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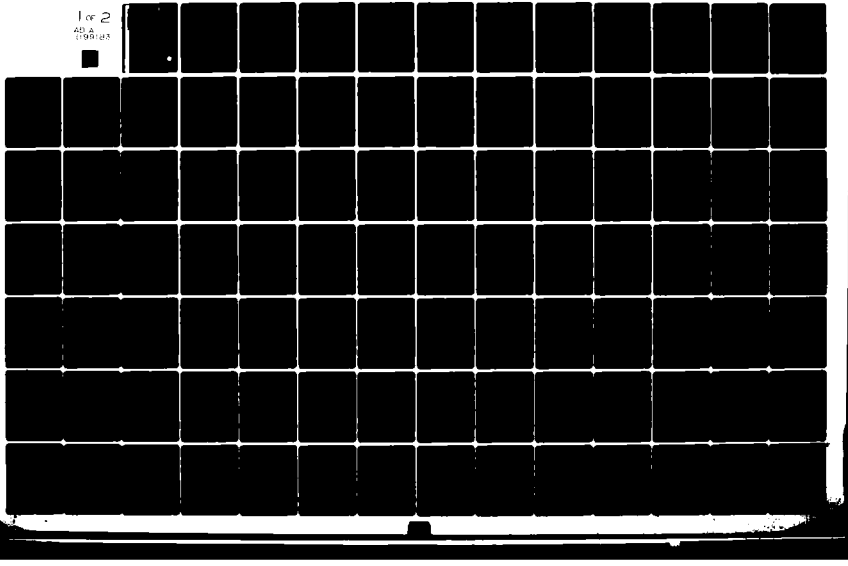

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PARAMETRIC INVESTIGATION OF RADOME ANALYSIS METHODS:

COMPUTER–AIDED RADOME ANALYSIS USING THE HUYGENS–FRESNEL PRINCIPLE AND LORENTZ RECIPROCITY

By

G. K. Huddleston, H. L. Bassett, & J. M. Newton

Prepared for

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (AFSC)
BOLLING AIR FORCE BASE, D. C. 20332

FINAL TECHNICAL REPORT, VOLUME III OF IV
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30 September 1977 – 31 December 1980

February 1981

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Atlanta, Georgia 30332

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A Fortran computer program is described for computing the effects of a tangent ogive radome on the receiving patterns and boresight directions of a monopulse antenna. A receiving formulation with the inside surface of the radome being the surface of integration is used. Aperture integration is used to compute the near fields of the antenna. The main program and seven subroutines are well documented.

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Georgia Institute of Technology

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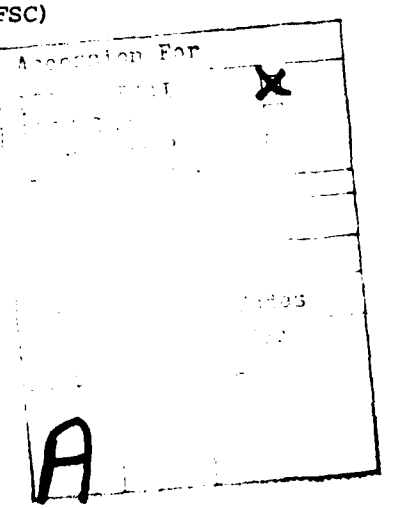


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

Chapter 1

INTRODUCTION AND SUMMARY

1-1. Introduction

This Volume III of this final technical report of four volumes documents a surface integration radome analysis computer program written in Fortran IV for use on the Cyber 70/74 computing system at Georgia Institute of Technology and the IBM 3033 computing system at Johns Hopkins University Applied Physics Laboratory. The program was developed at Georgia Institute of Technology over the past three years under grant AFOSR-77-3469 and documented herein under the cognizance of R. C. Mallaleiu (APL Contract 60153).

The analysis package described was used during the research to analyze the antennas and radomes as described in Volumes I and IV. Its documentation was done in conjunction with an on-going radome technology program at JHU/APL. It is intended to serve as part of a technology base for the radome technical community.

This report is organized by chapters, where each chapter describes the main program or one subprogram not already described in Reference 1 (Ray Tracing Formulation). The main program (Chapter 2) described herein differs only slightly from that in Reference 1. Only six new subroutines are required for the surface integration formulation as described in Chapters 3-8. References cited in each chapter are listed therein. Each chapter is terminated with the program listing.

This software us currently being used in a parametric investigation of radome analysis methods, and additional information concerning its speed and accuracy is presented in Volume I [2].

1-2. Description of the Analysis

The basis of analysis is illustrated in Figure 1-1. The inner surface of the radome S_1 is chosen as one surface of integration in the Lorentz reciprocity integral (upper left in figure). A surface S_2 enclosing the antenna and extending into its interior, as illustrated, comprises the second surface. Together, $S_1 + S_2$ enclose the source-free Volume V indicated; hence, the Lorentz surface integral is identically zero and the integral over S_1 equals the negative of the integral over S_2.

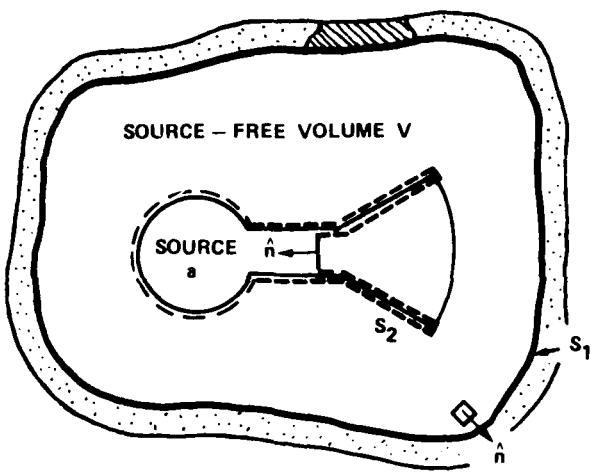
Consider the surface S_2 more closely. The surface integral over S_2 is zero except over that part of S_2 which is placed across the waveguiding structure that connects the Source "a" to the radiating (flared) part of the antenna. Call this surface S_2'. If there can be defined a single dominant mode in the waveguide when Source "a" is activated, then voltage and current V_a, I_a can be defined at this terminal plane [4]. When Source "b" is activated, voltage and current V_b, I_b at S_2' can also be defined; in fact, V_b is the "received voltage". The received current I_b is related to V_b by a linear impedance relationship

$$V_b = I_b Z_a \tag{1}$$

where Z_a is the impedance seen at S_2' looking toward Source "a" (sinusoidal steady state assumed; time variations of the form $e^{j\omega t}$ understood and suppressed). Also, I_a and V_a are related by

$$V_a = I_a Z_1 \tag{2}$$

$$\oint_{s_1+s_2} (\underline{E}_a \times \underline{H}_b - \underline{E}_b \times \underline{H}_a).\hat{n}da = 0$$



$$\int_{s_1} (\underline{E}_a \times \underline{H}_b - \underline{E}_b \times \underline{H}_a) .\hat{n}da$$

$$= -\int_{s_2} (\underline{E}_a \times \underline{H}_b - \underline{E}_b \times \underline{H}_a).\hat{n}da$$

$$= V_a I_b + V_b I_a$$

$$\underline{E}(x,y,z) = 1/4\pi \int_s [\, -j\omega\mu\psi (\hat{n} \times \underline{H}) + (\hat{n} \times \underline{E}) \times \nabla\psi + (\hat{n} \cdot \underline{E})\nabla\psi \,] \, dS$$

$$\underline{H}(x,y,z) = 1/4\pi \int_s [\, j\omega\epsilon(\hat{n} \times \underline{E})\, \psi + (\hat{n} \times \underline{H}) \times \nabla\psi + (\hat{n} \cdot \underline{H})\, \nabla\psi \,] \, dS$$

FIGURE 1–1. THEORETICAL BASIS OF RADOME ANALYSIS.

where Z_1 is the impedance seen at S_2' looking to the right in Figure 1-1. Combining these results yields the desired expression for the received voltage V_b; viz.,

$$V_b = V_{REC} = \frac{Z_1 Z_a}{V_a (Z_1 + Z_a)} \int_{S_1} (\underline{E}_a \times \underline{H}_b - \underline{E}_b \times \underline{H}_a) \cdot \hat{n} \, da \qquad (3)$$

Note that the unit normal is directed positively outward from volume V as dictated by Gauss' theorem.

When Source "b" in Figure 1-1 is removed a great distance from the antenna/radome structure, the fields of "b" approach those of an electromagnetic plane wave (target return). The practical analysis approach then takes the form shown in Figure 1-2. The inner radome surface is divided into a number of contiguous elemental areas ΔA, each of which is represented by a sample point P' at its center. The fields $\underline{E}_T$ $\underline{H}_T$ at P' are assumed to be those present there in the absence of the radome and are found by aperture integration, the theoretical basis of which is the Huygens-Fresnel principle [5] as stated by the lower integrals in Figure 1-1. The fields $\underline{E}_R$, $\underline{H}_R$ at P' are found by applying the normal voltage transmission coefficients [6] to the plane wave incident on the outside at point P. The received voltage is found by summing all the contributions as indicated in Equation (3).

The method of analysis indicated by Equation (3) is exact; however, certain approximations are necessarily introduced in its implementation. The fields $\underline{E}_T$, $\underline{H}_T$ should correctly include reflections from the inner radome surface. The use of the flat panel transmission coefficients to transform the incident plane wave at P to P' is an approximate method based on the theory of geometrical optics (zero wavelength) and whose

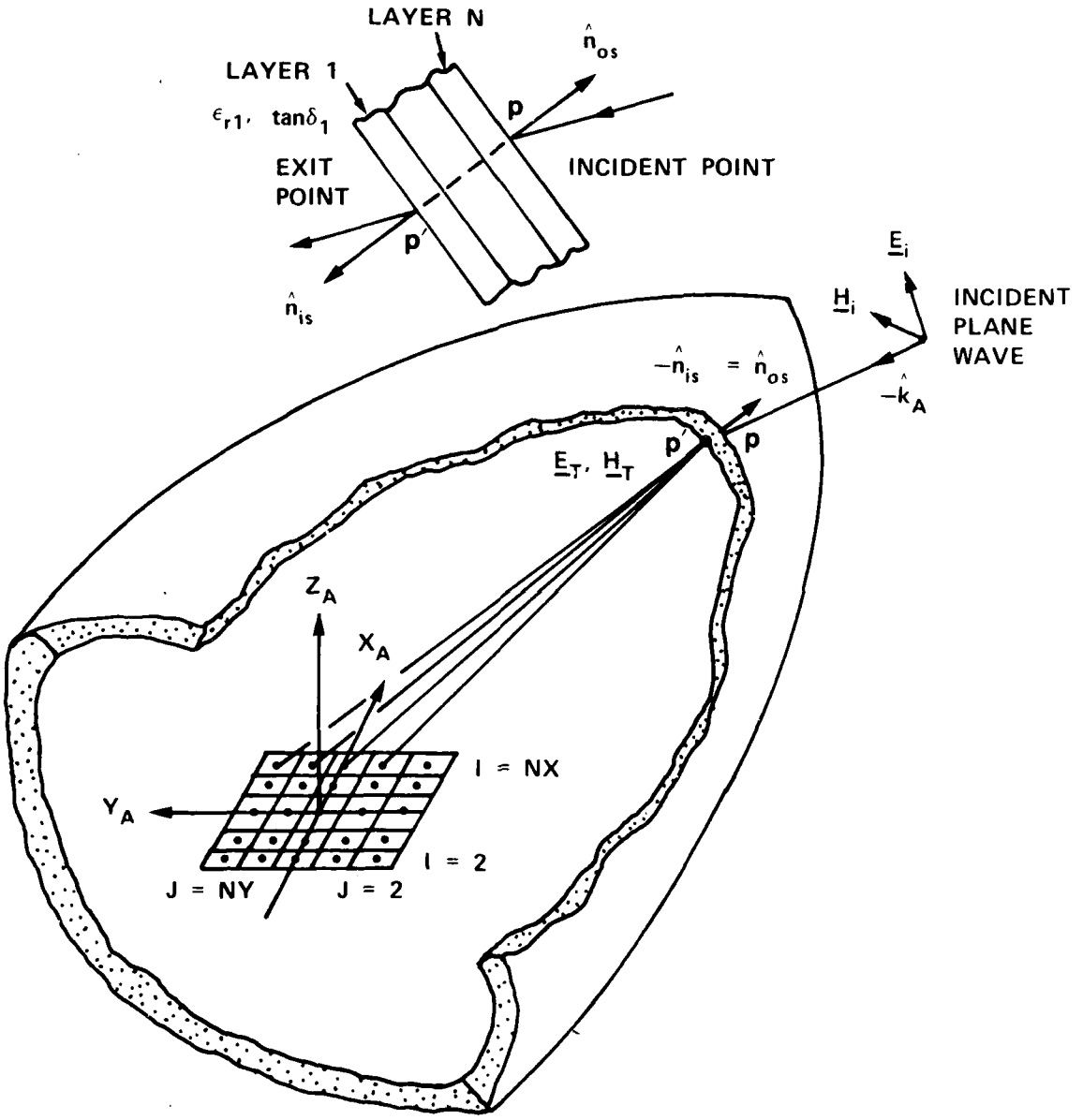


FIGURE 1–2. ILLUSTRATION OF RADOME ANALYSIS METHOD USING INSIDE RADOME SURFACE AS SURFACE OF INTEGRATION IN RECIPROCITY INTEGRAL.

accuracy depends upon the radius of curvature of the radome wall. The accuracy of the method also depends on the size of the samples used to represent the radiating aperture as well as the radome surface. The computational speed of the analysis most certainly depends on the number of these samples.

1-3. References

1. G. K. Huddleston, H. L. Bassett, & J. M. Newton, "Parametric Investigation of Radome Analysis Methods: Computer-aided Radome Analysis Using Geometrical Optics and Lorentz Reciprocity", Final Technical Report, Volume II of IV, Grant AFOSR-77-3469, February 1981.

2. G. K. Huddleston, H. L. Bassett, J. M. Newton, "Parametric Investigation of Radome Analysis Methods: Salient Results", Final Technical Report, Volume I of IV, Grant AFOSR-77-3469, February 1981.

3. R. E. Collin and F. J. Zucker, Antenna Theory, Part 1, Section 4.2, McGraw-Hill, New York, 1969.

4. S. Silver, Microwave Antenna Theory and Design, Ch. 2, Mc-Graw-Hill, New York, 1949.

5. Ibid, Ch. 3.

6. J. H. Richmond, "Calculation of Transmission and Surface Wave Data for Plane Multilayers and Inhomogeneous Plane Layers", Air Force Contract AF 33(615)-1081, The Antenna Laboratory, Ohio State University, Columbus, Ohio, October 1963.

Chapter 2

PROGRAM SIIRACP

2-1. Purpose: SIIRACP is a Fortran computer program used to analyze the effects of a tangent ogive radome on the performance of a monopulse aperture antenna. It consists of a main program and 28 subroutines, 22 of which are identical to those used in Program RTFRACP [1]. It uses complex arithmetic and requires 66600 octal words of core memory for execution on the CDC Cyber 70 system (60-bit words) at Georgia Institute of Technology. Execution time to compute boresight error on the Cyber 70 is approximately 255 seconds per look direction when the small antenna aperture is represented by 7 x 7 = 49 sample data points and the radome is represented by 826 sample points; i.e., approximately 1.26 millisecond per aperture sample point per radome sample point.

The computer-aided radome analysis uses a receiving formulation based on the Lorentz reciprocity theorem as described earlier [1,2]. The voltage produced at the terminals of a linear antenna by an incident plane wave is given by

$$V_R(\hat{k}) = \iint_S (\underline{E}_T \times \underline{H}_R - \underline{E}_R \times \underline{H}_T) \cdot \hat{n}\, da \qquad (1)$$

where $\underline{E}_T$, $\underline{H}_T$ are the fields produced on the surface S enclosing the antenna when the antenna is transmitting; $\underline{E}_R$, $\underline{H}_R$ are the incident fields produced on S by the incident plane wave or perturbations thereof; $\hat{k}$ is a unit vector which points from the antenna toward the direction from which the plane

wave arrives; and $\hat{n}$ is a unit vector normal to the surface S and pointing into the source-free region.* The fields $\underline{E}_T$, $\underline{H}_T$ are taken to be those produced by the planar aperture on surface S when the antenna is transmitting in the absence of the radome. The geometrical optics approximation

$$\underline{H}_T + \frac{\hat{n} \times \underline{E}_T}{\eta} \tag{2}$$

is used to generate the magnetic field in the aperture from the aperture illumination specified by $\underline{E}_T$.

The surface S is taken to be the inner surface of the radome. At each sample point P'on this surface, the plane wave fields $\underline{E}_R$, $\underline{H}_R$ incident from the outside are weighted with the flat panel normal voltage transmission coefficients as determined by the radome wall configuration, the angle of incidence, and the plane of incidence. The fields $\underline{E}_T$, $\underline{H}_T$ at P'are found by aperture integration. The individual contributions are summed up as indicated in Equation (1) and was illustrated in Figure 1-2.

The parameters of the tangent ogive radome are indicated in Figure 2-1. The outside base diameter D_{os} and fineness ratio F_{os} determine the outside length according to

$$F_{os} = L_{os}/D_{os} \tag{3}$$

A similar relation holds for the inside dimensions; viz.,

$$F_{is} = L_{is}/D_{is} \tag{4}$$

*By choosing $\hat{n}$ this way, the minus sign in Figure (1-1) is removed.

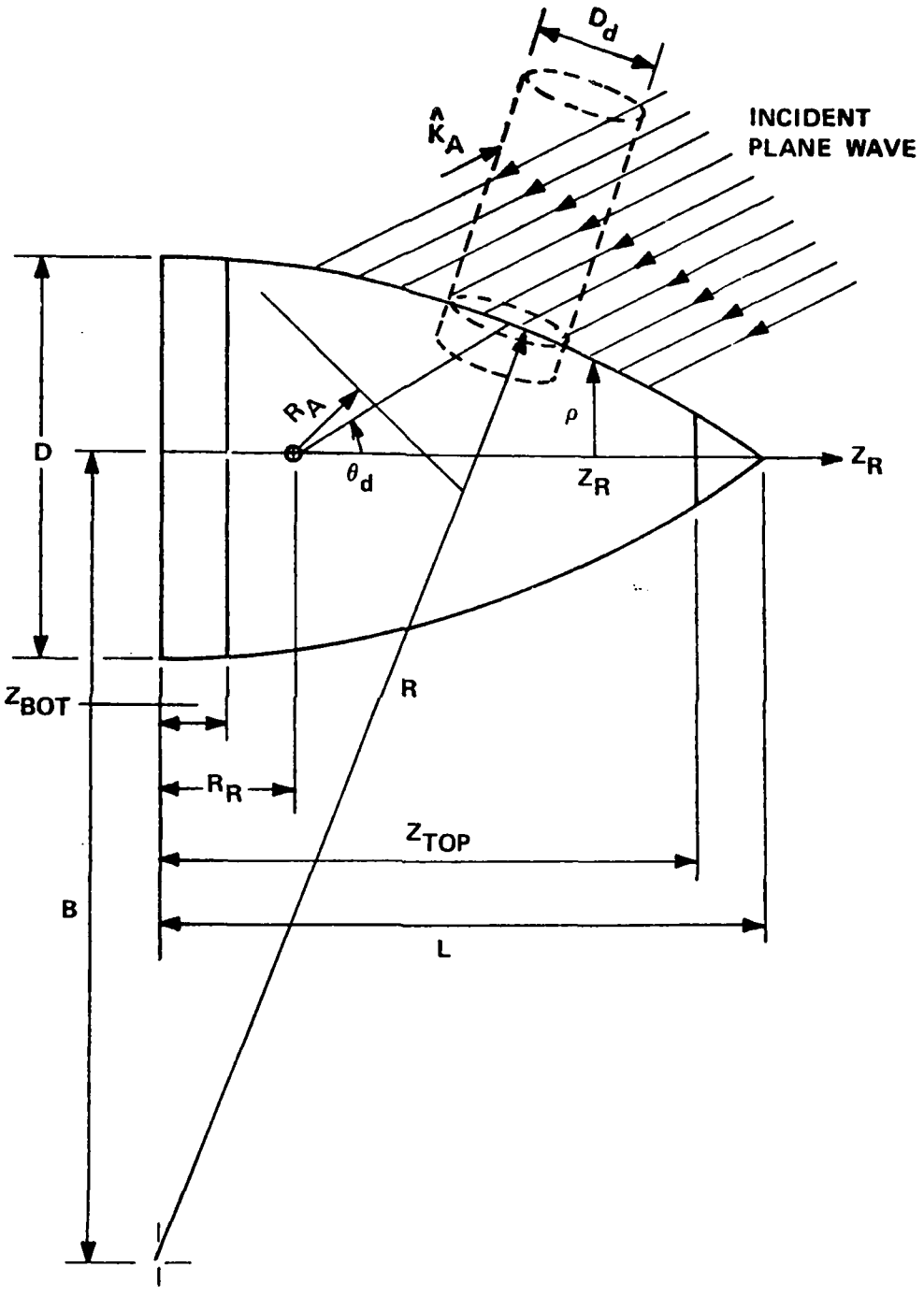


Figure 2-1. Tangent Ogive Radome Geometry.

The radius of curvature of the outside wall R_{os} is given by

$$R_{os} = F_{os} D_{os} / \sin (\pi - 2 \text{Tan}^{-1}(2F_{os})) \quad (5)$$

and the dimension B is given by

$$B = R_{os} - D_{os}/2 \quad (6)$$

The placements of a bulkhead (bottom disk) and metal tip (top disk) can be specified by Z_{BOT} and Z_{TOP}, respectively. The thickness, dielectric constant, and loss tangent of the wall may also be specified for up to N=5 layers. The radome is assumed to be a body of revolution with uniform wall dimensions independent of location. The dashed cylindrical shape of a diameter D_d in Figure 2-1 was used earlier to simulate a laser-induced defect and is not pertinent here.

The subroutine which generates the antenna aperture fields represents three types of antennas: circular or square aperture with tapered (cos x) illumination and any one of four polarizations (vertical, horizontal, RHC, LHC); flat plate antenna with tapered illumination and vertical polarization. For either antenna, the fields are computed for one of three selected channels: sum, azimuth difference, elevation difference. Inputs include the number of samples N_X, N_Y and the aperture diameter D_{AP}/λ in wavelengths.

The antenna/radome orientation is specified according to the parameters defined in Figure 2-2. The angle ϕ_p selects the plane of scan of the radome tip with respect to the antenna coordinate system: $\phi_p = 0°$ selects the azimuth plane; $\phi_p = 90°$ selects the elevation plane. The angle θ_L scans the tip in the selected plane.

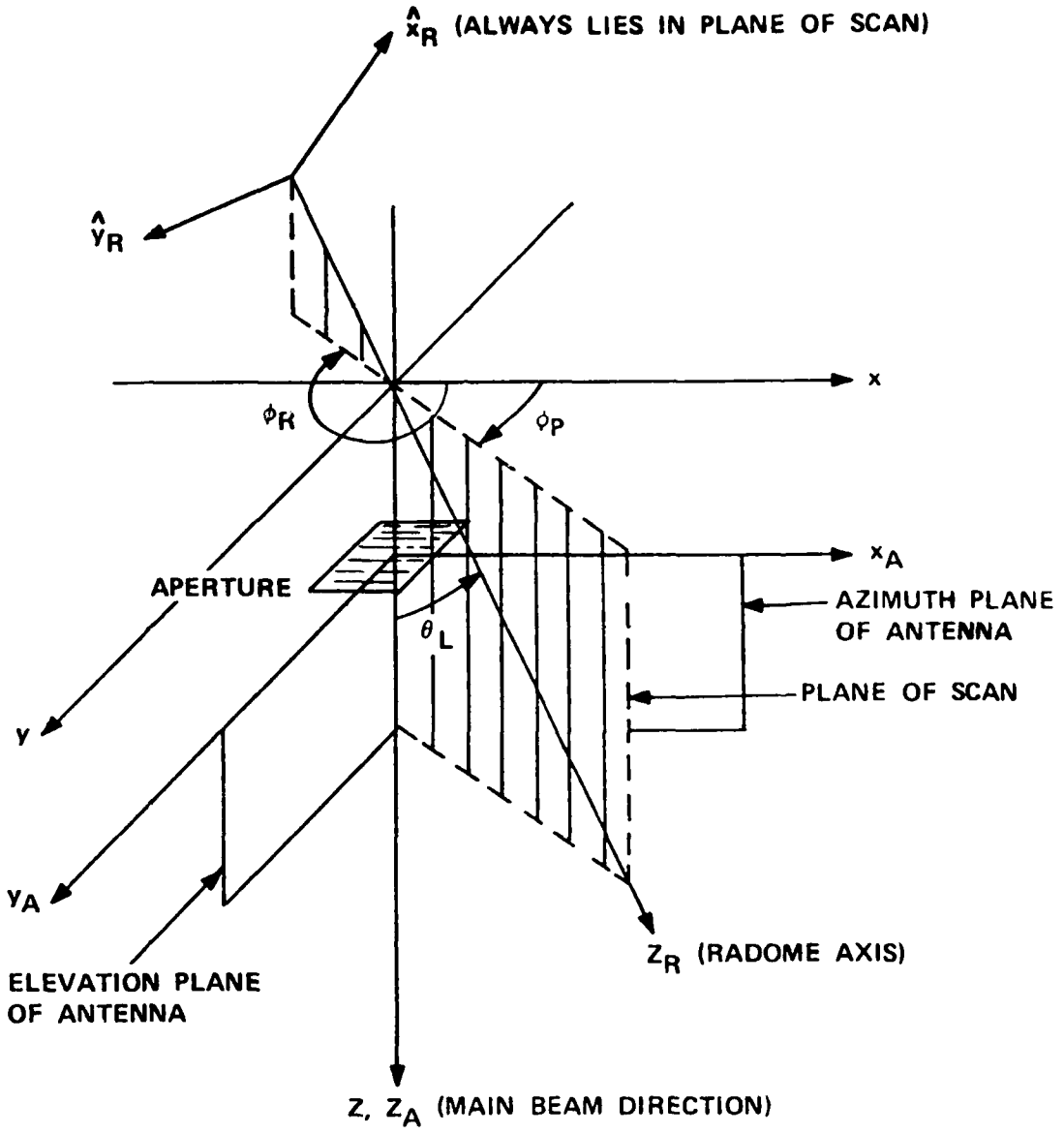


Figure 2-2. Coordinate Systems Used in Radome Analysis.

The program computes boresight errors in the azimuth and elevation planes of the antenna. The radome orientation is specified by ϕ_p and ϕ_L. The first target return (plane wave) is made to arrive from the direction

$$k_1 = x_A \sin \theta_{os} + y_A \sin \theta_{os} + z_A \sqrt{1 - 2 \sin^2 \theta} \tag{7}$$

where θ_{os} is the initial specified offset angle; e.g., 2°. The voltage received by each channel is computed and stored. The second return is made to arrive from

$$k_2 = x_A(-\sin \theta_{os}) + y_A(-\sin \theta_{os}) + z_A \sqrt{1 - 2 \sin^2 \theta_{os}} \tag{8}$$

and the voltages are again computed. The data from these two points are used to construct a linear tracking model in the two planes, and a direction of arrival k is predicted which will yield null indications in both planes. The process is repeated until a desired error tolerance is satisfied or a maximum number of iterations is exceeded. Upon completion, the output k indicates the direction from which the plane arrives which yields an electrical boresight indication. If ϵ and τ represent the boresight error angles in the azimuth and elevation planes, respectively, then they are related to the direction $k = x_A k_x + y_A k_y + z_A k_z$ by

$$\sin \epsilon = \frac{k_x}{\sqrt{1 - k_y^2}} \tag{9}$$

$$\sin \tau = \frac{k_y}{\sqrt{1 - k_x^2}} \tag{10}$$

where $$k_z = \sqrt{1 - k_x^2 - k_y^2} \quad . \tag{11}$$

Options are also provided whereby principal plane patterns as shown in Figure 2-3 and additional outputs around boresight can be computed and printed. These options are useful when preparing software for a new type of antenna and to ensure correct operation whenever curious results are obtained.

