NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED FROM MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED IN THE INTEREST OF MAKING AVAILABLE AS MUCH INFORMATION AS POSSIBLE
COMPUTER PREDICTION OF
DUAL REFLECTOR ANTENNA RADIATION PROPERTIES
(North Carolina State Univ.)

North Carolina State University
COMPUTER PREDICTION OF DUAL REFLECTOR ANTENNA RADIATION PROPERTIES

by

Christos Christodoulou

DEPARTMENT OF ELECTRICAL ENGINEERING
NORTH CAROLINA STATE UNIVERSITY
Raleigh, North Carolina

November 1981

This research was supported by the National Aeronautics and Space Administration through grant NSG 1588.
ABSTRACT

A new program for calculating dual reflector antenna radiation patterns has been developed adding one more option to the original program developed jointly by NCSU and NASA. The previous program was capable of computing patterns for single reflector antennas with either smooth analytic surfaces or with surfaces composed of a number of panels.

Techniques based on the geometrical optics (GO) approach are used in tracing rays over the following regions:

1) From a feed antenna to the first reflector surface (subreflector).
2) From this reflector to a larger reflector surface (main reflector).
3) From the main reflector to a mathematical plane (aperture plane) in front of the main reflector.

The equations of GO are also used to calculate the reflected field components for each ray making use of the feed radiation pattern and the parameters defining the surfaces of the two reflectors. These resulting fields form an aperture distribution which is integrated numerically to compute the radiation pattern for a specified set of angles.

Spillover, diffraction and other factors [2] that affect the accuracy of the calculation of the far-out sidelobes, are neglected.
Examples and all test cases are mentioned to support the validity of the new algorithm.
ACKNOWLEDGEMENTS

For his constant encouragement, aid and advice in the preparation of this thesis, I would like to express my gratitude to Dr. J. F. Kauffman, the Chairman of my Advisory Committee. I would also like to thank Dr. M. C. Bailey of NASA, Langley Research Center, for his constructive criticism and suggestions. Special thanks are also extended to Mr. Alan Botula of A.A.I. Corporation for his significant assistance. And, finally, I would like to express my appreciation to Dr. C. C. Chen of TRW Corporation, and Mr. N. C. Albertsen of TICRA ApS. in Copenhagen, Denmark, for providing calculations which were used to check the algorithm reported herein.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. ANALYSIS AND FORMULATION</td>
<td>3</td>
</tr>
<tr>
<td>2.1 Theoretical Development</td>
<td>3</td>
</tr>
<tr>
<td>A) Dual Reflector System</td>
<td>11</td>
</tr>
<tr>
<td>B) Single Reflector System</td>
<td>15</td>
</tr>
<tr>
<td>2.2 Calculation of Radiation Patterns</td>
<td>15</td>
</tr>
<tr>
<td>2.3 Transition from the Old Algorithm to the New One</td>
<td>16</td>
</tr>
<tr>
<td>3. STRUCTURE OF REFLECTOR</td>
<td>20</td>
</tr>
<tr>
<td>3.1 New Variables</td>
<td>20</td>
</tr>
<tr>
<td>3.2 NPUT.</td>
<td>25</td>
</tr>
<tr>
<td>3.3 SUBPNT.</td>
<td>26</td>
</tr>
<tr>
<td>3.4 APRTUR, APRIN, and FILL</td>
<td>27</td>
</tr>
<tr>
<td>3.5 FINDXC.</td>
<td>33</td>
</tr>
<tr>
<td>3.6 CASSA</td>
<td>36</td>
</tr>
<tr>
<td>3.7 Main Procedure and the Utility Routines</td>
<td>38</td>
</tr>
<tr>
<td>4. EXAMPLES AND TEST CASES</td>
<td>39</td>
</tr>
<tr>
<td>4.1 Introduction</td>
<td>39</td>
</tr>
<tr>
<td>4.2 Example and First Test Case</td>
<td>39</td>
</tr>
<tr>
<td>4.3 General Input File</td>
<td>44</td>
</tr>
<tr>
<td>A) Dual Reflector Cases</td>
<td>44</td>
</tr>
<tr>
<td>B) Single Reflector Cases</td>
<td>45</td>
</tr>
<tr>
<td>4.4 Development of a Uniformly Illuminated, Classical Cassegrain Antenna</td>
<td>46</td>
</tr>
<tr>
<td>4.5 Second Test Case - Dual Offset Reflector Antenna</td>
<td>52</td>
</tr>
<tr>
<td>5. A SINGLE REFLECTOR ANTENNA EXAMPLE</td>
<td>58</td>
</tr>
<tr>
<td>(A SEGMENTED SPHERICAL REFLECTOR)</td>
<td></td>
</tr>
<tr>
<td>5.1 Description of the Problem</td>
<td>58</td>
</tr>
<tr>
<td>5.2 Results and Comments</td>
<td>58</td>
</tr>
<tr>
<td>5.3 Input File</td>
<td>59</td>
</tr>
<tr>
<td>6. CONCLUSIONS</td>
<td>67</td>
</tr>
<tr>
<td>7. LIST OF REFERENCES</td>
<td>69</td>
</tr>
</tbody>
</table>
Table of Contents (Continued)

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>Appendix A. Cassegrain Antenna Geometry</td>
<td>70</td>
</tr>
<tr>
<td>8.2</td>
<td>Appendix B. Addition of Hyperboloid.</td>
<td>74</td>
</tr>
<tr>
<td>8.3</td>
<td>Appendix C. Subroutine SUBPNT.</td>
<td>78</td>
</tr>
<tr>
<td>8.4</td>
<td>Appendix D. Development of Normals on a Plane Panel</td>
<td>81</td>
</tr>
<tr>
<td>8.5</td>
<td>Appendix E. Fill Routine for a Vertically Polarized Feed</td>
<td>83</td>
</tr>
<tr>
<td>8.6</td>
<td>Appendix F. Listing of the Code for Reflectr</td>
<td>85</td>
</tr>
<tr>
<td>8.7</td>
<td>Appendix G. Output for Test Cases A and B.</td>
<td>108</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

The objective of the work reported herein was to develop an algorithm to calculate the radiation patterns of Cassegrain antennas, which belong to the general group of dual reflector antennas. (See Appendix A.) The approach taken is to adopt and extend an existing algorithm which was developed for single reflector antennas.

The original algorithm for single reflector antennas was published in 1976 [1]. Later on that year this program appeared as a NCSU report [2], but in a modified version. Between 1976 and 1978 this algorithm was extended to deal with new surfaces such as ellipsoids and spheres [3]. In 1980, Botula modified the algorithm giving it the capability to analyze antennas with either smooth analytic surfaces or with surfaces composed of a number of panels [5].

The method of the electric vector potential and the geometrical optics approach were used to compute the radiation field of the antenna in question.

This thesis includes:

1) All modifications and additions inserted into the program to increase the accuracy of the calculated results for multipanel single reflector antennas;

2) The equations written to describe hyperbolic surfaces; and

3) The equations used to describe all reflections of rays from both surfaces of a Cassegrain antenna and the
intersections of these rays with the two surfaces.

FORTRAN G level was the language used in writing the algorithm. The computing time was slightly increased due to the fact that more ray tracing is involved in a dual reflector antenna case.
2. ANALYSIS AND FORMULATION

2.1 Theoretical Development

The majority of operations in this algorithm are essentially the same as those in the single reflector algorithm. The GO approach is applied to calculate the reflected electric field using the feed radiation pattern and all parameters defining the surfaces comprising a reflector antenna. The electric field is computed over a planar aperture in front of the reflector surface. As a result, an integration over the aperture plane yields the radiation patterns of the antenna in question.

To understand the line of thought and development of the new algorithm it is necessary to review some aspects of the old program and see where the new additions appear. A more refined and detailed explanation of all equations in the old algorithm is given in references [1] to [5].

Figures 2.1 and 2.2 depict the coordinate systems used in the single and dual reflector algorithms.

The first difference is that the new algorithm has the capability of analyzing both dual reflector antennas and single reflector antennas, i.e., the old algorithm became part of the new one. The two reflector surfaces are described in terms of the reference coordinate system (x, y, and z) in which most of the mathematical operations are performed. The second difference between the old and new programs lies in the types of reflector surfaces that can
be analyzed. Previously, five types were available: planes, spheres, ellipsoids, paraboloids, and parabolic cylinders, whereas now hyperboloids can also be treated as another type of surface.

![Fig. 2.1. Coordinate system for a single reflector antenna system](image)

It should be stressed here that these six types of surfaces are available for each reflector for the case of dual reflector antennas.

![Fig. 2.2. Coordinate system for a dual reflector antenna system](image)

Spherical coordinates are used for the radiation pattern calculations. The convention used concerning the angles $\theta$ and $\phi$ is shown in Figure 2.3.
Fig. 2.3. Convention used for angles $\theta$ and $\phi$

The feed position is expressed in terms of the primed coordinates $x'$, $y'$, and $z'$. The feed radiation pattern is expressed in spherical coordinates, based on the feed cartesian coordinate system using the same convention for the angles $\theta'$ and $\phi'$ as the reference spherical system. Here, $\theta'$ and $\phi'$ are referred to the feed coordinate system. The phase center of the feed antenna is the origin of its coordinate system.

The two coordinate systems are related to each other via a three-dimensional rotational matrix $[A]$, whose derivation can be found in [2]. The rotational operation of this matrix is used to make the feed system parallel to the reference system, making use of the three angles ALPHA, BETA, and GAMMA as shown in Figure 2.4. All counterclockwise rotations are defined as positive when looking in the negative direction along the axis of rotation.
Fig. 2.4. Feed rotation angles
ALPHA is the rotation about the z'-axis, BETA is the rotation about the x'-axis and GAMMA is the rotation about the v'-axis.

Each ray starts from the feed and is traced up to the aperture plane. Five pieces of information are associated with each ray: a set of angles $\theta'$ and $\phi'$, the appropriate $\theta'$ and $\phi'$ polarized electric field strengths and the initial phase, all taken from the feed antenna pattern. Figures 2.5 and 2.6 show all vector operations involved in ray tracing.

Fig. 2.5. Vector operations for a single reflector antenna

Fig. 2.6. Vector operations for a dual reflector antenna
The symbols in these figures are defined as follows:

1) $\hat{s}_i$ is a unit vector in the direction of an arbitrary ray incident on the reflector (or on the subreflector).

2) $R$ is the distance from the phase center of the feed to the point at which the incident ray strikes the reflector (or the subreflector).

3) $\hat{n}_O$ is the unit normal vector to the reflector surface (or the subreflector).

4) $\hat{s}_r$ is a vector in the direction of the reflected ray, (or reflected from the subreflector) and incident on the main reflector in the case of a dual reflector antenna.

5) $R_{M}$ is the distance from $(x_0, y_0, z_0)$ on the subreflector to $(x_{02}, y_{02}, z_{02})$ on the main reflector, i.e., the distance from a point on the subreflector to a point at which the reflected ray strikes the main reflector.

6) $\hat{s}_{r2}$ is a vector in the direction of the ray reflected by the main reflector.

7) $D$ is the distance from the point of reflection $(x_0, y_0, z_0)$ to the aperture plane for a single reflector or from the point $(x_{02}, y_{02}, z_{02})$ on the main reflector to the aperture plane for the dual reflector case.
The unit vector $\mathbf{s}_i$ which is expressed in spherical feed coordinates is written in its cartesian coordinate system as:

$$\mathbf{s}_i = s_x \hat{x} + s_y \hat{y} + s_z \hat{z}$$

where

$$s_x = \sin \theta' \cos \phi'$$
$$s_y = \sin \theta' \sin \phi'$$
$$s_z = \cos \theta'$$

$\theta'$ and $\phi'$ are also expressed in terms of the feed cartesian coordinates. The feed system is not only rotated but translated with respect to the reference system. That means that a rotation as well as a translation should be performed to express the vector $\mathbf{s}_i$ in the reference system. To achieve this task, the origin of the reference system must be known in the feed system.

The intersection of a ray having the unit vector $\mathbf{s}_i$, with the reflector or subreflector surface is defined by a vector $\mathbf{v}$ as shown in Figure 2.7.
Thus $\hat{V} = r \hat{s}_i - 0^*0$ provided that $\hat{s}_i$ and $0^*0$ are expressed in the reference coordinate system. To accomplish the transformation a 3x2 matrix $[BB]$ is formed. This matrix has the ray unit vector $(\hat{s}_i)$ and the translation vector as its columns. The rotational operation takes place by premultiplying $[BB]$ by the rotation matrix $[A]$.

$$[A][BB] = [B]$$

Each ray is now described in the reference system by the parametric equations

$$x = B_{11}r - B_{12}$$
$$y = B_{21}r - B_{22}$$
$$z = B_{31}r - B_{32}$$

The point of intersection is found by solving simultaneously the equations mentioned above and the equation of the reflector surface. To find a vector $(\hat{s}_r)$ in the direction of the reflected ray, the unit normal to the reflector surface, at the incident point is evaluated and Snell's Law is used, i.e.

$$\hat{s}_r = \hat{s}_i - 2(n_0 \cdot \hat{s}_i) n_0$$

Similarly, the reflected field except for phase, is given by

$$\hat{E}_r - 2(n_0 \cdot \hat{E}_i) n_0 - \hat{E}_i$$

where $\hat{E}_i$ is the incident field, attenuated, of course, by a factor $\frac{1}{R'}$, since we assume that the reflector is in the far field of the feed antenna.

All vector operations are the same for both the single and dual reflector antenna options.
The two options are now considered separately.

A) **Dual Reflector System**

The parametric equations for a ray along $\hat{s}_r$, which is treated now as the incident ray on the main reflector, are:

$$x = x_0 + h \cos \alpha x$$

$$y = y_0 + h \cos \alpha y$$

$$z = z_0 + h \cos \alpha z$$

where $h$ is the distance travelled from the point $(x_0, y_0, z_0)$ on the subreflector along the ray, and

$$\cos \alpha x = \frac{s_{rx}}{s^+_r}$$

$$\cos \alpha y = \frac{s_{ry}}{s^+_r}$$

$$\cos \alpha z = \frac{s_{rz}}{s^+_r}$$

and $s_{rx}, s_{ry}, s_{rz}$ are the components of the reflected vector $\hat{s}_r$. To find the intersections of the ray and the main reflector, simultaneous solution of the above parametric equations with the equations of the surface of the main reflector is required.

