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RADOME EFFECTS ON THE PERFORMANCE
OF GROUND MAPPING RADAR

by

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td></td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>II.</td>
<td></td>
</tr>
<tr>
<td>MATHEMATICS OF RADOME ANALYSIS</td>
<td>4</td>
</tr>
<tr>
<td>A. Coordinate Systems and Transformations</td>
<td>5</td>
</tr>
<tr>
<td>B. Plane Wave Spectrum of Antenna Without Radome</td>
<td>19</td>
</tr>
<tr>
<td>C. Far Field Calculation</td>
<td>27</td>
</tr>
<tr>
<td>D. Radome Transmission</td>
<td>32</td>
</tr>
<tr>
<td>1. Ray Tracing Geometry</td>
<td>35</td>
</tr>
<tr>
<td>2. Radome Surface Approximation</td>
<td>45</td>
</tr>
<tr>
<td>3. Transmission Through Multilayered Walls</td>
<td>46</td>
</tr>
<tr>
<td>E. Internal Radome Reflection</td>
<td>60</td>
</tr>
<tr>
<td>F. Far Field Parameters</td>
<td>62</td>
</tr>
<tr>
<td>1. Boresight Direction</td>
<td>63</td>
</tr>
<tr>
<td>2. Sidelobe Level</td>
<td>63</td>
</tr>
<tr>
<td>3. Transmitted Power</td>
<td>64</td>
</tr>
<tr>
<td>4. Pattern Plots</td>
<td>65</td>
</tr>
<tr>
<td>G. Radome Produced Errors</td>
<td>70</td>
</tr>
<tr>
<td>III. APPENDICES (COMPUTER PROGRAMS)</td>
<td>74</td>
</tr>
<tr>
<td>A. MAIN PROGRAM</td>
<td>75</td>
</tr>
<tr>
<td>B. SUBROUTINE PWS</td>
<td>81</td>
</tr>
<tr>
<td>C. SUBROUTINE FAR</td>
<td>85</td>
</tr>
<tr>
<td>D. SUBROUTINE ORIENT</td>
<td>91</td>
</tr>
<tr>
<td>E. SUBROUTINE RADOME</td>
<td>94</td>
</tr>
<tr>
<td>F. SUBROUTINE WALL with Entries TRANS and REFLCT</td>
<td>101</td>
</tr>
<tr>
<td>G. SUBROUTINE TRACE</td>
<td>112</td>
</tr>
<tr>
<td>H. SUBROUTINE POINT</td>
<td>116</td>
</tr>
<tr>
<td>I. SUBROUTINE VECTOR</td>
<td>119</td>
</tr>
<tr>
<td>J. SUBROUTINE TDISK With Entry TDISKN</td>
<td>121</td>
</tr>
<tr>
<td>K. SUBROUTINE BDISK With Entry BDISKN</td>
<td>123</td>
</tr>
<tr>
<td>L. SUBROUTINE CONE With Entry CONEN</td>
<td>125</td>
</tr>
<tr>
<td>M. SUBROUTINE OGVIE With Entry OGIVEN</td>
<td>128</td>
</tr>
<tr>
<td>N. SUBROUTINE PARA With Entry PARAN</td>
<td>132</td>
</tr>
<tr>
<td>O. SUBROUTINE HEMI With Entry HEMIN</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>SUBROUTINE NAME</td>
</tr>
<tr>
<td>---</td>
<td>---------------------------</td>
</tr>
<tr>
<td>P</td>
<td>SUBROUTINE SNELL</td>
</tr>
<tr>
<td>Q</td>
<td>SUBROUTINE AXB</td>
</tr>
<tr>
<td>R</td>
<td>SUBROUTINE IPLANE With Entry PLANE</td>
</tr>
<tr>
<td>S</td>
<td>SUBROUTINE INTRPO With Entry PW</td>
</tr>
<tr>
<td>T</td>
<td>SUBROUTINE FFT</td>
</tr>
<tr>
<td>U</td>
<td>SUBROUTINE BRSITE</td>
</tr>
<tr>
<td>V</td>
<td>SUBROUTINE SDLOBE</td>
</tr>
<tr>
<td>W</td>
<td>SUBROUTINE ERRORS</td>
</tr>
<tr>
<td>X</td>
<td>SUBROUTINE DB</td>
</tr>
<tr>
<td>Y</td>
<td>SUBROUTINE PLOT3D</td>
</tr>
<tr>
<td>Z</td>
<td>SUBROUTINE CNTOUR</td>
</tr>
<tr>
<td>AA</td>
<td>SUBROUTINE SAPLOT</td>
</tr>
<tr>
<td>AB</td>
<td>SUBROUTINE XY</td>
</tr>
<tr>
<td>AC</td>
<td>SUBROUTINE VSWR</td>
</tr>
<tr>
<td>AD</td>
<td>SUBROUTINE QUARTC</td>
</tr>
</tbody>
</table>

REFERENCES ................................................. 200
**LIST OF FIGURES**

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Coordinate Systems Used in Radome Analysis</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Reference System: $(X,Y,Z)$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Antenna System: $(X_A,Y_A,Z_A)$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radome System: $(X_R,Y_R,Z_R)$</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Geometry Used to Determine $r_a$ and $\theta_a$</td>
<td>18</td>
</tr>
<tr>
<td>3.</td>
<td>Far Field Coordinate System</td>
<td>19</td>
</tr>
<tr>
<td>4.</td>
<td>New Far Field Coordinate System</td>
<td>21</td>
</tr>
<tr>
<td>5.</td>
<td>Near Field Lattice</td>
<td>25</td>
</tr>
<tr>
<td>6.</td>
<td>Far Field Coordinate System with Ground</td>
<td>29</td>
</tr>
<tr>
<td>7.</td>
<td>Plane Electromagnetic Wave Incident on Plane Multilayer</td>
<td>52</td>
</tr>
<tr>
<td>8.</td>
<td>Two Dimensional Graph of Far Field Pattern</td>
<td>66</td>
</tr>
<tr>
<td>9.</td>
<td>Contour Plot of Far Field Pattern</td>
<td>67</td>
</tr>
<tr>
<td>10.</td>
<td>Ground Coordinate System</td>
<td>68</td>
</tr>
</tbody>
</table>
FOREWORD

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ABSTRACT

A new method of radome analysis is presented which uses a combination of plane wave expansion of the radiating fields and ray tracing to transfer plane waves from within the radome to the outer surface of the radome. The radome is then removed and the quasi plane waves are then retraced back to the aperture plane. The new method has the advantage of utilizing the Fast Fourier Transform algorithm to greatly reduce computation time. The computer time has been reduced approximately two orders of magnitude in comparison to other techniques of approximately equal accuracy.

A computer program is included which carries out the new method of radome analysis and is fully explained in the report. The computer program is written in FORTRAN V.

The computer program is written such that the following parameters of an antenna-radome may be easily changed:

1. **Antenna far field pattern.** This parameter in effect allows any antenna which will physically fit within the radome, with known far field pattern to be used in the analysis.

2. **Radome geometry for cylindrical radomes.** Any radome which can be approximated as a composite of ogives, paraboloids, cones, hemispheres and disks may be analyzed.

3. **Radome wall characteristics.** The radome wall may have any number of layers, each layer having locally parallel surfaces. The thickness, dielectric constant, and loss tangent of each layer may be independently specified. Also portions of the radome wall may be specified to be conducting.

4. **Orientation of the antenna with respect to the radome.** The location and orientation of the antenna within the radome may be easily changed, thus allowing the analysis of scanning antenna systems.
5. **Far field surface.** The surface over which the far field of the radome enclosed antenna is to be determined may be specified as a sphere centered about the antenna or a plane with specified location and orientation with respect to the antenna.

It is to be emphasised that the radome analysis carried out by the computer program presented herein is a three-dimensional, vector analysis of an antenna-radome system, and no symmetry of the system, except for the cylindrical radome restriction, is assumed in the analysis.
Section I

INTRODUCTION

The purpose of this research is to develop a computer program for the radome simulation of a ground mapping radar system. Where possible the computer program has been generalized such that a variety of antenna configurations, antenna patterns, radome shapes and radome wall materials can be used in the simulation.

The simulation of a radome can be very simple or very complex depending on the desired accuracy, the shape of the radome, the composition of the radome wall and the pattern of the antenna.

The simplest radome analysis utilizes ray tracing to transfer the aperture field on the antenna within the radome to a parallel plane outside the radome. The exterior aperture has the same geometric size and number of points as the inner aperture. Each point of the exterior aperture field is determined from the corresponding points of the inner aperture. A line is traced connecting corresponding points of the interior and exterior aperture field and at the intersection point of the radome with this line the transmission properties of the radome wall are applied to the amplitude of the interior field to obtain the amplitude of the exterior field. The far field of the radome enclosed antenna is then calculated from the exterior aperture field. Although extremely simple this method of analysis becomes increasingly accurate as the electrical size of the aperture increases for apertures which focus their energy in one direction. Ray tracing analysis would be suitable, for example, for the analysis of a linear, homogeneous, isotropic, parallel plate lens radome over a one inch flashlight.

The basic premise of ray tracing is that all the energy of the aperture has a single direction of propagation, the direction normal to the aperture.
For antennas designed to have broad beams, multibeam, or antennas which are electrically small, significant amounts of energy propagate at other than the direction normal to the aperture, and for these cases ray tracing fails.

Ray tracing is most inadequate for the determination of the field reflected from the inner surface of the radome back to the aperture plane. The inaccuracy arises due to the change in propagation direction due to reflection at the inner radome wall. The direction of the reflected ray depends on the inward normal of the radome wall and could be different (and usually is) for each ray, thus the basic premise of unidirectional propagation is violated. It is to be noted that in the transmitting case, the transmitted ray (for flat parallel radome walls) propagates in the same direction as the incident ray thus preserving the single direction premise.

The most accurate radome analyses carried out to date utilize some form of modal expansion of the aperture field. Paris (4) used Huggens' spherical wave expansion of the aperture field and Wu and Rudduck (1) used a plane wave expansion of the aperture field. The field on the inner surface of the radome wall is calculated from the aperture expansion. The field on the outer surface of the radome is calculated by weighting the field on the inner surface by the complex vector transmission coefficients of the radome wall. Paris and Wu and Rudduck used slightly different approaches to this weighting. Paris let the direction of propagation through the wall coincide with the Poynting vector of the inner surface field at the point of wall penetration, where as Wu and Rudduck weighted each plane wave contribution to the inner surface field according to its direction of propagation. The far field pattern of the radome enclosed antenna was then calculated using the outer surface of the radome as the aperture surface. These analyses have only one disadvantage: computation time on the fastest computers
must be measured in hours for the calculation of typical far field patterns. In addition neither Paris nor Wu and Rudduck calculated the reflected field; although this calculation appears to be a straightforward extension of their techniques.

The ideal radome analysis would be both accurate and require a minimum of computer time. A method of radome analysis is developed which combines plane wave expansion of the aperture field with ray tracing to trace each plane wave. It is thought that this method of radome analysis is both accurate and computationally fast. The inaccuracy in the computation is discussed and an example of computation time comparison is given. The computer program which carries out the analysis is included and explained. The new radome analysis technique also includes calculation of the reflected field and is subsequently used to determine a voltage standing wave ratio in the feed system of the radome enclosed antenna.

Section II of this report discusses the mathematics of the radome analysis.

Section III contains a listing of the main computer program and all subroutines with argument lists defined.
SECTION II

MATHEMATICS OF RADOME ANALYSIS

The mathematical techniques used in the analysis of a general radome enclosed antenna system are developed in this section. The section begins with a discussion of the coordinate systems used for the radome and the antenna and relationships are derived to convert vectors and points given in one coordinate system to the other coordinate system. Next, the plane wave spectrum of an antenna is derived from the far field pattern of the antenna and the plane wave spectrum is related to the radiating components of the aperture field of the antenna. The calculation of the far field pattern of the antenna on a flat plane (earth) is derived for various orientations of the antenna.

The mathematics of transmission of electromagnetic energy through curved multilayered lossy dielectric walls is presented. A new approach to the radome analysis problem is derived as a combination of the plane wave spectrum approach of Wu and Rudduck and ray tracing of geometric optics. The advantage of this new approach is shown to be the great speed of computation. In addition to the transmission properties of a general radome wall the inner reflections are calculated and subsequently used to calculate the VSWR in the transmission link to the antenna within the radome.

Performance parameters of an antenna system are defined and calculated. The effect of the radome is determined as changes in these performance parameters with radome insertion.
A. Coordinate Systems and Transformations

The coordinate systems used in the radome analysis were chosen because of the peculiarities of the particular antenna/radome system under study. These coordinate systems are shown in Figure 1. Three Cartesian coordinate systems are used: (1) the reference system (x, y, z) in which the z-axis is vertical to the ground (and points toward the ground), the xy-plane is parallel to the ground, and the xz-plane is used as a reference direction for antenna scan; (2) the antenna system (x_A, y_A, z_A) in which the x_Ay_A-plane is parallel to the radiating aperture, and the z_A-axis coincides with the main beam of the radiation pattern; (3) the radome system (x_R, y_R, z_R) in which the z_R-axis coincides with the axis of revolution of the symmetric radome shape, and the base of the radome is at the z_R = 0 plane.

The antenna system is oriented in the reference system such that the main beam axis always makes an angle of (\cos^{-1} \gamma_{3A}) degrees with the vertical z-axis, where \gamma_{3A} is the direction cosine of the z_A-axis with respect to the z-axis. The x_A and y_A axes are oriented so that the y_Az_A-plane coincides with the elevation pattern of the radiation pattern, and the x_Az_A-plane coincides with the azimuth plane of the radiation pattern. The origin of the antenna system is located by the spherical coordinates (r_a, \theta_a, \phi_a) in the reference system. The variables r_a, \theta_a are fixed by the geometry of the problem as discussed below while \phi_a is varied to produce the scan of the antenna pattern on the ground such that the locus of the main beam axis is a circle on the ground. The angle \phi_a is equal to the angle denoted by SCAN in Figure 1 and has the range 0 \leq \phi_a \leq 2\pi. Note that the xz-plane is the reference
Figure 1. Coordinate Systems Used in Radome Analysis.

Reference System: \((X, Y, Z)\)

Antenna System: \((X_A, Y_A, Z_A)\)

Radome System: \((X_R, Y_R, Z_R)\)
The radome coordinate system is oriented in the reference system such that the gimbal point on the radome axis is located at the origin of the reference system. The origin of the radome system is located by the spherical coordinates \((r, \theta, \phi)\) in the reference system. The attitude of the radome in the reference system is denoted by the angles PITCH and YAW shown in Figure 1. The angles PITCH and YAW are related to the angles \(\theta_r, \phi_r\) by

\[
\theta_r = \frac{\pi}{2} - \text{PITCH} \tag{1}
\]

\[
\phi_r = \pi - \text{YAW} \tag{2}
\]

where PITCH < 0 corresponds to the pitch down toward the ground and YAW > 0 corresponds to yaw to the right. The variable \(r_r\) is equal to the distance along the radome axis from the base of the radome to the gimbal point. From the figure, it is seen that YAW is the angle between the xz-plane and the plane formed by the z-axis and the \(z_R\)-axis; PITCH is the angle in this \(zz_R\)-plane between \(z_R\) and the (horizontal) xy-plane.

It is noted that the xz-plane of the reference system serves as a reference plane from which the angles YAW and SCAN are measured. Since the gimbal point coincides with the origin of the reference system, the xz-plane may be interpreted as the plane of the trajectory of the gimbal point during flight as defined by the velocity vector of the gimbal point at any time or position. The xz-plane has been chosen
as a reference plane for definiteness.

The radome analysis requires transformations of points and vectors from antenna system to radome system and vice versa. These transformations are derived in what follows using the reference coordinate system as an intermediate step.

The antenna coordinate system is obtained from the basic coordinate system by a rotation defined by the matrix of direction cosines

\[
[\mathbf{Y}] = \begin{bmatrix}
\cos \alpha_1 \cos \beta_1 & \cos \gamma_1 \\
\cos \alpha_2 \cos \beta_2 & \cos \gamma_2 \\
\cos \alpha_3 \cos \beta_3 & \cos \gamma_3
\end{bmatrix}
\]

followed by a translation of the origin \(O_A\) to the point \((X_a, Y_a, Z_a)\) in the basic system. In the above matrix, \(\alpha\) denotes an angle between the \(x\)-axis and the axis of the antenna coordinate system specified by the subscript (1A denotes \(x_A\)-axis, 2A denotes \(y_A\)-axis, 3A denotes \(z_A\)-axis); \(\beta\) denotes an angle between \(z\)-axis, etc. The translation distances are given in terms of \((r_a, \theta_a, \phi_a)\) by

\[
X_a = r_a \sin \theta_a \cos \phi_a
\]

\[
Y_a = r_a \sin \theta_a \sin \phi_a
\]

\[
Z_a = r_a \cos \theta_a
\]
Transformation of a point \((x,y,z)\) in the basic system to the same point \((x_A,y_A,z_A)\) in the antenna system is given by

\[
\begin{bmatrix}
  x_A \\
  y_A \\
  z_A
\end{bmatrix} = [Y_{ij}] \begin{bmatrix}
  x - x_a \\
  y - y_a \\
  z - z_a
\end{bmatrix}
\]  

(7)

whereas the inverse transformation is given by

\[
\begin{bmatrix}
  x \\
  y \\
  z
\end{bmatrix} = [Y_{ij}]^T \begin{bmatrix}
  x_A \\
  y_A \\
  z_A
\end{bmatrix} + \begin{bmatrix}
  x_a \\
  y_a \\
  z_a
\end{bmatrix}
\]  

(8)

where \(T\) denotes matrix transpose. Note that since a matrix of direction cosines is a unitary matrix, its inverse is equal to its transpose.

In a similar manner, the radome coordinate system is obtained from the basic coordinate system by a rotation defined by the matrix of direction cosines

\[
[p_{ij}] = \begin{bmatrix}
  \cos\alpha_1R & \cos\beta_1R & \cos\gamma_1R \\
  \cos\alpha_2R & \cos\beta_2R & \cos\gamma_2R \\
  \cos\alpha_3R & \cos\beta_3R & \cos\gamma_3R
\end{bmatrix}
\]  

(9)

followed by a translation of the origin \(O_R\) to the point \((X_r,Y_r,Z_r)\) in the basic system. The translation distances are given in terms of
(r_r, \theta_r, \phi_r) by

\begin{align}
X_r &= r_r \sin \theta_r \cos \phi_r \\
Y_r &= r_r \sin \theta_r \sin \phi_r \\
Z_r &= r_r \cos \theta_r
\end{align}

Transformation of a point (x,y,z) in the basic system to the same point (x_R,y_R,z_R) in the radome system is given by

\begin{align}
\begin{bmatrix}
x_R \\
y_R \\
z_R
\end{bmatrix} &= \begin{bmatrix}
x - X_r \\
y - Y_r \\
z - Z_r
\end{bmatrix}
\end{align}

whereas the inverse transformation is given by

\begin{align}
\begin{bmatrix}
x \\
y \\
z
\end{bmatrix} &= \begin{bmatrix}
x_R \\
y_R \\
z_R
\end{bmatrix} + \begin{bmatrix}
x_r \\
y_r \\
z_r
\end{bmatrix}
\end{align}

The transformations of vectors (with components along the Cortesian coordinate axes) are also important. Let a vector \( \mathbf{F} \) be given by
\[ F = \hat{x}_x F_x + \hat{y}_y F_y + \hat{z}_z F_z \]  
\[ F = \hat{x}_A x_A F_x + \hat{y}_A y_A F_y + \hat{z}_A z_A \]  
\[ F = \hat{x}_R x_R F_x + \hat{y}_R y_R F_y + \hat{z}_R z_R \]

where the hats denote unit vectors. Then

\[
\begin{pmatrix}
F_x \\
F_y \\
F_z
\end{pmatrix}
= [\gamma_{ij}]^T
\begin{pmatrix}
F_{x_A} \\
F_{y_A} \\
F_{z_A}
\end{pmatrix}
\]

Similar transformations hold between the basic system and the radome system when \( \gamma_{ij} \) is replaced by \( \rho_{ij} \) and the subscripts "A" replaced everywhere by "R". The translation of the rotated system does not affect the transformation of vectors from one coordinate system to another.

Using the above results as an intermediate step, the transformations between antenna and radome coordinate systems may be obtained.

The results are as follows:
From antenna system to radome system:

\[
\begin{bmatrix}
  x_R \\
  y_R \\
  z_R 
\end{bmatrix} = \left[ p_{ij} \right] \begin{bmatrix}
  x_A \\
  y_A \\
  z_A 
\end{bmatrix} + \begin{bmatrix}
  X_a - X_r \\
  Y_a - Y_r \\
  Z_a - Z_r 
\end{bmatrix}
\] (20)

\[
\begin{bmatrix}
  F_{xR} \\
  F_{yR} \\
  F_{zR} 
\end{bmatrix} = \left[ p_{ij} \right]\left[ y_{ij} \right]^T \begin{bmatrix}
  F_{xA} \\
  F_{yA} \\
  F_{zA} 
\end{bmatrix} \quad \text{(Vector Components)}
\] (21)

From radome system to antenna system:

\[
\begin{bmatrix}
  x_A \\
  y_A \\
  z_A 
\end{bmatrix} = \left[ p_{ij} \right]^T \begin{bmatrix}
  x_R \\
  y_R \\
  z_R 
\end{bmatrix} + \begin{bmatrix}
  X_r - X_a \\
  Y_r - Y_a \\
  Z_r - Z_a 
\end{bmatrix}
\] (22)

\[
\begin{bmatrix}
  F_{xA} \\
  F_{yA} \\
  F_{zA} 
\end{bmatrix} = \left[ y_{ij} \right]\left[ p_{ij} \right]^T \begin{bmatrix}
  F_{xR} \\
  F_{yR} \\
  F_{zR} 
\end{bmatrix} \quad \text{(Vector Components)}
\] (23)

Note that the transformation from antenna coordinates to radome coordinates may be rewritten to eliminate the use of the reference system as an intermediate step. From Equation (20), define
Then the transformations of Equations (20)-(23) may be written in terms of these new variables.

From antenna to radome system:

\[
\begin{bmatrix}
  x_R \\
y_R \\
z_R
\end{bmatrix} = \begin{bmatrix} R_{ij} \end{bmatrix} \begin{bmatrix} x_A \\
y_A \\
z_A \end{bmatrix} + \begin{bmatrix} T_x \\
T_y \\
T_z \end{bmatrix}
\] (20a)

\[
\begin{bmatrix}
  F_{xR} \\
F_{yR} \\
F_{zR}
\end{bmatrix} = \begin{bmatrix} R_{ij} \end{bmatrix} \begin{bmatrix}
  F_{xA} \\
  F_{yA} \\
  F_{zA}
\end{bmatrix}
\] (21a)

From radome to antenna system:

\[
\begin{bmatrix}
  x_A \\
y_A \\
z_A
\end{bmatrix} = \begin{bmatrix} R_{ij} \end{bmatrix}^T \begin{bmatrix}
  x_R - T_x \\
y_R - T_y \\
z_R - T_z
\end{bmatrix}
\] (22a)
The more concise transformations given by Equations (20a) - (23a) result in fewer computations and are therefore more desirable for computer implementation.

Subroutines POINT and VECTOR carry out the transformations of points and vectors, respectively, given in either coordinate system, from one system to the other. POINT is listed in Appendix H. VECTOR is listed in Appendix I.

In order to determine the matrices of direction cosines \([\gamma_{ij}], \[\rho_{ij}]\), the peculiar aspects of the antenna/radome system under study must be considered. The location and orientation of the antenna coordinate system is specified by using spherical coordinates \((r_a, \theta_a, \phi_a)\) of \(O_A\) in the basic \(\hat{r}\) system. Associated with the point \((r_a, \theta_a, \phi_a)\) are the unit vectors \((\hat{r}_a, \hat{\theta}_a, \hat{\phi}_a)\) in the direction of increasing spherical coordinates. The center of the main beam of radiation from the antenna always makes an angle of \(\cos^{-1} \gamma_{3A}\) with the vertical \(z\)-axis. Choosing \(z_A\) to coincide with the main beam axis and letting \(\hat{x}_A = -\hat{\phi}_a\) produces the desired result that by varying only \(\phi_a\) from 0 to \(2\pi\) radians \((r_a, \theta_a\) are fixed by the location of the aperture plane with respect to the actual reflector surface) causes the locus of the intersection of the main beam axis with the ground to be a circle. Defining \(\psi_a = \theta_a - \cos^{-1} \gamma_{3A}\) and performing the necessary vector operations results in the following

\[
\begin{bmatrix}
F_{xA} \\
F_{yA} = [R_{ij}]^T F_{xR} \\
F_{zA}
\end{bmatrix}
\begin{bmatrix}
F_{xR} \\
F_{yR} \\
F_{zR}
\end{bmatrix}
\]
expressions for \( (\hat{x}_A, \hat{y}_A, \hat{z}_A) \) in the basic system of coordinates:

\[
\hat{x}_A = \hat{x}(\sin \phi_a) + \hat{y}(-\cos \phi_a) + \hat{z}(0)
\]

\[
\hat{y}_A = \hat{x}(\sin \psi_o \sin \theta \cos \phi_a + \cos \psi_o \cos \theta \cos \phi_a)
+ \hat{y}(\sin \psi_o \sin \theta \sin \phi_a + \cos \psi_o \cos \theta \sin \phi_a)
+ \hat{z}(\sin \psi_o \cos \theta - \cos \psi_o \sin \theta)
\]

\[
\hat{z}_A = \hat{x}(\cos \psi_o \sin \theta \cos \phi_a - \sin \psi_o \cos \theta \cos \phi_a)
+ \hat{y}(\cos \psi_o \sin \theta \sin \phi_a - \sin \psi_o \cos \theta \sin \phi_a)
+ \hat{z}(\cos \psi_o \cos \theta + \sin \psi_o \sin \theta)
\]

The direction cosines \( \gamma_{ij} \) are then found by performing vector dot product operations; e.g.,

\[
\gamma_{ll} = \cos \phi_a = \hat{x} \cdot \hat{x}_A = \sin \phi_a.
\]

Using the above results and defining the positive x-axis as the direction of forward motion of the gimbal point, the following are found to be true:
\[ \phi_a = 0 \rightarrow \text{Main beam looking forward}, \]

\[ \phi_a = \pi/2 \rightarrow \text{Main beam looking starboard}, \]

\[ \phi_a = \pi \rightarrow \text{Main beam looking aft}, \]

\[ \phi_a = 3\pi/2 \rightarrow \text{Main beam looking port}. \]

The location and orientation of the radome in the basic system is defined by the spherical coordinates of \( \mathbf{O}_R : (r_r, \theta_r, \phi_r) \) in the basic system. If \( (\hat{r}_r, \hat{\theta}_r, \hat{\phi}_r) \) denote the usual unit vectors at \( (r_r, \theta_r, \phi_r) \) and the axis of the radome coincides with \( z_R \), then \( \hat{z}_R = -\hat{r}_r \) always. By choosing \( \hat{x}_R = \hat{\theta}_r \), \( \hat{y}_R = -\hat{\phi}_r \), there results

\[ \hat{x}_R = \hat{x}(\cos \theta_r \cos \phi_r) + \hat{y}(\cos \theta_r \sin \phi_r) + \hat{z}(-\sin \theta_r) \]  \hfill (30)

\[ \hat{y}_R = \hat{x}(\sin \phi_r) + \hat{y}(-\cos \phi_r) + \hat{z}(0) \]  \hfill (31)

\[ \hat{z}_R = \hat{x}(-\sin \theta_r \cos \phi_r) + \hat{y}(-\sin \theta_r \sin \phi_r) + \hat{z}(-\cos \theta_r) \]  \hfill (32)

from which the direction cosines \( p_{ij} \) follow. Subroutine ORIENT calculates the transformation matrices when the origins of both the antenna and the radome are given. ORIENT is listed in Appendix D.

The values of \( r_a, \theta_a \) are obtained from the geometry of the particular system under study and are determined according to the following considerations. The reflector antenna used remains within a sphere of radius \( R_G \) centered at the gimbal point for any gimbal position; this sphere is wholly contained within the radome for any radome rotation.
rotation about the gimbal point. The radiating properties of the antenna are characterized by the tangential components of the antenna electric field on a planar (aperture) surface \((z_A=0\) plane) close to the actual reflector such that the axis of the main beam is perpendicular to this planar surface. In addition, it is necessary that the aperture plane be limited in size and so located that it too will remain within the sphere of radius of \(R_G\). At the same time, it is desired that the aperture be as large as possible so that the tangential components of the electric field be insignificant at its edges.

Using the above considerations, the geometry of Figure 2 results to yield the largest aperture located forward of the reflector yet contained within the sphere of radius \(R_G\). As it turns out, \(r_a\) is colinear with \(z_A\) and \(\theta_a\) is identically equal to \(\cos^{-1} \gamma_{3A}\) as shown. The distance \(r_a\) is given by

\[
r_a = R_A \gamma_{3A}
\]  \hspace{1cm} (33)

where \(\gamma_{3A}\) is the direction cosine defined earlier. The diagonal length of the rectangular near-field aperture is given by

\[
D = 2\sqrt{R_G^2 - r_a^2}.
\]  \hspace{1cm} (34)

The diagonal length \(D\) then determines the length and width of the rectangular aperture. For the particular antenna under study, a square aperture was chosen whose length along each side is given by \(D/\sqrt{2}\). These choices of \(r_a, \theta_a\), and square aperture result in an aperture that
Figure 2. Geometry Used to Determine $r_a$ and $\theta_a$. 

Figure 2. Geometry Used to Determine $r_a$ and $\theta_a$. 

18
is compatible with the choices of sampling distances and number of
samples required in characterizing the radiating properties of the
actual antenna used.

B. Plane Wave Spectrum of Antenna Without Radome

The plane wave spectrum of an antenna may be calculated from
the far field pattern of the antenna. Often the far field pattern is
given in a coordinate system which is inconvenient for further computa-
tions and must be transformed to a new coordinate system. As an
eexample let the following ground mapping "csc^2" far field power pattern
be given in the coordinate system of Figure 3. This far field pattern
is specified on a sphere concentric with the antenna whose radius R is
sufficiently large such that the pattern varies only as 1/R^2 with R.
The constant R includes the efficiency of the antenna; other normalizing
constants are lumped together to form the constant P_0.

![Figure 3. Far Field Coordinate System.](image-url)
\[
P(\beta, \theta) = P_o \left[ \csc^2 \beta \cos^{1/2} \beta \right] \left[ J_o \left( 2.26 \frac{\theta}{\theta_o} \right) \right]^2 \quad \beta_o \leq \beta \leq \beta_2 \tag{35}
\]

\[
= P_o \left[ J_o \left( 2.26 \frac{\beta-\beta_o}{\phi_o} \right) \right] \left[ J_o \left( 2.26 \frac{\theta}{\theta_o} \right) \right]^2 \quad \beta \geq \beta_o
\]

\[
= P_o \left[ J_o \left( 2.26 \frac{\beta-\beta_2}{\phi_o} \right) \right] \left[ \frac{\csc^2 \beta_2 \cos^{1/2} \beta_2}{\csc^2 \beta_o \cos^{1/2} \beta_o} \right] \left[ J_o \left( 2.26 \frac{\theta}{\theta_o} \right) \right]^2 \quad \beta \geq \beta_2
\]

where \( P_o, \beta_o, \phi_o, \theta_o, \beta_2 \) are constants which may be adjusted to approximate a wide variety of "csc^2" patterns.

To determine the elevation (\( \beta \)) and azimuth (\( \alpha \)) components of the far field from the far field power pattern, the polarization ratio of the far field must be known for each point of the far field. Let the complex polarization ratio \( R(\beta, \alpha) \) be defined as:

\[
R(\beta, \alpha) = \frac{E_\alpha(\beta, \alpha)}{E_\beta(\beta, \alpha)} \tag{36}
\]

The \( \beta \) and \( \alpha \) components are related to the far field power pattern as

\[
\frac{|E_\alpha(\beta, \alpha)|^2}{\eta} + \frac{|E_\beta(\beta, \alpha)|^2}{\eta} = P(\beta, \alpha) \tag{37}
\]

where \( \eta \) is the intrinsic impedance of free space.
Solving Equations (36) and (37) for $E_\beta$ and $E_\alpha$ yields:

$$E_\beta(\beta,\alpha) = \frac{n \rho(\beta,\alpha)}{\sqrt{1 + |R(\beta,\alpha)|^2}}$$  \hspace{1cm} (38)$$

$$E_\alpha(\beta,\alpha) = R(\beta,\alpha) \frac{n \rho(\beta,\alpha)}{\sqrt{1 + |R(\beta,\alpha)|^2}}$$

where it is assumed that in the far field the radial component $E_r(\beta,\alpha)$ is equal to zero.

The $z'$ and $y'$ components of the far field may be determined from the beta and alpha components as follows:

$$E_{z'}(\beta,\alpha) = -E_\beta(\beta,\alpha) \sin \beta$$  \hspace{1cm} (40)$$

$$E_{y'}(\beta,\alpha) = E_\beta(\beta,\alpha) \cos \beta \sin \alpha + E_\alpha(\beta,\alpha) \cos \alpha$$  \hspace{1cm} (41)$$

Now it is necessary to change coordinate systems to facilitate plane wave expansion of the fields. The new coordinate system is shown in Figure 4. (This is also the $X_A$, $Y_A$, $Z_A$ coordinate system of Figure 1.)
Wavenumbers are now defined as:

\[ K_x = K_o \sin \theta \cos \phi \]  \hspace{1cm} (42)

\[ K_y = K_o \sin \theta \sin \phi \]  \hspace{1cm} (43)

\[ K_z = K_o \cos \theta \]  \hspace{1cm} (44)

where \( K_o = 2\pi/\lambda \).

The relations between the two systems are:

\[ y' = \sin \beta \sin \alpha = x = \sin \theta \cos \phi = K_x/K_o \]  \hspace{1cm} (45)

\[ x' = \sin \beta \cos \alpha = z = \cos \theta = K_z/K_o \]  \hspace{1cm} (46)

\[ z' = \cos \beta = y = \sin \theta \sin \phi = K_y/K_o \]  \hspace{1cm} (47)

Beta and alpha may then be related to \( K_x, K_y, K_z \), and \( K_o \) as:

\[ \beta = \text{ARCCOS}(K_y/K_o) \]  \hspace{1cm} (48)

\[ \alpha = \text{ARCTAN}(K_x/K_z) \]  \hspace{1cm} (49)

Also the x and y components of the field are related to the \( y' \) and \( z' \); components as follows:

\[ E_x = E_{y'} \]  \hspace{1cm} (50)

\[ E_y = E_{z'} \]  \hspace{1cm} (51)
In summary:

\[ E_x(Kx, Ky) = E_b \left( \text{ARC COS}(K_y/K_o), \text{ARC TAN}(K_y/K_z) \right) \frac{K_y K_x / (K_o \sqrt{K_x^2 + K_z^2})}{K_x K_y / (K_o \sqrt{K_x^2 + K_z^2})} \] (52)

\[ + E_d \left( \text{ARC COS}(K_y/K_o), \text{ARC TAN}(K_y/K_z) \right) \frac{K_z / \sqrt{K_x^2 + K_z^2}}{K_z / \sqrt{K_x^2 + K_z^2}} \]

\[ E_y(Kx, Ky) = E_b \left( \text{ARC COS}(K_y/K_o), \text{ARC TAN}(K_y/K_z) \right) \sqrt{K_x^2 + K_z^2} / K_o \] (53)

Finally the x and y components of the plane wave spectrum, XPWS and YPWS, respectively, of the antenna may be obtained from the x and y components of the far field pattern by inverting the following relationships

\[ E_x(Kx, Ky) = \frac{-j(K_x + K_y + K_z)}{\sqrt{x^2 + y^2 + z^2} \text{xpsw}(K_x, K_y)} \] (54)

\[ E_y(Kx, Ky) = \frac{-j(K_x + K_y + K_z)}{\sqrt{x^2 + y^2 + z^2} \text{ypsw}(K_x, K_y)} \] (55)

where \((x, y, z)\) are the coordinates of points on a sphere of constant radius \(R = \sqrt{x^2 + y^2 + z^2}\) and where \(R\) approaches infinity.

Only the radiating components of the plane wave spectrum of an antenna can be obtained from the far field pattern of an antenna as described above. The reactive components are not known but are not needed for this radome analysis.
The subroutine which calculates the \( x \) and \( y \) components of the plane wave spectrum as discussed above is called PWS and is listed in Appendix B.

The \( x \) and \( y \) components of the aperture field of an antenna can be calculated from the \( x \) and \( y \) components of the plane wave spectrum using the Fourier transform relationship between the two as follows:

\[
E_{\text{XA}}(X,Y) = \text{FT}^{-1}[X_{\text{pws}}(K_x,K_y)]
\]

\[
E_{\text{YA}}(X,Y) = \text{FT}^{-1}[Y_{\text{pws}}(K_x,K_y)]
\]

(56)

(57)

where \( \text{FT}^{-1} \) is the two-dimensional inverse Fourier transform operator.

Likewise the \( x \) and \( y \) components of the plane wave spectrum of an antenna can be calculated from the \( x \) and \( y \) components of the aperture field as follows:

\[
X_{\text{pws}}(K_x,K_y) = \text{FT}[E_{\text{XA}}(X,Y)]
\]

\[
Y_{\text{pws}}(K_x,K_y) = \text{FT}[E_{\text{YA}}(X,Y)]
\]

(58)

(59)

where \( \text{FT} \) is the Fourier transform operator.

The Fast Fourier Transform (FFT) Algorithm is used to evaluate the required Fourier transforms and inverse Fourier transforms. The use of the FFT greatly reduces computation time. This reduction of computation time makes it possible to carry out a sophisticated radome analysis, which would otherwise require prohibitively large amounts of
computer time.

The FFT requires that the field or the plane wave spectrum which is to be transformed be sampled in accordance with the Fourier sampling theorem. This theorem has been recast in terms of electromagnetic spaces and variables by Joy (2). The required sample spacings to accurately represent an electromagnetic field on a planar surface when it is known that the plane wave spectrum of the field is contained in a rectangular wavenumber region in which \(-K_{x\text{max}} \leq K_x \leq K_{x\text{max}}\) and \(-K_{y\text{max}} \leq K_y \leq K_{y\text{max}}\) are given by

\[
\Delta X = \frac{\lambda}{2} \left( \frac{K_o}{K_{x\text{max}}} \right)
\]

\[
\Delta Y = \frac{\lambda}{2} \left( \frac{K_o}{K_{y\text{max}}} \right)
\]

The samples must be taken at the intersections of a finite rectangular lattice, with lattice spacings \(\Delta X\) and \(\Delta Y\) as shown in Figure 5.

![Figure 5. Near Field Lattice](image-url)
Likewise the required sample spacings to accurately represent a plane wave spectrum for which it is known that the spectrum was produced by a planar electromagnetic field contained in a rectangular region where \(-X_{\text{max}} \leq X \leq X_{\text{max}}\) and \(-Y_{\text{max}} \leq Y \leq Y_{\text{max}}\) are given by

\[
\Delta K_x = K_0 \left( \frac{\lambda/2}{X_{\text{max}}} \right) \tag{62}
\]

\[
\Delta K_y = K_0 \left( \frac{\lambda/2}{Y_{\text{max}}} \right) \tag{63}
\]

The samples must be taken at the intersection of a finite rectangular lattice, with lattice spacings \(\Delta K_x\) and \(\Delta K_y\).

It will be assumed throughout all further discussions that the sampling criteria for both fields and plane wave spectra are being adhered to.

The FFT requires that the number of samples in each of the two dimensions of the input array of data values be equal to some power of two. Let the two dimensions be \(N_X\) and \(N_Y\). The assumed origin of the array is location with indices \((N_X/2+1, N_Y/2+1)\). The most negative location of the array is the location \((1,1)\). This choice of origin makes the array unsymmetrical. Consider the center row of the input array. On the negative side of row there are \(N_X/2\) samples, not counting the origin, and on the positive side of the row there are only \((N_X/2-1)\) samples, not counting the origin. This nonsymmetry of the input array is a quirk of the FFT algorithm and must be carefully dealt with. The FFT, during the course of its computations, removes the nonsymmetry by adding a fictitious row and column to the input array. The new row
becomes the \((NX+1)th\) row and the new column becomes the \((NY+1)th\) column. The values in these additions are the same as the values in the first row and first column, respectively. The value of the \((NX+1, NY+1)\) location is the same as the \((1,1)\) value. Where possible, the problem is usually avoided by specifying that the values in the first row and column of the input array be equal to zero. The FFT subroutine is listed in Appendix T.

C. Far Field Calculation

In this section the calculation procedure for calculating various far field power patterns from the plane wave spectra will be presented. Three far field power patterns are of importance. They are: (1) the total power pattern, (2) the power pattern of the elevation component, and (3) the power pattern of the azimuth component.

The \(x\) and \(y\) components of the far field are calculated from the \(x\) and \(y\) components of the plane wave spectrum as follows:

\[
E_x(R,K_x,K_y) = j \frac{K_z e^{-j(R \cdot \hat{r})}}{R} \text{Xpws}(K_x, K_y) \quad \text{for } K_x \text{ and } K_y \text{ such that } |K_x| \leq |K_{x\max}| \quad |K_y| \leq |K_{y\max}| \quad K_x^2 + K_y^2 \leq K^2 \tag{65}
\]

\[
E_y(R,K_x,K_y) = j \frac{K_z e^{-j(K \cdot \hat{r})}}{R} \text{Ypws}(K_x, K_y) \quad \text{for } K_x^2 + K_y^2 \leq K^2 \tag{66}
\]

\[
\begin{align*}
E_x(R,K_x,K_y) &= 0 \\
E_y(R,K_x,K_y) &= 0
\end{align*}
\]

For other \(K_x\) and \(K_y\)
where

\[ \hat{K} = \hat{x} K_x + \hat{y} K_y + \hat{z} K_z \]  
\[ \hat{R} = \hat{x} \hat{x} + \hat{y} \hat{y} + \hat{z} \hat{z} \]  
\[ R = |\hat{R}| \]

The z component of the far field is calculated from the plane wave equation:

\[ \hat{E} \cdot \hat{K} = 0 \]  

(71)

Expanding the above equation yields:

\[ E_x K_x + E_y K_y + E_z K_z = 0. \]  

(72)

This equation may be solved for \( E_z \) yielding:

\[ E_z = \frac{-1}{K_z} [E_x K_x + E_y K_y]. \]  

(73)

To calculate the far field on a flat surface (the ground) an equation for \( R \) must be determined. \( R \) is the distance from the origin of the planar aperture to the point on the ground where the field is to be determined. Figure 6 shows the parameters relating the location and orientation of the planar aperture with respect to the ground.

\( \theta_A, \phi_A \) and ALTITUDE specify the orientation of the aperture with
Figure 6. Far Field Coordinate System With Ground.
respect to the ground. In normal flight $\theta_A$ and $\phi_A$ are fixed and ALTITUDE varies. The points on the ground are defined by the following equation:

$$\hat{r} \cdot \hat{n} = \text{ALTITUDE}$$  \hspace{1cm} (74)

where $\hat{r}$ is the unit vector in the radial direction

$\hat{n}$ is the unit vector in the ALTITUDE direction.

The equations for $\hat{r}$ and $\hat{n}$ are

$$\hat{r} = \hat{x} \sin \theta \cos \phi + \hat{y} \sin \theta \sin \phi + \hat{z} \cos \theta$$  \hspace{1cm} (75)

$$\hat{n} = \hat{x} \sin \theta_A \cos \phi_A + \hat{y} \sin \theta_A \sin \phi_A + \hat{z} \cos \theta_A$$  \hspace{1cm} (76)

These equations may be written using wavenumbers as:

$$\hat{r} = \hat{x} Kx + \hat{y} Ky + \hat{z} Kz$$  \hspace{1cm} (77)

$$\hat{n} = \hat{x} KxA + \hat{y} KyA + \hat{z} KzA$$  \hspace{1cm} (78)

Substituting the above relations into the equation for $R$ yields:

$$\hat{r} \cdot \hat{n} = R(Kx KxA + Ky KyA + Kz KzA) = \text{ALTITUDE}$$  \hspace{1cm} (79)

This equation may be solved for $R$ yielding:
The x, y and z components of the far field may then be calculated from Equations (64), (65), and (73), respectively, at any point on the far field planar surface specified by \((R,kx,ky)\). Subroutine FAR listed in Appendix C performs these calculations for either of two far field surfaces. One surface is the standard far field spherical surface of constant radius and the other surface is the flat plane with orientation and location specified by \(\theta, \phi, \) and \(\text{ALTITUDE}\). An input variable \((IS)\) specifies which surface is to be used.

The far field power patterns are calculated from the \(x, y\) and \(z\) components of the far field calculated above. The total power is calculated as follows:

\[
P_{T}(R,kx,ky) = \frac{|E_{x}(R,kx,ky)|^{2} + |E_{y}(R,kx,ky)|^{2} + |E_{z}(R,kx,ky)|^{2}}{\eta}
\]

where \(\eta\) is the intrinsic impedance of the medium. The component of the far field in the elevation direction (illustrated in Figure 3) is calculated from the \(x, y, z\) components as follows:

\[
E_{\phi}(R,kx,ky) = \frac{E_{x}(R,kx,ky)KxKy}{\sqrt{K_{x}^{2} + K_{y}^{2}}} + E_{y}(R,kx,ky)\sqrt{K_{z}^{2} + K_{x}^{2}} - \frac{E_{z}(R,kx,ky)KyKz}{\sqrt{K_{z}^{2} + K_{x}^{2}}} \tag{82}
\]

The power pattern of the elevation components is given by
The component of the far field in the azimuth direction (illustrated in Figure 3) is calculated from the $x$, $y$, and $z$ components as follows:

$$E_a(R,Kx,Ky) = \frac{-E_x(R,Kx,Ky)K_z}{\sqrt{K_x^2 + K_y^2}} - \frac{E_z(R,Kx,Ky)K_x}{\sqrt{K_x^2 + K_z^2}}$$ \hspace{1cm} (84)$$

The power pattern of the azimuth component is given by:

$$P_a(R,Kx,Ky) = \frac{E_a(R,Kx,Ky)^2}{\eta}$$ \hspace{1cm} (85)$$

Subroutine FAR also calculates the specified far field power pattern. An input variable (IPWR) specifies which power pattern is to be calculated.