2-2. Usage:

		Line No.
DATA APIN/0./		47
DATA ZBOTIN/0.00/		49
DATA RADIUS/1E0/		52
DATA THETAA, PHIA, AGAM3A/0.0,90.0,0.0/		53
DATA NX, NY, NYE, NXY/4,4,1,512/		56
DATA MY/1/,NREC/61		57
READ (5,6) TITLE		63
READ (5,*) GRAF3D, GRAFSA, GRAFTR, GRAFRV, SUPPRS, IPENCD, SQUARE		65
READ (5,*) NFINE, NPHI, NTHE, DIAOS, RAIN, RRIN, ZTOPIN, FREQ, OSANG		67
READ (5,*) LMAX, DMRAD, IOPT, RAPMAX, VAIRM, IPOL, ICASE, N, IPWR, KMAX, NXE		76
READ (5,*) DSTHIN, DSPHIN, NTHMIN, NPHIMIN		79
READ (5,*) DIN(I), ER(I), TD(I)	(I=1,N)	115
READ (5,*) FINR(I)	(I=1,NFINE)	124
READ (5,*) PHI(I)	(I=1, NPHI)	127
READ (5,*) THETA(I)	(I=1,NTHE)	129

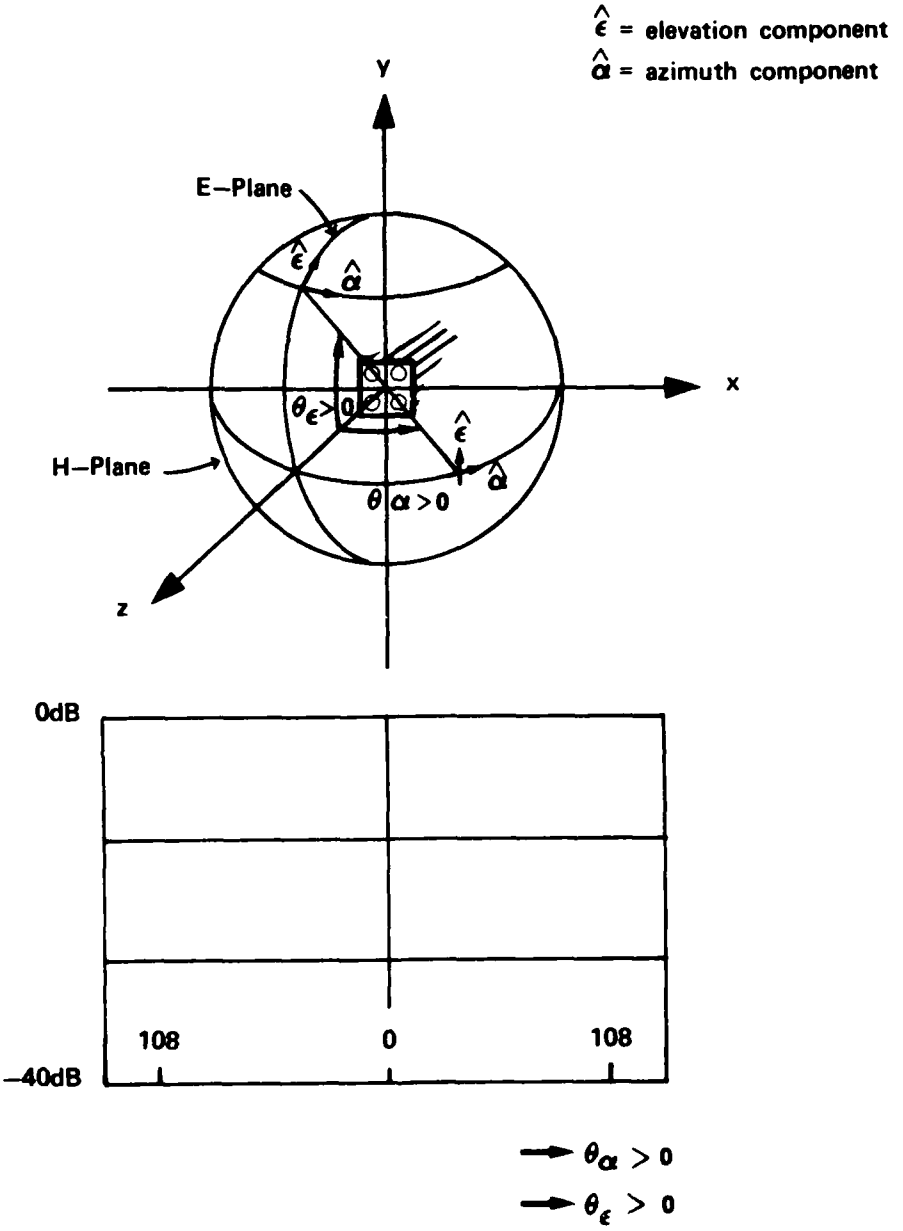


Figure 2.3 Coordinate System for Far Field Patterns

2-3. Arguments

a. Inputs. Units of arguments on input are distances in inches, angles in degrees, and frequency in gigahertz, unless otherwise noted. Units of arguments passed to subroutines are centimeters, radians, and gigahertz. An asterisk is used to denote those DATA arguments that do not normally need to be changed by the user.

APIN* - Height of a cylindrical base section of the tangent ogive radome. It is no longer included in the ray tracing algorithms and should not be changed from its zero value.

ZBOTIN - Distance from base of tangent ogive radome to missile bulkhead (Figure 2-1).

RADIUS* - The radius R used in the far field factor e^{-jkR}/R by Subroutine FAR. Do not change.

THETAA* - Angle θ_a between z-axis and the position vector $\underline{r}_a$ to the antenna origin. This angle was used in earlier work to locate the antenna origin in the reference system using spherical coordinates (r_a, θ_a, ϕ_a). Do not change.

PHIA* - Angle ϕ_a between the projection of z_A axis onto the xy-plane and the x-axis. Do not change.

AGAMJA* - Angle between z_A-axis and z-axis in Figure 2-2. Do not change.

NX,NY - Integer powers of two equal to the number of sample points in the antenna aperture; e.g., 16, 32, 64, etc. Changing NX and NY necessitates compatible changes in Lines 16-18.

NYE (NXE) - Integer powers of two which specify the expanded number of sample points desired when computing the transmitting patterns of the antenna by inverse Fourier transforming the aperture fields. Subroutine JOYFFT provides this capability of increased resolution in one or both dimensions. Changes in NXE, NYE necessitate compatible changes in Lines 16, 20, 22 and 23. Note that NXE*NYE≤NX*NY and either NXE≤NX or NYE≤NY.

NXY - Integer power of two used by Subroutine JOYFFT for dimension of complex working array XYFFT. Note that MX*NX≤NXY and MY*NY≤NSY. See below for MX and MY.

NREC - Integer variable equal to the number of points at which to compute the receiving pattern in either principal plane. The received voltage is computed at points θ_i equally spaced in $\sin\theta$, where θ is the angle measured from the z_A-axis as indicated in Figure 2-3, where $\sin\theta_i$ = -KMAX + (I-1)*2*KMAX/NREC, and where KMAX = $\sin\theta_{max}$ < 1.0.

NS - Not used. It was originally used by Subroutine RECBS. Do not remove.

MX,MY - Integer powers of two equal to the magnification factors desired in the k_x (H-plane) and k_y (E-plane) directions, respectively, of the transmitting antenna patterns. Note that the restrictions MX*NY≤NXY and MY*NY≤NXY must be observed. The data cited

above indicates increased resolutions in the NX direction of MX=16 and no magnification (MY=1) in the NY direction. Consequently, note that NXE=MX*NX=256.

TITLE - A Hollerith string of up to 72 characters which describes briefly the analysis being done. A format of 18A4 is specified and should work for machines with word length greater than or equal to 32 bits. The dimension of TITLE (Line 31) should be at least 18.

GRAF3D - A logical variable used to control the plotting of the incident fields on the antenna aperture. This feature has been removed from the program, and GRAF3D should always be FALSE.

GRAFSA - A logical variable which (if TRUE) controls the plotting of the transmitting power patterns of the antenna as follows: E-plane sum, E-plane difference equation (Δ_{EL}), H-plane sum, and H-plane difference azimuth (Δ_{AZ}). The radome is absent.

GRAFTR - A logical variable which controls the plotting of the amplitude and phase of the antenna aperture fields in the following order:

$E_{X\Sigma}$, $E_{Y\Sigma}$, $E_{X\Delta EL}$, $E_{Y\Delta EL}$, $E_{X\Delta AZ}$, $E_{Y\Delta AZ}$.

GRAFRV - A logical variable which controls the plotting of the receiving patterns of the antenna with radome in the same order as specified under GRAFSA above.

SUPPRS - A logical variable which controls the printing of numerous results. When TRUE, the printing of these numerous results are suppressed. This feature is convenient to aid in debugging new portions of software prior to making production runs.

IPENCD - An integer variable which selects pen and paper for the Calcomp. This variable may be system dependent. For the Cyber 70, IPENCD=00 yields ballpoint pen and 11" wide plain paper; IPENCD=40 yields a heavier ink pen and the same paper.

SQUARE - Logical input variable which selects a square aperture (TRUE) in Subroutine TRECNF.

NFINE - Integer variable equal to the number of fineness ratios to be considered for the tangent ogive radome; e.g., NFINE=1.

NPHI - Integer variable equal to the number of scan planes; e.g., NPHI=2.

NTHE - Integer variable equal to the number of angles in each scan plane at which to compute boresight errors, etc. Note: The program is set up to iterate on fineness ratio, scan plane, and scan angle as outer loop, middle loop, and inner loop, respectively. Therefore, for each of NFINE fineness ratios, the analysis will be done for NTHE scan angles in NPHI different scan planes.

DIAOS - Real variable equal to the outside base diameter (in.) of the radome. See Figure 2-1.

RAIN - Real variable equal to the distance (in.) from the gimbal point to the antenna aperture.

RRIN - Real variable equal to the distance (in.) from the gimbal point to the base of the radome.

ZTOPIN - Real variable equal to the distance (in.) from the base of the radome to the face of a metal tip on the radome.

FREQ - Real variable equal to the frequency of operation in gigahertz.

OSANG - Real variable equal to the offset angle in degrees at which the first target return is to arrive on the antenna; e.g., OSANG=3.0.

LMAX - Integer variable equal to the maximum number of iterations allowed by Subroutine RECBS in computing boresight error; e.g., LMAX=5.

DMRAD - Real variable equal to the tolerance in milliradians allowed on computing boresight error; e.g., DMRAD=0.1.

IOPT - Integer variable which selects the polarization of the incident plane wave as follows:

1. Linear, elevation component
2. Linear, azimuth component
3. Right hand circular
4. Left hand circular

RAPMAX - Real variable equal to the maximum radius (in.) of the antenna aperture.

VAIRM - Real variable equal to the maximum amplitude of sum channel received voltage without radome. Any

real value can be entered for this variable since a subsequent program modification (Lines 345-362) causes VAIRM to be computed automatically.

IPOL - Integer variable which selects the polarization of the antenna when ICASE=1 according to the same code as used above for IOPT.

ICASE - Integer variable which selects the type of antenna aperture for the analysis: ICASE=1 or 2 selects a circular or square aperture with tapered illumination; ICASE=3 selects a flat plate antenna with programmed illumination. See Subroutine TRECNF in Chapter 4.

N - Integer variable equal to the number of layers (up to 5) in the radome wall. For cases where more than 5 layers are required, the dimensional arrays on Line 37 must be changed to NN=N+1.

IPWR - Integer variable which selects the component for which to compute the transmitting power patterns as follows:

1. Elevation Components
2. Azimuth Component
3. Total power

KMAX - Real variable equal to the sine of the maximum angle at which receiving patterns are to be computed.

NXE - Integer variable used by JOYFFT as explained above.

DSTHIN, DSPHIN - Real variables equal to the distance between adjacent sample points on the radome surface in the

longitudinal (θ) and circumferential (ϕ) directions, respectively. See Chapter 3.

NTHMIN, NPHIMIN - Integer variables equal to the minimum acceptable number of radome sample points in the two directions.

DIN,ER,TD - Subscripted real variables equal to the thickness (in.), dielectric constant (ε_r), and loss tangent (tan δ) of each layer of the radome wall. I=1 corresponds to the first layer and is the layer on exit side of the wall. Layer N is the first layer encountered by the incident plane wave. See Subroutine WALL.

FINR - Subscripted real variable equal to NFINE fineness ratios.

PHI - Subscripted real variable equal to NPHI angles (degrees) which specify the scan planes.

THETA - Subscripted real variable equal to NTHE angles (degrees) which specify the scan angles in the scan plane.

b. Outputs. The parameters of analysis which are computed and outputted by the program depend on whether SUPPRS is true. In what follows, it is assumed that SUPPRS=FALSE so that all possible outputs are obtained. Since many of the original input parameters are printed directly, only those parameters not already explained above will be included below. Additional clarification may be found in Section 2-6.

TABLE - Logical variable which, if TRUE, causes a look-up table to be used in computing transmission coefficients. When SUPPRS=FALSE, an abbreviated table

of transmission coefficients of the radome wall is printed by Subroutine WALL with variables as explained immediately below.

ANGLE - Real variable equal to the angle of incidence (degrees) of the plane wave on a plane sheet of infinite extent having the layered configuration specified for the radome wall. The entries in the table are computed at 250 equal increments in sin θ_i, but only every fifth result is printed.

TPERI,TPARI - Complex variables equal to the normal voltage transmission coefficients of the sheet for the two cases of $\underline{E}_i$ perpendicular to the plane of incidence ($T_\perp$) and $\underline{E}_i$ parallel to the plane of incidence ($T_{||}$). In the printed table, the power transmission coefficients $|T_\perp|^2$ are $|T_{||}|^2$ are printed; adjacent to each, the phases of $T_\perp$ and $T_{||}$ are also printed.

RPERI,RPARI - Complex variables equal to the reflection coefficients $R_\perp$, $R_{||}$ of the plane dielectric sheet. Actually, $|R_\perp|^2$ and $|R_{||}|^2$ are printed, accompanied by the phases of $R_\perp$ and $R_{||}$.

KXMAX - Real variable equal to the folding wavenumber associated with sampling the aperture fields according to KXMAX = 1./(2($\Delta x/\lambda$), where x is the distance between samples.

DXWL - Real variable equal to $\Delta x/\lambda$.

KXM,KYM - Real variables equal to the folding wavenumbers of the principal plane patterns after magnification

for increased resolution. KXM=KYMAX*NXE/(MX*NX) and applies to the H-plane.

KYM=KYMAX*NYE/(MY*NY) and applies to the E-plane. Usually, the expanded dimension NXE and magnigication factor MX are selected so that KXM=KXMAX. Also, NYE and MY are usually selected so that KYM<<KYMAX.

MIN,MAX - Real variables equal to the minimum and maximum values of the amplitude of the complex arrays containing the aperture fields are processed by Subroutine NORMH in preparation for 3D plotting by Subroutine PLT3DH.

ROS - Real variable equal to the radius of curvature of the outside shape of the tangent ogive radome.

BOS - Real variable equal to the distance B in inches defined in Figure 2-1.

FINOS - Real variable equal to the fineness ratio of the radome as based on the outside dimensions.

FINIS - Real variable equal to the fineness ratio of the radome as based on the inside dimensions.

The following variables are printed when the receiving patterns are computed and printed:

ICUT - Integer variable which defines the E-plane (ICUT=1) or H-plane (ICUT=2) pattern. See Figure 2-3.

ICOMP - Integer variable which defines the field component of the plane wave incident on the receiving antenna: ICOMP=1 for elevation component; ICOMP=2 for azimuth component.

KMAX - Real variable equal to the sine of the maximum angle off broadside for which the received voltage is computed.

NREC - Integer variable (power of 2) equal to the number of points at which the receiving pattern is computed. The pattern is computed at NREC points spaced equally in $k_{xy}=\sin\theta$ according to $\Delta k_{xy} = 2$ KMAX/NREC.

DK - Real variable equal to 2*KMAX/NREC.

ANGMAX - Real variable equal to $\sin^{-1}$(KMAX).

The receiving pattern is computed at NREC points and magnified using Subroutine MAGFFT to 256 points equally spaced in sin θ over the range (-KMAX, KMAX-DK). Three parameters are printed: angle in degrees, amplitude in decibels, and phase in degrees. Only every fourth point in the 256 points is printed. The receiving patterns are printed in the following order:

E-Plane: Σ_{EL}, Δ_{EL}

H-Plane: Σ_{AZ}, Δ_{AZ}

Subroutine RECBS computes the boresight error of the antenna as produced by the radome. When SUPPRS=FALSE, the following parameters are printed:

K1, K2 - Real subscripted variables containing the direction cosines (k_{xi},k_{yi},k_{zi}) of the last and next to last true directions to the target. One of these variables is equal to K, the subscripted variable containing the direction cosines of the last target return.

AZTM,ELTM - Real variables equal to the boresight error in the H-plane and E-plane associated with the last target return (k_x,k_y,k_z). Expressed in milliradians, these errors are computed according to

$$AZTM = \mathrm{Sin}^{-1}(k_x/\sqrt{1-k_y^2}) * 1000.$$

$$ELTM = \mathrm{Sin}^{-1}(k_y/\sqrt{1-k_x^2}) * 1000.$$

Let $\hat{k} = \hat{x}_A k_x + \hat{y}_A k_y + \hat{z}_A k_z$. Then AZTM is the angle between the z_A-axis and the projection of $\hat{k}$ onto the $x_A z_A$ (azimuth) plane. ELTM is the angle between the z_A-axis and the projection of $\hat{k}$ onto the $y_A z_A$ (elevation) plane.

MESAZ,MESEL - Real variables equal to the monopulse error slopes in the azimuth and elevation channels expressed in units of volts per degree, where the maximum signal received by the sum channel is considered to be one volt.

UAZ,UEL - Real subscripted variables equal to the received tracking functions $I_{mag}\{\Delta/\Sigma\}$ corresponding to the target returns K1 and K2 above; e.g., UAZ(1) = $I_{mag}\{\Delta_{AZ}/\Sigma_{AZ}\}$ for K1.

SMAX - Real variable equal to the maximum amplitude of the received sum channel voltage.

LCTR - Integer variable equal to the number of iterations (target returns) used by Subroutine RECBS to compute boresight error.

Subroutine RECBS also computes and prints six additional monopulse outputs around the apparent boresight direction $\hat{k}_o$. The directions $\hat{k}$ chosen lie in the plane $k_x=k_y$ and are spaced one milliradian apart over the range ±3 mrad and centered on the direction $\hat{k}_o$. The variables printed are as follows:

ANG - Real variable equal to the angle in milliradians between $\hat{k}_o$ and $\hat{k}$.

VRAZ,VREL - Real variables equal to $I_{mag}\{\Delta/\Sigma\}$ for the target return from direction $\hat{k}$ for the azimuth and elevation channels, respectively.

DAZ,DEL - Amplitude and phase (degrees) of the complex voltages received on the Δ_{AZ} and Δ_{EL} channels, respectively, for target return $\hat{k}$.

SLPAZ,SLPEL - Average values of the monopulse error slopes (volts/degree) in the azimuth and elevation channels, respectively, obtained by a linear approximation of the tracking functions based on their values at ANG = ±3 mrad. For example,

SLPAZ = [VRAZ(3 mrad) - VRAZ(-3 mrad)]/(.006*57.3)

The main program always prints the boresight error in azimuth (BSEAZ) and elevation (BSEEL), and the values printed are identical to AZTM and

ELTM defined above. Main also computes the gain of the antenna in decibels with the radome in place according to

$$GAIN = 20. * ALOG10(SMAX/VAIRM)$$

For other than an "air radome", GAIN is negative and indicates a loss in antenna maximum gain due to radome reflections and ohmic (tan δ) losses. The amplitude of received sum voltage, VAIRM, is always printed as the last item prior to termination of the program.

2-4. Comments and Method

a. Method. The method of analysis has been presented in Section 2.1. Additional details of analysis are presented in the descriptions of each subroutine, especially Subroutine RECM.

b. Supporting Subroutines. Twenty eight supporting subroutines are required by SIIRACP, 22 of which are identical to those used by RTFRACP. The purpose of each one is briefly described below. Those subroutines peculiar to SIIRACP and explained in Chapters 3-8 are denoted by asterisks below.

*(1) TRECNF--Computes complex vector aperture electric fields of antenna for all three monopulse channels at NX x NY sample points.

(2) ORIENT--Computes matrices ROTATE and TRANSLate used for coordinate transformations by Subroutines POINT and VECTOR.

(3) POINT--Transforms a point $P(x_A, y_A, z_A)$ in antenna system to the same point $P(x_R, y_R, z_R)$ in radome coordinate system, and vice versa.

(4) VECTOR--Transforms a vector from radome to antenna coordinate system, and vice versa.

(5) INCPW--Computes the rectangular electric field components of a plane wave incident from the direction k_A in antenna coordinates. The power density of the plane wave is unity.

*(6) RECM--Computes the voltage received by each channel of the antenna for a plane wave EINC(E_x, E_y, E_z) incident on the radome from the direction KA(k_x, k_y, k_z).

(7) OGIVEN--Computes the unit inward normal to the tangent ogive radome surface at a specified point.

(8) RXMIT--Computes the transmitted electric fields of the plane wave traveling in direction $-\hat{k}$ and incident on a flat dielectric wall with unit inner normal $\hat{n}$. The unit vectors $\hat{k}$, $\hat{n}$ are used to resolve the incident plane wave into vector components perpendicular and parallel to the plane of incidence, and to determine the angle of incidence.

*(9) WALL-Computes the normal voltage transmission coefficients of flat panel model of the radome wall as function of the sine of the incidence angle.

(10) AXB--Computes real vector cross product $\underline{C} = \underline{A} \times \underline{B}$.

(11) CAXB--Computes the complex vector cross product $\underline{C} = \underline{A} \times \underline{B}$, where $\underline{A}$ is complex and $\underline{B}$ is real.

(12) RECBS--Computes boresight errors of antenna enclosed by the radome for the specified orientation, fineness ratio, etc.

(13) RECPTN--Computes receiving patterns of all three channels.

*(14) APINT--Computes the fields of specified planar aperture fields using equivalent currents.

*(15) DIPOLES--Computes the fields of electric and magnetic dipoles located on a planar surface as required by Subroutine APINT.

*(16) CAXCB--Computes the complex vector product $\underline{C} = \underline{A} \times \underline{B}$, where $\underline{A}$ and $\underline{B}$ are complex.

(17) FAR--Computes the amplitude of the power pattern from the complex plane wave spectra $A_x(k_x,k_y)$, $A_y(k_x,k_y)$ of an antenna.

(18) AMPHS--Converts a complex number from rectangular to polar form. This subroutine utilizes the intrinsic function ATAN2. The amplitude produced is linear (not decibels), and the phase is in degrees on the range (-180, 180).

(19) DBPV--Converts a real, two-dimensional array from linear to logarithmic values in decibels on the range 0 to -40 dB.

(20) NORMH--Normalizes a two-dimensional real array to values between 0 and 1.

(21) CNPLTH--Plots single dimensional far field patterns on axes patterned after standard pattern recorder paper. CNPLTH calls Subroutine PSI in addition to the usual Calcomp subroutines.

(22) PSI--Used by Subroutine CNPLTH to compute the azimuthal angle ψ.

(23) PLT3DH--Yields three-dimensional plots of the data in the two-dimensional real array FIELD. PLT3DH calls Subroutines PLTT, NORMH as well as the usual Calcomp subroutines.

(24) PLTT-Used by Subroutine PLT3DH to eliminate moving the pen for hidden lines.

(25) FFTA--Computes the Fast Fourier Transform of a one-dimensional complex array having 2**IEXP elements. Proper operation is machine dependent.

(26) MAGFFT--Provides increased resolution of a sampled function using FFT and Discrete Fourier Transform techniques.

(27) JOYFFT--Provides increased resolution of selected portions of a two-dimensional Fourier transform. JOYFFT calls Subroutines FFTA and PWRTWO.

(28) PWRTWO--Used by Subroutine JOYFFT to ensure that a given integer is a power of 2.

2-5. Program Flow

For the following, refer to the program listing in Section 2-8 and the line numbers shown on the right-hand margin of that listing.

Line Nos.	Explanation
15	All variables beginning with the letter K in the main program are real.
16-21	Declare variables and array dimensions. Note equivalence statements in Lines 23-25. The dimension of IBUF in Line 25 may be computer system dependent. Note in Line 21 that only twenty fineness ratios, scan planes, and scan angles can be accommodated.
27-35	Label common is used as a convenient means to transmit variables to subroutines not directly called by MAIN. The labels are generated from the names of the subroutines which receive the variables, and each label is terminated with the letter C to denote common; e.g., REC1C denotes variables common to MAIN and Subroutine REC1M.

40-42	Declare namelists for printing data. These namelists are no longer used except for occasional debugging purposes.
43-57	Set data in DATA statements as described above in Section 2-3.
61-62	Set SMAX and VMAX to unity to prevent division by zero.
63-64	Read and write TITLE according to 18A4 format.
65-67	Read input data using free-field format.
68	Compute sine of the offset angle θ_{OS}.
69	Set TABLE=FALSE so that normalizing factor VAIRM can be computed via a call to Subroutines RECM and RXMIT. In the latter, TABLE=FALSE causes $T_{\perp}$, $T_{\parallel}$ to be set unity as in the case of no radome.
71-75	Write input data.
76-80	Read input data and set VAIRM needlessly.
81-111	Comments explaining input variables.
112	Set NN=N+1= Number of wall layers plus one.
113	Initialize DINCH= total thickness of radome wall in inches.
114	Read wall data and compute total thickness.
117	Compute DIAIN= inside base diameter of the radome in inches.
118-119	Compute indices of the center element of near-field arrays corresponding to $x_A = y_A = 0$.
120-121	Write array dimensional data.
122-129	Read fineness ratios, scan planes, and scan angles.

130-133 Compute wavelength in inches and centimeters. Compute $\beta=2\pi/\lambda_{cm}$.

134 Compute DAPWL= diameter of antenna aperture in wavelengths.

135-148 Convert variables in inches to centimeters for input to subroutines. Some variables are multiply defined to avoid conflicts in labeled common; e.g., ZBOT and Z1. Note that DIACM is the inside diameter of the radome in centimeters.

149-153 Convert angles from degrees to radians using RAD=π/180.

154-160 Compute near fields of three channel monopulse antenna using Subroutine TRECNF.

161-168 Set KYMAX=KXMAX, compute magnified folding wavenumbers KXM, KYM, and print results.

169-187 Initialize Calcomp plotter, if required. The commented initialization (Lines 175-185) applies to the IBM 3033 system at JHU/APL.

Note: Lines 188-268 are used to plot the near fields of the antenna and/or the transmitting principal plane power patterns.

189-190 Initialize the maximum values FMXEL, FMXDAZ of the E- and H-plane patterns so that when used initially as inputs to Subroutine FAR, the resulting pattern will be normalized with respect to its own maximum and FMXEL and FMXDAZ will be set equal to these respective maxima. On subsequent calls to FAR, the resulting patterns will be normalized with respect to FMXEL and FMXDAZ. Hence,

the relative gain of the difference and sum patterns will be correctly displayed in the graphs.

191 Iterate for each of three monopulse antenna channels.

192-201 Equate complex arrays EXT, EYT to the selected near field and compute the amplitude NF of EXT.

202 Assume transmitting near fields are to be plotted (GRAFTR=T).

204 Call Subroutine PLT3DH to plot the amplitude of EXT. The inputs XSIZE=6., YSIZE=2.5, HEIGHT=2.5 yield a 3D plot that will fit on a 8½" x 11" report page. The inputs NF, NX, NY specify the real array to be plotted and its dimensions. The input NMZ=.TRUE. directs the subroutine to normalize NF so that its values be between 0 and 1. The input LDB=.FALSE indicates that the array NF contains linear values rather than logarithmic values (decibels).

205-212 Compute and plot phase of EXT on a scale of -180 degrees to +180 degrees. Note that Line 210 ensures that the real array NF contains these phase values scaled to the required 0 to 1 range.

213-226 Repeat amplitude and phase 3D plots for EYT.

227 Assume GRAFSA=T so that principal plane patterns are plotted.

230 If IP=3, go to Line 254 and plot H-plane patterns; otherwise, plot E-plane patterns.

233 Call Subroutine JOYFFT to calculate the inverse Fourier transform of the x_A-component of near field EXT to

produce the plane wave spectrum XEEL from which the radiation field can be computed. In the process of computing the transform, provide increased resolution from NX x NY points to NYE x NXE points through point (NXC,NYC) in the array EXT. In the k_x direction, the plane wave spectrum is magnified by MY; it is magnified by MX in the k_y direction. The array FFTXY is a working array.

234 Repeat for EYT to produce the plane wave spectrum YEEL for the y_A-component of field.

235 Call Subroutine FAR to calculate the E-plane elevation (IPWR=3) power pattern FFSEL of the near field at equal samples in $\sin\theta$ over the range (-KXM, KXM -ΔK). If FMXEL$\leq$0 (and it is for IP=1), normalize FFSEL with respect to its own maximum.

237 Call Subroutine DBPV and convert the power pattern to decibels on a scale of 0 to -40 dB.

238-241 Scale the values in FFSEL to the range of 0 to 1 for plotting.

242 Call Subroutine CNPLTH and plot the power pattern. If KXM<1, the pattern is plotted over the angular range corresponding to $\sin^{-1}$(KXM); if KXM$\geq$1, the angular range is (-90°, 90°). Subroutine CNPLTH actually plots conical cuts corresponding to k_x= constant or k_y= constant as specified by inputs KXC, KYC. In the call here, KXY=KYC=0 so that a principal pattern is produced.

243-247	Write a figure title for the plot and establish a new origin for the next plot.
248	If IP=2, the E-plane patterns are finished.
249-253	Since JOYFFT changes the input arrays EXT,EYT it is necessary to recompute them so that increased resolution can be obtained in the plane wave spectra in the H-plane.
254-269	Repeat computation and plotting for H-plane power patterns.
271	Iterate the radome analysis for NFINE fineness ratios.
272	Set FINE = outside fineness ratio.
273-277	Calculate and write R_{OS}, B, F_{OS}, F_{IS} as defined in Figure 2-1 for the radome geometry.
278	Compute RDML = distance from the base of the radome to the theoretical tip on the inside of the radome.
279-283	If ZTOPIN<RDML, the radome has a metal tip, and a message is written to that effect.
284-309	Compute parameters needed by Subroutine OGIVE to describe the radome shape. R and B are in centimeters and apply to the inside dimensions. AP, the height of the cylinder in centimeters, is not used. RTSQ= square of the radius of the top disk. RBSQ= square of the radius of the bottom disk (bulkhead). The other variables, BSQ, RINV, RSQ1, RP, and RP2, are precalculated here to speed later computations in OGIVE.

310	Compute conversion factor DPMR for converting milli-radians to degrees.
311-314	Initialize the "last" values of boresight error in azimuth (AZL) and elevation (ELL) and the "last" value THL of scan angle. These variables are used later to compute boresight error slope in degrees per degree from the present and last values of boresight error.
315-316	Write title for analysis results.
317-319	Write parameters of radome wall.
320-322	Write heading for table of boresight error and gain data.
323-334	Write this same data to logical unit 7 for subsequent storage as a disk file, if desired.
335	Iterate the radome analysis for NPHI scan planes.
336-338	Compute ϕ_r in radians as required by Subroutine ORIENT.
339	Iterate the analysis for NTHE scan angles in each scan plane.
340-342	Compute θ_r in radians as required by Subroutine ORIENT.
343	Call Subroutine ORIENT and compute the rotation matrix ROTATE and translation matrix TRANSL required for coordinate transformations using Subroutines POINT and VECTOR.
344	On the first iteration, TABLE is false so that the maximum amplitude of the received voltage on the sum channel is computed without the radome.