The unit normal to the surface is evaluated at this point and used to compute a vector in the direction of the reflected ray, i.e.,

$$\hat{s}_{r2} = \hat{s}_{i2} - 2 (n_{02} \cdot \hat{s}_{i2}) n_{02}$$

where $\hat{s}_{i2} = \hat{s}_r$ is a unit vector incident on the main reflector,
and \( \hat{n}_{02} \) is the unit normal on the surface of the main reflector in cartesian components.

\[
\hat{s}_{r2} = \hat{x} \left[ s_{ix2} - 2n_{x02} (n_{x02} \cdot \hat{i} x_2 + n_{y02} \cdot \hat{i} y_2 + n_{z02} \cdot \hat{i} z_2) \right] \\
+ \hat{y} \left[ s_{iy2} - 2n_{y02} (n_{x02} \cdot \hat{i} x_2 + n_{y02} \cdot \hat{i} y_2 + n_{z02} \cdot \hat{i} z_2) \right] \\
+ \hat{z} \left[ s_{iz2} - 2n_{z02} (n_{x02} \cdot \hat{i} x_2 + n_{y02} \cdot \hat{i} y_2 + n_{z02} \cdot \hat{i} z_2) \right]
\]

where

\[
s_{ix2} = s_{rx} \\
s_{iy2} = s_{ry} \\
s_{iz2} = s_{rz}
\]

are the components of the ray vector reflected by the sub-reflector. Now if

\[
s_{rx2} = s_{ix2} - 2n_{x02} (n_{x02} \cdot \hat{i} x_2 + n_{y02} \cdot \hat{i} y_2 + n_{z02} \cdot \hat{i} z_2) \\
s_{ry2} = s_{iy2} - 2n_{y02} (n_{x02} \cdot \hat{i} x_2 + n_{y02} \cdot \hat{i} y_2 + n_{z02} \cdot \hat{i} z_2) \\
s_{rz2} = s_{iz2} - 2n_{z02} (n_{x02} \cdot \hat{i} x_2 + n_{y02} \cdot \hat{i} y_2 + n_{z02} \cdot \hat{i} z_2)
\]

then

\[
\hat{s}_{r2} = \hat{x} s_{rx2} + \hat{y} s_{ry2} + \hat{z} s_{rz2}
\]

TO THE APERTURE PLANE

Fig. 2.3. Electric field vectors
Similarly, the reflected field (Figure 2.8), assuming a perfectly conducting reflector, is given by:

\[ \mathbf{E}_{r2} = 2 \left( n_{02} \mathbf{E}_{i2} \right) n_{02} \mathbf{E}_{i2} - \mathbf{E}_{i2} \]

where \( \mathbf{E}_{i2} = \frac{\mathbf{E}_r}{RM} \).

\( \mathbf{E}_{i2} \) is the incident electric field on the main reflector and \( \mathbf{E}_r \) is the electric field reflected by the subreflector. It is seen here that \( \mathbf{E}_r \) is multiplied by a factor \( 1/RM \) since the main reflector is assumed to be in the far field of the subreflector.

In component form,

\[ \mathbf{E} = \hat{x} \mathbf{E}_{rx} + \hat{y} \mathbf{E}_{ry} + \hat{z} \mathbf{E}_{rz} \]

\[ = \hat{x} E_{ix2} + \hat{y} E_{iy2} + \hat{z} E_{iz2} \]

and \( \mathbf{E}_{r2} \) becomes

\[ \mathbf{E}_{r2} = \hat{x} \left[ 2n_x02(n_x02 \mathbf{E}_{ix2} + n_y02 \mathbf{E}_{iy2} + n_z02 \mathbf{E}_{iz2}) - E_{ix2} \right] \\
+ \hat{y} \left[ 2n_y02(n_x02 \mathbf{E}_{ix2} + n_y02 \mathbf{E}_{iy2} + n_z02 \mathbf{E}_{iz2}) - E_{iy2} \right] \\
+ \hat{z} \left[ 2n_z02(n_x02 \mathbf{E}_{ix2} + n_y02 \mathbf{E}_{iy2} + n_z02 \mathbf{E}_{iz2}) - E_{iz2} \right] \]

The procedure of finding the intersection of the reflected ray (by the main reflector) and the aperture plane is as follows:

Find the parametric equation for a line along \( \mathbf{s}_{r2} \)
given by:
\[ x = x_{02} + h' \cos \alpha' x \]
\[ y = y_{02} + h' \cos \alpha' y \]
\[ z + z_{02} + h' \cos \alpha' z \]

where
\[ \cos \alpha' x = \frac{x \cdot s_{r2}}{s_{r2} \cdot s_{r2}} = \frac{s_{rx2}}{s_{r2}} \]
\[ \cos \alpha' y = \frac{y \cdot s_{r2}}{s_{r2} \cdot s_{r2}} = \frac{s_{ry2}}{s_{r2}} \]
\[ \cos \alpha' z = \frac{z \cdot s_{r2}}{s_{r2} \cdot s_{r2}} = \frac{s_{rz2}}{s_{r2}} \]

and \( h' \) is the distance travelled along the ray. The aperture plane is at \( x = x_c \), which defines \( h' = \frac{x_c - x_{02}}{\cos \alpha' x} \). The \((y, z)\) coordinates where this ray strikes the aperture plane are:

\[ y = y_{02} + (x_c - x_{02}) \frac{\cos \alpha' y}{\cos \alpha' x} = y_{02} + (x_c - x_{02}) \frac{s_{ry2}}{s_{rx2}} \]
\[ z = z_{02} + (x_c - x_{02}) \frac{\cos \alpha' z}{\cos \alpha' x} = z_{02} + (x_c - x_{02}) \frac{s_{rz2}}{s_{rx2}} \]

Then
\[ D = \sqrt{(x_c - x_{02})^2 + (y - y_{02})^2 + (z - z_{02})^2} \]

and the phase of the field upon reaching the aperture plane is given as:

\[ \psi_2 = \frac{2\pi}{\lambda} (R + RM + D) + \text{Initial Phase.} \]
Thus, five parameters are computed for each ray at a point on the aperture plane: the y and z coordinates, the y and z components of the electric field, and the phase of the field.

B) Single Reflector System

In this case each ray is traced from the feed to the reflector up to the aperture plane in the same way as before. It is clear that in this case a smaller number of equations have to be written and the phase is given by

$$\psi = \frac{2\pi}{\lambda} (R+d) + \text{Initial phase}.$$ 

A more detailed discussion of the above operation is provided by Kauffman [2].

2.2 Calculation of Radiation Patterns

In both cases, the tangent aperture field is given by:

$$\mathbf{E}_{AP} = (\hat{y} E_{ry} + \hat{z} E_{rz}) e^{-j\psi}$$ for a single reflector

where $E_{ry}, E_{rz}$ are the tangential components of the aperture electric field, or $\mathbf{E}_{AP} = (\hat{y} E_{ry2} + \hat{z} E_{rz2}) e^{-j\psi_2}$ for a dual reflector.

In order to evaluate the secondary radiation pattern at a particular point in space, we integrate numerically over the aperture. The integrals to be evaluated are:

$$E_\theta = \int_{\text{Aperture}} \int_{\text{Surface}} E_{rz} \cos\phi \ e^{j\psi} e^{jk[y \sin\theta \ sin\phi + z \cos\theta]} dy dz$$

and
\[ E_\phi = \iint_{\text{Aperture Surface}} \left[ E_y \sin \theta + E_z \cos \theta \sin \phi \right] e^{-j\psi} \]
\[ e^{jk} \left[ y \sin \theta \sin \phi + z \cos \theta \right] dy dz \]

where the aperture surface is the area of the reflector aperture projected on the aperture plane. It is necessary to integrate only those points which result from reflections from the actual surface and not from its mathematical extension. This is achieved by interpolating a series of edge points on the boundary, using information from points which exist outside the aperture. All points then existing outside the reflector surface are disregarded.

Before the integration takes place, all points on the aperture plane are quantized in their \( y \)-coordinate. All details on quantization and integration are fully provided by Kauffman [2], Agrawal [3], and Botula [5].

2.3 Transition from the Old Algorithm to the New One

The block diagram in Figure 2.9 shows the locations where changes, additions and modifications were applied to the old algorithm to obtain the new one.

These general additions and changes, which will be explained later in more detail, are the following:

1. \text{NPUT:} Was enlarged to read in and print out data for both reflectors for a dual reflector antenna system. This feature
1. did not exist before. NPUT also calls an additional subroutine, named SUBPNT.

2. SUBPNT: Was added to determine the four extreme points on the subreflector, given the four extreme points on the main reflector.

3. APRTUR: Was extended for the following reasons:
   A) to incorporate hyperboloidal surfaces, as an addition to the previous list of surfaces.
   B) To compute, automatically, the location of the aperture plane \( x_c \) in terms of parameters pertinent to the antenna under consideration. This is accomplished by calling the subroutine FINDXC.

4. FINDXC: FINDXC was added to provide APRTUR with an approximate value of \( x_c \). \( x_c \) is evaluated for both reflector systems, following different approximations depending on whether the antenna is a dual or a single reflector system.

5. CASSA: A new subroutine was inserted in APRTUR to account for all the tracing from the subreflector to the main reflector, up to
the aperture plane for the case of a
dual reflector system.
The rest of the program is unchanged.
Fig. 2.9. Structure of new algorithm
3. STRUCTURE OF REFLECTR

3.1 New Variables

New variables were introduced to account for the increased complexity of the program. Some old variables and common storage blocks were changed to give the new algorithm a general character. Since the new variables come as a follow-up of the old ones, all common storage blocks and variables are introduced here.

1) BLOCKG/YCBL, ZCBL, HFMABL, HFMIBL (Aperture plane blockage information).
   YCBL, ZCBL: y and z center coordinates of the aperture plane blockage ellipse.
   HFMABL, HFMIBL:
   Half-major and half-minor axes of the aperture plane blockage ellipse.

2) CASS/SR(3), XO, YO, ZO, Y, Z, RM, D, XO2, YO2, ZO2,
   ER2(3), ER(3) (Only for Cassegrain antennas).
   XO, YO, ZO, A point where a ray emanating from the feed intersects the subreflector.
   XO2, YO2, ZO2 A point of intersection of the main reflector and the ray.
   Y, Z The y and z coordinates of each ray on the aperture plane.
   RM Length of a ray from the subreflector to the main reflector.
D        Distance of aperture plane from main reflector.
SR(3)    A vector $\mathbf{s}_r$ in the direction of a ray reflected by the subreflector.
ER2(3)   The three components of the electric field reflected by the main reflector.
ER(3)    The three components of the electric field reflected by the subreflector.

3)       COLOS/DELT, XC, ANGING, PM(3,4), RS, XMX, ZMX, ZMN, YMX (Parameters used for determining $x_c$.)
DELT     The $0^\circ$ angle subtended by the subreflector. (See Figure 2.2.)
ANGING   Angular increment. (See Botula [5] for more details.
PM(3,4)  Four extreme points on the main reflector.
RS       Distance from an extreme point on the subreflector to the origin.
XMX, YMX, ZMX A point on the subreflector which is the closest point to the origin.
ZMN      The minimum Z coordinate of the subreflector.

4)       CONTRL/NOPT(3), NLIST, IOPT, ICASS, ILIST (100)
NOPT(3)  Three number specifying options regarding printer, plotter, and aperture plane, data output, respectively. See [5] Section 6.)
NLIST  The number of panels for which the algorithm will print complete illumination and quantizing data.

IOPT  A variable which is zero when the program is to run normally, and one when the single-panel option is in effect.

ICASS  A variable which is one if a Cassegrain antenna is to be analyzed, and zero for a single reflector antenna.

ILIST(100)  The specific panels for which the algorithm is to provide complete illumination and quantizing data. (See Botula [5], Section 4.)

5) The common blocks: A) DIMENS, B) EXTENT, C) MATH and D) PATTRN, have remained the same as in [5].

6) FEED/EP(91), ET(91), NP, NT, XS, YS, ZS.

(Feed antenna parameters)

EP(91), ET(91)

Array containing the electric field strengths of the feed antenna in one-degree increments off-axis in the \( \theta = 90^\circ \) and \( \phi = 180^\circ \) planes, respectively.

NP, NT

The number of increments of \( \phi \) and \( \theta \) used in the illumination pattern, respectively.

XS, YS, ZS

A point on each panel which is the closest point to the origin of the reference coordinate system.
PARAMS/AORORF, BELLP, CELLP, DIST, PSI, PLNPNT (3), PLNORM (3), FEED (3), ALPHA, BETA, GAMMA, XLM, AOROR2, BELLP2, CELLP2, PSI2, DIST2, POINT (3), NORM (3), SURFC1, NPNL, NPOINT, SURFC2. (Antenna system parameters.)

In the following, the variables that appear first are defined on the subreflector, and those that appear second are defined on the main reflector.

AORORF, AOROR2: The focal length of a paraboloidal reflector, the focal length of a parabolic cylindrical reflector, the radius of a spherical reflector, the semi-major axis of an ellipsoidal reflector along X, or half the transverse axis (x-direction) of a hyperboloidal reflector (Appendix B), depending on which surface is intended to represent the reflector.

BELLP, BELLP2: The semi-minor axes (along y and z, respectively) of an ellipsoidal reflector surface. Note that this does not define a completely arbitrary ellipsoid since the axes along y and z must be equal. For the case of a hyperboloidal reflector surface, this value represents the y semi-axis of the ellipse in the yz plane of the hyperboloid.

CELLP, CELLP2: Used only for a hyperboloid and stands for the z semi-axis of the ellipse in the yz plane of the hyperboloid.
DIST: A parameter used in translating the origin of the hyperbolic subreflector coordinate system so that it coincides with that of the main reflector. (See Appendix B.)

PLNPNT(3), POINT(3): The coordinates of a point on a planar reflector surface \((x, y, z)\).

PLNORM(3), NORM(3): The components of a unit normal vector to a planar reflector surface \((x, y, z)\).

FEED(3): The reference coordinate system origin as expressed in the feed coordinate system \((x, y, z)\).

XLAM: Wavelength of the feed antenna radiation.

ALPHA, BETA, GAMMA: Rotation angles mentioned before (Figure 2.4.)

SURFC1, SURFC2: Integer variables which determine the type of reflector surface. (This code is applied to the subreflector as well as the main reflector.)

1) Surface is a plane.
2) Surface is an ellipsoid.
3) Surface is a sphere.
4) Surface is a paraboloid.
5) Surface is a parabolic cylinder.
6) Surface is a hyperboloid.

NPNL: Determines the number of panels the reflector is made of. The value of one means that a list of perimeter points and other surface parameters for each panel must be supplied. In this case, the aperture boundary is approxi-
mated by a polygon. The value of zero means that the single-panel option is in effect and hence an ellipse is used to represent the boundary of that panel.