D. Radome Transmission

The effects of a radome on the transmission of electromagnetic fields from a radiating antenna to a far field surface are calculated using a combination of the plane wave spectrum (PWS) formulation of radome analysis of Wu and Rudduck (1) and well-known ray tracing techniques of geometric optics. In the method of analysis to be presented, an equivalent aperture field is formed on a planar surface coincident with the original aperture field surface.

The radiating properties of the antenna without radome in place are represented by a discrete PWS. The PWS is a complex vector array of data values calculated from the vector far field pattern of the
antenna and from the complex polarization function of the antenna as discussed earlier. This PWS may be associated through a FFT of the PWS with a planar aperture field near the antenna. Each plane wave in the PWS is represented by a system of parallel rays emanating from the sample locations of the aperture field inside the radome. The number of such rays can be calculated as follows: If the PWS contains \((NX \times NY)\) plane waves, then the aperture plane has \((NX \times NY)\) sample locations producing a total of \((NX \times NY) \times (NX \times NY)\) rays.

Each ray is traced from its point of origin in the aperture plane in a direction specified by the particular plane wave it represents through the radome wall to the outer surface of the radome. The effects of reflection, refraction, and attenuation by the radome wall are applied to each ray using the theory of plane waves incident on a plane dielectric structure to be discussed in more detail later. The radome is then removed and the ray is retraced to its point of origin to be used in the formation of an equivalent aperture field. The equivalent field is formed as a summation of radome weighted rays and thus includes the effects of the radome. The PWS of the equivalent field is obtained through a FFT of the equivalent field. The \(x\), \(y\) and \(z\) components of the field are then calculated from the PWS as discussed earlier and subsequently the far field power patterns are calculated.

This analysis may seem to be error free when viewed one ray at a time. However, viewing the analysis in terms of each plane wave an error becomes apparent. The error is associated with the curvature of the radome wall. This error is quite small for each ray as the radome wall appears to be flat in the small region associated with each
ray but becomes greater when all the rays which represent one plane wave are considered together. Representing a plane wave as a system of parallel rays is quite legitimate; it is simply a method of sampling a plane wave. When the system of rays representing a plane wave intersect the radome, the reflection and transmission coefficients for each ray are also correct for the coefficients were determined for plane wave incidence which the ray represents. The problem exists in that the field on the exterior surface no longer behaves like a single plane wave. The exterior field would behave like a single plane wave if each ray were weighed equally in passing through the radome. Each incident ray, however, intersects the radome at a different point where the angle of incidence and even the wall construction may be different from the other intersection points, thus weighting each ray differently. The field on the exterior surface can no longer be represented as a single plane wave; instead, it must be represented by a whole spectrum of plane waves. Thus a single set of parallel rays is no longer adequate to represent this field. The error in this analysis is in using a single set of parallel rays (each ray with a different complex amplitude, however) to transfer the exterior field back to the aperture plane after removal of the radome. Wu and Rudduck do not ray trace the exterior field to any other surface; instead, they calculate the far field of the radome enclosed antenna using the exterior field directly. For each far field point to be determined, a time-consuming integration of the exterior field must be performed. The integration is time consuming as the distance from each point on the exterior surface of the radome to the far field point of interest must be calculated and the
incremental area size associated with each exterior field value must be
determined (3). It is estimated that the computation time on a Univac
1108 to calculate the far field pattern of a radome enclosed antenna
using exterior surface integration would be 6 hours for a PWS and an
aperture field of dimension (16,16).

Experience has shown that the PSW of the exterior field produced
by an incident plane wave is sufficiently close to a single plane wave
that the ray approximation is a good one. With this approximation
the radome is removed and the exterior field is ray traced back to the
aperture plane to form an equivalent aperture field. The far field of
the equivalent aperture field is then quickly calculated using the FFT.
In comparison to the computation time of 6 hours given above, the same
computation using retracing and the FFT requires approximately 4 minutes,
a reduction in time of almost two orders of magnitude.

This analysis, as with any radome analysis, depends heavily on
geometry. The basic geometry problem is to find the point of inter-
section of a ray and a surface. The ray is specified as a straight
line originating from a point interior to the radome \((X,Y,Z) =
(P_1, P_2, P_3)\), and with a specified direction \((Kx, Ky, Kz) = (K_1, K_2, K_3)\).
The point of intersection with the interior surface of the radome
\((X,Y,Z) = (X,Y,Z)\) and the inward unit normal vector at the intersection
point \((Kx, Ky, Kz) = (N_x, N_y, N_z)\) must be determined.

1. Ray Tracing Geometry

Radomes, which are symmetric about the \(z\) axis, can be approximated
by dividing the radome into \(Z\) sections such that each section can be
approximated by a cone, a plane, or an ogive. Once this has been done,
the problem reduces to one of calculating the point of intersection of
the ray and the shape which best approximates the radome at the point
of intersection. Once the point of intersection has been established,
the calculation of the unit normal at that point is relatively easy.

a. Intersection of Ray and Cone. The equation of a cone in
radome coordinates \((x,y,z)\) is

\[
Z - Z_T = -A\sqrt{x^2 + y^2}
\]  

(86)

where \(Z_T\) and \(A\) are parameters of the cone.

The equation of a straight line in radome coordinates is

\[
\frac{x - P_1}{K_1} = \frac{y - P_2}{K_2} = \frac{z - P_3}{K_3}
\]  

(87)

where \((P_1,P_2,P_3)\) specifies the point of origination of the line and
\((K_1,K_2,K_3)\) specify the direction of the line.

\[
Z_P = Z - P_3
\]  

(88)

This yields

\[
Z - Z_T = Z_P + P_3 - Z_T
\]  

(89)

\[
= Z_T - Z_C
\]  

(90)

where \(Z_C = Z_T - P_3\).
Assuming $K_3 \neq 0$, 

\[ X = \frac{K_1}{K_3} Z \pm \frac{P}{K_3} \quad (91) \]

\[ Y = \frac{K_2}{K_3} Z \pm \frac{P}{2} \quad (92) \]

Squaring the cone equation

\[ (Z_p - Z_c)^2 = A^2 (x^2 + y^2) \quad (93) \]

and substituting for $X$ and $Y$ yields:

\[ a Z_p^2 + b Z_p + C = 0 \quad (94) \]

where

\[ a = 1 - A^2 \left( \frac{K_1^2 + K_2^2}{K_3^2} \right) \quad (95) \]

\[ b = -2 \frac{Z_c}{A^2} - 2A^2 \left( \frac{K_1 P_1 + K_2 P_2}{K_3^2} \right) \quad (96) \]

\[ c = Z_c^2 - A^2 (P_1^2 + P_2^2) \quad (97) \]

Solving the quadratic equation of Equation (94) yields:

\[ Z_p = \frac{-b \pm \sqrt{b^2 - 4aC}}{2a} \quad (98) \]
To determine which of the two values is correct, the value of \( Z_p \) that has the same sign as \( K_3 \) and the smallest absolute value is selected. If neither of the solutions has the same sign as \( K_3 \), then the ray did not intersect the cone. The \( x,y,z \)-components of the point of intersection can now be calculated by:

\[
x = \frac{K_1}{K_3} Z_p + P_1
\]  \hspace{1cm} (99)

\[
y = \frac{K_2}{K_3} Z_p + P_2
\]  \hspace{1cm} (100)

\[
z = Z_p + P_3
\]  \hspace{1cm} (101)

These computations are performed by subroutine CONE, which is listed in Appendix L.

Once the point of intersection is established, the inward normal can be calculated by

\[
N_x = -x \frac{A \cos(cot^{-1}A)}{Z - Z_T}
\]  \hspace{1cm} (102)

\[
N_y = -y \frac{A \cos(cot^{-1}A)}{Z - Z_T}
\]  \hspace{1cm} (103)

\[
N_z = -\sin(cot^{-1}A)
\]  \hspace{1cm} (104)

The calculation of the unit normal is performed by Entry Point CONEN of subroutine CONE.
b. **Intersection of Ray and Plane.** The only planes to be considered here are the planes described by \( Z = \text{constant} \). The point of intersection of the line

\[
\frac{Z - P_3}{K_3} = \frac{X - P_1}{K_1} = \frac{Y - P_2}{K_2}
\]  

(105)

and the plane

\[ z = A \]

(106)

can be found from:

\[
x = \frac{K_1}{K_3} (A-P_3) + P_1
\]

(107)

\[
y = \frac{K_2}{K_3} (A-P_3) + P_2
\]

(108)

\[ z = A. \]

(109)

The inward normal if the plane is a top plate for the radome is

\[
N_x = 0
\]

(110)

\[
N_y = 0
\]

(111)

\[
N_z = -1
\]

(112)
The inward normal if the plane is a bottom plate for the radome is

\[ N_X = 0 \quad \text{(113)} \]
\[ N_Y = 0 \quad \text{(114)} \]
\[ N_Z = 1 \quad \text{(115)} \]

The calculation of the planar intersection point and the unit normals are calculated by subroutines TDISK and BDISK for the top and bottom disks, respectively.

TDISK is listed in Appendix J and BDISK is listed in Appendix K.

c. Intersection of Ray and Ogive. The equation of an ogive in radome coordinates is (5, p. 48)

\[ R = \left[ R_o^2 - (Z - A_P)^2 \right]^{1/2} - B \quad \text{(116)} \]

where

\[ R = \sqrt{x^2 + y^2} \quad \text{(117)} \]

The equation of a straight line in radome coordinates is

\[ \frac{z - P_3}{K_3} = \frac{x - P_1}{K_1} = \frac{y - P_2}{K_2} \quad \text{(118)} \]

Define

\[ Z_P = Z - P_3 \quad \text{(119)} \]
This yields

\[ z - A_p = Z_p + P_3 - A_p \quad (120) \]

\[ = Z_p + A \]

where

\[ A = P_3 - A_p \quad (122) \]

and, assuming \( K_3 \neq 0 \),

\[ X = \frac{K_1}{K_3} Z_p + P_1 \quad (123) \]

\[ Y = \frac{K_2}{K_3} Z_p + P_2 \quad (124) \]

From original ogive equations

\[ R = \sqrt{X^2 + Y^2} \quad (125) \]

\[ R^2 = X^2 + Y^2 \quad (126) \]

\[ R^2 = \left( \frac{K_1}{K_3} \right)^2 Z_p^2 + 2 \frac{K_1}{K_3} P_1 Z_p + P_1^2 + \left( \frac{K_2}{K_3} \right)^2 Z_p^2 + 2 \frac{K_2}{K_3} P_2 Z_p + P_2^2 \quad (127) \]

\[ = U Z_p^2 + V Z_p + W \quad (128) \]

where
\[ U = \left( \frac{K_1}{K_3} \right)^2 + \left( \frac{K_2}{K_3} \right)^3 \]  

\[ V = 2 \left( \frac{K_1}{K_3} \right)^2 + 2 \left( \frac{K_2}{K_3} \right)^2 \]  

\[ W = P_1^2 + P_2^2 \]  

Squaring the original ogive equation yields

\[(R+B)^2 = R_o^2 - (Z_p+A)^2\]  

\[(R^2+2RB+B^2) = R_o^2 - (Z_p+A)^2\]  

\[2RB = R_p - (Z_p+A)^2 - R^2\]

where

\[ R_p = R_o^2 - B^2\]  

Squaring again

\[4R^2B^2 = (R_p - (Z_p+A)^2 - R^2)^2\]  

Substituting for \(R^2\) and simplifying

\[Z_p^4 + C_4Z_p^3 + C_3Z_p^2 + C_2Z_p + C_1 = 0\]  

where
\[ C_4 = \frac{4A + 4AU + 2V + 2UV}{1 + 2U + U^2} \]  
\[ C_3 = \frac{-2R_p(1+U) + 6A^2 + 2W + 4AV + 2A^2U + 2UW + V^2 - 4B^2U}{1 + 2U + U^2} \]  
\[ C_2 = \frac{-2R_p(2A+V) + 4A^3 + 4AW + 2A^2V + 2W - 4B^2V}{1 + 2U + U^2} \]  
\[ C_1 = \frac{R_p^2 - 2R_p(A^2+W) + A^4 + 2A^2W + W^2 - 4B^2W}{1 + 2U + U^2} \]

All four roots of this polynomial may be found by use of the

resolvent cubic equation

\[ P^3 - C_3P^2 + (C_4C_2 - 4C_1)P - C_4^2C_1 + 4C_3C_1 - C_2^2 = 0 \]

This cubic equation has at least one real root. This root can be found by

\[ P = \sqrt[3]{-\frac{t}{2} + \sqrt{\frac{t^2}{4} + \frac{S^3}{27}}} + \sqrt[3]{-\frac{t}{2} - \sqrt{\frac{t^2}{4} + \frac{S^3}{27}}} \]

where

\[ S = \frac{1}{3} \left[ 3(C_4C_2 - 4C_1) - C_3^2 \right] \]

\[ t = \frac{1}{27} \left[ -2C_3^3 + 9C_3(C_4C_2 - 4C_1) + 27(-C_4C_1 + 4C_3C_1 - C_2^2) \right] \]

43
Once $P$ is found, the roots of the quartic equation can be calculated by

$$
Z_P = \frac{C_3}{4} + \frac{R_1}{2} \pm \frac{D}{2}
$$

(145)

$$
Z_P = \frac{C_3}{4} - \frac{R_1}{2} \pm \frac{E}{2}
$$

(146)

where

$$
R_1 = \sqrt{\frac{C_4^2}{4} - C_3 + P}
$$

(147)

$$
D = \sqrt{\frac{3C_4^2}{4} - R_1^2 - 2C_3 + \frac{4C_4C_3 - 8C_2 - C_4^3}{4R_1}}
$$

(148)

$$
E = \sqrt{\frac{3C_4^2}{4} - R_1^2 - 2C_3 - \frac{4C_4C_3 - 8C_2 - C_4^3}{4R_1}}
$$

(149)

Equations (145) and (146) yield two positive values for $Z_P$ and two negative values. The correct value of $Z_P$ is chosen as the value with the same sign as $K_3$ with the smallest absolute value. The $Z$ component of the point of intersection is

$$
Z = P_3 + Z_P
$$

(150)

The $X$ and $Y$ components of the intersection can be calculated using the method discussed in the cone section.

Once the point of intersection is established, the inward normal at that point can be calculated as:
\[
N_X = -x \frac{B + \sqrt{X^2 + Y^2}}{R_o \sqrt{X^2 + Y^2}} \quad (151)
\]
\[
N_Y = -y \frac{B + \sqrt{X^2 + Y^2}}{R_o \sqrt{X^2 + Y^2}} \quad (152)
\]
\[
N_Z = -\frac{z - A_P}{R} \quad (153)
\]

The ogive intersection point and unit normal computations are carried out by subroutine OGIVE which is listed in Appendix M.

2. Radome Surface Approximation

As an example of tracing a ray through a radome, consider a radome with an inner surface that can be approximated by a truncated cone fitted to an ogive at the base with the base of the ogive cut by a plane parallel to the x-y plane. The radome then consists of four regions: The top plane that truncates the cone, the cone, the ogive, and the bottom. A ray originating at a point interior to the radome must intersect the radome in one of these four sections.

Assume that the conical section of the radome is the largest section. Given the coordinates of the interior point and the wave number of the ray, calculate the point of intersection of the ray and the cone. If the point of intersection is within the region that the radome is approximated by the cone, the point of intersection of the ray and the radome has been found. However, if the intersection with the cone is too high or the cone, i.e., the z component of the point of intersection is too large, then the intersection of the ray and the top plate must be calculated. This will be the intersection of the ray and
the top plate must be calculated. This will be the intersection of the ray and the radome. If the intersection with the cone is too low or if no intersection exists, the next step is to calculate the intersection with the ogive. If the intersection is in the proper region, the point of intersection with the radome has been found. If the intersection with the ogive is too low, then the intersection of the ray with the bottom plate must be calculated. This will be the intersection of the ray with the radome.

Once the point of intersection has been calculated, the unit inward normal can be calculated using the formula appropriate for the shape which approximates the cone at the point of the intersection. The subroutine TRACE operates in this manner and is listed in Appendix G.

3. Transmission Through Multilayered Walls

A plane wave having direction of propagation \( \hat{K} \) is represented as a ray emanating from the point of interest \((x_A, y_A, 0)\). The intersection of this ray with the inside surface of the radome is determined. But more importantly, the unit normal \( \hat{n} \) to the inside surface of the radome at the point of intersection is computed and used to determine the weighting coefficients for that plane wave in the manner explained below.

Let the elementary plane wave have direction of propagation \( \hat{K} \) given by

\[
\hat{K} = \hat{x}_A x_A + \hat{y}_A y_A + \hat{z}_A z_A
\]

(154)
where \(|\hat{\mathbf{K}}| = 1\). Specification of \(K_xA, K_yA\) also specifies completely the plane wave; viz.,

\[ e = \hat{x}_A x_{pw}(K_xA, K_yA) + \hat{y}_A y_{pw}(K_xA, K_yA) \]

\[ + \hat{z}_A \left( \frac{K_xA x_{pw} + K_yA y_{pw}}{-K_z} \right) \]  

(155)

where \(x_{pw}, y_{pw}\) are obtained initially from \(E_xA, E_yA\), respectively, on the aperture plane. It is noted that \(e\) is perpendicular to \(\hat{\mathbf{K}}\) and that \(e_{ZA}\) (the \(Z_A\)-component of the electric field) is linearly dependent on the tangential components \(e_{xA}, e_{yA}\). The phase factor \(e^{-jk \cdot \hat{K} \cdot \Sigma}\) has been omitted from Equation (155) for reasons that will become clear.

Let the unit normal \(\hat{n}\) to the inside surface of the radome wall be given (in aperture coordinates) by

\[ \hat{n} = \hat{x}_A n_xA + \hat{y}_A n_yA + \hat{z}_A n_ZA \]  

(156)

where \(|\hat{n}| = 1\). Then the unit vectors \(\hat{n}, \hat{k}\) define the plane of incidence of the plane wave impinging on the radome wall. Since the flat panel transmission coefficients are generally different for components of \(e\) parallel and perpendicular to this plane of incidence, it is necessary to resolve \(e\) into such components. A unit vector \(\hat{k}_\perp\) perpendicular to the plane of incidence is that given by

\[ \hat{k}_\perp = \frac{\hat{k} \times \hat{n}}{|\hat{k} \times \hat{n}|} \]  

(157)
where "x" denotes vector cross product and "| |" denotes magnitude. The angle of incidence \( \theta_i \) is the acute angle between \( \mathbf{k} \) and \( \mathbf{n} \) and is given by the relation

\[
\sin \theta_i = |\mathbf{k} \times \mathbf{n}|. \tag{158}
\]

The component of \( \mathbf{e} \) that is perpendicular to the plane of incidence is given by

\[
e_{\perp} = \hat{\mathbf{k}}_\perp (\mathbf{e} \cdot \hat{\mathbf{k}}_\perp) \tag{159}
\]

where "\( \cdot \)" denotes vector dot product. The component of \( \mathbf{e} \) that is parallel to the plane of incidence is given by

\[
e_{\parallel} = \mathbf{e} - e_{\perp}. \tag{160}
\]

Equations (6) and (7) may be rewritten as follows to show explicitly the components of \( e_{\perp}, e_{\parallel} \) in the aperture coordinate system:

\[
e_{\perp} = x_A e_{\perp}^{xA} + y_A e_{\perp}^{yA} + z_A e_{\perp}^{zA} \tag{161}
\]

\[
e_{\parallel} = x_A e_{\parallel}^{xA} + y_A e_{\parallel}^{yA} + z_A e_{\parallel}^{zA}. \tag{162}
\]

The \( x_A \)-component of \( e_{\perp} \) is given by

\[
e_{\perp}^{xA} = (e \cdot \hat{k}_{\perp}) \hat{k}_{\perp}^{xA} \tag{163}
\]
and the $x_A$-component of $e_\parallel$ is given by

$$e_\parallel x_A = e_{x_A} - e_{x_A}'.$$

Similar relations hold for the $y_A$-components; the $z_A$-components are of no interest here.

Let $e'$ denote the electric field of the elementary plane wave after traversing the radome wall. The direction of propagation of this transmitted plane wave will be the same as that of the incident plane wave $e$. At any point along the ray on the outside of the radome, the $x_A$- and $y_A$-components of $e'$ are given by

$$e'_x = e_{x||A^T_1||} + e_{x\perp A^T_1||},$$

$$e'_y = e_{y||A^T_1||} + e_{y\perp A^T_1||}$$

where $T_{||1}$, $T_{\perp1}$ are the (complex) "insertion" voltage transmission coefficients of the radome wall as defined and derived in the following section. As will be seen, for a fixed radome wall configuration and operating frequency, the transmission coefficients are functions only of the angle of incidence $\theta_1$, or equivalently, $\sin\theta_1$.

The special case of normal incidence ($\theta_1=0$) requires special consideration in calculating $e'$. For the types of radome walls considered in the next section, the transmission coefficients are equal at normal incidence. Also, at normal incidence, the plane of incidence is arbitrary so that the tangential components of $e'$ are given simply by
As was mentioned above after Equation (2), no phase factor has been included in the above expressions other than that introduced by the transmission coefficients themselves. The reason for this omission is that \( e'_{xA} \) and \( e'_{yA} \) are themselves referred back to the point of interest \((x_A',y_A',0)\) on the aperture plane in the approach taken in the radome analysis. The total tangential electric field at \((x_A',y_A',0)\) with the radome in place is then the summation of the contributions \( e'_{xA} \) and \( e'_{yA} \) of the elementary plane waves considered; i.e.,

\[
E'_{xA}(x_A',y_A',0) = \sum_{kxA} \sum_{kyA} e'_{xA}
\]

\[
E'_{yA}(x_A',y_A',0) = \sum_{kxA} \sum_{kyA} e'_{yA}.
\]

These computations are carried out in subroutine TRANS which is an entry of subroutine WALL, which is listed in Appendix F.

In what follows, the perpendicular and parallel transmission and reflection coefficients are derived for a radome wall consisting of a stack of homogeneous, isotropic, dielectric slabs of finite thickness immersed in free space. For the derivation, it is assumed that the slabs are plane and of infinite extent although it is known that in the actual radome wall they are curved and of finite extent. The use of the
the flat panel coefficients thus represents one approximation used in
the radome analysis itself.

The derivation below and the computer program implementation
listed in Appendix F are based on work done by Richmond at Ohio State
University. Although Richmond’s matrix formulation for the analysis
of plane multilayers has been previously documented [3], an outline of
the theory is repeated here to provide a convenient reference in
defining the quantities described in the computer program of Appendix F.

Consider a plane electromagnetic wave incident on the surface of
a stack of plane, homogeneous, dielectric slabs of finite thickness
and infinite width surrounded by free space as shown in Figure 7(a).
The wave illustrated has perpendicular polarization (electric field
intensity vector perpendicular to the plane of incidence) and the
symbols $E_i$ and $E_r$ represent the electric field intensities of the
incident and reflected waves at the "incident point," $P$, and $E_t$ repre-
sents the electric field intensity of the transmitted wave at the
"normal exit point," $Q$. The reflection coefficient $R$ and the "normal
transmission coefficient," $T_n$, of the multilayer are defined by

$$R = \frac{E_r(P)}{E_i(P)} \quad \text{(perpendicular polarization)} \quad (171)$$

and

$$T_n = \frac{E_t(Q)}{E_i(P)} \quad \text{(perpendicular polarization)} \quad (172)$$
Figure 7. Plane Electromagnetic Wave Incident on Plane Multilayer.
The "insertion transmission coefficient" $T$ is defined as follows

$$T = \frac{E_t(Q)}{E_i(Q)} \quad \text{(perpendicular polarization)} \quad \text{(172)}$$

$$= T e^{jk d \cos \theta}$$

where $d$ is the total multilayer thickness, $\theta$ is the angle of incidence measured from the normal, and $k$ is the free-space phase constant

$$\omega \sqrt{\mu \varepsilon} = \frac{2\pi}{\lambda}. $$

The resultant field in each layer consists of an outgoing wave and a reflected wave. In Figure 7(b) the complex constants $A_n$ and $C_n$ represent the electric field intensity $E_x$ of the outgoing wave in layer $n$, evaluated at its two boundaries, and $B_n$ and $D_n$ represent the reflected field intensity at the two boundaries.

The field intensity in layer $n$ can be written as

$$E_x = (ae^{\gamma_n z} + be^{\gamma_n z}) e^{-jk \sin \theta} \quad \text{(173)}$$

The propagation constant $\gamma_n$ is expressed in terms of the attenuation constant $\alpha_n$ and the phase constant $\beta_n$ as

$$\gamma_n = \alpha_n + j\beta_n \quad \text{(174)}$$

It is assumed that the permeability of each layer is real and the complex permittivity is expressed as
Using the wave equations and Equations (173), (174), and (175), it can be found that

\[ \alpha = \frac{k}{\sqrt{2}} \sqrt{\left(\mu\varepsilon' - \sin^2 \theta \right)^2 + \left(\mu\varepsilon' \tan \delta \right)^2 - \left(\mu\varepsilon' - \sin^2 \theta \right)^2} \]  

(176)

\[ \beta = \frac{k}{\sqrt{2}} \sqrt{\left(\mu\varepsilon' - \sin^2 \theta \right)^2 + \left(\mu\varepsilon' \tan \delta \right)^2 + \left(\mu\varepsilon' - \sin^2 \theta \right)^2} \]  

(177)

where \( \mu_r \) and \( \varepsilon'_r \) are the relative permeability and permittivity:

\[ \mu_r = \mu / \mu_0 \]  

(178)

and

\[ \varepsilon'_r = \varepsilon'/\varepsilon_0 \]  

(179)

Evaluating \( E_x \) in Equation (173) at the left and right boundaries of layer \( n \), it can be shown that

\[ A_n = C_n \gamma_n d_n \]  

(180)

and

\[ B_n = D_n \gamma_n d_n \]  

(181)

where \( d_n \) is the thickness of layer \( n \). Equations (180) and (181) can be expressed by the following matrix equation:
Let $t_{n+1,n}$ and $r_{n+1,n}$ denote the interface transmission and reflection coefficients for a wave in layer $n+1$ incident on the boundary of layer $n$. Further, let $t_{n,n+1}$ and $r_{n,n+1}$ represent the interface coefficients for a wave in layer $n$ on the boundary of layer $n+1$. In terms of these coefficients, the electric field intensities, evaluated at both sides of the boundary between layers $n$ and $n+1$, are related linearly as follows:

\[
\begin{bmatrix}
C_n \\
B_{n+1}
\end{bmatrix} = 
\begin{bmatrix}
-e^{-\gamma_n d_n} & 0 \\
0 & e^{\gamma_n d_n}
\end{bmatrix} \begin{bmatrix}
t_{n+1,n} \\
0
\end{bmatrix} + \begin{bmatrix}
t_{n,n+1} \\
0
\end{bmatrix} \begin{bmatrix}
r_{n,n+1} \\
r_{n+1,n}
\end{bmatrix}
\]

(182)

The relations follow from the superposition theorem and the definitions of the interface coefficients.

It can be shown that

\[
\begin{align*}
r_{n,n+1} &= -r_{n+1,n} \\
t_{n+1,n} &= 1 + r_{n+1,n} \\
t_{n,n+1} &= 1 + r_{n+1,n} \equiv 1 - r_{n+1,n}
\end{align*}
\]

(183) 
(184) 
(185) 
(186) 
(187)
and

\[ t_{n+1,n} = t_{n,n+1} - r_{n+1,n} t_{n,n+1} = 1 \]  \hspace{1cm} (188)

By using Equations (185) through (188), Equations (183) and (184) can be arranged as

\[ C_n = \left( A_{n+1} + r_{n,n+1} B_{n+1} \right) t_{n,n+1} / t_{n,n+1} \]  \hspace{1cm} (189)

and

\[ D_n = \left( B_{n+1} - r_{n+1,n} A_{n+1} \right) t_{n,n+1} / t_{n,n+1} \]  \hspace{1cm} (190)

These can be expressed in matrix form as

\[
\begin{pmatrix}
C_n \\
D_n
\end{pmatrix}
= \frac{1}{t_{n,n+1}}
\begin{pmatrix}
1 & -r_{n+1,n} \\
-r_{n+1,n} & 1
\end{pmatrix}
\begin{pmatrix}
A_{n+1} \\
B_{n+1}
\end{pmatrix}.
\]  \hspace{1cm} (191)

The matrix Equations (182) and (191) can be combined to obtain the following:

\[
\begin{pmatrix}
C_{n-1} \\
D_{n-1}
\end{pmatrix}
= \frac{1}{t_{n-1,n}}
\begin{pmatrix}
\gamma_{n,d} e & -r_{n,n-1} e \\
-r_{n,n-1} e & \gamma_{n,d} e
\end{pmatrix}
\begin{pmatrix}
C_n \\
D_n
\end{pmatrix}.
\]  \hspace{1cm} (192)

Let the two-by-two matrix in Equation (192) be denoted by \( M_n \).
Repeated application of Equation (193) yields the following matrix relationship between the electric field intensities at the incidence and exit surfaces:

\[
M_n = \begin{pmatrix}
-\gamma_{n+1} & \gamma_n \\
-r_{n+1,n} & e_n & -r_{n,n-1} & e_n \\
-r_{n,n-1} & e_n & -r_{n-1,n} & e_n \\
\end{pmatrix}
\]  

(193)

where the dots denote matrix multiplication, \(N\) represents the total number of layers, \(S\) denotes the matrix

\[
S = \begin{pmatrix}
1 & -r_{N+1,N} \\
-r_{N+1,N} & 1 \\
\end{pmatrix}
\]

(195)

and

\[
t = t_0, t_1, t_2, t_3, \ldots t_{N,N+1}.
\]

(196)

In the situation used to define the transmission and reflection coefficients of the structure, a wave of unit amplitude is assumed to
be incident on one outer surface, so that

\[ A_{N+1} = 1 \]  \hspace{1cm} (197)
\[ B_{N+1} = R \]  \hspace{1cm} (198)
\[ C_0 = T_n \]  \hspace{1cm} (199)
\[ D_0 = 0 \]  \hspace{1cm} (200)

and

Thus Equation (194) becomes

\[
\begin{pmatrix}
T_n \\
0
\end{pmatrix}
= \frac{1}{t} M_1 \cdot M_2 \cdot M_3 \ldots M_N \cdot S \cdot
\begin{pmatrix}
1 \\
R
\end{pmatrix}
\]  \hspace{1cm} (201)

The solution for "parallel polarization" (electric field intensity parallel to the plane of incidence) is obtained by applying the theorem of duality to the above solution. Thus, the reflection and transmission coefficients are defined by

\[ R = \frac{H_{\parallel}(P)}{H_{\perp}(P)} \]  \hspace{1cm} (202)

and

\[ T_n = \frac{H_{\perp}(Q)}{H_{\parallel}(P)} \]  \hspace{1cm} (203)
The matrix equations given above apply also for parallel polarization, in which case the complex constants $A_n$, $B_n$, $C_n$, and $D_n$ represent the amplitudes of the magnetic field intensities $H_x$ of the traveling waves in layer $n$. Equations (185) through (188) also apply for parallel polarization, in which case the interface reflection and transmission coefficients are defined by the ratio of the magnetic field intensities $H_x$. The interface reflection coefficients are given by

\[
    r_{n+1,n} = \frac{u_n \gamma_{n+1} - u_{n+1} \gamma_n}{u_n \gamma_{n+1} + u_{n+1} \gamma_n} \quad \text{(perpendicular polarization)} \quad (204)
\]

and

\[
    r_{n+1,n} = \frac{\varepsilon_n \gamma_{n+1} - \varepsilon_{n+1} \gamma_n}{\varepsilon_n \gamma_{n+1} + \varepsilon_{n+1} \gamma_n} \quad \text{(parallel polarization)} \quad (205)
\]

where $\gamma$ is given by Equations (174), (176), and (177) if the permeability $\mu$ of each layer is real.

After the indicated matrix multiplications of Equation (44) are performed, and the division by $t$, the equation has the form

\[
    \begin{pmatrix}
        T_n \\
        0
    \end{pmatrix}
    \begin{pmatrix}
        a & b \\
        c & e
    \end{pmatrix}
    \begin{pmatrix}
        1 \\
        R
    \end{pmatrix}
    = -\frac{bc}{e} \quad (206)
\]

Thus,

\[
    T_n = a + bR = a - \frac{bc}{e} \quad (207)
\]

and

\[
    R = -\frac{c}{e} \quad (208)
\]
E. Internal Radome Reflection

Up to this point only the calculation of the transmitted field has been discussed. The reflected field is also of importance as it generates a VSWR in the feed system of the radome enclosed antenna. The reflected field is calculated using many of the same equations used in the calculation of the transmitted field.

A slightly different approach is used, however, in the calculation of the reflected field. The reflected field at each aperture point is calculated as a summation of rays, which were reflected from the inner surface of the radome and originated from the aperture plane. The directions of the rays approaching the aperture point from the inner surface intersection of the radome are the negative of the directions used in the transmitting case. The rays are first traced backwards from the aperture point of interest to the inner wall of the radome and from there possibly back to the aperture plane, depending on the angle of reflection at the radome wall. If the ray does indeed again intersect the aperture plane it will contribute to the reflected field. Subroutine PLANE is used to calculate the intersection of the ray with the aperture plane and is given in Appendix R.

The complex vector amplitude of the ray is determined by an interpolation of the transmitting PWS in the direction of the intersecting ray. The interpolation is calculated using a simple two dimensional quadratic approximation to the spectrum in the neighborhood of the interpolation point. The interpolation is carried out in subroutine INTPRO which is listed in Appendix S. Now proceeding in a transmitting sense, the ray is traced to the inner surface of the radome.
wall where the x, y and z components of the ray are used to calculate the perpendicular and parallel components of the ray. The calculation of the perpendicular and parallel components also requires the direction of propagation of the incident ray and the inward normal to the wall be known. All of these computations are performed as in the transmitting case. The perpendicular and parallel components are then weighted by the reflection coefficients of the wall from the table of reflection coefficients generated in subroutine WALL. The direction of the reflected ray is calculated using Snell's Law and is independent of the composition of the wall. The vector equation for Snell's Law may be written

\[
\hat{k}_r = \hat{k}_i - 2(\hat{k}_i \cdot \hat{N})\hat{N}
\]  

(209)

where \( \hat{k}_r \) is the reflected wavenumber direction triplet

\( \hat{k}_i \) is the incident wavenumber direction triplet

\( \hat{N} \) is the inward unit normal wavenumber triplet.

\( \hat{k}_r \) is determined from the above equation in subroutine SNELL which is listed in Appendix P. The x and y components of the reflected ray are determined from the reflected perpendicular and parallel components of the incident ray. The reflected ray is traced to the point of interest in the aperture plane and the amplitude of the ray is added to the existing value of the reflected field at that point. In this manner rays from all possible directions are summed to form a reflected aperture field. The path of each reflected ray may be fully described by
three points. The point of origination of the ray, the point of reflection at the inner radome surface, and the point of intersection with the aperture plane are known and are used to determine the path and thus the phase shift of the complex amplitude of the ray due to propagation of the ray in the inner space of the radome. The entire ray tracing procedure for the calculation of the equivalent transmitting aperture field and for the reflected aperture field is carried out in subroutine RADOME which is listed in Appendix E. The last calculation in subroutine RADOME is the determination of the PWS's of these two aperture fields. The PWS's are calculated by performing a FFT on the two fields as discussed earlier.

F. Far-Field Parameters

To determine the effect of a radome on the performance of a radome enclosed antenna system, it must be possible to determine antenna performance parameters. In this section four important performance parameters of the transmitted far field pattern of an antenna system are calculated. The determination of errors in these parameters due to radome insertion is then made by comparing the parameters calculated from the far-field patterns of the antenna without a radome in place to the far-field patterns of the same antenna with a radome in place. The four performance parameters determined are: (1) boresight direction; that is, the direction in which the average power appears to be directed; (2) the maximum side lobe level, the amplitude of the greatest sidelobe with respect to the peak of the main beam; (3) the transmitted power: the power contained in the far-field pattern, and
the RMS distortion of the pattern, a measure of the overall difference between the far-field of the antenna with and without the radome in place.

1. Boresight Direction

The boresight direction of a pattern is here defined as the first moment of the two dimensional power distribution. The first moments in the Kx and Ky direction are given by:

\[
\overline{K_x} = \int_{-K_0}^{K_0} \int_{-\sqrt{K_0^2 - K_x^2}}^{\sqrt{K_0^2 - K_x^2}} P_{FF}(R, K_x, K_y) \frac{R^2 dK_x dK_y}{K_0^2 \cos \theta}
\]

\[
\overline{K_y} = \int_{-K_0}^{K_0} \int_{-\sqrt{K_0^2 - K_y^2}}^{\sqrt{K_0^2 - K_y^2}} P_{FF}(R, K_x, K_y) \frac{R^2 dK_x dK_y}{K_0^2 \cos \theta}
\]

where \( \frac{R^2 dK_x dK_y}{K_0^2 \cos \theta} \) is the incremental area factor. Subroutine BRSITE carries out the computations and is listed in Appendix U.

2. Sidelobe Level

The level of the maximum sidelobe with respect to the peak of the main beam is determined by searching the two dimension array containing the far-field power values. The maximum local maximum in the array corresponds to the peak of the main beam, the second largest local maximum of the far-field pattern is the maximum side lobe level. The wavenumber coordinates \((K_x, K_y)\) of the maximum sidelobe is then determined from the indices \((I, J)\) of the array location containing the maximum
sidelobe level. The equation which relates the array indices to the wavenumber direction is as follows:

\[
K_x = 2K_{x_{\text{max}}} \frac{(1-(N_x/2+1))}{N_x} \quad (212)
\]

\[
K_y = 2K_{y_{\text{max}}} \frac{(1-(N_y/2+1))}{N_y} \quad (213)
\]

where \((N_x, N_y)\) are the dimensions of the array

\((K_{x_{\text{max}}}, K_{y_{\text{max}}})\) are the maximum wavenumber coordinates of the array.

Subroutine SDLOBE carries out this search and conversion procedure and is listed in Appendix V.

3. Transmitted Power

The power contained above a specified dB level of the far-field pattern is summed to find the total transmitted power. If the specified dB level is very low (i.e. -100 dB), then virtually all of the far-field pattern is used in the computation. If the dB level is set at say -10 dB, then only the power in the main beam will be calculated.

The equation for the power of a far-field pattern is:

\[
PWR = \int_{-K_0}^{K_0} \int_{-\sqrt{K_0^2-Kx^2}}^{\sqrt{K_0^2-Kx^2}} P_{FF}(R,Kx,Ky) \frac{R^2 dKx dKy}{K_0^2 \cos \theta} \quad (214)
\]

where \(P_{FF}(R,Kx,Ky)\) is the far-field power pattern.

Subroutine BRSITE, which is used to calculate the boresight direction discussed earlier, also calculates the transmitted power and is listed in Appendix U.
4. Pattern Plotting

Far-field patterns may be plotted using a CAL COMP plotter in three ways. First a two dimensional graph (three dimensional plot) may be drawn of the far-field power pattern. The power is plotted in decibels from zero dB to some specified minimum value (usually -40 dB) and is plotted in wavenumber coordinates. The center point in the graph is the wavenumber coordinate \((K_x, K_y) = (0,0)\) which is the direction normal to the aperture plane. Figure 8 is an example of such a plot of a "CSC\(^2\)" pattern. Subroutine PLOT3D which performs this type of plotting is listed in Appendix Y.

A second far-field plot is a contour plot of the far-field power pattern as it appears on the ground. Figure 9 is a contour pattern of the pattern in Figure 8. The user may specify how many contours are to be drawn and the value of each contour in decibels. The center point of the contour plot is the ground intersection of the ray leaving the origin of the aperture plane and traveling normal to the aperture plane. This point is marked with a + on the plot. Figure 10 shows the ground coordinating system \(x''\) and \(y''\) with respect to the aperture. From a previous equation for the distance from the origin of the aperture plane to the flat ground we see that the vector \(\hat{r}\) may be written as a function of \(K_x\) and \(K_y\), where the ALTITUDE, \(\theta_A\) and \(\phi_A\) are considered fixed constants. It is noted that \(K_z\) is not independent of \(K_x\) and \(K_y\) for

\[
K_z = \sqrt{\omega^2 - K_x^2 - K_y^2}
\]

To calculate the ground coordinates of the vector \(\hat{r}(K_x,K_y)\) the orthogonal projection of the vector \(\hat{r}(K_x,K_y) - \hat{r}(0,0)\) onto \(\hat{n}\) are found as follows:
Figure 8. Two Dimensional Graph of Far Field Pattern.
Figure 9. Contour Plot of Far Field Pattern.
Figure 10. Ground Coordinate System.
The x" and y" components of the ground vector may then be found as the projection of \( \hat{V}_g \) onto \( \hat{x}'' \) and \( \hat{y}'' \), respectively, as follows:

\[
x'' = \hat{V}_g \cdot \hat{x}''
\]

\[
y'' = \hat{V}_g \cdot \hat{y}''
\]
Subroutine SAPLOT carries out this type of plotting as well as plotting a replica of a standard far-field plotting graph paper. SAPLOT is listed in Appendix AA.

Each of the three plotting options plots the far-field in decibels, from a maximum of zero dB to a minimum of -40 dB. The conversion from linear power to dB is accomplished by SUBROUTINE DB, which is listed in Appendix X.

G. Radome Produced Errors

Five errors that result from insertion of a radome between the antenna and the ground are calculated. These are boresight error in milliradians, power loss in decibels, level of maximum sidelobe level change in dB, pattern distortion in percentage of total power, and the VSWR in the feed system of the antenna.

Boresight error is determined by calculating the boresight direction of the far-field patterns of the antenna with and without the radome present and calculating the angle between the two boresight directions. The boresight directions of the far-field power patterns of the antenna with and without the radome in place are respectively \((Kxw, Kyw)\) and \((Kxwo, Kywo)\). The \(Kzw\) and \(Kzwo\) wavenumbers are then:

\[
Kzw = \sqrt{K^2 - Kxw^2 - Kyw^2} \tag{220}
\]

\[
Kzwo = \sqrt{K^2 - Kxwo^2 - Kywo^2} \tag{221}
\]
The angle between these two directions is then calculated in milli-
radians as follows:

\[ A_{\text{error}} = 1000 \ \text{ARCSIN} \left( \frac{(Kxw-Kxwo)^2 + (Kyw-Kywo)^2 + (Kzw-Kzwo)^2}{2Ko^2} \right) \] (222)

An option of this calculation allows the use of only those far-field
values which are greater than a specified decibel level from the peak
of the pattern in the moment calculations. This option is useful when
determining the boresight direction of the main beam exclusive of lower
sidelobe regions.

Power loss due to radome insertion is determined by summing up
all the power in the far-field pattern of the antenna without the radome
in place and subtracting the total far-field power of the antenna with
radome in place. The loss calculation also incorporates the option of
neglecting all power less than a specified relative decibel level such
that power loss from the main beam may also be determined.

The maximum sidelobe level change is determined by subtracting
the maximum sidelobe levels of the two far-field patterns.

The distortion of the pattern is calculated as the RMS difference
of the two patterns. This total RMS difference power is then divided
by the total power of the pattern without radome to express the distor-
tion as a percentile.

The VSWR is determined from the power returned to the antenna
from internal radome reflections. The plane wave spectrum of the
reflected field is determined using the mathematical method described
earlier. It is assumed that without the radome no reflected power would enter the antenna and thus the VSWR in the feed system would be zero due to reflections from outside the antenna. The equation relating reflected power and VSWR is given as:

\[ VSWR = \sqrt{\frac{P_t + P_r}{P_t - P_r}} \]  

(223)

where \( P_t \) is the power transmitted from the antenna

\( P_r \) is the power received by the antenna due to internal radome reflections.

To calculate the transmitted and received powers, let

\[ p_{w t}(Kx,Ky) = \hat{x} x_{p w t}(Kx,Ky) + \hat{y} y_{p w t}(Kx,Ky) + \hat{z} z_{p w t}(Kx,Ky) \]  

(224)

be the complex vector amplitudes of the plane waves of the plane wave spectrum of the transmitted field and let

\[ p_{w r}(Kx,Ky) = \hat{x} x_{p w r}(Kx,Ky) + \hat{y} y_{p w r}(Kx,Ky) + \hat{z} z_{p w r}(Kx,Ky) \]  

(225)

be the complex, vector amplitudes of the plane waves of the plane wave spectrum of the received field. The transmitted plane wave spectrum was determined from the equivalent aperture field and the reflected plane wave spectrum was determined from the reflected field as discussed earlier. The transmitted power can be determined as a summation of the powers in the individual plane waves as:
\[ P_t = \sum_{K_x, K_y} \left| \hat{p}_{\text{tr}}(K_x, K_y) \right|^2 / n \] (226)

where \( n \) is the intrinsic impedance of free space.

The received power can be determined by the dot product of the transmitting spectrum and the spectrum of the incoming reflections, normalized by the total power of the transmitting spectrum as:

\[ P_r = \frac{1}{\eta P_t} \left| \sum_{K_x, K_y} \hat{p}_{\text{tr}}(K_x, K_y) \cdot \hat{p}_{\text{tr}}(K_x, K_y) \right|^2 \] (227)

Subroutine ERRORS listed in Appendix W calculates these errors and prints the results in tabular form.
APPENDIX A

MAIN PROGRAM

1. Purpose

This computer program computes the effect of a radome on the boresight direction, power contained in the far field pattern, sidelobe level, far field pattern shape, and VSWR of a radome enclosed antenna.