345-347	Set the direction cosines of the incident plane wave so that it arrives from the $\hat{z}_A$ direction.
348	Call Subroutine INCPW and compute the rectangular components PWI of the incident plane wave having polarization specified by IOPT.
349-354	Set TSUP=T and TABLE=F so that an air radome wall be used and so that printing by Subroutine RXMIT and RECM will be suppressed.
355-356	Call Subroutine RECM and compute the complex voltages VR received on the sum, difference elevation, and difference azimuth channels, respectively, corresponding to VR(I), I=1,3.
360	Compute VAIRM=|VR(1)|.
362	Set TABLE=T so that on subsequent iterations VAIRM will not be recomputed, and so that the table of transmission coefficients will be utilized when RXMIT is called.
363	If SUPPRS=F, compute and print the E-plane and H-plane receiving power patterns of the antenna with the radome in place.
366	Iterate in J for E-plane (ICUT=1) and H-plane (ICUT=2) patterns.
368	Set the desired far field component.
369	Set the temporary logical variable TSUP=T so that printing will be suppressed.

370-371	Call Subroutine RECPTN and compute the complex received voltages on each of three channels at NREC points over the range (-KMAX, KMAX - DK).
372-375	Increase the resolution and print results for all three channels. Do not print results that are known to be identically zero.
376-377	Transfer the received voltage into a one-dimensional array VREC.
378	If NREC>NXE, there is no need to increase the resolution.
379	Call Subroutine MAGFFT to increase the resolution of VREC from NREC points to NXE points. The result is contained in complex array XYFFT on output.
380-384	Compute linear power pattern.
385	Select NXX= larger of NXE and NREC.
386	Write heading for printed results from Subroutine NORMH.
388	Call Subroutine NORMH to normalize the NXX values in real array MVREC to be between zero and one. The input argument LDB=.FALSE. since the values are not in decibels.
389	Call Subroutine DBPV to convert the power pattern in MVREC to decibels.
390-391	Write correct heading for E-plane or H-plane.
392	Compute the increment in sinθ at which power pattern has been computed and resolved.
393-404	Scale the power pattern to have values between 0 and 1. If SUPPRS=F, compute the angle θ=ANG and the phase

of the pattern, and print the results for every fourth angle.

405 If GRAFRV=T, plot the receiving power patterns.

406-416 Call Subroutine CNPLTH and plot the receiving patterns in turn. Write an appropriate figure title following each pattern plot. Re-origin the plotter pen for subsequent plots. The result of Lines 330-383 is four principal plane patterns: E-plane sum, E-plane Δ_{EL}, H-plane sum, H-plane Δ_{AZ}.

417-419 Call Subroutine RECBS and compute the boresight errors AZT, ELT in the azimuth and elevation planes of the antenna as caused by the radome. On output, the real array KA contains the direction cosines of the last target return and, hence, gives the true direction to the target at the time that the tracking functions in the azimuth and elevation planes indicated the electrical boresight direction.

420 If this is the first iteration in scan angle, do not attempt to compute boresight error slope.

421-422 Compute boresight error slope (degrees/degree) in azimuth and elevation channels.

423-425 Set the "last" values of boresight errors and scan angle to the current values in preparation for next iteration.

426-428 Compute loss in maximum gain of the antenna sum channel due to the radome.

429-430	Write results to logical units 6 and 7.
434-435	Write maximum amplitude of received sum voltage VAIRM without radome.
436	Terminate plotting software.
	STOP
	END

2-6. Test Case

A test case has been delivered to JHU/APL under separate cover. Typical input data are shown in Table 2-1.

2-7. References

1. G. K. Huddleston and E. B. Joy, "Development of Fabrication and Processing Techniques for Laser Hardened Missile Radomes: Radome Electrical Design Analysis", Martin Marietta Purchase Agreement 573712, April 1977.

2. G. K. Huddleston, H. L. Bassett, and J. M. Newton, "Parametric Investigation of Radome Analysis Methods", IEEE AP-S Symposium Digest, pp. 199-202, May 1978; also, Proc. Fourteenth Symposium on Electromagnetic Windows, pp. 21-28, June 1978.

3. E. B. Joy and G. K. Huddleston, "Radome Effects on the Performance of Ground Mapping Radar," U.S. Army Missile Command, DAAH-01-72-C-0598, March 1973.

2-8. Program Listing: See following pages.

```
 TEST SIIRACP FEB 80
F,F,F,F,F,00,T                                                    1
1.1,1,1.1241,.01,.01,1.70,35.,3.                                  2
5.,5,1,.159,1.0,1,1,1,1,.5,4                                      3
.11241,.11241,8,8                                                 4
.001,1.00,0.000                                                   5
1.505                                                             6
0.                                                                7
0.                                                                8
                                                                  9
```

Table 2-1. Input Data for SIIRACP.

```
C  THIS RADOME ANALYSIS COMPUTER PROGRAM, SIIRACP, WAS PREPARED FOR          1
C  JOHNS HOPKINS APL BY G.K. HUDDLESTON, JANUARY 1980, UNDER THE            2
C  COGNIZANCE OF ROBERT C. MALLALIEU.                                       3
C  SUBR TRECNF COMPUTES NEAR FIELDS SUITABLE FOR THIS SURFACE               4
C  INTEGRATION (INNER RADOME SURFACE) ANALYSIS APPROACH.                    5
C  COMPUTED RESULTS ARE ALSO WRITTEN TO TAPE7 FOR LATER USE.                6
C                                                                           7
C-----------------------------------------------------------------------    8
C                                                                           9
C       IMPLEMENTATION AT APL/JHU  2/11/80  FOR IBM 3033                   10
C                                                                          11
C-----------------------------------------------------------------------   12
C  *** LIBRARIES LSIIRAC AND MISCFFT ARE REQUIRED FOR EXECUTION ***        13
      PROGRAM SIIRACP(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)         14
      IMPLICIT REAL(K)                                                     15
      REAL NF(4,4),MVREC(256),KA(3)                                        16
      COMPLEX SUMX(4,4),SUMY(4,4),DELX(4,4),DELY(4,4)                      17
      COMPLEX DAZX(4,4),DAZY(4,4),EXT(4,4),EYT(4,4)                        18
      COMPLEX VR(16),VREC3(6,3),VREC(32)                                   19
      REAL FFS(256,1),FFSEL(1,256)                                         20
      COMPLEX XE(256,1),YE(256,1),XYFFT(512),PWI(3)                        21
      COMPLEX XEEL(1,256),YEEL(1,256)                                      22
      EQUIVALENCE(XE(1,1),XEEL(1,1))                                       23
      EQUIVALENCE(YE(1,1),YEEL(1,1))                                       24
      EQUIVALENCE(FFS(1,1),MVREC(1),FFSEL(1,1))                            25
C                                                                          26
      LOGICAL GRAF3D,GRAFSA,GRAFTR,GRAFRV,TABLE,SUPPRS,TSUP,SQUARE         27
      INTEGER IBUF(512)                                                    28
C                                                                          29
      REAL ROTATE(3,3),TRANSL(3),TITLE(18)                                 30
      REAL FINR(20),PHI(20),THETA(20)                                      31
      COMMON/RECIC/DSTH,DSPHI,NTHMIN,NPHIMIN,AREA,NPOINTS,ROS,RIS,         32
     $ZBOTCM,ZTOPCM,BCM,RR                                                 33
      COMMON/TDISKC/ZTOP,RTSQ                                              34
      COMMON/TRACC/Z2,Z1                                                   35
      COMMON/BDISKC/ZBOT,RBSQ                                              36
      COMMON/TRANSC/DIN(6),ER(6),TD(6),TZ,WALTOL,N,NN,D(6),ZB,TK           37
      COMMON/OGIVC/RP,BSQ,AP,RINV,B,RSQ1,RP2                               38
```

```
C                                                                       39
      NAMELIST/GEOM/RR,RA,APIN,ZBOTIN,NX,NY,NXE,NYE,NXY,MX,MY,NXC,NYC  40
      NAMELIST/KDATA/KXMAX,KYMAX,KXM,KYM                               41
      NAMELIST/NEW/LMAX,DMRAD,IOPT,RAPMAX,VAIRM                        42
C  BOUNDARY VALUES NEEDED BY SUBR TRACE (INCHES, CONVERT TO CM BELOW)   43
C Z1=ZR COORDINATE OF BOTTOM DISK                                       44
C Z2=ZR COORDINATE OF TOP DISK (Z1,Z2 IN CM)                            45
C  APIN IS HEIGHT OF CYLINDER IN INCHES, CONVERT TO CM BELOW            46
      DATA APIN/0./                                                     47
C  ZBOTIN IS ZR COORD OF BOTTOM DISK (BULKHEAD) IN RADOME COORD IN INCHE 48
      DATA ZBOTIN/0.00/                                                 49
C  KXMAX,KYMAX ARE OUTPUTS OF NEAR FIELD SUBR                           50
C  INITIALIZE CONSTANTS                                                 51
      DATA RADIUS/1E0/                                                  52
      DATA THETAA,PHIA,AGAM3A/0.0,90.0,0.0/                             53
      DATA PI/3.1415926535898/                                          54
C************                                                           55
      DATA NX,NY,NYE,NXY/4,4,1,512/                                     56
      DATA MY/1/,NREC/6/                                                57
C************                                                           58
C                                                                       59
C  READ IN DESCRIPTION OF RADOME WALL                                   60
      SMAX=1.0                                                          61
      VMAX=1.0                                                          62
      READ(5,6)TITLE                                                    63
      WRITE(6,6) TITLE                                                  64
      READ(5,*) GRAF3D,GRAFSA,GRAFTR,GRAFRV,SUPPRS,IPENCD,SQUARE        65
  260 FORMAT(4L6)                                                       66
      READ(5,*) NFINE,NPHI,NTHE,DIAOS,RAIN,RRIN,ZTOPIN,FREQ,OSANG      67
      SINOS=SIN(OSANG*PI/180.)                                          68
      TABLE=.FALSE.                                                     69
C  TABLE IS SET FALSE SO THAT NORMALIZING FACTOR CAN BE COMPUTED.       70
      WRITE(6,265) GRAF3D,GRAFSA,GRAFTR,GRAFRV,TABLE                    71
  265 FORMAT(" GRAF3D=",L2," GRAFSA=",L2," GRAFTR=",L2," GRAFRV=",L2,   72
     $ "  TABLE=",L2)                                                   73
      WRITE(6,270) NFINE,NPHI,NTHE,OSANG                                74
  270 FORMAT(/" NFINE=",I5," NPHI=",I3,"  NTHETA=",I3,"  OSANG= ",F5.2/) 75
      READ(5,*) LMAX,DMRAD,IOPT,RAPMAX,VAIRM,IPOL,ICASE,N,IPWR,KMAX,NXE 76
```

```
      MX=NXE/NX                                                          77
      IF (MX.LT.1) MX=1                                                  78
      READ(5,*) DSTHIN,DSPHIN,NTHMIN,NPHIMIN                             79
      IF (VAIRM.LE.0.) VAIRM=1.0                                         80
C DIAOS=OUTSIDE DIAMETER OF BASE OF TANGENT OGIVE RADOME                 81
C VAIR=MAXIMUM REC"D VOLTAGE W/O RADOME AT KX=0.,KY=0.                   82
C NFINE=NO. OF FINENESS RATIOS                                           83
C  NPHI=NUMBER OF SCAN PLANES                                            84
C  NTHE=NUMBER OF ANGLES IN EACH SCAN PLANE                              85
C DIAIN=INSIDE BASE DIAMETER OF RADOME IN INCHES                         86
C ZTOPIN=ZR COORD (IN) OF TOP DISK (METAL TIP)                           87
C FREQ=FREQUENCY IN GHZ                                                  88
C GRAF3D=.TRUE. GIVES 3D PLOTS OF INCIDENT FIELDS ON APERTURE (DELETED)  89
C GRAFRV=.TRUE. GIVES SA PLOTS OF RECEIVING PATTERNS (AZ & EL)           90
C GRAFSA=.TRUE. GIVES SA PLOTS OF TRANSMITTING PATTERN WITHOUT RADOME    91
C SUPPRS=.TRUE. SUPPRESSES THE PRINTING OF NUMEROUS RESULTS              92
C RAPMAX=MAX RADIUS OF ANTENNA APERTURE IN INCHES.                       93
C  IOPT SELECTS POLARIZATION OF INCIDENT PLANE WAVE:                     94
C      =1 ELEV (VERTICAL)                                                95
C      =2 AZIMUUTH (HORIZONTAL)                                          96
C      =3 RHC                                                            97
C      =4 LHC                                                            98
C  IPOL SELECTS POLARIZATION OF ANTENNA WHEN ICASE=1:                    99
C      = SAME CODE AS FOR IOPT                                          100
C  ICASE=1 OR 2 FOR CIRC APERTURE, UNIFORM ILLUMINATION                 101
C       =3 FOR FLAT PLATE WITH SPECIFIED ILLUM, VERT POL (CASE III)     102
C  N=NUMBER OF LAYERS IN RADOME WALL                                    103
C  OSANG=ANGLE IN DEG IN 45 PLANE OFF BORESIGHT OF FIRST TARGET RETURN  104
C       USED BY SUBR RECBS IN GETTING INITIAL DATA.                     105
C  IPWR=1 FOR POWER IN ELEV COMP OF FAR FIELD PATTERN                   106
C      =2 FOR AZIMUTH COMP,=3 FOR TOTAL POWER.                          107
C  DSTHIN=SAMPLE DISTANCE (IN.) ON RADOME SURFACE IN THETA DIRECTION    108
C  DSPHIN=  -DITTO-                                    PHI DIRECTION    109
C  NTHMIN=MINIMUM NUMBER OF SAMPLES IN THETA DIRECTION                  110
C NPHIMIN=  -DITTO-                        PHI DIRECTION                111
      NN=N+1                                                           112
      DINCH=0.                                                         113
      DO 5 I=1,N                                                       114
```

```
      READ(5,*) DIN(I),ER(I),TD(I)
    5 DINCH=DIN(I)+DINCH
      DIAIN=DIAOS-DINCH*2.
      NXC=NX/2+1
      NYC=NY/2+1
      WRITE(6,4) NX,NY,NXE,NYE,NXY,MX,MY
    4 FORMAT(" NX,NY,NXE,NYE,NXY,MX,MY:",7I4)
C READ FINENESS RATIOS FOR THIS RUN--BASED ON OUTSIDE DIMENSIONS
      DO 13 I=1,NFINE
   13 READ(5,*) FINR(I)
C READ ORIENTATIONS FOR THIS RUN (DEGREES)
      DO 14 I=1,NPHI
   14 READ(5,*) PHI(I)
      DO 15 I=1,NTHE
   15 READ(5,*) THETA(I)
C  COMPUTE WAVELENGTH:
      WLIN=29.97925/(FREQ*2.54)
      WLCM=WLIN*2.54
      BETA=2.*PI/WLCM
      DAPWL=2.*RAPMAX/WLIN
C  CONVERT TO CENTIMETER AND RADIANS
      ZBOT=ZBOTIN*2.54
      Z1=ZBOT
      RSQMAX=(2.54*RAPMAX)**2
      DIACM=DIAIN*2.54
      ZTOP=ZTOPIN*2.54
      ZB=ZTOP
      Z2=ZTOP
      ZTOPCM=ZTOP
      ZBOTCM=ZBOT
      RA=RAIN*2.54
      RR=RRIN*2.54
      DSTH=DSTHIN*2.54
      DSPHI=DSPHIN*2.54
      RAD=PI/180.0
    6 FORMAT(18A4)
      THETAA=THETAA*RAD
      PHIA=PHIA*RAD
```

```
 A JAM A-A JAM A*HA.
ME IE FIEL   E ANTENNA WEEN XM  IN
  A   IHF NF  OMA,NX,NY,  IP   ,IAPW ,DXW ,KXMAX,I A E,SQUARE,
  A   IHF NF  OMY,NX,NY,  IP   ,  APW ,IXW ,KXMAX,I A E,SQUARE,
  A   IHF NF IEIX,NX,NY,  IP   ,IAPWI,DXW ,KXMAX,I A E,SQUARE,
  A   IHF NF IEIY,NX,NY,  IP   ,IAPWI,IXWI,KXMAX,I A E,SQUARE,
  A   IHF NF  AIX,NX,NY,  IP   , AFW ,IXWI,KXMAX,I A E,SQUARE,
  A   IHF NF  AIY,NX,NY,  IP   , AFW ,IXWI,KXMAX,I A E, QUARE
 KYMAX=KXMAX
 KXM=KXMAX*NXF MA NX
 KYM=KYMAX*NY  M  NY
  W    W
 WRITE     KXMAX,IXW ,KYM,KYM,  HIN,  PHIN,NTHMIN,NPHIMIN
  FRMAT " KXMAX=KYMAX=",F   ,"    XWI=IYW =",F   ," WAVELENGTHS",
 $"  KXM ",F   ,"  KYM=",F   ,"    HIN=",F   ,"   PHINE=",
 $F   ,"  NTHMIN=",I ,"  NPHIMIN ",I
 
NITIAL   E P  TIER   ETWARE
  IF  GRAPHI  R  RAP A   R  RAPTI  R  RAPHN
   
   NTINUE

            -   -  AL  ME INITIALIZATION ----------------------------

  R        "RAD ME ANALY I    ME IER PR GRAM",
 *              "           RI  R  ILE TI N         ",
 *              "  R R  IA IN TIT IF  E IF  RN    Y"
  A   N      M A

  R
  A  R     IF F,    PEN

                                     -- ----------------------------

  IF   RAPTI  R  RAP A
 
  M
  M  A
```

```
      DO 30 IP=1,3                                                      191
      DO 35 I=1,NX                                                      192
      DO 35 J=1,NY                                                      193
      IF (IP.EQ.1) EXT(I,J)=SUMX(I,J)                                   194
      IF  IP.EQ.1) EYT(I,J)=SUMY(I,J)                                   195
      IF (IP.EQ.2) EXT(I,J)=DELX(I,J)                                   196
      IF (IP.EQ.2)EYT(I,J)=DELY(I,J)                                    197
      IF (IP.EQ.3) EXT(I,J)=DAZX(I,J)                                   198
      IF (IP.EQ.3) EYT(I,J)=DAZY(I,J)                                   199
      NF(I,J)=CABS(EXT(I,J))                                            200
   35 CONTINUE                                                          201
      IF (.NOT.GRAFTR) GO TO 215                                        202
C PLOT 3D NEAR FIELDS X-COMPONENTS                                      203
      CALL PLT3DH(6.,2.5,2.5,NF,NX,NY,.TRUE.,.FALSE.)                   204
C  PLOT PHASE ALSO                                                      205
      DO 40 I=1,NX                                                      206
      DO 40 J=1,NY                                                      207
      NF(I,J)=0.                                                        208
      CALL AMPHS(EXT(I,J),RLF,AIF)                                      209
      NF(I,J)=(AIF+180.)/360.                                           210
   40 CONTINUE                                                          211
      CALL PLT3DH(6.,2.5,2.5,NF,NX,NY,.FALSE.,.FALSE.)                  212
C PLOT 3D NEAR FIELDS Y-COMPONENTS                                      213
      DO 45 I=1,NX                                                      214
      DO 45 J=1,NY                                                      215
      NF(I,J)=CABS(EYT(I,J))                                            216
   45 CONTINUE                                                          217
      CALL PLT3DH(6.,2.5,2.5,NF,NX,NY,.TRUE.,.FALSE.)                   218
C  PLOT PHASE ALSO                                                      219
      DO 50 I=1,NX                                                      220
      DO 50 J=1,NY                                                      221
      NF(I,J)=0.                                                        222
      CALL AMPHS(EYT(I,J),RLF,AIF)                                      223
      NF(I,J)=(AIF+180.)/360.                                           224
   50 CONTINUE                                                          225
      CALL PLT3DH(6.,2.5,2.5,NF,NX,NY,.FALSE.,.FALSE.)                  226
      IF (GRAFSA) GO TO 215                                             227
      GO TO 30                                                          228
```

```
  215 CONTINUE                                                          229
      IF (IP.EQ.3) GO TO 220                                            230
C CALC EL CUT OF SUM                                                    231
C  NOTE THAT  JOYFFT CHANGES EXT,EYT.                                  232
      CALL JOYFFT(EXT,NX,NY,MY,MX,NXC,NYC,XEEL,NYE,NXE,XYFFT,NXY,3)     233
      CALL JOYFFT(EYT,NX,NY,MY,MX,NXC,NYC,YEEL,NYE,NXE,XYFFT,NXY,3)     234
      CALL FAR(FFSEL,XEEL,YEEL,NYE,NXE,FREQ,KYM,KXM,RADIUS,IPWR,FMXEL)  235
C SA PLOTS OF ELEVATION RESULTS                                         236
      CALL DBPV(FFSEL,NYE,NXE,1)                                        237
      DO 216 I=1,NYE                                                    238
      DO 216 J=1,NXE                                                    239
      FFSEL(I,J)=1.0+FFSEL(I,J)/40.                                     240
  216 CONTINUE                                                          241
      CALL CNPLTH(FFSEL,NXE,KXM,0.,0.)                                  242
      CALL SYMBOL(.5,6.5,.140000,39HFIGURE     TRANSMITTING ELEVATION PO 243
     $WER,0.,39)                                                        244
      RPWR=FLOAT(IPWR)                                                  245
      CALL NUMBER(999.,999.,.14,RPWR,0.,0)                              246
      CALL PLOT(8.5,0.,-3)                                              247
      IF (IP.EQ.2) GO TO 30                                             248
C  RECOMPUTE SUMX,SUMY FOR JOYFFT:                                      249
      CALL TRECNF(EXT,NX,NY,1,IPOL,1,DAPWL,DXWL,KXMAX,ICASE,SQUARE)     250
      WRITE(6,219) IPWR                                                 251
  219 FORMAT(" IPOWER OF PATTERN=",I2)                                  252
      CALL TRECNF(EYT,NX,NY,1,IPOL,2,DAPWL,DXWL,KXMAX,ICASE,SQUARE)     253
  220 CALL JOYFFT(EXT,NX,NY,MX,MY,NXC,NYC,YE,NXE,NYE,XYFFT,NXY,3)       254
      CALL JOYFFT(EYT,NX,NY,MX,MY,NXC,NYC,YE,NXE,NYE,XYFFT,NXY,3)       255
      CALL FAR(FFS,XE,YE,NXE,NYE,FREQ,KXM,KYM,RADIUS,IPWR,FMXDAZ)       256
C SA PLOTS OF AZIMUTH RESULTS                                           257
      CALL DBPV(FFS,NXE,NYE,1)                                          258
      DO 10 I=1,NXE,1                                                   259
      DO 10 J=1,NYE                                                     260
      FFS(I,J)=1.0+FFS(I,J)/40.0                                        261
   10 CONTINUE                                                          262
      CALL CNPLTH(FFS,NXE,KXM,0.,0.)                                    263
  226 CALL SYMBOL(.5,6.5,.14000,37HFIGURE     TRANSMITTING AZIMUTH POWER 264
     $,0.,37)                                                           265
      CALL NUMBER(999.,999.,.14,RPWR,0.,0)                              266
```

```
      CALL PLOT(8.5,0.,-3)                                                  267
   30 CONTINUE                                                              268
  205 CONTINUE                                                              269
C                                                                           270
      DO 100 NG=1,NFINE                                                     271
      FINE=FINR(NG)                                                         272
C CALCULATE INSIDE FINENESS RATIO                                           273
      RIN=FINE*DIAOS/(SIN(PI-2.*ATAN(2.*FINE)))                             274
      ROS=RIN*2.54                                                          275
      BIN=RIN-DIAOS/2.                                                      276
      FINE=SQRT((RIN-DINCH)**2-BIN**2)/DIAIN                                277
      RDML=FINE*DIAIN+APIN                                                  278
      IF (ZTOPIN.LT.RDML) WRITE(6,25) ZTOPIN                                279
   20 FORMAT(" TANGENT OGIVE PARAMETERS: "," ROS(IN)="                      280
     $ ,F9.5," BOS(IN)=",F9.5,/26X," FINOS=",F5.3,                          281
     $ " FINIS=",F8.5,"  RINV=",E12.5)                                      282
   25 FORMAT(/" THIS RADOME HAS A TOP DISK AT ZTOPIN= ",E12.5/)              283
C  COMPUTE PARAMETERS NEEDED BY SUBR OGIVE                                 284
      R=FINE*DIACM/(SIN(PI-2.*ATAN(2.*FINE)))                               285
      RIS=R                                                                 286
      TLIS=DIAIN*FINE                                                       287
      IF (ZTOPIN.GT.TLIS) ZTOPIN=TLIS                                       288
      ZTOP=ZTOPIN*2.54                                                      289
      ZB=ZTOP                                                               290
      Z2=ZTOP                                                               291
      ZTOPCM=ZTOP                                                           292
      IF (ZTOPCM.GT.RIS) ZTOPCM=RIS                                         293
      B=R-DIACM/2.                                                          294
      BCM=B                                                                 295
      AP=APIN*2.54                                                          296
      RTSQ=R**2-(ZTOP-AP)**2                                                297
      IF (RTSQ.LT.0.) RTSQ=0.                                               298
      RTSQ=(SQRT(RTSQ)-B)**2                                                299
      RBSQ=R**2-(ZBOT-AP)**2                                                300
      IF (RBSQ.LT.0.) RBSQ=0.                                               301
      RBSQ=(SQRT(RBSQ)-B)**2                                                302
      BSQ=B**2                                                              303
      RINV=1./R                                                             304
```

```
      RSQ1=R**2                                                          305
      RP=RSQ1-BSQ                                                        306
      RP2=RSQ1+BSQ                                                       307
      WRITE(6,20) RIN,BIN,FINR(NG),FINE,RINV                             308
C                                                                        309
      DPMR=180./(PI*1000.)                                               310
      AZL=0.                                                             311
      ELL=0.                                                             312
      THL=0.                                                             313
      TLOS=DIAOS*FINR(NG)                                                314
      WRITE(6,2) TITLE,FINR(NG),DIAOS,TLOS,FREQ,RAIN,RRIN,DAPWL,IPOL,    315
     $ICASE,IOPT                                                         316
      DO 8 I=1,N                                                         317
    8 WRITE(6,7) I,DIN(I),ER(I),TD(I)                                    318
    7 FORMAT(2X,I3,F13.5,F10.3,F9.4)                                     319
      WRITE(6,9)                                                         320
    9 FORMAT(//"  PHI  THETA  BSEEL   BSEAZ   SLPEL     SLPAZ     GAIN"/  321
     $       " (DEG) (DEG)  (MRAD)  (MRAD) (DEG/DEG) (DEG/DEG)  (DB)"//)  322
      WRITE(7,2) TITLE,FINR(NG),DIAOS,ZTOPIN,FREQ,RAIN,RRIN,DAPWL,IPOL,  323
     $ICASE,IOPT                                                         324
      DO 18 I=1,N                                                        325
   18 WRITE(7,7) I,DIN(I),ER(I),TD(I)                                    326
      WRITE(7,9)                                                         327
    2 FORMAT(1H1,5X," RESULTS OF RADOME ANALYSIS USING INSIDE SURFACE IN  328
     1TEGRATION"/18A4/" FINENESS RATIO=",F8.5,2X,                        329
     2"DIAMETER=",F8.5," IN.  LENGTH=",F8.5," IN."/" FREQUENCY=",        330
     3F8.5," GHZ "/                                                      331
     4" RA=",F8.5," IN.  RR=",F8.5," IN.  ANTENNA D=",F8.4,              332
     5" WAVELENGTHS"/" IPOL=",I2,"  ICASE=",I2,"  IOPT=",I2//            333
     6" LAYER  THICKNESS(IN.)   ER      TAND"/)                          334
      DO 100 IPHI=1,NPHI                                                 335
      PHIP=PHI(IPHI)                                                     336
      PHIR=PHIP                                                          337
      PHIR=PHIR*RA                                                       338
      DO 100 ITHE=1,NTHE                                                 339
      THETAL=THETA(ITHE)                                                 340
      THETAR=180.-THETAL                                                 341
      THETAR=THETAR*RAD                                                  342
```

```
      CALL ORIENT(RA,THETAA,PHIA,RR,THETAR,PHIR,AGAM3A,ROTATE,TRANSL)        343
      IF (TABLE) GO TO 23                                                   344
C  COMPUTE NORMALIZING FACTOR:                                              345
      KA(1)=0.                                                              346
      KA(2)=0.                                                              347
      KA(3)=1.                                                              348
      CALL INCPW(KA,PWI,IOPT)                                               349
      TSUP=SUPPRS                                                           350
      TABLE=.FALSE.                                                         351
      ZTEMP=ZTOPCM                                                          352
      ZTOPCM=DIACM*FINE                                                     353
      IF (ZTOPCM.GT.RIS) ZTOPCM=RIS                                         354
      CALL RECM(PWI,KA,NX,NY,KXMAX,KYMAX,FREQ,ROTATE,TRANSL,                355
     $SUMX,SUMY,DELX,DELY,DAZX,DAZY,VR,TABLE,TSUP,RSQMAX)                   356
C  SET ZTOPCM BACK TO THE INPUTTED VALUE.                                   357
      IF (ZTOPCM.LT.ZTEMP) ZTEMP=ZTOPCM                                     358
      ZTOPCM=ZTEMP                                                          359
      VAIRM=CABS(VR(1))                                                     360
      WRITE(6,105) VAIRM                                                    361
      TABLE=.TRUE.                                                          362
   23 IF (.NOT.SUPPRS) GO TO 24                                             363
      GO TO 350                                                             364
   24 CONTINUE                                                              365
      DO 320 J=1,2                                                          366
      ICUT=J                                                                367
      ICOMP=IOPT                                                            368
      TSUP=.TRUE.                                                           369
      CALL RECPTN(SUMX,SUMY,DELX,DELY,DAZX,DAZY,NX,NY,ICUT,ICOMP,KMAX,      370
     $NREC,VREC3,KXMAX,KYMAX,FREQ,ROTATE,TRANSL,TABLE,TSUP,RSQMAX)          371
      DO 325 MM=1,3                                                         372
      ICHAN=MM                                                              373
      IF ((ICUT.EQ.1).AND.(ICHAN.EQ.3)) GO TO 325                           374
      IF ((ICUT.EQ.2).AND.(ICHAN.EQ.2)) GO TO 325                           375
      DO 26 I=1,NREC                                                        376
   26 VREC(I)=VREC3(I,ICHAN)                                                377
      IF (NREC.GE.NXE) GO TO 31                                             378
      CALL MAGFFT(VREC,NREC,XYFFT,NXE)                                      379
      DO 305 I=1,NXE                                                        380
```

```
  305 MVREC(I)=CABS(XYFFT(I))**2                                                  381
      GO TO 33                                                                    382
   31 DO 32 I=1,NREC                                                              383
   32 MVREC(I)=CABS(VREC(I))**2                                                   384
   33 NXX=MAX0(NXE,NREC)                                                          385
      WRITE(6,306)                                                                386
  306 FORMAT(/" MIN AND MAX VALUES OF REC""G PATTERN: "/)                         387
      CALL NORMH(MVREC,NXX,1,.FALSE.)                                             388
      CALL DBPV(MVREC,NXX,1,1)                                                    389
      IF (J.EQ.1) WRITE(6,308)                                                    390
      IF (J.EQ.2) WRITE(6,309)                                                    391
      DK=2.*KMAX/NXX                                                              392
      IMOD=4                                                                      393
      IF (NREC.GE.NXE) IMOD=1                                                     394
      DO 307 I=1,NXX,1                                                            395
      IF (SUPPRS) GO TO307                                                        396
      ANG=ASIN(-KMAX+(I-1)*DK)*180./PI                                            397
      CALL AMPHS(XYFFT(I),AMP,PHS)                                                398
      IF (NREC.GE.NXE) CALL AMPHS(VREC(I),AMP,PHS)                                399
      IF (MOD(I,IMOD).EQ.0) WRITE(6,310) ANG,MVREC(I),PHS                         400
  307 MVREC(I)=1.0+MVREC(I)/40.                                                   401
  308 FORMAT(/" REC""G PATTERN, EL CUT, EL COMP (DB): "/)                         402
  309 FORMAT(/" REC""G PATTERN, AZ CUT,EL COMP (DB): "/)                          403
  310 FORMAT(F9.1,5X,F8.3,3X,F6.1)                                                404
      IF (.NOT.GRAFRV) GO TO 325                                                  405
      CALL CNPLTH(MVREC,NXX,KMAX,0.,0.)                                           406
      IF (J.EQ.1) CALL SYMBOL(.5,6.5,.140,43HFIGURE       RECVG POWER PA          407
     $TTERN-ELEV PLANE,0.,43)                                                     408
      IF (J.EQ.2) CALL SYMBOL(.5,6.5,.140,41HFIGURE       RECVG POWER PA          409
     $TTERN-AZ PLANE,0.,41)                                                       410
      CALL PLOT(8.5,0.,-3)                                                        411
  325 CONTINUE                                                                    412
  320 CONTINUE                                                                    413
  350 CONTINUE                                                                    414
C COMPUTE BORESIGHT ERROR                                                         415
  275 CONTINUE                                                                    416
      CALL RECBS(SUMX,SUMY,DELX,DELY,DAZX,DAZY,NX,NY,                             417
     $ LMAX,NS,IOPT,VR,DMRAD,ROTATE,TRANSL,FREQ,KXMAX,KYMAX,                      418
```

```
     $ TABLE,SINOS,KA,AZT,ELT,RSQMAX,VMAX,SMAX,SUPPRS)                    419
      IF (ITHE.EQ.1) GO TO 300                                            420
      SLPAZ=(AZT-AZL)*DPMR/(THETAL-THL)                                   421
      SLPEL=(ELT-ELL)*DPMR/(THETAL-THL)                                   422
  300 AZL=AZT                                                             423
      ELL=ELT                                                             424
      THL=THETAL                                                          425
      GAINM=SMAX/VAIRM                                                    426
      IF (GAINM.LT.1E-2) GAINM=1E-2                                       427
      GAINM=20.*ALOG10(GAINM)                                             428
      WRITE(6,11) PHIP,THETAL,ELT,AZT,SLPEL,SLPAZ,GAINM                   429
      WRITE(7,11) PHIP,THETAL,ELT,AZT,SLPEL,SLPAZ,GAINM                   430
   11 FORMAT(1X,F5.1,F6.1,F8.2,F8.2,F9.4,F10.4,F7.1)                      431
C  GRAF3D OPTION HAS BEEN REMOVED.                                        432
  100 CONTINUE                                                            433
      WRITE(6,105) VAIRM                                                  434
  105 FORMAT(//" RECEIVED SUM VOLTAGE WITHOUT RADOME=",E12.5//)           435
      IF (GRAF3D.OR.GRAFSA.OR.GRAFTR.OR.GRAFRV) CALL PLOT(0.,0.,999)      436
      STOP                                                                437
      END                                                                 438
```

```
      BLOCK DATA                                                        1
C                                                                       2
      COMMON/TRANSC/DIN(6),ER(6),TD(6),TZ,WALTOL,N,NN,D(6),ZB,TK        3
C                                                                       4
      DATA WALTOL,TK,TZ/0.,0.,0./                                       5
C                                                                       6
      END                                                               7
```