NPOINT: The number of rays stored for processing in the P array at any given time.

3.2 NPUT

This is an input/output routine. If ICASS = 0, the program is to analyze a single reflector antenna system with two options:

1) With IOPT = 1 for a single-panel option.
2) With IOPT = 0 for a multipanel option.

In both cases, the four extreme points of the reflector surface are required. If ICASS = 1 a dual reflector antenna is to be analyzed. For this case, the four extreme points of the main reflector are read in and used to find the four extreme points of the subreflector by calling subroutine SUBPNT. (SUBPNT explained later in this Section.)

NPUT also reads other parameters concerning the feed. This is important since all pieces of information read here are used in conjunction with the FILL routine which is called later in the program. The connecting agent in this operation is the common storage block, named FEED.

Previously, the four extreme points on the reflector were read into the P array only when NPNL was zero, and the variable $x_c$ was also provided by the user. In this algorithm the four extreme points are read regardless of the particular
value of NPNL. The reason for this is that the above points are needed to compute the variable $x_c$ later in the program. Furthermore, new printing statements were added to be used for dual reflector antennas.

3.3 SUBPNT

![Diagram showing the calculation of RR and the direction cosines]

**Fig. 3.1. Finding the four extreme points**

SUBPNT is called only for a dual reflector antenna. There is a "Do" loop which computes the distance (RR) from the extreme point on the main reflector to the reference point:

$$RR = \left[ (PM(1,K))^2 + (PM(2,K))^2 + (PM(3,K))^2 \right]^{1/2}$$

where $PM(1,K)$, $PM(2,K)$, and $PM(3,K)$ are the coordinates of each extreme point on the main reflector. Then, the direction cosines are found as:

$$DIR_1 = PM(1,K)/RR \text{ (direction cosine in the x-direction)}$$
DIR2 = PM(2,K)/RR (direction cosine in the y-direction)

DIR3 = PM(3,K)/RR (direction cosine in the z-direction)

The parametric equations of a line passing through the origin (reference point), and a point on the main reflector are given by:

\[
P(1,K) = PM(1,K) - RR \cdot DIR1
\]

\[
P(2,K) = PM(2,K) - RR \cdot DIR2
\]

\[
P(3,K) = PM(3,K) - RR \cdot DIR3
\]

where \(P(1,K), P(2,K), P(3,K)\) is an extreme point on the reflector. To determine this point, the above parametric equations and the equation of the surface of the subreflector are solved simultaneously. (See Appendix C for details.)

This operation is repeated four times, i.e., once for each extreme point of the subreflector.

3.4 APRTUR, APRIN, AND FILL

APRTUR does all the ray tracing for the single reflector antenna and it calls a new subroutine named CASSA for additional tracing in the dual reflector case. Figure 11 shows the difference in approach between the old and new algorithms in determining the location of the aperture plane before integration for a multipanel, single reflector antenna.

This difference gives some increased accuracy in predicting the radiation pattern of a multipanel, single reflector antenna. (See results, Section 5.) In the case of a
single reflector, a short "Do" loop is used to find XMX, YMX, and ZMX, a point of the reflector which is the closest one to the origin.

Then a rotation matrix $A$ is computed from the rotation angles ALPHA, BETA, and GAMMA. The inverse of that matrix is also found. If the dual reflector option is in effect, the rotation matrix is calculated immediately skipping the above-mentioned "Do" loop. For single reflector antennas comprised of a number of panels, subroutine APRIN is called to provide data for each panel individually.

Two important additions have been made in APRIN: 1) For each plane reflector a normal is computed automatically using the principle of the CROSS product. (See Appendix D.) 2) Statements 20-28 make use of a "Do" loop to search for
\((x_s', y_s', z_s')\), a point on each panel, which is also the closest point to the origin. It is an important point because it is used later, in APTRUR, to find the location of the aperture plane \((x_{ci})\) for each panel individually. (See Figure 3.2 for geometry). For a complete discussion of APRIN, see [5].

From statements 50 to 65, APRTUR finds the angles subtended by the reflector or the reflector panel. Notice that in the dual reflector case, the angles subtended by the subreflector are the ones to be measured and not those for the main reflector. All points, either the perimeter points for a panel, or the four extreme points for a single panel option, are expressed as angles in the feed system. Then, a search for the maximum and minimum \(\theta^\prime\) and \(\phi^\prime\) angles represented by the above-mentioned set of points is performed to determine the angles subtended by a panel or a subreflector. (See Appendix B in [5].)

**ILLUMINATION ARRAY** - Statements 65-95 generate the appropriate illumination array to insure a well-ordered illumination of the chosen reflector option. The previous method of illumination has been kept the same since it serves the purpose of the new algorithm in a rather convenient way. (See Section 2.3 in [5].)

For the dual reflector case, the angles subtended by the subreflector are the ones to be considered instead of those of the main reflector. The reason for this is the fact that an overillumination of the subreflector results in an
overillumination of the main reflector. Overillumination is
desired so that the projected boundary of the main reflector
on the aperture plane can be defined before integration is
performed. The rays corresponding to the upper and lower
limits of $\theta'$ miss the real subreflector. They get reflected
by its mathematical extension, and as a result, they miss
the main reflector too.

If a Cassegrain antenna is to be studied, as soon as
ANGINC is computed in APRTUR, subroutine FINDXC is called.
(See Section 3.5.) This is the first time where FINDXC ap-
ppears in the program to provide APRTUR with the location of
the aperture plane ($x_c$). APRTUR, with a "Do" loop in state-
ment 95, loads all illumination angles into the $P$ array just
after the angle pairs corresponding to the perimeter points.
SUBROUTINE FILL is called to provide the angle pairs in the
$P$ array with the field strength and phase values.

FILL - This routine is changed and adjusted to each
antenna whose radiation pattern is to be computed. A detail-
ed description of this subroutine and its various forms ap-
pear in [2], [3] and [5]. A new subroutine has been written
for a vertical polarization case. (See Appendix E.)

Furthermore, in APRTUR for single reflector antennas as
the $(x_y, y_0, z_0)$ point is found, the location of a separate
plane are determined. This part of the algorithm is not
carried out for dual reflectors. The procedure for determin-
ing $xx$ and $x_ci$ is as follows:
If the single panel option is in effect, then subroutine FINDXC is called. This is the second location in the program where FINDXC appears. (See Section 3.5.) If a multipanel option is in effect, then $R_1$ (Figure 12) is expressed as:

$$R_1 = \left[ (x_s + B12)^2 + (y_s + B22)^2 + (z_s + B32)^2 \right]^{1/2} - 1.0 = R' - 1.0$$

where $R' = \left[ (x_s + B12)^2 + (y_s + B22)^2 + (z_s + B32)^2 \right]^{1/2}$ is the distance between $(x_s, y_s, z_s)$ and $(B12, B22, B32)$.

Fig. 3.3. Computation of $x_c$'s and $xx$

Also, the angle $\theta_{\text{max}}$ subtended by the reflector is expressed as:

$$\theta_{\text{max}} = \tan^{-1}\left( -\frac{x_s + B32}{y_s + B12} \right)$$

where $(x_s + B12)$ is a negative value and $(z_s + B12)$ a positive one. Hence, to obtain a positive $\theta_{\text{max}}$ angle, a negative sign is added. The
angle $\theta_{\text{max}}$ is augmented by 2.5 ANGING, i.e., 2.5 times an angular increment. The reason that $R_1 = R' - 1.0$ and $\theta_{\text{aug}} = \theta_{\text{max}} + 2.5 \text{ANGING}$ are used instead of $R'$ and $\theta_{\text{max}}$ is to make sure that the panel will be overilluminated. Thus $x_c$ is found as:

$$x_c = -(R_1 \cos(\theta_{\text{aug}}) + B(1,2)).$$

The distance between $x_c$ and $x_s$ for the first panel is computed as $\text{CONST} = |x_c - x_s|$. This number becomes an important factor in locating the aperture plane for the rest of the panels. The idea is to put an aperture plane in front of every panel and with a distance equal to CONST away from it. This results in having an ordered arrangement of aperture planes in front of the reflector. So, the rest of the $x_c$'s are given as:

$$x_c = x_s + \text{CONST}$$

where $x_s$ is provided by APRIN, in advance. Once all $x_c$'s have been found, the location of a general plane ($xx$) is determined, using FINDXC. (See Section 3.5.) Each panel is first projected onto its own individual aperture plane, and then phase-referenced to the general aperture plane. Thus, the general plane sums up all these projections that comprise the total projection of the antenna on the aperture plane. This method of preparation of the aperture plane before integration yields better results compared with the previous method.

The difference in phase is written as:
DIFF = \left| x_c - x_s \right| and the PHASE = \frac{2 \pi}{\lambda} (R + D + DIF) + Initial Phase

where R = distance from the feed to reflector.

D = a distance from the reflector to the individual aperture plane.

DIF = distance from the individual aperture plane to the general one.

If the dual reflector antenna option is in effect, subroutine CASSA is called by APRTUR to continue the ray tracing operation over the region lying between the subreflector and the main reflector. (See Section 3.6.)

3.5 FINDXC

This subroutine is called, as mentioned before, at two different locations in APRTUR.

\[ \left[ PM(1;M), PM(2;M), PM(3;M) \right] \]

Fig. 3.4. Location of an aperture plane at \( x_c \) for a dual reflector
In the dual reflector antenna case, FINDXC is called immediately after ANGING is computed. In this case, $x_c$ is evaluated directly from the geometry of the two reflectors. From Figure 3.4, a point with the largest $z$ coordinate on the main reflector is determined and its distance ($R'$) from the reference system is computed. Then, new parameter RSM is computed as:

$$RSM = \left[ (PM(1,M))^2 + (PM(2,M))^2 + (PM(3,M))^2 \right]^{1/2} - 1.0 = R' - 1.0$$

where $R' = \left[ (PM(1,M))^2 + (PM(2,M))^2 + (PM(3,M))^2 \right]^{1/2}$

Also, $\theta_{\text{max}}$ the angle subtended by the main reflector is expressed:

$$\theta_{\text{max}} = \tan^{-1}\left(-\frac{PM(3,M)}{PM(2,M)}\right)$$

where the negative sign is provided here to obtain a positive $\theta_{\text{max}}$ angle, since $PM(3,M)$ is positive and $PM(1,M)$ is negative. In the reference system another angle, called $\theta_{\text{augmented}}$ is estimated as:

$$\theta_{\text{aug}} = \theta_{\text{max}} + 3.0 \cdot \text{ANGING} \text{(in radians)}$$

and $x_c$ is then calculated using the expression.

$$x_c = -RSM \cos (\theta_{\text{aug}})$$

The fact that RSM is used instead of $R'$ and $\theta_{\text{aug}}$ instead of $\theta_{\text{max}}$ is to insure overillumination and to make sure that this subroutine works for all sub and main reflector combinations, no matter what their geometrical relationships are. This subroutine could, if necessary, be changed to deal with each sub and main reflector combinations separately.
The second call of FINDXC by APRTUR is concerned with finding the location \((xx)\) of the general aperture plane for the multipanel option reflector, or \(x_c\) for the single panel option. This task is accomplished as follows: (See Figure 3.5.)

\[
(x_{mx}, y_{mx}, z_{mx})
\]

First, find the distance \(R'\) between the point \((x_{mx}', y_{mx}', z_{mx}')\), and the feed, i.e.,

\[
R' = \left[ (x_{mx}' + B12)^2 + (y_{mx}' + B22)^2 + (z_{mx}' + B32)^2 \right]^{1/4}
\]

where \((x_{mx}', y_{mx}', z_{mx}')\) is the point on the reflector which is the closest to the origin of the reference system. It should be noted that this point is computed at the beginning of the APRTUR routine. Second,
\[
\theta_{\text{max}} = \tan^{-1}\left( -\frac{(z_{mx} + B_{32})}{x_{mx} + B_{12}} \right)
gives the maximum angle
\]
subtended by the reflector. This angle is increased by a 2.5 ANGING to give \(\theta_{\text{aug}} = \theta_{\text{max}} + 2.5\) ANGING (in radians) and third, to find \(x_c\), \(R'\) is reduced by 1.5 to yield
\[
RSM = \left[ (x_{mx} + B_{12})^2 + (y_{mx} + B_{22})^2 + (z_{mx} + B_{32})^2 \right]^{1/2} - 1.5
\]
and hence
\[
x_c \text{ or } xx = -RSM \cos(\theta_{\text{aug}}) + B(1,2) \text{ for a single panel or a multipanel antenna, respectively.}
\]
It is noted here that the distance \(R'\) is reduced by 1.5 instead of 1.0 (as was done in the case of individual panels) to insure that \(xx\) will be less than \(x_c\), in the multipanel case. The whole arrangement of separate aperture places and a general one is shown in Figure 11, Part B.

It can be seen that \(xx\) has to be behind all individual aperture planes. If the multipanel option is not in effect, \(xx\) becomes \(x_c\).

3.6 CASSA

This subroutine accomplishes all the ray tracing from the subreflector to the main reflector up to the aperture plane. It starts with finding the direction cosines of a vector along the ray reflected by the subreflector. Parametric equations of a line are expressed as:

\[
x_{02} = x_0 + RM \cdot DC(1)
\]
\[
y_{02} = y_0 + RM \cdot DC(2)
\]
\[
z_{02} = z_0 + RM \cdot DC(3)
\]
where \((x_{02}, y_{02}, z_{02})\) is a point on the main reflector, 
\((x_0, y_0, z_0)\) is a point on subreflector, RM distance be-
tween these two points and DC(1) DC(2) DC(3) are the direc-
tion cosines with respect to x, y and z axes, respectively. 
The solution of simultaneous equations consisting of the 
above parametric equations and the equation of the reflector 
surface yield the point \(x_{02}, y_{02}, z_{02}\). Although this sub-
routine has been written to deal with six analytical sur-
faces, it could be extended to incorporate any other number 
of types of surfaces, if desired. Surfaces expressed numeri-
cally could also be added to this algorithm, especially for 
the dual reflector antenna option, where shaping of one or 
both of the reflectors is now widely used in their actual 
design.

Once the point \(x_{02}, y_{02}, z_{02}\) is evaluated, the normal 
\((\mathbf{n}_{\text{HAT}2(1)}, \mathbf{n}_{\text{HAT}2(2)}, \mathbf{n}_{\text{HAT}2(3)})\) on the surface at that point 
is computed as follows:

Let the surface be represented as \(g(x, y, z) = C\).