2. Program flow

a. Initialize input variables:
   Frequency in gigahertz: FGHZ
   Wavelength in centimeters: LAMBDA
   Location of antenna coordinate system origin: RA, PHIA, THETA
   Altitude vector in antenna coordinates: ALT, THETA, PHI
   Angle between z axes of two coordinate systems: AGAM3A
   Normalized wavenumber limits: KXMAX and KYMAX
   Far Field power pattern control: IPWR
   Sidelobe selector: TSID
   Far field surface selector: IS
   Number of points used in sidelobe search: NPTS
   Decibel level used in boresight and total power calculation: DBCTR

b. Calculate x component of plane wave spectrum: CALL PWS()
c. Calculate y component of plane wave spectrum: CALL PWS()
d. Calculate far field power pattern of antenna without radome: CALL FAR()
e. Calculate boresight direction and total power of antenna without radome: CALL BRSITE()
f. Calculate sidelobe level of antenna without radome: CALL SDLOBE()
g. Calculate plane wave spectrum of antenna after radome insertion and calculate plane wave spectrum of reflected field: CALL RADOME()
h. Calculate far field power pattern of antenna with radome: CALL FAR()
i. Calculate boresight direction and total power of antenna with radome: CALL BRSITE()
j. Calculate sidelobe level of antenna with radome: CALL SDLOBE()
k. Calculate VSWR existing in feed system of antenna due to radome reflections: CALL VSWR()
l. Calculate boresight error, transmission loss, pattern distortion percentile, sidelobe changes, and print out the results, also print out the VSWR due to the radome: CALL ERRORS()
m. Convert the far field power pattern of antenna without radome form linear power to decibels: CALL DB()
n. Convert the far field pattern of the antenna with radome in place from linear power to decibels: CALL DB()
o. Plot a two dimensional graph of the entire far field pattern of the antenna without radome: CALL PLOT3D()
p. Plot a two dimensional graph of the entire far field pattern of the antenna with radome: CALL PLOT3D()

q. Plot a contour map of the far field pattern of the antenna without radome: CALL CNTOUR()

r. Plot a contour map of the far field pattern of the antenna with radome: CALL CNTOUR()

s. Plot a single slice of the far field pattern of the antenna without radome: CALL SAPLOT()

t. Plot a single slice of the far field pattern of the antenna with radome: CALL SAPLOT()

u. END

3. Comments

a. The electrical parameters of the radome wall may be changed in subroutine WALL which is called by subroutine RADOME. These parameters are: 1) number of layers, 2) thickness of each layer in centimeters, 3) relative dielectric constant of each layer, and 4) the loss tangent of each layer.

b. The geometry of the radome may be changed in subroutine TRACE which is called by subroutine RADOME. The radome must be symmetric about the z axis. Any such radome may be approximated by a composite of symmetric cones, parabolas, ogives, hemispheres and disks. The parameters of the individual cones, parabolas, ogives, hemispheres and disks may be changed in subroutines CONE, PARA, OGIVE, HEMI, TDISK, and BDISK respectively. These subroutines are called by subroutine TRACE.

c. The three types of plotting are not necessary to the operation of the radome analysis program and may be omitted.

d. Unless otherwise stated, distances are given in centimeters and angles are given in degrees.

4. Listing

See following page.
<table>
<thead>
<tr>
<th>Line</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00101</td>
<td>1* PARAMETER NX=16, NY=16, NVALS=5</td>
</tr>
<tr>
<td>00103</td>
<td>2* REAL KXMAX, KYMAX, LAMBDA</td>
</tr>
<tr>
<td>00104</td>
<td>3* COMPLEX XFIELD(NX, NY), YFIELD(NX, NY)</td>
</tr>
<tr>
<td>00105</td>
<td>4* REAL TFIELD(NX, NY), RFIELD(NX, NY)</td>
</tr>
<tr>
<td>00106</td>
<td>5* REAL ROTATE(3), TRANSL(3)</td>
</tr>
<tr>
<td>00107</td>
<td>6* DIMENSION VALUES(NVALS)</td>
</tr>
<tr>
<td>00110</td>
<td>7* INTEGER IBJF(10000)</td>
</tr>
<tr>
<td>00111</td>
<td>8* COMPLEX P(NX, NY), Q(NX, NY), PR(NX, NY), QR(NX, NY)</td>
</tr>
<tr>
<td>00112</td>
<td>9* DATA VALUES/-1, -3, -5, -10, -20/</td>
</tr>
<tr>
<td>00114</td>
<td>10* CALL PLOTS(IBJF, 10000, 3)</td>
</tr>
<tr>
<td>00115</td>
<td>11* FGHZ=16.5</td>
</tr>
<tr>
<td>00116</td>
<td>12* FREQ=FGHZ*1E9</td>
</tr>
<tr>
<td>00117</td>
<td>13* LAMBDA=0.299725/FGHZ</td>
</tr>
<tr>
<td>00120</td>
<td>14* ISD=1</td>
</tr>
<tr>
<td>Line</td>
<td>Value</td>
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<td>00138</td>
<td>32*</td>
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</tbody>
</table>
CALL PnS(P,NX,NY,KXMAX,KYMAX,1)
CALL PnS(P,NX,NY,KXMAX,KYMAX,2)
CALL FAC(TFIELD,P,NX,NY,LAMBDAX,KXMAX,KYMAX,ALT,THETA,PHI)
CALL 3761 .1E(TFIEL3,F4X,NY,KXMAX,KYMAX,TMOCTR,TFMX,1DIV)
CALL 3Q3E(TFIELD,NX,NY,NPT5,TKX5L,TKYSL,TD5LSL,KXMAX,KYMAX,ISD)
CALL D53E(RA,FIELD,YFIELD,PR,QR,NX,NY,KXMAX,KYMAX,FREQ,}
$ ROTATE,TRANSL)
CALL FAR(RFIELD,XFIELD,YFIELD,NX,NY,LAMBDAX,KXMAX,KYMAX,ALT,
$ THETA,PHI,IS,RFML,IPWR)
CALL BRSITE(RFIELD),NX,NY,KXMAX,KYMAX,JACTR,RFMX,IDIV,
CALL RTPWR,RXBS,RKYBS,THETA,PHI,ALT
CALL SDLOC(RFIELD),NX,NY,NPTS,RKXSL,RKYSL,RDBSL,KXMAX,KYMAX,ISD
CALL VSXR(P,PX,RY,NX,NY,KXMAX,KYMAX,SWR)
CALL ERRORS(TFIELD),RFIELD,NX,NY,TKXRS,TKYBS,RXBS,RKYBS,
CALL CLST(RMBSL,ROSL,TKXSL,TKYSL,RKXSL,RKYSL,ROXSL,RKYSL,SWR,SWR)
CALL B(MCT),NX,NY)
CALL D3(RFIELD),NX,NY)
CALL FACTOR(.4)
CALL PLOT3D(3,5,TFIELD,NX,NY,TRUE)
CALL PLOT3D(3,5,TFIELD,NX,NY,TRUE)
CALL SAPLOT(TFIELD,NX,NY,KXMAX,KYMAX,-30.0,30.0,0.0,0.0,60,501)
CALL SAPLOT(TFIELD,NX,NY,KXMAX,KYMAX,-30.0,30.0,0.0,0.0,60,501)
END OF COMPILATION: NO DIAGNOSTICS.
APPENDIX B

SUBROUTINE PWS

1. Purpose

This subroutine computes the x or y component of a two dimensional plane wave spectrum for a general class of "csc^2" antenna far field patterns.

2. Call

CALL PWS(FIELD, NX, NY, KXMAX, KYMAX, IXY)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIELD</td>
<td>complex array, output</td>
</tr>
<tr>
<td>NX</td>
<td>FORTRAN integer, input</td>
</tr>
<tr>
<td>NY</td>
<td>FORTRAN integer, input</td>
</tr>
<tr>
<td>KXMAX</td>
<td>floating-point variable, input</td>
</tr>
<tr>
<td>KYMAX</td>
<td>floating-point variable, input</td>
</tr>
<tr>
<td>IXY</td>
<td>FORTRAN integer, input</td>
</tr>
</tbody>
</table>

3. Comments

a. IXY must be equal to 1 or 2.

b. KXMAX and KYMAX are normalized wavenumbers with values between -1 and 1. Values for FIELD which correspond to \( Kx^2 + Ky^2 \geq 1 \) are set equal to zero.

c. A DATA statement within PWS is used to change the assumed polarization constant relating Theta and Phi components of the "csc^2" far field pattern.

d. A DATA statement within PWS is used to change the parameters of the general "csc^2" far field pattern.

4. Listing

See following page.
SUBROUTINE POS(FIELD, NX, NY, KXMAX, KYMAX, IXY)

COMPLEX FIELD(NX, NY), R
REAL KX, KY, KZ, KXMAX, KYMAX, JO
R=CMPLX(0, 0, 0, 0)

IF(Ixy, NE, 1) GO TO 2
DO 1 IXY = 1, NX
    KX=(-1, +2, *(IKX-1)/NX)*KXMAX
    DO 1 IXY = 1, NY
    KY=(-1, +2, *(IKY-1)/NY)*KYMAX
    FIELD(IKX, IKY)=CMPLX(0, 0)
        KZ=1-KX**2-KY**2
    IF(KZ.LE.0, 0) GO TO 1
    KZ=SORT(KZ)
    A=SORT(KX**2+KZ**2)
    FIELD(IKX, IKY)=SPCTR(KX, KY, KZ)*(KY*KX+R*KZ)/A

1 CONTINUE
2 CONTINUE
IF(IXY, NE, 2) RETURN
DO 3 IXY = 1, NX
    KX=(-1, +2, *(IKX-1)/NX)*KXMAX
    DO 3 IXY = 1, NY
    KY=(-1, +2, *(IKY-1)/NY)*KYMAX
    FIELD(IKX, IKY)=CMPLX(0, 0)
        KZ=1-KX**2-KY**2
    IF(KZ.LE.0, 0) GO TO 3
    KZ=SORT(KZ)
    A=SORT(KX**2+KZ**2)
    FIELD(IKX, IKY)=SPCTR(KX, KY, KZ)*A

3 CONTINUE
RETURN
FUNCTION SPCTR(KX,KY,KZ)  
REAL KZ,KX,KY  
DATA BETA0/.47/BETA2/.925/PHI0/.262/THETA0/.115/  
BETA=ACOS(KX)  
BETA=BETA1+(BETAO+RETA2)/2-1.57079633  
THETA=ATAN2(KX,KZ)  
IF(BETA.LT.BETA0) GO TO 3  
IF(BETA.GT.BETA2) GO TO 4  
SPCTR=J0(2.26*THETA/THETA0)*SIN(BETA0)*COS(BETA)**0.25/  
SIN(BETA)/COS(BETA)**0.25/KZ  
RETURN  
3 SPCTR=J0(2.26*(BETAO-BETA)/PHI0)*J0(2.26*THETA/THETA0)/KZ  
RETURN  
4 SPCTR=J0(2.26*(BETA-BETA2)/PHI0)*J0(2.26*THETA/THETA0)*SIN(BETA0)  
*COS(BETA2)**0.25/SIN(BETA2)/COS(BETA0)**0.25/KZ  
RETURN  
FUNCTION J0(X)  
THIS FUNCTION CALCULATES THE BESSEL FUNCTION OF THE FIRST  
ORDER ZERO FOR THE VALUE X.  
The polynomial approximations used were taken from the  
'Handbook of Mathematical Functions' (1970) by the  
U.S, Department of Commerce, page 369.  
PX=ABS(X)  
PX1=PX/3  
IF(PX.GT.3.0) PX2=3/PX  
IF(PX.GT.3.0) GO TO 5  
J0=1.0+.2499997*PX1**2+.12656208*PX1**4-0.3163866*PX1**6  
-.0044479*PX1**8-.003944*PX1**10+0.0002100*PX1**12  
RETURN  
5 J0=0.79788456-.00000077*PX2-.00552740*PX2**2-.0009512*PX2**3  
-.00137237*PX2**4-.00072805*PX2**5+0.00014476*PX2**6  
RETURN  
MAGNITUDE OF ERROR < 5.0E-08.  
MAGNITUDE OF ERROR < 1.6E-08.
T0=PX-0.78539816-0.04166397*PX2-0.0003954*PX2**2
- +0.00262573*PX2**3-0.00054125*PX2**4-0.0029333*PX2**5
- +0.0013558*PX2**6

MAGNITUDE OF ERROR < 7.0E-08.

J0=F0*COS(T0)/SQRT(PX)

RETURN

END OF COMPIILATION: NO DIAGNOSTICS.
# APPENDIX C

## SUBROUTINE FAR

### 1. Purpose

This subroutine computes the far field power pattern associated with the x and y components of a plane wave spectrum. The far field power pattern may be calculated on a far field sphere or on a far field planar surface.

### 2. Call

CALL FAR (FIELD, XFIELD, YFIELD, NX, NY, LAMBDA, KXMAX, KYMAX, ALT, THETA, PHI, IS, FMAX, IPWR)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIELD</td>
<td>a two dimension array containing the far field power pattern</td>
</tr>
<tr>
<td>XFIELD</td>
<td>a two dimensional array containing the x component of the plane wave spectrum</td>
</tr>
<tr>
<td>YFIELD</td>
<td>a two dimensional array containing the y component of the plane wave spectrum</td>
</tr>
<tr>
<td>NX</td>
<td>the number or rows in the arrays FIELD, XFIELD, YFIELD</td>
</tr>
<tr>
<td>NY</td>
<td>the number of columns in the arrays FIELD, XFIELD, YFIELD</td>
</tr>
<tr>
<td>LAMBDA</td>
<td>the wavelength of the field in meters</td>
</tr>
<tr>
<td>KXMAX</td>
<td>the range of Kx wavenumbers is from $-KXMAX$ to $(1-2/NX)KXMAX$</td>
</tr>
<tr>
<td>KYMAX</td>
<td>the range of Ky wavenumbers is from $-KYMAX$ to $(1-2/NY)KYMAX$</td>
</tr>
<tr>
<td>ALT</td>
<td>the altitude in meters of the origin of the near field coordinate system from the far field planar surface</td>
</tr>
<tr>
<td>THETA</td>
<td>the theta direction of the altitude vector in the near field coordinate system</td>
</tr>
<tr>
<td>PHI</td>
<td>the phi direction of the altitude vector in the near field coordinate system</td>
</tr>
</tbody>
</table>
IS

a control variable which specifies which far field surface is used in the far field computations

= 1  the planar surface is used
= 2  the spherical surface is used

FMAX

the maximum value of the far field power pattern

FORTRAN integer, input

IPWR

a control variable which specifies what power pattern will be calculated

= 1  the power in the elevation component of the far field
= 2  the power in the azimuth component of the far field
= 3  the total power in the far field

FORTRAN integer, input

3. Comments
   a. If FMAX is greater than zero on input, a new FMAX is not calculated.
   b. All values of FIELD are divided by FMAX.
   c. If IS = 2, the radius of the sphere is ALT.
   d. IS must equal to 1 or 2.
   e. If IPWR is not equal to 1, 2, or 3 it will be set equal to 3.

4. Listing
   See next page.
SUBROUTINE FAR(FIELD, XFIELD, YFIELD, NX, NY, LAMBDA, KMAX, KYMAX, ALT, THETA, PHI, IS, FMAX, IPWR)

FIELD IS A TWO DIMENSIONAL ARRAY. ON OUTPUT IT CONTAINS THE FAR FIELD OF THE INPUT X AND Y COMPONENTS OF AN APERTURE FIELD.
FIELD HAS DIMENSIONS NX BY NY.

XFIELD AND YFIELD ARE TWO DIMENSIONAL COMPLEX ARRAYS WHICH CONTAIN RESPECTIVELY THE X AND Y COMPONENTS OF A PLANE WAVE SPECTRUM. XFIELD AND YFIELD HAVE DIMENSION NX BY NY.

LAMBDA IS THE WAVELENGTH OF THE APERTURE FIELD IN METERS. KMAX AND KYMAX ARE RESPECTIVELY THE MAXIMUM ABSOLUTE VALUES OF KX AND KY WAVENUMBERS FOR WHICH THE FAR FIELD IS CALCULATED. KMAX AND KYMAX ARE NORMALIZED SUCH THAT KXMAX=1.0 AND KYMAX=1.0 CORRESPOND TO THE VISIBLE REGION OF WAVENUMBER SPACE.

ALT IS THE ALTITUDE OF THE ORIGIN OF THE APERTURE FIELD COORDINATE SYSTEM IN METERS.

THETA AND PHI SPECIFY THE DIRECTION FROM THE NORMAL OF THE APERTURE PLANE TO THE GROUND AND HAVE UNITS OF DEGREES. (SEE REPORT FOR APERTURE-GROUND COORDINATE SYSTEM).

IS SPECIFIES THE SURFACE OVER WHICH THE FAR FIELD WILL BE CALCULATED, FOR IS=1 THE SURFACE IS A PLANE NORMAL TO THE LINE SPECIFIED BY THETA AND PHI, LOCATED ALT METERS AWAY, FOR IS=2 THE SURFACE IS A SPHERE OR RADIUS ALT METERS.

FMAX IS AN INPUT-OUTPUT VARIABLE. IF FMAX IS LESS THAN OR EQUAL TO ZERO ON INPUT, THE FIELD ARRAY IS NORMALIZED FROM ZERO TO ONE AND FMAX IS THE NORMALIZING FACTOR. IF FMAX IS GREATER THAN ZERO ON INPUT IT REMAINS UNCHANGED AND IS USED AS THE NORMALIZING FACTOR.
IPWR determines which power component will be used in the far field calculations. IPWR=1 for elevation components, IPWR=2 for azimuth components, and IPWR=3 for total power. This subroutine calls the FFT subroutine.

```
REAL FIELD(NX, NY)
COMPLEX XFIELD(NX, NY), YFIELD(NX, NY), QC, EZ, EX, EY
IF(IPWR.EQ.1 .OR. IPWR.EQ.2 .OR. IPWR.EQ.3) GO TO 101
WRITE(*,100)
100 FORMAT(1X, 'VALUE ASSIGNED TO THE ARGUMENT IPWR IN SUBROUTINE -FAR IS NOT ALLOWED. IPWR=3 ASSUMED.')
IF(IPWR.EQ.3) GO TO 101

CONTINUE

REAL K, KX, KY, KZ, KXA, KYA, KZA, KXMAX, KYMAX, LAMBDA
PI = 3.141592653
K = 2.0*PI/LAMBDA
Q = (0.0, 1.0, 0.0)
NX2 = NX/2
NY2 = NY/2
IF(IS.EQ.1) GO TO 1
IF(IS.EQ.2) GO TO 2
GO TO 12

DO 4 I = 1, NX, 1
DO 4 J = 1, NY, 1
KX = (I-NX2-1.0)/NX2*KXMAX
KY = (J-NY2-1.0)/NY2*KYMAX
KZ = 1.0-KX**2-KY**2
D = SQRT(1.0-KZ**2)
IF(KZ.LT.0.0) GO TO 3
R = ALT/RD
RE = MOD(K*R, 2.0*PI)
C = Q*K*CEXP(-Q*RE)/R
```
E_z = (-K_x * X_FIELD(I, J) - K_y * Y_FIELD(I, J)) * C

E X = C * K_z * X_FIELD(I, J)

E Y = C * K_z * Y_FIELD(I, J)

IF(IPWR.EQ.1) FIELD(I, J) = CABS(-EX*K_Y*X/D + EY*D - EZ*K_Z*Y/D)**2

IF(IPWR.EQ.2) FIELD(I, J) = CABS(-EX*K_Z*D - EZ*K_X/D)

IF(IPWR.EQ.3) FIELD(I, J) = CABS(EX)**2 + CABS(EY)**2 + CABS(EZ)**2

GO TO 4

FIELD(I, J) = 0.

CONTINUE

GO TO 61

CALCULATE THE POWER PATTERN ON A SPHERE.

R = ALT

RE = AMOD(K*R, 2.0*PI)

C = K*K*EXP(-Q*RE)/R

DO 6 I = 1, NX, 1

DO 6 J = 1, NY, 1

KK = (I - NX2 - 1.0)/NX2*KMAX

KJ = (J - NY2 - 1.0)/NY2*KMAX

KZ = 1.0 - KK**2 - KY**2

IF(KZ .LT. 0.0) GO TO 5

KZ = SQRT(KZ)

E = 507(1, .. KY**2)

E*X = C*(K_Z*X_FIELD(I, J) + K_Y*Y_FIELD(I, J))

E = C*K_Z*X_FIELD(I, J)

FIELD(I, J) = CABS(-EX*K_Y*X/D + EY*D - EZ*K_Z*Y/D)**2

FIELD(I, J) = CABS(-EX*K_Z*D - EZ*K_X/D)

FIELD(I, J) = CABS(EX)**2 + CABS(EY)**2 + CABS(EZ)**2
GO TO 6
FIELD(I,J)=0.
6 CONTINUE
CONTINUE
C
NORMALIZE THE POWER PATTERN.
C
IF(FMAX.GT.0.0)  GO TO 9
DO 3 I=1,NX
DO 8 J=1,NY
R=FIELD(I,J)
IF(R.GT.FMAX) FMAX=R
8 CONTINUE
9 CONTINUE
DO 11 I=1,NX
DO 12 J=1,NY
FIELD(I,J)=FIELD(I,J)/FMAX
11 CONTINUE
12 CONTINUE
RETURN
END
END OF COMPILATION: NO DIAGNOSTICS.
APPENDIX D

SUBROUTINE ORIENT

1. Purpose

This subroutine computes the transformation matrices for coordinate transformations between the aperture coordinate system and the radome coordinate system. The inputs consist of the orientation parameters of the aperture and radome coordinate systems in the reference coordinate system.

2. Call

CALL ORIENT(RA, THETA, PHIA, RR, THETAR, PHIR, AGAM3A, ROTATE, TRANSL)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA, THETA, PHIA</td>
<td>real, input</td>
</tr>
<tr>
<td>RR, THETAR, PHIR</td>
<td>real, input</td>
</tr>
<tr>
<td>AGAM3A</td>
<td>real, input</td>
</tr>
<tr>
<td>ROTATE</td>
<td>real array, output</td>
</tr>
<tr>
<td>TRANSL</td>
<td>real array, output</td>
</tr>
</tbody>
</table>

3. Comments

a. Ordering of elements on ROTATE(I,J): I denotes row number, J denotes column number in the matrix [Rij].

b. Ordering of elements in TRANSL(I): I denotes row number in the column vector [T]; there is only one column in [T]

c. No supporting subroutines are required.

4. Listing

See following page.
SUBROUTINE ORIENT(RA,THETAA,PHIA,RR,THETAR,PHIR,AGAM3A,
        ROTATE(3,3), TRANSL(3)
        DIMENSION REAL GAM(3,3), RHO(3,3)
        DIMENSION T(3)
        PSI=THETAA-AGAM3A
        GAM(1,1)=SIN(PHIPHIA)
        GAM(1,2)=-COS(PHIPHIA)
        GAM(1,3)=0.
        GAM(2,1)=SIN(PSI)*SIN(THETAA)*COS(PHIPHIA)+COS(PSI)*COS(THETAA)
        GAM(2,2)=SIN(PSI)*SIN(THETAA)*COS(PSI)*COS(THETAA)
        GAM(2,3)=SIN(PSI)*COS(THETAA)-COS(PSI)*SIN(THETAA)
        GAM(3,1)=COS(PSI)*COS(THETAA)*SIN(PHIPHIA)-SIN(PSI)*COS(THETAA)
        GAM(3,2)=COS(PSI)*SIN(THETAA)*SIN(PHIPHIA)-COS(THETAA)
        GAM(3,3)=COS(AGAM3A)
        RHO(1,1)=COS(THETAR)*COS(PHIPIR)
        RHO(1,2)=COS(THETAR)*SIN(PHIPIR)
        RHO(1,3)=-SIN(THETAR)
        RHO(2,1)=COS(PHIPIR)
        RHO(2,2)=-COS(PHIPIR)
        RHO(2,3)=0.
        RHO(3,1)=SIN(THETAR)*COS(PHIPIR)*-1.
        RHO(3,2)=SIN(THETAR)*SIN(PHIPIR)
        RHO(3,3)=COS(THETAR)
        X=RA*(GAM(THETAA)*COS(PHIPHIA)
YR = RR * SIN(THETAR) * SIN(PHR)
XR = RR * SIN(THETAR) * COS(PHR)
ZR = RR * COS(THETAR)

C COMPUTE THE ROTATE ARRAY BY MULTIPLYING THE RHO ARRAY
   AND THE TRANSPOSE OF THE GAM ARRAY.
C
DO 2 I=1,3
   DO 1 J=1,6
      ROTATE(I,J) = 0.
   1 CONTINUE
2 CONTINUE

C EBJ VERSION OF ORIENT
C COMPUTE TRANSL ARRAY FOR EBJ VERSION OF ORIENT
T(1) = XA - XR
T(2) = YA - YR
T(3) = ZA - ZR
DO 10 I = 1,3
   TRANSL(I) = 0.0
10 CONTINUE

RETURN
END
APPENDIX E
SUBROUTINE RADOME

1. Purpose

This subroutine computes the tangential components of the electric field on the aperture plane as modified by the presence of the radome. The modified aperture field includes the effects of the radome on the transmitted field and the first-order reflected field. The plane wave spectra of the modified aperture fields are computed via the Fast Fourier Transform (FFT) and returned as outputs.

2. Call

CALL RADOME(XPWS,YPWR,EXT,EYT,EXR,EYR,NX,NY,KXMAX,KYMAX,FREQ,ROTATE,TRANSL)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>XPWS</td>
<td>is a two-dimensional array of NX by complex array, input NY elements which contains the plane wave spectrum of the x_A-component of the antenna aperture field in the absence of the radome</td>
</tr>
<tr>
<td>YPWS</td>
<td>is a two-dimensional array of NX by complex array, input NY elements which contains the plane wave spectrum of the y_A-component of the antenna aperture field in the absence of the radome</td>
</tr>
<tr>
<td>EXT</td>
<td>is a two-dimensional array of NX by complex array, output NY elements which contains the plane wave spectrum of the x_A-component of the aperture field as modified by the transmitting properties of the radome</td>
</tr>
<tr>
<td>EYT</td>
<td>is a two-dimensional array of NX by complex array, output NY elements which contains the plane wave spectrum of the y_A-component of the aperture field as modified by the transmitting properties of the radome</td>
</tr>
<tr>
<td>EXR</td>
<td>is a two-dimensional array of NX by complex array, output NY elements which contains the plane wave spectrum of the x_A-component of the aperture field as produced by reflections from the radome wall</td>
</tr>
<tr>
<td>EYR</td>
<td>is a two-dimensional array of NX by complex array, output NY elements which contains the plane wave spectrum of the y_A-component of the aperture field as produced by reflections from the radome wall</td>
</tr>
</tbody>
</table>
NX is the number of rows of the array listed above
NY is the number of columns of the arrays listed above
KXMAX the plane wave spectrum will include all k_x wavenumbers from -KXMAX to (1-2/NX)KXMAX
KYMAX the plane wave spectrum will include all k_y wavenumbers from -KYMAX to (1-2/NY)KYMAX
FREQ is the frequency of operation in hertz of the antenna
ROTATE is a two-dimensional array of 3 by 3 elements which contains the direction cosines describing the rotation of the radome coordinate system in the antenna coordinate system (see Appendix D)
TRANSL is a one-dimensional array of three elements which specifies the location of the origin of the radome coordinate system in the antenna coordinate system (see Appendix D)

3. Comments
a. An array (e.g., XPWS(I,J)) containing sample values of a plane wave spectrum P(k_x,k_y) is ordered such that the elements in the array correspond to the following values of P(k_x,k_y):
   XPWS(1,1) → P(-KXMAX,-KYMAX)
   XPWS(1,NY) → P(-KXMAX,KYMAX-DELKY)
   XPWS(NX+1, NY+1) → P(0,0)
   XPWS(NX,1) → P(KXMAX-DELKX,-KYMAX)
   XPWS(NX,NY) → P(KXMAX-DELKX,KYMAX-DELKY)

b. The increments in wavenumbers are given by
   DELKX = 2(KXMAX/NX)
   DELKY = 2(KYMAX/NY)

c. Specification of KXMAX, KYMAX determines the sample spacing in x,y according to
   DELX = λ/(2KXMAX)
   DELY = λ/(2KYMAX)
where λ is the free-space wavelength
d. An array (e.g., EXT(I,J) containing sample values of the aperture electric field $E_x(x,y)$ is ordered such that the elements in the array correspond to the following values of $E_x(x,y)$:

- $\text{EXT}(1,1) \rightarrow E_x\left(-\frac{\text{NX}}{2}\text{DELX},-\frac{\text{NY}}{2}\text{DELY}\right)$
- $\text{EXT}(1,\text{NY}) \rightarrow E_x\left(-\frac{\text{NX}}{2}\text{DELX},-(\frac{\text{NY}}{2}+\text{DELY})\right)$
- $\text{EXT}(\frac{\text{NX}}{2}+1,\frac{\text{NY}}{2}+1) \rightarrow E_x(0,0)$
- $\text{EXT}(\text{NX},1) \rightarrow E_x\left((\frac{\text{NX}}{2}-1)\text{DELX},-\frac{\text{NY}}{2}\text{DELY}\right)$
- $\text{EXT}(\text{NX},\text{NY}) \rightarrow E_x\left((\frac{\text{NX}}{2}-1)\text{DELX},((\frac{\text{NY}}{2}-1)\text{DELY}\right)$

e. The following supporting subroutines are required:

- WALL (Appendix F)
- INTRPO (Appendix S)
- IPLANE (Appendix R)
- VECTOR (Appendix I)
- POINT (Appendix H)
- TRACE (Appendix G)
- SNELL (Appendix P)
- FFT (Appendix T)

f. The origin of the aperture plane ($x_A=0$, $y_A=0$, $z_A=0$) is used as the phase reference in all computations.

4. Listing

See following page.
SUBROUTINE RADIUS(XPWS, YPWS, EXT, EYT, EYR, EYR, NX, NY, KXMAX, KYMAX)

$ FREQ, ROTATE, TRANSL, VSRR

REAL XPWS(NX, NY), YPWS(NX, NY), EAT(NX, NY), EYT(NX, NY), EXR(NX, NY), EYR(NX, NY)

DATA ATOR, ROTLA, TRUE, FALSE, PI=3.141592653

LAMBDA=2.97925E8/FREQ

KO=2*PI/LAMBDA

DELX=LAMBDA/(2*KXMAX)

DELY=LAMBDA/(2*KYMAX)

MIX=NX/N2+1

MNY=NY/N2+1

FOR A TABLE OF TRANSMISSION AND REFLECTION COEFFICIENTS FOR WALL

TRANS AND REFLECT ARE ENTRY POINTS TO WALL

CALL WALL(FREQ)

INITIALIZE PLANE WAVE INTERPOLATION SUBROUTINE - PW AND UPW

ARE ENTRY POINTS OF INTERPO

CALL INTERPO(XPWS, YPWS, NX, NY, KXMAX, KYMAX)

INITIALIZE PLANAR INTERSECTION SUBROUTINE - PLANE IS THE ENTRY

POINT OF INTER
CALL IPLANE(ROTALE,TRANSL)

C INITIALIZE OUTPUT FIELD ARRAYS
DO 1 J=1,NX
DO 1 J=1,NY
EXT(I,J)=CMPLX(0.0,0.0)
ETY(I,J)=CMPLX(0.0,0.0)
EXR(I,J)=CMPLX(0.0,0.0)
EYR(I,J)=CMPLX(0.0,0.0)
1 CONTINUE

C ITERATE FOR EACH PLANE WAVE
DO 11 I=1,NX,1
DO 11 J=1,NY,1
KA(1)=(I-MIDNX)*DELKX
KA(2)=(J-MIDNY)*DELKY
KA(3)=1-KA(1)**2-KA(2)**2
IF(KA(3),LE,0.0) GO TO 11
KA(3)=SQRT(KA(3))
CALL VECTUR(KA,KFACTOR,ROOTATE)
11 CONTINUE

C ITERATE FOR EACH APERTURE POINT
DO 10 L=1,NX,1
DO 10 M=1,NY,1
PA(1)=(L-MIDNX)*DELX
PA(2)=(M-MIDNY)*DELY
PA(3)=0.0
CALL POINT(PA,PATOR,ROTATE,TRANSL)
10 CONTINUE

C TRACE Ray TO FIRST INTERSECTION POINT
CALL TRACE(P,K,P1,N1,METAL1)
CALL VECTOR(N1,N1A,RTOA,ROTATE)
CALL TRANS(XPN,YPN,XP,WYP,YPWT,KARN1A,METAL1)

PHASE=K0*(P1(1)*K(1)+P2(2)*K(2)+P3(3)*K(3))
PC=EXP(I*PHASE(0.0,-AMOD(2*PI,PHASE)))

CALL EXT(L,0,EXT(L,0)+XPWT*PC)

CALL EYT(L,0)+YPWT*PC

CALL DIRECTION OF REFLECTED PLANE WAVE
CALL SHELL(K,N1,KR)

CALL SECOND INTERSECTION POINT
CALL VECTOR(K,KRA,RTOA,ROTATE)
IF(KRA(3),LE,0.0) GO TO 3

GOTO 10

CALL PLANE(P1,KP,KP3)
D1SQ=(P1(1)—P2(1))**2+(P1(2)—P2(2))**2+(P1(3)—P2(3))**2
D2SQ=(P1(1)—P3(1))**2+(P1(2)—P3(2))**2+(P1(3)—P3(3))**2
IF(D1SQ,LE,D1SQ) GO TO 4
IF(D2SQ,LE,D2SQ) GO TO 10

CALL PLANE(P1,KP,KP3)
D1SQ=(P1(1)—P2(1))**2+(P1(2)—P2(2))**2+(P1(3)—P2(3))**2
D2SQ=(P1(1)—P3(1))**2+(P1(2)—P3(2))**2+(P1(3)—P3(3))**2
IF(D1SQ,LE,D1SQ) GO TO 4
IF(D2SQ,LE,D2SQ) GO TO 10

CALL TRANSM(XPN,YPN,XP,WYP,YPWT,KARN2A,METAL2)

XPN=WPN
YPN=WPN

CALL CONTINUE

CALL REFLCT(XPN,YPN,XP,WYP,YPWT,KRA,N1A,METAL1)

PHASE=K0*(P1(1)*K(1)+P2(2)*K(2)+P3(3)*K(3))

PC=EXP(I*PHASE(0.0,-AMOD(2*PI,PHASE)))

CALL XR(L,M)=XR(L,M)+XPWT*PC

CALL ETYR(L,M)=ETYR(L,M)+YPWT*PC

CALL REFLECT(XPN,YPN,XP,WYP,YPWT,KRA,N1A,METAL1)
CONTINUE
CONTINUE
CALCULATE PLANE WAVE SPECTRUM OF EACH PLANAR FIELD
CALL FFT(EXT,NX,NY,+1)
CALL FFT(EYT,NX,N10,+1)
CALL FFT(EXR,NX,NY,+1)
CALL FFT(EYR,NX,NY,+1)

WEIGHT REFLECTED PLANE WAVE SPECTRUM BY THE NORMALIZED PLANE
WAVE SPECTRUM OF THE ANTENNA AND SUM THEN SQUARE TO FIND
THE REFLECTED POWER
T=CMPLX(0.0,0.0)
R=CMPLX(0.0,0.0)
DO 20 I=1,NX,1
DO 20 J=1,MY,1
T=T+XPWS(I,J)+YPWS(I,J)
R=R+XPWS(I,J)*EXR(I,J)+YPWS(I,J)*EYR(I,J)

20 CONTINUE
R=R/T
PR=CAAS(R)**2
PT=CAAS(T)**2
VR=R=SQRT((PT+PR)/(PT-PR))
RETURN
END
APPENDIX F

SUBROUTINE WALL

1. Purpose

This subroutine computes the insertion voltage transmission coefficient and reflection coefficients for an N layer dielectric panel immersed in free space (perpendicular and parallel polarization) at equally spaced values of the sine of the incidence angle. In addition, this subroutine (ENTRY TRANS and ENTRY REFLECT) computes the \( x_A \) and \( y_A \) components of the transmitted and reflected plane waves when a plane wave of arbitrary polarization is incident on such a dielectric panel oriented in the antenna coordinate system \( (x_A, y_A, z_A) \) as specified by the unit vector normal to the incident side of the panel.

2. Calls

a. CALL WALL(FREQ)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FREQ</td>
<td>is the frequency in hertz of the incident radiation floating-point variable, input</td>
</tr>
<tr>
<td>N</td>
<td>is the number of dielectric layers comprising the multilayer panel FORTRAN integer, PARAMETER input</td>
</tr>
<tr>
<td>NN</td>
<td>is ( N + 1 ) FORTRAN integer, PARAMETER input</td>
</tr>
<tr>
<td>D</td>
<td>is a one-dimensional array of ( N ) elements which contains the thickness in centimeters of each layer real array, DATA input</td>
</tr>
<tr>
<td>ER</td>
<td>is a one-dimensional array of ( (N+1) ) elements which contains the relative dielectric constant of each layer; ( ER(NN) ) is set equal to 1.0, the dielectric constant of free space real array, DATA input</td>
</tr>
<tr>
<td>TD</td>
<td>is a one-dimensional array of ( (N+1) ) elements which contains the loss tangent of each layer; ( TD(NN) ) is set equal to 0.0, the loss tangent of free space real array, DATA input</td>
</tr>
<tr>
<td>NANGLE</td>
<td>is the number of values of sine of the incidence angle at which the transmission and reflection coefficients are computed FORTRAN integer PARAMETER input</td>
</tr>
<tr>
<td>TPER</td>
<td>is a one-dimensional array of ( NANGLE ) elements which contains the complex insertion voltage transmission coefficients for perpendicular polarization complex array, used by ENTRY TRANS</td>
</tr>
</tbody>
</table>
TPAR is a one-dimensional array of NANGLE elements which contains the complex insertion voltage transmission coefficients for parallel polarization.

RPER,PRAR are one-dimensional arrays of NANGLE elements each which contain the complex voltage reflection coefficients for perpendicular and parallel polarization, respectively.

b. CALL TRANS(XPW,YPW,XPWT,YPWT,K,NORM,METAL)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>XPW is the $x_A$-component of the incident</td>
<td>complex variable, input</td>
</tr>
<tr>
<td>plane wave</td>
<td></td>
</tr>
<tr>
<td>YPW is the $y_A$-component of the incident</td>
<td>complex variable, input</td>
</tr>
<tr>
<td>plane wave</td>
<td></td>
</tr>
<tr>
<td>XPWT is the $x_A$-component of the transmitted</td>
<td>complex variable, output</td>
</tr>
<tr>
<td>plane wave</td>
<td></td>
</tr>
<tr>
<td>YPWT is the $y_A$-component of the transmitted</td>
<td>complex variable, output</td>
</tr>
<tr>
<td>plane wave</td>
<td></td>
</tr>
<tr>
<td>K is a one-dimensional array of three</td>
<td>real array, input</td>
</tr>
<tr>
<td>elements which contains the direction cosines</td>
<td></td>
</tr>
<tr>
<td>of the direction of propagation of the</td>
<td></td>
</tr>
<tr>
<td>incident plane wave in antenna coordinates</td>
<td></td>
</tr>
<tr>
<td>NORM is a one-dimensional array of three</td>
<td>real array, input</td>
</tr>
<tr>
<td>elements which contains the direction cosines</td>
<td></td>
</tr>
<tr>
<td>of the unit vector normal to the incident side</td>
<td></td>
</tr>
<tr>
<td>of the panel</td>
<td></td>
</tr>
<tr>
<td>METAL is a logical control variable which</td>
<td>logical variable, input</td>
</tr>
<tr>
<td>if .TRUE. causes the transmitted plane wave</td>
<td></td>
</tr>
<tr>
<td>to be zero (as if the incident plane wave</td>
<td></td>
</tr>
<tr>
<td>impinged on a perfect conductor)</td>
<td></td>
</tr>
</tbody>
</table>

c. CALL REFLECT(XPW,YPW,XPWR,YPWR,K,NORM,METAL)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>XPW,YPW,K,NORM same as for ENTRY TRANS</td>
<td></td>
</tr>
<tr>
<td>XPWR,YPWR are $x_A$ and $y_A$-components of the</td>
<td>complex variable, outputs</td>
</tr>
<tr>
<td>reflected plane wave</td>
<td></td>
</tr>
<tr>
<td>METAL is a logical control variable which</td>
<td>logical variable, input</td>
</tr>
<tr>
<td>if .TRUE. causes the reflected plane wave to be</td>
<td></td>
</tr>
<tr>
<td>totally reflected (as if the incident plane</td>
<td></td>
</tr>
<tr>
<td>wave impinged on a perfect conductor) with</td>
<td></td>
</tr>
<tr>
<td>XPWR=-XPW,</td>
<td></td>
</tr>
<tr>
<td>YPWR=-YPW</td>
<td></td>
</tr>
</tbody>
</table>
3. Comments
   a. Layer number 1 corresponds to the first layer on the exit side of the panel; layer N is the first layer on the incident side of the panel. The arrays ER,TD,D are ordered accordingly.
   b. ER(I) ≥ 1.0, TD(I) ≥ 0.0, D(I) ≥ 0.0 for all I = 1,N.
   c. Transmission and reflection coefficients are computed at equal increments of the sine of the incidence angle (rather than at equal increments of incidence angle) because of computational speed advantage in later computations.
   d. K and NORM represent unit vectors.
   e. No supporting subroutines are required.
   f. The transmission coefficients for a multilayer dielectric panel are the same for a plane wave incident from either side of the panel; however, the reflection coefficients are not the same. Hence, the ordering of the arrays ER,TD,D as described in a above is important.

4. Listing
   See following page.
SUBROUTINE WALL (FREN)  
SUBROUTINE WALL COMPUTES THE TRANSMISSION AND REFLECTION  
COEFFICIENTS TO ANY LAYER OF A PLANAR DIELECTRIC PANEL FOR PLANE  
WAVE INCIDENT AT AN ANGLE THETA IN RADIANS FOR PERPENDICULAR  
AND  
PARALLEL POLARIZATIONS:  
PARAMETERS OF THE WALL:  
THE NUMBER OF LAYERS  
DIMENSION ARRAYS  
THICKNESS OF EACH LAYER IN CENTIMETERS  
RELATIVE DIELECTRIC CONSTANT OF EACH LAYER  
THE LOSS TANGENT FOR EACH LAYER  
ALL THE COEFFICIENTS;  
COEFFICIENTS TO THE NORMAL VOLTAGE XWL COEFFICIENTS;  
TPER,TPAR ARE THE  
THE NORMAL VOLTAGE XWL COEFFICIENT;  
NOTE THAT THE XWL COEFF S ARE THE SAME FOR PLANE WAVE INCIDENT FROM  
NEITHER SIDE OF THE STRATIFIED DIELECTRIC PANEL IMMERSED IN FREE SPACE;  
HOWEVER, THE REFLECTION COEFF S ARE NOT. THAT IS;  
FOR COMPUTING RPER,  
RPAR, THE ORDERING OF E(R(N)),T(D(N)) IS IMPORTANT WITH LAYER 1 BEING  
THE FIRST LAYER ON THE EXIT SIDE, LAYER N BEING THE FIRST LAYER ON THE  
INCIDENT SIDE. LAYER NN AND LAYER 0 ARE JUST FREE SPACE LAYERS  
OF SEMI-INFINITE DEPTH.  
E, R, T1, T2, ARE ARRAYS USED IN THE SUBROUTINE HAVING NN DIM'L LIMITS  
PARAMETER NN=1,NNH=1+1,NANGLE=100  
DIMENSION D(N),E(R(N)),T(D(N))  
COMPLEX E(R(N)),T(D(N)),R1(N),R2(N),G(N),R1(N),R2(N),G(N)  
1, 2, 3, 4, Y1, Y2, Y3, Y4, U1, U2, U3, U4, V1, V2, V3, V4, P1, P2, P3, P4, Q1, Q2, Q3, Q4.  
2000, 3000, 4000, T1, T2  
COMPLEX TPER(NANGLE),TPAR(NANGLE),RPER(NANGLE),RPAR(NANGLE)  
0 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000  
PER=0.5  
PHI = 3.1415926  
T(1) = 0.5 P1  
0 E(0)=0.
C A = (TUPL/WL) / SORT(2.)

C CALCULATE TOTAL THICKNESS OF WALL IN CM

C DO 1 IA=1,NANGLE,1

C FORM A TABLE OF TRANSMISSION AND REFLECTION COEFFICIENTS AS A

C FUNCTION OF THE SINE OF THE INCIDENT ANGLE

C THE SINE OF THE ANGLE IS EQUALLY INCREMENTS AS SINE = (IA-1)/NANGLE

C S IS THE SINE OF THE ANGLE SQURED

C C IS THE COSINE OF THE ANGLE

C S=((IA-1.0)/NANGLE)**2

C C =SORT(1.,0-5)

A = ER(1) - S

ET = ER(1) * TD(1)

SR = SQRT(AD**2 + ET**2)

IF(SR=AL) 76,76,77

76 A = .

77 A = AR * SORT(SR = AD)

B = AB * SQRT(SK + AD)

C(1) = CMPLX(A,B)

G0=CMPLX(0.,(TUPL/WL)*C)

ER1=

SUM=0.