Chapter 3

SUBROUTINE RECM

3-1. Purpose: To compute the complex voltages produced at the terminals of the three channels of a radome enclosed monopulse antenna by a plane wave of specified polarization and direction of arrival.

3-2. Usage: CALL RECM (EINC, KA, NX, NY, KXMAX, FREQ, ROTATE, TRANSL, SUMX, SUMY, DELX, DELY, DAZX, DAZY, VREC, TABLE, SUPPRS, RSQMAX)

COMMON/RECIC/DSTH, DSPHI, NTHMIN, NPHIMIN, AREA, NPOINTS, ROS, RIS, ZBOTCM, ZTOPCM, BCM, RR

3-3. Arguments

EINC - A complex array of three elements containing E_x, E_y, E_z of the incident plane wave. See Subroutine INCPW.

KA - A real array of three elements containing the direction cosines k_{xA}, k_{yA}, k_{zA} of the unit vector k_A which points from the antenna origin in the direction from whence the plane wave emanates.

NX,NY - The even integer number of sample points in x_A and y_A directions used to represent the antenna aperture fields.

KXMAX,KYMAX - Real variables which represent the normalized folding wavenumbers corresponding to the sample distances Δx_A, Δy_A according to $\Delta x_A = \lambda/(2*KXMAX)$, $\Delta y_A = \lambda/(2*KYMAX)$, where λ is the free space wavelength.

FREQ - Frequency in gigahertz of the monochromatic plane wave.

ROTATE,TRANSL- Real matrices of direction cosines and translation distances used to carry out coordinate transformations of points and vectors from antenna to radome coordinate systems, and vice versa. See Subroutine ORIENT.

SUMX,SUMY - Two dimensional (NX X NY) complex arrays of the x and y vector components of the antenna aperture fields for the sum channel of a three-channel monopulse antenna. The element at I=NX/2+1, J=NY/2+1, corresponds to that at $x_A=0$, $y_A=0$ in the aperture. The general correspondence is given by

$$x_A = -x_{max} + (I-1)*\Delta x_A = (I-MIDNX)*\Delta x_A$$

$$y_A = -y_{max} + (J-1)*\Delta y_A = (J-MIDNY)*\Delta y_A$$

where $x_{max} = \Delta x_A*NX/2$ and $y_{max} = \Delta y_A*NY/2$.

Also see Subroutine TRECNF.

DELX,DELY - Antenna aperture fields for the difference elevation channel.

DAZX,DAZY - Antenna aperture fields for the difference azimuth channel.

VREC - Complex array of three elements which on output contains the complex terminal voltage of the antenna

for the sum, elevation difference, and azimuth difference channels, respectively.

TABLE - Logical variable required by Subroutine RXMIT: if TRUE, a look-up table is used to calculate the transmission coefficients of the radome wall; if FALSE, these coefficients are calculated exactly for each angle of incidence specified.

SUPPRS - Logical variable used to control the printing of results from Subroutine RXMIT: if FALSE, a table of power transmission and reflection coefficients for equal increments in the sine of the incidence angle is printed. The phases of the complex voltage transmission and reflection coefficients of the radome wall are also printed.

RSQMAX - Real variable denoting the maximum radius of the antenna aperture such that any point $(x_A^2+y_A^2)>$RSQMAX is omitted from the summation procedure used to compute the received voltages VREC.

DSTH,DSPHI - Real input variables which specify the sample distance in the θ and ϕ directions on the radome surface; e.g., $\lambda/3$.

NTHMIN, NPHIMIN - Integer input variables which specify the minimum acceptable number of samples N_θ, N_ϕ in the two directions; e.g., $N_{\phi MIN}=4$.

AREA - Real output variable equal to the surface area of the radome included in the surface integration.

NPOINTS - Integer output variable equal to the number of sample points on the radome surface.

ROS,RIS - Real input variables equal to the generating radii of the inside and outside surfaces of the tangent ogive radome shape (Figure 3-1).

ZBOTCM, ZTOPCM - Real input variables which specify the Z_R coordinates of the bulkhead and opaque tip (if any), respectively (Figure 3-1).

BCM,RR - Real input variables defined in Figure 3-1.

3-4. Comments and Method

a. Subroutines Required: APINT, VECTOR, POINT, RXMIT, CAXB, OGIVEN, CAXCB.

b. Method: The voltage V_R induced at the terminals of a linear antenna by a "received" electromagnetic plane wave $\underline{E}_R$, $\underline{H}_R$ is given by the Lorentz reciprocity theorem as [1]

$$V_R(\hat{k}_A) = C \oint_S (\underline{E}_T \times \underline{H}_R - \underline{E}_R \times \underline{H}_T) \cdot \hat{n} da \qquad (1)$$

where $\hat{k}_A$ is the unit vector which points in the direction from whence the plane wave emanates and where $\underline{E}_T$, $\underline{H}_T$ are the electromagnetic fields of the antenna as produced on the closed surface S which surrounds the antenna when it is transmitting. The unit vector $\hat{n}$ is the normal to S pointing into the region not containing any sources, and C is a complex constant.

When the inside surface of the radome is chosen as (closed) surface of integration, the source-free volume is that inside the radome, excluding the space occupied by the antenna; hence, $\hat{n}$ is equal to the unit inward

normal n_{is} to the inside radome surface. The surface can be divided into elemental areas ΔA_{lm}, and the received voltage can be approximated by

$$V_R(\hat{k}_A) = C \sum_l \sum_m (\underline{E}_T \times \underline{H}_R - \underline{E}_R \times \underline{H}_T) \cdot \hat{n}_{is} \Delta A_{lm} \qquad (2)$$

where the fields are evaluated at the same points P'_{lm} on the radome surface. The elemental areas ΔA_{lm} differ, in general, from point to point, and must be included under the summation.

It is assumed that the fields $\underline{E}_T$, $\underline{H}_T$ on S with the radome in place are the same as those that would exist in the absence of the radome. They are computed at points P' from their specified aperture values $\underline{E}_{ap}$, $\underline{H}_{ap}$ via the Huygens-Fresnel principle as explained in Chapters 5 and 6. The received fields $\underline{E}_R$, $\underline{H}_R$ at P' are computed by applying the flat panel normal transmission coefficients $T_{n\perp}$, $T_{n\parallel}$ to the incident plane wave $\underline{E}_i$, $\underline{H}_i = \underline{E}_i \times \hat{k}_A/\eta$ at the point P on the outside surface of the radome that is colinear with the inside point P' with respect to the unit normal $\hat{n}_{is}$. (See Figure 1-2).

The tangent ogive radome surface is divided into elemental (trapezoidal) areas by sections made in the longitudinal (θ) and circumferential (ϕ) directions. In both cases, desired sampling intervals ΔS_θ, ΔS_ϕ (e.g., $\lambda/3$) are specified as input data. For the θ direction of Figure 3-1, the number of samples N_θ is given by

$$N_\theta = MAX \left\{ \frac{R(\theta_{TOP} - \theta_{BOT})}{\Delta S_\theta} , N_{\theta MIN} \right\} \qquad (3)$$

where R is the generating radius of the ogive surface

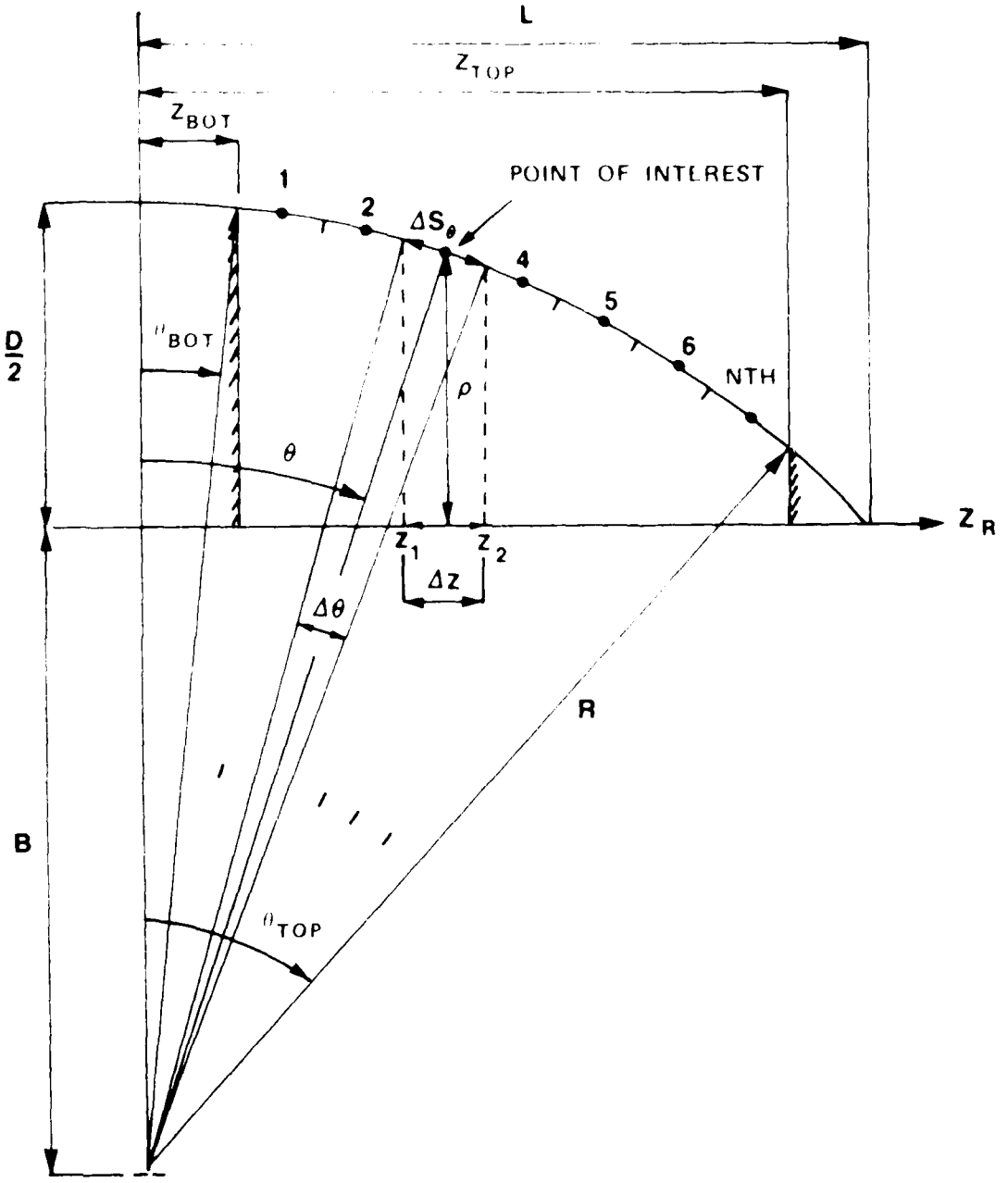


FIGURE 3–1. RADOME GEOMETRY FOR DEFINING ELEMENTAL SURFACE AREA IN θ DIRECTION.

$$R = L/\ \sin(\pi - 2\ \mathrm{Tan}^{-1}(2L/D)) \tag{4}$$

and where the other variables are defined in Figure 3-1. (A minimum acceptable number of samples $N_{\theta MIN}$ is also specified). The angular limits are given by

$$\theta_{BOT} = \sin^{-1}\ (Z_{BOT}/R) \tag{5}$$

$$\theta_{TOP} = \sin^{-1}\ (Z_{TOP}/R) \tag{6}$$

Since N_θ is an integer, the sample interval ΔS_θ must be recomputed as

$$\Delta S_\theta' = R(\theta_{TOP} - \theta_{BOT})/N_\theta = R\Delta\theta \tag{7}$$

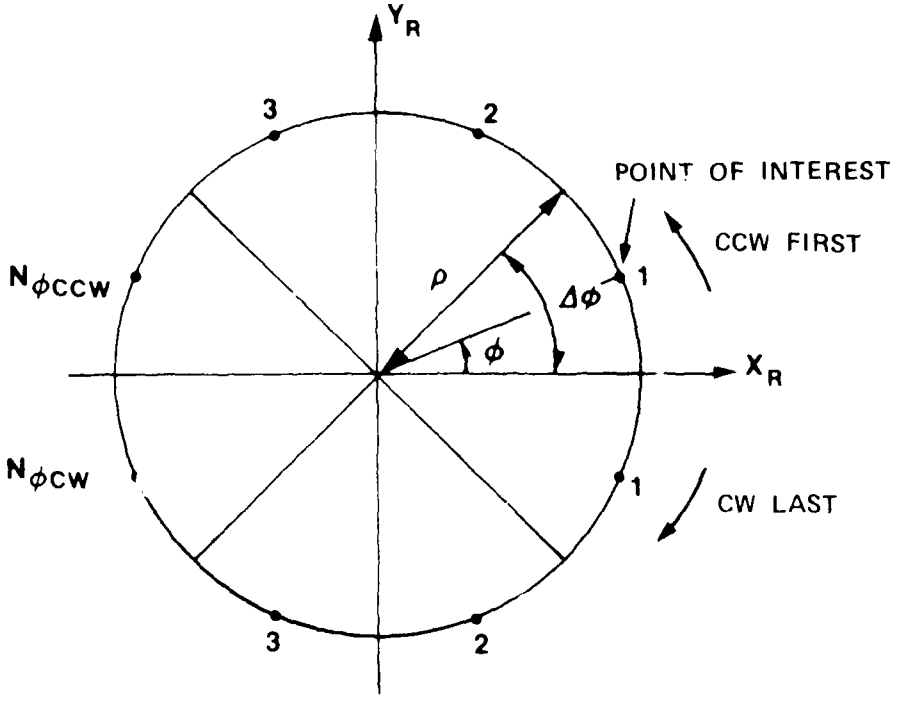
For iteration in I, a sample point at the center of an elemental area on the radome surface is specified by

$$\theta = \theta_{BOT} + \Delta\theta/2 + (I-1)*\Delta\theta\ , \tag{8}$$

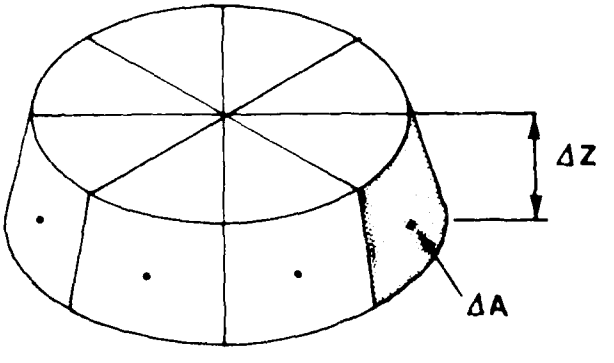
and the corresponding Z_R coordinate is given by

$$Z_R = R \sin\ \theta \tag{9}$$

The elemental areas are formed in the circumferential (ϕ) direction as indicated in Figure 3-2. Using ΔS_ϕ as input data, the number of samples N_ϕ in the ϕ direction is given by



(a) DEFINITIONS IN ϕ–DIRECTION



(b) TYPICAL ELEMENTAL VOLUME

FIGURE 3–2 DEFINITION OF ELEMENTAL SURFACE AREA IN ϕ DIRECTION.

$$N_\phi = \text{MAX}\left\{\frac{2\pi\rho}{\Delta S_\phi},\ N_{\phi MIN}\right\} \tag{10}$$

where ρ is defined in Figure 3-1 and is given by

$$\rho = \sqrt{R^2 - Z_R^2} - B \tag{11}$$

Since N_ϕ is an integer, the sampling distance in ϕ must be recomputed as

$$\Delta S'_\phi = 2\pi\rho/N_\phi \tag{12}$$

The sample point at the center of an elemental area is specified in ϕ by (for iteration J)

$$\phi = \phi_o + (J-1)\Delta\phi \tag{13}$$

where $\Delta\phi=2\pi/N_\phi$ and where ϕ_o is a specified initial point in ϕ. The area ΔA of a surface element specified by (θ,ϕ) is given by

$$\Delta A = R(\Delta Z - B\Delta\theta) \tag{14}$$

where

$$\Delta Z = Z_2 - Z_1 = R[\sin(\theta + \frac{\Delta\theta}{2}) - \sin(\theta - \frac{\Delta\theta}{2})] \tag{15}$$

It is deemed advantageous to set ϕ_o above in Equation (13) to some midpoint of the illuminated surface of the radome. This is done by transforming the unit vector $\hat{k}_A$ to radome coordinates; i.e.,

$$\hat{k}_A = x_A \hat{k}_{xA} + y_A \hat{k}_{yA} + z_A \hat{k}_{zA} = x_R \hat{k}_{xR} + y_R \hat{k}_{yR} + z_R \hat{k}_{zR} \tag{16}$$

The angle ϕ_o follows as

$$\phi_o = \cos^{-1} \left(\frac{k_{xR}}{\sqrt{k_{xR}^2 + k_{yR}^2}} \right) \tag{17}$$

The computations in ϕ proceed first in the counterclockwise (CCW) direction and then in the clockwise (CW) direction as indicated in Figure 3-2(a). For the CCW direction, the coordinates of the sample point are given by (J=1, $N_\phi/2+1$)

$$x_R = \rho \cos (\phi_o + (J-1)\Delta\phi) \tag{18}$$

$$y_R = \rho \sin (\phi_o + (J-1)\Delta\phi) \tag{19}$$

For the CW direction, there results

$$x_R = \rho \cos (\phi_o - J\Delta\phi) \tag{20}$$

$$y_R = \rho \sin (\phi_o - J\Delta\phi) \tag{21}$$

where J is incremented from unity to $N_\phi/2$. (The z_R coordinate is given by Equation (9).)

For each elemental area specified, two tests may be performed to determine if the contribution of the fields on that surface element should be included in the received voltage. The first test consists of ensuring that the sample point (x_R, y_R, z_R) lies forward of the aperture plane of the antenna; i.e., that $z_A \geq 0$. The second test (which may be disabled as deemed appropriate) determines if the surface element is directly illuminated by the incident plane wave. The test is performed by computing the angle of incidence θ according to

$$\cos \theta = n_{is} \cdot \hat{k}_A \tag{22}$$

If $\cos \theta < 0$, the point is illuminated and should certainly be included in the summation indicated in Equation (2); if $\cos \theta \geq 0$, the point lies in the shadow region, and, under certain circumstances, may be omitted from the computation to save time. The effect of this omission is not completely understood in all cases.

3-5. Program Flow (Refer to Program Listing below)

Line Number(s)	Comments
1-39	Declare variables, initialize constants.
40-52	Initialize Subroutines DIPOLES and APINT; compute and write fields $\underline{E}_T$, $\underline{H}_T$ at point $(0, 0, 2D^2/\lambda)$ for reference.
53-55	Initialize Subroutine RXMIT.
56-67	Compute θ_{TOP}, θ_{BOT}, N_θ, $\Delta S'_0$, $\Delta\phi$.
68-76	Compute ϕ_o and initialize summation of V_{REC}.
77-85	Iterate in θ on radome surface.

86-90	Compute Z_{ROS}, Z_{RIS}, r_{OS}, r_{IS} and ensure that surface element does not lie forward of metal tip or aft of bulkhead.
91-97	Compute $N_{\ddagger}$ and $\Delta S'_{\phi}$.
98-104	Compute $N_{\phi CCW}$, $N_{\phi CW}$, and $\Delta\phi$.
105-106	Compute ΔZ and ΔA.
107-119	Iterate in $\ddagger$: CCW first, CW second.
120-125	Compute inside coordinates x_{RIS}, y_{RIS}.
126-135	Compute unit inward normal $\hat{n}_{IS}$ and apply illumination test (disabled).
136-141	Convert coordinates of sample point on surface to antenna coordinates to ensure $z_A \geq 0$.
142-152	Compute phase of incident plane wave at outside point (x_{ROS}, y_{ROS}, z_{ROS}) with respect to the antenna origin. Adjust phase of the specified incident plane wave and store temporarily as $\underline{H}_{RP}$.
153-156	Compute antenna coordinates of inside point in wavelengths.
157-163	Compute transmitted plane wave $\underline{E}'_R$, $\underline{H}'_R$ at inside point.
164-171	Use aperture integration to compute the transmitted fields $\underline{E}_{Ti}$, $\underline{H}_{Ti}$ of the antenna at the inside point for each channel of the monopulse antenna.
172-176	Disabled statements pertaining to surface integration using the outside radome surface.
177-179	Form the vector cross products $\underline{S}_1 = \underline{E}_T \times \underline{H}'_R$, $\underline{S}_2 = \underline{E}'_R \times \underline{H}_T$.

180-182	Add contribution to received voltage V_{Ri}.
183-184	Incement AREA.
185-186	Increment NCUS = number of points omitted.
187-189	Increment NPOINTS.
190-197	If SUPPRS=.FALSE., compute and write total surface area, received voltages, number of points used, and number of points omitted.

3-6. Test Case: None

3-7. References

1. G. K. Huddleston, H. L. Bassett, and J. M. Newton, "Parametric Investigation of Radome Analysis Methods", 1978 IEEE AP-S Symposium Digest, pp. 199-201, May 1978.