Then \(\mathbf{n}_{02} = \frac{\nabla g(x_{02}, y_{02}, z_{02})}{|\nabla g|}\)

A detailed explanation of computing normals and intersec-
tions of rays with surfaces is not given in this thesis, 
since a complete discussion can be found in all references 
from [1] to [5], in their description of subroutine APRTUR. 
The only difference lies in the fact that the parameters used
in CASSA are pertinent to the surface of the main reflector and not the subreflector.

The normal on the main reflector is used to apply Snell's law of reflection to find a vector in the direction of the reflected ray (SR2(1), SR2(2), SR2(3)). This part of the algorithm is described in Section 2.1. A point, \((y, z)\) on the aperture plane is then computed, and passed over to APRTUR where it is stored, to be retrieved later by QUANTZ.

The principles of geometrical optics are used to determine the electric field during these two phases of ray tracing. All equations in this part of the algorithm are mentioned in Section 2.1. In general, all operations taking place in CASSA are depicted in Figures 2.6 and 2.8.

3.7 Main Procedure and the Utility Routines

The main procedure and all the rest of the utility subroutines were kept the same as before with a minor change in their storage blocks. A complete development of these subroutines and the main procedure is provided by Botula in [5].
4. EXAMPLES AND TEST CASES

4.1 Introduction

Two test cases on the Cassegrain antennas are provided here to demonstrate the use of the program and support the validity of the algorithm. These cases are the following:

FIRST, a classical Cassegrain antenna which was used to check the algorithm in the case of uniform illumination, but with no blockage.

SECOND, a dual offset reflector antenna, used to check the results obtained by this algorithm against calculated data obtained from two other algorithms.

4.2 Example and First Test Case

The classical Cassegrain antenna, shown in Figure 4.1 employs a hyperboloid for the subreflector and a paraboloid for the main reflector. One of the two foci of the hyperboloid is the real focal point of the system, and is located at the origin of the feed coordinate system; the other is a virtual focal point which is located at the focus of the paraboloid which coincides with the origin of the reference system. As a result, all rays originating from the real focus and reflected from both surfaces travel equal distances to a plane in front of the antenna. (See Figure 4.1.)
Table 4.1 gives a number of parameters that define completely the geometry of the antenna system. All parameters required by NPUT will now be evaluated from this Table.

**TABLE 4.1.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main reflector focal length</td>
<td>( F_m ) 100.0 in.</td>
</tr>
<tr>
<td>Main reflector illumination angle</td>
<td>( \theta_2 ) 60.785</td>
</tr>
<tr>
<td>Eccentricity of subreflector</td>
<td>( e ) 1.50177</td>
</tr>
<tr>
<td>Distance between two foci</td>
<td>( F_C ) 91.0 in.</td>
</tr>
<tr>
<td>Wavelength</td>
<td>( \lambda ) 4.734 in.</td>
</tr>
</tbody>
</table>
FEED PARAMETERS

Since the origin of the feed coordinate system is located at the real focus of the hyperboloid and at distance $x = -91.0$ from the origin of the reference system, the feed parameters can be given as:

1) Feed (1) = -91.0 in., Feed (2) = 0.0, Feed (3) = 0.0
2) ALPHA = 0.0, BETA = 0.0, GAMMA = -180.0

MAIN REFLECTOR PARAMETERS

SURFC2 is set equal to 4, since a paraboloidal reflector is to be used as a main reflector.

$F_m = 100.0$, as was given in the Table.

The four extreme points of that reflector to be read in are:

**Upper point**

\[
r = \frac{2 F_m}{1 + \cos \theta_{\text{max}}} = \frac{2 \cdot 100.0}{1 + \cos(60.785^\circ)} = 134.4
\]

\[
x = r \cos \theta_{\text{max}} = -r \cos(60.785^\circ) = -65.599
\]

\[
y = 0.0
\]

\[
z = r \sin \theta_{\text{max}} = r \sin(60.785^\circ) = 117.304
\]

**Lower point**

\[
r = \frac{2F_m}{1 + \cos \theta_{\text{min}}} = \frac{2 \cdot 100.0}{1 + \cos(-60.785^\circ)} = 134.4
\]

\[
x = -r \cos \theta_{\text{min}} = -65.599
\]

\[
y = 0.0
\]

\[
z = r \sin \theta_{\text{min}} = r \sin (-60.785^\circ) = -117.304
\]
These two points correspond to the \( \theta \) extrema in the feed system. Also, the two points representing the \( y \) - extrema are almost exactly the \( \phi \) extrema as well. The \( z \) coordinates of these points are identical.

\[
z = \frac{z_{\text{min}} + z_{\text{max}}}{2} = \frac{117.304 - 117.304}{2} = 0.0
\]

The reflector, as seen from the geometry of the antenna system, is 234.608 inches wide and symmetric with respect to the \( xz \) plane, hence \( y = \pm \frac{234.608}{2} = \pm 117.304 \) in.

Finally, the paraboloid equation provides the \( x \) coordinates

\[
x = \sqrt{\frac{y^2 + z^2}{4F_m}} - F_m = 65.599
\]

Thus, the four aperture points become:

- Upper point: \((-65.599, 0.0, 117.304) = PM(1,1), PM(2,1), PM(3,1))\)
- Lower point: \((-65.699, 0.0, -117.304) = PM(1,2), PM(2,2), PM(3,2))\)
- Leftmost point: \((-65.599, -117.304, 0.0) = PM(1,3), PM(2,3), PM(3,3))\)
- Rightmost point: \((-65.599, 117.304, 0.0) = PM(1,4), PM(2,4), PM(3,4))\)

It should be noted here that the diameter of the main reflector can also be found from the relationship given in Appendix A as follows:

\[
\tan \frac{\theta}{2} = \frac{1}{4} \frac{D_m}{F_m} + D_m = 4F_m \tan \frac{60.785^\circ}{2} = 234.608
\]
SUBREFLECTOR PARAMETERS

SURFC1 is set equal to 6, since a hyperboloidal surface is to be used for a subreflector. NPNL takes the value of zero, since neither the subreflector nor the main reflector is composed of panels.

The parameters $a$ (semi-transverse axis along $x = \text{AORORF}$),

$b$ (semi-axis along the $y$ direction = \text{BELLP}), and

$c$ (semi-axis along $z$ direction = \text{CELLP})

are computed as follows: (See Appendix B for details.)

$$a = \frac{F_c}{2} = \frac{91.0}{2 \times 1.50177} = 30.2976$$

$$c = b = a \sqrt{\epsilon^2 - 1} = 30.2976 \sqrt{(1.50177)^2 - 1} = 33.95$$

Also, $\text{DIST} = \frac{F_c}{2} = \frac{91.00}{2} = 45.0$ which is a parameter used in translating the origin of the subreflector coordinate system so that it coincides with that of the main reflector. (See Appendix B for details.)

There is no need to read in $x_c$, since this value is computed in the program as a function of the antenna system parameters. In this case, the FILL routine was not used, and no data for the $E$ and $H$ plane patterns of the feed were used in the input file.
### 4.3 General Input File

For format information, refer to the program listing, Appendix F.

#### A) Dual Reflector Cases

<table>
<thead>
<tr>
<th>Cards</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>Title Cards</td>
</tr>
<tr>
<td>5</td>
<td>Feed (1-3), ALPHA, BETA, GAMMA, XLAM</td>
</tr>
<tr>
<td>6</td>
<td>SURFC2, AOROR2, BELLP2, CELLP2, DIST2, PSI2</td>
</tr>
<tr>
<td>7</td>
<td>POINT(1-3), NORM(1-3)</td>
</tr>
<tr>
<td>8</td>
<td>SURFC1, NPNL, AORORF, BELLP, CELLP, DIST, PSI</td>
</tr>
<tr>
<td>9</td>
<td>PLNPNT(1-3), PLNORM(1-3)</td>
</tr>
<tr>
<td>10,11,12,13</td>
<td>Four extreme points ((x_0, y_0, z_0)), on the edge of the main reflector. One point goes on each card.</td>
</tr>
<tr>
<td>14</td>
<td>YCBL, ZCBL, HFMABL, HMIBL (Blockage of main reflector by subreflector)</td>
</tr>
<tr>
<td>15-N</td>
<td>Any data required by the FILL routine</td>
</tr>
<tr>
<td>N+1</td>
<td>NOPT, NLIST</td>
</tr>
<tr>
<td>N+2</td>
<td>MAJOR, AMAJOR, MINOR, AMINOR(1-3) (Pattern request cards)</td>
</tr>
<tr>
<td>N+3</td>
<td>DONE typed in the first four columns of the card</td>
</tr>
</tbody>
</table>
B) Single Reflector Cases

<table>
<thead>
<tr>
<th>Cards</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>Title Cards</td>
</tr>
<tr>
<td>5</td>
<td>Feed (1-3), ALPHA, BETA, GAMMA, XLAM</td>
</tr>
<tr>
<td>6</td>
<td>SURFCL, NPNL, AORORF, BELLP, CELLP, DIST, PSI</td>
</tr>
<tr>
<td>7</td>
<td>PLNPNT(1-3), PLNORM(1-3)</td>
</tr>
<tr>
<td>8,9,10,11</td>
<td>Four extreme points (x, y, z) on the reflector. One point goes on each card (single panel option only)</td>
</tr>
<tr>
<td>12</td>
<td>YCBL, ZCBL, HFMAVL, HMIBL (Blockage of reflector feed)</td>
</tr>
<tr>
<td>12-N</td>
<td>Any data required by FILL ROUTINE</td>
</tr>
<tr>
<td>N+1</td>
<td>NOPT, NLIST(if NOPT specifies that only certain panels are to be printed or plotted, cards containing the list of these panels follow this card)</td>
</tr>
<tr>
<td>N+2</td>
<td>MAJOR, AMAJOR, MINOR, AMINOR(1-3)</td>
</tr>
<tr>
<td>N+3</td>
<td>DONE is typed in the first four columns of the card</td>
</tr>
</tbody>
</table>

These cards are followed by the panel data. The organization of the panel data is as follows:
4.4 Development of a Uniformly Illuminated, Classical Cassegrain Antenna

All parameters needed for this case were computed in Section 4.2. None of the available FILL subroutines was used and the $H$ and $E$ plane patterns (for the feed) were not read in as data in this particular case. The reason for that was to insure uniform illumination over the main reflector. The procedure adopted to achieve this task was as follows:

1. FILL is not called in APERTUR.
2. All lines in APERTUR related to the amplitude and phase of the $E$ field were moved to subroutine CASSA.
3. In subroutine CASSA the following modifications took place:

$$P1 = R \cdot RM \text{ and } P2 = 0.0$$
$$E_{T_i} = \frac{P_1}{R} \quad \text{(i.e., equal to } R\text{)} \text{ and } E_{P_i} = \frac{P_2}{R} = 0.0$$

where $E_{T_i}$ and $E_{P_i}$ are the $\theta$ and $\phi$ electric field components of the incident (on the subreflector) ray, respectively.

From $E_{T_i}$, and applying Snell's law to rays reflected by the two surfaces, $E_r$ and $E_{i2}$ were evaluated, where $E_r$ is the electric field vector along a ray reflected by the subreflector, and $E_{i2}$ is the electric field vector along a ray incident on the main reflector.

It is obvious that in the far field, $E_{i2} = \frac{E_r}{RM}$

Also, $E_r/RM = \frac{E_{T_i}/R}{RM} = \frac{P_1/R}{RM} = \frac{P_1}{R \cdot RM} = \frac{R \cdot RM}{R \cdot RM} = 1.0$

which means that the E field was kept constant at the value of one along every ray. Thus, the constant amplitude requirement for uniform illumination was met.

4. The constant phase requirement was also satisfied by the above arrangement, since the phase was set equal to:

$$\text{PHASE} = \frac{2\pi}{\lambda}(R+RM+D).$$

Notice that $R+RM+D$ is always constant for a focused Cassegrain antenna. (See Appendix A.)

Table 4.2 shows the input file for Case A. The first four cards contain title information which is also reproduced at the printout. Information about the feed coordinate system (FEED, ALPHA, BETA, GAMMA, and XLAM) appear on Card 5.
Cards 6 and 7 contain information about the surface of the main reflector. Card 6 is for SURFC2, AOROR2, BELLP2, CELLP2, DIST2, PSI2 and Card 7 is for POINT, NORM. For this main reflector, SURFC2 = 4 and AOROR2 = 100.0. None of the other parameters is required for this surface, so all are given the value of zero. Cards 8 and 9 contain information for the subreflector surface. Card 8 is for SURFC1, NPNL, AORORF, BELLP, CELLP, DIST, PSI and Card 9 for PLNPNT and PLNORM. For that type of subreflector surface SURFC1 = 6, NPNL = 0.0, AORORF = 30.2976, BELLP = 33.95, CELLP = 33.95, and DIST = 45.500. The rest of the other parameters are given the value zero, since none of them is required for this surface. Cards 10, 11, 12 and 13 contain the four extreme points (x02, Y02, Z02) of the main reflector. Card 14 carries the required blockage information, i.e., YCBL, ZCBL, HFMABL, and HFMIBL. In this case, aperture blockage is not considered and so all the above parameters are set equal to zero. Since the FILL routine is not used in this case and no data for the feed radiation patterns are needed, Card 15 is used to determine the output option code. Here the computer is instructed to print and plot information about the two surfaces, as follows:

\[
\begin{align*}
\text{NOPT(1)} &= 2 \quad \text{(print all results)} \\
\text{NOPT(2)} &= 2 \quad \text{(plot aperture after quantizing)} \\
\text{NOPT(3)} &= 1 \quad \text{(print aperture array onto a disc file at the end of QUANTZ).}
\end{align*}
\]
NLIST is equal to zero since the antenna in question is not divided into panels. Cards 16 and 17 are the radiation pattern requests. One pattern is required in $\phi = 0^\circ$ plane for $\theta$ from $85.0^\circ$ to $95.0^\circ$ by increments of $0.5^\circ$, and another one in the $\theta = 90.0^\circ$ plane for $\phi = -4.0^\circ$ to $4.0^\circ$ by $0.5^\circ$. The next and last card (No. 18) has DONE typed in the first four columns, which signifies the end of the pattern requests and the end of the input file. The result of this check case are shown in Appendix G.