SU=SUM+D(1)/SORT(AD)

RR1 = (G(1)-G0)/(G(1)+G0)
00162  60*  \[ R12 = \frac{E_1 \cdot G(1) - E(1) \cdot G \cdot G}{E \cdot E_1 \cdot G(1) \cdot G(1) \cdot G} \]
00163  76*  DC 64 I=1,N
00166  77*  I1 = I+1
00167  78*  AI = ER(I1)*S
00170  79*  ET = ER(I1)*T0(I1)
00171  80*  IF (I=1) 176;177;177
00174  81*  176 SUM=SUM+T(I1)/SQRT(AO)
00175  82*  177 CONTINUE
00176  83*  SK = SQRT(AO**2 + ET**2)
00177  84*  IF(SR-AD) 79,79,80
00202  85*  79 A = 0.
00203  86*  GO TO 81
00204  87*  80 A = AB * SQRT(SR-AD)
00205  88*  81 B = AB * SQRT(SR+AD)
00206  89*  82 G(I1) = COMPLX(A,B)
00207  90*  83 R1(I) = (G(I1)-G(I))/G(I1)+G(I))
00210  91*  84 R2(I) = (E(I)*G(I1)-E(I)*G(I))/E(I)*G(I1)+E(I)*G(I))
00212  92*  85 SUM=SUM*SUM
00213  93*  86 AA1 = 1. - RR1
00214  94*  87 AA2 = 1. - RR2
00215  95*  88 DO 85 I=1,N
00220  96*  89 AA1 = AA1 * (1. - R1(I))
00221  97*  90 AA2 = AA2 * (1. - R2(I))
00223  98*  91 AA1 = 1. / AA1
00224  99*  92 AA2 = 1. / AA2
00225  100*  93 U = - G(I) * D(1)
00226  101*  94 V = G(I) * D(1)
00227  102*  95 X1 = CEXP(U)
00228  103*  96 X4 = CEXP(V)
00230  104*  97 X2 = - RR1 * X4
00231  105*  98 X3 = - RR1 * X1
00233  106*  99 Y1 = X1
00234  107*  100 Y4 = X4
00235  108*  101 Y2 = - RR2 * Y4
00236  109*  102 Y3 = - RR2 * Y1
00237  110*  103 DO 105 I=6,NN
00242  111*  104 IF(I-I1=1) 45,90,1
00245  112*  105 90 U1 = 1.
00246  113*  106 U2 = - R1(N)
00247  114*  107 U3 = - R1(N)
00248  115*  108 U4 = - R1(N)
\[ V_1 = \frac{1}{u} \]

\[ V_2 = -L \cdot v \]

\[ V_3 = -F \cdot u \]

\[ V_4 = 1 \]

\[ V_5 : U 1 \]

\[ II = I - 1 \]

\[ U = -g(I) \cdot u(I) \]

\[ v = g(I) + f(I) \]

\[ U_1 = \text{EXP}(U) \]

\[ U_2 = -p(I) + u_1 \]

\[ U_3 = -p(I) \cdot u_1 \]

\[ U_4 = U_1 \]

\[ V_1 = U_1 \]

\[ V_2 = -r(I) \cdot V_4 \]

\[ V_3 = -r(I) \cdot V_1 \]

\[ P_1 = X_1 \cdot U_1 + X_2 \cdot U_3 \]

\[ P_2 = X_1 \cdot U_2 + X_2 \cdot U_4 \]

\[ P_3 = X_3 \cdot U_1 + X_4 \cdot U_3 \]

\[ P_4 = X_3 \cdot U_2 + X_4 \cdot U_4 \]

\[ Q_1 = Y_1 + V_1 + Y_2 \cdot V_3 \]

\[ Q_2 = Y_1 + V_2 + Y_2 \cdot V_4 \]

\[ Q_3 = Y_3 + V_1 + Y_4 \cdot V_3 \]

\[ Q_4 = Y_3 + V_2 + Y_4 \cdot V_4 \]

\[ X_1 = P_1 \]

\[ X_2 = P_2 \]

\[ X_3 = P_3 \]

\[ X_4 = P_4 \]

\[ Y_1 = Q_1 \]

\[ Y_2 = Q_2 \]
$Y_3 = 03$

$Y_4 = 04$

$R_{PE}(IA) = -X_3/Y_4$

$R_{PA}(IA) = -Y_3/Y_4$

$T_1 = (X_1 + X_2 * R_{PE}(IA)) * AA_1$

$U = CMPLX (C_0 - SUM*T(PI/WL))$

$U = CEXP(U)$

$T_{PE}(IA) = T_{NI} * U$

$T_{NE} = (Y_1 + Y_2 * R_{PA}(IA)) * AA_2$

$T_{PA}(IA) = T_{NE} * U$

C MODIFY TRANSMISSION COEFFICIENTS FOR INSERTION

$U = CMPLX (C_0 + T(PI/WL)*TOTAL*C/WL)$

$U = CEXP(U)$

$T_{PE}(IA) = T_{NI} * U$

$T_{PA}(IA) = T_{NE} * U$

1 CONTINUE

300 RETURN

C ENTRY TRANS(XX,YY,XXWT,YPWT,K,NORM,METAL)

COMPLEX XX,YY,XXWT,YPWT,XXPW,YPWT

COMPLEX EXPEP,EPERP,EXPER,EPERP,TPAR,TPEP,DUT

REAL K(3),NORM(3),KPER(3)

LOGICAL METT

IF(METAL) GOTO 4

C FIND VECTOR NORMAL TO NORM AND K

CALL AXB(K,NORM,KPER)

C FIND MAGNITUDE OF KPER (THIS IS ALSO THE SINE OF THE INCLUDED ANGLE)

SINE = SQRT(KPER(1) * KPER(1) + KPER(2) * KPER(2) + KPER(3) * KPER(3))

IF(SINE < LT.1E-10) GOTO 2

C UNI TIZE VECTOR

SEC = 1/ SINE

KPER(1) = KPER(1) * SEC

KPER(2) = KPER(2) * SEC

KPER(3) = KPER(3) * SEC

C FIND Z COMPONENT OF INCIDENT PLANE WAVE

ZPW = -(K(1) * XXPW + (2) * YPW)/K(3)
C FIND DOT PRODUCT OF INCIDENT ELECTRIC FIELD WITH KPER
DOT=XPW*KPER(1)+YPW*KPER(2)+ZPW*KPER(3)

C FIND PERPENDICULAR COMPONENTS OF ELECTRIC FIELD
EXPER=DOT*KPER(1)
EYP=DOT*KPER(2)
GO TO 3

C FIND PARALLEL COMPONENTS OF ELECTRIC FIELD
EXPAR=XPW-EXPER
EYPAR=YPW-EYPER

C FIND PERPENDICULAR AND PARALLEL TRANSMISSION COEFFICIENTS
ISINE=SINE*MANGLE+1.5
THEP=THET(ISINE)
TPAR=THET(ISINE)

C FIND X AND Y COMPONENTS OF TRANSMITTED FIELD
XPWT=EXPAR*TPAR+EXPER*TPERI
YPWT=EYPAR*TPAR+EYPER*TPERI
RETURN

C FIND X AND Y COMPONENTS OF TRANSMITTED FIELD
XPWT=CMPLX(0.0,0.0)
YPWT=CMPLX(0.0,0.0)
RETURN
ENTRY REFLECT(XPR,YPR,XPR,YPR,K*NORM,METAL)
COMPLEX XPR,YPR
IF(METAL) GO TO 7
C FIND VECTOR NORMAL TO NORM AND K
CALL AX2(K,NORM,KPER)
C FIND MAGNITUDE OF KPR (THIS IS ALSO THE SINE OF THE INCLUDED ANGLE)
SINESQ=KPER(1)*KPER(1)+KPER(2)*KPER(2)+KPER(3)*KPER(3)
IF(SINESQ.LE.1E-10) GO TO 5
C UNITIZE VECTOR
SLC=1/SINESQ
KPER(1)=KPER(1)*SLC
KPER(2)=KPER(2)*SLC
KPER(3)=KPER(3)*SLC
C FIND Z COMPONENT OF INCIDENT PLANE WAVE
ZP=(KPER(1)*XPR+KPER(2)*YPR)/K(3)
C FIND DOT PRODUCT OF INCIDENT ELECTRIC FIELD WITH KPER
DOT=XPR*KPER(1)+YPR*KPER(2)*ZP*KPER(3)
C FIND PERPENDICULAR COMPONENTS OF ELECTRIC FIELD
EXPER=DOT*KPER(1)
EYPER=DOT*KPER(2)
GO TO 6
S CONTINUE
C
C FIND PARALLEL COMPONENTS OF ELECTRIC FIELD
EXPAR=EXPAR+EXPER
EYPAR=EYPAR+EYPER

C FIND PERPENDICULAR AND PARALLEL REFLECTION COEFFICIENTS
ISINE=SINE*NANGLE+1.5
RPARI=RPAR(ISINE)
RPERI=RPER(ISINE)

C FIND X AND Y COMPONENTS OF REFLECTED FIELD
XPWR=EXPAR*RPARI+EXPER*RPERI
YPWR=EYPAR*RPARI+EYPER*RPERI

RETURN
7 CONTINUE
XPWR=-XPWR
YPWR=-YPWR
RETURN
APPENDIX G

SUBROUTINE TRACE

1. Purpose

Many radomes can be approximated by a truncated cone which is joined to an ogive at its base and having metal disks for a top and bottom. For a ray emanating from a point, P0, interior to the radome and traveling in the K direction, this subroutine calculates the coordinates of the point of intersection of the ray with the radome and the inward normal of the radome at the point of intersection.

2. Call

CALL TRACE(P0, K, P, N, METAL)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PO</td>
<td>is the three-dimensional array of coordinates of the interior point, P0</td>
</tr>
<tr>
<td>K</td>
<td>is the three-dimensional array of wavenumbers of the ray</td>
</tr>
<tr>
<td>P</td>
<td>is the three-dimensional array of coordinates of the point of intersection</td>
</tr>
<tr>
<td>N</td>
<td>is the three-dimensional array of components of the inward normal at the point of intersection</td>
</tr>
<tr>
<td>METAL</td>
<td>is set to .TRUE. if the ray hits either the top or bottom disk and .FALSE. otherwise</td>
</tr>
</tbody>
</table>

3. Comments

a. K(3) ≠ 0.0

b. The main axis of the radome is assumed to be the z-axis.

c. Other Subprograms Required: CONE, OGIve, QUARTC, BDISK, TDISK, XY.

d. Parameters: Z1 the z-coordinate at which the cone is truncated; In the subprogram TDISK the parameter ZTOP must be equal to Z1

Z2 the z-coordinate at which the cone meets the ogive

Z3 the z-coordinate at which the ogive is terminated; In the subroutine BDISK the parameter ZBOT must be equal to Z3.

4. Listing

See following page
SUBROUTINE TRACE(P0,K,P,N,METAL)
A GENERAL RESTRICTION OF THIS PROGRAM IS K(3) MUST NOT BE ZERO
REAL P0(3),K(3),P(3),N(3)
LOGICAL METAL,HIT
SET BOUNDARY Z VALUES:
DATA Z1,Z2=73/69,890/20.488,0/0
DATA ISURF/=2/
1 GO TO (10,20,30,40),ISURF
ISURF=2
GO TO 1
ISURF=4
GO TO 1
ISURF=3
GO TO 1

CALL DISK(P0,K,P,HIT)
IF(HIT) GO TO 110
ISURF=2
GO TO 1

CALL CONE(P0,K,Z,HIT)
IF(Z.LT.Z1+0.1.AND.Z.GE.Z2-0.1) GO TO 120
ISURF=1
GO TO 1

IF(Z.LT.Z2) ISURF=3
GO TO 1
DETERMINE IF RAY HIT THE OGIVE

CALL OGIVE(PO,K,Z,HIT)
IF(HIT) GO TO 31
IF(Z.LE.Z2+0.1 .AND.Z.GE.Z3-0.1) GO TO 130
ISURF=2
GO TO 1

DETERMINE IF RAY HIT THE BOTTOM DISK

CALL DISK(PO,K,P,HIT)
IF(HIT) GO TO 140
ISURF=3
GO TO 1

CALCULATE INWARD NORMAL OF TOP DISK

CALL DISKN(N)
METAL=.TRUE.
RETURN

CALCULATE INWARD NORMAL OF CONE

CALL CONEN(P,N)
METAL=.FALSE.
RETURN

CALCULATE INWARD NORMAL OF OGIVE

CALL OGIVEN(P,N)
METAL=.FALSE.
RETURN

CALCULATE INWARD NORMAL OF BOTTOM DISK
<table>
<thead>
<tr>
<th>Line</th>
<th>Instruction(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>CALL BDISK(N)</td>
</tr>
<tr>
<td>72*</td>
<td>MEITAL=TRUE.</td>
</tr>
<tr>
<td>73*</td>
<td>RETURN</td>
</tr>
<tr>
<td>74*</td>
<td>END</td>
</tr>
</tbody>
</table>

END OF COMPILATION: NO DIAGNOSTICS.
APPENDIX H

SUBROUTINE POINT

1. Purpose

This subroutine transforms a point \((x_a, y_a, z_a)\) in the antenna coordinate system to the corresponding point \((x_r, y_r, z_r)\) in the radome coordinate system, and vice versa.

2. Call

CALL POINT(P, PT, ATOR, T, PO)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>is a one-dimensional array of three elements containing the Cartesian coordinates of the point specified in one coordinate system</td>
</tr>
<tr>
<td>PT</td>
<td>is a one-dimensional array of three elements containing the Cartesian coordinates of the same point in the other coordinate system</td>
</tr>
<tr>
<td>ATOR</td>
<td>is a logical variable such that if ATOR is .TRUE., the transformation from antenna to radome coordinates is made; if ATOR is .FALSE., the transformation from radome to antenna coordinates is made</td>
</tr>
<tr>
<td>T</td>
<td>is a two-dimensional array ((3 \times 3)) of nine elements which contains the direction cosines which describe the rotation of the radome coordinate system in the antenna coordinate system.</td>
</tr>
<tr>
<td>PO</td>
<td>is a one-dimensional array of three elements which contains the coordinates of the origin of the radome coordinate system in the antenna coordinate system.</td>
</tr>
</tbody>
</table>

3. Comments

a. Ordering of elements in \(T(I,J)\) here is the same as that in \(ROTATE(I,J)\) of Appendix D.

b. Ordering of elements in \(P(I)\), \(PT(I)\), \(PO(0)\) is identical to that of \(TRANSL(I)\) of Appendix D.
c. Although no supporting subroutines are required, subroutine ORIENT of Appendix D is used to generate the input arrays $T$ and $P_0$.

4. Listing

See following page.
SUBROUTINE POINT(P,PT,ATOR,T,PO)

   THIS SUBROUTINE TRANSFORMS A POINT P GIVEN IN ONE COORDINATE SYSTEM
   TO THE SAME POINT GIVEN IN ANOTHER COORDINATE SYSTEM, PT.
   THE TRANSFORMATION IS ACCOMPLISHED USING THE TRANSFORM MATRIX T
   THE LOGICAL VARIABLE ATOR DIRECTS WHICH TRANSFORM IS TO BE MADE
   IF ATOR IS TRUE THE TRANSFORM IS FROM ANTENNA COORDINATES TO
   RADOME COORDINATES. IF ATOR IS FALSE THE OPPOSITE TRANSFORM IS MADE
   T IS THE MATRIX OF DIRECTION COSINES WHICH DESCRIBE THE ROTATION
   OF THE RADOME COORDINATE SYSTEM WITH RESPECT TO THE ANTENNA
   COORDINATE SYSTEM. PO IS THE ORIGIN OF THE RADOME COORDINATE
   SYSTEM IN ANTENNA COORDINATES

   REAL P(3),PT(3),T(3,3),PS(3)
   LOGICAL ATOR

   IF(.NOT.ATOR) GO TO 1
   PS(1)=P(1)-PO(1)
   PS(2)=P(2)-PO(2)
   PS(3)=P(3)-PO(3)
   PT(1)=T(1,1)*PS(1)+T(1,2)*PS(2)+T(1,3)*PS(3)
   PT(2)=T(2,1)*PS(1)+T(2,2)*PS(2)+T(2,3)*PS(3)
   PT(3)=T(3,1)*PS(1)+T(3,2)*PS(2)+T(3,3)*PS(3)
   CONTINUE

   PS(1)=P(1)+T(1,1)*P(2)+T(1,2)*P(3)+PO(1)
   PS(2)=P(2)+T(2,1)*P(1)+T(2,2)*P(3)+PO(2)
   PS(3)=P(3)+T(3,1)*P(1)+T(3,2)*P(2)+T(3,3)*P(3)+PO(3)
   RETURN

END OF COMPILED: NO DIAGNOSTICS.
1. Purpose

This subroutine transforms a real vector in the antenna coordinate system to the corresponding vector in the radome coordinate system, and vice versa.

2. Call

CALL VECTOR(V, VT, ATOR, T)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>is a one-dimensional array of three elements containing the rectangular components of the vector specified in one coordinate system</td>
</tr>
<tr>
<td>VT</td>
<td>is a one-dimensional array of three elements containing the rectangular components of the same vector in the other coordinate system</td>
</tr>
<tr>
<td>ATOR, T</td>
<td>see Appendix G</td>
</tr>
</tbody>
</table>

3. Comments

a. See Appendix G for ordering of elements.

b. No supporting subroutines are required.

4. Listing

See following page.
00101 1*
00101 2*
00101 3*
00101 4*
00101 5*
00101 6*
00101 7*
00101 8*
00101 9*
00101 10*
00101 11*
00101 12*
00103 13*
00104 14*
00105 15*
00107 16*
00107 17*
00111 18*
00112 19*
00113 20*
00114 21*
00115 22*
00116 23*
00117 24*

DIMENSION VECTOR(VT, TOR, T)

THIS SUBROUTINE TRANSFORMS A VECTOR V GIVEN IN ONE COORDINATE SYSTEM TO THE SAME VECTOR GIVEN IN ANOTHER COORDINATE SYSTEM, VT.

THE TRANSFORMATION IS ACCOMPLISHED USING THE TRANSFORM MATRIX T.

THE LOGICAL VARIABLE ATOR DIRECTS WHICH TRANSFORM IS TO BE MADE.

IF ATOR IS TRUE THE TRANSFORM IS FROM ANTEU COORDINATES TO RADIOE COORDINATES. IF ATOR IS FALSE THE OPPOSITE TRANSFORM IS MADE.

T IS THE MATRIX OF DIRECTION COSINES WHICH DESCRIBE THE ROTATION OF THE RADIOE COORDINATE SYSTEM WITH RESPECT TO THE ANTEU COORDINATE SYSTEM.

REAL VT(3), V(3), T(3,3)
LOGICAL ATOR

IF(ATOR) GO TO 1

VT(1) = (1, 1) * V(1) + T(1, 2) * V(2) + T(1, 3) * V(3)
VT(2) = (1, 3) * V(3)
VT(3) = T(3, 1) * V(1) + T(3, 2) * V(2) + T(3, 3) * V(3)

CONTINUE

VT(1) = (1, 1) * V(1) + T(2, 1) * V(2) + T(3, 1) * V(3)
VT(2) = (1, 2) * V(2)
VT(3) = T(3, 1) * V(1) + T(3, 2) * V(2) + T(3, 3) * V(3)

RETURN

END
APPENDIX J

SUBROUTINE TDISK WITH ENTRY TDISKN

1. Purpose

This subroutine calculates the coordinates of the point of intersection of a disk and a ray emanating from a point, \( P \), below the disk and traveling in the \( K \) direction.

The entry TDISKN sets the values of the array \( N \) to \((0.0, 0,0, -1.0)\) which are the components of the inward normal to a radome at the top disk.

2. Calls

a. CALL TDISK (P, L, PI, HIT)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>is the three-dimensional array of coordinates of the point ( P ) floating-point input</td>
</tr>
<tr>
<td>K</td>
<td>is the three-dimensional array of wavenumbers of the ray floating-point input</td>
</tr>
<tr>
<td>PI</td>
<td>is the three-dimensional array of coordinates of the point of intersection floating-point output</td>
</tr>
<tr>
<td>HIT</td>
<td>is set to .TRUE. if the ray intersects the disk and .FALSE. otherwise logical output</td>
</tr>
</tbody>
</table>

b. CALL TDISKN(N)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>is the three-dimensional array of components of the inward normal for the top disk floating-point output</td>
</tr>
</tbody>
</table>

3. Comments

a. \( K(3) \neq 0.0 \)

b. The disk is assumed to be centered on the z-axis and parallel to the xy-plane.

c. Parameters: 
   - \( ZTOP \) The top disk lies in the plane \( Z = ZTOP \)
   - \( RSQ \) The square of the radius of the disk

4. Listing

See following page.
TO CALCULATE THE NORMAL OF INTERSECTING DISK ORIZONS

TO THE ORIG. PNT. ON OF DISK ORIZONS

THE END OF THE FOR LoOp TOP DISK PNT. FOR (X**2+Y**2)<RSD

SET FOR DISK PARAMETERS

ENTRY TDLK (1)

REAL T (3)

INITIAL PNT.

ZT=TOP=0.5)

IF (ZT<0.5) RETURN

P (3)=TOP

P (1)=ZT*X (3)

P (2)=ZT*X (1)+ZT*X (2)

P (2)=ZT*X (1)+ZT*X (2)

RETURN

RETURN

RETURN

RETURN

RETURN

ENTRY TDLK (4)

REAL T (3)

T (1)=1.0

T (2)=1.0

T (3)=1.0

RETURN

END

END OF COMPILED  NO DIAGNOSTIC.
1. Purpose

This subroutine calculates the coordinates of the point of intersection of a disk and a ray emanating from a point, P, above the disk and traveling in the K direction.

The entry BDISK sets the values of the array N to (0.0, 0.0, +1.0) which are the components of the inward normal to a radome at the bottom disk.

2. Calls

a. CALL BDISK (P, K, PI, HIT)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td></td>
</tr>
<tr>
<td>is the three-dimensional array of</td>
<td>floating-point</td>
</tr>
<tr>
<td>coordinates of the point P</td>
<td>input</td>
</tr>
<tr>
<td>K</td>
<td></td>
</tr>
<tr>
<td>is the three-dimensional array of</td>
<td>floating-point</td>
</tr>
<tr>
<td>wavenumbers of the ray</td>
<td>input</td>
</tr>
<tr>
<td>PI</td>
<td></td>
</tr>
<tr>
<td>is the three-dimensional array of</td>
<td>floating-point</td>
</tr>
<tr>
<td>coordinates of the point of inter-</td>
<td>output</td>
</tr>
<tr>
<td>section</td>
<td></td>
</tr>
<tr>
<td>HIT</td>
<td></td>
</tr>
<tr>
<td>is set to .TRUE. if the ray inter-</td>
<td>logical</td>
</tr>
<tr>
<td>sects the disk and .FALSE. otherwise</td>
<td>output</td>
</tr>
</tbody>
</table>

b. CALL BDISK(N)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td></td>
</tr>
<tr>
<td>is the three-dimensional array of</td>
<td>floating-point</td>
</tr>
<tr>
<td>components of the inward normal for</td>
<td>output</td>
</tr>
<tr>
<td>the bottom disk</td>
<td></td>
</tr>
</tbody>
</table>

3. Comments

a. K(3) ≠ 0.0

b. The disk is assumed to be centered on the z-axis and parallel to the xy-plane.

c. Parameters: ZBOT The bottom disk lies in the plane Z = ZBOT.
   RSQ The square of the radius of the disk.

4. Listing

See following page.
Structured Disk Program

DISK CALCULATES THE POINT OF INTERSECTION PI OF A DISK HORIZONTAL TO THE X-Y PLANE, GIVEN Z BY EQUATING FROM POINT P AND TRAVELING IN THE Z-ORTHOGONAL.

THE EQUATION USED FOR THE BOT DISK IS Z=Z0+T FOR (X**2+Y**2)=R50.

GET BOTTOM DISK PARAMETERS:
DATA Z30,T30,A0.0442,0.080/
REAL P0(3),A0(3),PI0(3)
LOGICAL HIT
ZE=Z0+T
IF(ZE=.LT.0.0) GO TO 1
PI0(3)=Z30
10 T0=T/43
PL0=PO(1)+K(1)*T
PI0(2)=PO(2)+K(2)*T
PI0=PL0+PI0(1)+PI0(2)*PI0(2)
IF(PI0,.GT.R50) GO TO 1
HIT=TRUE
RETURN
30 1 HIT=FALSE
RETURN

CALCULATE INVARIANT NORMAL OF BOTTOM DISK
ENTRY DOTSMN(N)
REAL X0(3)
X0(1)=0.0
X0(2)=0.0
X0(3)=0.0

RETURN

END

END OF COMPILED. NO DIAGNOSTICS.
APPENDIX L
SUBROUTINE CONE WITH ENTRY CONEN

1. Purpose
This subroutine calculates the z-coordinate of the point of intersection of a cone with a ray emanating from a point, P, interior to the surface and traveling in the K direction. CONEN calculates the inward normal, N, of a cone at a point PI, on the surface.

2. Calls
a. CALL CONE(P, K, Z, HIT)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>is the three-dimensional array of coordinates of the interior point</td>
</tr>
<tr>
<td>K</td>
<td>is the three-dimensional array of wavenumbers of the ray</td>
</tr>
<tr>
<td>Z</td>
<td>is the z-coordinate of the point of intersection</td>
</tr>
<tr>
<td>HIT</td>
<td>is set to .TRUE. if the ray intersects the surface and .FALSE. otherwise</td>
</tr>
</tbody>
</table>

b. CALL CONEN(PI, N)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>is the three-dimensional array of coordinates of a point on the surface</td>
</tr>
<tr>
<td>N</td>
<td>is the three-dimensional array of components of the inward normal at the point PI</td>
</tr>
</tbody>
</table>

3. Comments
a. Restriction: K(3) ≠ 0.0
b. The main axis of the cone is assumed to be the z-axis.
c. The cone is described by the equation (Z-ZTIP) = \( A^2 (x^2 + y^2) \)
d. The required parameters are

\[
\begin{align*}
ZTIP \\
S &= A^2 \\
ZNORM &= -\sin(\cot^{-1}A) \\
RNORM &= -\cos(\cot^{-1}A)
\end{align*}
\]

4. Listing
See following page.

125
SPECIAL ROUTINE Z=C(X,K,Z,HI)

SUBROUTINE Z=C(X,K,Z,HI)

C ROUTINE TO COMPUTE THE Z COORDINATE OF THE POINT OF INTERSECTION OF A
C CIRCLE AND A CYLINDER INITIATING FROM A POINT INTERIOR TO THE CIRCLE AND
C TRAVELLING IN THE DIRECTION K

THE EQUATION USED FOR THE CIRCLE IS (Z-ZTPT) = -A*SQR(X**2+Y**2)

SET CIRCLE PARAMETERS WHERE C = A**2:

DATA S,STPT/TIP/13.792,64.173/

REAL P(3),K(3),K(3),K(3)
LOGICAL HIT

Hit=.TRUE.
ZT=STPT-P(3)
K(3)=1-K(3)
PTSP=P(1)*P(1)+P(2)*P(2)
PTKP=P(1)*P(1)+P(2)*P(2)
K3I=1/K(3)
K3I=S*K3I*K3I*K3I
K3I=1/A
S=ZT+S*PTKP*K3I
C=ZT*ZT-PTSP*S
R=D=SQR(B**2-A*C)
Z2=(B-RAD)*AT+P(3)
Z2=(B+RAD)*AT+P(3)
Z=MINT(Z2,Z2)
IF(Z.GT.P(3)) GO TO 1
IF(K(3).LT.0.0) RETURN
Z=MAX(Z1,Z2)
END OF COMPILATION: NO DIAGNOSTICS.
1. Purpose

This subroutine calculates the z-coordinate of the point of intersection of a ogive with a ray emanating from a point, P, interior to the surface and traveling in the K direction.

OGIVEN calculates the inward normal, N, of a ogive at a point, PI, on the surface.

2. Calls

a. CALL OGIVE(P, K, Z, HIT)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>floating-point input</td>
</tr>
<tr>
<td>is the three-dimensional array of coordinates of the interior point.</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>floating-point input</td>
</tr>
<tr>
<td>is the three-dimensional array of wavenumbers of the ray.</td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>floating-point output</td>
</tr>
<tr>
<td>is the z-coordinate of the point of intersection</td>
<td></td>
</tr>
<tr>
<td>HIT</td>
<td>logical output</td>
</tr>
<tr>
<td>is set to .TRUE. if the ray intersects the surface and .FALSE. otherwise</td>
<td></td>
</tr>
</tbody>
</table>

b. CALL OGIVEN(PI, N)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>floating-point input</td>
</tr>
<tr>
<td>is the three-dimensional array of coordinates of a point on the surface</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>floating-point output</td>
</tr>
<tr>
<td>is the three-dimensional array of components of the inward normal at the point PI.</td>
<td></td>
</tr>
</tbody>
</table>

3. Comments

a. Restriction: (K3) ≠ 0.0

b. The main axis of the ogive is assumed to be the z-axis.

c. Subroutine OGIVE calls subroutine QUARTC.

d. The ogive is described by the equation

\[ \sqrt{K^2 + Y^2} = \sqrt{R^2 - (Z - AP)^2} - B. \]

e. The required parameters are

\[ \begin{align*}
RP &= R^2 - B^2 \\
BSQ &= B^2 \\
AP &= \frac{1}{R} \\
RINV &= \frac{1}{R} \\
B &= \frac{1}{R}
\end{align*} \]

4. Listing

See following page.
SUBROUTINE OGIVE (PO, K, Z, HIT)

THIS SUBROUTINE SOLVES FOR THE INTERSECTION OF A RAY AND AN OGIVE.

INPUT
PO REAL ARRAY OF COEFFICIENTS OF INSIDE POINT
K REAL ARRAY OF DIRECTION COSINES OF RAY

OUTPUT
Z VALUE OF Z COMPONENT OF INTERSECTION
HIT TRUE, IF THE RAY HIT THE SURFACE

IT IS ASSUMED THAT THIS SUBROUTINE WILL NOT BE CALLED WITH K(3)=0.

REAL PO(3), K(3), M1, M2, COEF(4)
REAL Z TEMP(4)
COMPLEX ZA(4)
LOGICAL HIT
HIT TRUE.

THE OGIVE SHAPE IS DESCRIBED BY THE EQUATION
5RT(x**2+y**2)=5RT(R**2-(Z-AP)**2) = B

THE DATA NEEDED FOR THE DATA STATEMENT IS

RP = R**2-B**2
ZS = B**2
AP = AP
RINV = 1.0/R
B = H
RSO1 = R**2

DATA RP, B, 503, AP/6128.393, 16562.22, -18.3034317/
DATA RINV, H, RS01/0.0066298462, 128.69429, 22750.613/
A = PO(3) - AP
M1 = 1.0/K(3)
M2 = K(2)*M1
M1 = K(1)*M1
00174  62*  212  ZP=REAL(ZA(3))
00175  63*  IF (ZP,GT,0.) GO TO 213
00177  64*  ZTEMP(I)=ZP
00206  65*  I=I+1
00201  66*  213  ZTEMP(I)=REAL(ZA(4))
00202  67*  Z=P0(3)+AMAX1(ZTEMP(1),ZTEMP(2))
00203  68*  RETURN
00204  69*  ENTRY OSIVEN (PI,N)
00204  70*  C  THIS ENTRY POINT CALCULATES THE INWARD NORMAL TO THE OGIVE SURFACE
00204  71*  C  AS A PARTICULAR POINT.
00204  72*  C  INPUT  PI--REAL ARRAY OF COEFFICIENTS OF THE POINT
00204  73*  C  OUTPUT  N--REAL ARRAY OF DIRECTION COSINES OF NORMAL TO
00204  74*  C  SURFACE AT POINT OF INTERSECTION
00206  75*  22  REAL N(3),NTAN,PI(3)
00207  76*  N(3)=-(PI(3)-AP)*RINV
00210  77*  R=SQRT(PI(1)*PI(1)+PI(2)*PI(2))
00211  78*  NTAN=-(R+3)*RINV/R
00212  79*  N(1)=PI(1)*NTAN
00213  80*  N(2)=PI(2)*NTAN
00214  81*  RETURN
00215  82*  END

END OF COMPILATION:  NO DIAGNOSTICS.
APPENDIX N

SUBROUTINE PARA WITH ENTRY PARAN

1. Purpose

This subroutine calculates the z-coordinate of the point of intersection of a paraboloid with a ray emanating from a point, P, interior to the surface and traveling in the K direction.

The entry PARAN, calculates the inward normal, N, of a paraboloid at a point, PI, on the surface.

2. Calls

a. CALL PARA(P, K, Z, HIT)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>is the three-dimensional array of coordinates of the interior point floating-point</td>
</tr>
<tr>
<td>K</td>
<td>is the three-dimensional array of wavenumbers of the ray floating-point</td>
</tr>
<tr>
<td>Z</td>
<td>is the z-coordinate of the point of intersection floating-point</td>
</tr>
<tr>
<td>HIT</td>
<td>is set to .TRUE. if the ray intersects the surface and .FALSE. otherwise logical output</td>
</tr>
</tbody>
</table>

b. CALL PARAN(PI, N)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>is the three-dimensional array of coordinates of a point on the surface floating-point</td>
</tr>
<tr>
<td>N</td>
<td>is the three-dimensional array of components of the inward normal at the point PI floating-point</td>
</tr>
</tbody>
</table>

3. Comments

a. Restriction: K(3) ≠ 0.0

b. The main axis of the paraboloid is assumed to be the z-axis.

c. The paraboloid is described by the equation

\[-2F(Z-ZTIP) = X^2 + Y^2.\]

d. The required parameters are F and ZTIP.

4. Listing

See following page.
SUBROUTINE PARA(P,K,Z,HIT)
C PARA CALCULATES THE Z COORDINATE OF THE POINT OF INTERSECTION OF A
C PARABOLA AND A RAY ORIGINATING FROM A POINT INTERIOR TO THE PARABOLA
C AND TRAVELING IN THE DIRECTION K
C
C THE EQUATION USED FOR THE PARABOLA IS -P*(Z-ATIP)=X**2+Y**2
C
C SET PARABOLA PARAMETERS:
DATA F*ATIP/5.35212, 77.75275/
C
REAL P(3),K(3),ATS0,K31
LOGICAL HIT
HIT=TRUE
I=1-1.*K(3)
IFS=P(1)*I+P(2)*I
PBT=P(1)*K(1)+P(2)*K(2)
K31=I/K(3)
A=R*KTS0*K31*31
A=1/1.*A=12)
C=PTSO-K*P(3))
C=(C+R)*A=2*A*C)
Z=Z+R0)*A=1+P(3)
RETURN
Z=P(3)
RETURN

END OF COMPILED:      NO DIAGNOSTICS.
SUBROUTINE HEMI WITH ENTRY HEMIN

1. Purpose

This subroutine calculates the z-coordinate of the point of intersection of a sphere with a ray emanating from a point, P, interior to the surface and traveling in the K direction.

HEMIN calculates the inward normal, N, of a sphere, at a point, PI, on the surface.

2. Calls

a. CALL HEMI(P, K, Z, HIT)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>is the three-dimensional array of coordinates of the interior point floating-point input</td>
</tr>
<tr>
<td>K</td>
<td>is the three-dimensional array of wavenumbers of the ray floating-point input</td>
</tr>
<tr>
<td>Z</td>
<td>is the z-coordinate of the point of intersection floating-point output</td>
</tr>
<tr>
<td>HIT</td>
<td>is set to .TRUE., if the ray intersects the surface and .FALSE. otherwise logical output</td>
</tr>
</tbody>
</table>

b. CALL HEMIN(PI, N)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>is the three-dimensional array of coordinates of a point on the surface floating-point input</td>
</tr>
<tr>
<td>N</td>
<td>is the three-dimensional array of components of the inward normal at the point PI floating-point output</td>
</tr>
</tbody>
</table>

3. Comments

a. Restriction: K(3) ≠ 0.0
b. The main axis of the sphere is assumed to be the z-axis.
c. The sphere is described by the equation

\[ x^2 + y^2 + (z-z_cntr)^2 = rsq. \]

d. The required parameters are

\[ \begin{align*}
  z_cntr \\
  rsq \\
  radinv = \frac{1}{rsq}
\end{align*} \]

4. Listing

See following page.
SUBROUTINE HEMI(P,K,Z,HIT)

HEMI CALCULATE THE Z COORDINATE OF THE POINT OF INTERSECTION OF A SPHERE AND A RAY EMINATING FROM A POINT P INTERIOR TO THE SPHERE AND TRAVELING IN THE K DIRECTION.

THE EQUATION USED FOR THE SPHERE IS X**2+Y**2+(Z-ZCNTR)**2 = RSQ

SET HEMISPHERE PARAMETERS:

DATA ZCNTR,R5Q/10.325,100.654/
REAL P(3),K(3),KTSQ,K3I
LOGICAL HIT

ZT=P(3)-ZCNTR
KTSQ=1-K(3)*K(3)
K3I=1/K(3)

A=2*(1-KTSQ*K3I*K3I)
AI=1/A
PTKT=P(1)-K(1)*P(2)*K(2)

B=2*(ZT+PTKT*K3I)
C=PTSQ+ZT*ZT-RSQ

RAD=SQRT(3*B-2*A*C)
Z1=(-B-RAD)*AI+P(3)
Z2=(-B+RAD)*AI+P(3)

IF(K(3),GE,.0) GO TO 1

Z=MIN(Z1,Z2)
RETURN

1 Z=MAX(Z1,Z2)
RETURN
00102   31*   C   CALCULATE inward NORMAL OF HEMISPHERE
00102   32*   C
00102   33*   C   ENTRY DEMIN(PJ,0)
00102   34*   REAL PI(5)*PI(3)
00102   35*   C
00102   36*   C
00102   37*   C   FIND INVERSE OF THE RADIUS FROM RSO
00102   38*   C   RADI=1/SQRT(RSO)
00102   39*   C
00102   40*   C   J=16 RADIUS/0.10542/
00103   41*   C   N(1)=PI(1)*RADIUS
00103   42*   C   N(2)=PI(2)*RADIUS
00103   43*   C   N(3)=(PI(3)-CENTER)*RADIUS
00103   44*   C   RETURN
00104   45*   C

END OF Compilation.  NO DIAGNOSTICS.
APPENDIX P

SUBROUTINE SNELL

1. Purpose

This subroutine computes the direction of reflection of a plane wave incident on a plane.

2. Call

CALL SNELL(K, N, KR)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>floating-point</td>
</tr>
<tr>
<td>N</td>
<td>floating-point</td>
</tr>
<tr>
<td>KR</td>
<td>floating-point</td>
</tr>
</tbody>
</table>

K: wavenumber direction (Kx, Ky, Kz) of incident plane wave
N: wavenumber direction of inward normal of plane (Nx, Ny, Nz)
KR: wavenumber direction of reflected plane wave (KRx, K Ry, KRz)

3. Comments

a. K, N, and NR are each three dimensional.
b. K, N, and Kr have unity magnitude.

4. Listing

See following page.
SUBROUTINE SHELL(K,N,KR)
C CALCULATE THE UNIT VECTOR KR WHICH IS THE NEGATIVE OF THE
C REFLECTION OF K THROUGH H.
REAL K(3),N(3),KR(3)
C=2*(K(1)*N(1)+K(2)*N(2)+K(3)*N(3))
KR(1)=K(1)-C*N(1)
KR(2)=K(2)-C*N(2)
KR(3)=K(3)-C*N(3)
RETURN
END

END OF COMPILATION: NO DIAGNOSTICS.
APPENDIX Q

SUBROUTINE AXB

1. Purpose

This subroutine computes the vector cross product of two real vectors. A rectangular coordinate system is assumed for the discussion below.

2. Call

CALL AXB(A,B,C).

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>real array, input</td>
</tr>
<tr>
<td>B</td>
<td>real array, input</td>
</tr>
<tr>
<td>C</td>
<td>real array, output</td>
</tr>
</tbody>
</table>

3. Comments

a. A(1) is the x-component of the vector a, A(2) is the y-component of the vector a, etc.

b. The order of the arrays A and B in the call of AXB is important since b x a = -a x b.

c. No supporting subroutines are required.

4. Listing

See following page.
SUBROUTINE AXB(A, B, C)
DIMENSION A(3), B(3), C(3)
C THIS SUBR COMPUTES VECTOR CROSS PRODUCT OF A, B; RESULTS IN C.
C(1) = A(2) * B(3) - A(3) * B(2)
C(2) = A(3) * B(1) - A(1) * B(3)
C(3) = A(1) * B(2) - A(2) * B(1)
RETURN
END

END OF COMPILATION: NO DIAGNOSTICS.
APPENDIX R

SUBROUTINE IPLANE WITH ENTRY PLANE

1. Purpose

IPLANE computes the equation of a plane in a second coordinate system. PLANE then computes the intersection of a straight line with that plane in the second coordinate system.

2. Calls

a. Call IPLANE(T, PO)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>the rotation matrix (3,3) describing a second coordinate system with respect to another coordinate system</td>
</tr>
<tr>
<td>PO</td>
<td>the translation matrix (3) describing the translation of a second coordinate system with respect to another coordinate system</td>
</tr>
</tbody>
</table>

b. CALL PLANE(P, K, PI)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>the coordinates (X,Y,Z) of a point on the line in the second coordinate system</td>
</tr>
<tr>
<td>K</td>
<td>wavenumber direction of the line in the second coordinate system (Kx,Ky,Kz)</td>
</tr>
<tr>
<td>PI</td>
<td>the coordinates of the point of intersection given in the second coordinate system (XI,YI,ZI)</td>
</tr>
</tbody>
</table>

3. Comments

a. PO, P, K, and PI and all three dimensional arrays.
b. T is a three by three array of direction cosines.
c. K must have unity magnitude.

4. Listing

See following page.
00101  1*  D/JR(OUT) = PLAN(T*PO)
00103  2*  PLAN(T(3,3) + D0(3) + C(4))
00104  3*  C(4) = 3,
00105  4*  D7 = 1 I=1, 011
00106  5*  1 C(1) = T(1, 0)
00112  6*  002  I=1, 011
00115  7*  2 C(4) = C(4) + C(T)*PO(1)
00117  8*  RETURN
00120  9*  ENTRY PLANPE(P*K*P1)
00122 10*  R = L P(3), K(3), P1(3)
00123 11*  D/T = C(1)*P(1) + C(2)*P(2) + C(3)*K(3)
00124 12*  DOTK = C(1)*K(1) + C(2)*K(2) + C(3)*K(3)
00125 13*  D = (D)TP + C(4) / DOTK
00126 14*  P1(1) = K(1)*5 + P(1)
00127 15*  P1(2) = K(2)*5 + P(2)
00128 16*  P1(3) = K(3)*5 + P(3)
00131 17*  RETURN
00132 18*  END

END OF COMPIIATION:  NO DIAGNOSTICS.
APPENDIX S

SUBROUTINE INTRPO WITH ENTRY PW

1. Purpose

This subroutine computes interpolated values from a discrete plane wave spectrum using a second order bivariate interpolation formula. INTRPO is called to calculate some initializing values and load in the plane wave spectrum to be interpolated.

2. Calls

a. CALL INTRPO (XPWS, YPWS, NX, NY, KXMAX, KYMAX)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>XPWS the x component of the plane wave spectrum</td>
<td>complex array, input</td>
</tr>
<tr>
<td>YPWS the y component of the plane wave spectrum</td>
<td>complex array, input</td>
</tr>
<tr>
<td>NX the number of rows in the plane wave spectrum</td>
<td>FORTRAN integer, input</td>
</tr>
<tr>
<td>NY the number of columns in the plane wave</td>
<td>FORTRAN integer, input</td>
</tr>
<tr>
<td>wave spectrum, where increasing row indices</td>
<td></td>
</tr>
<tr>
<td>correspond to increasing Kx</td>
<td></td>
</tr>
<tr>
<td>KXMAX the range of the Kx wavenumbers in the</td>
<td>floating-point</td>
</tr>
<tr>
<td>plane wave spectrum is from -KXMAX to</td>
<td>variable, input</td>
</tr>
<tr>
<td>(1-2/NX) KXMAX</td>
<td></td>
</tr>
<tr>
<td>KYMAX the range of the Ky wavenumbers in the</td>
<td>floating-point</td>
</tr>
<tr>
<td>plane wave spectrum is from -KYMAX to</td>
<td>variable, input</td>
</tr>
<tr>
<td>(1-2/NY) KYMAX</td>
<td></td>
</tr>
</tbody>
</table>

b. CALL PW(K,XPW,YPW,WITHIN)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>K the wavenumber coordinate for which the value</td>
<td>floating-point array,</td>
</tr>
<tr>
<td>of the wavenumber spectrum is to be determined</td>
<td>input</td>
</tr>
<tr>
<td>(Kx,Ky,Kz)</td>
<td></td>
</tr>
<tr>
<td>XPW the x component of the interpolated plane</td>
<td>complex variable,</td>
</tr>
<tr>
<td>wave spectrum</td>
<td>output</td>
</tr>
<tr>
<td>YPW the y component of the interpolated plane</td>
<td>complex variable,</td>
</tr>
<tr>
<td>wave spectrum</td>
<td>output</td>
</tr>
<tr>
<td>WITHIN an indicator of the interpolation</td>
<td>logical variable,</td>
</tr>
<tr>
<td>= .TRUE. the input K was within the wavenumber</td>
<td></td>
</tr>
<tr>
<td>limits of the spectrum</td>
<td></td>
</tr>
<tr>
<td>= .FALSE. the input K was not within the limits</td>
<td></td>
</tr>
<tr>
<td>of the wavenumber spectrum</td>
<td></td>
</tr>
</tbody>
</table>
3. Comments
   a. The wavenumber coordinate $K$ must have unit magnitude, in which $K_x^2 + K_y^2 \leq 1$ corresponds to visible energy.
   b. $K$ is a one dimensional array.

4. Listing
   See following page.
SUBROUTINE INTERPOLXPW(XPWS,YPWS,KX,KY,KMAX,KMAX)

  INTERPOLATE THE X AND Y COMPONENT OF A PLANE WAVE SPECTRUM, XPWS
  AND YPWS RESPECTIVELY, TO FIND THE X AND Y COMPONENTS, IN A
  SPECIFIED WAVENUMBER DIRECTION K.