3-8. Program Listing (See following pages)

```
      SUBROUTINE RECM(EINC,KA,NX,NY,KXMAX,KYMAX,FREQ,ROTATE,TRANSL,          1
     $ SUMX,SUMY,DELX,DELY,DAZX,DAZY,VREC,TABLE,SUPPRS,RSQMAX)               2
C  SUBR RECM COMPUTES THE RECEIVED VOLTAGE OF AN ANTENNA INSIDE A TANGENT
C  OGIVE RADOME AS PRODUCED BY A PLANE WAVE INCIDENT FROM THE DIRECTION     4
C  SPECIFIED BY KA.  THE INSIDE SURFACE OF THE RADOME IS USED AS THE SURFACE
C  OF INTEGRATION IN THE RECIPROCITY INTEGRAL, AND THE NORMAL TRANSMISSION
C  COEFFICIENT IS USED TO TRANSFER THE INCIDENT PLANE WAVE FROM THE POINT
C  P ON THE OUTSIDE SURFACE TO THE POINT P' ON THE INSIDE SURFACE, WHERE    8
C  P AND P' ARE COLINEAR WITH THE NORMAL TO EITHER SURFACE.                 9
C  THE CALL TO THIS SUBR IS IDENTICAL TO THE CALL TO SUBR RECM              10
C  USED IN THE RAY TRACING FORMULATION  HOWEVER, ADDITIONAL VARIABLES       11
C  ARE NEEDED BY THIS SUBR AND ARE PASSED FROM MAIN PROGRAM VIA LABEL       12
C  COMMON/RECIC/ AS SHOWN BELOW.                                            13
      COMPLEX ET(3),HT(3),ERP(3),HRP(3)                                     14
      COMPLEX S1(3),S2(3),U,C,EINC(3),VREC(3)                               15
      COMPLEX SUMX(NX,NY),SUMY(NX,NY),DELX(NX,NY),DELY(NX,NY),              16
     $ DAZX(NX,NY),DAZY(NX,NY)                                              17
      REAL KXMAX,KYMAX,ROTATE(3,3),TRANSL(3),LAMBDA,NISA(3)                 18
      REAL PIR(3),NIS(3),KR(3),KA(3),PT(3),PISR(3),PO(3),PTWL(3)            19
      LOGICAL TABLE,ATOR,RTOA,SUPPRS,INIT                                   20
      COMMON/RECIC/DSTH,DSPHI,NTHMIN,NPHIMIN,AREA,NPOINTS,ROS,RIS,          21
     $ZBOTCM,ZTOPCM,BCM,RR                                                  22
      NAMELIST/ATDR/DSTH,BETA,DKX,DKY,DKXY,THTOP,THBOT,STH,NTH              23
      DATA ATOR/.TRUE./,RTOA/.FALSE./                                       24
      DATA PI/3.14159265/                                                   25
      DATA ZERO/1E-6/                                                       26
      DATA TUPI/6.28318530/                                                 27
      DATA ETA/376.9911185/,NDO/0/                                          28
      DATA NISA/0.,0.,-1./,PT/0.,0.,0./                                     29
      AREA=0.                                                               30
      B=BCM                                                                 31
      NPOINTS=0                                                             32
      NCUS=0                                                                33
      DKX=2.*KXMAX/NX                                                       34
      DKY=2.*KYMAX/NY                                                       35
      NXMID=NX/2+1                                                          36
      NYMID=NY/2+1                                                          37
      DXWL=.5/KXMAX                                                         38
```

```
      DYWL=.5/KYMAX                                                          39
      IF (NDO.CT.0) GO TO 4                                                  40
C  INITIALIZE CONSTANTS IN SUBR DIPOLES:                                     41
      LAMBDA=29.97925/FREQ                                                   42
      BETA=2.*PI/LAMBDA                                                      43
      INIT=.TRUE.                                                            44
      PTWL(1)=0.                                                             45
      PTWL(2)=0.                                                             46
      PTWL(3)=2.*4.*RSQMAX/LAMBDA                                            47
      CALL APINT(PTWL,SUMX,SUMY,NX,NY,NXMID,NYMID,DXWL,DYWL,ET,HT,INIT)      48
      WRITE(6,3) PTWL(3),ET,HT                                               49
    3 FORMAT(" SUBR DIPOLES INITIALIZED BY SUBR RECI"/                       50
     $"  AT Z=2*D**2/WL= ",E12.5,"  ET= ",6E12.5/                            51
     $30X,"  HT= ",6E12.5/)                                                  52
      RTD=180./PI                                                            53
      CALL RXMIT(HRP,ERP,KA,NISA,PT,TABLE,SUPPRS,BETA)                       54
    4 CONTINUE                                                               55
      DKXY=DKX*DKY                                                           56
      THTOP=ASIN(ZTOPCM/RIS)                                                 57
      THBOT=ASIN(ZBOTCM/RIS)                                                 58
      STH=RIS*(THTOP-THBOT)                                                  59
      NTHP=STH/DSTH                                                          60
      IF(NTHP.GE.NTHMIN) GO TO 10                                            61
      NTH=NTHMIN                                                             62
      GO TO 15                                                               63
10    NTH=NTHP                                                               64
15    DSTHP=STH/NTH                                                          65
      DTH=(THTOP-THBOT)/NTH                                                  66
      IF (.NOT.SUPPRS) WRITE(6,ATDR)                                         67
C  DETERMINE ANGLE PHI0 OF CENTER OF ILLUMINATED AREA ON RADOME:             68
      CALL VECTOR(KA,KR,ATOR,ROTATE)                                         69
      RAD=KR(1)**2+KR(2)**2                                                  70
      IF (RAD.GT.ZERO) GO TO 16                                              71
      PHI0=0.                                                                72
      GO TO 31                                                               73
   16 PHI0=ACOS(KR(1)/SQRT(RAD))                                             74
   31 DO 32 I=1,3                                                            75
   32 VREC(I)=(0.,0.)                                                        76
```

```
C     SELECT CIRCLE ON SURFACE OF RADOME AT CONSTANT THETA                    77
C     AND ITERATE IN I                                                        78
      TH=THBOT-DTH/2.                                                         79
      IF ((NDO.EQ.0).AND.(.NOT.SUPPRS)) WRITE(6,33)                           80
   33 FORMAT(3X,"THDEG",4X,"PHIDEG",12X,"PT",23X,"NIR"/)                      81
      DO 20 I=1,NTH                                                           82
      TH=TH+DTH                                                               83
      THD=TH*RTD                                                              84
      SINTH=SIN(TH)                                                           85
      PIR(3)=ROS*SINTH                                                        86
      RHOOS=SQRT(ROS**2-PIR(3)**2)-B                                          87
      PISR(3)=RIS*SINTH                                                       88
      IF ((PISR(3).GT.ZTOPCM).OR.(PISR(3).LT.ZBOTCM)) GO TO 20                89
      RHOIS=SQRT(RIS**2-PISR(3)**2)-B                                         90
      NPHIP=TUPI*RHOIS/DSPHI                                                  91
      IF(NPHIP.GE.NPHIMIN) GO TO 40                                           92
      NPHI=NPHIMIN                                                            93
      GO TO 50                                                                94
40    NPHI=NPHIP                                                              95
C     DIVIDE THE INNER SURFACE INTO NPHI EQUAL PARTS                          96
50    DSPHIP=TUPI*RHOIS/NPHI                                                  97
      NPHI2=NPHI/2                                                            98
      NPHICW=NPHI2                                                            99
      NPHICCW=NPHI2                                                          100
      IF(2.*NPHICCW.LT.NPHI) GO TO 55                                        101
      GO TO 60                                                               102
55    NPHICCW=NPHICW+1                                                       103
60    DPHI=TUPI/NPHI                                                         104
      DZ=RIS*(SIN(TH+DTH/2.)-SIN(TH-DTH/2.))                                 105
      DA=RIS*(DZ-B*DTH)*DPHI                                                 106
110   DO 61 J1=1,2                                                           107
      JMAX=NPHICCW                                                           108
      IF(J1.EQ.2) JMAX=NPHICW                                                109
C   SELECT A POINT ON INNER SURFACE OF RADOME AT CONSTANT PHI                110
C   AND ITERATE IN J, FIRST CCW, THEN CLOCKWISE.                             111
      PHI=PHI0-DPHI                                                          112
      IF (J1.EQ.2) PHI=PHI0                                                  113
120   DO 62 J=1,JMAX                                                         114
```

```
      IF (J1.EQ.2) GO TO 41                                              115
      PHI=PHI+DPHI                                                       116
      GO TO 42                                                           117
   41 PHI=PHI-DPHI                                                       118
   42 CONTINUE                                                           119
      PHID=PHI*RTD                                                       120
      CPHI=COS(PHI)                                                      121
      SPHI=SIN(PHI)                                                      122
      PISR(1)=RHOIS*CPHI                                                 123
      PISR(2)=RHOIS*SPHI                                                 124
C    THE POINT OF INTEREST ON INSIDE SURFACE HAS RADOME COORD PISR(XR,YR,ZR).
C    CALL OGIVEN TO FIND INNER UNIT NORMAL NIS TO RADOME SURFACE        126
      CALL OGIVEN(PISR,NIS)                                              127
      IF ((NDO.EQ.0).AND.(.NOT.SUPPRS)) WRITE(6,56) THD,PHID,PISR,NIS    128
   56 FORMAT(2(2X,F7.2),6E10.3)                                          129
C    TEST NOW IF THIS POINT IS ILLUMINATED BY PLANE WAVE                130
C      CUS=NIS(1)*KR(1)+NIS(2)*KR(2)+NIS(3)*KR(3)                       131
C      IF CUS IS GREATER THAN ZERO,AREA IS NOT ILLUMINATED              132
C      IF(CUS.GT.0.) GO TO 59                                           133
C      IF(CUS.LT.0.) GO TO 65                                           134
C      GO TO 59                                                         135
C   CONVERT INSIDE POINT PISR(XR,YR,ZR) TO ANTENNA COORD PT(XA,YA,ZA):  136
   65 CALL POINT(PISR,PT,RTOA,ROTATE,TRANSL)                           137
C    TEST TO INSURE THAT POINT XR,YR,ZR IS ILLUMINATED                  138
C    BY THE ANTENNA INSIDE THE RADOME                                   139
C       IF ZA>0.,POINT IS ILLUMINATED                                   140
      IF (PT(3).LT.0.) GO TO 59                                          141
C    COMPUTE PHASE OF INCIDENT PLANE WAVE AT OUTSIDE POINT:             142
      PIR(1)=RHOOS*CPHI                                                  143
      PIR(2)=RHOOS*SPHI                                                  144
      CALL POINT(PIR,PO,RTOA,ROTATE,TRANSL)                              145
      PHS=AMOD(BETA*(KA(1)*PO(1)+KA(2)*PO(2)+KA(3)*PO(3)),TUPI)          146
      U=CMPLX(0.,PHS)                                                    147
      C=CEXP(U)                                                          148
C   ADJUST PHASE OF INCIDENT ELECTRIC FIELD AT OUTSIDE POINT AND STORE AS HRP:
      HRP(1)=EINC(1)*C                                                   150
      HRP(2)=EINC(2)*C                                                   151
      HRP(3)=EINC(3)*C                                                   152
```

```
C  COMPUTE ANTENNA FIELDS AT INSIDE POINT PISR:                          153
      PTWL(1)=PT(1)/LAMBDA                                              154
      PTWL(2)=PT(2)/LAMBDA                                              155
      PTWL(3)=PT(3)/LAMBDA                                              156
C  TRANSMIT INCIDENT PLANE WAVE THRU WALL USING NORMAL XMN COEFS:        157
      CALL VECTOR(NIS,NISA,RTOA,ROTATE)                                 158
      IF ((NDO.EQ.0).AND.(.NOT.SUPPRS)) WRITE(6,57) THD,PHID,PT,NISA    159
   57 FORMAT(2(2X,F7.2),6E10.3/)                                        160
      CALL RXMIT(HRP,ERP,KA,NISA,PT,TABLE,SUPPRS,BETA)                  161
C COMPUTE CORRESPONDING MAGNETIC FIELD*ETA:                             162
      CALL CAXB(ERP,KA,HRP)                                             163
      DO 58 ICH=1,3                                                     164
      IF (ICH.EQ.1)                                                     165
     $CALL APINT(PTWL,SUMX,SUMY,NX,NY,NXMID,NYMID,DXWL,DYWL,ET,HT,INIT) 166
      IF (ICH.EQ.2)                                                     167
     $CALL APINT(PTWL,DELX,DELY,NX,NY,NXMID,NYMID,DXWL,DYWL,ET,HT,INIT) 168
      IF (ICH.EQ.3)                                                     169
     $CALL APINT(PTWL,DAZX,DAZY,NX,NY,NXMID,NYMID,DXWL,DYWL,ET,HT,INIT) 170
C  SUBR APINT COMPUTES HT*ETA.                                          171
C ******************************                                      172
C  THE NEXT TWO STATEMENTS ARE FOR OUTSIDE SURFACE CASE.                173
C     CALL POYNTIN(E,H,S)                                               174
C     CALL RXMIT(ETR,HTR,STR,NIS,PISP,TABLE,BETA,ETRP,HTRP)             175
C ******************************                                      176
C   FORM CONTRIBUTION TO RECEIVED VOLTAGE                               177
      CALL CAXCB(ET,HRP,S1)                                             178
      CALL CAXCB(ERP,HT,S2)                                             179
      VREC(ICH)=VREC(ICH)-((S1(1)-S2(1))*NIS(1)+(S1(2)-S2(2))*NIS(2)+   180
     $ (S1(3)-S2(3))*NIS(3))*DA                                         181
   58 CONTINUE                                                          182
      AREA=AREA+DA                                                      183
      GO TO 62                                                          184
59    NCUS=NCUS+1                                                       185
62    CONTINUE                                                          186
      NPOINTS=NPOINTS+JMAX                                              187
61    CONTINUE                                                          188
20    CONTINUE                                                          189
      NDO=1                                                             190
```

```
      IF (SUPPRS) RETURN                                                  191
      PERCNT=100.*(1.-FLOAT(NCUS)/FLOAT(NPOINTS))                         192
      WRITE(6,25) AREA,VREC,NPOINTS,PERCNT,NCUS                           193
   25 FORMAT(//" SUBR RECI: AREA=",E12.5/" VREC=",6E12.5/" NPOINTS=",     194
     &I5,"   PERCENT=",F5.1,"   NCUS=",I6//)                             195
      RETURN                                                              196
      END                                                                 197
```

Chapter 4

SUBROUTINE TRECNF

4-1. Purpose: To compute near-field aperture distributions for four types of three-channel monopulse antennas: (1) circular aperture with tapered amplitude and uniform phase distributions; (2) flat plate antenna with a programmed amplitude distribution and uniform phase; (3) square aperture with cos x amplitude and uniform phase; (4) single element. Four polarizations can be selected for the circular and square apertures. The flat plate antenna is vertically ($\hat{y}_A$) polarized only.

4-2. Usage: CALL TRECNF (E, NX, NY, ICHAN, IPOL, IXY, DAPWL, DXWL, KXMAX, ICASE, SQUARE)

4-3. Arguments

E - Complex array of NX by NY elements which, on output, contains the values of the specified (IXY) rectangular component (x_A or y_A) of the electric field distribution over the specified (ICASE) antenna aperture having the specified (IPOL) polarization for the specified (ICHAN) channel of a three-channel monopulse antenna.

NX,NY - Even integer number of points in a rectangular array at which the aperture distribution is computed in the x_A and y_A directions, respectively. The point I=NX/2 + 1, J=NY/2 + 1 corresponds to x_A=0, y_A=0. For the single element case, NX=NY=2.

ICHAN - Integer control variable with values 1, 2, or 3 which selects the sum, elevation difference, or azimuth difference channel, respectively.

IPOL - Integer control variable which selects the antenna polarization as follows:

1 - Vertical ($\hat{y}_A$) polarization

2 - Horizontal ($\hat{x}_A$) "

3 - Right-hand circular "

4 - Left-hand circular "

IXY - Integer control variable having values 1 or 2 to select the x_A or y_A component of aperture electric field.

DAPWL - Diameter, in wavelengths, of the antenna aperture.

DXWL - Spacing, in wavelengths, between samples in aperture in x_A and y_A directions (output).

KXMAX - Maximum value of normalized wavenumber corresponding to KXMAX = 1./(2.*DXWL) (output).

ICASE - Integer control variable having values 1 or 2 to specify a circular aperture antenna with uniform amplitude and phase. If ICASE=3, a flat plate antenna having a programmed amplitude distribution (see Table 4-3) with vertical polarization is selected.

SQUARE - Logical input variable; if TRUE, square aperture is used.

4-4. Comments and Method

a. The integers NX,NY must each be equal to each other and even; e.g., NX=NY=16. In addition, when ICASE=3 (flat plate antenna), NX and NY must equal 16. If NX=NY=2, the fields of a single element at $x_A=y_A=0$ are specified. If NX=NY=32, only the central 15 x 15 elements are non-zero.

b. The actual shape of the circular aperture, as approximated by a rectangular array of sample points, is shown in Figure 4-1 for the case of NX=NY=16. Row 1 and Column 1 of the array contain null elements. The elements inside and on the boundary of the aperture may contain non-zero values as shown in Table 4-1 for the various cases when ICHAN=1 (sum channel). Note that specification of D_{AP} in Figure 4-1 determines the sample spacings according to

$$\Delta x_A = \Delta y_A = \frac{D_{Ap}\cos\alpha}{(N_x-2)} = \frac{D_{Ap}\cos\alpha}{(N_y-2)} \qquad (1)$$

where $\alpha = \mathrm{Tan}^{-1}(2/7)$.

The aperture distributions for three monopulse channels are formed by phasing the elements in the four quadrants of the aperture appropriately. The sum channel distribution is formed by assigning equal phases to all elements. The azimuth difference channel is formed by multiplying all elements in Quadrants II and III of the sum distribution by minus one and by zeroing all elements along $x_A=0$. For the elevation difference channel, Quadrants III and IV are negated, and all elements along the line $y_A=0$ are made zero for symmetry reasons.

The phasing chosen models a tracking antenna and provides outputs in two orthogonal channels from which the direction of arrival of a target return can be mathematically determined. Let k be a unit vector which

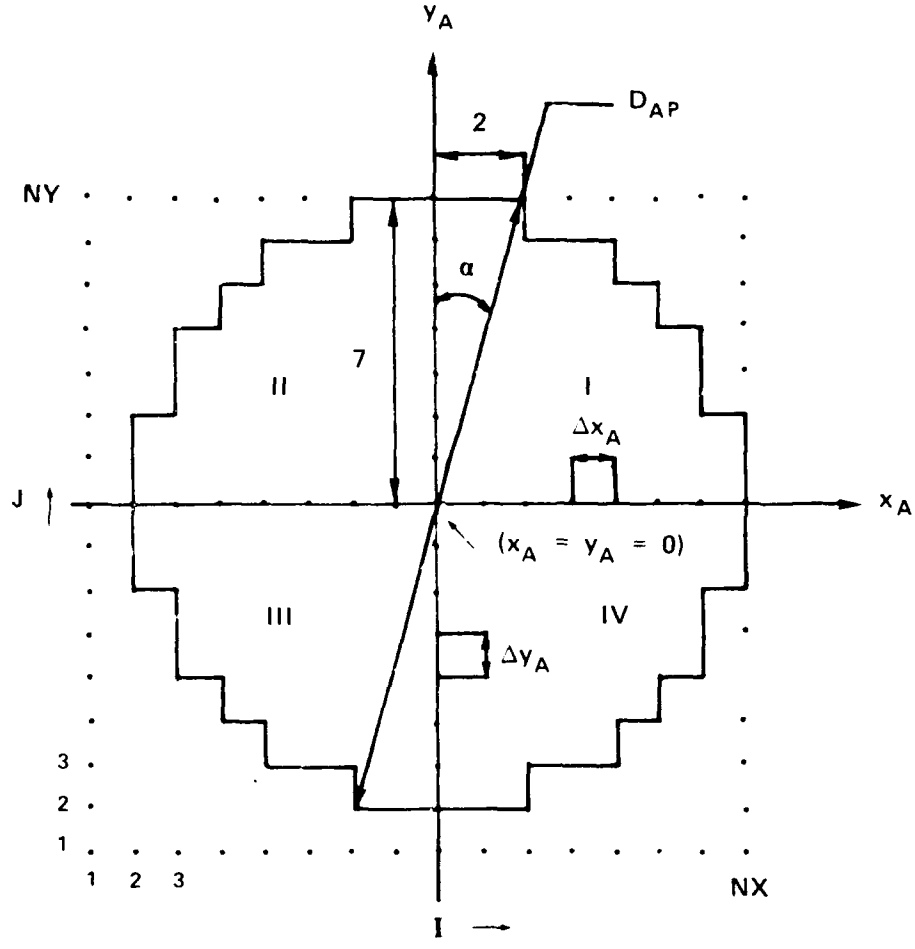


FIGURE 1–1. APPROXIMATION OF CIRCULAR APERTURE BY RECTANGULAR GRID OF SAMPLE POINTS.

points from the antenna origin toward the direction from whence the plane wave (target return) emanates; i.e.,

$$\hat{k} = \hat{x}_A k_x + \hat{y}_A k_y + \hat{z}_A k_z \tag{2}$$

Define the tracking functions for this plane wave as

$$f_i(k_x,k_y) = \frac{\Delta_i(k_x,k_y)}{\Sigma(k_x,k_y)} \tag{3}$$

where Δ_i represents the output of the elevation (ε) or azimuth (α) difference channel and Σ represents the sum channel output. Then for small $k_x>0$, the phase of f_α is + $\pi/2$; for small $k_x<0$, the phase of f_α is $-\pi/2$. Similarly, for small $k_y>0$, arg $(f_\varepsilon) = \pi/2$; for small $k_y<0$, arg $(f_\varepsilon) = -\pi/2$. Hence, the change in phase by π in either channel represents the boresight direction of the antenna, and tracking is done using the imaginary parts of the tracking functions rather than their real parts.

c. The shape and sampling grid used to model the flat plate antenna are shown in Figure 4-2. In Subroutine TRECNF, the integers NX and NY must both equal 16, and only linear polarization ($\hat{y}_A$) is applicable to the flat plate antenna (ICASE=3). The phasing of the four quadrants is done as described above to model the three monopulse channels so that tracking can be simulated. Note that specification of D_{Ap} determines the sample spacing according to

$$\Delta x_A = \Delta y_A = \frac{D_{Ap} \cos\alpha}{\left(\frac{N_x}{2} - 2\right)} \tag{4}$$

where $\alpha = \text{Tan}^{-1}$ (4/6).

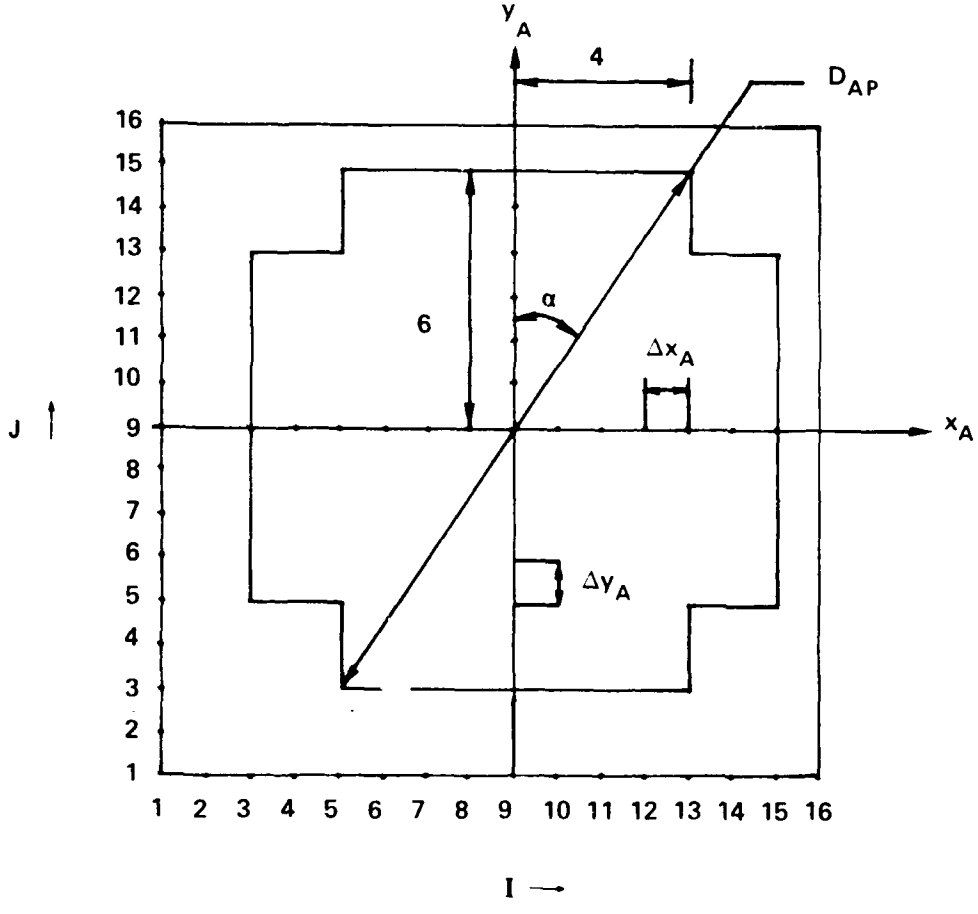


FIGURE 4–2. GEOMETRY OF FLAT PLATE ANTENNA.

Table 4-1. Values of Non-Zero Elements in Circular Aperture (ICHAN=1, ICASE=1 or 2)

IPOL	IXY	Value	Polarization Type
1	1	(0 + j0)	Vertical
1	2	(1 + j0)	"
2	1	(1 + j0)	Horizontal
2	2	(0 + j0)	"
3	1	(0 + j1)	RHC
3	2	(1 + j0)	"
4	1	(0 - j1)	LHC
4	2	(1 + j0)	"

The phase of each sample point in Figure 4-2 for the sum channel is made equal, but the amplitudes are tapered in the x_A and y_A directions as shown in Table 4-2. The amplitude distribution is separable and symmetrical so that

$$E_{yA}(x_A,y_A) = g(x_A)h(y_A) = E_{yA}(-x_A,y_A) = E_{yA}(x_A,-y_A) \tag{5}$$

It is noted that samples 10, 12, 14, and 16 are actually specified in the program, and samples 9, 11, 13, and 15 are obtained from them by averaging.

d. The square aperture is formed by setting to zero Row 1 and Column 1 of the array of Figure 4-1 for symmetry reasons. The values of field at the other points in the aperture are computed to yield a cos x amplitude taper in the x_A direction and a uniform amplitude in y_A; i.e.,

$$E(x,y) = \cos \frac{\pi x}{2\, x_{max}} \tag{5}$$

where x_{max} corresponds to the sample at I=NX.

3-5. Program Flow

Line Nos.	Comments
19	Assign complex values to CFAC to use in generating vertical, horizontal, RHC, and LHC polarization according to IPOL.
20-22	Compute the angle α and the upper bound R_{max} of the radius of the circular aperture.
23-24	Ensure that IPOL has correct values of 1, 2, 3, or 4.

Table 4-2. Symmetrical Amplitude Distribution for Flat Plate Antenna

Sample No.	x_A	Amplitude	y_A	Amplitude
9	0	1.0280	0	1.0280
10	Δx	1.0280	Δy	1.0280
11	$2\Delta x$	.9120	$2\Delta y$	.9170
12	$3\Delta x$	.7959	$3\Delta y$	.8060
13	$4\Delta x$	.6077	$4\Delta y$	.6155
14	$5\Delta x$	.4194	$5\Delta y$	.4250
15	$6\Delta x$	.2097	$6\Delta y$	.2125
16	$7\Delta x$	0.0	$7\Delta y$	0.0

25	If NX≠NY and SQUARE=FALSE, write error message and stop the program.
26-29	Compute indices of midpoint ±7.
30-31	Ensure that IXY=1 or 2.
32	If NX and NY are not even, stop the program.
33	Test value of ICASE: if ICASE=3 generate fields of flat plate antenna (Lines 64-105); otherwise, generate fields of circular or square aperture (Lines 34-60).
34-56	Assign complex field value to each sample point $(x_A, y_A, 0)$ in the circular aperture according to the values shown in Table 4-1. If $\sqrt{x_A^2 + y_A^2} > R_{max}$, make the field value zero. Multiply the non-zero elements by CFAC(IPOL) to generate the correct polarization. For the square aperture, zero Column 1 and Row 1, and insert cos x taper (Line 37).
57-60	Compute sample spacing $\Delta x_A/\lambda$ and go to statement 60.
61-63	Error message and STOP.
64-65	Flat plate antenna-- if NX≠16, write error message and STOP (Lines 131-133).
66-67	Compute sample spacing $\Delta x_A/\lambda$.
68	Ensure NX=NY
69-72	Zero all elements in the aperture. If IXY=1 (x_A-component), to to statement 60.

73-80	Assign tapered amplitude values to eight "even" elements in Quadrant III.
81-89	Compute amplitude values for the "odd" elements in Quadrant III.
90-93	Compute amplitude values for elements 3-9 along $y_A=0$ line and along $x_A=0$ line.
94-97	Generate symmetrical amplitude values in Quadrant IV.
98-105	Generate symmetrical amplitude values in Quadrants I and II.
106	Compute k_{xmax} and d_x/λ.
107-111	Test to determine if the sum channel data generated should be phased to produce the aperture distribution for a specified difference channel (ICHAN).
112-120	Form aperture distribution for difference elevation channel by zeroing all elements along $y_A=0$ and negating all elements for $y_A<0$. RETURN.
121-129	Form aperture distribution for difference azimuth channel by zeroing all elements along $x_A=0$ and negating all elements $x_A<0$. RETURN.
130-134	Error messag for ICASE=3 and NX≠16.
	END

4-6. Test Case: None.

4-7. References

1. D. R. Rhodes, Introduction to Monopulse, McGraw Hill, New York, 1959.

4-8. Program Listing: See following pages.

```
      SUBROUTINE TRECNF(E,NX,NY,ICHAN,IPOL,IXY,DAPWL,DXWL,KXMAX,ICASE,
     &SQUARE)
C *** MODIFIED JAN 80 FOR SQUARE APERTURE AND FOR SINGLE ELEMENT***
C SUBR TRECNF COMPUTES ELECTRIC FIELDCOMPONENTS OVER A CIRCULAR APERTURE
C OF RADIUS RMAX=(NX/2-1)/COS(ATAN(2/7)) AND RETURNS SAME IN E(NX,NY).
C NX MUST EQUAL NY AND MUST BE EVEN.
C  ICHAN=1 FOR SUM CHANNEL   IPOL=1 FOR VERT-Y POL.    IXY=1 FOR X-COMP.
C       =2 FOR ELEV DIFF          =2 FOR HORIZ-X POL       =2 FOR Y-COMP.
C       =3 FOR AZ DIFF            =3 FOR RHC POL
C       =                         =4 FOR LHC POL
C DAPWL=DIAMETER OF APERTURE IN WAVELENGTHS (INPUT)
C  DXWL=SAMPLE SPACING IN APERTURE (OUTPUT)
C KXMAX=MAXIMUM WAVENUMBER (OUTPUT)
C  ICASE=1 OR 2 FOR UNIFORM, CIRCULAR APERTURE (ADA M.'S CASE I AND II)
C       =3 FOR FLAT-PLATE ANTENNA, VERTICAL POL (CASE III).
      COMPLEX E(NX,NY),CFAC(4)
      REAL KXMAX
      LOGICAL SQUARE
      DATA CFAC/(1.,0.),(1.,0.),(0.,+1.),(0.,-1.)/
      ANG=ATAN(2./7.)
      IF (ICASE.EQ.3) ANG=ATAN(4./6.)
      RMAX=(NX/2-1)/COS(ANG)+.001
      IF (IPOL.GT.4) IPOL=4
      IF (IPOL.LT.1) IPOL=1
      IF ((.NOT.SQUARE).AND.(NX.NE.NY)) GO TO 15
      NXMM7=NX/2+1-7
      NXMP7=NX/2+1+7
      NYMM7=NY/2+1-7
      NYMP7=NY/2+1+7
C  FOR NX,NY=32, ONLY THE CENTRAL 15 X 15 ELEMENTS ARE NONZERO.
      IF ((IXY.LT.1).OR.(IXY.GT.2)) IXY=2
      IF (MOD(NX,2).NE.0) GO TO 15
      IF (ICASE.EQ.3) GO TO 25
      TUXMX=FLOAT(NX)
      DO 10 I=1,NX
      X=FLOAT(-(NX/2)+I-1)
      COSX=COS(3.14159265*X/TUXMX)
      DO 10 J=1,NY
```

```
      IF ((I.EQ.1).OR.(J.EQ.1)) GO TO 9                                    39
      IF (NX.EQ.16) GO TO 1                                                40
      IF ((I.LT.NXMM7).OR.(I.GT.NXMP7).OR.(J.LT.NYMM7).OR.(J.GT.NYMP7))    41
     $GO TO 9                                                              42
    1 IF(SQUARE) GO TO 8                                                   43
      Y=FLOAT(-(NY/2)+J-1)                                                 44
      R=SQRT(X**2+Y**2)                                                    45
      IF (R.GT.RMAX) GO TO 9                                               46
    8 IF ((IPOL.EQ.1).AND.(IXY.EQ.1)) GO TO 9                              47
      IF ((IPOL.EQ.2).AND.(IXY.EQ.2)) GO TO 9                              48
C   IF RHC, EY=(1,0), EX=(0,1)  I.E., EX LEADS EY BY 90 DEG.               49
C   IF LHC,EY=(1,0), EX=(0,-1)  I.E., EX LAGS EY BY 90 DEG.                50
      E(I,J)=CMPLX(COSX,0.)                                                51
      IF ((IPOL.LT.3).OR.(IXY.EQ.2)) GO TO 10                              52
      E(I,J)=E(I,J)*CFAC(IPOL)                                             53
      GO TO 10                                                             54
    9 E(I,J)=(0.,0.)                                                       55
   10 CONTINUE                                                             56
      IF (NX.EQ.2) GO TO 56                                                57
      DXWL=(DAPWL/2.)*COS(ANG)/(NX/2-1)                                    58
      IF(SQUARE) DXWL=(DAPWL/SQRT(2.))/(NX-2)                              59
      GO TO 60                                                             60
   15 WRITE(6,20)                                                          61
   20 FORMAT(//" NX.NE.NY OR NX NOT EVENIN SUBR TRECNF"//)                 62
      STOP                                                                 63
C THE FOLLOWING IS FOR ADA M.'S CASE III (ICASE=2):                        64
   25 IF (NX.NE.16) GO TO 90                                               65
      DXWL=(DAPWL/2.)*COS(ANG)/(NX/2-2)                                    66
      IF(SQUARE) DXWL=(DAPWL/SQRT(2.))/(NX-2)                              67
      NY=NX                                                                68
      DO 26 I=1,NX                                                         69
      DO 26 J=1,NY                                                         70
   26 E(I,J)=(0.,0.)                                                       71
      IF (IXY.EQ.1) GO TO 60                                               72
      E(6,4)=(.2824,0.)                                                    73
      E(8,4)=(.4250,0.)                                                    74
      E(4,6)=(.2888,0.)                                                    75
      E(6,6)=(.5218,0.)                                                    76
```

```
      E(8,6)=(.8060,0.)                                                  77
      E(4,8)=(.4194,0.)                                                  78
      E(6,8)=(.7959,0.)                                                  79
      E(8,8)=(1.028,0.)                                                  80
      DO 30 J=4,8,2                                                      81
      DO 30 I=3,8,1                                                      82
      IF ((MOD(J,2).EQ.0).AND.(MOD(I,2).EQ.0)) GOTO 30                   83
      E(I,J)=(E(I-1,J)+E(I+1,J))/2.                                      84
   30 CONTINUE                                                           85
      DO 35 I=3,8,1                                                      86
      DO 35 J=3,8,2                                                      87
      E(I,J)=(E(I,J-1)+E(I,J+1))/2.                                      88
   35 CONTINUE                                                           89
      DO 40 I=3,9                                                        90
   40 E(I,J)=E(I,8)                                                      91
      DO 45 J=3,9                                                        92
   45 E(9,J)=E(8,J)                                                      93
      DO 50 J=3,9                                                        94
      DO 50 I=1,6                                                        95
      E(9+I,J)=E(9-I,J)                                                  96
   50 CONTINUE                                                           97
      DO 55 I=3,15                                                       98
      DO 55 J=1,6                                                        99
      E(I,9+J)=E(I,9-J)                                                 100
   55 CONTINUE                                                          101
      GO TO 60                                                          102
   56 DXWL=DAPWL/SQRT(2.)                                               103
      KXMAX=.5/DXWL                                                     104
      RETURN                                                            105
   60 KXMAX=1./(2.*DXWL)                                                106
      IF (ICHAN.EQ.1) RETURN                                            107
      IF ((IXY.EQ.1).AND.(ICASE.EQ.3)) RETURN                           108
      IF ((IXY.EQ.1).AND.(IPOL.EQ.1)) RETURN                            109
      IF ((IXY.EQ.2).AND.(IPOL.EQ.2)) RETURN                            110
      IF (ICHAN.EQ.3) GO TO 75                                          111
C  LOAD ELEVATION DIFFERENCE CHANNEL:                                   112
      J=NY/2+1                                                          113
      DO 65 I=1,NX                                                      114
```

```
   65 E(I,J)=(0.,0.)                                                    115
      JMAX=NY/2                                                         116
      DO 70 J=1,JMAX                                                    117
      DO 70 I=1,NX                                                      118
   70 E(I,J)=-E(I,J)                                                    119
      RETURN                                                            120
C  LOAD AZIMUTH DIFFERENCE CHANNEL:                                     121
   75 I=NX/2+1                                                          122
      DO 80 J=1,NY                                                      123
   80 E(I,J)=(0.,0.)                                                    124
      IMAX=NX/2                                                         125
      DO 85 I=1,IMAX                                                    126
      DO 85 J=1,NY                                                      127
   85 E(I,J)=-E(I,J)                                                    128
      RETURN                                                            129
C   DAPWL=5.047 FOR ADA M.'S CASE III                                   130
   90 WRITE(6,95)                                                       131
   95 FORMAT(//"***ERROR EXIT! NX NOT EQUAL TO 16 IN SUBR TRECNF***"//) 132
      STOP                                                              133
      END                                                               134
```

Chapter 5

SUBROUTINE APINT

5-1. Purpose: To compute the electromagnetic fields $\underline{E}$, $\underline{H}$ of a rectangular aperture in the z=0 plane at a point P(x,y,z>0), where the amplitude and phase of the aperture electric fields E_{xap}, E_{yap} are specified at N_x by N_y discrete points spaced d_x/λ and d_y/λ apart. The aperture magnetic fields H_{xap}, H_{yap} are derived from $\underline{E}_{ap}$ via the geometrical optics approximation.