Figure 4.2 shows a comparison of the results obtained by this algorithm with those results reported by Silver for a uniformly illuminated circular aperture [6].
UNIFORMLY ILLUMINATED CLASSICAL CASSEGRAIN ANTENNA (CIRCULAR APERTURE)

E-PLANE

CALCULATED

SILVER'S DATA[6]
<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CASSEGRAIN ANTENNA EXAMPLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>A PARABOLOID-HYPERBOLOID COMBINATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>FEBRUARY 13, 1981, NCSU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PGMR:CHRISTOS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FCLTY:RD-DAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PRT:HILLSBORO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>(A BLANK CARD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-91.005</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>-180.0</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>030.2976</td>
<td>33.95</td>
<td>33.95</td>
<td>45.50</td>
<td>0.0</td>
</tr>
<tr>
<td>9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>10</td>
<td>-65.5997</td>
<td>-117.304</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>-65.5997</td>
<td>117.304</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>-65.5997</td>
<td>0.0</td>
<td>-117.304</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>-65.5997</td>
<td>0.0</td>
<td>117.304</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>221</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>PHI</td>
<td>0.0</td>
<td>THETA</td>
<td>85.0</td>
<td>95.0</td>
<td>0.5</td>
</tr>
<tr>
<td>17</td>
<td>THETA</td>
<td>90.0</td>
<td>PHI</td>
<td>-4.0</td>
<td>4.0</td>
<td>0.5</td>
</tr>
<tr>
<td>18</td>
<td>DONE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.5 Second Test Case

**Dual Offset Reflector Antenna**

Here, the algorithm is tested with calculated data reported by TICRA A/S [8], and C. C. Chen [9]. The reason for choosing an offset case as a second test case is the fact that offset geometry does not have the symmetry of the first test case, which can sometimes mask errors.

---

**Fig. 4.3. Dual offset antenna geometry**
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\epsilon$</td>
<td>2.47</td>
</tr>
<tr>
<td>$F_c$</td>
<td>33.07 in</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.98425 in</td>
</tr>
<tr>
<td>$F_m$</td>
<td>69.685 in</td>
</tr>
<tr>
<td>Offset angle ($\theta^0$)</td>
<td>37.6°</td>
</tr>
<tr>
<td>Aperture diameter ($D_m$)</td>
<td>64.8 $\lambda$</td>
</tr>
<tr>
<td>Tilted angle of feed axis ($\alpha_1$)</td>
<td>16.4°</td>
</tr>
<tr>
<td>-11 db taper was used.</td>
<td></td>
</tr>
</tbody>
</table>
Using the relationships between the hyperboloid and paraboloid from Appendix B, and using the given data in Table 4.3, one can estimate AORORE, BELLP, CELLP and DIST. Furthermore, in this case, ALPHA = 0.0, BETA = 0.0 and GAMMA = -163.6, since the axis of the feed makes an angle (α₁) of 14.6° with the x axis of the reference system, as shown in Figure 4.3. Feed (1), Feed (2), and Feed (3), as well as the four extreme points of the main reflector are easily calculated. The input file is shown in Table 4.4. In this case, the input file is arranged in the same way as before up to the fourteenth card. Cards 15 to 52 contain information about the feed radiation pattern. Card 53 contains NOPT, NLIST, and Cards 54 and 55 are used for the pattern requests. Finally, DONE is typed on Card 56. The secondary radiation pattern is shown in Figure 4.4, and compared with data obtained from the other two algorithms.
### TABLE 4.4

**CASE B INPUT FILE**

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OFFSET CASSEGRAIN ANTENNA EXAMPLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>A PARABOLOID - HYPERBOLOID COMBINATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>FEBRUARY 19, 1981 NCSU PGMR-CHRISTOS FCLTY:RD-DAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>TICRA AP/S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-31.72544</td>
<td>0.0</td>
<td>9.337276</td>
<td>0.0</td>
<td>0.0</td>
<td>-163.6</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>69.685</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>6.694507</td>
<td>15.119643</td>
<td>15.119643</td>
<td>16.535433</td>
<td>0.0</td>
</tr>
<tr>
<td>9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>10</td>
<td>-57.18974</td>
<td>31.88699</td>
<td>49.66035</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>-57.18974</td>
<td>31.88699</td>
<td>49.66035</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>-45.82776</td>
<td>0.0</td>
<td>81.54734</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>-68.55171</td>
<td>0.0</td>
<td>17.77336</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1.000000</td>
<td>.99053</td>
<td>.96266</td>
<td>.91793</td>
<td>.85878</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>.78830</td>
<td>.70997</td>
<td>.62737</td>
<td>.54392</td>
<td>.46269</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>.38617</td>
<td>.31623</td>
<td>.25407</td>
<td>.20029</td>
<td>.15491</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>.11756</td>
<td>.08755</td>
<td>.06394</td>
<td>.04563</td>
<td>.03223</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>32.000000</td>
<td>.00000</td>
<td>.00000</td>
<td>.00000</td>
<td>.00000</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>.00000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>1.0000</td>
<td>.99053</td>
<td>.96266</td>
<td>.91793</td>
<td>.85878</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>.78830</td>
<td>.70997</td>
<td>.62737</td>
<td>.54392</td>
<td>.46269</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>.38617</td>
<td>.31623</td>
<td>.25407</td>
<td>.20029</td>
<td>.15491</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>.11756</td>
<td>.08755</td>
<td>.06394</td>
<td>.04563</td>
<td>.03223</td>
<td></td>
</tr>
</tbody>
</table>
Table 4.4 (continued)

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>38-51</td>
<td>0.00000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>52</td>
<td>0.00000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>53</td>
<td>221</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>54</td>
<td>PHI</td>
<td>0.0</td>
<td>THETA</td>
<td>87.0</td>
<td>93.0</td>
</tr>
<tr>
<td>55</td>
<td>THETA</td>
<td>90.0</td>
<td>PHI</td>
<td>-3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>56</td>
<td>DONE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 4.4. Offset Cassegrain E-plane pattern
5. A SINGLE REFLECTOR ANTENNA EXAMPLE
(A SEGMENTED SPHERICAL REFLECTOR)

5.1 Description of the Problem

A single reflector composed of 54 panels was constructed and tested by NASA at the Langley Research Center. Its measured radiation patterns were compared twice: First, with calculated results obtained by using the old version [5]; and second, with calculated results obtained via the modified version incorporated in the new algorithm. A complete description of the antenna and its parameters is provided by Botula in [5]. Here, the input file and the results only are given.

5.2 Results and Comments

Figures 5.1 and 5.2 depict the projections on all panels on the aperture plane. The result obtained by the old version is shown in Figure 5.1, whereas the result from the revised algorithm is shown in Figure 5.2.

Figures 5.3-5.6, inclusively, show the secondary radiation pattern for both versions. The reason for this discrepancy in the above results lies in the amount of overlapping between the projected panels on the aperture plane. The more the overlapping, the less accurate results are obtained compared to measured data.

The reason for this overlapping is due to the fact that the rays reflected by the perimeter points of each panel tend to diverge on their way to the aperture plane. To reduce their divergence, the aperture plane is brought closer to
each panel so that the rays travel over shorter distances before they strike the aperture plane. Once this occurs, the projected panel is then phase referenced to the general aperture plane.

This procedure, which is summarized in Figure 3.2, yields less overlapping and better results than the old version.

5.3 Input File

<table>
<thead>
<tr>
<th>TABLE 5.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT FILE FOR A SINGLE REFLECTOR ANTENNA</td>
</tr>
</tbody>
</table>

1 Faceted Spherical Reflector Test Case (LSST)
2 Surface composed of 54 panels, three perimeter points per panel,
3 no blockage, Feed phase center 0.5 lambda inside horn aperture, E-plane only
4 (Blank Card)
5 9.441 0.00 8.026 0.0 0.0 -40.0 0.3335
6 3 5424.0 0.0 0.0 0.0
7 0.0 0.0 0.0 0.0 0.0 0.0 0.0
8 -19.6617 0.0 13.7628
9 -20.7015 5.0252 11.0542
10 -22.2826 5.0581 7.4916
11 -23.8206 0.0 2.9285
12 0.0 0.0 0.0 0.0
13-50 Illumination data for FILL routine
51 101 3
Table 5.1 (continued)

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>52</td>
<td>1</td>
<td>15</td>
<td>51</td>
</tr>
<tr>
<td>53</td>
<td>THETA</td>
<td>91.0</td>
<td>PHI</td>
</tr>
<tr>
<td>54</td>
<td>PHI</td>
<td>0.0</td>
<td>THETA</td>
</tr>
<tr>
<td>55</td>
<td>DONE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>3</td>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>57</td>
<td>X1</td>
<td>Y1</td>
<td>Z1</td>
</tr>
<tr>
<td>58</td>
<td>X2</td>
<td>Y2</td>
<td>Z2</td>
</tr>
<tr>
<td>59</td>
<td>X3</td>
<td>Y3</td>
<td>Z3</td>
</tr>
<tr>
<td>60</td>
<td>3</td>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>61</td>
<td>X1</td>
<td>Y1</td>
<td>Z1</td>
</tr>
<tr>
<td>62</td>
<td>X2</td>
<td>Y2</td>
<td>Z2</td>
</tr>
<tr>
<td>63</td>
<td>X3</td>
<td>Y3</td>
<td>Z3</td>
</tr>
</tbody>
</table>

64-273 This process is repeated for all 54 panels.
MAP OF PANEL PROJECTIONS

Fig. 5.1. Old algorithm
Fig. 5.2. New algorithm
Fig. 5.3. Sphere E-plane pattern (old algorithm)
Fig. 5.4. New algorithm
Fig. 5.5. Sphere H-plane (old algorithm)
Fig. 5.6. New algorithm
6. CONCLUSIONS

An algorithm capable of computing radiation patterns of single reflector antennas has been modified and extended to analyze dual reflector antennas. A new technique for determining the aperture plane for multipanel single reflector antennas has been incorporated into the new program. The location of any aperture plane and the normals on each plane panel are computed automatically. Furthermore, equations for hyperbolic surfaces have been added.

The capability of expressing any non-analytic surface numerically will render the present algorithm very versatile. This fact will make the analysis of dual reflector antennas with shaped surfaces possible.

Presently, the algorithm requires that the feed center coincide with the real focus of the hyperboloid for a Cassegrain antenna, but modifications could be inserted to deal with any off-focus applications.

The results for the dual reflector antennas obtained by this algorithm show good agreement with those obtained by other algorithms. It is believed that a direct comparison with measured patterns will give a better estimate of the accuracy of the present algorithm.
7. LIST OF REFERENCES


8. APPENDICES
8.1. APPENDIX A

CASSEGRAIN ANTENNA GEOMETRY

Fig. 8.1. Geometry of classical Cassegrain antenna

The classical Cassegrain geometry shown above employs a parabolic contour for the main reflector and a hyperbolic contour for the subreflector. One of the foci of the hyperboloid is the real focal point of the system and is located at the origin of the feed coordinate system; the other is a virtual focal point which is located at the focus of the paraboloid. As a result, all parts of a wave emanating from the real focal point and then reflected from both reflector
surfaces, travel equal distances to a plane in front of the antenna.

Four fixed parameters are adequate to completely describe a Cassegrain system, two for each reflector. In Figure 8.1, seven parameters are shown. If four are known, the other three can be derived from the mathematical relationships between the two reflector surfaces. For the main reflector,

\[
\tan \frac{1}{2} \theta_2 = \frac{1}{4} \frac{D_m}{F_m}, \text{ and}
\]

for the subreflector:

\[
\frac{1}{\tan \theta_1} + \frac{1}{\tan \theta_2} = \frac{2 F_c}{D_s}, \text{ and}
\]

\[
1 - \frac{\sin^2(\theta_2 - \theta_1)}{\sin^2(\theta_2 + \theta_1)} = 2 \frac{f_1}{f_2}
\]

where: \( F_c \) - distance between two foci,

\( f_1, f_2 \) = focal lengths of hyperboloid,

\( D_m \) = diameter of main reflector,

\( D_s \) = diameter of subreflector,

\( F_m \) = focal length of paraboloid

\( \theta_2 \) = one-half of the angle subtended by the main reflector

\( \theta_1 \) = one-half of the angle subtended by the subreflector.

For example, if \( D_m, F_m, F_c \) and \( \theta_1 \) are determined by considerations of antenna performance and space limitations, then \( \theta_2, D_s, \) and \( f_2 \) can be derived.
Note $\theta$, which determines the beamwidth required of the feed radiation pattern, may be determined independently of the ratio $F_m/D_m$ which specified the shape of the main reflector.

The surface of the main reflector is given by:

$$y^2 + z^2 = 4F_m(F_m + x),$$

and the surface of the subreflector is expressed as:

$$\left(\frac{x + \text{DIST}}{a}\right)^2 - \frac{y^2}{b^2} - \frac{z^2}{c^2} = 1$$

where $\text{DIST} = \frac{F_c}{2} = a + \left| -x_0 \right|$ (See Figure A.2) is the distance used to translate the origin of the hyperbola coordinate system so that it coincides with the origin of the referenced system.

**Fig. 8.2.** Subreflector coordinate system

- $a =$ half the transverse axis (along $x$-axis)
- $b =$ semi-axis along the $y$ direction in the ellipse lying in the $yz$ plane.
- $c =$ semi-axis along the $z$ direction in the ellipse lying in the $yz$ plane.
If $\varepsilon$ (eccentricity) of the hyperboloid is known, the following equations can be used:

$$
\varepsilon = \frac{\sinh^{2}(\theta_2+\theta_1)}{\sinh^{2}(\theta_2-\theta_1)}
$$

$$
a = \frac{F_c}{2\varepsilon}, \quad b = a \sqrt{\varepsilon - 1}, \quad \text{and} \quad \frac{f_2}{f_1} = \frac{\varepsilon+1}{\varepsilon-1} = M
$$

where $M$ is the magnification factor of the hyperboloid.
8.2. APPENDIX B

ADDITION OF HYPERBOLOID

The equation of the hyperboloid, depicted in Figure 8.3, in the cartesian system is given as:

\[
\frac{x^2}{a^2} - \frac{y^2}{b^2} - \frac{z^2}{c^2} = 1, \quad \text{where } a = \text{half the transverse axis along } x
\]

\[b = \text{semi-axis of the ellipse in the } yz \text{ plane}\]

\[c = \text{semi-axis of the ellipse in the } yz \text{ plane}\]

In this equation, the hyperboloid is expressed in the \(x_s', y_s, z_s\) coordinate system. To express the same surface in the \(x, y, z\) system, a translation has to take place along the \(x\) axis, so that the origins of the two systems \(O_s\) and \(O\) coincide. It is clear that \(y_s = y\) and \(z_s = z\), and hence no
charge is needed to be made in the y and z directions.