  COMPLEX XPRW(KX,KY),YPW(KX,KY)
  REAL KMAX(KX,KY)
  DELI=NX/(2*KX*KMAX)
  DELJ=NY/(2*KY*KMAX)
  CI=NX/2+1
  CJ=NY/2+1

  ENTRY PW(K,XPW,YPW,WITHIN)

  IF THE WAVE NUMBER K IS NOT WITHIN THE DEFINED LIMITS OF THE PLANE
  WAVE SPECTRUM KMAX AND KYMAX A 'FALSE' VALUE FOR THE LOGICAL VARIABLE
  WITHIN IS RETURNED

  ENTRY PW(K,XPW,YPW,WITHIN)

  REAL K(3)
  COMPLEX XPRW,YPW
  LOGICAL WITHIN
  R1=K(1)*DELI+CI
  R2=K(2)*DELJ+CJ
  IL=RI
  I=IL+1
  JR=RJ
  JH=JL+1
  IF(I1.LT.1.OR.JL.LT.1) GO TO 1
  IF(IH.GT.KX.OR.JH.GT.KY) GO TO 1
  R1=RI-I
  JR=JR-J

  FORM CONSTANTS FOR INTERPOLATION EQUATION
THE FOUR POINT BIVARIATE INTERPOLATION FORMULA IS FROM THE
HANDBOOK OF MATHEMATICAL FUNCTIONS OF THE NATIONAL BUREAU OF
STANDARDS, PAGE 882.

RIJ = (1 - RI)
RJJ = (1 - RJ)
C1 = RI * RJ
C2 = RI * RJ
C3 = RJ * RI
C4 = RI * RJ

XPW = C1 * XPWS(IL, JL) + C2 * XPWS(IH, JL) + C3 * XPWS(IL, JH) + C4 * XPWS(IH, JH)
YPW = C1 * YPWS(IL, JL) + C2 * YPWS(IH, JL) + C3 * YPWS(IL, JH) + C4 * YPWS(IH, JH)

WITHIN = TRUE.
RETURN

1 IF(ABS(K(1)),GE,KXMAX) RETURN
2 IF(ABS(K(2)),GE,KYMAX) RETURN
3 XPW = CMPLX(1.0,0.0)
4 YPW = CMPLX(1.0,0.0)
5 WITHIN = TRUE.
6 RETURN
7 END
APPENDIX T
SUBROUTINE FFT

1. Purpose
This subroutine computes the Fast Fourier transform or the inverse Fast Fourier transform of a two dimensional complex array of data values. The results are returned in the same array. Each of the two dimensions of the input array must be equal to two raised to some integer power.

2. Call
CALL FFT(FIELD, NX, NY, ISN)
where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIELD</td>
<td>complex array, input/output</td>
</tr>
<tr>
<td>NX</td>
<td>FORTRAN integer, input</td>
</tr>
<tr>
<td>NY</td>
<td>FORTRAN integer, input</td>
</tr>
<tr>
<td>ISN</td>
<td>FORTRAN integer, input</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIELD</td>
<td>complex array, input/output</td>
</tr>
<tr>
<td>NX</td>
<td>FORTRAN integer, input</td>
</tr>
<tr>
<td>NY</td>
<td>FORTRAN integer, input</td>
</tr>
<tr>
<td>ISN</td>
<td>FORTRAN integer, input</td>
</tr>
</tbody>
</table>

3. Comments
a. NX and NY just be equal to two raised to some integer power.
b. The origin of the input and output arrays corresponds to the array location (NX/2 + 1, NY/2 + 1) and the most negative location is (1,1).
c. ISN must be equal to 1 or -1.

4. Listing
See following page.
SUBROUTINE FFT(FIELD, NX, NY, ISN)

THIS SUBROUTINE CALCULATES THE FAST FOURIER TRANSFORM OR
THE INVERSE FAST FOURIER TRANSFORM OF AN INPUT TWO
DIMENSIONAL, COMPLEX ARRAY (FIELD) AND RETURNS THE
RESULT IN SAME ARRAY.

NX AND NY ARE THE DIMENSIONS OF THE ARRAY FIELD AND MUST
BE EQUAL TO 2 RAISED TO SOME POSITIVE INTEGER POWER.

ISN IS AN INTEGER CONTROL VARIABLE WHICH MUST BE EITHER
+1 OR -1. IF ISN=-1 THE FAST FOURIER TRANSFORM IS
CALCULATED, IF ISN=+1 THE INVERSE FAST FOURIER TRANSFORM
IS CALCULATED.

THE ORIGIN OF BOTH THE INPUT AND OUTPUT COORDINATE SYSTEMS
IS LOCATED AT THE (NX/2 + 1, NY/2 +1) POINT OF THE ARRAY.

IF(IABS(ISN).NE.1) RETURN

COMPLEX FIELD(NX,NY), T1, T2
DOUBLE PRECISION PI2, 50, CO, SI, CI, SN, CS
PI2 = 6.2831853071795864800

IX = 0
1 IX = IX + 1
M = 2**IX
IF(NX-M) 2, 4, 1
WRITE(6,3)
2 FORMAT("NX IS NOT EQUAL TO 2 RAISED TO ANY POSITIVE INTEGER POWER.
$R")
RETURN

IY = 0
4 IY = IY + 1
M = 2**IY
IF(NY-M) 6, 8, 5
C
00150  32*
00152  33*
00153  34*
00154  35*
00155  36*
00156  37*
00157  38*
00158  39*
00159  40*
00160  41*
00161  42*
00162  43*
00163  44*
00164  45*
00165  46*
00166  47*
00167  48*
00168  49*
00169  50*
00170  51*
00171  52*
00172  53*
00173  54*
00174  55*
00175  56*
00176  57*
00177  58*
00178  59*
00179  60*
00180  61*
00181  62*
00182  63*
00183  64*
00184  65*
00185  66*
00186  67*
00187  68*
00188  69*
00189  70*
00190  71*
00191  72*
00192  73*
00193  74*
00194  75*
00195  76*
00196  77*
00197  78*
00198  79*
00199  80*
00200  81*
00201  82*
00202  83*
00203  84*
00204  85*
00205  86*
00206  87*
00207  88*
00208  89*
00209  90*
00210  91*
00211  92*
00212  93*
00213  94*
00214  95*
00215  96*
00216  97*
00217  98*
00218  99*
00219  100*
00220  101*
00221  102*
00222  103*
00223  104*
00224  105*
00225  106*
00226  107*
00227  108*
IF(J.LE.JFLIP) GO TO 16
J1=J+1
J2=JFLIP+1
DO 15 I=1,NX,1
T2=FIELD(I,J2)
FIELD(I,J2)=FIELD(I,J1)
15 FIELD(I,J1)=T2
CONTINUE
DO 18 I=1,NX,1
NEL=2**I
NEL2=NEL/2
NSET=NX/NEL
SI=D*SIN(P12/NEL)
CI=D*COS(P12/NEL)
DO 18 K=1,NSET,1
INCR=(K-1)*NEL
I1=L+INCR
I2=I1+NEL2
T2=FIELD(I2,J)*CMPLX(CO,ISN*SO)
FIELD(I2,J)=T1-T2
17 FIELD(I2,J)=T1+T2
SN=SO*CI+CO*SI
CS=CO*CI-SO*SI
CS=CS
DO 20 J=1,NY,1
NEL=2**J
NEL2=NEL/2
NSET=NY/NEL
SI=D*SIN(P12/NEL)
CI=D*COS(P12/NEL)
DO 20 K=1,NSET,1
INCR=(K-1)*NEL
SO=0.0D0
CO=1.0D0
DO 20 L=1, NEL2
J1=J+1NCR
J2=J1+NEL2
DO 19 I=1, NX, 1
T1=FIELD(I,J1)
T2=FIELD(I,J2)*C*PL*X(C0+ISN*50)
FIELD(I,J1)=T1+T2
FIELD(I,J2)=T1-T2
SN=SN+CI+CO*51
CS=CO*CI-SN*51
CO=CS
20 SN=SN

SHIFT ORIGIN FROM 1,1 TO NX/2+1,NY/2+1

DO 21 I=1,NX2+1
II=I+NX2

DO 21 J=1,NY,1
T1=FIELD(I,J)
FIELD(I,J)=FIELD(I1,J)
FIELD(I1,J)=T1
DO 22 J=1,NY2+1
J1=J+NY2
DO 22 I=1,NX,1
T2=FIELD(I,J)
FIELD(I,J)=FIELD(I,J1)
FIELD(I,J1)=T2
C

IF(ISN,LT,0) RETURN

R=NX*NY

DO 23 I=1,NX,1

DO 23 J=1, NY,1

23 FIELD(I,J)=FIELD(I,J)/R

RETURN

END

END OF COMPILATION:  NO DIAGNOSTICS.
APPENDIX U

SUBROUTINE BRSITE

1. Purpose

This subroutine computes the total power of a far field power pattern and the boresight direction of the far field pattern using in these computations only those values of the pattern which are greater than a specified decibel level from the peak of the pattern.

2. Call

CALL BRSITE(FIELD,NX,NY, KXMAX, KYMAX, DBCTR, FMAX, IDIV, TPWR, KXBS, KYBS, THETA,PHI, ALT)

where

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIELD</td>
<td>far field pattern as a function of the wavenumbers (Kx,Ky) floating-point array, input</td>
</tr>
<tr>
<td>NX</td>
<td>the number of rows of FIELD, increasing row indices corresponds to increasing Kx FORTRAN integer variable, input</td>
</tr>
<tr>
<td>NY</td>
<td>the number of columns of FIELD increasing column indices corresponds to increasing Ky FORTRAN integer variable, input</td>
</tr>
<tr>
<td>KXMAX</td>
<td>the range of Kx of wavenumbers in the far field pattern is from -KXMAX to (1-2/NX)KXMAX floating-point variable, input</td>
</tr>
<tr>
<td>KYMAX</td>
<td>the range of Ky wavenumbers in the far field pattern is from -KYMAX to (1-2/NY)KYMAX floating-point variable, input</td>
</tr>
<tr>
<td>DBCTR</td>
<td>decibel level for including values to be used in the computation floating-point variable, input</td>
</tr>
<tr>
<td>FMAX</td>
<td>the maximum value of the power pattern floating-point variable, input</td>
</tr>
<tr>
<td>IDIV</td>
<td>a control variable which sub-divides each cell of the FIELD array into IDIV^2 sub-cells for greater accuracy in computation when the particular cell contains the DBCTR value FORTRAN integer variable, input</td>
</tr>
<tr>
<td>TPWR</td>
<td>the total power in the far field power pattern floating-point variable, output</td>
</tr>
<tr>
<td>KXBS</td>
<td>the Kx coordinate of the boresight direction floating-point variable, output</td>
</tr>
<tr>
<td>KYBS</td>
<td>the Kx coordinate of the boresight direction floating-point variable, output</td>
</tr>
</tbody>
</table>
THETA the theta direction of the amplitude vector in the near field coordinate system floating-point variable, input

PHI the phi direction of the altitude vector in the near field coordinate system floating-point variable, input

ALT the altitude of the origin of the near field coordinate system from the flat ground floating-point variable, input

3. Comments
   a. The values of FIELD must be normalized such that the maximum value in FIELD is equal to one.
   b. DBCTR must be a negative number.

4. Listing
   See following page.
SUBROUTINE BRSITE(FIELD,NX, NY, KXMAX, KYMAX, DBCTR, FMAX, IDIV, TPWR, 
- KX3S, KY3S, THETA, PHI, ALT)

SUBROUTINE BRSITE (BORESIGHT DIRECTION) CALCULATES THE TOTAL 
POWER OF A FAR FIELD PATTERN (TPWR) AND THE BORESIGHT 
DIRECTION (KX3S, KY3S) OF THE FAR FIELD PATTERN USING IN 
THESE COMPUTATIONS ONLY THOSE VALUES OF THE PATTERN WHICH 
ARE GREATER THEN DBCTR (DECIBEL CONTOUR) DECIBELS FROM 
THE PEAK OF THE PATTERN.

FIELD(NX, NY) CONTAINS THE NORMALIZED FAR FIELD POWER PATTERN FOR 
ALL DIRECTIONS WITHIN THE RECTANGULAR WAVENUMBER REGION 
-KXMAX TO KXMAX AND -KYMAX TO KYMAX. 
FMAX IS THE NORMALIZING COEFFICIENT USED IN NORMALIZING 
FIELD.

IDIV IS A SUBDIVISION CONTROL VARIABLE WHICH SUBDIVIDES EACH 
CELL OF THE FIELD ARRAY INTO IDIV*IDIV SQUARES FOR 
GREATER ACCURACY IN COMPUTATION WHEN THE PARTICULAR CELL 
CONTAINS THE DBCTR VALUE.
REAL  KXA,KXB,KXC,KXD,KYA,KYB,KYC,KYD,KXP,KYP,INTP,KXMAX,KYMAX,
-     KXCT,KYCT,KXBS,KYBS,KX,KY,KZ,KXAF,KYAF,KZAF

INTEGER  SDIN

DIMENSION  FIELD(NX,NY)

R(KX,KY,KZ)=ALT/(KXAF*KX+KYAF*KY+KZAF*KZ)

AREA(KX,KY,KZ,DKX,DKY)=(R(KX,KY,KZ)**2/(KZ*(KX**2+KY**2)))
-     *SORT(KX**2*DKX**2+KY**2*DKY**2)*SORT(KX**2*DKX**2+

PI=3.141592653

KXAF=SIN(THETA*PI/180.)*COS(PHI*PI/180.)

KYAF=SIN(THETA*PI/180.)*SIN(PHI*PI/180.)

KZAF=COS(THETA*PI/180.)

KXP=0.

KYP=0.

TPWR=0.

DKX=2*KXMAX/NX

DKY=2*KYMAX/NY

SDKX=DKX/IDIV

SDKY=DKY/IDIV

INX=NX-1

JNY=NY-1

CTR=10**(DBCTR/10.)

ADD CONTRIBUITIONS TO TPWR AND MOMENTS FROM EACH CELL
OF FIELD.
COUNT THE NUMBER OF THE FOUR CELL CORNERS THAT ARE ABOVE THE DBCTR VALUE.

IF(A .GE. CTR) IN=IN+1
IF(B .GE. CTR) IN=IN+1
IF(C .GE. CTR) IN=IN+1
IF(D .GE. CTR) IN=IN+1
IF(IN .EQ. 0) GO TO 10

CALCULATE THE WAVENUMBER COORDINATES OF THE FOUR CORNERS.

IF(IN .NE. 4) GO TO 5

SUBDIVIDE CELLS CONTAINING DBCTR VALUE.
P0=1./IDIV
DO 100 J2=1,IDIV
SDIN = 0
SA=INTP(J2-1)*PD*I2*PD,A,B,C,D)
S3=INTP(J2*PD,I2*PD,A,B,C,D)
SC=INTP(J2-1)*PD,(I2-1)*PD,A,B,C,D)
SD=INTP(J2*PD,(I2-1)*PD,A,B,C,D)

IF(SA.GE.CTR) SDIN=SDIN+1
IF(SB.GE.CTR) SDIN=SDIN+1
IF(SC.GE.CTR) SDIN=SDIN+1
IF(SD.GE.CTR) SDIN=SDIN+1
IF(SDIN.EQ.0) GO TO 100
SKXA=INTP((J2-1)*PD*I2*PD,KXA,KXZ,KXD)
SKYA=INTP((J2-1)*PD*I2*PD,KYA,KYB,KYC,KYD)

SKXB=SKXA
SKXD=SKXA+SDKX
SKXC=SKXD
SKYB=SKYA+SDKY
SKYC=SKYB
SKYD=SKYA
KX=(SKXA+SKXD)/2.
KY=(SKYA+SKYB)/2.
KZ=SORT(1.*KX**2-KY**2)

CALCULATE CELL POWER AND MOMENT FOR SUBDIVIDED CELLS.
AVPR=(SA+S3+S5+SD)/4.
KXCT=(SA*SKYA+SB*SKX+SC*SKXC+SD*SKYD)/(4.*AVPR)
KYCT=(SA*SKYA+SB*SKYB+SC*SKYC+SD*SKYD)/(4.*AVPR)
AR=AREA(KX,KY,KZ,SDKX,SDKY)
S4=SDIN/4.0
KXP=KXP+AVPR*AR*KXCT*S4
KYP=KYP+AVPR*AR*KYCT*S4
TPWR=TPWR+AVPR*AR*S4
CONTINUE
$K_x = (K_x A + 0 0) / 2.$

$K_y = (K_y A + 0 3) / 2.$

$K_z = \sqrt{1 - K_x^2 - K_y^2}$

C cell power=

Lac: $C_{cell} = \sum_{vpR} (A + C + D) / 4.$

$K_x c = (A * K_x A - 3 * K_x C + 0 * (D) / (4 * AvPR)$

$K_y c = (A * K_y C + 0 * (D) / (4 * AvR) / 2)$

$A(x) = \text{AREA}(K_x, K_y, K_z, D)$

$K_p = K_x + AvPR * AvR * K_x C$

$K_t P = K_y + AvR * AvR * K_y C$

$T_P = \text{TPW} * F_{v1AX}$

$R = \text{TURN}$

C*********************************************************************

FUNCTION

$F_{TPW} (P_{P0} F_{File F3}, F2, F0)

IQTP = (1 - P) * (1.41) * F0 + P * (10) * F2 + 0 * (1 - 1.2) * F1 + P * AvP * F3$

RETURN

END OF Compilation: NO DIAGNOSTIC.
APPENDIX V

SUBROUTINE SDLOBE

1. Purpose

This subroutine computes the magnitude in decibels and the wavenumber coordinates of the specified side lobe of a normalized far field power pattern.

2. Call

CALL SDLOBE (FIELD,NX,NY,NPTS,KXSL,KYSL,DBSL,KXMAX,KYMAX,ISD)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIELD normalized far field power</td>
<td>floating-point</td>
</tr>
<tr>
<td>pattern as a function of Kx and Ky wavenumbers</td>
<td>array, input</td>
</tr>
<tr>
<td>NX the number of rows of FIELD,</td>
<td>FORTRAN integer</td>
</tr>
<tr>
<td>where increasing row indices</td>
<td>variable, input</td>
</tr>
<tr>
<td>correspond to increasing Kx</td>
<td></td>
</tr>
<tr>
<td>NY the number of columns of FIELD</td>
<td>FORTRAN integer</td>
</tr>
<tr>
<td>where increasing column indices</td>
<td>variable, input</td>
</tr>
<tr>
<td>correspond to increasing Kx wave numbers</td>
<td></td>
</tr>
<tr>
<td>NPTS the number of points in each</td>
<td>FORTRAN integer</td>
</tr>
<tr>
<td>of eight direction searched to</td>
<td>variable, input</td>
</tr>
<tr>
<td>determine if the center point is</td>
<td></td>
</tr>
<tr>
<td>a local maximum</td>
<td></td>
</tr>
<tr>
<td>KXSL Kx coordinate of the sidelobe</td>
<td>floating-point</td>
</tr>
<tr>
<td>variable, output</td>
<td></td>
</tr>
<tr>
<td>KYSL the Ky coordinate of the</td>
<td>floating-point</td>
</tr>
<tr>
<td>sidelobe</td>
<td>variable, output</td>
</tr>
<tr>
<td>DBSL the magnitude in decibels of</td>
<td>floating-point</td>
</tr>
<tr>
<td>the sidelobe</td>
<td>variable, output</td>
</tr>
<tr>
<td>KXMAX the range of the Kx wavenumbers</td>
<td>floating-point</td>
</tr>
<tr>
<td>numbers in the far field pattern</td>
<td>variable, input</td>
</tr>
<tr>
<td>is from KXMAX to (1 - 2/NY) KYMAX</td>
<td></td>
</tr>
<tr>
<td>KYMAX the range of the Ky wavenumbers</td>
<td>floating-point</td>
</tr>
<tr>
<td>numbers in the far field pattern</td>
<td>variable, input</td>
</tr>
<tr>
<td>is from -KYMAX to (1 - 2/NY) KYMAX</td>
<td></td>
</tr>
</tbody>
</table>

161
ISD  a control variable  FORTRAN integer
   = 1 the maximum sidelobe
      variable, input
      is found
   = 2 the second largest
      sidelobe is found

3. Comments
   a. FIELD is normalized such that the maximum value of FIELD is one.
   b. ISD must be either 1 or 2.
   c. Wavenumbers are normalized such that $K_x^2 + K_y^2 \leq 1$ correspond
to visible radiation.

4. Listing
   See following page.
SUBROUTINE SDLOBE(FIELD,NX,NY,NPTS,KXSL,KYSL,DBSL,KXMAX,KYMAX,ISD)

SUBROUTINE SDLOBE(SIDEL) FINDS THE MAGNITUDE IN DB (DBSL) AND WAVENUMBER COORDINATE (KXSL,KYSL) OF THE SPECIFIED SIDELobe OF A NORMALIZED FAR FIELD POWER PATTERN (FIELD(NX,NY)).

THIS PROGRAM FINDS ALL LOCAL MAXIMUMS OF THE POWER PATTERN. THE SECOND LARGEST MAXIMUM IS CALLED THE MAXIMUM SIDELobe. NPTS CONTROLS THE SIZE OF THE REGION IN WHICH A MAXIMUM IS SOUGHT.

IF ISD=1 THE VALUES RETURNED ARE FOR THE LARGEST SIDELobe.
IF ISD=2 VALUES ARE RETURNED FOR THE SECOND LARGEST SIDELobe.

DIMENSION FIELD(NX,NY)
REAL KXSL,KYSL,KXMAX,KYMAX
INTEGER NPTS
LOGICAL LMAX
PI=3.141592653
ISL1=1
ISL2=1
ISL3=1
JSL1=1
JSL2=1
JSL3=1
SLMIN=10,*(10)

N=NPTS-1
NP=NPTS+1
INX=NX-NPTS
JNY=NY-NPTS
DO 10 TEMP=MX
DO 10 JENP=NY
IF(FIELD(I,J).LE.SLMIN) GO TO 10

Determine if Field(I,J) is a local maximum.
IF(.NOT.LMAX(I,J)) GO TO 10
IF(FIELD(I,J).LT.FIELD(ISL3,JSL3)) GO TO 10

Update the coordinates of the three highest maxima
ISL3=I
JSL3=J
IF(FIELD(I,J).LT.FIELD(ISL3,JSL3)) GO TO 10

ISL3=ISL2
JSL3=JSL2
ISL2=I
JSL2=J
IF(FIELD(I,J).LT.FIELD(ISL2,JSL2)) GO TO 10

ISL2=ISL1
JSL2=JSL1
ISL1=I
JSL1=J
IF(FIELD(I,J).LT.FIELD(ISL1,JSL1)) GO TO 10

ISL1=ISL2
JSL1=JSL2
ISL2=ISL3
JSL2=JSL3
10 CONTINUE

IF(FIELD(ISL,JSL).LT.SLMIN) RETURN

RETURN

FUNCTION LMAX(I,J)
LMAX=.FALSE.
GOTO 100
00211  72*  IF(FIELD(I-M,J+M) .LE. FIELD(I-M-1,J+M+1)) GO TO 100
00213  73*  IF(FIELD(I,J+M) .LE. FIELD(I,J+M+1)) GO TO 100
00215  74*  IF(FIELD(I+M,J+M) .LT. FIELD(I+M+1,J+M+1)) GO TO 100
00217  75*  IF(FIELD(I+M,J) .LT. FIELD(I+M+1,J)) GO TO 100
00221  76*  IF(FIELD(I+M,J-M) .LT. FIELD(I+M+1,J-M-1)) GO TO 100
00223  77*  IF(FIELD(I,J-M) .LT. FIELD(I,J-M-1)) GO TO 100
00225  78*  IF(FIELD(I-M,J-M) .LE. FIELD(I-M-1,J-M-1)) GO TO 100
00227  79*  50  CONTINUE
00231  80*  LMAX=.TRUE.
00232  81*  100  CONTINUE
00233  82*  RETURN
00234  83*  END

END OF COMPILATION:  NO DIAGNOSTICS.
APPENDIX W

SUBROUTINE ERRORS

1. Purpose

This subroutine calculates differences between four far field parameters of two far field patterns and prints the results in tabular form. The far field patterns are the patterns of the same antenna with and without radome in plane.

2. Call

CALL ERRORS (TFIELD,RFIELD,NX,NY,TKXBS,TKYBS,RKXBS,RKYBS,TDBSL,RDBSL,TKXSL,TKYSL,RKXSL,RKYSL,DBCTR,TTPWR,RTPWR,VSWR)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFIELD</td>
<td>the far field power pattern of the antenna without radome floating-point array, input</td>
</tr>
<tr>
<td>RFIELD</td>
<td>the far field power pattern of the antenna with radome floating-point array, input</td>
</tr>
<tr>
<td>NX</td>
<td>the number of rows in TFIELD and RFIELD, where increasing floating-point variable, input</td>
</tr>
<tr>
<td>NY</td>
<td>the number of columns in TFIELD and RFIELD, where increasing column indices correspond to increasing Ky floating-point variable, input</td>
</tr>
<tr>
<td>TKXBS</td>
<td>Kx direction of boresight without radome floating-point variable, input</td>
</tr>
<tr>
<td>TKYBS</td>
<td>Ky direction of boresight without radome floating-point variable, input</td>
</tr>
<tr>
<td>RKXBS</td>
<td>Kx direction of boresight with radome floating-point variable, input</td>
</tr>
<tr>
<td>RKYBS</td>
<td>Ky direction of boresight with radome floating-point variable, input</td>
</tr>
<tr>
<td>TDBSL</td>
<td>sidelobe level in decibels without radome floating-point variable, input</td>
</tr>
<tr>
<td>RDBSL</td>
<td>sidelobe level in decibels with radome floating-point variable, input</td>
</tr>
<tr>
<td>TKXSL</td>
<td>Kx direction of sidelobe without radome floating-point variable, input</td>
</tr>
<tr>
<td>Variable</td>
<td>Description</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>TKYSL</td>
<td>Ky direction of sidelobe without radome</td>
</tr>
<tr>
<td>RKSBL</td>
<td>Kx direction of sidelobe with radome</td>
</tr>
<tr>
<td>RKYSL</td>
<td>Ky direction of sidelobe with radome</td>
</tr>
<tr>
<td>DBCTR</td>
<td>Decibel level used in computation of boresight direction and total power</td>
</tr>
<tr>
<td>TTPWR</td>
<td>Total power of antenna without radome</td>
</tr>
<tr>
<td>RTPWR</td>
<td>Total power of antenna with radome</td>
</tr>
<tr>
<td>VXWR</td>
<td>VSWR in the feed system of the radome inclosed antenna due to reflections from the inner radome surface.</td>
</tr>
</tbody>
</table>

3. Comments

a. TTPWR must be greater than zero.

b. All wavenumbers are normalized and must be greater than -1 and less than +1.

c. Both TFIELD and RFIELD are normalized to a maximum value of one.

4. Listing

See following page.
CPCALCULATION OF ELEVATION AND AZIMUTH FOR DORESIGHT DIRECTION

1. \( \text{EL} = 90 - \cos(\sqrt{1 - \text{KY}^2}) \times 100 / \pi \)
2. \( \text{AZ} = 90 - \cos(\sqrt{1 - \text{KY}^2}) \times 100 / \pi \)

CPCALCULATION OF SIDELOBE CHANGE

3. \( \text{CS} = \text{TGSL} - \text{ROBSL} \)

CPCALCULATION OF AZIMUTH AND ELEVATION FOR MAXIMUM SIDELOBE

4. \( \text{TSL} = \text{AZ} (\text{KXSL}, \text{TKYSL}) \)
5. \( \text{RSL} = \text{AZ} (\text{RAXSL}, \text{RKYSL}) \)

CPCALCULATION OF SIDELOBE CHANGE

6. \( \text{CSL} = \text{TSL} - \text{SL} \)

CPCALCULATION OF LOSS
```
00123  31*  C  
00124  32*  C  
00124  33*  C  
00124  34*  C  
00124  35*  C  
00125  36*  C  
00126  37*  C  
00127  38*  C  
00127  39*  C  
00128  40*  C  
00129  41*  C  
00130  42*  C  
00131  43*  C  
00131  44*  C  
00131  45*  C  
00132  46*  C  
00132  47*  C  
00133  48*  C  
00133  49*  C  
00133  50*  C  
00134  51*  C  
00135  52*  C  
00135  53*  C  
00136  54*  C  
00136  55*  C  
00137  56*  C  
00137  57*  C  
00138  58*  C  
00138  59*  C  
00139  60*  C  
00139  61*  C  
00140  62*  C  
00140  63*  C  
00141  64*  C  
00141  65*  C  
00142  66*  C  
00142  67*  C  
00143  68*  C  
00143  69*  C  
00144  70*  C  
00144  71*  C  
00145  72*  C  
00145  73*  C  
00145  74*  C  
00146  75*  C  
00146  76*  C  
00147  77*  C  
00147  78*  C  
00148  79*  C  
00148  80*  C  
00149  81*  C  
00149  82*  C  
00149  83*  C  
00149  84*  C  
00150  85*  C  
00150  86*  C  
00151  87*  C  
00151  88*  C  
00152  89*  C  
00152  90*  C  
00153  91*  C  
00153  92*  C  
00154  93*  C  
00154  94*  C  
00155  95*  C  
00155  96*  C  
00156  97*  C  
00156  98*  C  
00157  99*  C  
00157 100*  C  
00158 101*  C  
00158 102*  C  
00159 103*  C  
00159 104*  C  
00160 105*  C  
00160 106*  C  
00161 107*  C  
00161 108*  C  
00162 109*  C  
00162 110*  C
```

```
CPWR=-10.0*LOG10(RTPWR/TPWR)

DISTORTION CALCULATION

PWR=0.
DIST=0.
DO 20 I=1,NX
    DO 20 J=1,NY
        PWR=TFIELD(I,J)+PWR
        DIST=DIST+((TFIELD(I,J)-RFIELD(I,J))**2
    CONTINUE

DIST=SQR(DIST/(NX*NY))*100/PWR

PRINT RESULTS

WRITE(6,1)
FORMAT(1H1,/,132('*'),/132('*'),3(/),53X,'FAR FIELD POWER PATTERN'
- ' STATISTICS',7(/),15X,'PARAMETER',33X,'TRUE PATTERN',18X,
50X,'WITH RADOME',13X,'CHANGE IN PARAMETER',4(/))

WRITE(6,2)
FORMAT(2X,'1. BORESIGHT DIRECTION')
WRITE(6,3)
FORMAT(17X,'AZIMUTH',30X,F7.3,' DEGREES',15X,F7.3,' DEGREES',11X,
F8.4,' MILLIRADIANS')
WRITE(6,4)
FORMAT(15X'ELEVATION',30X,F7.3,' DEGREES',15X,F7.3,' DEGREES',
11X,F8.4,' MILLIRADIANS')
WRITE(6,5)
FORMAT(2X,'2. MAXIMUM SIDELOBE LEVEL',26X,F7.3,' DB' DECIBELS',
14X,F7.3,' DB' DECIBELS')
WRITE(6,6)
FORMAT(2X,'3. DIRECTION OF MAXIMUM SIDELOBE')
WRITE(6,7)
FORMAT(2X,'4. DIRECTION OF MAXIMUM SIDELOBE')
WRITE(6,8)
FORMAT(2X,'5. DIRECTION OF MAXIMUM SIDELOBE')
WRITE(6,9)
```

00217  71*  9  FORMAT(2X,14.  RELATIVE POWER BY 1X,F3.1)  OR CONTOUR:17X1
00217  72*  -  *0.00 DECIMELS:14X,F7.3* DECIMELS:10X,F8.4* DECIMELS
00217  73*  -  *3(7))  WRITE(5,11) DISTRIJST
00224  75*  10  FORMAT(2X,5.  RELATIVE PATTERN DISTORTION:17X,F9.3 PERCENT.
00224  76*  -  15X,F7.3* PERCENT:11X,F8.4* PERCENT:3(7))
00225  77*  ZER0=0.1  WRITE(5,12) ZER0,USR,USR
00226  78*  WRITE(5,12) ZER0,USR,USR
00233  80*  -  17X,F9.3,10(7))  WRITE(5,11).
00234  81*  11  FORMAT(132(*))/132(*))
00236  82*  RETURN
00237  83*  END
00240  84*  END

END OF COMPILATION: NO DIAGNOSTICS.
APPENDIX X

SUBROUTINE DB

1. Purpose

The subroutine converts the units of an input array which is normalized from zero to one in linear power units to decibels. All values of the array which are less than -40 dB are set equal to -40 dB.

2. Call

CALL DB (FIELD,NX,NY)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIELD data values</td>
<td>floating-point array, input/output</td>
</tr>
<tr>
<td>NX the number of rows of FIELD</td>
<td>FORTRAN integer variable, input</td>
</tr>
<tr>
<td>NY the number of columns of FIELD</td>
<td>FORTRAN integer variable, input</td>
</tr>
</tbody>
</table>

3. Comments

None

4. Listing

See following page.
SUBROUTINE DB (FIELD, NX, NY):

SUBROUTINE DB CONVERTS AN INPUT ARRAY (FIELD(NX, NY)) OF
POWER VALUES TO DECIBLES AND RETURNS DB VALUES IN THE
SAME ARRAY.

ALL VALUES OF POWER LESS THAN 40 DB DOWN ARE SET EQUAL TO 40 DB

DIMENSION FIELD(NX, NY)

DO 10 I=1, NX

DO 10 J=1, NY

IF (FIELD(I, J) .LE. 1E-4) FIELD(I, J) = 1E-4

FIELD(I, J) = 10.0 * ALOG10(FIELD(I, J))

10 CONTINUE

RETURN

END
APPENDIX Y

SUBROUTINE PLOT3D

1. Purpose

This subroutine plots on a CAL COMP Plotter a two dimensional graph of data values.

2. Call

CALL PLOT3D (XSIZE, YSIZE, HEIGHT, FIELD, IMAX, JMAX, NMZ)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>XSIZE</td>
<td>the width of the plot in inches</td>
</tr>
<tr>
<td>YSIZE</td>
<td>the height of a plot of an array of zeros in inches</td>
</tr>
<tr>
<td>HEIGHT</td>
<td>the height of a plot of non zero values above the plot of zero values in inches</td>
</tr>
<tr>
<td>FIELD</td>
<td>the data values to be plotted</td>
</tr>
<tr>
<td>IMAX</td>
<td>the number of rows of the array FIELD</td>
</tr>
<tr>
<td>JMAX</td>
<td>the number of columns of the array FIELD</td>
</tr>
<tr>
<td>NMZ</td>
<td>control variable for normalizing the input array</td>
</tr>
</tbody>
</table>

= .TRUE. the data values will be normalized from zero to one.

= .FALSE. the data values will not be normalized

3. Comments

   a. The maximum possible height of a plot may be determined by:

      \[ \frac{1}{2} + \text{YPAGE} + \text{HEIGHT} \text{ (maximum value of array)} \text{ in inches.} \]

   b. In all cases the minimum value of the data must \( \geq \) zero.

   c. This subroutine calls PLOT, a CAL COMP subroutine.

4. Listing

   See following page. 173
SUBROUTINE PLOT3D(XSIZE,YSIZE,HEIGHT,FIELD,IMAX,JMAX,NMZ)

XSIZE IS THE MAXIMUM LENGTH OF THE PLOT IN INCHES.

YSIZE IS THE MAXIMUM WIDTH OF A ZERO PLOT IN INCHES.

THE SUM OF 1/2 INCH + YSIZE + HEIGHT MUST BE LESS THAN

OR EQUAL TO THE PAPER WIDTH.

FIELD(IMAX,JMAX) IS THE TWO-DIMENSIONAL REAL ARRAY TO

BE PLOTTED. IF FIELD IS NOT NORMALIZED ON INPUT, NMZ

MUST BE .TRUE.

NMZ(NORMALIZE) IS A LOGICAL INPUT VARIABLE. IF ITS VALUE

IS .TRUE. THE VALUES IN FIELD WILL BE REPLACED WITH

THEIR NORMALIZED(ZERO TO ONE) COMPONENTS.

DIMENSION FIELD(IMAX,JMAX)
LOGICAL NMZ
DIMENSION HID(600)
REAL LASTX,LASTY,LASTH,LASTHM
IF(NMZ).CALL NORMAL
XPAGE=0.0
YPAGE=0.0
LASTHM=0.0
NIJ=IMAX+JMAX

RI=IMAX-1.0
RJ=JMAX-1.0
CALL PLOT(0.0,-12.5,-3)
CALL PLOT(0.0,0.5,-3)

DO 1 I=1,NIJ
1 HID(I)=0.5
DO 7 J=1,JMAX
AJ=J-1.0
DO 7 I=1,IMAX
00135   32*     AI=I-1,0
00136   33*     LASTX=XPAGE
00137   34*     XPAGE=(AJ+AI)*XSIZE/(RI+RJ)
00140   35*     LASTY=YPAGE
00141   36*     YPAGE=(AJ*RI/AI*RJ/RI+RJ)*YSIZE/(RJ+RI)+HEIGHT*FIELD(I,J)
00142   37*     LASTH=LASTHM
00143   38*     LASTHM=HID(I+J)
00144   39*     IF(YPAGE-HID(I+J)) 5,5,2
00147   40*     2 IF(I,NE.1) GO TO 3
00151   41*     CALL PLTT(XPAGE,YPAGE,3)
00152   42*     IPEN=2
00153   43*     GO TO 4
00154   44*     3 CALL PLTT(XPAGE,YPAGE,IPEN)
00155   45*     IPEN=2
00156   46*     4 HID(I+J)=YPAGE
00157   47*     GO TO 7
00160   48*     5 IF(I,EQ.1) IPEN=3
00162   49*     IF(IPEN,EQ.3) GO TO 6
00164   50*     X1N=LASTX*HID(I+J)-LASTY*XPAGE-LASTX*YPAGE+XPAGE*LASTY
00165   51*     X1D=HID(I+J)-LASTH-YPAGE+LASTY
00166   52*     X1=X1N/X1D
00167   53*     Y1=(X1*HID(I+J)-LASTH)+LASTH*XPAGE-LASTX*HID(I+J))/(XPAGE-LASTX)
00170   54*     CALL PLTT(X1,Y1,2)
00171   55*     IPEN=3
00172   56*     6 CALL PLTT(XPAGE,YPAGE,IPEN)
00173   57*     7 CONTINUE
00176   58*     DO 8 I=1,NIJ
00201   59*     8 HID(I)=-0.5
00203   60*     DO 16 I=IMAX,1,-1
00206   61*     AI=I-1.0
00207   62*     DO 16 J=1,JMAX
00212   63*     AJ=J-1
00213   64*     LASTX=XPAGE
00214   65*     XPAGE=(AJ+AI)*XSIZE/(RI+RJ)
00215   66*     LASTY=YPAGE
00216   67*     YPAGE=(AJ*RI/AI*RJ/RI+RJ)*YSIZE/(RJ+RI)+HEIGHT*FIELD(I,J)
00217   68*     LASTH=LASTHM
00220   69*     LASTHM=HID(I+J)
00221   70*     7 IF(YPAGE-HID(I+J)) 13,14,9
00224   71*     9 IF(J,NE.1) GO TO 10
CALL PLTT(XPAGE,YPAGE,3)

IPEN=2

GO TO 12

IF(IPEN.EQ.2) GO TO 11

CALL PLTT(XPAGE,YPAGE,IPEN)

HID(I+J)=YPAGE

GO TO 16

IPEN=3

GO TO 15

IF(J.EQ.1) IPEN=3

CALL PLTT(XPAGE,YPAGE,IPEN)

CONTINUE

CALL PLTT(XSIZE+4.0,1,0,-3)

RETURN

SUBROUTINE PLTT(X,Y,IPEN)

SIROUTINE PLTT ELIMINATES MOVING PEN FOR HIDDEN LINES.

XLAST=XN

YLAST=YN

ILAST=IN

XN=X

YN=Y

IN=IPEN

IF(IPEN.EQ.2.AND.ILAST.EQ.2) CALL PLOT(X,Y,IPEN)
IF(IPEN.EQ.2 .AND. ILAST .EQ. 3) CALL PLOTO(LASTFYLAST,ILAST)
IF(IPEN.EQ.2 .AND. ILAST .EQ. 3) CALL PLOT(X,Y,IPEN)
IF(IPEN.NE.2 .AND. IPEN.NE.3) CALL PLOT(X,Y,IPEN)
RETURN

********************************************************************
SUBROUTINE NORM

NORMALIZE FIELD SO THAT ALL VALUES ARE BETWEEN ZERO AND ONE.

REAL MN,MX
MX=FIELD(I+1)
MN=MX
MN=MIN(MN,FIELD(I,J))
MX=MAX(MX,FIELD(I,J))

CONTINUE
DR=MX-MN
DO 21 I=1,IMAX
DO 21 J=1,JMAX
FIELD(I,J)=(FIELD(I,J)-MN)/DR
CONTINUE
WRITE(6,22) MN,MX
FORMAT(6,22) MN,MX
RETURN
END
1. Purpose

This subroutine plots and labels constant decibel contours of a far field pattern on a flat surface. The plotting is done on a CAL COMP plotter and uses CAL COMP software.

2. Call

CALL CNTOUR (FIELD, IMAX, JMAX, VALUES, NVALS, KXMAX, KYMAX, ALT, THETA, PHI, XYPMAX)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIELD</td>
<td>floating-point array, input</td>
</tr>
<tr>
<td>IMAX</td>
<td>FORTRAN integer variable, input</td>
</tr>
<tr>
<td>VALUES</td>
<td>floating-point variable, input</td>
</tr>
<tr>
<td>NVALS</td>
<td>FORTRAN integer variable, input</td>
</tr>
<tr>
<td>KXMAX</td>
<td>floating-point variable, input</td>
</tr>
<tr>
<td>ALT</td>
<td>floating-point variable, input</td>
</tr>
<tr>
<td>THETA</td>
<td>floating-point variable, input</td>
</tr>
<tr>
<td>PHI</td>
<td>floating-point variable, input</td>
</tr>
</tbody>
</table>
XYPMAX the size of the area in which floating-point
the contours will be plotted variable, input
is a square with side XYPMAX
-\frac{1}{2} inches.

3. Comments
   
   a. Field must be normalized between zero and one.

   b. The values in VALUES must be negative.

   c. The wavenumbers must be normalized such that \( Kx^2 + Ky^2 \leq 1 \) correspond to the visible region of radiation.

4. Listing
   
   See following page.
SUBROUTINE CNTOUR(FIELD, IMAX, JMAX, VALUES, NVALS, KXMAX, KYMAX, ALT, -  
   THETA, PHI, XYPMAX)
  BUILD ERROR CALCULATIONS IN MILLIRADIANS.

SUBROUTINE CNTOUR PLOTS AND LABELS CONSTANT DB CONTOURS.
FIELD(IMAX, JMAX) IS A REAL ARRAY WITH VALUES IN DECIBELS.
VALUES(NVALS) IS A REAL ARRAY WITH NVALS ENTRIES WHICH
  DETERMINE VALUES FOR WHICH CONTOURS WILL BE PLOTTED.
XYPMAX DEFINES THE SIZE OF THE AREA IN WHICH THE CONTOURS
  WILL BE PLOTTED. CONTOURS WILL BE DRAWN INSIDE A BOX
  WITH DIMENSIONS XYPMAX-.5 BY XYPMAX-.5.

KXMAX AND KYMAX ARE RESPECTIVELY THE MAXIMUM ABSOLUTE
  VALUES OF KX AND KY WAVENUMBERS FOR WHICH THE FAR FIELD
  IS CALCULATED.

ALT IS THE ALTITUDE OF THE ORIGIN OF THE APERTURE FIELD
  COORDINATE SYSTEM IN METERS.

THETA AND PHI SPECIFY THE DIRECTION FROM THE NORMAL OF
  THE APERTURE PLANE TO THE GROUND AND HAVE UNITS OF
  DEGREES. (SEE REPORT FOR APERTURE-GROUND COORDINATE
  SYSTEM).