5-2. Usage: CALL APINT (PFWL, EX, EY, NX, NY, MIDX, MIDY, DXWL, DYWL, E, H, INIT)

5-3. Arguments

PFWL - Real input array of three elements which specifies the Cartesian coordinates in wavelengths of the point P(x/λ, y/λ, z/λ) at where the fields are to be computed; i.e., PFWL(1) = x/λ, etc.

EX,EY - Complex input arrays of NX by NY elements each which specify the aperture electric field.

NX,NY - Integer input variables equal to the number of sample points in the aperture in the x and y directions, respectively. NX and NY must be even.

MIDX, MIDY - Integer input variables equal to the indices in the arrays EX, EY corresponding to x=y=0; i.e., MIDX=NX/2+1, MIDY=NY/2+1.

DXWL, DYWL - Real input variables equal to the sample spacings in wavelengths in the x and y directions, respectively.

E,H - Complex output arrays of three elements each equal to the rectangular vector components of the electric and magnetic fields at P; i.e., E(1)=E_x, etc.

INIT - Logical input variable which controls initialization of subroutine DIPOLES.

C-4. Comments and Method

The fields at P(x,y,z) due to the sampled aperture fields are computed by summing the individual fields of equivalent electric and magnetic dipoles located at each sample point as explained in Section C-4.

C-5. Program Flow

1-11 Declare variables, initialize constants.

13-14 Compute initial source point, minus $d_x/2$. Set z-coordinate of source points to zero.

17-18 Initialize summations of the fields E,H.

20-21 Compute first source point $P_x(x,y,0)$.

23-24 Compute electric J^e_x, J^e_y and magnetic J^m_x, J^m_y currents according to $\underline{J}^e = \hat{z} \times \underline{H}_{ap}$ and $\underline{J}^m = \underline{E}_{ap} \times \hat{z}$.

26 Call subroutine DIPOLES to compute the fields of the electric and magnetic dipoles J^e, J^m located at the specified source point.

28-31 Add contribution from each similar component to the field at P(x,y,z).

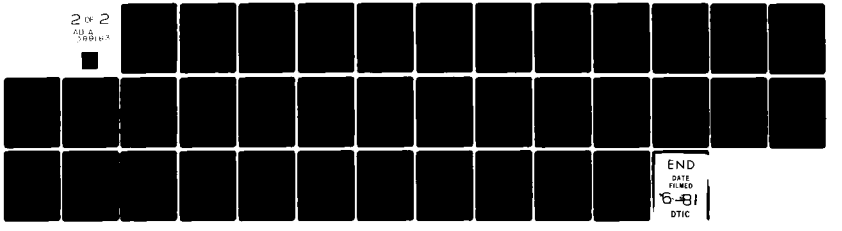
33 Repeat for all source points.

C-6. Test Cases (See Chapter 6).

C-7. References (See Chapter 6).

C-8. Program Listing (See Appendix B).

AD-A099 183 GEORGIA INST OF TECH ATLANTA F/G 17/9
PARAMETRIC INVESTIGATION OF RADOME ANALYSIS METHODS. VOLUME III--ETC(U)
FEB 81 G K HUDDLESTON, H L BASSETT AFOSR-77-3469
UNCLASSIFIED AFOSR-TR-81-0461 NL



```
      SUBROUTINE APINT(PFWL,EX,EY,NX,NY,MIDX,MIDY,DXWL,DYWL,E,H,INIT)          1
C  SUBR APINT COMPUTES FRESNEL FIELDS OF RECTANGULAR APERTURE WITH             2
C  APERTURE FIELDS GIVEN BY EX,EY( H FIELDS ARE DERIVED USING G.O. APPROX.)
C  FIELDS E,H ARE COMPUTED AT THE POINT PFWL.                                  4
      COMPLEX E(3),H(3),EX(NX,NY),EY(NX,NY),JE(2),JM(2),ES(3),HS(3)           5
C  JE,JM ARE ELECTRIC AND MAGNETIC SURFACE CURRENT DENSITIES FOUND FROM       6
C  EAPXZHAT AND ZHAT X HAP.                                                    7
      LOGICAL INIT                                                            8
      REAL PSWL(3),PFWL(3)                                                    9
      DATA ETA/376.9911185/                                                   10
C  NX,NY MUST BE EVEN SO THAT OMITTING ROW 1 AND COL 1 YIELDS SYM APERTURE
C  INIT=.TRUE. TO INITIALIZE CONSTANTS IN SUBR DIPOLES                        12
      PSWL(1)=(1-MIDX)*DXWL                                                   13
      PSWL(3)=0.                                                              14
      DO 1 L=1,3                                                              15
      E(L)=(0.,0.)                                                            16
      H(L)=(0.,0.)                                                            17
    1 CONTINUE                                                                18
      DO 10 I=2,NX                                                            19
      PSWL(1)=PSWL(1)+DXWL                                                    20
      PSWL(2)=(1-MIDY)*DYWL                                                   21
      DO 10 J=2,NY                                                            22
      PSWL(2)=PSWL(2)+DYWL                                                    23
      JE(1)=-EX(I,J)/ETA                                                      24
      JM(1)=EY(I,J)                                                           25
      JE(2)=-EY(I,J)/ETA                                                      26
      JM(2)=-EX(I,J)                                                          27
      CALL DIPOLES(JE,JM,PSWL,PFWL,DXWL,DYWL,ES,HS,INIT)                      28
      DO 5 L=1,3                                                              29
      E(L)=E(L)+ES(L)                                                         30
      H(L)=H(L)+HS(L)                                                         31
    5 CONTINUE                                                                32
   10 CONTINUE                                                                33
      RETURN                                                                  34
      END                                                                     35
```

Chapter 6

SUBROUTINE DIPOLES

6-1. Purpose: To compute the electromagnetic fields $\underline{E} = \hat{x} E_x + \hat{y} E_y + \hat{z} E_z$ and $\underline{H} = \hat{x} H_x + \hat{y} H_y + \hat{z} H_z$ at point $P_f(x/\lambda, y/\lambda, z/\lambda)$ as produced by electric $\underline{J}^e = \hat{z} \times \underline{H}$ and magnetic $\underline{J}^m = \underline{E} \times \hat{z}$ surface currents flowing on the planar rectangular surface of dimensions $\Delta x/\lambda$, $\Delta y/\lambda$ located at source point P_s $(x'/\lambda, y'/\lambda, z'/\lambda)$ and oriented in the $z=z'$ plane. All dimensions are in wavelengths.

6-2. Usage: CALL DIPOLES (JE, JM, PSWL, PFWL, DXWL, DYWL, E, H, INIT)

6-3. Arguments

JE, JM - Complex input arrays of two elements each containing the x and y components of the electric and magnetic surface current densities at the center of the planar element as found from $\underline{E} \times \hat{z}$ and $\hat{z} \times \underline{H}$, respectively, where $\hat{z}$ is the unit normal to the element and $\underline{E}$, $\underline{H}$ are the fields at the center of the element.

PSWL, PFWL - Real input arrays of three elements each which contain the coordinates $P_s(x'/\lambda, y'/\lambda, z'/\lambda)$, $P_f(x/\lambda, y/\lambda, z/\lambda)$ of the center of the source element and the point at which the field is to be computed, respectively.

DXWL, DYWL - Real input variables equal to the dimensions $\Delta x/\lambda$, $\Delta y/\lambda$ of the rectangular source element.

E, H - Complex output arrays of three elements each containing the fields $\underline{E}$, $\eta\,\underline{H}$ at the point P_f. Note that $\eta\,\underline{H}$ is computed rather than $\underline{H}$ above (to save time).

INIT - Logical input variable which controls initialization of various constants for repetitive calls to the subroutine: if TRUE, the constants are computed; if FALSE, the constants are not computed, and their last computed values are used.

6-4. Comments and Method

a. Comment. The source and field points cannot be any closer together than $r = .01\lambda$. This restriction is necessary to prevent division by zero due to the r^{-1} variation of the dipole fields as explained below. Actually, field points should be removed to the order of $r = \sqrt{(\Delta x/\lambda)^2 + (\Delta y/\lambda)^2}$ for validity of the discretized approximation to the physical model.

b. Method. The subroutine computation is motivated by the problem of computing the fields of a rectangular antenna aperture located in the $z=z'$ plane as illustrated in Figure 1. Let the electric and magnetic fields $\underline{E}_{ap}$, $\underline{H}_{ap}$ be specified at discrete points $(x_m, y_n, 0)$. Then, at each point, the equivalent surface current densities $\underline{J}^e$ and $\underline{J}^m$ are given by [1]

$$\underline{J}^e = \hat{z} \times \underline{H}_{ap} = \hat{x}\,(-H_{yap}) + \hat{y}\,H_{xap} = \hat{x}\,J^e_x + \hat{y}\,J^e_y \qquad (1)$$

$$\underline{J}^m = \underline{E}_{ap} \times \hat{z} = \hat{x}\,E_{yap} + \hat{y}\,(-E_{xap}) = \hat{x}\,J^m_x + \hat{y}\,J^m_y \qquad (2)$$

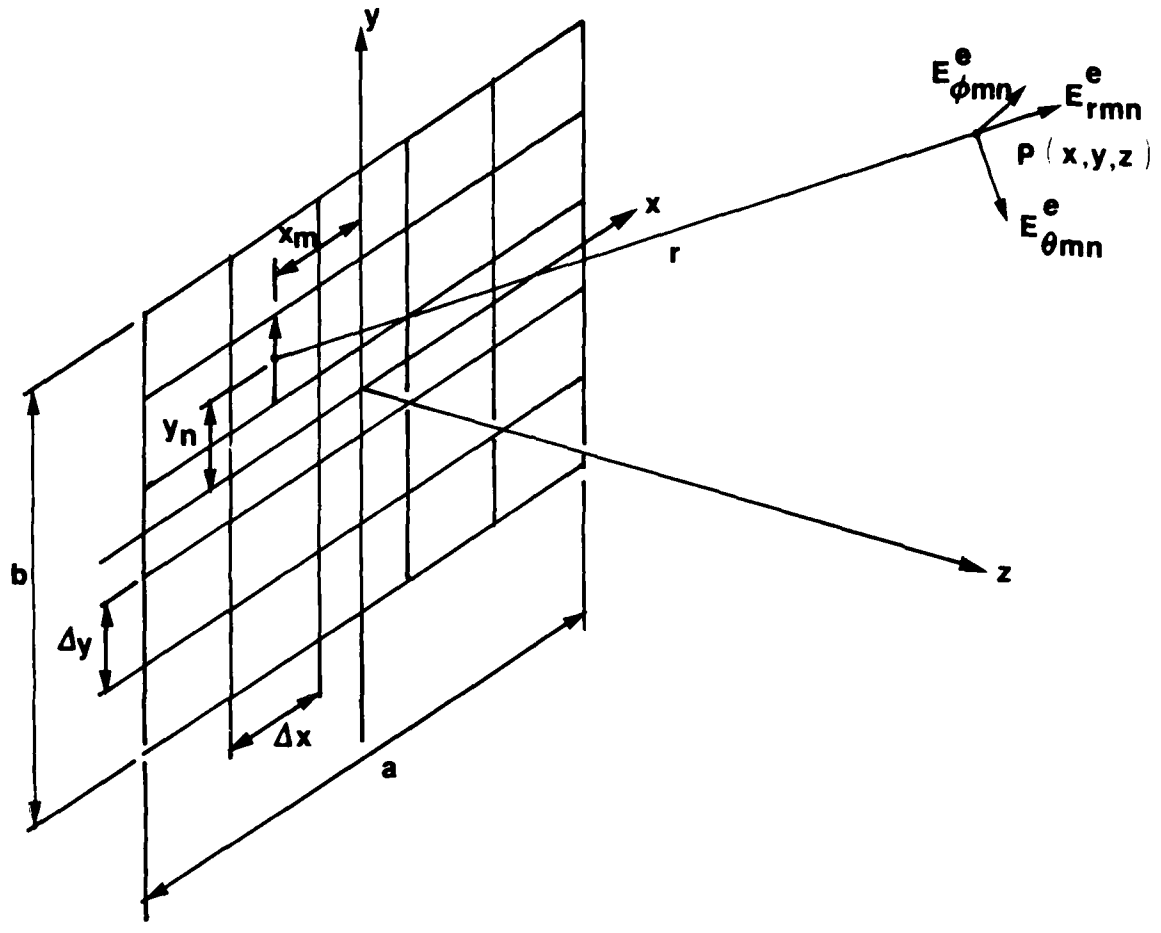


Figure 6–1. Geometry of Rectangular Aperture Antenna Approximated by Elementary Dipoles.

The surface current densities so defined can be discretized for each element $\Delta x \Delta y$ as follows. Consider the current density J_y^e. The total current entering the lower boundary and leaving the upper boundary of the element is $J_y^e \Delta x$ and can be regarded as an elementary dipole concentrated at the center of the element. The dipole moment is

$$p_o = q\ell = \frac{J_y^e \, \Delta x}{j\omega} \, \Delta y \tag{3}$$

where q is the charge and ℓ is the separation [2], and where the following relation for the sinusoidal steady state has been used:

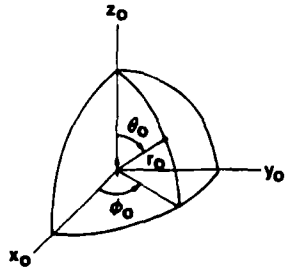
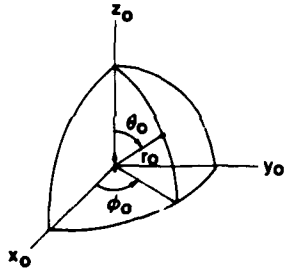
$$q = \int I \, dt = \frac{I}{j\omega} \tag{4}$$

Similar relations hold for the other component of $\underline{J}^e$ and, by duality, for $\underline{J}^m$ as will be summarized below.

The next step in the development is to obtain expressions for the dipole fields of $\underline{J}^e$ and $\underline{J}^m$. To facilitate this step, first consider the fields radiated by electric and magnetic dipoles oriented along the z_o axis as shown in Table 1 [2]. Note that these expressions require r_o in wavelengths, and that Δx and Δy refer to the element size in the original aperture.

Matters are simplified if the spherical coordinate components of Table 1 are transformed to their corresponding rectangular components according to [3]

Table 6–1. Elementary Dipole Fields of Z–Directed Currents.

Electric	⟷ Duality ⟷	Magnetic
	$\underline{E}^e$	
	$\underline{H}^e$	$\underline{H}^m$
	$-\underline{E}^m$	
	ϵ	μ
	μ	ϵ
	η	η^{-1}
$E^e_{ro} = J^e_{zo}\, e_o \left[\frac{1}{r_o^3} + \frac{j2\pi}{r_o^2}\right] \cos\theta_o\, e^{-j2\pi r_o}$		$H^m_{ro} = J^m_{zo}\, h_o \left[\frac{1}{r_o^3} + \frac{j2\pi}{r_o^2}\right] \cos\theta_o\, e^{-j2\pi r_o}$
$E^e_{\theta o} = J^e_{zo}\, \frac{e_o}{2} \left[\frac{1}{r_o^3} + \frac{j2\pi}{r_o^2} - \frac{(2\pi)^2}{r_o}\right] \sin\theta_o\, e^{-j2\pi r_o}$		$H^m_{\theta o} = J^m_{zo}\, \frac{h_o}{2} \left[\frac{1}{r_o^3} + \frac{j2\pi}{r_o^2} - \frac{(2\pi)^2}{r_o}\right] \sin\theta_o\, e^{-j2\pi r_o}$
$H^e_{\phi o} = J^e_{zo}\, e_o\, \frac{j\pi}{r} \left[\frac{1}{r_o^2} + \frac{j2\pi}{r_o}\right] \sin\theta_o\, e^{-j2\pi r_o}$		$E^m_{\phi o} = -J^m_{zo}\, h_o\, j\pi\eta \left[\frac{1}{r_o^2} + \frac{j2\pi}{r_o}\right] \sin\theta_o\, e^{-j2\pi r_o}$
$e_o = \frac{\left(\frac{\Delta x}{\lambda}\right)\left(\frac{\Delta y}{\lambda}\right)\eta}{j(2\pi)^2}$		$h_o = \frac{\left(\frac{\Delta x}{\lambda}\right)\left(\frac{\Delta y}{\lambda}\right)}{j(2\pi)^2\eta}$
r_o in wavelengths		r_o in wavelengths

$$A_{xo} = (\bar{A}_{ro} \cos\theta_o) \sin\theta_o \cos\phi_o + (\bar{A}_{\theta o} \sin\theta_o) \cos\theta_o \cos\phi_o \quad (5a)$$

$$A_{yo} = (\bar{A}_{ro} \cos\theta_o) \sin\theta_o \sin\phi_o + (\bar{A}_{\theta o} \sin\theta_o) \cos\theta_o \sin\phi_o \quad (5b)$$

$$A_{zo} = (\bar{A}_{ro} \cos\theta_o) \cos\theta_o - (\bar{A}_{\theta o} \sin\theta_o) \sin\theta_o \quad (5c)$$

$$C_{xo} = -(\bar{C}_{\phi o} \sin\theta_o) \sin\phi_o \quad (5d)$$

$$C_{yo} = (\bar{C}_{\phi o} \sin\theta_o) \cos\phi_o \quad (5e)$$

$$C_{zo} = 0 \quad (5f)$$

In the above, the trigonometric function in parentheses comes from the field expressions in Table 1; hence, the "minus" superscript indicates the field expression from Table 1 without the orientation factor $\cos\theta_o$ or $\sin\theta_o$, weighting e_o or h_o, and without the current $\bar{J}^m_{zo}$ or J^e_{zo}.

Define direction cosines k_{xo}, k_{yo}, k_{zo} related to θ_o, ϕ_o according to

$$k_{xo} = \sin\theta_o \cos\phi_o \quad (6a)$$

$$k_{yo} = \sin\theta_o \sin\phi_o \quad (6b)$$

$$k_{zo} = \cos\theta_o \quad (6c)$$

Then Equations (5) can be rewritten succinctly as

$$A_{xo} = (\bar{A}_{ro} + \bar{A}_{\theta o})\ k_{xo}\ k_{zo} \tag{7a}$$

$$A_{yo} = (\bar{A}_{ro} + \bar{A}_{\theta o})\ k_{yo}\ k_{zo} \tag{7b}$$

$$A_{zo} = (\bar{A}_{ro} + \bar{A}_{\theta o})\ k_{zo}^{2} - \bar{A}_{\theta o} \tag{7c}$$

$$C_{xo} = -\ \bar{C}_{\phi o}\ k_{yo} \tag{7d}$$

$$C_{yo} = \bar{C}_{\phi o}\ k_{xo} \tag{7e}$$

$$C_{zo} = 0 \tag{7f}$$

Similar expressions for cases of x-directed and y-directed dipoles may be derived from those given above merely redefining the axes in Table 1. When this is done, the generalized expressions shown in Table 2 result for all three cases.

When both electric and magnetic currents are present (x-directed and y-directed components) the expressions for $\underline{E}$ and $\underline{H}$ are obtained by adding the contributions due to each current as given in Table 2. Note that $\bar{A}_r$, $\bar{A}_\theta$, and $\bar{A}_r$ are identical for both types and directions of currents so that the expressions for the field components may be written, for example, as follows:

$$E_x = e_o \left\{ J_x^e [(\bar{A}_r + \bar{A}_\theta)\ k_x^2 - \bar{A}_\theta] + J_y^e\ k_x k_y\ (\bar{A}_r + \bar{A}_\theta) \right\}$$

$$- h_o\ j\pi\eta\ J_y^m\ k_z\ \bar{C}_\phi \tag{8a}$$

Table 6-2. Rectangular Field Components of Elementary Dipoles

Field Component	Dipole Orientation x-directed	y-directed	z-directed
A_x	$\bar{A}_{r\theta} k_x^2 - \bar{A}_\theta$	$\bar{A}_{r\theta} k_x k_y$	$\bar{A}_{r\theta} k_x k_z$
A_y	$\bar{A}_{r\theta} k_x k_y$	$\bar{A}_{r\theta} k_y^2 - \bar{A}_\theta$	$\bar{A}_{r\theta} k_y k_z$
A_z	$\bar{A}_{r\theta} k_x k_z$	$\bar{A}_{r\theta} k_y k_z$	$\bar{A}_{r\theta} k_z^2 - \bar{A}_\theta$
C_x	0	$\bar{C}_\phi k_z$	$-\bar{C}_\phi k_y$
C_y	$-\bar{C}_\phi k_z$	0	$\bar{C}_\phi k_x$
C_z	$\bar{C}_\phi k_y$	$-\bar{C}_\phi k_x$	0

where:

$$\bar{A}_{r\theta} = (\bar{A}_r + \bar{A}_\theta)$$

$$\bar{A}_r = \left(\frac{1}{r_o^3} + \frac{j2\pi}{r_o^2}\right) e^{-j2\pi r_o}$$

$$\bar{A}_\theta = \frac{1}{2}\left(\frac{1}{r_o^3} + \frac{j2\pi}{r_o^2} - \frac{(2\pi)^2}{r_o}\right) e^{-j2\pi r_o}$$

$$\bar{C}_\phi = \left(\frac{1}{r_o^2} + \frac{j2\pi}{r_o}\right) e^{-j2\pi r_o}$$

$$\eta H_x = \eta h_o \left\{ J_x^m [(\bar{A}_r + \bar{A}_\theta)\, k_x^2 - \bar{A}_\theta] + J_y^m\, k_x k_y\, (\bar{A}_r + \bar{A}_\theta) \right\}$$

$$+ e_o\, j\pi\, J_y^e\, k_z\, \bar{C}_\phi \qquad (8b)$$

Similar expressions may be obtained for the other rectangular components of $\underline{E}$ and $\underline{H}$ as given in Table 6-3 and by Lines 56-57 and 62-65 of the program listing.

6-6. Program Flow

Lines	Comment
15	If INIT=.TRUE., compute constants in Lines 18-29.
18-29	Compute $(2\pi)^2$, j, e_o, h_o, $j2\pi$, $j\pi$, $h_{oe}=-h_o\eta$, $e_{oh}=e_o/\eta$. Lines 26-27 have been added to cause $\eta\underline{H}$ to be computed instead of $\underline{H}$ to save time in Subroutine RECM (See Chapter 3).
30-33	Compute r in wavelengths; i.e., the distance from the source point to the field point.
34	If $r<.01\lambda$, write error message and stop (Lines 67-69).
35-37	Compute direction cosines k_x, k_y, k_z.
38-40	Compute exponential phase factor $e^{-j2\pi r}$.
41-45	Compute $\bar{A}_{ro}$, $\bar{A}_{\theta o}$, $\bar{C}_{\phi o}$, $(\bar{A}_{ro} + \bar{A}_{\theta o})$, and $C_\theta = (\bar{A}_{ro} + \bar{A}_{\theta o})\, k_x^2 - \bar{A}_{\theta o}$
46-49	These commented lines contain only 1/r terms and can be used to replace lines 41-45.
50-51	Precalculate $(\bar{A}_{ro} + \bar{A}_{\theta o})\, k_x\, k_y$ and $\bar{C}_{\phi o}\, k_z$ to facilitate computation of E_x and H_x.

Table 6-3. Fields of Elementary x-Directed and y-Directed Dipoles

$$\underline{E} = \underline{E}^e + \underline{E}^m$$

$$\underline{H} = \underline{H}^e + \underline{H}^m$$

$$E_x = e_o[J_x^e(\bar{A}_{r\theta}\, k_x^2 - \bar{A}_\theta) + J_y^e(k_x k_y\, \bar{A}_{r\theta})] - h_o\, j\pi\eta\, J_y^m\, k_z\, \bar{c}_\phi$$

$$E_y = e_o[J_x^e(k_x k_y\, \bar{A}_{r\theta}) + J_y^e(\bar{A}_{r\theta}\, k_y^2 - \bar{A}_\theta)] + h_o\, j\pi\eta\, J_x^m\, k_z\, \bar{c}_\phi$$

$$E_z = e_o[J_x^e(k_x k_z\, \bar{A}_{r\theta}) + J_y^e(k_y k_z\, \bar{A}_{r\theta})] + h_o\, j\pi\eta\, \bar{c}_\phi(-J_x^m\, k_y + J_y^m\, k_x)$$

$$H_x = e_o\, \frac{j\pi}{\eta}\, J_y^e\, k_z\, \bar{c}_\phi + h_o[J_x^m(\bar{A}_{r\theta}\, k_x^2 - \bar{A}_\theta) + J_y^m\, k_x k_y\, \bar{A}_{r\theta}]$$

$$H_y = -e_o\, \frac{j\pi}{\eta}\, J_x^e\, k_z\, \bar{c}_\phi + h_o[J_x^m(k_x k_y\, \bar{A}_{r\theta}) + J_y^m(\bar{A}_{r\theta}\, k_y^2 - \bar{A}_\theta)]$$

$$H_z = e_o\, \frac{j\pi}{\eta}\, \bar{c}_\phi(k_y\, J_x^e - k_x\, J_y^e) + h_o[J_x^m(k_x k_z\, \bar{A}_{r\theta}) + J_y^m(k_y k_z\, \bar{A}_{r\theta})]$$

Where: $e_o = \dfrac{(\frac{\Delta A}{\lambda^2})\eta}{j(2\pi)^2}$ $\qquad$ $h_o = \dfrac{(\frac{\Delta A}{\lambda^2})}{j(2\pi)^2\eta}$

52-53 Compute E_x and H_x due to the x-directed and y-directed electric and magnetic currents: J_x^e = JE(1), J_y^e = JE(2), J_x^m = JM(1), J_y^m = JM(2).

54 Precalculate $(\bar{A}_{ro} + \bar{A}_{\theta o})\, k_y^2 - \bar{A}_{\theta o}$.

55 See lines 46-49 above.

56-57 Compute E_y and H_y.

58-61 Precalculate common variables for E_z, H_z.

62-65 Compute E_z and H_z.

RETURN

67-69 Error message and halt.