If DIST is the distance between $O_s$ and $O$, then $x$ can be expressed as $x = x_s - \text{DIST}$, or $x_s = x + \text{DIST}$, and hence the hyperboloid equation in the $x, y, z$ system becomes:

$$\frac{(x + \text{DIST})^2}{a^2} - \frac{y^2}{b^2} - \frac{z^2}{c^2} = 1,$$

where DIST = $\frac{F_c}{2}$ \hspace{1cm} (8.1)

and $F_c$ = distance between the two foci of the hyperboloid.

The parametric equations for a ray are:

$$x = RB_{11} - B_{12}$$
$$y = RB_{21} - B_{22}$$
$$z = RB_{31} - B_{32}$$ \hspace{1cm} (8.2)

Substitute Equation (8.1) back into the equation of the hyperboloid to obtain:

$$\frac{(RB_{11} - B_{12} + \text{DIST})^2}{a^2} - \frac{(RB_{21} - B_{22})^2}{b^2} - \frac{(RB_{31} - B_{32})^2}{c^2} - 1 = 0$$

or

$$\frac{R^2 B_{11}^2}{a^2} + \frac{B_{12}^2}{a^2} + \frac{\text{DIST}^2}{a^2} - \frac{2R B_{11} B_{12}}{a^2} - \frac{2R B_{11} \text{DIST}}{a^2} - \frac{2B_{12} \text{DIST}}{a^2}$$
$$- \frac{R^2 B_{21}^2}{b^2} - \frac{B_{22}^2}{b^2} + \frac{2R B_{21} B_{22}}{b^2} - \frac{R^2 B_{31}^2}{c^2} - \frac{B_{32}^2}{c^2} + \frac{2B_{31} B_{32}}{c^2} - 1 = 0$$

Equation (8.3) is of the form...
\[ AR^2 + BR + C = 0 \]  \hspace{1cm} (8.4)

where

\[ A = \frac{B_{11}^2}{a^2} - \frac{B_{21}^2}{b^2} - \frac{B_{31}^2}{c^2} \]  \hspace{1cm} (8.5)

\[ B = -2 \left( \frac{B_{11}B_{12}}{a^2} - \frac{B_{11}\text{DIST}}{a^2} - \frac{B_{21}B_{22}}{b^2} - \frac{B_{31}B_{32}}{c^2} \right) \]  \hspace{1cm} (8.6)

\[ C = \frac{B_{12}^2}{a^2} + (\text{DIST})^2 \frac{B_{12}^2}{a^2} - \frac{B_{22}^2}{b^2} - \frac{B_{32}^2}{c^2} - 1 \]  \hspace{1cm} (8.7)

Equations (8.5), (8.6), and (8.7) are evaluated by the program and (8.4) is solved to find the intersection point of the ray with the surface.

Now, to find the inside normal of the surface, the gradient of Equation (8.1) is taken as:

\[ \nabla g(x, y, z) = \mathbf{n}(x, y, z) \]  \hspace{1cm} (8.8)

where

\[ g(x, y, z) = \left( \frac{x + \text{DIST}}{a} \right)^2 - y^2 - \frac{z^2}{c} - 1 \]  \hspace{1cm} (8.9)

it follows that:

\[ \nabla g = \hat{x} \frac{\partial g}{\partial x} + \hat{y} \frac{\partial g}{\partial y} + \hat{z} \frac{\partial g}{\partial z} = \hat{x} \frac{2(x + \text{DIST})}{a^2} - \hat{y} \frac{2y}{b^2} - \hat{z} \frac{2z}{c^2} \]  \hspace{1cm} (8.10)

or

\[ \frac{\partial g}{\partial x} = \frac{2(x + \text{DIST})}{a^2} \]

\[ \frac{\partial g}{\partial y} = -\frac{2y}{b^2} \]

\[ \frac{\partial g}{\partial z} = -\frac{2z}{c^2} \]  \hspace{1cm} (8.11)
Normalization results in obtaining the unit vector \( \hat{n} \) as:

\[
\hat{n} = \frac{\nabla g(x,y,z)}{\|\nabla g\|} = \frac{x}{a^2} \frac{2(x + \text{DIST})}{a^2} - \frac{y}{b^2} \frac{2y}{b^2} - \frac{z}{c^2} \frac{2z}{a^2} \frac{1}{\left( \frac{4(x + \text{DIST})^2}{a^4} + \frac{4y^2}{b^4} + \frac{4z^2}{c^4} \right)^{1/2}} \tag{8.12}
\]

The factor 2 cancels out from both numerator and denominator.

Let the denominator be expressed as:

\[
\text{DEN} = \left( \frac{x + \text{DIST}}{a} \right)^2 + \frac{y^2}{b^4} + \frac{z^2}{c^4} \tag{8.13}
\]

then

\[
n_x = \frac{(x + \text{DIST})/a^2}{\text{DEN}}
\]

\[
n_y = \frac{-y/b^2}{\text{DEN}}
\]

\[
n_z = \frac{-z/c^2}{\text{DEN}}
\]
In this subroutine, the four extreme points of the main reflector are used to find the four extreme points on the subreflector. This task is accomplished as follows:

Take a given extreme point on the main reflector and write the parametric equations of the line (RR) connecting that point to the origin of the reference system (0).

Express the direction cosines as:

\[ \text{DIR1} = \cos A = \frac{PM(1,K)}{RR} \quad (8.14) \]
\[ \text{DIR2} = \cos B = \frac{PM(2,K)}{RR} \quad (8.15) \]
\[ \text{DIR3} = \cos C = \frac{PM(3,K)}{RR} \quad (8.16) \]
Hence, the parametric equation of that line is given by:

\[
\begin{align*}
    x_0 &= P(1,K) = PM(1,K) - RR \cdot DIR_1 \\
    y_0 &= P(2,K) = PM(2,K) - RR \cdot DIR_2 \\
    z_0 &= P(3,K) = PM(3,K) - RR \cdot DIR_3
\end{align*}
\]  

(8.17)  

(8.18)  

(8.19)

where \((P(1,K), (P(2,K) and P(3,K))\) is a point on the sub-reflector which is to be found.

Now, substitute Equations (8.17), (8.18), and (8.19) in the equation for the surface of the hyperboloid, that is in

\[
\frac{(x + DIST)^2}{a^2} - \frac{y^2}{b^2} - \frac{z^2}{c^2} = 1
\]

(8.20)

to obtain:

\[
\left[ \frac{PM(1,K) - RR \cdot DIR_1 + DIST}{a^2} \right]^2 - \left[ \frac{PM(2,K) - RR \cdot DIR_2}{b^2} \right]^2 - \left[ \frac{PM(3,K) - RR \cdot DIR_3}{c^2} \right]^2 = 1
\]

(8.21)

or

\[
\frac{(PM(1,K))^2}{a^2} + \frac{(DIST)^2}{a^2} + \frac{(RR)^2(DIR_1)^2}{a^2} - 2RR \cdot DIR_1 \cdot PM(1,K) \\
- 2RR \cdot DIR_1 \cdot DIST + \frac{2PM(1,K) \cdot DIST}{a^2} - \frac{(PM(2,K))^2}{b^2} - \frac{(RR)^2(DIR_2)^2}{b^2} \\
+ \frac{2PM(2,K) \cdot RR \cdot DIR_2}{b^2} - \frac{(PM(3,K))^2}{c^2} - \frac{(RR)^2(DIR_3)^2}{c^2} \\
+ \frac{2 \cdot RR \cdot PM(3,K) \cdot DIR_3}{c^2} = 0
\]

(8.22)
This equation is of the form \( (ARR) \ (RR)^2 + BRR \cdot RR + CRR = 0 \) \( (8.23) \)

where \( ARR = \frac{(DIR1)^2}{a^2} - \frac{(DIR2)^2}{b^2} - \frac{(DIR3)^3}{c^2} \) \( (8.24) \)

\[
BRR = 2 \left[ (-PM(1,K) - DIST) \cdot DIR1/a^2 + PM(3,K) \cdot DIR2/b^2 + PM(3,K) \cdot DIR3/c^2 \right] \]

\[
CRR = \left[ \frac{(PM(1,K))^2 + (DIST)^2 + 2.0 \cdot PM(1,K) \cdot DIST}{a^2} - \frac{(PM(2,K))^2/b^2 - (PM(3,K))^2/c^2}{-1} \right] \]

Equations (8.24), (8.25), and (8.26) are evaluated by the program and (8.23) is solved to find RR. Substituting for the value of RR in Equations (8.14), (8.15), and (8.16), a point on the subreflector is obtained.
8.4. APPENDIX D

DEVELOPMENT OF NORMALS ON A PLANE PANEL

In the APRIN routine a certain number of perimeter points for each panel are read in. To determine a unit normal on each panel, the following procedure is applied:

1) Any three perimeter points are used to form two vectors, as shown in Figure 8.2.

\[ \vec{A} = (x_1-x_2)i + (y_1-y_2)j + (z_1-z_2)k, \]
\[ \vec{B} = (x_1-x_3)i + (y_1-y_3)j + (z_1-z_3)k. \]

2) The cross product operation is used to find a vector normal \( \hat{N} \) to the plane defined by the vectors \( \vec{A} \) and \( \vec{B} \):

\[ \hat{N} = \begin{vmatrix} i & j & k \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix} = \begin{vmatrix} i & j & k \\ x_1-x_2 & y_1-y_2 & z_1-z_2 \\ x_1-x_3 & y_1-y_3 & z_1-z_3 \end{vmatrix} = \]
\[ \hat{N} = (y_1-y_2)(z_1-z_3)-(y_1-y_3)(z_1-z_2)i \]
\[ + (x_1-x_3)(z_1-z_2)-(x_1-x_2)(z_1-z_3)j \]
\[ + (x_1-x_2)(y_1-y_3)-(x_1-x_3)(y_1-y_2)k \]
3) The unit normal \( \hat{N} \) is computed by: \( \hat{N} = \frac{\mathbf{N}}{|\mathbf{N}|} \)

4) If this normal on the surface of the panel has a negative x component, then the vector is inverted to yield a positive x component, since any normal vector on the surface of the reflector should be directed toward the origin of the reference system, i.e., along the positive x axis. (See Figure 2.5).
8.5. APPENDIX E

FILL ROUTINE FOR A VERTICALLY POLARIZED FEED

The basis of this subroutine can be found in (5). To use it, the E- and H-plane patterns of the feed must be provided by the programmer in increments of 1°.

Fig. 8.6. Definition of angles δ and ε

Fig. 8.7. Ellipse used for interpolation
In Figure C.3, the angles used in FILL are shown.

(From (5).)

\[ \delta = \cos^{-1} (\sin \theta' \cos \phi') \quad (8.27) \]

where \( \theta' \) and \( \phi' \) are angles in the feed system.

and \( \epsilon = \tan^{-1} \frac{\cos \phi'}{\sin \theta' \sin \phi'} \quad (8.28) \)

Figure 8.4 depicts the interpolation ellipse which is given by:

\[ \frac{u^2}{E^2} + \frac{v^2}{H^2} = 1 \quad (8.29) \]

where

\[ u = r \cos \epsilon, \quad v = r \sin \epsilon, \quad (8.30) \]

\[ E = E_{\phi'} = 90^\circ, \quad \text{and} \quad H = E_{\phi'} = 180^\circ \quad (8.31) \]

Hence:

\[ r = \frac{E_{\phi'} = 90 \cdot E_{\phi'} = 180}{(E_{\phi'} = 90 \sin^2 \epsilon + E_{\phi'} = 180 \cos^2 \epsilon)^{\frac{1}{2}}} \quad (8.32) \]

The code of this subroutine is shown in Appendix F. In that code, PROJX = \( \cos \delta \) and PROJEX = \( \sin \epsilon \). To insure vertical (i.e., \( \theta' \)) polarization, PROJEX is set equal to zero. That means \( u = r \cos \epsilon \) and \( v = 0 \). Substitution for \( u \) and \( v \) is Equation (8.32).

\[ \text{Etot} = \frac{\frac{E_{\theta'} = 90 \cdot E_{\phi'} = 180}{E_{\phi'} = 180 \cdot \cos^2 \epsilon^2} = \frac{E_{\phi'} = 90}{\cos^2 \epsilon}} \]

where \( \cos^2 \epsilon = 1 - \sin^2 \epsilon \). Since a \( \theta' \) polarized feed is associated with the \( z \) component of a cartesian system \( P(3, I) \), and \( P(4, I) \) are given as:

\[ P(3, I) = \text{Etot (along z)} \]
\[ P(4, I) = 0.0 \text{ (along y)} \]
8.6. APPENDIX F

LISTING OF THE CODE FOR REFLECTR
```fortran
IMPLICIT REAL*8 (A-H,O-Z)
REAL*8 MAJOR(8),MINOR(8),NORM
COMPLEX*16 ETOT(400),FIELDO(400),FIELDZ(400)
INTEGER SURFC1,SURFC2
COMMON/NAMSMA/NAMMA,BELLP,CELLP,DIST,PS1,PLNPHI(3),PLNPHI(3),
     FEED(3),ALPHA,BETA,GAMMA,XLAM,XX,AUROR,BELLP,CELLP2,
     PS12,STZ,POINT(3),NORM(3),SURFC1,NPHL,NPOINT,SURFC2
COMMON/APPRPH/MPTPPLE,NPERIN
COMMON/COLOS/DEL,T,XC,ANGINC,PM(3),R8,XMA,XH,XMAX,YMAX
COMMON/CNTL/NOPT(3),MLIST,IOPT,ICASE,ELIST(100)
COMMON/DIMNS/YDIST,YDIST,YCT,YCT
COMMON/EXTENT/YMIN,YMAX,ZMIN,ZMAX
COMMON/HATH/PI,P12,P120,TOR,RTOR
COMMON/PATRN/ETOT,MINOR(3),MAJOR(8),MINOR,MAJOR,NANGLE(9)
DIMENSION PS1(2750),FILDL(75),FIELZ(75),P(2,100)
DATA DONE/SMOONE fMLVL,NPART W Go 7.0
    DATA VLO,YMI,ZLO,ZMI/1.0*10.0,N0,1.0*10.0*10/20.0*LOG10(X)
P064X1=10.0*LOG10(X)
MAXPTS=2750
CALL NPUT(P,NPAT)
DO 400 I=1,NPAT
CALL APPLRT(P)
PRINT 777
CALL QUANTZ(P,NPERIN)
PRINT 778
IF(IOPT(1).EQ.0) GO TO 80
ISW=1
IF(IOPT.EQ.1) ISW=-1
CALL APPLRT(P,NPOINT,ISW)
PRINT 780
CONTINUE
DO 401 (IY,IY)=YMIN,YMAX
IF (YMAX.GT.YH) YH=YMAX
IF (YMIN.LT.ZLO) ZLO=YMIN
IF (YMAX.GT.ZHI) ZHI=YMAX
IF (ICAS=EQ.0) NPERIM=4
DO 55 L=1,NPERIM
PR(L,MLVL)=P(L,NPOINT)
55 PR(2,MLVL)=P(2,NPOINT)
MLVL=KLVL+NPERIM+1
PR(1,MLVL)=1.0*40
1 JUNK=0
DO 200 K=1,NPAT
CALL INTERP(MAJOR(K)*MAJOR(K)*MINOR(1)*K,FIELD,L,FIELDZ)
PRINT 779
NANG=NANGLE(K)
DO 150 L=1,NANG
ETOT(I+ISUM)=ETOT(I+ISUM)+FIELDL(L)
150 ETOT(2+ISUM)=ETOT(2+ISUM)+FIELDZ(L)
200 ISUM=ISUM+NANG
CONTINUE
PRINT 701
IF(IOPT.EQ.1) GO TO 420
IF(IOPT(2).EQ.0) GO TO 420
YHIM=YHI-YLO
```
ZD1M=ZHI-ZLD
YCT=(YTH+YLD)/2.0
ZCT=(ZHI+ZLD)/2.0
CALL APMAP(CR,NPNL,-1)
PRINT 762