DIMENSION FIELD(IMAX, JMAX), VALUES(NVALS)
LOGICAL DOWN
REAL KX, KY, KXMAX, KYMAX, KX1, KX2, KY1, KY2, KZ, KS, XG, YG, KXA, KYA, KZA
REAL XGP, YGP, LSZ
CALL PLOT(XYPMAX, -12, -3)
CALL PLOT(XYPMAX/2, XYPMAX/2, -3)
CALL PLOT(0, 0, .07, 3)
CALL PLOT(0, -07, 0, 2)
CALL PLOT(.07, 0, 3)
CALL PLOT(-.07, 0, 2)
NLAB3 = 0
PI = 3.141592653
LSZ = .07
DIST = 4 * LSZ
DA = .01

PMOD IS USED TO SCALE THE CONTOUR PLOT TO THE DESIRED SIZE.
40* PM0D=XYPMAX/ALT/2
41* XYM=XYPMAX/2.-.5
42* CALL PLOT(XYM,XYM,3)
43* CALL PLOT(XYM,-XYM,2)
44* CALL PLOT(-XYM,-XYM,2)
45* CALL PLOT(-XYM,XYM,2)
46* CALL PLOT(XYM,XYM,2)
47* MXP=XYM*1000.
48* KXA=SIN(THETA*PI/180.0)*COS(PHI*PI/180.0)
49* KYA=SIN(THETA*PI/180.0)*SIN(PHI*PI/180.0)
50* KZA=COS(THETA*PI/180.0)
51* RO=ALT/KZA
52* XGD=SQRT(2.0-2.0*KXA)
53* XGX=(1.0-KXA)/XGD
54* XGY=-KYA/XGD
55* XGZ=-KZA/XGD
56* YGD=SQRT(2.0-2.0*KYA)
57* YGX=-KXA/YGD
58* YGY=(1.0-KYA)/YGD
59* YGZ=-KZA/YGD
60* IE=IMAX-1
61* JE=JMAX-1
62* JC=1
63* DOWN=.TRUE.
64* EXAMINE EACH CELL IN THE ARRAY TO LOCATE THE DESIRED CONTOURS.
<table>
<thead>
<tr>
<th>Line</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>00162</td>
<td>72* A = FIELD(I, J+1)</td>
</tr>
<tr>
<td>00163</td>
<td>73* B = FIELD(I+1, J+1)</td>
</tr>
<tr>
<td>00164</td>
<td>74* C = FIELD(I, J)</td>
</tr>
<tr>
<td>00165</td>
<td>75* D = FIELD(I+1, J)</td>
</tr>
<tr>
<td>00166</td>
<td>76* PMAX = AMAX1(A, B, C, D)</td>
</tr>
<tr>
<td>00167</td>
<td>77* PMIN = AMIN1(A, B, C, D)</td>
</tr>
<tr>
<td>00170</td>
<td>78* IF((PMAX-PMIN)**2 LT 1.0E-10) GO TO 100</td>
</tr>
<tr>
<td>00170</td>
<td>79* PLOT ALL CONTOURS THAT GO THROUGH CELL.</td>
</tr>
<tr>
<td>00170</td>
<td>80*</td>
</tr>
<tr>
<td>00170</td>
<td>81*</td>
</tr>
<tr>
<td>00172</td>
<td>82* DO 70 K=1,NVALS</td>
</tr>
<tr>
<td>00175</td>
<td>83* IP=3</td>
</tr>
<tr>
<td>00176</td>
<td>84* IF (DOWN) GO TO 60</td>
</tr>
<tr>
<td>00200</td>
<td>85* IF (WITHIN(C, D, I, J, I+1, J)) CALL PLC</td>
</tr>
<tr>
<td>00202</td>
<td>86* IF (WITHIN(A, B, I, J, I+1, J)) CALL PLC</td>
</tr>
<tr>
<td>00204</td>
<td>87* IF (WITHIN(D, B, I+1, J, I+1, J+1)) CALL PLC</td>
</tr>
<tr>
<td>00206</td>
<td>88* IF (WITHIN(C, A, I, J, I+1, J)) CALL PLC</td>
</tr>
<tr>
<td>00210</td>
<td>89* IF (*NOT DOWN) GO TO 70</td>
</tr>
<tr>
<td>00212</td>
<td>90* IF (WITHIN(C, D, I, J, I+1, J)) CALL PLC</td>
</tr>
<tr>
<td>00214</td>
<td>91* CONTINUE</td>
</tr>
<tr>
<td>00216</td>
<td>92* CONTINUE</td>
</tr>
<tr>
<td>00220</td>
<td>93* JC = -JC</td>
</tr>
<tr>
<td>00221</td>
<td>94* JT = JB</td>
</tr>
<tr>
<td>00222</td>
<td>95* JE = JE</td>
</tr>
</tbody>
</table>
RETURN

C********************************************************************
FUNCTION WITHIN(P1,P2,I1,J1,I2,J2)
C
FUNCTION WITHIN RETURNS A 'TRUE' VALUE ONLY IF THE CONTOUR
VALUES(K) PASSES THROUGH THE SIDE OF THE CELL DEFINED
BY P1 AND P2.

WITHIN='FALSE'.
IF((P1-P2)**2.LT.1.E-10) RETURN
S=(VALUES(K)-P1)/(P2-P1)
IF((S.LT.0.0).OR.(S.GT.1.0)) RETURN
WITHIN='TRUE'.
C
COMPUTE THE WAVENUMBER COORDINATES FOR THE INTERSECTION
OF THE SIDE OF THE CELL AND THE CONTOUR.

C
KX1=((I1-(IMAX/2+1))*KXMAX)/(IMAX/2)
KY1=((J1-(JMAX/2+1))*KYMAX)/(JMAX/2)
KX2=((I2-(IMAX/2+1))*KXMAX)/(IMAX/2)
KY2=((J2-(JMAX/2+1))*KYMAX)/(JMAX/2)
KX=KX1+S*ABS(KX1-KX2)
KY=KY1+S*ABS(KY1-KY2)
RETURN

C********************************************************************
SUBROUTINE PLC
KS=1.0-Kx**2-Ky**2
IF(KS<0.0) RETURN

C DETERMINE CONVERSION FROM WAVENUMBER COORDINATES TO GROUND COORDINATES USED IN PLOTTING THE CONTOUR.

KZ=SQRT(KS)
R=ALT/(Kx*Kxa+Ky*Kya+Kz*Kza)
RX=R*Kx
RY=R*Ky
RZ=R*Kz
XG=RX*XGx+RY*XGy+(RZ-R0)*XGz
YG=RX*YGx+RY*YGy+(RZ-R0)*YGz
XG=XG*PMOD
YG=YG*PMOD
CALL EFPLT
IP=2
RETURN

C***************************************************************************
SUBROUTINE EFPLT

SUBROUTINE EFPLT ELIMINATES CALLS TO PLOT WHEN THE PEN IS ALREADY IN THE DESIRED LOCATION, AND ALSO INHIBITS PLOTTING CONTOURS OUTSIDE THE BOX DEFINED BY XYPMAX.

IXG=XG*1000.
IYG=YG*1000.
00301  153*   IF((IXG.EQ.IXGP).AND.(IYG.EQ.IYGP)) RETURN
00303  154*   IF(ABS(IXG).GT.MAXP.OR,ABS(IYG).GT.MAXP) GO TO 300
00305  155*   IF(ABS(IXGP).GT.MAXP.OR.ABS(IYGP).GT.MAXP) IP=3
00307  156*   CALL PLOT(XG,YG,IP)
00309  157*   IF(IP.EQ.2) CALL CNUM
00312  158*   IXGP=IXG
00313  159*   IYG=IYG
00314  160*   XGP=XG
00315  161*   YGP=YG
00316  162*   RETURN
00317  163*   C*********************************************************************
00317  164*   SUBROUTINE CNUM
00317  165*   C
00317  166*   INTEGER CASE
00317  167*   DIMENSION X(50),Y(50)
00322  168*   IF(NLAB.EQ.50) RETURN
00323  169*   IF(MIN(XG,XGP).LT.0.0..AND.MAX(XG,XGP).GE.0.) GO TO 400
00324  170*   IF(MIN(YG,YGP).LT.0.0..AND.MAX(YG,YGP).GE.0.) GO TO 420
00326  171*   RETURN
00326  172*   CASE=1
00326  173*   CASE=2
00326  174*   CASE=3
00326  175*   CASE=4
00326  176*   CASE=5
00327  177*   400 CASE=1
00329  178*   IF(YG.LT.0.) CASE=2
00330  179*   X=0.
00331  180*   Y=(YG-YGP)*(-XGP)/(XG-XGP)+YGP
00334  181*   GO TO 430
00334  182*   420 CASE=3
IF(XG.LT.0.) CASE=4
YI=0.
XI=(XG-XGP)*(-YG)/((YG-YGP)+XG)
CONTINUE
Dj=2.*LSZ+INT(ALOG10(ABS(VALUEs(K))))*LSZ
IF(XG.GE.XGP) SLOPE=ATAN2(YG-YGP,XG-XGP)
IF(XG.LT.XGP) SLOPE=ATAN2(YG-YGp,XG-XGP)
DP=DA
IF(CASE.EQ.2) DP=-DA-LSZ
IF(CASE.EQ.3.AND.SLOPE.GE.0.) DP=-DA-LSZ
IF(CASE.EQ.4.AND.SLOPE.LE.0.) DP=-DA-LSZ
XP=XI-DP*SIN(SLOPE)-DD*COS(SLOPE)
YP=YI+DP*COS(SLOPE)-DD*SIN(SLOPE)
SLOPE=SLOPE*180./PI
DETERMINE THAT THERE IS SUFFICIENT SPACE BETWEEN THE CURRENT
CONTOUR LABEL AND ALL PREVIOUS LABELS DRAWN. IF SPACE
IS AVAILABLE, THE LABEL IS DRAWN ON THE CONTOUR AND ITS
COORDINATES RECORDED IN ARRAYS X AND Y. IF SUFFICIENT SPACE
IS NOT AVAILABLE, THE LABEL IS NOT DRAWN.
A MAXIMUM OF 50 LABELS CAN BE DRAWN.
IF(NLAB.EQ.0) GO TO 450
DO 440 IC=1,NLAB
IF(SQRT((XP-X(IC))^2+(YP-Y(IC))^2).LE.DIST) RETURN
CONTINUE
NLAB=NLAB+1
X(NLAB)=XP
Y(NLAB)=YP
CALL NUMBER(XP,YP,LSZ,VALUES(K),SLOPE,+1)
CALL PLOT(XG,YG,3)
RETURN
END
APPENDIX AA

SUBROUTINE SAPLOT

1. Purpose

This subroutine plots one dimensional graphs of the far field power patterns. The plots are in decibels and range from zero to -40 decibels. This subroutine also plots far field graph paper similar to the far field graph paper of Scientific Atlanta. A choice of angular scales is available.

2. Call

CALL SAPLOT (FIELD,NX, NY, KXMAX, KYMAX, ELMIN, ELMAX, AZMIN, AZMAX, ISCALD, NPTS)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>data values to be plotted</td>
<td>floating-point, array, input</td>
</tr>
<tr>
<td>with units of decibels</td>
<td></td>
</tr>
<tr>
<td>NX</td>
<td>FORTRAN integer variable, input</td>
</tr>
<tr>
<td>where increasing row indices correspond to increasing Kx</td>
<td></td>
</tr>
<tr>
<td>NY</td>
<td>FORTRAN integer variable, input</td>
</tr>
<tr>
<td>where increasing column indices correspond to increasing Ky</td>
<td></td>
</tr>
<tr>
<td>KXMAX</td>
<td>floating-point variable, input</td>
</tr>
<tr>
<td>the range of Kx wave numbers in the far field pattern is from -KXMAX to (1 - 2/NX) KXMAX</td>
<td></td>
</tr>
<tr>
<td>KYMAX</td>
<td>floating-point variable, input</td>
</tr>
<tr>
<td>the range of Ky wave numbers in the far field pattern is from -KYMAX to (1 - 2/NY) KYMAX</td>
<td></td>
</tr>
<tr>
<td>ELMIN</td>
<td>floating-point variable, input</td>
</tr>
<tr>
<td>the minimum elevation angle of the far field slice to be plotted</td>
<td></td>
</tr>
<tr>
<td>ELMAX</td>
<td>floating-point variable, input</td>
</tr>
<tr>
<td>the maximum elevation angle of the far field slice to be plotted</td>
<td></td>
</tr>
<tr>
<td>AZMIN</td>
<td>floating-point variable, input</td>
</tr>
<tr>
<td>the minimum azimuth angle of the far field slice to be plotted in degrees</td>
<td></td>
</tr>
<tr>
<td>AZMAX</td>
<td>floating-point variable, input</td>
</tr>
<tr>
<td>the maximum azimuth angle of the far field slice to be plotted in degrees</td>
<td></td>
</tr>
</tbody>
</table>

187
ISCALE  a control variable which determines the maximum angle to the right and left of the center of the plot.

\[ = 10 \pm 5 \text{ degree plot} \]
\[ = 60 \pm 30 \text{ degree plot} \]
\[ = 360 \pm 180 \text{ degree plot} \]

NPTS  The number of points plotted on the graph

3. Comments

a. The height of the plot is approximately 10½ inches.
b. The length of the plot is approximately 20 inches.
c. Either ELMIN = ELMAX or AZMIN = AZMAX must be true.
d. ISCALE must be 10, 60 or 360.
e. No values of FIELD below -40 dB will be plotted.
   No values of FIELD above 0 dB will be plotted.
f. This subroutine requires a CAL COMP subroutine PLOT.

4. Listing

See following page.
SUBROUTINE SAPLOT(FIELD, IX, NY, KXMAX, KMAX, ELMIN, ELMAX, AZMIN, 
ISCALE, NPTS)

ISCALE CONTROLS THE SCALE OF THE HORIZONTAL AXIS

TO CONFORM TO SCIENTIFIC ATLANTA'S PAPER ISCALE SHOULD BE 
EQUAL TO 10, 60, OR 360

DIMENSION FIELD(IX, NY)

REAL IX, KX, KMAX, KMAX

PI=3.141592653

CALL PLOT(0.0, 10.625, 3)

Y=0.75

CALL PLOT(0.0, Y, 2)

DO 1 I=1, 5, 1

CALL PLOT(0.0, Y, 3)

CALL PLOT(5.0, Y, 2)

CALL NUMBER(5.0, 5, 0.07, 0.14, 0.0, 0, 0, -1)

CALL PLOT(5.3333, Y, 3)

CALL PLOT(15.3333, Y, 2)

CALL NUMBER(15.3333, Y, 0.07, 0.14, 0.0, 0, 0, -1)

CALL PLOT(15.6666, Y, 3)

CALL PLOT(20.0, Y, 2)

Y=Y+2.466675

CALL PLOT(20.0, 0.75, 2)

X=0.6666667

DO 2 I=1, 29, 1

CALL PLOT(X, 0.75, 3)

CALL PLOT(X, 0.85, 2)

X=X+3.6666667

DO 3 I=1, 9, 1

ANG=ABS(5-I)*ISCALE/10.0+0.0001
DO 5 J=1,4+1
DO 4 K=1,4+1
Y=Y+9.875/20.0
CALL PLOT(X+Y+1)
CALL PLOT(Y+1)
CALL NUMBER(X+Y+1)
CONTINUE

54* DO 4 K=1,4+1
DO 4 K=1,4+1
Y=Y+9.875/20.0
CALL PLOT(X+Y+1)
CALL PLOT(Y+1)
CALL NUMBER(X+Y+1)
CONTINUE

DO 10 K=1,NPTS,1
IF(IA.EQ,1)30 TO 7
IF(IA.EQ,2)60 TO 6

IF(Abs(EL-ELMIN).LT.0.001) IA=1
IF(Abs(AZ-AZMIN).LT.0.001) IA=2
IF (IA.EQ.1)CALL SYMBOL(9.09,0.54,0.14,13,HAZIMUTH ANGLE,0.0,13)
IF (IA.EQ.2)CALL SYMBOL(8.95,0.54,0.14,15,HELEVATION ANGLE,0.0,15)
IPEN=3
DO 10 K=1,NPTS,1
IF(IA.EQ.1)GO TO 7
IF(IA.EQ.2)GO TO 8
GO TO 11
7 AZ=AZMIN+(K-1)*(AZMAX-AZMIN)/(NPTS-1)
10 X=10.0+20*AZ/ISCALE
20 AZ=PI/2-AZ*PI/180
30 KX=-SIN*AZ*COS(AZ)
40 KY=COS(AZ)
50 CONTINUE
8 EL=ELMIN+(K-1)*(ELMAX-ELMIN)/(NPTS-1)
11 X=10.0+20*EL/ISCALE
21 EL=PI/2-EL*PI/180
31 KX=-SIN(EL)*COS(AZ
41 KY=COS(EL)
51 CONTINUE
P=RI-I
Q=RJ-J
11 Y=(1-P)*(1-Q)*FIELD(I,J)+P*(1-Q)*FIELD(I+1,J)+Q*(1-P)*FIELD(I,J+1)+P*Q*FIELD(I+1,J+1)
12 IF(Y.LT.0.0) Y=0.0
13 IF(Y.GT.1.0) Y=1.0
14 CALL PLOT(X,Y,IPEN)
15 IPEN=2
16 CONTINUE
17 CALL PLOT(20.0,0.0,0,-3)
18 RETURN
19 END
APPENDIX AB

SUBROUTINE XY

1. Purpose

This subroutine calculates the X and Y components of a point, PI, on a ray emanating from the point P and traveling in the K direction given the z-coordinate of the point PI.

2. Call

CALL XY(P,K,Z,PI)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P is the three-dimensional array of coordinates of the point P.</td>
<td>floating-point input</td>
</tr>
<tr>
<td>K is the three-dimensional array of wave numbers of the ray.</td>
<td>floating-point input</td>
</tr>
<tr>
<td>Z is the z-coordinate of the point PI</td>
<td>floating-point input</td>
</tr>
<tr>
<td>PI is the three-dimensional array coordinates of the point PI.</td>
<td>floating-point output</td>
</tr>
</tbody>
</table>

c. Comments

Restriction: K(3) ≠ 0.0

4. Listing

See following page.
SUBROUTINE XY(P, K, Z, PI)

C XY CALCULATES THE X AND Y COMPONENTS OF AN INTERSECTION POINT PI

C FOR THE CASE WHEN THE POINT OF EMINATION P, THE DIRECTION OF
C PROPAGATION K AND THE Z COORDINATE OF THE INTERSECTION POINT
C ARE GIVEN

REAL P(3), K(3), PI(3)

PI(3) = Z

T = (PI(3) - P(3))/K(3)

PI(1) = P(1) + K(1)*T

PI(2) = P(2) + K(2)*T

RETURN

END
APPENDIX AC

SUBROUTINE VSWR

1. Purpose

This subroutine calculates the VSWR in the feed system of the enclosed antenna due to reflections from the inner surface of the radome.

2. Call

CALL VSWR(XPWT,YPWT,XPWR,YPWR,NX,NY,KKMAX,KYMAX,SWR)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>XPWT</td>
</tr>
<tr>
<td>YPWT</td>
</tr>
<tr>
<td>XPWR</td>
</tr>
<tr>
<td>YPWR</td>
</tr>
<tr>
<td>NX</td>
</tr>
<tr>
<td>NY</td>
</tr>
<tr>
<td>KKMAX</td>
</tr>
<tr>
<td>KYMAX</td>
</tr>
</tbody>
</table>

**DESCRIPTION**

- the x component of the plane wave spectrum of the antenna
- the y component of the plane wave spectrum of the antenna
- the x component of the reflected plane wave spectrum
- the y component of the reflected plane wave spectrum
- the number of rows of XPWT, YPWT, XPWR, and YPWR, where increasing row indices correspond to increasing Kx
- the number of columns of XPWT, YPWT, XPWR, and YPWR, where increasing column indices correspond to increasing Ky
- the range of Kx wavenumbers in the plane wave spectra is from -KKMAX to (1 - 2/NY) KYMAX
- the range of Ky wave numbers in the plane wave spectra is from -KYMAX to (1 - 2/NY) KYMAX

**TYPE**

- complex array, input
- complex array, input
- complex array, input
- complex array, input
- FORTRAN integer variable, input
- FORTRAN integer variable, input
- floating-point variable, input
- floating-point variable, input
3. Comments
   a. The plane wave spectrum of the antenna must contain at least one non-zero value.
   b. The wavelumbers are normalized such that $K_x^2 + K_y^2 \leq 1$ corresponds to the visible region of radiation.
   c. The equality in (b) must not be met.

4. Listing
   See following page.
SUBROUTINE VSWR(CPWT,YPWT,XPWR,YPWR,NX,NY,KXMAX,KYMAX,SWR)

COAPLEX XPWT(NX,NY),YPWT(NX,NY),XPWR(NX,NY),YPWR(NX,NY),ZPWT,ZPWR

REAL KXMAX,KYMAX,KX,KY,KZ

THIS SUBROUTINE CALCULATES THE VSWR IN THE FEED SYSTEM OF A
RADOME ENCLOSED ANTENNA DUE TO REFLECTIONS FROM THE INNER SURFACE

OF THE RADOME.

XPWT(NX,NY) AND YPWT(NX,NY) ARE THE X AND Y COMPONENTS RESPECTIVELY

OF THE TRANSMITTING AND RECEIVING PLANE WAVE SPECTRUM OF THE
ANTENNA WITHOUT THE RADOME IN PLACE.

XPWR(NX,NY) AND YPWR(NX,NY) ARE THE X AND Y COMPONENTS
RESPECTIVELY OF THE REFLECTED PWS.

PT=0.0
PR=0.0

DO 1 IKX=1,NX
KX=(-1+2*(IKX-1.0)/NX)*KXMAX

1 CONTINUE

DO 1 IKY=1,NY
KY=(-1+2*(IKY-1.0)/NY)*KYMAX

KZ=SQR(XZ)

KZ=SQRT(KZ)

FIND Z COMPONENT OF TRANSMITTED AND REFLECTED PWS

ZPWR=-(KX*XPWR(IKX,IKY)+KY*YPWR(IKX,IKY))/KZ
ZPWT=X*XPWT(IKX,IKY)+KY*YPWT(IKX,IKY))/KZ

FIND TOTAL POWER OF TRANSMITTED PWS BY SUMMING POWERS IN EACH PW
P=CABS(XPWR(IKX,IKY))**2+CABS(YPWR(IKX,IKY))**2+CABS(ZPWT)**2
PT=P+PT

FIND TOTAL POWER OF REFLECTED PWS BY SUMMING POWERS IN EACH
P=CABS(XPWT(IKX,IKY)*XPWR(IKX,IKY))**2+CABS(YPWT(IKX,IKY))**2+CABS(ZPWT*ZPWR)**2

REFLECTED PW WEIGHTED BY TOTAL POWER IN RECEIVING PWS
PR=PR+P

CONTINUE
PR=PR/PT

CALCULATE VOLTAGE STANDING WAVE RATIO

SWR=SQRT((PT+PR)/(PT-PR))

RETURN

END

* HAVE BEEN CHANGED (SEE P.73, EQU. (227))
APPENDIX AD

SUBROUTINE QUARTC

1. Purpose

This subroutine calculates the four roots of the polynomial

\[ x^4 + A_4 x^3 + A_3 x^2 + A_2 x + A_1 = 0 \]

2. Call

CALL QUARTC (A,X)

where:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A is the array of coefficients of</td>
<td>floating-point input</td>
</tr>
<tr>
<td>the polynomial.</td>
<td></td>
</tr>
<tr>
<td>X is the array of roots of the</td>
<td>floating-point output</td>
</tr>
<tr>
<td>polynomial.</td>
<td></td>
</tr>
</tbody>
</table>

3. Comments

The coefficients A must be real and such that all four roots are real.
If any roots are not real the subroutine will produce incorrect results.

4. Listing

See following page.
SUBROUTINE QUARTIC (A,X)

DIMENSION (4)

COMPLEX A(4)*R,5,DL,X

C THIS SUBROUTINE SOLVES THE EQUATION X**4+A(4)*X**3+A(3)*X**2+
A(2)*X+A(1)=0.

C INPUT A IS A REAL ARRAY OF COEFFICIENTS.

C OUTPUT X IS A COMPLEX ARRAY OF ROOTS OF THE QUARTIC EQUATION.

A2=-A(3)
A1=A(2)*A(4)+A(4)-A(1)*A(3)
A0=A1/3.*(-A(2)+A(4))**.5.

R1=(-A2-3.*A0**2/6.0-A2**3/27.)

RADSQ=0.+R1*R1

IF (RADSQ,LT.1.0) GO TO 10

RAD=SORT(RADSQ)

S1=CBRT(R1*RAD)
S2=CBRT(R1/RAD)

Y=S1+S2-A2/3.;

RSJ=(-A4)*A(4)/4.*1.-A(3)+Y

IF (ABS(RSJ),LT.1.*10.08) GO TO 20

R=CSORT(COMPLEX(RSJ)+0.))

D1=3.*A(4)*A(4)/4.*1.-RSJ-2.*A(1)*A(3)

D2=4.*A(4)+A(4)-A(0)*A(2)-A(0)**3

D=CSORT(COMPLEX(D1,0.))//COMPLEX(D2,0.)/(4.0*R))

E=CSORT(COMPLEX(D1,0.))//COMPLEX(D2,0.)/(4.0*R))
00131  21  \text{x1=cmplx}(-4.4/4.0,0.0)+r/2.0.
00132  27  \text{x(1)=x1+d/2.}
00133  28  \text{x(2)=x1-d/2.}
00134  29  \text{x1=cmplx}(-4.4/4.0,0.0)-r/2.0.
00135  30  \text{x(3)=x1+d/2.}
00136  31  \text{x(4)=x1-e/2.}
00137  32  \text{return}
00140  33  \text{d1=3.0*a(4)*a(4)/4.0-2.0*a(3)}
00141  34  \text{d2=y*y-4.0*a(1)}
00142  35  \text{d=csqrt(cmplx(d1,0.0)+2.0*csqrt(cmplx(d2,0.0)))}
00143  36  \text{e=csqrt(cmplx(d1,0.0)-2.0*csqrt(cmplx(d2,0.0)))}
00144  37  \text{g0 to 21}
00145  38  10  \text{phi=acos(r1/sqrt(-r**3))}
00146  39  \text{y=2.0*sort(-2)*cos(phi/3.0)-a2/3.0}
00147  40  \text{g0 to 15}
00150  41  \text{end}

\text{end of compilation: no diagnostics.}
REFERENCES


RADOME EFFECTS ON THE PERFORMANCE OF GROUND MAPPING RADAR

By
Edward B. Joy and G. Keith Huddleston

School of Electrical Engineering
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

FINAL RESEARCH REPORT
Contract DAAH01–72–C–0598
7 March 1972 – 6 August 1973

Prepared for
RF GUIDANCE TECHNOLOGY BRANCH
ADVANCED SENSORS DIRECTORATE
RESEARCH, DEVELOPMENT, ENGINEERING
AND MISSILE SYSTEMS LABORATORY
U. S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA
OVERLAY OF FAR FIELD POWER PATTERN ON GROUND WITHOUT RADOME
GEORGIA INSTITUTE OF TECHNOLOGY
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FINAL REPORT
PROJECT E-21-614

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TABLE OF CONTENTS

Section | Page
-------|-----
I. INTRODUCTION | 1
II. SUBROUTINES RADEFT AND EFFECT | 2
III. TRADEF | 14

APPENDICES
A. COMPUTER PROGRAM | 31
B. FAR-FIELD POWER PATTERN CONTOUR PLOTS | 97
C. RADOME EFFECTS | 152
D. REAL FUNCTION INTERP | 157

REFERENCES | 160

LIST OF FIGURES

Number | Description | Page
-------|-------------|-----
1. Coordinate System Used in Radome Analysis | 6
2. Format of Radome Effects Data Arrays | 7
3. Graph of Boresight Errors in Azimuth Versus Pitch and Scan Angles | 153
4. Graph of Boresight Errors in Elevation Versus Pitch and Scan Angles | 154
5. Graph of Change in Power Gain Versus Pitch and Scan Angles | 155
6. Graph of VSWR Versus Pitch and Scan Angles | 156
FOREWORD

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"The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U. S. Army Missile Command or the U. S. Government."
ABSTRACT

The effects of the radome on the performance of a ground mapping radar are presented. A computer program for interfacing the radome effects data to a computer simulation of the radar system is described. The radome analysis computer program used to generate the radome effects data is presented. Contour plots of the far-field power pattern on the ground with the radome in place are presented.
SECTION I
INTRODUCTION

This research report presents the results of work performed during the period 6 March 1973 to 6 August 1973 in fulfillment of Amendment No. 1 of TR1548, Contract No. DAAH01-72-C-0598. Specifically, the radome analysis computer program developed earlier [1] was executed on the Univac 1108 computer system at Georgia Tech to compute the effects of the radome on the ground mapping radar system under study for various radome/antenna orientations. A quickly executable computer program was prepared (SUBROUTINE RADEFT) which may be used to interface the radome effects data to a computer simulation of the ground mapping radar system.

Section II is a description of SUBROUTINE RADEFT and presents instructions for its use.

Section III presents a description of a computer program (TRADEF) used to test the correct operation of RADEFT.

Appendix A presents a complete listing of the radome analysis computer program used to generate the radome effects data.

Appendix B presents contour plots of the far-field power pattern on the ground with the radome in place for the fifty-five antenna/radome orientations used in generating the radome effects data.

Appendix C presents plots of the radome effects data as functions of radome pitch angle and antenna scan angle.

Appendix D describes the computer program (REAL FUNCTION INTERP) used for interpolating the original radome effects data.
SECTION II

SUBROUTINES RADEFT AND EFFECT

1. Purpose

The purpose of these subroutines is to provide a means of interfacing radome effects data to the computer simulation of the ground mapping radar system studied under Contract No. DAAH01-72-C-0598. For a given orientation of the antenna and radome, the radome effects data consist of four performance parameters: (1) boresight error in the azimuthal direction; (2) boresight error in elevation; (3) change in power gain of the antenna due to the radome; and (4) the voltage standing wave ratio of the antenna due to the radome. The radome effects data were computed using the radome analysis computer program developed earlier under the subject contract and described in Reference 1. These data are provided in the form of punched cards for fifty-five unique orientations of the antenna/radome system and are read into data arrays on call of RADEFT. Before returning control to the calling program, the data for the unique orientations are manipulated to fill those array positions corresponding to antenna/radome orientations for which the radome effects data are identical because of symmetry in the system. A complete array of radome effects data consists of a two-dimensional array of 13 x 17 elements corresponding to radome pitch angles in the range -30 to -150 degrees in increments of -10 degrees, antenna scan angles in the range 0 to 360 degrees in increments of 22.5 degrees, and for a radome yaw of zero degrees. Radome effects data for other antenna/radome orientations (specified by pitch, scan, and yaw) are obtained from interpolation of the basic data through the call of EFFECT.
2. Calls

a. CALL RADEFT (NROW, NCOL, BSEEL, BSEAZ, GAINDB, VSWR, PITCH1, DELPIT, SCAN1, DELSCN, PRINT, PANGLE, SANGLE)

where:

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DESCRIPTION</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NROW</td>
<td>is the number of rows in each of the arrays BSEEL, BSEAZ, GAINDB, VSWR (viz., NROW = 13)</td>
<td>integer input</td>
</tr>
<tr>
<td>NCOL</td>
<td>is the number of columns in the above arrays (viz., NCOL = 17)</td>
<td>integer input</td>
</tr>
<tr>
<td>BSEEL</td>
<td>is the two-dimensional array of boresight errors in elevation (milliradians)</td>
<td>floating-point output</td>
</tr>
<tr>
<td>BSEAZ</td>
<td>is the two-dimensional array of boresight errors in azimuth (milliradians)</td>
<td>floating-point output</td>
</tr>
<tr>
<td>GAINDB</td>
<td>is the two-dimensional array of changes in power gain of the antenna due to the radome (decibels)</td>
<td>floating-point output</td>
</tr>
<tr>
<td>VSWR</td>
<td>is the two-dimensional array of voltage standing wave ratios of the antenna due to the radome (unitless)</td>
<td>floating-point output</td>
</tr>
<tr>
<td>PITCH1</td>
<td>is the maximum value of radome pitch angle (degrees) considered and corresponds to row #1 of the above arrays (viz., PITCH1 = -30)</td>
<td>floating-point input</td>
</tr>
<tr>
<td>DELPIT</td>
<td>is the increment in radome pitch angle (degrees) corresponding to the angular difference between the Ith and the (I + 1)th row of the above arrays (viz., DELPIT = -10)</td>
<td>floating-point input</td>
</tr>
<tr>
<td>SCAN1</td>
<td>is the minimum value of antenna scan angle (degrees) considered and corresponds to column #1 of the above arrays (viz., SCAN1 = 0)</td>
<td>floating-point input</td>
</tr>
</tbody>
</table>
DELSCN is the increment in antenna scan angle (degrees) corresponding to the angular difference between the Jth and (J+1)th column of the above arrays (viz., DELSCN=22.5)

PRINT is a logical variable; if .TRUE., the above arrays are outputted as printed data

PANGLE is a one-dimensional array of NROW elements containing the pitch angles (degrees) corresponding to the rows of the above arrays

SANGLE is a one-dimensional array of NCOL elements containing the scan angles (degrees) corresponding to the columns of the above arrays

b. CALL EFFECT (YAWD,PITCHD,SCAND,BSAZ,BSEL,CGAIN,SWR,WITHIN)

where:

YAWD, PITCHD, SCAND are the yaw, pitch, and scan angles (degrees) corresponding to a antenna/radome orientation for which radome effects data are desired

BSAZ, BSEL, CGAIN, SWR are the radome effects data for the specified orientation (see BSEAZ,BSEEL, GAINDB, VSWR, defined above)

WITHIN is a logical variable which is .FALSE. if the specified orientation is not within the ranges of pitch and scan angles previously established in the call to RADEFT

3. Comments

a. RADEFT

(1) In the four output arrays (e.g. BSEEL(I,J)), the I subscript corresponds to rows (pitch) and the J subscript corresponds to columns (scan).
(2) In practice, RADEFT will be referenced by the calling program only once. At this time, the punched data cards will be read into the four radome effects data arrays. If the calling program utilizes any other punched data cards, care must be exercised in arranging all data cards.

(3) The number NRNC of punched data cards to be read is computed within RADEFT according to

\[ NRNC = \frac{\text{NROW} - 1}{2} + 1 \]

\[ + \frac{\text{NCOL} + 1}{2} + 1 \]

(4) In general, NROW and NCOL must both be odd integers greater than or equal to 3. For the radome effects data provided under the subject contract, the appropriate values used in the call of RADEFT are given in parentheses in 2a above.

b. EFFECT

(1) The angles yaw, pitch, and scan are defined in Figure 1 of Reference 1 which is repeated here for convenience. Pitch is measured from the horizontal, where \( \text{PITCH} < 0 \) corresponds to pitch down toward the ground. \( \text{YAWD} > 0 \) corresponds to yaw to the right for an observer at the gimbal point looking in the x direction.

(2) Figure 2 shows the organization and format of each of the four arrays BSEEL, BSEAZ, GAINDB, VSWR. The ranges of pitch and scan of these arrays for the radome effects data supplied under the subject contract are also shown. The array elements corresponding to unique orientations of the antenna are enclosed within the
Figure 1. Coordinate Systems Used in Radome Analysis.

Reference System: \((X, Y, Z)\)

Antenna System: \((X_A', Y_A', Z_A)\)

Radome System: \((X_R', Y_R', Z_R)\)
Figure 2. Format of Radome Effects Data Arrays.
broad line; other positions in the array for which the radome effects data are identical to that in the unique positions are shown by the numbers in the small blocks.

(3) The radome effects for an orientation YAWD, PITCHD, SCAND corresponding to intermediate positions in the arrays are found by interpolation of the basic data. The four-point bivariate interpolation formula used is taken from the Handbook of Mathematical Functions of the National Bureau of Standards (p. 882). The interpolation computation is accomplished by REAL FUNCTION INTERP described in Appendix D.

(4) The variable YAWD must lie in the range -90. to +90. degrees. A nonzero value of YAWD is interpreted in EFFECT as a correction to the true value of scan angle (SCAN) according to SCAN = AMOD ((SCAND - YAWD),360.).

(5) The angular directions of the boresight errors are defined with respect to the plane formed by the z and $z_A$ axes of Figure 1. Boresight errors in azimuth correspond to angular displacements perpendicular to this plane with positive values corresponding to the direction indicated by the angle SCAN shown in Figure 1. Boresight errors in elevation correspond to angular displacements in this plane with negative values corresponding to the direction indicated by the angle $\theta_a$.

c. Supporting subroutines required: REAL FUNCTION INTERP

d. The signs of the boresight errors in azimuth are the same in quadrants II and IV of the table shown in Figure 2. However, the signs of the boresight errors in azimuth in quadrants I and III are opposite to
those in quadrant II. Quadrant II is indicated in Figure 2 by the dark border lines, and quadrants are counted counterclockwise.

4. Listing

See following pages.
SUBROUTINE RAEFT (NR, NC, NROW, NCOL, BSEL, BSEAZ, GAINDB, VSWR, PITCH1, DELPIT, SCANC, DELPIT, PANGLE, SANGLE)

C INPUTS:
C NROW=NUMBER OF ROWS IN ARRAYS BSEL, BSEAZ, GAINDB, VSWR (MUST BE ODD)
C NCOL=NUMBER OF COLUMNS IN ABOVE ARRAYS (MUST BE ODD)
C PITCH1=PITCH ANGLE IN DEGREES CORRESPONDING TO ROW 1 OF ARRAYS
C DELPIT=INCREMENT IN PITCH ANGLE FROM ROW 1 TO ROW (I+1) (DEGREES)
C SCANC=INCREMENT IN DEGREES CORRESPONDING TO COLUMN 1 OF ARRAYS
C DELSCN=INCREMENT IN SCAN ANGLE FROM COLUMN J TO COLUMN (J+1) (DEGREES)
C PRINT=LOGICAL VARIABLE: IF .TRUE., OUTPUT ARRAYS ARE PRINTED
C OUTPUTS: (I=Row, J=Column)
C BSEEL(I,J)=RESIGHT ERROR IN ELEVATION (MILLIRADIANS)
C BSEAZ(I,J)=RESIGHT ERROR IN AZIMUTH (MILLIRADIANS)
C GAINDB(I,J)=CHANGE IN POWER GAIN OF ANTENNA DUE TO RADOME (DECIBELS)
C VSWR(I,J)=VOLTAGE STANDING WAVE RATIO OF ANTENNA DUE TO RADOME
C FOR PITCH ANGLE=PICTH1+(I-1)*DELPIT (DEG.)
C SCAN ANGLE=SCANT*(J-1)*DELPIT (DEG.)
C
C REMARKS: DATA IS INITIALLY ENTERED INTO POSITIONS I=1, (NROW-1)/2
C AND J=1, (NCOL+1)/2) TO (NROW/2, J=1) OF THE OUTPUT ARRAYS
C FROM DATA CARDS (FORMAT 10). TOTAL NUMBER OF DATA CARDS
C IS GIVEN BY THE VARIABLE NRNC. NROW AND NCOL MUST BE
C GREATER THAN OR EQUAL TO 3.
C DIMENSION USEF(NROW,NCOL),BSFAZ(NROW,NCOL),GAINDB(NROW,NCOL),
C VSWR(NROW,NCOL)
C LOGICAL PRINT
C DIMENSION PANGLE(NROW),SANGLE(NCOL)
C COMPUTE NUMBER OF DATA CARDS AND READ DATA INTO ARRAYS
C NR=(NROW-1)/2
C NC=(NCOL+1)/2
C NRNC=NR*NC+1
C READ DATA INTO QUADRANT I OF ARRAYS.
C DO 5 I=1,NR
C READ(I+10) IR0W,JCOL,CBSAZ,CSBEL,CSTWR,SWR
C BSEEL(I,J)=CSBEL
C BSEAZ(I,J)=CBSAZ
C GAINDB(I,J)=CSTWR
C VSWR(I,J)=SWR
C 5 CONTINUE
C READ DATA INTO QUADRANT II OF ARRAYS.
C DO 10 I=1,NC
C READ(I+10) IR0W,JCOL,CBSAZ,CSBEL,CSTWR,SWR
C BSEEL(I,J)=CSBEL
C BSEAZ(I,J)=CBSAZ
C GAINDB(I,J)=CSTWR
C VSWR(I,J)=SWR
C 10 CONTINUE
C FILL ROW-ANGLE POSITIONS IN OUTPUT ARRAYS
C I=N11+1
C FILL PITCH=PICTH1+I*DELPIT ROW OF ARRAYS
C DO 15 J=1,NC
C BSEEL(I,J)=BSEEL(1,1)
C BSEAZ(I,J)=BSFAZ(I,1)
C GAINDB(I,J)=GAINDB(I,1)
C VSWR(I,J)=VSWR(I,1)
C 15 CONTINUE
C FILL QUAD I OF ARRAYS USING QUAD II DATA
C DO 20 I=1,NR
C DO 20 J=1,NC
C VX=NC-1
C VX=NC+1
C VX=NC
C VX=NC+1
**RADEF**