END

6-6. Test Case

Selected test cases shown in Figure 2-15 of Reference 1 were executed. The square, 4" x 4", uniform aperture (λ= 1.18") was sampled at M=15, N=15 points in the x and y directions, respectively. Cases were done for $\underline{E}_{ap} = \hat{y}(1)$, $\underline{H}_{ap} = 0$, and for $\underline{E}_{ap} = \hat{y}(1)$, $\underline{H}_{ap} = -\hat{x}(1/\eta)$ In the latter case, the amplitudes obtained were twice as large (as expected). Although exact comparison to the graphical results in Figure 2-15 was not possible, agreement was obtained so far as could be determined. Some benchmarks as computed by Subroutine DIPOLES are shown in Tables 4 through 6.

6-7. References

1. C. H. Walter, Traveling Wave Antennas, McGraw-Hill, New York, 1965, Ch. 2.

2. S. Silver, Microwave Antenna Theory and Design, McGraw-Hill, New York, 1949, Ch. 3.

3. D. T. Paris and F. K. Hurd, Basic Electromagnetic Theory, McGraw-Hill, New York, 1969, Ch. 1.

6-8. Program Listing. See following pages.

```
      SUBROUTINE DIPOLES(JE,JM,PSWL,PFWL,DXWL,DYWL,E,H,INIT)                1
C *** MODIFIED 1-23-80 TO INCLUDE ONLY 1/R TERMS **** NULLIFIED 1-24-80**
C  SUBR DIPOLES COMPUTES THE RECTANGULAR COMPONENTS OF THE FIELDS E,H OF     3
C  ELECTRIC AND MAGNETIC DIPOLES LOCATED AT PSWL(X',Y',Z')                   4
C  AND ORIENTED IN THE X' AND Y' DIRECTIONS.  THE FIELDS ARE COMPUTED AT     5
C  THE POINT PFWL(X,Y,Z).  ALL DIMENSIONS ARE IN WAVELENGTHS.  MKS SYSTEM
C  IS USED.  FREE SPACE (ETA=377 OHMS) IS ASSUMED.                           7
      COMPLEX JE(2),JM(2),E(3),H(3),JAY,HO,EO,CPHS,JPI,JAY2PI               8
      COMPLEX ARO,ATO,CPO,ARTO,CT,ARTOK,CPOK,EOH,HOE                        9
      REAL PSWL(3),PFWL(3),KX,KY,KZ                                        10
      LOGICAL INIT                                                         11
C  DXWL,DYWL=X' AND Y' DIMENSIONS OF THE RECTANGULAR ELEMENT OVER WHICH     12
C            CURRENT DENSITIES JE AND JM FLOW TO MAKE THE DIPOLES.          13
      DATA TUPI/6.283185301/,ETA/376.9911185/                              14
      IF (INIT) GO TO 1                                                    15
      GO TO 2                                                              16
C  COMPUTE EO,HO (SEE DERIVATION DATED 7-23-79):                           17
    1 TUPI2=TUPI**2                                                        18
      JAY=(0.,1.)                                                          19
      EO=DXWL*DYWL*ETA/(JAY*TUPI2)                                         20
      HO=DXWL*DYWL/(JAY*TUPI2*ETA)                                         21
      JAY2PI=JAY*TUPI                                                      22
      JPI=JAY*TUPI/2.                                                      23
      HOE=-HO*ETA                                                          24
      EOH=EO/ETA                                                           25
      HO=HO*ETA                                                            26
      EOH=EOH*ETA                                                          27
C  THE ABOVE TWO LINES CAUSE ETA*H TO BE COMPUTED FOR USE IN RECI.          28
      INIT=.FALSE.                                                         29
    2 X=PFWL(1)-PSWL(1)                                                    30
      Y=PFWL(2)-PSWL(2)                                                    31
      Z=PFWL(3)-PSWL(3)                                                    32
      R=SQRT(X*X+Y*Y+Z*Z)                                                  33
      IF (R.LT..01) GO TO 90                                               34
      KX=X/R                                                               35
      KY=Y/R                                                               36
      KZ=Z/R                                                               37
      PHS=AMOD(TUPI*R,TUPI)                                                38
```

```
      CPHS=CMPLX(0.,-PHS)                                                    39
      CPHS=CEXP(CPHS)                                                        40
      ARO=CPHS*(1./R**3+JAY2PI/R**2)                                         41
      ATO=.5*(ARO-CPHS*TUPI2/R)                                              42
      CPO=JPI*ARO*R                                                          43
      ARTO=ARO+ATO                                                           44
      CT=ARO*KX**2-ATO*(1.-KX**2)                                            45
C     ATO=-.5*CPHS*TUPI2/R                                                   46
C     CPO=JPI*CPHS*JAY2PI/R                                                  47
C     ARTO=ATO                                                               48
C     CT=-ATO*(1.-KX*KX)                                                     49
      ARTOK=ARTO*KX*KY                                                       50
      CPOK=CPO*KZ                                                            51
      E(1)=EO*(JE(1)*CT+JE(2)*ARTOK)+JM(2)*HOE*CPOK                          52
      H(1)=HO*(JM(1)*CT+JM(2)*ARTOK)+EOH*JE(2)*CPOK                          53
      CT=ARO*KY**2-ATO*(1.-KY**2)                                            54
C     CT=-ATO*(1.-KY*KY)                                                     55
      E(2)=EO*(JE(1)*ARTOK+JE(2)*CT)-JM(1)*HOE*CPOK                          56
      H(2)=HO*(JM(1)*ARTOK+JM(2)*CT)-JE(1)*EOH*CPOK                          57
      ARTOK=ARTO*KY*KZ                                                       58
      ARTO=ARTO*KX*KZ                                                        59
      CPOK=CPO*KY                                                            60
      CPO=CPO*KX                                                             61
      E(3)=EO*(JE(1)*ARTO+JE(2)*ARTOK)+HOE*(JM(1)*CPOK                       62
     $-JM(2)*CPO)                                                            63
      H(3)=HO*(JM(1)*ARTO+JM(2)*ARTOK)+EOH*(JE(1)*CPOK                       64
     $-JE(2)*CPO)                                                            65
      RETURN                                                                 66
   90 WRITE(6,91)                                                            67
   91 FORMAT(" **** R.LT..01 WAVELENGTH IN SUBR DIPOLES--STOP****")          68
      STOP                                                                   69
      END                                                                    70
```

Table 6-4. Fields Computed by Subroutine DIPOLES Along z-Axis for 4" x 4" Uniform Aperture (λ=1.18").

```
1 TEST PROGRAM FOR USING ELEMENTARY SOURCES FOR COMPUTING FRESNEL FIELDS
 (REF:  WALTER(1967), PP.66-97)
 AIN= 4.00  BIN= 4.00  M,N=  15  15 LAMBDA= 1.180
 FIELD IS -1.0 DB AT Z= 24.00 INCHES
 APERTURE FIELDS:  TAP= (1.0000,0.0000)  (1.0000,0.0000)  HAP= (0.0000,0.0000)
 RO,HRO=  .8742ZE+00  .2318BE-02  IAXIS= 3  PFWL:  0.00  0.00  4.00
```

N	XYZIN	XYZWL	EX / HX AMPDB	EX / HX PHSDEG	EY / HY AMPDB	EY / HY PHSDEG	EZ / HZ AMPDB	EZ / HZ PHSDEG
1	4.00	3.39	-40.1	-180.0	-.1	-139.2	-40.0	177.4
			-.1	40.9	-40.0	-180.0	-40.0	-4.4
2	4.30	3.64	-40.0	-180.0	-.0	139.3	-40.0	92.5
			.0	-44.6	-40.0	-180.0	-40.0	-86.1
3	4.59	3.89	-40.0	-180.0	-.0	49.5	-40.0	10.1
			-.0	-130.4	-40.0	-180.0	-40.0	-168.7
4	4.89	4.14	-40.0	-180.0	-.1	-36.7	-40.0	-72.5
			-.1	143.4	-40.0	-180.0	-40.0	105.2
5	5.18	4.39	-40.0	-180.0	-.2	-123.1	-40.0	-157.1
			-.2	56.9	-40.0	-180.0	-40.0	19.5
6	5.48	4.64	-40.0	-180.0	-.3	156.1	-40.0	118.2
			-.3	-29.8	-40.0	-180.0	-40.0	-69.4
7	5.77	4.89	-40.0	-180.0	-.4	63.1	-40.0	30.8
			-.4	-110.8	-40.0	-180.0	-40.0	-154.4
8	6.07	5.14	-40.0	-180.0	-.6	-24.1	-40.0	-50.7
			-.6	150.0	-40.0	-180.0	-40.0	129.2
9	6.36	5.39	-40.0	-180.0	-.8	-111.5	-40.0	-138.0
			-.8	68.5	-40.0	-180.0	-40.0	38.1
10	6.66	5.64	-40.0	-180.0	-1.0	160.9	-40.0	136.4
			-1.0	-19.1	-40.0	-180.0	-40.0	-50.0
11	6.95	5.89	-40.0	-180.0	-1.2	73.1	-40.0	48.9
			-1.2	-106.9	-40.0	-180.0	-40.0	-139.9
12	7.25	6.14	-40.0	-180.0	-1.4	-14.8	-40.0	-39.3
			-1.4	165.2	-40.0	-180.0	-40.0	133.6
13	7.54	6.39	-40.0	-180.0	-1.6	-102.9	-40.0	-131.3

			(	-1.6	77.1	-40.0	-180.0	-40.0	53.6)
14	7.84	6.64		-40.0	-180.0	-1.8	168.9	-40.0	147.1
			(	-1.8	-11.1	-40.0	-180.0	-40.0	-32.2)
15	8.13	6.89		-40.0	-180.0	-2.0	80.6	-40.0	58.0
			(	-2.0	-99.4	-40.0	-180.0	-40.0	-121.4)
16	8.43	7.14		-40.0	-180.0	-2.2	-7.8	-40.0	-25.3
			(	-2.2	172.2	-40.0	-180.0	-40.0	149.3)
17	8.72	7.39		-40.0	-180.0	-2.4	-96.3	-40.0	-113.5
			(	-2.4	83.7	-40.0	-180.0	-40.0	59.3)
18	9.02	7.64		-40.0	-180.0	-2.6	175.1	-40.0	159.8
			(	-2.6	-4.9	-40.0	-180.0	-40.0	-26.4)
19	9.31	7.89		-40.0	-180.0	-2.8	86.4	-40.0	70.0
			(	-2.8	-93.6	-40.0	-180.0	-40.0	-108.5)
20	9.61	8.14		-40.0	-180.0	-3.0	-2.4	-40.0	-16.4
			(	-3.0	177.7	-40.0	-180.0	-40.0	161.1)
21	9.90	8.39		-40.0	-180.0	-3.2	-91.2	-40.0	-105.2
			(	-3.2	88.9	-40.0	-180.0	-40.0	71.3)
22	10.20	8.64		-40.0	-180.0	-3.4	179.9	-40.0	164.6
			(	-3.4	-.0	-40.0	-180.0	-40.0	-18.9)
23	10.49	8.89		-40.0	-180.0	-3.6	91.9	-40.0	71.1
			(	-3.6	-89.0	-40.0	-180.0	-40.0	-106.5)
24	10.79	9.14		-40.0	-180.0	-3.8	2.0	-40.0	-17.4
			(	-3.8	-178.0	-40.0	-180.0	-40.0	166.8)
25	11.08	9.39		-40.0	-180.0	-4.0	-87.0	-40.0	-104.3
			(	-4.0	93.0	-40.0	-180.0	-40.0	76.7)
26	11.38	9.64		-40.0	-180.0	-4.1	-176.1	-40.0	168.8
			(	-4.1	3.9	-40.0	-180.0	-40.0	-13.8)
27	11.67	9.89		-40.0	-180.0	-4.3	94.8	-40.0	76.7
			(	-4.3	-85.2	-40.0	-180.0	-40.0	-104.2)
28	11.97	10.14		-40.0	-180.0	-4.5	5.6	-40.0	-8.1
			(	-4.5	-174.4	-40.0	-180.0	-40.0	168.6)
29	12.26	10.39		-40.0	-180.0	-4.7	-83.6	-40.0	-97.5
			(	-4.7	96.4	-40.0	-180.0	-40.0	80.5)
30	12.56	10.64		-40.0	-180.0	-4.9	-172.9	-40.0	172.5
			(	-4.9	7.1	-40.0	-180.0	-40.0	-7.5)
31	12.85	10.89		-40.0	-180.0	-5.0	97.8	-40.0	84.9
			(	-5.0	-82.1	-40.0	-180.0	-40.0	-96.9)
32	13.15	11.14		-40.0	-180.0	-5.2	8.5	-40.0	-5.4

		(	-5.2	-171.5	-40.0	-180.0	-40.0	174.2)	77
33	13.44	11.31	-40.0	-180.0	-5.4	-80.8	-40.0	-91.0	78
		(	-5.4	99.2	-40.0	-180.0	-40.0	84.9)	79
34	13.74	11.64	-40.0	-180.0	-5.5	-170.2	-40.0	177.5	80
		(	-5.5	9.6	-40.0	-180.0	-40.0	-3.3)	81
35	14.03	11.84	-40.0	-180.0	-5.7	100.4	-40.0	89.5	82
		(	-5.7	-79.9	-40.0	-180.0	-40.0	-96.0)	83
36	14.33	12.14	-40.0	-180.0	-5.9	11.0	-40.0	-.6	84
		(	-5.9	-169.0	-40.0	-180.0	-40.0	176.0)	85
37	14.62	12.34	-40.0	-180.0	-6.0	-78.4	-40.0	-89.6	86
		(	-6.0	101.0	-40.0	-180.0	-40.0	90.0)	87
38	14.92	12.64	-40.0	-180.0	-6.2	-107.9	-40.0	-179.1	88
		(	-6.2	12.1	-40.0	-180.0	-40.0	-.2)	89
39	15.21	12.84	-40.0	-180.0	-6.3	102.7	-40.0	91.2	90
		(	-6.3	-77.3	-40.0	-180.0	-40.0	-96.0)	91
40	15.51	13.14	-40.0	-180.0	-6.5	13.2	-40.0	4.0	92
		(	-6.5	-166.8	-40.0	-180.0	-40.0	-179.1)	93
41	15.80	13.34	-40.0	-180.0	-6.6	-76.4	-40.0	-85.1	94
		(	-6.6	103.6	-40.0	-180.0	-40.0	90.0)	95
42	16.10	13.64	-40.0	-180.0	-6.8	-169.9	-40.0	-176.0	96
		(	-6.8	14.1	-40.0	-180.0	-40.0	2.1)	97
43	16.39	13.84	-40.0	-180.0	-6.9	104.0	-40.0	93.8	98
		(	-6.9	-75.4	-40.0	-180.0	-40.0	-90.0)	99
44	16.69	14.14	-40.0	-180.0	-7.0	15.0	-40.0	5.1	100
		(	-7.0	-165.0	-40.0	-180.0	-40.0	-175.9)	101
45	16.98	14.33	-40.0	-180.0	-7.2	-74.0	-40.0	-85.2	102
		(	-7.2	105.4	-40.0	-180.0	-40.0	90.0)	103
46	17.28	14.64	-40.0	-180.0	-7.3	-164.2	-40.0	-175.9	104
		(	-7.3	15.8	-40.0	-180.0	-40.0	6.1)	105
47	17.57	14.84	-40.0	-180.0	-7.5	106.2	-40.0	97.7	106
		(	-7.5	-73.0	-40.0	-180.0	-40.0	-83.4)	107
48	17.87	15.14	-40.0	-180.0	-7.6	10.6	-40.0	8.8	108
		(	-7.6	-163.4	-40.0	-180.0	-40.0	-172.6)	109
49	18.16	15.39	-40.0	-180.0	-7.7	-73.0	-40.0	-83.3	110
		(	-7.7	107.7	-40.0	-180.0	-40.0	97.1)	111
50	18.46	15.64	-40.0	-180.0	-7.8	-162.7	-40.0	-173.7	112
		(	-7.8	17.3	-40.0	-180.0	-40.0	7.6)	113
51	18.75	15.84	-40.0	-180.0	-8.0	107.7	-40.0	95.7	114

		(	-8.0	-72.3	-40.0	-180.0	-40.0	-82.0)
52	19.05	16.14	-40.0	-180.0	-8.1	18.3	-40.0	8.2
		(	-8.1	-162.0	-40.0	-180.0	-40.0	-171.5)
53	19.34	16.39	-40.0	-180.0	-8.2	-71.7	-40.0	-82.9
		(	-8.2	108.3	-40.0	-180.0	-40.0	98.8)
54	19.64	16.64	-40.0	-180.0	-8.3	-161.4	-40.0	-172.2
		(	-8.3	18.6	-40.0	-180.0	-40.0	9.1)
55	19.93	16.88	-40.0	-180.0	-8.5	108.9	-40.0	99.2
		(	-8.5	-71.0	-40.0	-180.0	-40.0	-80.6)
56	20.23	17.14	-40.0	-180.0	-8.6	19.2	-40.0	11.9
		(	-8.6	-160.8	-40.0	-180.0	-40.0	-170.3)
57	20.52	17.39	-40.0	-180.0	-8.7	-70.5	-40.0	-80.6
		(	-8.7	109.5	-40.0	-180.0	-40.0	100.7)
58	20.82	17.64	-40.0	-180.0	-8.8	-160.2	-40.0	-168.4
		(	-8.8	19.8	-40.0	-180.0	-40.0	11.1)
59	21.11	17.89	-40.0	-180.0	-8.9	110.1	-40.0	103.9
		(	-8.9	-69.9	-40.0	-180.0	-40.0	-78.6)
60	21.41	18.14	-40.0	-180.0	-9.1	20.4	-40.0	17.4
		(	-9.1	-159.0	-40.0	-180.0	-40.0	-168.5)
61	21.70	18.39	-40.0	-180.0	-9.2	-69.4	-40.0	-74.7
		(	-9.2	110.6	-40.0	-180.0	-40.0	102.0)
62	22.00	18.64	-40.0	-180.0	-9.3	-159.1	-40.0	-164.2
		(	-9.3	20.9	-40.0	-180.0	-40.0	12.5)
63	22.29	18.89	-40.0	-180.0	-9.4	111.1	-40.0	104.9
		(	-9.4	-68.9	-40.0	-180.0	-40.0	-77.1)
64	22.59	19.14	-40.0	-180.0	-9.5	21.4	-40.0	15.4
		(	-9.5	-158.6	-40.0	-180.0	-40.0	-166.2)
65	22.88	19.39	-40.0	-180.0	-9.6	-68.4	-40.0	-72.6
		(	-9.6	111.5	-40.0	-180.0	-40.0	104.3)
66	23.18	19.64	-40.0	-180.0	-9.7	-158.2	-40.0	-164.6
		(	-9.7	21.8	-40.0	-180.0	-40.0	16.4)
67	23.47	19.89	-40.0	-180.0	-9.8	112.0	-40.0	104.9
		(	-9.8	-68.0	-40.0	-180.0	-40.0	-72.0)
68	23.77	20.14	-40.0	-180.0	-9.9	22.3	-40.0	14.9
		(	-9.9	-157.7	-40.0	-180.0	-40.0	-162.5)

Table 6-5. Fields Computed by Subroutine DIPOLES Along x-Axis at z=8 inches.

```
1 TEST PROGRAM FOR USING ELEMENTARY SOURCES FOR COMPUTING FRESNEL FIELDS
 (REF: WALTER(1965), PP.55-57)
 AIN= 4.30  BIN= 4.00 M,N=  15  15 LAMBDA= 1.180
 FIELD IS -10.0 DB AT Z= 24.00 INCHES
 APERTURE FIELDS:  EAP= (0.0000,0.0000)  (1.0000,0.0000)   HAP= (0.0000,0.0000)
 TR0,HR0=  .874228+01  .231685-02   IAXIS= 1  PFWLD:   0.00   0.00   8.00
```

N	XYZIN	XYZWL	EX (HX) AMPDB	EX (HX) PHSDEG	EY (HY) AMPDB	EY (HY) PHSDEG	EZ (HZ) AMPDB	EZ (HZ) PHSDEG
1	0.30	0.00	-40.0	-180.0	-1.9	119.5	-40.0	96.3
		(	-1.9	-60.4	-40.0	-180.0	-40.0	-83.6)
2	.30	.25	-40.0	-180.0	-2.1	118.5	-40.0	96.4
		(	-2.1	-61.4	-40.0	-180.0	-30.8	65.7)
3	.59	.50	-40.0	-180.0	-2.7	115.5	-40.0	91.9
		(	-2.7	-64.2	-40.0	-180.0	-25.4	61.6)
4	.89	.75	-40.0	-180.0	-3.7	110.9	-40.0	87.9
		(	-3.7	-68.6	-40.0	-180.0	-23.0	54.7)
5	1.18	1.00	-40.0	-180.0	-5.2	104.9	-40.0	86.2
		(	-5.1	-74.2	-40.0	-180.0	-22.2	45.1)
6	1.48	1.25	-40.0	-180.0	-7.0	98.5	-40.0	77.5
		(	-6.9	-80.2	-40.0	-180.0	-22.6	33.2)
7	1.77	1.50	-40.0	-180.0	-9.2	93.0	-40.0	67.2
		(	-9.0	-85.4	-40.0	-180.0	-24.3	19.3)
8	2.07	1.75	-40.0	-180.0	-11.5	90.2	-40.0	71.7
		(	-11.2	-88.6	-40.0	-180.0	-27.7	5.0)
9	2.36	2.00	-40.0	-180.0	-13.2	90.0	-40.0	76.9
		(	-12.8	-89.9	-40.0	-180.0	-34.6	-.6)
10	2.66	2.25	-40.0	-180.0	-13.8	65.1	-40.0	60.3
		(	-13.5	-93.1	-40.0	-180.0	-38.7	83.6)
11	2.95	2.50	-40.0	-180.0	-13.6	74.9	-40.0	56.7
		(	-13.6	-102.7	-40.0	-180.0	-30.1	86.2)
12	3.25	2.75	-40.0	-180.0	-13.4	61.8	-40.0	39.5
		(	-13.6	-119.3	-40.0	-180.0	-26.3	63.4)
13	3.54	3.00	-40.0	-180.0	-13.5	38.5	-40.0	5.5

			(	-13.9	-141.7	-40.0	-180.0	-24.4	34.6)
14	3.84	3.25		-40.0	-180.0	-14.0	10.9	-40.0	7.1
			(	-14.5	-168.5	-40.0	-180.0	-23.5	2.3)
15	4.13	3.50		-40.0	-180.0	-14.8	-20.3	-40.0	-31.6
			(	-15.5	161.5	-40.0	-180.0	-23.5	-32.6)
16	4.43	3.75		-40.0	-180.0	-16.1	-53.9	-40.0	-67.6
			(	-16.8	129.0	-40.0	-180.0	-24.1	-69.6)
17	4.72	4.00		-40.0	-180.0	-17.8	-89.1	-40.0	-109.1
			(	-18.4	95.1	-40.0	-180.0	-25.3	-108.2)
18	5.02	4.25		-40.0	-180.0	-19.9	-124.9	-40.0	-136.0
			(	-20.4	60.6	-40.0	-180.0	-27.2	-147.7)
19	5.31	4.50		-40.0	-180.0	-22.3	-154.5	-40.0	-159.9
			(	-22.6	26.8	-40.0	-180.0	-29.9	173.4)
20	5.61	4.75		-40.0	-180.0	-24.9	169.5	-40.0	165.1
			(	-24.8	-4.7	-40.0	-180.0	-33.7	139.6)
21	5.90	5.00		-40.0	-180.0	-26.9	144.1	-40.0	139.6
			(	-26.5	-33.7	-40.0	-180.0	-38.0	123.9)
22	6.20	5.25		-40.0	-180.0	-27.3	119.3	-40.0	64.5
			(	-27.2	-63.3	-40.0	-180.0	-37.5	124.2)
23	6.49	5.50		-40.0	-180.0	-26.5	87.0	-40.0	56.1
			(	-27.1	-97.9	-40.0	-180.0	-34.1	97.5)
24	6.79	5.75		-40.0	-180.0	-25.5	45.7	-40.0	15.1
			(	-26.7	-139.0	-40.0	-180.0	-31.4	53.8)
25	7.08	6.00		-40.0	-180.0	-24.6	-1.9	-40.0	-8.7
			(	-26.3	174.4	-40.0	-180.0	-29.7	3.3)
26	7.38	6.25		-40.0	-180.0	-24.1	-53.8	-40.0	-70.2
			(	-26.0	123.7	-40.0	-180.0	-28.6	-50.9)
27	7.67	6.50		-40.0	-180.0	-23.8	-108.7	-40.0	-128.1
			(	-26.0	69.9	-40.0	-180.0	-27.9	-107.6)
28	7.97	6.75		-40.0	-180.0	-23.7	-166.1	-40.0	-167.4
			(	-26.1	13.6	-40.0	-180.0	-27.5	-166.2)
29	8.26	7.00		-40.0	-180.0	-23.8	134.6	-40.0	148.5
			(	-26.4	-44.7	-40.0	-180.0	-27.3	133.5)
30	8.56	7.25		-40.0	-180.0	-24.1	73.7	-40.0	63.8
			(	-26.4	-104.8	-40.0	-180.0	-27.3	71.8)
31	8.85	7.50		-40.0	-180.0	-24.4	11.3	-40.0	-6.3
			(	-27.4	-166.3	-40.0	-180.0	-27.5	8.8)
32	9.15	7.75		-40.0	-180.0	-24.9	-52.4	-40.0	-76.2

			(-34.	13.8	-43.6	-103.6	-27.9	-55.4)	77
33	9.44	4....	-42.	-18.9	-25.5	-117.2	-4..3	-134.1	78
			(-29.7	60.7	-43.6	-1n3.3	-28.2	-12..7)	79
34	9.74	5.25	-4(..	-18).6	-26.1	178.9	-46.6	172.9	80
			(-29.5	1.5	-43.6	-1P..3	-2P.7	173.3)	81