420 ISUM=0
DO 770 I=1,NPAT
NANG=NANGLE(I)
FMAXX=-1.00+40
FMAXZ=-1.00+40
DO 450 J=1,NANG
YFLD(J)=CDABS(ETOT(1,J)+ISUM))
ZFLD(J)=CDABS(ETOT(2,J)+ISUM))
FMAXX=DMAX(FMAXX,YFLD(J))
FMAXZ=DMAX(FMAXZ,ZFLD(J))
ISUM=ISUM+NANG
D=AMINDR(I,1)
FMYDB=-60.000
FMZDB=-60.000
PWRDB=-60.000
PWR=MAX(FMAXZ*FMAXX*FMAXY*FMAXY
IF (FMAXX.GT.1.00-10) FMYDB=PDB(FMAXX)
IF (FMAXX.GT.1.00-10) FMZDB=PDB(FMAXX)
IF (PWR.GT.1.00-10) PWRDB=PDB(PWR)
PRINT 600,MOR(I),MOR(I),MINOR(I),(AMINOR(J,1),J=1,3)

600 FORMAT(I13,4X,4X,4X,4X,4X,4X,4X,4X,4X,4X,4X)
DO 700 K=1,NANG
PWR(K)=PWRDB-100.000
DBY =FMYDB -100.000
DBZ =FMZDB -100.000
PWR=ZFLD(K)*ZFLD(K)+YFLD(K)+YFLD(K)
IF (YFLD(K).GT.1.00-15) DBY=FDB(YFLD(K))
IF (ZFLD(K).GT.1.00-15) DBZ=FDB(ZFLD(K))
IF (PWR.GT.1.00-20) PWR(K)=PDB(PWR)
IF (FMYDB.EQ.-60.000) DBY=-60.000
IF (FMZDB.EQ.-60.000) DBZ=-60.000
DBZ=DBZ-FMZDB
DBZ=DBZ-FMYDB
DBZ=DBZ-FMYDB
DBZ=DBZ-FMYDB

PRINT 690, D,DBYZ, DBZY, DBY, PWRDB

690 FORMAT(10X,F9.3,5F11.5)
D=D+AMINDR(I,1)
YFLD(K)=D0Y
ZFLD(K)=DBZ

700 CONTINUE

PRINT 750, FMAXZ,FMZDB,FMAXY,FMYDB

750 FORMAT(/I3X,'MAXIMUM FIELD VALUES=')/15X.
20LOG(MAX(FIELD-Z))=20LOG(*1PE15.7,*)=*0PF12.7//ISX,
20LOG(MAX(FIELD-Y))=20LOG(*1PE15.7,*)=*0PF12.7
PRINT 755, NPARTS

FORMAT(//14X,
INTERPOLATION NUMBER USED FOR INTEGRATION IS............(15)
PRINT 765,MAJOR(I),AMIOR(I)
FORMAT(1H1,1//20X,1PRINCIPAL PLANE = 4.55+F7.3* DEGREES*)
CALL PLOT4(64H NORMALIZED Z-COMPONENT OF SECONDARY PATTERN (DB)
.*FMYDB,ZFLD,NANG,MINOR(I),AMINOR(I,1.1))
PRINT 765,MAJOR(I),AMIOR(I)
CALL PLOT4(64H NORMALIZED Y-COMPONENT OF SECONDARY PATTERN (DB)
.*FMYDB,YFLD,NANG,MINOR(I),AMINOR(I,1.1))
PRINT 765,MAJOR(I),AMIOR(I)
CALL PLOT4(64H NORMALIZED POWER PATTERN (DB)
.*PERMDP,PER,NANG,MINOR(I),AMINOR(I,1.1))

CONTINUE
IF (101(1.1).EQ.1) WRITE(7,775)
IF (101(5.1).EQ.0) STOP
REWIND 7
CALL PLOT

775 FORMAT(1 ---- FINISHED INPUT ----)
776 FORMAT(1 ---- FINISHED APERTUR ----)
778 FORMAT(1 ---- FINISHED QUANTZ ----)
780 FORMAT(1 ---- FINISHED INTGR ----)
781 FORMAT(1 ---- PATTERN COMPUTATIONS COMPLETE ----)
782 FORMAT(1 ---- EXECUTED APPLT ----)
783 FORMAT(1 ---- EXECUTED APMAP ----)
STOP
END
SUBROUTINE NPUT(P,NPAT)

IMPLICIT REAL*8(A-H,O-Z)
REAL*8 MAJUR(5), MINOR(5), NORM
COMPLEX*16 ETOT(2,400)
INTEGER SURFC1,SURFC2
COMMON/ BLOCKG/ZCOL.ECOL, HFMABL, HFMIBL
COMMON/ FEED/EP(41), ET(91), NP, NT, XS, YS, ZS
COMMON/ COLUS/DELT, XC, ANINC,PNIJ,4), RS, XM, ZM, ZN, YM
COMMON/ CONTRL/NOPT(1), NLIST, IOPT, ICASS, ILIST(100)
COMMON/ MARS/AORDR, BELLP, CELLP2, DIST, PSI, PLNPNT(3), PLNORM(3),
FEED(J), ALPHA, BETA, GAMMA, XAM, XX, AORDR2, BELLP2, CELLP2,
PSI2, DIST2, POINT(J), NORM(J), SURFC1, NP, NPNT, SURFC2
COMMON/ PATTEN/ETOT, ANINC(3,5), ANMAJOR(5), MINOR, MAJOR, NANGLE(5)
COMMON/ MATH/P1, P2, P3, D1, D2, DTU, RTCD
DIMENSION P(5,2750), TITLE(40)
DATA DONE, SHOWN, ICASS = 0

IOPT = 0
READ 5, TITLE
FORMAT (10A8)
READ(11,10) FEED, ALPHA, BETA, GAMMA, XAM
10 FORMAT (IF10.4)
IF (ICASS .NE. 1) GO TO 39
READ(11,20) SURFC2, AORDR2, BELLP2, CELLP2, DIST2, PSI2, POINT, NORM
20 FORMAT (11,9X,5F10.4/6F10.4)
35 READ(1,37) SURFC1, NP, AORDR, BELLP, CELLP, DIST, PSI, PLNPNT, PLNORM
37 FORMAT (11,7X,12,5F10.4/6F10.4)
IF (ICASS .NE. 1) GO TO 40
READ (1,39) (PM(J,J), J=1,3, J=1,4)
39 FORMAT (3F10.4)
C END OF MAIN REFLECTOR INPUT DATA
CALL SUBPNT(P)
GO TO 43
40 READ (1,41) ((PI(I,J), I=1,3, J=1,4)
41 FORMAT (3F10.4)
C END OF SUB REFLECTOR INPUT DATA
43 READ(1,50) XX, YCBLB, ZCLB, HFMABL, HFMIBL
50 FORMAT (5F10.4)
C FEED RADIATION PATTERN
READ(1,55) EP
READ(1,55) ET
55 FORMAT (5F15.5)
READ(1,60) NOPT, NLIST
60 FORMAT (3J1,2X,15)
IF (NOPT(J), I=1,10) GO TO 70
READ(1,70) I, LIST(J), I=1, NLIST
70 FORMAT (16I5)
SUMP=0
NPAT=1
77 READ(1,80) MAJOR(NPAT), ANMAJOR(NPAT), MINOR(NPAT), ANMINOR(1,NPAT),
I=1,3
80 FORMAT (A5,A5,F10.4,A5,X,3F10.4)
IF (MAJOR(NPAT), I=1,10) GO TO 88
NANGLE(NPAT) = (ANMINOR (2, NPAT) - ANMINOR(1, NPAT)) / ANMINOR(3, NPAT) + 1.5
T=NANGLE(NPAT) * GT75
GOTO 85
IF (NPAT.LT.6) GO TO 77
PRINT 330
STOP
85 PRINT 335
STOP
88 IF (ISUM.LE.400) GO TO 95
PRINT 340,ISUM
STOP
95 NPAT=NPAT-1
DO 98 L=1,ISUM
   ETOT(1,L)=(0.0000,0.0000)
98 ETOT(2,L)=(0.0000,0.0000)
PRINT 570,TITLE,XLAN,FEED,ALPHA,BETA,GAMMA
PRINT 577,XC,YCBL,ZCBL,HFMBL,HFMUBL,NPL
IF (ICASS.NE.1) GO TO 180
PRINT 578
GO TO (120,130,140,150,160,161),SURFC2
120 PRINT 579,POINT,NORM
GO TO 179
130 PRINT 580,AUROR2,BELLP2
GO TO 179
140 PRINT 581,AUROR2
GO TO 179
150 PRINT 582,AUROR2
GO TO 179
160 PRINT 583,AUROR2,PS12
GO TO 179
161 PRINT 584,AUROR2,BELLP2,CELLP2,DIST2
170 PRINT 585,(PM(I,J),I=1,3),J=1,4
PRINT 586
180 GO TO (220,230,240,250,260,270),SURFC1
220 PRINT 579,PLNPNMT,PLNORT
GO TO 300
230 PRINT 580,AURORF,BELLP
GO TO 300
240 PRINT 581,AURORF
GO TO 300
250 PRINT 582,AURORF
GO TO 300
260 PRINT 583,AURORF,PS1
GO TO 300
270 PRINT 584,AURORF,BELLP,CELLP,DIST
300 IF (NPLT.GE.1) GO TO 310
OPT=1
310 PRINT 585,(PM(I,J),I=1,3),J=1,4)
PRINT 587
PRINT 588
PRINT 589
PRINT 600,LP
PRINT 587
PRINT 588
PRINT 600,ET
PRINT 400,NPAT
GO 320 M=1,NPAT
320 PRINT 500,MAJUN(M),MAJUN(M),MIND(M),MIND(M),MIND(M),MIND(M)
330 FORMAT(**********ERROR-MORE THAN 5 PATTERN*)
*CALCULATIONS REQUESTED
MORE THAN 75 ANGLES IN*.
*ONE PATTERN REQUESTED*.
*ERROR - REQUESTED*.
*ANGLES TO BE*.
*CALCULATED EXCEEDS AVAILABLE STORAGE*.

*NUMBER OF PATTERN GROUPS REQUESTED*.
*ERROR - REQUESTED*.

*NUMBER OF ANGLES TO BE CALCULATED EXCEEDS AVAILABLE STORAGE*.

*INPUT PARAMETERS -
*WAVELENGTH OF ELECTRIC FIELD*.
*LOCATION OF COORDINATE ORIGIN
*WRT FEED (X,Y,Z)*.
*HALF MAJOR AXIS OF SUB DISH SHADOW*.
*HALF MINOR AXIS OF SUB DISH SHADOW*.

*NUMBER OF PANELS IN REFLECTOR*.

*MAIN DISH DESCRIPTION AND ITS PARAMETERS -

*IT IS A PLANAR REFLECTOR*.
*APERTURE PLANE LOCATION*.
*SUB DISH SHADOW CENTER COORDINATES IN APERT. PL*.
*HALF MAJOR AXIS OF SUB DISH SHADOW*.

*IT IS AN ELLIPTICAL REFLECTOR*.
*MAJOR AXIS OF THE ELLIPTICAL REFLECTOR*.
*MINOR AXIS OF THE ELLIPTICAL REFLECTOR*.

*IT IS A Spherical REFLECTOR*.
*RADIUS OF REFLECTOR SPHERE*.

*IT IS A PARABOLIC REFLECTOR*.
*FOCAL LENGTH OF THE REFLECTOR*.

*IT IS A PARABOLIC CYLINDRICAL REFLECTOR*.
*FOCAL LENGTH OF PARABOLIC CYLINDER*.
*ANGLE OF ROTATION ABOUT X-AXIS (PSI)*.

*IT IS A HYPERBOLIC REFLECTOR*.
*MAJOR AXIS OF REFLECTOR IN X DIRECTION*.
*AXIS OF REFLECTOR IN Y DIRECTION*.

*IT IS A HYPERBOLIC CYLINDRICAL REFLECTOR*.

*PROGRAM IN SINGLE PANEL MODE*.

*SUB DISH DESCRIPTION AND ITS PARAMETERS*.

*PATTERN OF FEED IN ONE DEG INCREMENTS OFF-AXIS*.