---

```fortran
C BSEIL(I,J) = BSEIL(I,J)
C CHANGE SIGN ON USEAZ FOR QUAD I
BSEEZ(I,J) = INSEE(E(I,J)
IF(J2.EQ.0 .OR. USEAZ(I+1,J) = BSEEZ(I,J))
GAIND(I,J) = GAINDB(I,J)
VSZR(I,J) = VSZR(I,J)

20 CONTINUE
C FILL QUADRANT IV OF ARRAYS WITH QUAD II DATA
DO 25 I = 1, NR
   I2 = NR + 1 - I
   DO 25 J = 1, NC
      BSEEL(I2,J) = BSEEZ(I,J)
      GAIND(I2,J) = GAINDB(I,J)
      VSZR(I2,J) = VSZR(I,J)
   25 CONTINUE

25 CONTINUE
C FILL QUADRANT III OF ARRAYS USING QUAD IV
NR2 = NR + 2
DO 30 I = NR2, NR
   DO 30 J = 1, NC
      BSEEZ(I,J) = USEAZ(IPJ)
      GAIND(I,J) = GAINDB(I,J)
      VSZR(I,J) = VSZR(I,J)
   30 CONTINUE
C IF PRINT = 'TRUE', PRINT OUTPUT ARRAYS
IF (PRINT) GO TO 35
GO TO 120
35 WRITE(4,*)
   DO 40 I = 1, NR
      WRITE(4,*)
      40 FORMAT(14H BORESIGHT ERROR IN ELEVATION, N MILLIRADIANS/8H)
      WRITE(4,*)
      WRITE(4,*)
      41 FORMAT(14H BORESIGHT ERROR IN AZIMUTH IN MILLIRADIAN/8H)
      WRITE(4,*)
      WRITE(4,*)
      42 FORMAT(14H SCANNING ANGLE (DEG)/)
      WRITE(4,*)
      WRITE(4,*)
      43 FORMAT(F8.5,6F12.3)
      WRITE(4,*)
      WRITE(4,*)
      44 FORMAT(1F12.2)
      WRITE(4,*)
      WRITE(4,*)
      45 FORMAT(1F12.2)
      WRITE(4,*)
      WRITE(4,*)
      46 FORMAT(1F12.2)
      WRITE(4,*)
      WRITE(4,*)
      47 FORMAT(1F12.2)
      WRITE(4,*)
      WRITE(4,*)
      48 FORMAT(1F12.2)
      WRITE(4,*)
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      49 FORMAT(1F12.2)
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      WRITE(4,*)
      50 FORMAT(1F12.2)
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      WRITE(4,*)
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      108 FORMAT(1F12.2)
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      109 FORMAT(1F12.2)
      WRITE(4,*)
      WRITE(4,*)
      110 FORMAT(1F12.2)
      WRITE(4,*)
      WRITE(4,*)
      111 FORMAT(1F12.2)
```
```
000110 000 85 WRITE(6,54) PANGLE(I), (BSEA2(I+J), J=1, NCOL)
000114 000 90 FORMAT(1H1, 55H CHANGE IN POWER GAIN OF ANTENNA DUE TO RADOME (DEG), 1H1, 55H SCAN ANGLE (DEG))
000118 000 WRITE(6,55) (ANGLE(J), J=1, NCOL)
000122 000 DO 95 I=1, NROW
000126 000 WRITE(6,56) PANGLE(I), (GAINDB(I+J), J=1, NCOL)
000130 000 WRITE(6,55) (ANGLE(J), J=1, NCOL)
000134 000 DO 100 I=1, NROW
000138 000 WRITE(6,57) PANGLE(I), (GAINDB(I+J), J=1, NCOL)
000142 000 WRITE(6,55) (ANGLE(J), J=1, NCOL)
000146 000 DO 110 I=1, NROW
000150 000 WRITE(6,58) PANGLE(I), (VSWR(I+J), J=1, NCOL)
000154 000 WRITE(6,55) (ANGLE(J), J=1, NCOL)
000158 000 DO 115 I=1, NROW
000162 000 WRITE(6,59) PANGLE(I), (VSWR(I+J), J=1, NCOL)
000166 000 C END OF OUTPUT
000170 000 RETURN;
000174 000 END

CODGAP  *****  REAL  *****
**EFFECT**

**CELT, INTERP.EFFECT**

**ELT004.R01067-10**

**CYCLE (01)**

000001  000  COMMON BSSEL(13.17), BSAZ(13.17), GAINDB(13.17), VSWR(13.17)

000002  000  COMMON PITCH1, DELPIT, SCAN1, DELSCAN, NROW, NCOL

000003  000  C INPUTS:
000004  000  C YAWD=Yaw of Radome Axis (Degrees) WRT XZ-plane (0 to 360 Deg.)
000005  000  C PITCHD=Pitch of Radome Axis (Degrees) WRT XY-plane (-30 to -150 Deg.)
000006  000  C SCAND=Scan Angle of Main Beam (Degrees) WRT XZ-plane (0 to 360 Deg.)

000007  000  C OUTPUTS: (For Antenna/Radome Orientation Specified by Inputs)
000008  000  C BSAZ=Disk Slew Error in Azimuth (Milliradians) Due to Radome
000009  000  C BSEL=Disk Slew Error in Elevation (Milliradians) Due to Radome
000010  000  C CGAIN=Change in Gain of Main Beam (Decibels) Due to Radome
000011  000  C SwR=VSWR Standing Wave Ratio of Antenna Due to Radome
000012  000  C WITHIN=.TRUE. IF INPUTS ARE WITHIN RANGE OF RADOME EFFECTS TABLE

000013  000  REAL INTERP
000014  000  LOGICAL WITHIN
000015  000  C CORRECT SCAN TO ACCOUNT FOR YAWD
000016  000  SCAN=SCAN-YAWD
000017  000  SCANMOD=SCAN-360.
000018  000  IF (SCANLT.0.) SCAN=360.-SCAN

000019  000  C COMPUTE POSITIONS IN RADOME EFFECTS TABLE CORRESPONDING TO INPUT ANGLES
000020  000  RJ=I+PIT1-H/PITCH1)/DELPIT
000021  000  RI=I+SCAN-SCAN1)/DELSCE
000022  000  J1R=1
000023  000  J1J=1

000024  000  WITHIN=.TRUE.
000025  000  C TEST TO ENSURE THAT INPUT IS WITHIN RANGE OF TABLE
000026  000  IF ((RI.LT.1).OR.(JI.LT.1)) GO TO 1
000027  000  IF ((RI.GT.NROW).OR.(JI.GT.NCOL)) GO TO 1
000028  000  IF (RI.EQ.NROW) RI=RI-1
000029  000  IF (JI.EQ.NCOL) JI=JI-1

000030  000  C COMPUTE INTERPOLATED VALUE OF SIGHT ERROR IN AZIMUTH, ELEVATION,
000031  000  C CHANGE IN GAIN AND VSWR DUE TO RADOME
000032  000  BSAZ=INT1P(BSAZ+PQ11%1J11NROW+NCOL)
000033  000  BSEL=INT1P(BSEL+PQ11%1J11NROW+NCOL)
000034  000  CGAIN=INT1P(GAINDB+PQ11%1J11NROW+NCOL)
000035  000  VSWr=INT1P(VSWr+PQ11%1J11NROW+NCOL)
000036  000  GO TO 2

000037  000  1 WITHIN=.FALSE.
000038  000  2 RETURN
000039  000   END

**QM0Gp **** INTERP ****
SECTION III
TRADEF

1. Purpose

The purpose of this program is to provide a means of testing subroutines RADEFT and EFFECT to insure their correct operation.

2. Program Flow

a. Read input data NROW, NCOL, and PITCH1, DELPIT and SCAN1, DELSCN (defined in description of SUBROUTINE RADEFT).

b. Set PRINT = .TRUE. so that radome effects data arrays of RADEFT are outputted as printed data.

c. Call RADEFT. RADEFT reads the radome effects data into the appropriate arrays from punched data cards and outputs the complete arrays as printed data for manual verification.

d. Read NTEST. This integer input variable is equal to the number of tests to be performed on the interpolation feature of EFFECT.

e. Read input data for testing the interpolation. For each interpolation test, two data cards (FORMAT 29 and FORMAT 30) are read: the first card specifies the antenna/radome orientation; the second card specifies the true values of radome effects data which apply to the specified orientation. These data cards for the interpolation tests have been generated earlier by the radome analysis computer program.

f. Call EFFECT. This subroutine interpolates the original radome effects data and outputs the values of radome effects data corresponding to the orientation specified in (e) above.
g. Write results. For each interpolation test, the true values and the interpolated values of the radome effects data are printed out for comparison.

3. Comments
   a. Two sets of punched data cards are provided for use with TRADEF. One set consists of simplified data which is used to insure the proper operation of RADEFT. In this test data, all four arrays (BSEEL, BSEAZ, GAINDB, VSWR) of RADEFT are filled with identical data values to facilitate manual verification of proper operation. This test data was generated by a separate computer program. The data values correspond to distances from the origin of a rectangular coordinate system to the intersection point of a line (making a constant 15 degree angle with the z-axis) with a plane passing through the point (0,0,5) for various tilts (PITCH) of the plane and for various angles (SCAN) of the plane formed by the line and the z-axis. This geometrical problem was chosen because of its similarity to the actual radome geometrical problem under study.
   
b. The second set of data cards provided for use with TRADEF consists of the actual radome effects data generated by the radome analysis computer program [1]. Data are also provided to test the accuracy of the interpolation; the true values of the radome effects data for these tests were also generated by the analysis program.
   
c. The results of TRADEF using the two sets of data cards as input are presented following the listing.

4. Listing
   
   See following pages.
**TRADF**

**DELT15** INTERPOL TRADE
ELTOA-RJdD7-10 08/06/73:15:48:28

**CYCLE** (00)

000001 000 C THIS PROGRAM IS USED TO TEST SUBROUTINE RADEF7 WITH ENTRY EFFECT
000002 000 COMMON BSSEL(13,17),BSFAZ(13,17),GAINDB(13,17),VSWR(13,17)
000003 000 COMMON PITCH1,DELPIT,SCAN1,DELSCN,NROW,NCOL
000004 000 DIMENSION PANALF(13),SANGLE(17)
000005 000 LOGICAL PRINT,WITHIN
000006 000 READ(4,5) NROW,NCOL
000007 000 5 FORMAT(2I5)
000008 000 READ(10) PITCH1,DELPIT
000009 000 10 FORMAT(2F2.2)
000010 000 READ(4,10) SCAN1,DELSCN
000011 000 PRINT=TRUE
000012 000 CALL RADEF7(NROW,NCOL,BSSEL,BSFAZ,GAINDB,VSWR,PITCH1,DELPIT,
000013 000 SCAN1,DELSCN,PRINT,PANGLE,SANGLE)
000014 000 READ(5,15) NTST
000015 000 15 FORMAT(15)
000016 000 WRITE(6,+2)
000017 000 20 FORMAT(1H7X,31H TEST RESULTS FOR INTERPOLATION/23H YAW P
000018 000 01A 1H12H TRUE VALUES/31X 20H INTERPOLATED VALUES/115H
000019 000 2(I6,1E12.5)
000020 000 3(I6,1E16.9)
000021 000 25 FORMAT(3F2.2/12.5)
000022 000 DO 50 NI=1,TEST
000023 000 READ(291 IRN,JCOL,YAW,PITCHD,SCAND
000024 000 29 FORMAT(2I4,3F10.2)
000025 000 READ(4,30) IRN,JCOL,TRSAZ,BSSEL,TGAIN,TSWR
000026 000 30 FORMAT(2I4,6E16.9)
000027 000 CALL FFFER7(YAW,PITCH,SCAND,BSAZ,BSSEL,TGAIN,TSWR)
000028 000 IF (.NOT.WITHIN) GO TO 45
000029 000 WRITE(b,25) YAW,PITCH,SCAND,BSAZ,BSSEL,TGAIN,TSWR
000030 000 1 NTST
000031 000 GO TO 50
000032 000 45 WRITE(b+2A) YAW,PITCH,SCAND
000033 000 46 FORMAT(3F2.2) YAW,PITCH,SCAND
000034 000 50 CONTINUE
000035 000 STOP
000036 000 END

**GHGp ****** TRADF ******
<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<td>000</td>
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<td>.536429274+01 .535529274+01 .535529274+01 .535529274+01</td>
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<tr>
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<td>.943604391+01 .541264391+01 .541264391+01 .541264391+01</td>
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<td>000</td>
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<td></td>
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<tr>
<td>Pitch (Deg)</td>
<td>Scan Angle (Deg)</td>
<td>Scan Angle (Deg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>------------------</td>
<td>------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.00</td>
<td>45.00</td>
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<td></td>
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<td>0.35355 + 01</td>
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<td></td>
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<tr>
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<td></td>
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<td>0.44901 + 01</td>
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<td>0.50000 + 01</td>
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<td>30.00</td>
<td>0.51764 + 01</td>
<td>0.51790 + 01</td>
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<td>40.00</td>
<td>0.54597 + 01</td>
<td>0.54810 + 01</td>
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<td>50.00</td>
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<td>0.57717 + 01</td>
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<td>0.60961 + 01</td>
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<td>70.00</td>
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<td>0.64224 + 01</td>
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<td>0.67572 + 01</td>
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<td>90.00</td>
<td>0.70023 + 01</td>
<td>0.70839 + 01</td>
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<td></td>
</tr>
</tbody>
</table>

**NOTE:**
- All values are in milliradians.
- The table provides pitch and scan angle values for various degrees of pitch and scan angle.

**Elevation Error in Milliradians:**

<table>
<thead>
<tr>
<th>Elevation (Deg)</th>
<th>0.00</th>
<th>22.50</th>
<th>45.00</th>
<th>67.50</th>
<th>90.00</th>
<th>112.50</th>
<th>135.00</th>
<th>157.50</th>
<th>180.00</th>
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<td>-90.00</td>
<td>0.36230 + 01</td>
<td>0.35477 + 01</td>
<td>0.34720 + 01</td>
<td>0.33963 + 01</td>
<td>0.33205 + 01</td>
<td>0.32446 + 01</td>
<td>0.31687 + 01</td>
<td>0.30928 + 01</td>
<td>0.30169 + 01</td>
</tr>
<tr>
<td>-80.00</td>
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<td>0.35477 + 01</td>
<td>0.34720 + 01</td>
<td>0.33963 + 01</td>
<td>0.33205 + 01</td>
<td>0.32446 + 01</td>
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<td>0.30928 + 01</td>
<td>0.30169 + 01</td>
</tr>
<tr>
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<td>0.35477 + 01</td>
<td>0.34720 + 01</td>
<td>0.33963 + 01</td>
<td>0.33205 + 01</td>
<td>0.32446 + 01</td>
<td>0.31687 + 01</td>
<td>0.30928 + 01</td>
<td>0.30169 + 01</td>
</tr>
<tr>
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<td>0.34720 + 01</td>
<td>0.33963 + 01</td>
<td>0.33205 + 01</td>
<td>0.32446 + 01</td>
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<td>0.30169 + 01</td>
</tr>
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<td>0.34720 + 01</td>
<td>0.33963 + 01</td>
<td>0.33205 + 01</td>
<td>0.32446 + 01</td>
<td>0.31687 + 01</td>
<td>0.30928 + 01</td>
<td>0.30169 + 01</td>
</tr>
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<td>0.35477 + 01</td>
<td>0.34720 + 01</td>
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<td>0.33205 + 01</td>
<td>0.32446 + 01</td>
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<td>0.30928 + 01</td>
<td>0.30169 + 01</td>
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<tr>
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<td>0.34720 + 01</td>
<td>0.33963 + 01</td>
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<td>0.33963 + 01</td>
<td>0.33205 + 01</td>
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<td>0.34720 + 01</td>
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<td>0.35477 + 01</td>
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<td>0.30928 + 01</td>
<td>0.30169 + 01</td>
</tr>
</tbody>
</table>
### Sinesight Error in Azimuth in Milliradians:

#### Pitch (Deg)

<table>
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<tr>
<th>θG</th>
<th>0°</th>
<th>2°</th>
<th>4°</th>
<th>6°</th>
<th>8°</th>
<th>10°</th>
<th>12°</th>
<th>14°</th>
<th>16°</th>
<th>18°</th>
<th>20°</th>
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### Change in Power Gain of Antennas Due to Hadio (Decibels):

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DATE 081373 PAGE 1
### TEST OF INTERPOLATION ROUTINE USING ACTUAL DATA

**DATE 081373**

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| Deg | 0.00 | 22.50 | 45.00 | 67.50 | 90.00 | 112.50 | 135.00 | 157.50 | 180.00 |

Date 081373 Page 6
### TEST OF INTERPOLATION ROUTINE USING ACTUAL DATA

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## TEST OF INTERPOLATION ROUTINE USING ACTUAL DATA

<table>
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<tr>
<th>TIME (DEG)</th>
<th>PITCH (DEG)</th>
<th>SCAN (DEG)</th>
<th>TSSEL</th>
<th>TRUFL VALUE</th>
<th>TACCLN</th>
<th>TSWR</th>
<th>BSAZ</th>
<th>INTERPOLATED VALUE</th>
<th>BSSEL</th>
<th>CGAIN</th>
<th>SWR</th>
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<tr>
<td>0.00</td>
<td>-55.00</td>
<td>101.25</td>
<td>101.25</td>
<td>0.3694+00</td>
<td>0.554u9+01</td>
<td>-4.09938+00</td>
<td>0.10002+01</td>
<td>-3.5915+00</td>
<td>0.52365+01</td>
<td>-4.572+00</td>
<td>0.10004+01</td>
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<td>228.75</td>
<td>0.3694+00</td>
<td>0.31125+01</td>
<td>-5.1135+00</td>
<td>0.10002+01</td>
<td>0.39915+00</td>
<td>0.52365+01</td>
<td>-4.572+00</td>
<td>0.10004+01</td>
</tr>
</tbody>
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PLOT: 17.8 Min. 3.8 FT 00F 0a1373156n8

END: 15129 MSEC
APPENDIX A
Computer Program

The computer program used to calculate the effects on the performance of a ground mapping radar is listed in this appendix. The computer program is essentially the same program listed in the Final Report dated 6 March 1973. As several modifications have been made in the main program and in some subroutines a new listing is included for completeness. The major changes are as follows:

1. The position of the antenna with respect to the radome is now read in from data cards which are generated using the table of unique pitch and scan positions previously described.
2. Subroutine SDLOBE has been removed. This subroutine calculated the magnitude and position of the maximum sidelobe of the far field pattern. As this information was not needed, the subroutine was removed to save computation time.
3. Subroutine ERRORS has been modified to delete the printing of maximum sidelobe level and positions and to add the printing of the positions of the antenna with respect to the radome.
4. Subroutine EXPAND has been added to the program. This subroutine expands the aperture field array from a 16 x 16 size to a 64 x 64 size. The original 16 x 16 array is Fourier interpolated to generate the 64 x 64 array using the Fast Fourier Transform algorithm. The increased resolution of the 64 x 64 was needed for more precise calculation of the boresight direction, power in the -3dB contour and for contour plotting of the far field pattern.
The execution of the radome analysis computer program is controlled by the main program called CONTROL. The logical flow of CONTROL is as follows:

1. Set parameters, declare dimensions, declare namelists, declare variable types, initialize plotter.

2. Read input data which remains fixed throughout execution of program:

   TITLE - An alphanumeric description of the input data consisting of up to 72 alphanumeric characters.

   FIXED1 - A namelist of the following input data variables:
       
       RA(= r_a in inches)
       THETAA(= \theta_a in degrees)
       RR(= r_r in inches)
       AGAM3A(= \cos^{-1}(\nu_{3A}) in degrees)
       FGHZ = (frequency in gigahertz)
   
   where the variables are defined in Figure 1.

   PATRN - A namelist of the following input variables:
       
       THETA (in degrees; see SUBR FAR)
       PHI (in degrees; see SUBR FAR)
       ALT (altitude of antenna in meters)
       KYMAX (unitless; see SUBR FAR)
       KYMAX (unitless; see SUBR FAR)
       DBCTR (far-field power pattern contour on the ground to be used in computing boresight errors; see SUBR BRSITE)
   
   FIXED2 - A namelist of the following input data variables:
       
       IS (see SUBR FAR)
       IPWR (see SUBR FAR)
       VALUES (decibel values for which contours are to be plotted; see SUBR CNTOUR)
3. Print the above input data for verification.
4. Convert input data in inches, degrees, and meters to centimeters and radians.
5. Read NPOSIT, the number of antenna/radome orientations for which radome effects data are to be computed.
6. Call PWS to compute the plane wave spectrum P of the x-component of the aperture electric field.
7. Call PWS to compute the plane wave spectrum Q of the y-component of the aperture electric field.
8. Call FFT (twice) to compute x and y-components, respectively, of aperture electric field.
9. Form PT and QT arrays by nulling the first row and first column of P and Q. The arrays PT and QT are then symmetrical in extent about their midpoints the same as the near-field arrays to be calculated in subroutine RADOME.
10. Call FFT (twice) using P and Q to recover plane wave spectra x and y-components of aperture electric field.
11. Call FFT (twice) using PT and QT to calculate the plane wave spectra of the symmetrical aperture electric field.
12. Call EXPAND to increase the resolution of PT(NX,NY) to XE(NXE,NYE) using Fourier interpolation.
13. Call EXPAND to increase the resolution of QT(NX,NY) to YE(NXE,NYE) using Fourier interpolation.
14. Call FAR to compute the far-field power pattern on the ground (IS = 1) of the antenna (TFIELD).
15. Call BRSITE to compute the true boresight direction of the antenna and the total power in the DBCTR contour.
16. DO 100 I = 1, NPOSIT; i.e., compute radome effects data for each of
the NPOSIT orientations as described below.

17. Read POSIT, where POSIT is a namelist of the following input variables
used to specify the antenna/radome orientation:
   IROW (integer which specifies row number in Figure 2)
   JCOL (integer which specifies column number in Figure 2)
   YAWD (in degrees; see Figure 1)
   PITCHD (in degrees; see Figure 1)
   SCAND (in degrees; see Figure 1)

18. Compute angles $\theta_r$, $\theta_p$, $\theta_a$ (see Figure 1) needed by subroutine ORIENT.

19. Call ORIENT to compute matrices needed by subroutine RADOME in making
transformations from antenna to radome coordinate system and vice versa.

20. Call RADOME to compute the plane wave spectra of x and y-components
of aperture electric field with radome in place (XFIELD,YFIELD);
also compute plane wave spectra of x and y-components of electric
field on aperture plane caused by first-order reflections (PR,QR).

21. Set RFMX = 0 so that far-field power pattern of antenna with radome
will be normalized with respect to its own maximum in the call of
subroutine FAR below.

22. Call EXPAND (twice) to increase the resolution of XFIELD(NX,NY),
YFIELD(NX,NY) to XE(NXE,NYE),YE(NXE,NYE) respectively, using Fourier
interpolation.

23. Call FAR to compute the far-field power pattern of the antenna with
radome in place (RFIELD).

24. Call BRSITE to compute the boresight direction of the antenna and the
total power in the DBCTR contour. The boresight direction is defined
as the first moment (centroid) of the DBCTR (e.g., -3dB) contour on the
ground.
25. Call VSWR to compute the voltage standing wave ratio of the antenna with radome.

26. Call ERRORS to compute the boresight errors in azimuth and elevation, (milliradians) the change in the total power in the DBCTR contour, (decibels), and the voltage standing wave ratio caused by the radome. Subroutine ERRORS outputs these radome effects data as printed data (1 page) and on two punched cards.

27. Plot far-field contour pattern (decibels) of antenna with radome as it appears on the ground.

28. 100 CONTINUE

29. END

The listing of the program begins with a listing of the main program, CONTROL, followed by an alphabetical listing of the subroutines.

The data used in the executions of the program is listed after the subroutines.

The execution time of the radome analysis computer program for a single orientation of the antenna/radome combination was approximately three minutes on the Univac 1108 computer system at Georgia Tech using 16 x 16 arrays in the computations (NX = 16 NY = 16). This array size corresponds to representing the radiating characteristics of the antenna by 256 plane waves and the tangential aperture electric field by 256 sampled values. It has been found that if the basic array size is doubled (NX = 32, NY = 32), the execution time increases by a factor of $2^4 = 16$. 

35
*** CONT,40L ***

GELT=, RAHOME, CONTROL
ELT00a=ALTU00-10 08/09/73 16:16:21

CYCLE (07)

000001 000 C CAUTION ALL VARIABLES BEGINNING K ARE REAL!!

000002 000 REAL TENEK XE=16*NYE=64

000003 000 DIMENSION VALNES(INVALS)

000004 000 REAL TAEAL(K)

000005 000 NAMELTST/TRAN/THETA, RAGAM3A*G6HZ

000006 000 NAMELTST/GRAT/THETA + ALT*KXMAK*NYMAK*DBCTA

000007 000 NAMELTST/FIXEDZ/1.5*IPW= VALUES

000008 000 NAMELTST/POSIT/1000, YAWD, PITCH, SCAND

000009 000 DIMENSION TITLE(12)

000010 000 REAL TEGA, A, B, C

000011 000 COMPLEX XFIELD, YFIELD, N=NX*NY

000012 000 DATA PI, 3.1415926/3, 65/6

000013 000 REAL TFIEI1(NY*NTE) PFIELD(NY*NTE)

000014 000 REAL N0TAL(3,3) TRANSL(3)

000015 000 INTEGER IAF(10000)

000016 000 COMPLEX PT(NX,NY)*OT(NY*NY), P(NX*NY)*Q(NX*NY)*PR(NX*NY)*QR(NX*NY)

000017 000 COMPLEX XF(NX,NE), YF(NX*NY)

000018 000 C PLTME=60.

000019 000 CALL PLOTO(101, 10000, 3, PLTIM)

000020 000 CALL FACTA(0, 4)

000021 000 REAL TPSI/180.0

000022 000 READ(T,51 TITLE)

000023 000 READ(T,51 TITLE)

000024 000 FORM(12,4)

000025 000 READ(T,51 TITLE)

000026 000 READ(T,51 TITLE)

000027 000 READ(T,51 TITLE)

000028 000 READ(T,51 TITLE)

000029 000 READ(T,51 TITLE)

000030 000 READ(T,51 TITLE)

000031 000 READ(T,51 TITLE)

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000034 000 READ(T,51 TITLE)

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000036 000 READ(T,51 TITLE)

000037 000 READ(T,51 TITLE)

000038 000 READ(T,51 TITLE)

000039 000 READ(T,51 TITLE)

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000051 000 READ(T,51 TITLE)

000052 000 READ(T,51 TITLE)

000053 000 READ(T,51 TITLE)

000054 000 READ(T,51 TITLE)

000055 000 READ(T,51 TITLE)

000056 000 READ(T,51 TITLE)

000057 000 READ(T,51 TITLE)

000058 000 READ(T,51 TITLE)
IF(I.1T-0.1) GO TO 80
IF(J.1T-0.1) GO TO 80
PT(1,J)=PT(I,J)
C(0,J)=C(1,J)
CALL FXPA(D:UT:Y:Z+NX:NY+XE:NXE:NYE)
- 15,TEFLY:IPR)
DO 10 =1:1:NP0S1T
RFAD(X,P0:1T)
PH1=PI/2.-PITCHD*ANG
PHI=PI/2.-PITCHD*ANG
RFM(X:Y:Z+NX:NY+XE:NXE:NYE)
CALL FXPA(D:UX:Y:Z+NX:NY+XE:NXE:NYE)
- 15,TEFLY:IPR)
CALL VSWR(X:Y:Z+NP0R:NP0R:NP0R:NP0R)
CALL FMOSIT(10:NP0R:NP0R:NP0R:NP0R:NP0R:NP0R:NP0R:NP0R)
- DBCTR:TFM)
CALL ROT(A:1:10:1:10:1:10:1:10)
CALL SMOLE(17.6.17.75..7.PITCH:SCAN:7.75..14)
CALL NUMFRK(17.6.17.75..7.PITCH:0.42)
CALL HUMR(K:20.6.17.75..7.SCAN:0.42)
CALL NUMFRK(REF:10:1:10:1:10:1:10:1:10)
- PHI:15.0)
100 CONTINUE
END
SUBROUTINE BDISK(P,K,P1,HIT)

BDISK CALCULATES THE POINT OF INTERSECTION PI OF A DISK HORIZONTAL TO THE XY PLANE WITH A RAY EMINATING FROM POINT P AND TRAVELING IN THE K DIRECTION.

THE EQUATION USED FOR THE BOTTOM DISK IS Z=ZBOT FOR \((X**2+Y**2)\leq R^2\)

SET BOTTOM DISK PARAMETERS:

DATA ZBOT=RSQ/0.506,4419/

REAL P(3),K(3),PI(3)

LOGICAL HIT

IF(ZT.GE.0.0) GO TO 1

PI(1)=ZBOT

T=ZT/K(3)

PI(1)=PI(1)+K(1)*T

PI(2)=PI(2)+K(2)*T

IF(PI(1)*R*0+0.1) GO TO 1

HIT=.TRUE.

RETURN

HIT=.FALSE.

RETURN

C CALCULATE INVARD NORMAL OF BOTTOM DISK

ENTRY BDISKMN(N)

REAL N(3)

N(1)=0.0

N(2)=0.0

N(3)=1.0

RETURN

END
SUBROUTINE OURSITE

SUBROUTINE OURSITE (ORESIGHT DIRECTION) CALCULATES THE TOTAL
POWER OF A FAR FIELD PATTERN (TPWR) AND THE ORESIGHT
DIRECTION (KX0S,KY0S) OF THE FAR FIELD PATTERN USING
THESE COMPUTATIONS ONLY THOSE VALUES OF THE PATTERN WHICH
ARE GREATER THEN DECIBEL (DECIBEL CONTOUR) DECIBELS
FROM THE PEAK OF THE PATTERN.

FIELD(X,NY) CONTAINS THE NORMALIZED FAR FIELD POWER PATTERN FOR
ALL DIRECTIONS WITHIN THE RECTANGULAR WAVENUMBER REGION
-KXMAX TO KXMAX AND -KYMAX TO KYMAX.

FMAX IS THE NORMALIZING COEFFICIENT USED IN NORMALIZING
FIELD.

IMPLICIT REAL(K)

DIMENSION: FIELD(INX,NY)

PI=3.14159265

K0=2*PI/LAMBDA

KYAF=2*N1*(100.)*(180.)*COS(PHI*PI/180.)

KXAF=2*N1*(100.)*SIN(PHI*PI/180.)

KZAF=COS(TETA*PI/100.)

KX=0.

KY=0.

TPWR=1.

DKX=2.**(AX/NX)

DKY=2.**(AY/NY)

CTR=1.**(L*/10.)

DO 10 I=1,NX

DO 10 J=1,NY,1

CALCULATE THE WAVENUMBER COORDINATES OF THE POINT.

KK=2*I-KX02-KY**2)

WPWR=FIELD(I,J)**AREA(KX,KY,KZ0KX0DKX0DKY)

KPSK=KX+P0KX

KPSKY=P0KY

TPWR=TPWR*PAR

CONTINUE

CALCULATE ORESIGHT WAVENUMBERS.

KXUS=XP/TPWR

KYUS=YP/TPWR

TPWR=TPWR/FMAX

RETURN

C *******************************************************
FUNCTION \texttt{AREA}(KX+KY+KZ)\texttt{DKX+DKY)}
\textbf{IMPLICIT REAL (K)}
\texttt{IF(KX)1,2,1}
\texttt{IF(KY)1,3,1}
\texttt{P=0.}
\texttt{GO TO 4}
\texttt{P=ATA_2(KY*KX)}
\texttt{REAL7/(KyAF*KX+KYAF*KY+KZAF*KZ)**2}
\texttt{C=COS(P)**2}
\texttt{S=SIN(P)**2}
\texttt{DX=DX**2}
\texttt{DY=DY**2}
\texttt{AREA=4*SQR((C*DX+S*DY)*(S*DX+C*DY))/(K0**2*KZ)}
\texttt{RETURN}
\texttt{END}

**CHANGES**

\texttt{ENDP}
SUBROUTINE CNTOU(R,IMAX,JOYMAX,NVALUES,NVALUES,KXMAX,KYMAX,ALT,THETA,PHI,XYPMAX)

SUBROUTINE CNTOU PLOTS AND LABELS CONSTANT DB CONTOURS.
FIELD(IMAX,JOYMAX) IS A REAL ARRAY WITH VALUES IN DECIBELS.
VALUES(NVALUES) IS A REAL ARRAY WITH NVALUES ENTRIES WHICH
DETERMINE VALUES FOR WHICH CONTOURS WILL BE PLOTTED.
XYPMAX DEFINES THE SIZE OF THE AREA IN WHICH THE CONTOURS
WILL BE PLOTTED. CONTOURS WILL BE DRAWN INSIDE A BOX
WITH DIMENSIONS XYPMAX/2 AT XYPMAX/2.
KXMAX AND KYMAX ARE RESPECTIVELY THE MAXIMUM ABSOLUTE
VALUES OF KX AND KY WAVE NUMBERS FOR WHICH THE FAR FIELD
IS CALCULATED.
ALT IS THE ALTITUDE OF THE ORIGIN OF THE APERTURE FIELD
COORDINATE SYSTEM IN METERS.
THETA AND PHI SPECIFY THE DIRECTION FROM THE NORMAL OF
THE APERTURE PLANE TO THE GROUND AND HAVE UNITS OF
DEGREES. (SEE REPORT FOR APERTURE—GROUND COORDINATE
SYSTEM).
DIMENSION FIELD(IMAX,JOYMAX),VALUES(NVALUES)
LOGICAL DOWN
REAL KX,KY,KXMAX,KYMAX,KX2,KY2,K1,K2,K3,K4,K5,K6,K7,K8,K9
REAL X0,Y0,Z0
CALL PLOT(XYPMAX/2,XYPMAX/2,-3)
CALL PLOT(0.07,0.07,3)
CALL PLOT(0.0,0.0)
CALL PLOT(-0.07,0.07,3)
CALL PLOT(0.07,0.07,3)
CALL PLOT(-0.07,0.07,3)
CALL PLOT(0.0,0.0)
CALL PLOT(-0.07,0.07,3)
CALL PLOT(0.07,0.07,3)
CALL PLOT(-0.07,0.07,3)
CALL PLOT(0.0,0.0)
CALL PLOT(-0.07,0.07,3)
CALL PLOT(0.07,0.07,3)
REAL X3D=XYPMAX/ALT/2
REAL X3D=SYMPAX/ALT/2
REAL X3D=XYPMAX/ALT/2
REAL X3D=XYPMAX/ALT/2
REAL X3D=XYPMAX/ALT/2
REAL X3D=XYPMAX/ALT/2
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REAL X3D=XYPMA
**FUNCTION WITHIN**

**FUNCTION WITHIN** returns a TRUE, value only if the contour values pass through the side of the cell defined by P1 and P2.

```
FUNCTION WITHIN (PI,P2,IX,JX,JY)
RETURN
```

**WITHIN** = TRUE.

```
IF ((P1-P2)**2 LT 1.E-10) RETURN
```

**WITHIN** = FALSE.

```
RETURN
```
SUBROUTINE PLC

* S=1.0-KX2-KT*2

IF(KS.LT.0.0) RETURN

Determine conversion from wavenumber coordinates to Ground
coordinate used in plotting the contour.

SUBROUTINE EFPLT

SUBROUTINE EFPLT eliminates calls to plot when the pen
is already in the desired location, and also inhibits
plotting contours outside the box defined by XYPMAX.

SUBROUTINE CNUM

SUBROUTINE CNUM writes contour values beside contours.

***** C:TOUR *****
C:TOUR

INTEGER CASE
DIMENSION X(50), Y(50)

CASE = 1
IF(YG.LT.0.) CASE = 2
X1 = 0.
Y1 = (YG - YGP) / (XG - XGP) + YGP
GO TO 430
CASE = 3
IF(XG.LT.0.) CASE = 4
Y1 = 0.
X1 = (XS - XGP) / (YG - YGP) + XGP
CONTINUE

CASE = 5
J0 = 2, LSP + INT(ALOG10(ABS(NAMES(K)))) * LSZ
IF(XG.GE.XGP) SLOPE = ATAN2(YG - YGP, XG - XGP)
IF(XG.LT.XGP) SLOPE = ATAN2(YGP - YGP, XG - XGP)
DP = DA
IF(CASE.EQ.2) DP = DA - LSZ
IF(CASE.EQ.4) DP = DA - LSZ
XP = X1 - DP * SIN(SLOPE) - DO.0.S(SLOPE)
YP = Y1 + DP * COS(SLOPE) + DO.0.S(SLOPE)
SLOPE = SLOPE + 180./PI

CASE = 6
DO = 2, LSZ + INT(ALOG10(ABS(NAMES(K)))) * LSZ
IF(YG.LT.0.) CASE = 7
Y1 = 0.
X1 = (XS - XGP) / (YG - YGP) + XGP
CONTINUE

CASE = 7
CASE = 8
CASE = 9
CASE = 10
CASE = 11
CASE = 12
CASE = 13
CASE = 14
CASE = 15
CASE = 16
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CASE = 47
CASE = 48
CASE = 49
CASE = 50

C DETERMINE THAT THERE IS SUFFICIENT SPACE BETWEEN THE CURRENT CONTOUR LABLE AND ALL PREVIOUS LABLES DRAWN. IF SPACE IS AVAILABLE, THE LABEL IS DRAWN ON THE CONTOUR AND ITS COORDINATES RECORDED IN ARRAYS X AND Y. IF SUFFICIENT SPACE IS NOT AVAILABLE, THE LABEL IS NOT DRAWN.
A MAXIMUM OF 50 LABELS CAN BE DRAWN.

IF(NLAB.EQ.0) GO TO 450
UO 440 IC = 1, NLAB
IF(SORT((XP-X1)**2+(YP-Y1)**2).LE.DIST) RETURN

440 CONTINUE
450 NLAB = NLAB + 1
X(NLAB) = XP
Y(NLAB) = YP
CALL NUMBER(XP, YP, LSZ, NAMES(K), SLOPE, 1)
CALL PLOT(XG, YG, 3)
RETURN
END
SUBROUTINE CONEW(KZ,HIT)

C COLE CALCCLATES THE Z COORDINATE OF THE POINT OF INTERSECTION OF A
C CONE AND A RAY EMANATING FROM A POINT INTERIOR TO THE CONE AND
C TRAVELING IN THE DIRECTION K

C THE EQUATION USED FOR THE CONE IS (Z-ZTIP) = -A*SQRT(X**2+Y**2)

SET CONE PARAMETERS WHERE S = A*2

DATA 5.27TP/13.027901.9700/

REAL K(3)AKTSQ#K3I
LOGICAL HIT

HIT=.TRUE.
Zr=r1P-R(3)
K3I=I/K(3)
A=1-SAKTS0K3IAK3I
AI=1/A
B=ZT+50DTKT.K3I
C=ZT-ZT**2
RQP=S0RT(32-AsC)
Z=MIN(Z1,22)
IF(Z.GE.P(3)) GO TO 1
IF(03).LT.0.0) RETURN
Z=MAX(Z1,Z2)
1 = 3),GE.0.0)
RETURN
HIT=.FALSE.
RETURN

C CALCULATE INVARD NORMAL OF CONE
ENTRY CONEN(PI,N)

REAL PI(3),RN(3)

ENTER DATA ON ZNORM AND RNORM
ZNORM = RNORM =

DATA ZNORM,RNORM/-0.26001,-3.586/

HIT=HIT*PI(3))
N(1)=PI(1)*RN
N(2)=PI(2)*RN
RETURN
END
SUBROUTINE DB (FIELD,NX,NY)

SUBROUTINE DB CONVERTS AN INPUT ARRAY (FIELD(NX,NY)) OF POWER VALUES TO DECIBELS AND RETURNS DB VALUES IN THE SAME ARRAY.

ALL VALUES OF POWER LESS THAN 40 DB DOWN ARE SET EQUAL TO -40 DB.

DIMENSION FIELD(NX,NY)

DO 10 I=1,NX
DO 10 J=1,NY
IF(FIELD(I,J) .LE. 1E-4) FIELD(I,J) = 1E-4
IF(FIELD(I,J) .LE. 1E-4) FIELD(I,J) = 1E-4
FIELD(I,J) = 10.0*LOG10(FIELD(I,J))
10 CONTINUE
RETURN
END
**CALCULATION OF ELEVATION AND AZIMUTH FOR BORESIGHT DIRECTION**

**CTPAR**: $+10.0*\text{AiOGI0}(RTpWR/TTpWR)$

**PRINT RESULTS**

**WRITE**(6,1) **FORMAT**(21,'1.1HORESIGHT DIRECTION')

**WRITE**(6,1) **FORMAT**(19,'1.2RELATIVE POWER IN',2(I5,1X))

**RETURN**
SUBROUTINE EXPAND(FIELD1, FIELD2, NX, NY, NEWX, NEWY)

CALL FFT(FIELD1(NX, NY), NEWX, NEWY)

DO 90 I = NX, -1
    DO 90 J = NY, -1
        FIELD2(I, J) = FIELD1(I, J)

90 CONTINUE

CALL FFT(FIELD2(NEWX, NEWY), NX, NY)

RETURN
END

** *** EXPAND *** **

GELT.1  RAUME.EXPAND

ELT400=RLJUG7-10  08/09-20:16:35

CYCL ( 02 )

DATA 080973  PAGE 1
SUBROUTINE FAR(FIELD,XFIELD,YFIELD Nx Ny,LAMBDA,KxMAX, KYMAX,IPWR)

FIELD IS A TWO DIMENSIONAL ARRAY. ON OUTPUT IT CONTAINS
THE FAR FIELD OF THE INPUT X AND Y COMPONENTS OF
AN APERTURE FIELD.

FIELD HAS DIMENSIONS Nx BY Ny.

XFIELD AND YFIELD ARE TWO DIMENSIONAL COMPLEX ARRAYS WHICH
CONTAIN RESPECTIVELY THE X AND Y COMPONENTS OF AN
PLANE WAVE FIELD. XFIELD AND YFIELD HAVE DIMENSION
Nx BY Ny.

LAMBDA IS THE WAVELENGTH OF THE APERTURE FIELD IN CM.

KxMAX AND KYMAX ARE RESPECTIVELY THE MAXIMUM ABSOLUTE
VALUES OF KK X AND KY WAVENUMBERS FOR WHICH THE FAR FIELD
IS CALCULATED. KXMAX AND KMAX ARE NORMALIZED SUCH THAT
KXMAX=1.0 AND KYMAX=1.0 CORRESPOND TO THE VISIBLE
REGION OF WAVELENGTH SPACE.

ALT IS THE ALTITUDE OF THE ORIGIN OF THE APERTURE FIELD
COORDINATE SYSTEM IN CENTIMETERS.

THETA AND PHI SPECIFY THE DIRECTION FROM THE NORMAL OF
THE APERTURE PLANE TO THE GROUND AND HAVE UNITS OF
DEGREES. (SEE REPORT FOR APERTURE-GROUND COORDINATE
SYSTEM)

FMAX IS THE INPUT-OUTPUT VARIABLE. IF FMAX IS LESS
EQUAL TO ZERO ON INPUT, THE FIELD ARRAY IS
FROM ZERO TO ONE AND FMAX IS THE
NORMALIZING FACTOR.

IF FMAX IS GREATER THAN ZERO ON
INPUT IT REMAINS
UNCHANGED AND IS USED AS THE NORMALIZING FACTOR.

IPWR DETERMINES WHICH POWER COMPONENT WILL BE USED IN THE
FAR FIELD CALCULATIONS. IPWR=1 FOR ELEVATION COMPONENTS,
IPWR=2 FOR AZIMUTH COMPONENTS. AND IPWR=3 FOR TOTAL POWER.

THIS SUBROUTINE CALLS THE FFT SUBROUTINE.

! SUBROUTINE CALLS THE FFT SUBROUTINE.

REAL FIELD(Nx,Ny)

COMPLEX XFIELD(Nx,Ny),YFIELD(Nx,Ny)

IF(IPWR.EQ.1 OR IPWR.EQ.2 OR IpwR.EQ.3) Go TO 101

WRITE(6,100)

100 FORMAT(2X,11,3X,'VALUE ASSIGNED TO THE ARGUMENT IPWR IN SUBROUTINE
-FAR IS NOT ALLOWED. IPWR=3 ASSUMED.	,)

IPWR=3

CONTINUE

REAL K,KXY,X2,Y2,KX,KY,KMAX,LAMBDA

PI=3.14159265

K2=ELU/PILAMBD

K2=0.0+1.0

KX=0.0

KX=0.0

KX=KX+0.1

!Y=KX/2

!Y=KX/2

IF(K2.EQ.1) Go TO 1

IF(K2.EQ.2) Go TO 2

GO TO 12
**FAR**

**DATE 07/24/73**

### CALCULATE THE POWER PATTERN ON A PLANE.

1. \( P_x = \sin(\Theta) \sin(\Phi) \times \cos(\Theta) \cos(\Phi) \)
2. \( P_y = \sin(\Theta) \sin(\Phi) \times \sin(\Theta) \cos(\Phi) \)
3. \( P_z = \cos(\Theta/2 - K) \times \sin(\Theta/2) \)

### CALCULATE THE POWER PATTERN ON A SPHERE.

1. \( P_x = e^{2\pi k r^2} \times \cos(\Theta) \times \sin(\Phi) \)
2. \( P_y = e^{2\pi k r^2} \times \sin(\Theta) \times \cos(\Phi) \)
3. \( P_z = e^{2\pi k r^2} \times \cos(\Theta) \times \sin(\Phi) \)

### NORMALIZE THE POWER PATTERN.

1. \( \text{FIELD}(i,j) = \frac{\text{FIELD}(i,j)}{\text{MAX}} \)
2. \( \text{FIELD}(i,j) = 0 \) if MAX > 0.0

---

**Note:** The above text is a simplified representation of the code for calculating power patterns on a plane and a sphere. The actual code includes additional calculations and conditions not shown here for brevity.
*** FOR ***

040112 000 GO TO 1=1*NX
040113 000 GO TO J=1*NY
040114 000 H=FIELD(I,J)
040115 000 IF(H.GT.FMAX) FMAX=H
040116 000 8 CONTINUE
040117 000 9 CONTINUE
040118 000 GO TO 1=1*NX
040119 000 GO TO J=1*NY
040120 000 FIELD(I,J)=FIELD(I,J)/FMAX
040121 000 11 CONTINUE
040122 000 12 CONTINUE
040123 000 RETURN
040124 000 END

2MS *P *** FFT ***
**FFT**

SUBROUTINE FFT(FIELD,NX,NY,ISN)
C THIS SUBROUTINE CALCULATES THE FAST FOURIER TRANSFORM OR
C THE INVERSE FAST FOURIER TRANSFORM OF AN INPUT TWO
C DIMENSIONAL, COMPLEX ARRAY (FIELD) AND RETURNS THE
C RESULT IN SAME ARRAY
C NX AND NY ARE THE DIMENSIONS OF THE ARRAY FIELD AND MUST
C BE EQUAL TO 2 RAISED TO SOME POSITIVE INTEGER POWER
C ISN IS AN INTEGER CONTROL VARIABLE WHICH MUST BE EITHER
C +1 OR -1, IF ISN=-1 THE FAST FOURIER TRANSFORM IS
C CALCULATED, IF ISN=+1 THE INVERSE FAST FOURIER TRANSFORM
C IS CALCULATED
C THE ORIGIN OF BOTH THE INPUT AND OUTPUT COORDINATE SYSTEMS
C IS LOCATED AT THE (NX/2 + 1*NY/2 + 1) POINT OF THE ARRAY
C IF(ISN).NE.1) RETURN
COMPLEX FIELD(NX,NY).T102
PI2=6.283185307179586 9800
1=0 IX=1X+1 
IX=2**IX IF(NY-4)5.8P5 WRITE(6,7)
FOR I=1,NY IF(NY IS NOT EQUAL TO 2 RAISED TO ANY POSITIVE INTEGER POWER) RETURN
8 UX2=RX/2 
NX2=NX/2 
11=1NX2 
J1=1NY1 
FIELD(J1,J)=FIELD(I1,J)
9 FIELD(I1,J)=T1 
UD 10 J=1NY21
J1=J+1 
UD 10 I=1NX1
I2=FIELD(J1,J)
FIELD(I1,J)=FIELD(I1,J1)
10 FIELD(I1,J1)=T2 
UD 11 J=1NY1
I1=I+1 
UD 11 I=1NX1
IF(ISN).NE.1) RETURN
11 IF(ISN).NE.1) RETURN
RETURN
END
**FFT**

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**DATE 07/24/73**

**PAGE 2**
**FTT**

040112  000  T1=FIELD(I,J1)
040113  000  T2=FIELD(I,J2)*CMPLX(C0+ISN+SO)
040114  000  FIELD(I,J1)=T1*T2
040115  000  19 FIELD(I,J2)=T1-T2
040116  000  CS=SO*I1+C0*ST
040117  000  C0=CS
040118  000  20 SO=SN
040119  000  U0 21 I=1,NX2+1
040120  000  II=I+NY2
040121  000  U0 21 J=1,NY+1
040122  000  I1=FIELD(I,J)
040123  000  FIELD(I,J)=FIELD(I1,J)
040124  000  21 FIELD(I,J)=T1
040125  000  J0 22 J=1,NY2+1
040126  000  J1=J+NY2
040127  000  U0 22 J=1,NX+1
040128  000  T2=FIELD(I,J)
040129  000  FIELD(I,J)=FIELD(I,J)
040130  000  22 FIELD(I,J)=T2
040131  000  IF(ISN,LT,0) RETURN
040132  000  NX=NY
040133  000  JO 23 I=1,NX+1
040134  000  JO 23 J=1,NY+1
040135  000  23 FIELD(I,J)=FIELD(I,J)/R
040136  000  RETURN
040137  000  END

**MSGP**

**INITPO**

**DATE 072473**

**PAGE 3**
SUBROUTINE INTERPO(XPWS,YPWS,NX,NY,KMAX,KMAX)

INTERPOLATE THE X AND Y COMPONENT OF A PLANE WAVE SPECTRUM, XPWS
AND YPWS RESPECTIVELY, TO FIND THE X AND Y COMPONENTS IN A
SPECIFIED WAVEVECTOR DIRECTION K.

COMPLEX XPWS(NX,NY),YPWS(NX,NY)
REAL KMAX,KMAX

IF THE WAVEVECTOR K IS NOT WITHIN THE DEFINED LIMITS OF THE PLANE
WAVE SPECTRUM KMAX AND KMAX A *FALSE* VALUE FOR THE LOGICAL VARIABLE
WITHIN IS RETURNED.

REAL K(3)
COMPLEX XPW,YPW
LOGICAL WITHIN
H=K(1)+DEL1*CI
HJ=K(2)+DEL4*CI
I=1
JL=JL+1
I1=I1+IL
JL=JL+1
IF(I1,LT,1.OR.JL,LT,1) GO TO 1
IF(I1,LT,NX.OR.JL,LT,NY) GO TO 1
I=I1-IL
JL=JL-IL
HL=H-JL

FORM CONSTANTS FOR INTERPOLATION EQUATION
THE FOUR-POINT QUADRATIC INTERPOLATION FORMULA IS FROM THE
STANAG, PAGE 882.

H1=I1-RI
HJ=J1-RJ
C1=II*JJ
C2=RI*JJ
C3=RI*RJ
C4=II*JJ
XP=CI*XPWS(I1,J1)+C2*XPWS(I1,J1)+C3*XPWS(I1,J1)+C4*XPWS(I1,J1)
YP=CI*YPWS(I1,J1)+C2*YPWS(I1,J1)+C3*YPWS(I1,J1)+C4*YPWS(I1,J1)

HIT=YES,TRUE.
RETURN
I WITHIN=.FALSE.
RETURN
END
***** IPLANL *****

CALL IPLANL

ENTRY IPLANE,

REAL T(3,3), P0(3), C(I)

DO 1 I=1,3

1 C(I)=T(I,I)

DO 2 I=1,3

2 C(I)=C(I)-C(I)*P0(I)

RETURN

ENTRY IPLANL

REAL P(3), K(3), P1(3)

J0TR: C(1)=C(1)+C(2)+C(3)

U=(DOT+C(4))/D0TK

PI(1)=K(1)*P(1)

PI(2)=K(2)*P(2)

PI(3)=K(3)*P(3)

RETURN

END

***** GIVE *****
SUBROUTINE OGIVE (PO, K, HIT)

This subroutine solves for the intersection of a ray and an ogive.

INPUT:
- PO -- REAL ARRAY OF COEFFICIENTS OF INSIDE POINT
- K -- REAL ARRAY OF DIRECTION COSINES OF RAY

OUTPUT:
Z -- VALUE OF Z COMPONENT OF INTERSECTION

IT IS ASSUMED THAT THIS SUBROUTINE WILL NOT BE CALLED WITH K(3)=0.

THE OGIVE SHAPE IS DESCRIBED BY THE EQUATION

\[ \sqrt{X^4 + Z^2} + \frac{X}{K(3)} = MP \]

THE DATA NEEDED FOR THE DATA STATEMENT IS

Z AND AP ARE GIVEN WITH RESPECT TO AN ASSUMED ORIGIN.

R = WS**2 + 2**2
BSQ = WS**2
AP = 4
HIT = .TRUE. IF THE RAY HITS THE SURFACE

IT IS ASSUMED THAT THIS SUBROUTINE WILL NOT BE CALLED WITH K(3)=0.

CALL OUARTC (PO, K, HIT)

DATE 07/24/14
PAGE 1
**OGIVE**

**RETURN**

04C55 000 210 IF (ZP.GT.0.) GO TO 211
04C56 000 ZTEMP(1)=ZP
04C57 000 IS2
04C58 000 211 ZP=REAL(ZA(2))
04C59 000 212 ZP=REAL(ZA(3))
04C60 000 IF (ZP.GT.0.) GO TO 213
04C61 000 ZTEMP(I)=ZP
04C62 000 I=I+1
04C63 000 RETURN
04C64 000 END

**Orient**

**RETURN**

06C05 000 210 IF (ZP.GT.0.) GO TO 211
06C06 000 ZTEMP(1)=ZP
06C07 000 IS2
06C08 000 211 ZP=REAL(ZA(2))
06C09 000 212 ZP=REAL(ZA(3))
06C10 000 IF (ZP.GT.0.) GO TO 213
06C11 000 ZTEMP(I)=ZP
06C12 000 I=I+1
06C13 000 RETURN
06C14 000 END

**This Entry Point Calculates the Inward Normal to the Ogive Surface As a Particular Point.**

**Input P0 -- Real Array of Coefficients of the Point**

**Output N -- Real Array of Direction Cosines of Normal to Surface at Point of Intersection**

REAL N(3), NTAN
06C67 000 22 N(3) = (PI(3) - AP) . INV
06C68 000 H = SQRT(P(1) * P(1) + PI(2) * PI(2))
06C69 000 NTAN = (R+3) . INV / R
06C70 000 N(1) = P(1) * NTAN
06C71 000 N(2) = P(2) * NTAN
06C72 000 RETURN
06C73 000 END
**C** SUBROUTINE ORIENT(RA,TETAA,PHIA,RH,THETAR,PHIR,AAGmA3A,

  DIMENSION TRANS(3), ROTATE(3,3), GAM(3,3), RHO(3,3)

  PHIA=PHIA AAGmA3A

  GAM(1,1)=SIN(PHIA)

  GAM(1,2)=-COS(PHIA)

  GAM(1,3)=0.

  GAM(2,1)=SIN(PHI)*SIN(TETAA)*COS(PHI)*COS(TETAA)

  GAM(2,2)=SIN(PHI)*COS(TETAA)*COS(PHI)*COS(TETAA)

  GAM(2,3)=SIN(PHI)*COS(TETAA)*SIN(PHI)*COS(TETAA)

  GAM(3,1)=COS(PHI)*SIN(PHI)*COS(TETAA)

  GAM(3,2)=COS(PHI)*SIN(PHI)*SIN(TETAA)*COS(PHI)*COS(TETAA)

  GAM(3,3)=COS(PHI)*SIN(PHI)*SIN(TETAA)*SIN(PHI)*COS(TETAA)

  RHO(1,1)=RHO(THETAA)*COS(PHI) RHO(1,2)=RHO(THETAA)*SIN(PHI)

  RHO(1,3)=-SIN(THETAA)

  RHO(2,1)=SIN(THETAA)*COS(PHIA)

  RHO(2,2)=SIN(THETAA)*SIN(PHIA)

  RHO(2,3)=0.

  RHO(3,1)=RHO(THETAA)

  RHO(3,2)=-SIN(THETAA)*COS(PHIA)

  RHO(3,3)=-SIN(THETAA)*SIN(PHIA)

  CALL ROTATE(3,3, GAM, RHO, ROTATE)

  CALL TRANS(TRANSL, ROTATE, T)

  RETURN

END
SUBROUTINE PLOT3D(XSIZE, YSIZE, HEIGHT, FIELD, IMAX, JMAX, NMZ)

XSIZE IS THE MAXIMUM LENGTH OF THE PLOT IN INCHES.

YSIZE IS THE MAXIMUM WIDTH OF A ZERO PLOT IN INCHES.

THE SUM OF 1/2 INCH + YSIZE + HEIGHT MUST BE LESS THAN OR EQUAL TO THE PAPER WIDTH.

FIELD(IMAX, JMAX) IS THE TWO-DIMENSIONAL REAL ARRAY TO BE PLOTTED. IF FIELD IS NOT NORMALIZED ON INPUT, NMZ MUST BE FALSE.

NMZ(NORMALIZED) IS A LOGICAL INPUT VARIABLE. IF ITS VALUE IS TRUE, THE VALUES IN FIELD WILL BE REPLACED WITH THEIR NORMALIZED ZERO TO ONE COMPONENTS.

DIMENSION FIELD(IMAX, JMAX)
LOGICAL NMZ
DIMENSION HID(600)
REAL LASTX, LASTY, LASTH, LASTHM
IF(NMZ) CALL NORM

DIMENSION XPAGE(2)
YPAGE=0.0

LASTH=0.0
HID(I+J) = 2

CALL PLIT(0.0, 0.412, 5, 3)
CALL PLIT(0.0, 0.0, 0.5, 4, 0.3)

LASTX=XPAGE
LASTY=YPAGE

IF(NMZ) HID(I+J) = 2

IF(I .EQ. 1) THEN
    IF(NMZ) HID(I+J) = 2
    IF(I .GT. 1) THEN
        IF(NMZ) HID(I+J) = 2
        IF(J .EQ. 1) THEN
            IF(NMZ) HID(I+J) = 2
            IF(NMZ) HID(I+J) = 2
        END IF
    END IF
END IF

A1 = (LASTX + (HID(I+J) - LASTH) + LASTY - XPAGE) / XPAGE

CALL PLTT(X1, Y1, F2)
**SUBROUTINE PLTT**

**C**

**SUBROUTINE PLTT ELIMINATES MOVING PEN FOR HIDDEN LINES.**

**C**

**SUBROUTINE NORM**

**C**

**NORMALIZE FIELD SO THAT ALL VALUES ARE BETWEEN ZERO AND ONE.**
*** PLOT3D ***

040112 000 C
040113 000 \* REAL MN,MX
040114 000 MZ=FIELD(I+1)
040115 000 "MN=MX
040116 000 JO 20 I=1,IMAX
040117 000 JO 20 J=1,JMAX
040118 000 "MIN=MIN(MN+FIELD(I,J))
040119 000 MZ=MZ1(MZ+FIELD(I,J))
040120 000 20 CONTINUE
040121 000 DR=MZ-MN
040122 000 JO 21 I=1,IMAX
040123 000 JO 21 J=1,JMAX
040124 000 FIELD(I,J)=FIELD(I,J)-MN/DR
040125 000 21 CONTINUE
040126 000 RETURN
040127 000 END

*** PLOT3D ***

GMSR.P ****** POINT ******

**DATE 07/24/73**

**PAGE** 3
**POINT**

**RADOME POINT**

ELT:06-RL1J67-10 07/24-22:58:08

**CIRCLE (00)**

**SUBROUTINE POINT(P,PT,ATOR,T,PO)**

**THIS SUBROUTINE TRANSFORMS A POINT P GIVEN IN ONE COORDINATE SYSTEM TO THE SAME POINT GIVEN IN ANOTHER COORDINATE SYSTEM, PT. THE TRANSFORMATION IS ACCOMPLISHED USING THE TRANSFORM MATRIX T. THE LOGICAL VARIABLE ATOR DIRECTS WHICH TRANSFORMATION TO BE MADE.**

**IF ATOR IS TRUE THE TRANSFORM IS FROM ANTENNA COORDINATES TO RADOME COORDINATES. IF ATOR IS FALSE THE OPPOSITE TRANSFORM IS MADE.**

**T IS THE MATRIX OF DIRECTION COSINES WHICH DESCRIBE THE ROTATION OF THE RADOME COORDINATE SYSTEM WITH RESPECT TO THE ANTENNA. PO IS THE ORIGIN OF THE RADOME COORDINATE SYSTEM IN ANTENNA COORDINATES.**

**REAL P(3),PT(3),T(3,3),PS(3),PO(3)**

**IF(ATOR) GO TO 1**

**CONVERSION FROM RADOME TO ANTENNA COORDINATES**

**FT(1)=T(1,1)*P(1)+T(1,2)*P(2)+T(1,3)*P(3)+PO(1)**

**FT(2)=T(2,1)*P(1)+T(2,2)*P(2)+T(2,3)*P(3)+PO(2)**

**FT(3)=T(3,1)*P(1)+T(3,2)*P(2)+T(3,3)*P(3)+PO(3)**

**RETURN END**

**CONVERSION FROM ANTENNA TO RADOME COORDINATES**

**PSTPV=(1)**

**PSTPV=(1)**

**PS(2)=P(2)-PO(2)**

**PS(3)=P(3)-PO(3)**

**PT(1)=T(1,1)*PS(1)+T(1,2)*PS(2)+T(1,3)*PS(3)+P0(1)**

**PT(2)=T(2,1)*PS(1)+T(2,2)*PS(2)+T(2,3)*PS(3)+P0(2)**

**PT(3)=T(3,1)*PS(1)+T(3,2)*PS(2)+T(3,3)*PS(3)+P0(3)**

**RETURN END**
**SATE 080973 **

**CYCLE (02) **