Table 6-6. Fields Computed by Subroutine DIPOLES Along x-Axis at z=24 inches.

```
1 TEST PROGRAM FOR USING ELEMENTARY SOURCES FOR COMPUTING FRESNEL FIELDS          1
 (REF: WALTER(1965), PP.55-57)                                                   2
 AIN= 4.00  BIN= 4.00 M,N=  15  15 LAMBDA= 1.180                                 3
 FIELD IS -10.0 DB AT Z= 24.00 INCHES                                            4
 APERTURE FIELDS: EAP= (0.0000,0.0000)  (1.0000,0.0000)   HAP= (0.0000,0.0000)
 IRC,HRC=  .874225+01  .231886-02   IAXIS= 1  PFWLC:   0.00   0.00  24.00
                                                                                 7
                                                                                 8
                          EX              EY              EZ                     9
                       ( HX              HY              HZ )                   10
  N  XYZIN XYZWL  AMPDB PHSDEG   AMPDB PHSDEG   AMPDB PHSDEG                    11
                                                                                12
                                                                                13
  1  0.00  0.00  -40.0 -180.0  -10.0  -49.3  -40.0  -56.7                      14
                ( -10.0  130.7  -40.0 -180.0  -40.0  124.4 )                    15
  2   .30   .25  -40.0 -180.0  -10.0  -49.8  -40.0  -60.2                      16
                ( -10.0  130.2  -40.0 -180.0  -40.0  -67.5 )                    17
  3   .59   .50  -40.0 -180.0  -10.1  -51.4  -40.0  -59.6                      18
                ( -10.1  128.6  -40.0 -180.0  -40.0  -69.2 )                    19
  4   .89   .75  -40.0 -180.0  -10.2  -54.0  -40.0  -66.6                      20
                ( -10.2  126.0  -40.0 -180.0  -38.9  -71.9 )                    21
  5  1.18  1.00  -40.0 -180.0  -10.4  -57.7  -40.0  -69.8                      22
                ( -10.4  122.4  -40.0 -180.0  -36.6  -75.7 )                    23
  6  1.48  1.25  -40.0 -180.0  -10.6  -62.4  -40.0  -71.8                      24
                ( -10.7  117.7  -40.0 -180.0  -34.9  -80.5 )                    25
  7  1.77  1.50  -40.0 -180.0  -10.9  -68.2  -40.0  -73.8                      26
                ( -11.0  111.9  -40.0 -180.0  -33.6  -86.5 )                    27
  8  2.07  1.75  -40.0 -180.0  -11.3  -75.0  -40.0  -80.8                      28
                ( -11.3  105.2  -40.0 -180.0  -32.6  -93.5 )                    29
  9  2.36  2.00  -40.0 -180.0  -11.7  -82.8  -40.0  -90.0                      30
                ( -11.7   97.4  -40.0 -180.0  -31.9 -101.6 )                    31
 10  2.66  2.25  -40.0 -180.0  -12.1  -91.6  -40.0  -99.4                      32
                ( -12.2   88.6  -40.0 -180.0  -31.3 -110.8 )                    33
 11  2.95  2.50  -40.0 -180.0  -12.7 -101.4  -40.0 -109.9                      34
                ( -12.7   78.9  -40.0 -180.0  -31.0 -121.0 )                    35
 12  3.25  2.75  -40.0 -180.0  -13.2 -112.2  -40.0 -123.0                      36
                ( -13.3   68.1  -40.0 -180.0  -30.7 -132.2 )                    37
 13  3.54  3.00  -40.0 -180.0  -13.9 -124.2  -40.0 -133.5                      38
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			(	-14.3	93.4	-40.0	-180.0	-33.7	-144.0)
14	3.84	3.25		-40.0	-140.0	-14.6	-138.7	-40.0	-145.0
			(	-14.7	43.8	-40.0	-180.0	-36.7	-157.9)
15	4.13	3.50		-40.0	-180.0	-15.5	-150.2	-40.0	-158.0
			(	-15.6	30.4	-40.0	-180.0	-31.0	-172.3)
16	4.43	3.75		-40.0	-140.0	-16.4	-164.7	-40.0	-171.0
			(	-16.5	16.1	-40.0	-180.0	-31.3	172.3)
17	4.72	4.00		-40.0	-180.0	-17.4	-179.9	-40.0	165.3
			(	-17.5	1.0	-40.0	-180.0	-31.8	155.9)
18	5.02	4.25		-40.0	-180.0	-18.5	164.3	-40.0	167.9
			(	-18.6	-14.7	-40.0	-180.0	-32.5	138.6)
19	5.31	4.50		-40.0	-180.0	-19.7	147.8	-40.0	139.4
			(	-19.9	-31.0	-40.0	-180.0	-33.3	120.3)
20	5.61	4.75		-40.0	-180.0	-21.1	131.1	-40.0	134.8
			(	-21.3	-47.5	-40.0	-180.0	-34.4	101.1)
21	5.90	5.00		-40.0	-180.0	-22.7	114.2	-40.0	101.9
			(	-22.8	-64.1	-40.0	-180.0	-35.8	81.0)
22	6.20	5.25		-40.0	-180.0	-24.4	97.9	-40.0	97.9
			(	-24.5	-80.2	-40.0	-180.0	-37.5	60.3)
23	6.49	5.50		-40.0	-180.0	-26.4	82.9	-40.0	81.7
			(	-26.4	-94.9	-40.0	-180.0	-39.8	39.2)
24	6.79	5.75		-40.0	-180.0	-28.4	70.6	-40.0	80.5
			(	-28.3	-107.2	-40.0	-180.0	-40.0	18.5)
25	7.08	6.00		-40.0	-140.0	-30.3	62.5	-40.0	57.1
			(	-30.1	-119.9	-40.0	-180.0	-40.0	1.4)
26	7.38	6.25		-40.0	-180.0	-31.4	58.4	-40.0	57.5
			(	-31.1	-121.5	-40.0	-180.0	-40.0	18.2)
27	7.67	6.50		-40.0	-180.0	-31.2	53.4	-40.0	90.0
			(	-31.0	-127.9	-40.0	-180.0	-40.0	86.2)
28	7.97	6.75		-40.0	-180.0	-30.2	42.4	-40.0	17.7
			(	-30.2	-139.2	-40.0	-180.0	-40.0	72.6)
29	8.26	7.00		-40.0	-180.0	-28.9	26.0	-40.0	1.7
			(	-29.1	-156.0	-40.0	-180.0	-40.0	48.4)
30	8.56	7.25		-40.0	-180.0	-27.6	4.6	-40.0	5.1
			(	-28.1	-177.3	-40.0	-180.0	-39.2	21.0)
31	8.85	7.50		-40.0	-180.0	-26.6	-20.2	-40.0	-33.3
			(	-27.2	158.3	-40.0	-180.0	-37.4	-8.1)
32	9.15	7.75		-40.0	-180.0	-26.1	-47.4	-40.0	-60.1

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			(	-26.5	131.3	-40.0	-180.0	-36.0	-38.5)
33	9.44	8.00		-40.0	-180.0	-25.5	-76.5	-40.0	-68.6
			(	-26.0	102.5	-40.0	-180.0	-35.0	-70.0)
34	9.74	8.25		-40.0	-180.0	-25.0	-107.1	-40.0	-118.6
			(	-25.6	72.1	-40.0	-180.0	-34.2	-102.5)
35	10.03	8.50		-40.0	-180.0	-24.7	-139.1	-40.0	-130.0
			(	-25.3	40.4	-40.0	-180.0	-33.5	-136.1)
36	10.33	8.75		-40.0	-180.0	-24.5	-172.2	-40.0	-169.9
			(	-25.2	7.4	-40.0	-180.0	-33.0	-170.5)
37	10.62	9.00		-40.0	-180.0	-24.4	153.5	-40.0	150.8
			(	-25.1	-26.6	-40.0	-180.0	-32.7	154.2)
38	10.92	9.25		-40.0	-180.0	-24.4	118.3	-40.0	106.3
			(	-25.2	-61.7	-40.0	-180.0	-32.4	118.0)
39	11.21	9.50		-40.0	-180.0	-24.5	82.0	-40.0	82.3
			(	-25.3	-97.8	-40.0	-180.0	-32.2	81.0)
40	11.51	9.75		-40.0	-180.0	-24.6	44.9	-40.0	46.7
			(	-25.4	-134.8	-40.0	-180.0	-32.2	43.1)
41	11.80	10.00		-40.0	-180.0	-24.8	6.9	-40.0	-17.0
			(	-25.7	-172.6	-40.0	-180.0	-32.2	4.4)
42	12.10	10.25		-40.0	-180.0	-25.1	-32.0	-40.0	-40.3
			(	-26.0	148.7	-40.0	-180.0	-32.3	-35.1)
43	12.39	10.50		-40.0	-180.0	-25.4	-71.7	-40.0	-93.6
			(	-26.4	109.2	-40.0	-180.0	-32.4	-75.3)
44	12.69	10.75		-40.0	-180.0	-25.9	-112.2	-40.0	-121.7
			(	-26.9	68.9	-40.0	-180.0	-32.7	-116.3)
45	12.98	11.00		-40.0	-180.0	-26.3	-153.4	-40.0	-171.9
			(	-27.4	27.8	-40.0	-180.0	-33.0	-159.1)
46	13.28	11.25		-40.0	-180.0	-26.9	164.6	-40.0	153.1
			(	-28.0	-13.9	-40.0	-180.0	-33.4	159.4)
47	13.57	11.50		-40.0	-180.0	-27.5	121.9	-40.0	96.3
			(	-28.6	-56.4	-40.0	-180.0	-33.9	116.2)
48	13.87	11.75		-40.0	-180.0	-28.2	78.6	-40.0	48.4
			(	-29.3	-99.5	-40.0	-180.0	-34.4	72.4)
49	14.16	12.00		-40.0	-180.0	-28.9	34.6	-40.0	7.6
			(	-30.1	-143.2	-40.0	-180.0	-35.0	27.8)
50	14.46	12.25		-40.0	-180.0	-29.8	-9.9	-40.0	-31.7
			(	-31.0	172.6	-40.0	-180.0	-35.8	-17.4)
51	14.75	12.50		-40.0	-180.0	-30.7	-55.0	-40.0	-68.1

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Table 6-7. Fields Computed by Subroutine DIPOLES Along x-Axis at z=48 inches.

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1 TEST PROGRAM FOR USING ELEMENTARY SOURCES FOR COMPUTING FRESNEL FIELDS
 (REF:  WALTER(1965), PP.55-57)
 AIN= 4.00  BIN= 4.00 M,N=  15  15 LAMBDA= 1.18
 FIELD IS -10.0 DB AT Z= 24.00 INCHES
 APERTURE FIELDS:  EAP= (0.0000,0.0000)  (1.0000,0.0000)   HAP= (0.0000,0.0000)
 R0,HR0=  .87422E+01  .23188E-02   IAXIS= 1  PFWLS:   0.00   1.00   48.00
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N	XYZIN	XYZWL	EX / HX AMPDB	EX / HX PHSDEG	EY / HY AMPDB	EY / HY PHSDEG	EZ / HZ AMPDB	EZ / HZ PHSDEG
1	0.00	0.00	-40.0	-180.0	-15.9	-162.7	-40.0	-166.1
			-15.9	17.3	-40.0	-180.0	-40.0	15.6
2	.30	.25	-40.0	-180.0	-15.9	-163.0	-40.0	-166.5
			-15.9	17.1	-40.0	-180.0	-40.0	-171.9
3	.59	.50	-40.0	-180.0	-15.9	-163.8	-40.0	-167.5
			-15.9	16.2	-40.0	-180.0	-40.0	-172.7
4	.89	.75	-40.0	-180.0	-15.9	-165.2	-40.0	-170.0
			-15.9	14.8	-40.0	-180.0	-40.0	-174.1
5	1.18	1.00	-40.0	-180.0	-16.0	-167.1	-40.0	-171.7
			-16.0	12.9	-40.0	-180.0	-40.0	-176.0
6	1.48	1.25	-40.0	-180.0	-16.0	-169.5	-40.0	-172.8
			-16.0	10.5	-40.0	-180.0	-40.0	-178.5
7	1.77	1.50	-40.0	-180.0	-16.1	-172.6	-40.0	-175.1
			-16.1	7.5	-40.0	-180.0	-40.0	178.5
8	2.07	1.75	-40.0	-180.0	-16.2	-176.1	-40.0	178.5
			-16.2	3.9	-40.0	-180.0	-40.0	174.9
9	2.36	2.00	-40.0	-180.0	-16.3	179.8	-40.0	175.9
			-16.3	-.2	-40.0	-180.0	-40.0	170.8
10	2.66	2.25	-40.0	-180.0	-16.4	175.2	-40.0	171.3
			-16.4	-4.8	-40.0	-180.0	-40.0	166.1
11	2.95	2.50	-40.0	-180.0	-16.5	170.3	-40.0	166.1
			-16.5	-10.0	-40.0	-180.0	-40.0	160.9
12	3.25	2.75	-40.0	-180.0	-16.7	164.3	-40.0	159.8
			-16.7	-15.7	-40.0	-180.0	-40.0	155.1
13	3.54	3.00	-40.0	-180.0	-16.8	158.3	-40.0	156.7

			(-17.8	-71.4	-40.0	-180.0	-39.6	140.8)	39
14	3.44	3.25	-40.0	-180.0	-17.0	151.2	-40.0	140.0	40
			(-17.0	-68.7	-40.0	-180.0	-39.0	142.0)	41
15	4.13	3.50	-40.0	-180.0	-17.2	143.9	-40.0	139.6	42
			(-17.2	-36.1	-40.0	-180.0	-38.2	134.6)	43
16	4.43	3.75	-40.0	-180.0	-17.4	136.0	-40.0	130.9	44
			(-17.4	-43.4	-40.0	-180.0	-38.1	126.6)	45
17	4.72	4.00	-40.0	-180.0	-17.6	127.6	-40.0	120.4	46
			(-17.6	-52.3	-40.0	-180.0	-37.6	118.1)	47
18	5.02	4.25	-40.0	-180.0	-17.8	118.0	-40.0	112.4	48
			(-17.9	-61.3	-40.0	-180.0	-37.5	109.1)	49
19	5.31	4.50	-40.0	-180.0	-18.1	109.1	-40.0	105.2	50
			(-18.1	-70.2	-40.0	-180.0	-37.2	99.5)	51
20	5.61	4.75	-40.0	-180.0	-18.3	99.1	-40.0	97.2	52
			(-18.4	-80.8	-40.0	-180.0	-37.0	89.4)	53
21	5.90	5.00	-40.0	-180.0	-18.6	88.6	-40.0	86.5	54
			(-18.6	-91.3	-40.0	-180.0	-36.9	78.8)	55
22	6.20	5.25	-40.0	-180.0	-18.9	77.5	-40.0	76.7	56
			(-18.9	-102.3	-40.0	-180.0	-36.7	67.6)	57
23	6.49	5.50	-40.0	-180.0	-19.2	65.9	-40.0	63.3	58
			(-19.3	-113.9	-40.0	-180.0	-36.7	55.9)	59
24	6.79	5.75	-40.0	-180.0	-19.5	53.8	-40.0	51.6	60
			(-19.6	-126.0	-40.0	-180.0	-36.6	43.6)	61
25	7.08	6.00	-40.0	-180.0	-19.9	41.1	-40.0	37.7	62
			(-19.9	-138.7	-40.0	-180.0	-36.6	30.8)	63
26	7.38	6.25	-40.0	-180.0	-20.2	28.0	-40.0	22.5	64
			(-20.3	-151.8	-40.0	-180.0	-36.6	17.5)	65
27	7.67	6.50	-40.0	-180.0	-20.6	14.3	-40.0	9.4	66
			(-20.7	-165.4	-40.0	-180.0	-36.7	3.6)	67
28	7.97	6.75	-40.0	-180.0	-21.0	.1	-40.0	1.1	68
			(-21.1	-179.0	-40.0	-180.0	-36.8	-10.7)	69
29	8.26	7.00	-40.0	-180.0	-21.5	-14.0	-40.0	-20.0	70
			(-21.6	165.7	-40.0	-180.0	-36.9	-25.7)	71
30	8.56	7.25	-40.0	-180.0	-21.9	-29.8	-40.0	-31.4	72
			(-22.0	150.0	-40.0	-180.0	-37.0	-41.1)	73
31	8.85	7.50	-40.0	-180.0	-22.4	-45.5	-40.0	-42.8	74
			(-22.5	134.9	-40.0	-180.0	-37.2	-57.0)	75
32	9.15	7.75	-40.0	-180.0	-22.9	-61.0	-40.0	-66.4	76

			(	-23.0	119.8	-40.0	-180.0	-37.5	-73.5)
33	9.44	8.00		-40.0	-180.0	-23.4	-78.3	-40.0	-79.6
			(	-23.6	102.2	-40.0	-180.0	-37.8	-90.5)
34	9.74	8.25		-40.0	-180.0	-24.0	-95.4	-40.0	-98.8
			(	-24.2	85.1	-40.0	-180.0	-38.1	-108.0)
35	10.03	8.50		-40.0	-180.0	-24.6	-113.6	-40.0	-118.0
			(	-24.8	67.5	-40.0	-180.0	-38.5	-126.0)
36	10.33	8.75		-40.0	-180.0	-25.3	-131.1	-40.0	-130.3
			(	-25.4	49.6	-40.0	-180.0	-38.9	-144.5)
37	10.62	9.00		-40.0	-180.0	-25.9	-149.5	-40.0	-157.9
			(	-26.1	31.1	-40.0	-180.0	-39.3	-163.5)
38	10.92	9.25		-40.0	-180.0	-26.7	-168.4	-40.0	-173.3
			(	-26.9	12.3	-40.0	-180.0	-39.8	176.9)
39	11.21	9.50		-40.0	-180.0	-27.5	172.3	-40.0	158.1
			(	-27.7	-6.9	-40.0	-180.0	-40.0	156.9)
40	11.51	9.75		-40.0	-180.0	-28.3	152.5	-40.0	145.7
			(	-28.5	-25.5	-40.0	-180.0	-40.0	136.4)
41	11.80	10.00		-40.0	-180.0	-29.2	132.7	-40.0	123.4
			(	-29.4	-46.4	-40.0	-180.0	-40.0	115.5)
42	12.10	10.25		-40.0	-180.0	-30.2	112.4	-40.0	119.9
			(	-30.4	-66.5	-40.0	-180.0	-40.0	94.0)
43	12.39	10.50		-40.0	-180.0	-31.3	92.0	-40.0	90.6
			(	-31.5	-86.7	-40.0	-180.0	-40.0	72.1)
44	12.69	10.75		-40.0	-180.0	-32.4	71.6	-40.0	63.8
			(	-32.6	-107.0	-40.0	-180.0	-40.0	49.8)
45	12.98	11.00		-40.0	-180.0	-33.7	51.2	-40.0	37.3
			(	-33.9	-127.2	-40.0	-180.0	-40.0	27.1)
46	13.28	11.25		-40.0	-180.0	-35.2	31.3	-40.0	9.5
			(	-35.4	-146.9	-40.0	-180.0	-40.0	4.1)
47	13.57	11.50		-40.0	-180.0	-36.6	12.3	-40.0	4.1
			(	-36.9	-165.7	-40.0	-180.0	-40.0	-19.1)
48	13.87	11.75		-40.0	-180.0	-38.6	-5.1	-40.0	-8.2
			(	-38.6	177.1	-40.0	-180.0	-40.0	-42.2)
49	14.16	12.00		-40.0	-180.0	-40.0	-19.5	-40.0	-3.5
			(	-40.0	162.7	-40.0	-180.0	-40.0	-64.5)
50	14.46	12.25		-40.0	-180.0	-40.0	-29.5	-40.0	-180.0
			(	-40.0	152.2	-40.0	-180.0	-40.0	-93.1)
51	14.75	12.50		-40.0	-180.0	-40.0	-34.7	-40.0	-90.0

			(-4[illegible]	14[illegible]	-4[illegible]	-1[illegible]	-4[illegible]	-72.8)	115
52	15.[illegible]	1[illegible].75	-4[illegible]	-1[illegible]	-40.[illegible]	-34.[illegible]	-4[illegible]	-47.8	116
			(-4[illegible]	133.5	-40.0	-1[illegible]	-40.[illegible]	-.2)	117
53	15.34	13.00	-40.0	-1[illegible]	-40.0	-48.0	-4[illegible]	-37.9	118
			(-40.[illegible]	124.4	-4[illegible]	-1[illegible]	-40.0	-11.8)	119
54	15.64	13.25	-4[illegible]	-1[illegible]	-4[illegible]	-65.7	-40.[illegible]	-130.0	120
			(-40.[illegible]	114.1	-40.0	-1[illegible]	-40.[illegible]	-34.8)	121
55	15.93	13.50	-40.0	-180.0	-39.0	-83.3	-40.0	-90.0	122
			(-39.3	94.7	-40.0	-18[illegible]	-4[illegible]	-60.7)	123
56	16.23	13.75	-40.0	-18[illegible]	-37.8	-106.[illegible]	-40.0	-95.0	124
			(-38.1	72.2	-40.0	-13[illegible]	-40.0	-87.9)	125
57	16.52	14.00	-40.0	-180.0	-35.7	-130.7	-40.0	-156.3	126
			(-37.0	47.7	-40.0	-180.0	-40.0	-116.1)	127
58	16.82	14.25	-40.0	-180.	-35.7	-157.0	-40.0	-159.9	128
			(-36.1	21.6	-40.0	-180.0	-40.0	-145.0)	129
59	17.11	14.50	-40.0	-180.0	-34.9	175.6	-40.0	-170.7	130
			(-35.4	-5.7	-40.0	-180.0	-40.0	-174.4)	131
60	17.41	14.75	-40.0	-180.0	-34.2	147.1	-40.0	143.5	132
			(-34.7	-33.9	-40.0	-180.0	-40.0	155.5)	133
61	17.70	15.00	-40.0	-180.0	-33.8	117.9	-40.0	110.0	134
			(-34.1	-63.1	-40.0	-180.0	-40.0	125.0)	135
62	18.00	15.25	-40.0	-180.0	-33.1	87.9	-40.0	90.0	136
			(-33.6	-92.9	-40.0	-180.0	-40.0	93.9)	137
63	18.29	15.50	-40.0	-180.0	-32.6	57.3	-40.0	61.3	138
			(-33.2	-123.5	-40.0	-180.0	-40.0	62.4)	139
64	18.59	15.75	-40.0	-180.0	-32.3	26.0	-40.0	14.3	140
			(-32.8	-154.6	-40.0	-180.0	-40.0	30.4)	141
65	18.88	16.00	-40.0	-180.0	-31.9	-5.6	-40.0	-2.2	142
			(-32.5	173.6	-40.0	-180.0	-40.0	-2.1)	143
66	19.18	16.25	-40.0	-180.0	-31.6	-38.2	-40.0	-37.5	144
			(-32.2	141.3	-40.0	-180.0	-40.0	-35.1)	145
67	19.47	16.50	-40.0	-180.0	-31.4	-71.1	-40.0	-73.0	146
			(-32.0	108.5	-40.0	-180.0	-40.0	-68.5)	147
68	19.77	16.75	-40.0	-180.0	-31.2	-104.5	-40.0	-90.0	148
			(-31.8	75.2	-40.0	-180.0	-39.7	-102.3)	149

Chapter 7

SUBROUTINE WALL

7-1. Purpose: To compute the normal transmission ($T_{\perp}$,$T_{||}$) and reflection coefficients of a N-layer dielectric sheet having thicknesses d_n, dielectric constants ε_{rn}, and loss tangents $\tan\delta_n$ for each layer when a plane wave is incident at angle θ_i.

7-2. Usage: CALL WALL (BETA, SINE, D, ER, TD, N, NN, TN1, TN2, RPER, RPAR)

7-3. Arguments

BETA - Real input variable = $2\pi/\lambda$, where λ is the free space wavelength.

SINE - Real input variable = $\sin\theta_i$.

D, ER, TD - Real input arrays containing the thickness (cm), dielectric constant ε_r, and loss tangent $\tan\delta$ of each layer.

N - Integer input variable equal to the number of layers.

NN - Integer input = N+1.

TN1,TN2 - Complex output variables equal to the normal voltage transmission coefficients for the components of the incident electric field perpendicular to and parallel to the plane of incidence, respectively.

RPER,RPAR - Complex output variables equal to the reflection coefficients $R_{\perp}$, $R_{||}$.

7-4. Comment and Method

a. Layer 1 is the first layer on the exit side of the panel; layer N is the first layer on the incident side. $T_{\perp}$, $T_{||}$ have the same value for either side of the panel being the incident side; however, $R_{\perp}$, $R_{||}$ are different (in phase) for the two cases.

b. The details of the method are presented in Appendix E of Reference 1.

7-5. Program Flow: See Reference 1.

7-6. Test Case: None.

7-7. References

1. G. K. Huddleston, "Radome Analysis Computer Program: Ray Tracing Formulation", Technical Report for JHU/APL, Contract No. 601053, November 1979.

7-8. Program Listing: See following pages.

```
      SUBROUTINE WALL(BETA,SINE,D,ER,TD,N,NN,TN1,TN2,RPER,RPAR)
C   SUBROUTINE WALL COMPUTES THE TRANSMISSION AND REFLECTION
C   COEFFICIENTS FOR AN N LAYER, PLANE DIELECTRIC PANEL FOR PLANE
C   WAVE INCIDENT AT SINE(ANGLE) FOR PERPENDICULAR AND
C   PARALLEL POLARIZATIONS.
C   PARAMETERS OF THE WALL: N= THE NUMBER OF LAYERS
C                           NN= N+1 REQUIRED TO DIMENSION ARRAYS
C                           D= THICKNESS OF EACH LAYER IN CENTIMETERS
C                           ER= RELATIVE DIELECTRIC CONSTANT OF EACH LAY
C                           TD= THE LOSS TANGENT FOR EACH LAYER
C TN1,TN2 ARE THE NORMAL VOLTAGE XMN COEFFICIENTS; TPER,TPAR ARE THE
C INSERTION VOLTAGE TRANSMISSION COEFFICIENTS. IT IS IMPORTANT TO
C NOTE THAT THE XMN COEFS ARE THE SAME FOR PLANE WAVE INCIDENT FROM
C EITHER SIDE OF THE STRATIFIED DIELECTRIC PANEL IMMERSED IN FREE SPACE;
C HOWEVER, THE REFLECTION COEFS ARE NOT. THAT IS, FOR COMPUTING RPER,
C RPAR, THE ORDERING OF ER(NN),TD(NN) IS IMPORTANT WITH LAYER 1 BEING
C THE FIRST LAYER ON THE EXIT SIDE, LAYER N BEING THE FIRST LAYER ON THE
C INCIDENT SIDE.  LAYER NN  AND  LAYER 0  ARE JUST FREE SPACE  LAYERS
C OF SEMI-INFINITE DEPTH.
C E,G,R1,R2, ARE ARRAYS USED IN THE SUBROUTINE HAVING NN DIM"L LIMITS
      COMPLEX E(6),G(6),R1(6),R2(6),GG,EE,RR1,RR2,AA1,AA2,X1,X2,
     $X3,X4,Y1,Y2,Y3,Y4,U1,U2,U3,U4,V1,V2,V3,V4,P1,P2,P3,P4,Q1,Q2,Q3,Q4
      COMPLEX TPER,TPAR,RPER,RPAR,U,V,TN1,TN2
      DIMENSION ER(NN),TD(NN),D(N)
      ER(NN)=1.0
      TD(NN)=0.
      DO 50 I=1,NN
   50 E(I)=CMPLX(ER(I),-ER(I)*TD(I))
      AB=BETA*0.70707070707071
C
C   CALCULATE TOTAL THICKNESS OF WALL IN CM
C
      DTOTAL=0.0
      DO 200 I=1,N
  200 DTOTAL=DTOTAL+D(I)
C   S IS THE SINE OF THE ANGLE SQUARED
C   C IS THE COSINE OF THE ANGLE
      S=SINE*SINE
```

```
      C=SQRT(1.0-S)                                                      39
      AD=ER(1)-S                                                         40
      ET=ER(1)*TD(1)                                                     41
      SR=SQRT(AD*AD+ET*ET)                                               42
      IF(SR-AD) 76,76,77                                                 43
   76 A=0.                                                               44
      GO TO 78                                                           45
   77 A=AB*SQRT(SR-AD)                                                   46
   78 B=AB*SQRT(SR+AD)                                                   47
      G(1)=CMPLX(A,B)                                                    48
      GG=CMPLX(0.0,BETA*C)                                               49
      EE=1.0                                                             50
      SUM=0.                                                             51
      SUM=SUM+D(1)/SQRT(AD)                                              52
      RR1=(G(1)-GG)/(G(1)+GG)                                            53
      RR2=(EE*G(1)-E(1)*GG)/(EE*G(1)+E(1)*GG)                            54
      DO 84 I=1,N                                                        55
      II=I+1                                                             56
      AD=ER(II)-S                                                        57
      ET=ER(II)*TD(II)                                                   58
      IF (I-N) 176,177,177                                               59
  176 SUM=SUM+D(II)/SQRT(AD)                                             60
  177 CONTINUE                                                           61
      SR=SQRT(AD*AD+ET*ET)                                               62
      IF(SR-AD) 79,79,80                                                 63
   79 A=0.                                                               64
      GO TO 81                                                           65
   80 A=AB*SQRT(SR-AD)                                                   66
   81 B=AB*SQRT(SR+AD)                                                   67
      G(II)=CMPLX(A,B)                                                   68
      R1(I)=(G(II)-G(I))/(G(II)+G(I))                                    69
   84 R2(I)=(E(I)*G(II)-E(II)*G(I))/(E(I)*G(II)+E(II)*G(I))              70
      SUM=S*SUM                                                          71
      AA1=1.0-RR1                                                        72
      AA2=1.0-RR2                                                        73
      DO 85 I=1,N                                                        74
      AA1=AA1*(1.0-R1(I))                                                75
   85 AA2=AA2*(1.0-R2(I))                                                76
```

```
      AA1=1.0/ AA1                                                    77
      AA2=1.0/ AA2                                                    78
      U=-G(1)*D(1)                                                    79
      V=G(1)*D(1)                                                     80
      X1=CEXP(U)                                                      81
      X4=CEXP(V)                                                      82
      X2=-RR1*X4                                                      83
      X3=-RR1*X1                                                      84
      Y1=X1                                                           85
      Y4=X4                                                           86
      Y2=-RR2*Y4                                                      87
      Y3=-RR2*Y1                                                      88
      DO 105 I=2,NN                                                   89
      IF(I-NN) 95,90,1                                                90
   90 U1=1.0                                                          91
      U2=-R1(N)                                                       92
      U3=-R1(N)                                                       93
      U4=1.0                                                          94
      V1=1.0                                                          95
      V2=-R2(N)                                                       96
      V3=-R2(N)                                                       97
      V4=1.0                                                          98
      GO TO 100                                                       99
   95 II=I-1                                                          100
      U=-G(I)*D(I)                                                    101
      V=G(I)*D(I)                                                     102
      U1=CEXP(U)                                                      103
      U4=CEXP(V)                                                      104
      U2=-R1(II)*U4                                                   105
      U3=-R1(II)*U1                                                   106
      V1=U1                                                           107
      V4=U4                                                           108
      V2=-R2(II)*V4                                                   109
      V3=-R2(II)*V1                                                   110
  100 P1=X1*U1+X2*U3                                                  111
      P2=X1*U2+X2*U4                                                  112
      P3=X3*U1+X4*U3                                                  113
      P4=X3*U2+X4*U4                                                  114
```

```
      Q1=Y1*V1+Y2*V3                                                    115
      Q2=Y1*V2+Y2*V4                                                    116
      Q3=Y3*V1+Y4*V3                                                    117
      Q4=Y3*V2+Y4*V4                                                    118
      X1=P1                                                             119
      X2=P2                                                             120
      X3=P3                                                             121
      X4=P4                                                             122
      Y1=Q1                                                             123
      Y2=Q2                                                             124
      Y3=Q3                                                             125
  105 Y4=Q4                                                             126
      RPER=-X3/X4                                                       127
C     TN1,TN2 ARE NORMAL VOLTAGE XMN COEFFICIENTS.                      128
      RPAR=-Y3/Y4                                                       129
      TN1=(X1+X2*RPER)*AA1                                              130
      U=CMPLX(0.0,-SUM*BETA)                                            131
      U=CEXP(U)                                                         132
C     TPER,TPAR HERE ARE VOLTAGE XMN COEFFICIENTS AT EXIT POINT OF RAY. 133
      TPER=TN1*U                                                        134
      TN2=(Y1+Y2*RPAR)*AA2                                              135
      TPAR=TN2*U                                                        136
C    MODIFY TRANSMISSION COEFFICIENTS FOR INSERTION                     137
      U=CMPLX(0.0,BETA*DTOTAL*C)                                        138
      U=CEXP(U)                                                         139
      TPER=TN1*U                                                        140
      TPAR=TN2*U                                                        141
    1 CONTINUE                                                          142
  300 RETURN                                                            143
      END                                                               144
```

Chapter 8

SUBROUTINE CAXCB

8-1. Purpose: To compute the complex vector cross product $\underline{C} = \underline{A} \times \underline{B}$, where $\underline{A}$ and $\underline{B}$ are a complex vectors expressed in rectangular coordinates.

8-2. Usage: CALL CAXCB (A, B, C)

8-3. Arguments

A - Complex input array containing the rectangular components of the vector $\underline{A} = \hat{x} A_x + \hat{y} A_y + \hat{z} A_z$; i.e., A ($A_x$, A_y, A_z).

B - Complex input array B (B_x, B_y, B_z) representing the vector $\underline{B}$.

C - Complex output array C (C_x, C_y, C_z) representing the vector $\underline{C} = \underline{A} \times \underline{B}$.

8-4. Comment and Method: None

8-5. Program Flow: See listing below.

8-6. Test Case: None.

8-7. References: None.

8-8. Program Listing: See following page.

```
      SUBROUTINE CAXCB(A,B,C)                                          1
      COMPLEX A(3),B(3),C(3)                                           2
C     SUBR CAXCB COMPUTES THE VECTOR CROSS PRODUCT C=AXB OF            3
C     TWO COMPLEX VECTORS A AND B                                      4
      C(1)=A(2)*B(3)-A(3)*B(2)                                         5
      C(2)=A(3)*B(1)-A(1)*B(3)                                         6
      C(3)=A(1)*B(2)-A(2)*B(1)                                         7
      RETURN                                                           8
      END                                                              9
```


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