Engineering from the University of Toronto in 1958. His technical experience is as follows: Senior Research Scholar at Calcutta University (1953-1954); Part-time Research Assistant and Teaching Assistant, Electrical Engineering Department, University of Toronto (1954-1958); Research Fellow - Electronics at Harvard University (1959); Radiation Laboratory, Electrical Engineering Department The University of Michigan, Associate Research Physicist (1959 - 1963); Assistant Professor, Electrical Engineering, University of Toronto (1963-1964); Assistant Director of the Central Electronics Engineering Research Laboratory, Pilani, India (1964-1965). He rejoined the Radiation Laboratory of The University of Michigan in October 1965 as an Associate Research Engineer. He is a member of the Institute of Electrical and Electronics Engineers.

SMITH, THOMAS M.

Research Associate

He received the B S. and M. S degrees in Electrical Engineering in 1960 and 1962 respectively from Marquette University, Milwaukee Wisconsin. From 1962 to 1964 he was an Assistant Professor of Electrical Engineering at Loyola University in Los Angeles and a member of the technical staff in the Plasma Research Laboratory of Aerospace Corporation, Los Angeles. From 1964-1965 he worked on the interaction of sound and light waves in solids at Zenith Corporation in Chicago Illinois. He joined the Radiation Laboratory in August 1965 and is engaged in research on radiometer antennas, plasma simulation and radar back scattering problems. He is a member of Eta Kappa Nu, Tau Beta Pi and Sigma Xi.

II PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

A meeting was held at the Radiation Laboratory on 5 November 1965 with representatives of the U. S. Army Electronics Command (S. Stiber, E. Ivone and A. DiGiacomo). The purpose and objectives of the Direction Finder Study were discussed from the standpoint of the interest and requirements of USAEC. Topics considered were: antenna array configurations; the advantage of spherical vs plane surfaces; the grating lobe problem; the possibility of determining direction in the presence of grating lobes; and proposed experimental investigations were briefly discussed.

III PROGRAM FOR NEXT INTERVAL

1. Theoretical

Radiation pattern expressions given in Section II of Quarterly Report No. 1 (7577-1-Q) will be investigated for a few special types of distribution of antenna elements on the spherical surface. The characteristics of the grating lobes in the patterns will be investigated for the case when the antenna elements are widely spaced on a curved surface.

2. Numerical Calculations

Radiation patterns produced by a spherical array using circularly polarized antenna elements will be computed numerically. Various kinds of element distribution will be used.

On the basis of the above theoretical and numerical investigation, the radius of the spherical array, the number and the required distribution of antenna elements will be determined.

3. Experimental Investigation

The polarization characteristics of the conical helix antennas will be studied. The mutual effects between the elements will be investigated. A prototype of the spherical array will be built for laboratory test purposes.

DLS/cfw