```fortran
DO 1 TKX=1,NX
DO 1 IKY=1,NY
FIELU(IKX,IKY)=CMPLX(0.0,0.0)
IF(IKX.EQ.0.1) GO TO 1
IF(IKY.EQ.0.1) GO TO 1
K7=1-61.4*KX*2
IF(K7.LE.0.1) GO TO 1
KZ=SOSK(T(KX/2*KY*KZ))
A=SCRT(KX**2+1**2)
FIELD(IKX,IKY)=SPECTR(KX,KY)*A
1 CONTINUE
DO 3 7KX=1,NX
DO 3 IKY=1,NY
FIELU(IKX,IKY)=CMPLX(0.0,0.0)
IF(IKX.EQ.0.1) GO TO 3
IF(IKY.EQ.0.1) GO TO 3
K7=1-61.4*KY*2
IF(K7.LE.0.1) GO TO 3
K3=SOSK(T(KX*2*KZ))
A=SPECTR(KX,KY,KZ)*A
3 CONTINUE
FUNCTION J0(X)
   VALUE=...
THIS FUNCTION CALCULATES THE BESSEL FUNCTION OF THE FIRST KIND, ORDER ZERO, FOR THE VALUE X.


PX=ABS(X)

IF(PX,.GT.3.0) PX2=3/PX

IF(PX,.GT.1.0) J0=1.0-2.24999797*PX**2+1.2664208*PX**4-3.3163866*PX**6

J0=-0.644479*PX**8+0.0039444*PX**16+0.000210*PX**24

MAGNITUDE OF ERROR < 5.0E-08.

J0=0.797580456-0.00000077*PX2+0.0000052740*PX2**2-0.00000512*PX2**3

MAGNITUDE OF ERROR < 1.6E-08.

T0=PX-0.76539815-0.04466397*PX2+0.00003954*PX2**2

MAGNITUDE OF ERROR < 7.0E-08.

JO=FD*COS(T0)/SQR(PX)

RETURN;

END.

PLAS
SUBROUTINE QUARTC (A,X)

DIMENSION A(4)

A=4.0

INPUT A IS A REAL ARRAY OF COEFFICIENTS

OUTPUT X IS A COMPLEX ARRAY OF ROOTS OF THE QUARTIC EQUATION

A2=-A(3)
AD=-A(2)*A(2)-A(3)*A(4)-4.0*A(1)

R1=(-A(1)*A(2)+A(3)*A(4)+4.0*A(1))/6.0-A2**3/27.

IF (A2.0.0.) GO TO 10

S=3.0.png

X1=-A(4)/4.0+R/2.

RETURN

END
S**0. RAD0KE
HATE 080973 PAGE 1

000001
OnUL
SUHRONTINF RAnO'EtZPWs,YRwStExTFEYTPEXR.EYR.NlerNY.KXmAX.KYMAXp
OnOLu, Onu S
Fbil7. ROTATE, TqANSL1
000u0A 000 REAL x, y, z, K(3), N(3), E(3), F(3), G(3), H(3), I(3), I(3), J(3), K(3), L(3), M(3), N(3), O(3), P(3), Q(3), R(3), S(3)

000001 000 LOGICAL WUMPATOR, RTOA, METALI

000001 000 DATA AT0R, RTOA, TGFHZ

nnuoll LA:

L sO .97p25/FGHZ

nt K0=2*PI/LAm.sDA

DELX=1Av11hA/(2*KXMAX)

DELY=7 1AcBilA1(2*,(YMAX)

DELKx=1*KyMAX/Nx

DELKY=2*KyMAX/Ny

MIDNY=-y/pfl

YvAX=cLY.NY/p fl

FORM Transmission and Reflection Coefficients for Wall

TRANS and REFLECT are Entry Points to Wall

CALL ,ALL(FGHZ)

CALL TNTR1,

INITIALIZE Planar Intersection Subroutine - Plane is the Entry Point of Interpolation (ROTATE, TRANSL)

CALL INTERP(X*NX,YPWS/(X+NY),XMAX+XMAX)

CALL VECTOR(KA,KATOR,ROTATE)

ITERATE FOR EACH Plane Wave

CALL ,ALL(FGHZ)

CALL TNTR1,

INITIALIZE Output Field Arrays

1 CONTINUE

ITERATE FOR Each Plane Wave

CALL VECTOR(KA,KATOR,ROTATE)
*** HADO, E DATE 080973 PAGE 2

Ono C
00005 C INCLUDE XMAX AND YMAX PLANE WAVES
00006 C
00007 C ITERATE FOR EACH APERTURE POINT
00008 C DO 10 L=1,NX+1
00009 C PA(1)=L-1*NX)*DELX
00010 C PA(2)=(M-1)*NY)*DELY
00011 C PA(3)=0.0
00012 C CALL POINT(PA,P,ATOR,ROTA,TRANSL)
00013 C IF APERTURE POINT HAS NEGATIVE Z COORDINATE
00014 C IF(P(3)>0.)GO TO 10
00015 C IRAY=IRAY+1
00016 C GO TO 10
00017 C
00018 C TRACE RAY TO FIRST INTERSECTION POINT
00019 C CALL TRACF(P,K,PI,N1,PLT1)
00020 C CALL VECTOR(KR,KRA,ROTATE)
00021 C TE(KRA(3))=0.0 GO TO 10
00022 C CALCULATE REFLECTED RAY WHICH CONTRIBUTES TO EXR AND EYR
00023 C KPA(1)=-KRA(1)
00024 C KPA(2)=KRA(2)
00025 C KPA(3)=-KRA(3)
00026 C CALL Ph(KPA,XPW,YPW)
00027 C IF(.NOT.3*PI4+TAU) GO TO 10
00028 C CALL PLANE(PR,P,3)
00029 C IF POINT(PR,PA,ATOR,ROTA,TRANSL)
00030 C IF(AHER(PA(3))=YMAX)GO TO 10
00031 C
00032 C CALCULATE DIRECTION OF REFLECTED PLANE WAVE
00033 C CALL SNE (P1*1,KR)
00034 C CALCULATE INTERSECTION WITH APERTURE PLANE
00035 C CALL VECTOR(KR,KRA,ROTA,ROTATE)
00036 C IF(KRA(3).GE.0.)GO TO 10
00037 C
00038 C CALCULATE DIRECTION OF REFLECTED PLANE WAVE
00039 C CALL DEFLR(XPW,YPW,KRA,NIA,METAL1)
00040 C CALL EXP(0.0,AMOR(PHASE,2*PI3))
00041 C EXR(L,M)=EXR(L,M)+XPW*PC
00042 C EYR(L,M)=EYR(L,M)+YPW*PC
00043 C
00044 C CONTINUE
**** HADOCE ******
00011O 01O C CALCULATE PLANE WAVE SPECTRUM OF EACH PLANAR FIELD
000114 01O CALL FFT(FXR+NX,NY+1)
000115 01O CALL FFT(FYT+NX,NY+1)
000116 01O CALL FFT(FYR+NX,NY+1)
000117 01O WRITE(6,I1) IRAY
000118 01O 13 FORMAT('NUMBER OF RAYS Hitting BULKHEAD =',I5)
000120 01O RETURN
000121 01O END

ENDGDP ****** SAPLOT ******
SUBROUTINE SAPLOT(FIELD,NX,NY,KXMAX,KYMAX,KXMIN,KYMIN,
                    ISAX,ISAY,ISCALE,NPTS)
       $ ISCALE CONTROLS THE SCALE OF THE HORIZONTAL AXIS
       TO CONFORM TO SCIENTIFIC ATLANTA'S PAPER ISCALE SHOULD BE
       EQUAL TO 10.60 ON 360

DIMENSION FIELD(NX,NY)
REAL KX,KY,KXMAX,KYMAX
PI=3.14159265
CALL PLOT(0.0,10.625,3)

Y=0.75
CALL PLOT(0.0,Y,2)

DO 1=1,6
  X=0.11
  CALL PLOT(X,Y,2)
  X=0.04
  CALL PLOT(X,Y,2)

1 CALL PLOTM(7.1,5.1)

DO 2=2,13
  IF(ANG.LT.100.0) THEN
    X=0.08
    CALL PLOT(X,Y,2)
  ELSE
    Y=0.04
    CALL PLOTM(7.1,5.1)
  ENDIF
2 CALL PLOT(20.0,0.75,2)

DO 4=4,40
  Y=0.08
  CALL PLOT(X,Y,2)
4 CALL PLOTM(7.1,5.1)

DO 6=6,87
  IF(ANG.LT.100.0) THEN
    X=0.08
    CALL PLOT(X,Y,2)
  ELSE
    Y=0.04
    CALL PLOTM(7.1,5.1)
  ENDIF
6 CALL PLOT(20.0,0.75,2)

DO 8=8,100
  IF(ANG.LT.100.0) THEN
    X=0.08
    CALL PLOT(X,Y,2)
  ELSE
    Y=0.04
    CALL PLOTM(7.1,5.1)
  ENDIF
8 CALL PLOT(20.0,0.75,2)

DO 10=10,128
  IF(ANG.LT.100.0) THEN
    X=0.08
    CALL PLOT(X,Y,2)
  ELSE
    Y=0.04
    CALL PLOTM(7.1,5.1)
  ENDIF
10 CALL PLOT(20.0,0.75,2)

DO 12=12,157
  IF(ANG.LT.100.0) THEN
    X=0.08
    CALL PLOT(X,Y,2)
  ELSE
    Y=0.04
    CALL PLOTM(7.1,5.1)
  ENDIF
12 CALL PLOT(20.0,0.75,2)

DO 14=14,187
  IF(ANG.LT.100.0) THEN
    X=0.08
    CALL PLOT(X,Y,2)
  ELSE
    Y=0.04
    CALL PLOTM(7.1,5.1)
  ENDIF
14 CALL PLOT(20.0,0.75,2)

CONTINUE
SUBROUTINE SNELL(K,N,KR)
C
C CALCULATE THE UNIT VECTOR KR WHICH IS THE NEGATIVE OF THE
C REFLECTION OF K THROUGH N.
C
C=2*(K(1)*N(1)+K(2)*N(2)+K(3)*N(3))
KR(1)=K(1)-C*N(1)
KR(2)=K(2)-C*N(2)
KR(3)=K(3)-C*N(3)
RETURN
END

3M86P ****** TOISK ******
**TDISK**

**EXEC** E15G5-RL1367-10 07/24-22:58:16

TCCL 101

SUBROUTINE TDISK(P,K,PI,HIT)

C TDISK CALCULATES THE POINT OF INTERSECTION PI OF A DISK HORIZONTAL TO THE XY PLANE WITH A RAY EMINATING FROM POINT P AND TRAVELING IN THE K DIRECTION.

C THE EQUATION USED FOR THE TOP DISK IS Z=ZTOP FOR (X**2+Y**2)<=Rsq

C SET TOP DISK PARAMETERS:

DATA ZTOP=.0/77.6878.14.6459/

C ENTRY TDISK(N)

REAL N(3)

N(1)=0.0

N(2)=0.0

N(3)=1.0

RETURN

END

ENTRY TDISK(N)

REAL N(3)

N(1)=0.0

N(2)=0.0

N(3)=1.0

RETURN

END
SUBROUTINE TRACE(P0X,K,P,N,METAL)

A GENERAL RESTRICTION OF THIS PROGRAM IS K(3) MUST NOT BE ZERO

REAL P0(3),K(3),P(3),N(3)
LOGICAL METAL,HIT

SET BOUNDARY Z VALUES:
DATA 21,22,23/77.6878.28.28511,00/

IF(Z.LE.NSURF) GO TO 2
WRITE(6,3)
FORMAT(2X,'NO INTERSECTION FOUND WITH RADOME SURFACE')
RETURN
2 GO TO (10,20,30,40),ISURF

DETERMINE IF RAY HIT THE TOP DISK
CALL TOISKIP0,P,HIT)
IF(HIT) GO TO 110
ISURF=2
GO TO 1

DETERMINE IF RAY HIT THE CONE
CALL CONE(P0,K,Z,HIT)
IF(HIT) GO TO 21
IF(Z.LE.22+0.1.AND.Z.GE.23-0.1) GO TO 120
ISURF=2
GO TO 1

DETERMINE IF RAY HIT THE OLIVE
CALL OGLIVE(P0,K,2,HIT)
IF(HIT) GO TO 31
IF(Z.LE.23) ISURF=4
GO TO 1

DETERMINE IF RAY HIT THE BOTTOM DISK
CALL BDISK(P0,K,P,HIT)
IF(HIT) GO TO 140
ISURF=3
GO TO 1

CALL TOISK(N)
METAL=.TRUE.
RETURN

CALL CONEN(P,N)
METAL=.FALSE.
RETURN

CALL CONEN(P,N)
METAL=.FALSE.
RETURN

CALL BOISK(N)
METAL=.TRUE.
RETURN

END
**VECTOR**

**VECTOR**

SUBROUTINE VECTOR(V, VT, ATR, T)

REAL V(3), VT(3), T(3,3)

LOGICAL ATR

IF (ATR) GO TO 1

1 CONTINUE

CONVERSION FROM RADOME TO ANTENNA COORDINATES

VT(1) = T(1,1) * V(1) + T(2,1) * V(2) + T(3,1) * V(3)
VT(2) = T(1,2) * V(1) + T(2,2) * V(2) + T(3,2) * V(3)
VT(3) = T(1,3) * V(1) + T(2,3) * V(2) + T(3,3) * V(3)

RETURN

CONVERSION FROM ANTENNA TO RADOME COORDINATES

VT(1) = T(1,1) * V(1) + T(1,2) * V(2) + T(1,3) * V(3)
VT(2) = T(2,1) * V(1) + T(2,2) * V(2) + T(2,3) * V(3)
VT(3) = T(3,1) * V(1) + T(3,2) * V(2) + T(3,3) * V(3)

RETURN

END
SUBROUTINE VSWR(XPWT,YPWT,XPWR,YPWR,NX,NY,KMAX,KMAX,SWR)

COMPLEX XPWT(NX,NY),YPWT(NX,NY),XPWR(NX,NY),YPWR(NX,NY),ZPWT,ZPWR

REAL KXMAX,KYMAX,KX,KY

C THIS SUBROUTINE CALCULATES THE VSWR IN THE FEED SYSTEM OF A
C RADOME ENCLOSED ANTENNA DUE TO REFLECTIONS FROM THE INNER SURFACE
C OF THE RADOME.
C
C XPWT(NX,NY) AND YPWT(NX,NY) ARE THE X AND Y COMPONENTS RESPECTIVELY
C OF THE TRANSMITTING AND RECEIVING PLANE WAVE SPECTRUM OF THE
C ANTENNA WITHOUT THE RADOME IN PLACE.
C
C XPWR(NX,NY) AND YPWR(NX,NY) ARE THE X AND Y COMPONENTS
C RESPECTIVELY OF THE REFLECTED PWS.
C
C PT=0.0
C PR=0.0
D1 1 IKX=1,NX-1

KX=(-1+2*(IKX-1.0)/NX)*KXMAX
D2 1 IKY=1,NY-1

KY=(-1+2*(IKY-1.0)/NY)*KYMAX
D3 1 IKZ=I-1-KX-KY

IF(KZ.LE.0) GO TO 1

KZ=SORT(KZ)
C
C FIND COMPONENT OF TRANSMITTED AND REFLECTED PWS
C
ZPWR=(XX*XPWR(IKX,IKY)+YY*YPWR(IKX,IKY))/KZ
ZPWT=(XX*XPWT(IKX,IKY)+YY*YPWT(IKX,IKY))/KZ
C
C FIND TOTAL POWER OF TRANSMITTED PWS BY SUMMING POWERS IN EACH PWS
C
PT=CABS(XPWT(IKX,IKY))**2+CABS(YPWT(IKX,IKY))**2+CABS(ZPWT)**2
C
C FIND TOTAL POWER OF REFLECTED PWS BY SUMMING POWERS IN EACH PWS
C
PR=CABS(XPWR(IKX,IKY))**2+CABS(YPWR(IKX,IKY))**2+CABS(ZPWR)**2
C
C REFLECTED PWS WEIGHTED BY TOTAL POWER IN RECEIVING PWS
C
\$ CABS(XPWR(IKX,IKY))**2+\$ CABS(YPWR(IKX,IKY))**2
C
C CALCULATE VOLTAGE STANDING WAVE RATIO
C
SWR=SQRT((PT+PR)/(PT-PR))
C
RETURN
END
SUBROUTINE WALL(FGHZ)

DIMENSION D(N), ER(NN), TO(NN)

COMPLEX E(NN), G(NN), RI(NN), EIGE, R1, R2, AA1, AA2

REAL PI=3.14159265

DATA 0, ER, TD/1.10744.3.3 01.0..0U2.0.0/

CALCULATE TOTAL THICKNESS OF WALL IN CM

DO 200 I=1, NN

DTOTAL=DTOTAL+D(I)

ITERATE FOR NANGLE NUMBER OF ANGLES OF INTEREST

DO 1 IA=1, NANGLE+1

FORM A TABLE OF TRANSMISSION AND REFLECTION COEFFICIENTS AS A FUNCTION OF THE SINE OF THE INCIDENT ANGLE

S IS THE SINE OF THE ANGLE SQUARED

S=(IA-1.0)/NANGLE**2

S=SORT(1.0-S)

DO 3 IA=1, NANGLE+1

50 E(I) = CVPLX(E(I-1)+ER(I)*TD(I))

W=29.97925/FGH2

AB = (TU*W)**2, TD(I)**2

M=3.14159265

UPJ = 2, * P1

ER(I))=1,

TC(I))=0,

DO 50 I=1, NN

50 E(I) = CVPLX(E(I-1)+ER(I)*TD(I))

W=29.97925/FGH2

AB = (TU*W)**2, TD(I)**2

M=3.14159265

UPJ = 2, * P1

ER(I))=1,

TC(I))=0,

DO 50 I=1, NN

50 E(I) = CVPLX(E(I-1)+ER(I)*TD(I))

W=29.97925/FGH2

AB = (TU*W)**2, TD(I)**2

M=3.14159265

UPJ = 2, * P1

ER(I))=1,

TC(I))=0,

DO 50 I=1, NN

50 E(I) = CVPLX(E(I-1)+ER(I)*TD(I))

W=29.97925/FGH2

AB = (TU*W)**2, TD(I)**2

M=3.14159265

UPJ = 2, * P1

ER(I))=1,

TC(I))=0,

DO 50 I=1, NN

50 E(I) = CVPLX(E(I-1)+ER(I)*TD(I))

W=29.97925/FGH2

AB = (TU*W)**2, TD(I)**2

M=3.14159265

UPJ = 2, * P1

ER(I))=1,

TC(I))=0,
00 0065 000   ET = ER(1) - TD(1)
00 0066 000   SR = SQR(AD*2 + ET*2)
00 0067 000   IF(C=AD) 76,76,77
00 0068 000
00 0069 000 #6 76 A = 0.
00 0069 000   DO 78 78
00 006A 000 77 A = AB * SQR(SR - AD)
00 006B 000 78 A = AB * SQR(SR + AD)
00 006C 000   G(1) = CMPLX(A,B)
00 006D 000   GES=CMPLX(0.1(TUP1/WL)*G)
00 006E 000   EE=1.
00 006F 000   S0=S0.
00 0070 000   SUM=SUM+G(1)/SQR(AD)
00 0071 000   R1 = (G(1)*G(1))/G(1)*G(1)
00 0072 000   R2 = (EE*G(1))/EE*G(1)*G(1)
00 0073 000   J1 = 1+1
00 0074 000   A = EK(I) - S
00 0075 000   IF (I = H) 176,177,177
00 0076 000   176 SUM=SUM+G(1)/SQR(AD)
00 0077 000   177 CONTINUE
00 0078 000   5A TO G6,
00 0079 000   80 A = AB * SQR(SR + AD)
00 007A 000   81 A = AB * SQR(SR - AD)
00 007B 000   G(1) = CMPLX(A,B)
00 007C 000   R1(I) = (G(I)*G(I))/G(I)*G(I)
00 007D 000   R2(I) = (EE*G(I))/EE*G(I)*G(I)
00 007E 000   SUM=SUM+G(I)/SQR(Ad)
00 007F 000   AA1 = 1. - RR1
00 0080 000   AA2 = 1. - RR2
00 0081 000   30 55 I1+N
00 0082 000   30 55 I1+N
00 0083 000   AA1 = AA1 + (1, - R1(I))
00 0084 000   85 AA2 = AA2 + (1, - R2(I))
00 0085 000   85 AA2 = AA2 + (1, - R2(I))
00 0086 000   AA4 = 1. / AA1
00 0087 000   AA2 = 1. / AA2
00 0088 000   30 55 I1+N
00 0089 000   AA1 = AA1 + (1, - R1(I))
00 008A 000   AA2 = AA2 + (1, - R2(I))
00 008B 000   AA4 = 1. / AA1
00 008C 000   AA2 = 1. / AA2
00 008D 000   U = G(I) * G(I)
00 008E 000   Y = G(I) * G(I)
00 008F 000   A1 = CEPR(U)
00 0090 000   A4 = CEPR(V)
00 0091 000   X2 = RR1 * X4
00 0092 000   X3 = RR1 * X1
00 0093 000   Y1 = X1
00 0094 000   Y4 = X4
00 0095 000   T2 = RR2 * Y4
00 0096 000   T1 = T1 + T1
00 0097 000   J0 105 I2=Z+I9,90,1
00 0098 000   IF(I=I) 95,90,1
00 0099 000
00 0100 000
00 0101 000
00 0102 000
00 0103 000
00 0104 000
00 0105 000
00 0106 000
00 0107 000
00 0108 000
00 0109 000
00 0110 000
00 0111 000
GO TO 100

P1 = X1 * U1 + X2 * U3

P2 = X1 * U2 + X2 * U4

P3 = X3 * U1 + X4 * U3

P4 = X3 * U2 + X4 * U4

Q1 = Y1 * V1 + Y2 * V2 + V3

Q2 = Y1 * V2 + Y2 * V4

Q3 = Y3 * V1 + Y4 * V3

Q4 = Y3 * V2 + Y4 * V4

X1 = P1

X2 = P2

X3 = P3

X4 = P4

Y1 = Q1

Y2 = Q2

Y3 = Q3

Y4 = Q4

RPER(IA) = -X3 / X4

TNI = (X1 + X2 * PPER(IA)) * P1

U = CEKP(U)

TPER(IA) = TNI * U

TPAR(IA) = TNI * U

CONTINUE

300 RETURN

ENTRY TRANS(XPWTYPW,XPWTYPWTK, METAL)

COMPLEX XP4,Tpw,xPwr,ypwTipvw

COMPLEX EXPAR,EYPARiExPEREYPER,IPAR/TPERIPDOT

HEAL K(3)1NOR4(3) , KPER(3)

LOGICAL METAL

IF (METAL) GO TO 4

CALL AXB (K,NORM,KPER)

C FIND MAGNITUDE OF KPER (THIS IS ALSO THE SINE OF THE INCLUDED ANGLE)

SIN=SORT(KPER(1) * KPER(1) * KPER(2) * KPER(2) * KPER(3) * KPER(3))
IF (SINE.LT.1E-10) GO TO 2

C UNITIZE VECTOR
SEC = 1/SINE
KPER(1) = KPER(1)*SEC
KPER(2) = KPER(2)*SEC
KPER(3) = KPER(3)*SEC

C FIND Z COMPONENT OF INCIDENT PLANE WAVE
Z = - (K(1)*XPW+K(2)*YPW+K(3) /K(3)

C FIND DOT PRODUCT OF INCIDENT ELECTRIC FIELD WITH KPER
DOT = XPW*KPER(1)+YPW*KPER(2)+ZPW*KPER(3)

C FIND PERPENDICULAR COMPONENTS OF ELECTRIC FIELD
EXPER = DOT*KPER(1)
LYPER = DOT*KPER(2)
GO TO 3

2 CONTINUE
EXPER = XPW
LYPER = YPW
3 CONTINUE

C FIND PARALLEL COMPONENTS OF ELECTRIC FIELD
EXPAR = XPW - EXPER
EYPAR = YPW - LYPER

C FIND PERPENDICULAR AND PARALLEL TRANSMISSION COEFFICIENTS
ISINE = SINE + NANGLE * 1.5
TPERI = TPER(ISINE)
TPARI = TPAR(ISINE)

C FIND X AND Y COMPONENTS OF TRANSMITTED FIELD
XPW = EXPER*TPARI + EXPER*TPERI
YPW = EYPAR*TPARI + EYPER*TPERI
RETURN
4 CONTINUE
XPW = CMPLX(0.0,0.0)
YPW = CMPLX(0.0,0.0)
RETURN
5 CONTINUE

C ENTRY REFLECT(XPW,YPW,XPWR,YPWR,K,NORM,METAL)
C FINDER VECTOR NORMAL TO NORM AND K
CALL AXDK(K,NORM,KPER)
C FIND MAGNITUDE OF KPER (THIS IS ALSO THE SINE OF THE INCLUDED ANGLE)
SINE=SQR(T(KPER(1)+KPER(2)+KPER(3))
IF (SINE.LT.1E-10) GO TO 5

C UNITIZE VECTOR
SEC = 1/SINE
KPER(1) = KPER(1)*SEC
KPER(2) = KPER(2)*SEC
KPER(3) = KPER(3)*SEC
FIND 2 COMPONENT OF INCIDENT PLANE WAVE
\[ ZP_W = -(K(1) \times XP_W + K(2) \times YP_W) / K(3) \]

FIND DOT PRODUCT OF INCIDENT ELECTRIC FIELD WITH KPER
\[ UOT = XP_W \times KPER(1) + YP_W \times KPER(2) + ZP_W KPER(3) \]

FIND PERPENDICULAR COMPONENTS OF ELECTRIC FIELD
\[ E_{XP} = DOT \times KPER(1), \quad E_{YP} = DOT \times KPER(2) \]
5 CONTINUE

FIND DOT PRODUCT OF INCIDENT ELECTRIC FIELD WITH KPER
\[ UOT = XP_W \times KPER(1) + YP_W \times KPER(2) + ZP_W KPER(3) \]

FIND PERPENDICULAR COMPONENTS OF ELECTRIC FIELD
\[ E_{XP} = DOT \times KPER(1), \quad E_{YP} = DOT \times KPER(2) \]
5 CONTINUE

FIND PARALLEL COMPONENTS OF ELECTRIC FIELD
\[ E_{XP} = E_{XP} - E_{DP} \]
\[ E_{YP} = E_{YP} - E_{DP} \]

FIND PERPENDICULAR AND PARALLEL REFLECTION COEFFICIENTS
\[ ISINE = SIN(ANGLE + 1.5), \quad RPARI = RPARI(\text{ISINE}) \]
\[ HPERI = HPERI(\text{ISINE}) \]

FIND X AND Y COMPONENTS OF REFLECTED FIELD
\[ XP_{PAR} = EXPAR \times RPARI \times EXPAR \times HPERI \]
\[ YP_{PAR} = EYPAR \times RPARI \times EYPAR \times HPERI \]
7 CONTINUE

SUBROUTINE AXB(A, B, C)
DIMENSION A(3), B(3), C(3)
C(1) = A(2) \times B(3) - A(3) \times B(2)
C(2) = A(3) \times B(1) - A(1) \times B(3)
C(3) = A(1) \times B(2) - A(2) \times B(1)
RETURN
END

SUBROUTINE AXB(A, B, C)
DIMENSION A(3), B(3), C(3)
C(1) = A(2) \times B(3) - A(3) \times B(2)
C(2) = A(3) \times B(1) - A(1) \times B(3)
C(3) = A(1) \times B(2) - A(2) \times B(1)
RETURN
END
SUBROUTINE XY(P,K,Z,PI)

XY CALCULATES THE X AND Y COMPONENTS OF AN INTERSECTION POINT PI

FOR THE CASE WHEN THE POINT OF EMINATION P, THE DIRECTION OF
PROPAGATION K AND THE Z COORDINATE OF THE INTERSECTION POINT
ARE GIVEN

REAL P(3),K(3),PI(3)

PI(1)=Z

T=(PI(3)-P(3))/K(3)

PI(1)=P(1)*K(1)*T

PI(2)=P(2)*K(2)*T

RETURN

END
INPUT DATA FOR VICOM RADOME EFFECTS ON GROUND MAPPING RADAR:

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INPUT DATA FOR MICOM RADOME EFFECTS ON GROUND MAPPING RADAR:

**Fixed1**

\[ \theta = 4.55 \]

\[ \phi = 50.0 \]

\[ \gamma = 4.165 \]

\[ \alpha = 50.0 \]

\[ \phi = 16.5 \]

\[ \gamma = 30.0 \]

\[ \alpha = 100.0 \]

\[ \theta_{max} = 66.61.6666 \]

\[ \phi_{max} = -3.0 \]

\[ \gamma = 10.0 \]

\[ \alpha = -10.0 \]

\[ \phi = 22.5 \]

\[ \alpha = 0.0 \]

\[ \theta_{max} = -40.0 \]

\[ \phi_{max} = 45.0 \]

\[ \gamma = 67.5 \]
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### Data for Ground Mapping Radar

#### Cycle (03)

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<tr>
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<tr>
<td>GAMMA</td>
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<td>FHZ</td>
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#### Values

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**Note:** The above data is for micromagnetic effects on ground mapping radar. The values are set for specific parameters and angles, indicating a detailed configuration for radar operations.
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**GNDG** **DATA4** **DATA4** **DATA4** **DATA4** **DATA4**


INPUT DATA FOR MICOM RADOME EFFECTS ON GROUND MAPPING RADAR:

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INPUT DATA FOR MCOM HADOME EFFECTS ON GROUND MAPPING RADAR:

1. **FIXED1**
   - R=4.165
   - T=50°
   - M2=100
   - XMAX=0.000000
   - YMIN=0.000000
   - ZMIN=0.000000
   - SCAND=0°
   - SCAM=0°
   - PITCH=-70°
   - YAW=0°

2. **FIXED2**
   - R=4.55
   - T=50°
   - M2=100
   - XMAX=0.000000
   - YMIN=0.000000
   - ZMIN=0.000000
   - SCAND=0°
   - SCAM=0°
   - PITCH=-70°
   - YAW=0°
INPUT DATA FOR MICOM RADOME EFFECTS ON GROUND MAPPING RADAR:

- FIXED:
  - MAX4=55°
  - THEETA450°

- RR=4.165
- AGAMMA=50°
- F0HZ=16.5

SEND

- SPATRN
- THEETA=50°

- PHI=90°
- ALT=10000
- KMAX=.555555

SEND

- IPAR=3
- VA5=1.5
- SCAND=0
- YAW0=0°

SEND

- IS=1
- JCOL=2
- YAW0=0°

SEND

- PHI=-90°
- ALT=10000
- KMAX=.555555
- SCAND=0
- YAW0=0°
The text appears to be a list of programmable parameters, possibly for a machine or system. Here's a structured representation of the data:

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The text ends with a comment indicating the start of a main section: "ENDGp ***** MAIN *****".
GEO) RANOME.DATA1
ELTUDA-PLIU67-10 08/09-20:16:24
CYCLE (10)

INPUT DATA FOR NICO RADOME EFFECTS ON GROUND MAPPING RADAR:

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16.5
16.5
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16.5
16.5

000010 000011 000012 000013 000014 000015 000016 000017 000018
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16.5
16.5
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000028 000029 000030 000031 000032 000033 000034 000035 000036
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16.5

ENDP **** DATA2 *****
APPENDIX B
Far-Field Power Pattern Contour Plots

The results of the radome analysis are depicted in the following 56 contour plots of the far-field power pattern as it appears on the ground. Each contour plot is for a different orientation of the antenna with respect to the radome, with the first plot being the far-field power pattern without a radome in place. Three contours of the pattern are plotted and labeled. They are the -3dB, the -10dB, and the -20dB contours.

The cross in the middle of the contour plots is the azimuth = 0, elevation = 0 ground location of the far-field power pattern. The true boresight direction is indicated by a circle on the first contour plot. The true boresight direction is in the azimuth = 0.0, elevation = 4.0° direction.
PITCH AND SCAN
-30.00   0.00
PITCH AND SCAN
-30.00   22.50
PITCH AND SCAN

-30.00  45.00
PITCH AND SCAN
-30.00  90.00
PITCH AND SCAN
-30.00  112.50
PITCH AND SCAN
-30.00  135.00
PITCH AND SCAN
-30.00  157.50
PITCH AND SCAN
-30.00  180.00
PITCH AND SCAN
-40.00  0.00
PITCH AND SCAN
-40.00   22.50
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-40.00  45.00
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PITCH AND SCAN
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PITCH AND SCAN
-70.00  180.00
PITCH AND SCAN
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PITCH AND SCAN
80.00   22.50
PITCH AND SCAN
-80.00  45.00
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-80.00  67.50
PITCH AND SCAN
-80.00    90.00
PITCH AND SCAN
-80.00  112.50
PITCH AND SCAN
-80.00  135.00
PITCH AND SCAN
-80.00  157.50
PITCH AND SCAN
-80.00  180.00
PITCH AND SCAN
-90.00   0.00
APPENDIX C
Radome Effects

Four two-dimensional graphs of radome effects are shown. Figure 3 is a graph of the boresight error in the azimuth direction introduced by the radome as a function of antenna pitch and scan with respect to the radome. The azimuth direction coincides with the direction of antenna scan on the ground. Figure 4 is a graph of the boresight error in the elevation direction introduced by the radome as a function of the pitch and scan of the antenna with respect to the radome. Figure 5 is a graph of the loss of power contained within the -3dB contour of the far-field power pattern of the antenna due to radome insertion. This power is the sum of the power actually absorbed by the radome and power diverted from the -3dB contour by defocusing and distortion of the beam due to radome insertion. Figure 6 is a graph of the voltage standing wave ratio in the antenna feed system as a function of the pitch and scan of the antenna with respect to the radome.
Figure 3. Graph of Boresight Errors in Azimuth
Versus Pitch and Scan Angles
Figure 4. Graph of Boresight Errors in Elevation Versus Pitch and Scan Angles
Figure 5. Graph of Change in Power Gain Versus Pitch and Scan Angles
Figure 6. Graph of VSWR Versus Pitch and Scan Angles

156
APPENDIX D
REAL FUNCTION INTERP

1. Purpose

This subroutine carries out four-point interpolation of data in a two-
dimensional array.

2. Call

X = INTERP (ARRAY,P,Q,I1,J1,NROW NCOL)

where:

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<th>VARIABLE</th>
<th>DESCRIPTION</th>
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<td>ARRAY</td>
<td>is the two-dimensional array of NROW x NCOL elements containing values of the data to be interpolated at equally-spaced unity increments in the orthogonal directions</td>
<td>floating-point input</td>
</tr>
<tr>
<td>P</td>
<td>is the fractional distance ((0 &lt; P &lt; 1)) in the I direction from the ((I1,J1)) position in the array at which the interpolated value is desired</td>
<td>floating-point input</td>
</tr>
<tr>
<td>Q</td>
<td>is the fractional distance ((0 &lt; Q &lt; 1)) in the J direction from the ((I1,J1)) position in the array at which the interpolated value is desired</td>
<td>floating-point input</td>
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<tr>
<td>I1, J1</td>
<td>are the coordinates of the reference position in the array</td>
<td>integer inputs</td>
</tr>
<tr>
<td>NROW</td>
<td>is the number of rows (I direction) in ARRAY</td>
<td>integer input</td>
</tr>
<tr>
<td>NCOL</td>
<td>is the number of columns (J direction) in ARRAY</td>
<td>integer input</td>
</tr>
</tbody>
</table>

3. Comments

a. \(1 \leq I1 \leq (NROW - 1)\)

b. \(1 \leq J1 \leq (NCOL - 1)\)
c. The interpolated data value is returned to the calling program as INTERP, which must be declared REAL in the calling program.

d. Interpolation is carried out according to the four-point bivariate formula on page 882 of the National Bureau of Standards Handbook of Mathematical Functions.

e. The reference position (II,JI) in the array is selected such that the four data elements involved in the interpolation are located at the following positions:

\[(II,JI) \quad (Reference \ Position)\]
\[(II,J1 + 1)\]
\[(II + 1,J1)\]
\[(II +1,J1 + 1)\]

4. Listing

See following page.
REAL FUNCTION INTERP(ARRAY,P,O,I1,J1,NROW,NCOL)

DIMENSION ARRAY(NROW,NCOL)

P1=1-P

Q1=1-Q

J2=J1+1

INTERP=P1*Q1*ARRAY(I1,J1)+P*Q1*ARRAY(I1,J1)+P*Q1*ARRAY(I2,J2)

RETURN
REFERENCE