PI=PI*2
PI2=PI*2
PI3=PI/1.80
PI4=PI/180.
RETURN
END
APTRUR

SUBROUTINE APTRUR(P, ICALL)
IMPLICIT REAL*8 (A-H,O-Z)
REAL*8 NMA(3),NMAG,NORM
INTEGER SURFC1,SURFC2
COMMON/ANHPRM/NPTPL,NPERIN
COMMON/CASS/AR(3),EN(3),XO,YO,ZO,RO,XO2,YO2,ZO2,ER(3)
COMMON/FLED/EPI(91),ET(11)E,SPRT,XT,YS,ZS
COMMON/MATH/P1,P12,P1D2,DTOR,TGUD
COMMON/COLOS/DELT, XC, ANGINC,P(3,4),RS,XMX,ZMX,ZMN,VMX
COMMON/CTRL/NOPT(3),NLIST,1OPT,ICASS,LIST(100)
COMMON/HPARM/ADGRF,BELL,P,CELLP,DIST,PSI,PLPMT(3),PLNORMAL(3)
COMMON/FEED(3),ALPHA,BETA,GAMMA,XP,LX,YL,ELLP2,BELL2,CELLP2
COMMON/MAT/PI,PI2,P1D2,DTOR
COMMON/NORM(3),SURFC1,NPPL,NPOIN,SURFC2
DIMENSION INV(3,3),I(3,2),BB(3,2),C(3),X(3),A(3,3),EI(3)
C(5,2750)
IF (ICASS.EQ.1) GO TO 10
M=1
DO 2 J=2,4
IF(P(3,M)-P(3,1))3,2.2
3 M=1
2 CONTINUE
XMAX=P(1,M)
YMAX=P(2,M)
ZMAX=P(3,M)
10 IF (ICALL.EQ.1) GO TO 50
ALPHAP=ALPHA+OTOR
BETAR=BETA+OTOR
GAMMAR= GAMMA+OTOR
A(1,1)=DCOS(ALPHAP)*DCOS(GAMMAR)-DSIN(ALPHAP)*DSIN(BETAR)
B(1,1)=DSIN(GAMMAR)
A(1,2)=DSIN(ALPHAP)*DCOS(GAMMAR)+DCOS(ALPHAP)*DSIN(BETAR)
B(1,2)=DSIN(GAMMAR)
A(2,1)=DCOS(ALPHAP)*DSIN(BETAR)-DSIN(ALPHAP)*DCOS(BETAR)
B(2,1)=DCOS(GAMMAR)
A(2,2)=DCOS(ALPHAP)*DCOS(BETAR)-DSIN(ALPHAP)*DSIN(BETAR)
B(2,2)=DCOS(GAMMAR)
A(3,3)=DCOS(BETAR)*DCOS(GAMMAR)
DO 40 I=1,3
DO 40 J=1,3
40 AINV(I,J)=A(I,J,1)
NPERIN=M
NPTPL=2000
50 IF (1OPT.EQ.0) CALL APRIN(P, ICALL)
TMAX=0.000
TMIN=PI
55 PRIN=P1+P1D2
PMAX=P1D2
58 DO 60 I=1,NPERIN
DO 60 J=1,3
60 X(J)=AINV(J,1)*P(1,1)+AINV(J,2)*P(2,1)+AINV(J,3)*P(3,1)
N=DSORT((X(1)+FED1(1))**2+(X(2)+FED2)**2+(X(3)+FED3)**2)
P(1,1)=DBRCUS((X(3)+FED3)**2/N)
SINTH$=SIN(P(1,1))
IF (SINTH$<LT;1.D-10) SINTH$=1.D-10
P(2,1)=P-DARSON((X(2)+FEED(2))/(NP*SINTH$))
61 IF (P(1,1).LT.TMIN) TMIN=P(1,1)
IF (P(1,1).GT.TMAX) TMAX=P(1,1)
IF (P(2,1).LT.TMIN) TMIN=P(2,1)
IF (P(2,1).LT.TMIN) TMIN=P(2,1)
65 CONTINUE
DELP=PHMAX-PMIN
DELT=TMAX-TMIN
NP=DOSQRT(DELPOFLOAT(NP)*PL)/DELT)+1.0
NP=((NP-1)/2)*2+1
ANGINC=DELP/(DFLGA-(NP)-2.6)
IF (ICASE.EQ.1) CALL FINDCEL(P,8)
NTDZ=DELT/(2.0*ANGINC)+1.0
NT=2*NTDZ+1
PMIN=PMIN-0.0*ANGINC
PMAX=PMAX+0.0*ANGINC
TCT=(TMAX+TMIN)/2.0
TMIN=TCT-DFLOAT(NTDZ)*ANGINC
TMAX=TCT+DFLOAT(NTDZ)*ANGINC
DO 95 J=1,NP
DO 95 K=1,NP
P(2,NPERIN+(J-1)+NPK1)=TMIN+(J-1)*ANGINC
NTNP=NTNP+1
NPINT=NPINT+1
TMIN=TMIN+NTDZ
TMAX=TMAX+NTDZ
PMIN=PMIN+NTDZ
PMAX=PMAX+NTDZ
ANGINC=ANGINC+NTDZ
IF (IUFF(Rolla,E1)=1) PRINT 107,TMIN,TMAX,PMIN,PMAX,
* ANGINC,NTNP,NPINT
107 FORMAT(//' ILLUMINATION DATA-//-
* ' Theta Illumination From............................",F9.3," TO 
* F9.3/
* ' Phi Illumination From............................",F9.3," TO 
* F9.3/
* ' Incremental Angle (Deg)................................",F7.4/
* ' Therefore Total Number of Generated Rays........",I7/
* ' Total Number of Aperture Plane Points...............",I7)
IF (SURFICE.EQ.5) GO TO 114
CPS1=DCOS(P(1,1))
SNP1=DSIN(P(1,1))
114 CALL FILLP(P,NPINT)
DO 990 I=1,NPINT
SNP=DSIN(P(2,1))
CPS=DCOS(P(2,1))
SIN=DSIN(P(1,1))
COS=DCOS(P(1,1))
D01(1,1)=INT*COS
D01(2,1)=SIN*SIN
D01(3,1)=COS
D01(3,2)=COS*FEED(1)
D01(3,2)=COS*FEED(2)
BB(3,2) = FEED(3)
CALL MULT32(Ba, BB)
GO TO (120,130,140,150,160,161), SURFC1

AR=0.0
BR=0.1

GO TO 160

120 AR=0.1
BR=0.1

GO TO 160

130 AR=0.1
BR=0.1

GO TO 160

140 AR=0.1
BR=0.1

GO TO 160

150 AR=0.1
BR=0.1

GO TO 160

160 AR=0.1
BR=0.1

GO TO 161

180 IF (ICASS.NE.1) GO TO 181
IF (UABS(AR)).LT.1.00-10) R=CR/BR
IF (UABS(AR)).LT.1.00-10) GO TO 185
R=-BA-DSRCR(BR*CR+4.0*AR*CR)/(AR+BR)
GO TO 185

181 IF (UABS(AR)).LT.1.00-10) R=-CR/BR
IF (UABS(AR)).LT.1.00-10) GO TO 185
V=BR*BA-4.0*AR*CR
R=(UR+DSTV)/(AR+BR)
GO TO 185

185 CONTINUE
X0=0.1
Y0=0.1
Z0=0.1
IF (ICASS.EQ.1) GO TO 219
IF (ICALL.EQ.1) GO TO 219
IF (ICALL.EQ.1) GO TO 189
IF (UOPT.EQ.1) GO TO 190
R=DSRT((X0+B11.1)*#2+(Y0+B1.2)*#2+(Z0+B3.2)*#2)-1.0
THTMAX=MATAN(-4.5+B13.2)/((X0+B11.1))
THTAUG=THTMAX+2.5*ANGINC+DTOR
XC*(RDCOS(THETA)+B(1:2))
CONST=DABS(AX-XX)
GO TO 190
189
XX=XX+CONST
AL=ZEN
IF(DOPLT.LT.1) GO TO 219
190
CALL FINDX(P,B)
XX=ZEN
IF(DOPLT.LE.1) XC=XX
219
GO TO (220-230,240,250,260,261),SURFC1
220
NHAT(1)=PLNORM(1)
NHAT(2)=PLNORM(2)
NHAT(3)=PLNORM(3)
GO TO 288
230
NHAT(1)=+XO/BELL**2/DSQRT(X**2+BELL**2*Y**2+Z**2)*AORDRFP4
NHAT(2)=-YO/BELL**2/DSQRT(X**2+BELL**2*Y**2+Z**2)*
  AORDRFP4
NHAT(3)=-ZO/BELL**2/DSQRT(X**2+BELL**2*Y**2+Z**2)*
  AORDRFP4
GO TO 288
240
NHAT(1)=-XO/AORDR
NHAT(2)=-YO/AORDR
NHAT(3)=-ZO/AORDR
GO TO 288
250
NHAT(1)=XO/AORDR/DSQRT(4.0*AORDRFP*2+Y**2+Z**2)
NHAT(2)=-YO/DSQRT(4.0*AORDRFP*2+Y**2+Z**2)
NHAT(3)=-ZO/DSQRT(4.0*AORDRFP*2+Y**2+Z**2)
GO TO 288
260
NMA=DSQRT((XO*DIST)**2/AORDRFP4)*((YO*Y)*BELL**4)*((Z0*Z/ merry_view)
  CELLP**2))
NHAT(1)=(XO*DIST)/(AORDRFP2)*DEN
NHAT(2)=YO/(BELL**2)*DEN
NHAT(3)=-ZO/(CELLP**2)*DEN
288
IF (ICASS.NE.1) GO TO 289
NHAT(1)=NHAT(1)
NHAT(2)=NHAT(2)
NHAT(3)=NHAT(3)
289
SCALAR=2.0*(B(1,1)*NHAT(1)+B(2,1)*NHAT(2)+B(3,1)*NHAT(3))
DO 295 J=1,3
295
SCALAR=2.0*(E(1,1)*NHAT(1)+E(2,2)*NHAT(2)+E(3,3)*NHAT(3))
SCALAR=2.0*(NHAT(1)+NHAT(2)+NHAT(3))
}
DO 500 K=1,3

500 LH(K)=SCALAR*MMAT(K)-EI(K)
IF (IASS.NE.1) GG TO 550
CALL CASSA(P)
PHASE=PI2*(R+R+D)/XLA.M
P(1,1)=Y
P(2,1)=Z
P(3,1)=ER2(2)
P(4,1)=ER2(3)
P(5,1)=PHASE
GG TO 500

550 Y=Y0*(X-X0)*SR(Z)/SR(1)
Z=Z0*(X-X0)*SR(Z)/SR(1)
D=SQRT((X-X0)*(X-X0)+(Y-Y0)*(Y-Y0)+(Z-Z0)*(Z-Z0))
DIF=DABS(XC-XX)
PHASE=PI2*(R+D+DIF)/XLA.M+P(5,1)
P(1,1)=Y
P(2,1)=Z
P(3,1)=ER2(2)
P(4,1)=ER2(3)
P(5,1)=PHASE
CONTINUE
RETURN
END

SUBROUTINE SUBPNT(P)
IMPLICIT REAL*8(A-H,O-Z)
REAL*8 NORM
INTEGER SURFC1,SURFC2
COMMON/COLS/DELX,XC,ANGINC,PM(1,4),RS,XM,ZM,ZM,YM
COMMON/PARAMS,AQRDR,BELLP,CELLP,DIST,PS1,PLNPNT(3),PLNORM(3),
. FEED(3),ALPHA,BETA,GAMMA,XYAM,XX,AQRDR,BELLP2,CELlp2,
. PS1Z,DIST2,POINT(3),NORM(3),SURFC1,NPNL,NPINT,SURFC2
DIMENSION P(5,2,750)
DO 33 K=1,4
RR=SQRT( PM(1,K)*PM(1,K)+PM(2,K)*PM(2,K)+PM(3,K)*PM(3,K))
DIR=PM(1,K)/RR
DIR2=PM(2,K)/RR
DIR3=PM(3,K)/RR
AAR=DIR**2/AQRDR**2-(DIR**2/CELLP**2)-(DIR3**2/CELLP**2)
BRR=2.*((DIR**2-(PM(1,K)*DIST)*DIR1/AQRDR**2)+(PM(2,K)*DIST)/
 (CELLP**2)+(PM(3,K)*DIST)/CELLP**2))
CRR=PM(1,K)*DIR3/CELLP**2+DIST**2*PM(1,K)*DIST/AQRDR**2-
 (PM(2,K)*CELLP**2-(PM(3,K)**2)/CELLP**2))**1.0
KRR=-(AAR+DSQRT(BRR**2-4.*AAR*CRR))/(AAR+KRR)
P(1,1)=PM(1,K)*KRR*DIR1
P(2,1)=PM(2,K)*KRR*DIR2
P(3,1)=PM(3,K)*KRR*DIR3
CONTINUE
RETURN
END
SUBROUTINE CASSA(P)

IMPLICIT REAL *8 (A-H,O-Z)
REAL*8 NMAT(3), MAGSR, MAG2, 3URF, SURF1, SURF2
INTEGER SURFC1, SURFC2

COMMON/PARAMS/AOROR, BELLP, CELLP, DIST, PS1, PLNPT(3), PLNORM(3),
  FEED(3), ALPHA, BETA, GAMMA, XLAN, XX, AOROR2, BELLP2, CELLP2,
  PS2, DIST2, POINT(3), NORM(3), SURFC1, SURFC2, NPOINT, NURM
COMMON/COLOs/DEL, XC, ANGINC, PM(3,4), RS, XM, ZM, ZK, YX
COMMON/CASS/ SR(3), ER(3), X0, Y0, Z0, RN, D, X02, Y02, Z02, ER2(3)
COMMON/MATH/PI, P12, PI02, JR, RTU, JTU, JC13, E1213, PI5, PI2750, SR2(3), C(3)

MAGSR = 0.0
SURFC1 = 0
SURFC2 = 0
NORM(1) = 0
NORM(2) = 0
NORM(3) = 0

C FIND DIRECTION COSINES

10 AA = 0.0
BB = NORM(1) * DC(1) + NORM(2) * DC(2) + NORM(3) * DC(3)
CC = (XO - POINT(1)) * NORM(1) + (YO - POINT(2)) * NORM(2) + (ZO - POINT(3)) * NORM(3)

GO TO 100

20 AA = (DC(1)**2 / AOROR2 + (DC(2)**2 / BELLP + DC(3)**2 / CELLP2) * DC(1) + Y0**2/BELLP2)**2
BB = DC(2) / AUROR2 + (DC(2)**2 / BELLP2) * DC(2) + Y0**2/BELLP2)**2
CC = DC(3) / (BELLP2)**2 + (Y0**2/BELLP2)**2 + (Z0**2/BELLP2)**2

GO TO 100

30 AA = (DC(1)**2 + DC(2)**2 + DC(3)**2) * DC(1) + Y0**2/BELLP2)**2
BB = DC(2) / (AUROR2 + (DC(2)**2 / BELLP2) * DC(2) + Y0**2/BELLP2)**2
CC = DC(3) / (AUROR2 + (DC(3)**2 / BELLP2 + (Y0**2/BELLP2)**2 + (Z0**2/BELLP2)**2)

GO TO 100

40 AA = DC(1)**2 + DC(2)**2 + DC(3)**2
BB = DC(2) / (AUROR2 + (DC(2)**2 / BELLP2 + (Y0**2/BELLP2)**2 + (Z0**2/BELLP2)**2)
CC = DC(3) / (AUROR2 + (DC(3)**2 / BELLP2 + (Y0**2/BELLP2)**2 + (Z0**2/BELLP2)**2)

GO TO 100

50 SNPS1 = NSNPS1 + SNPS1**2 * DTOR
SNPS1 = SNPS1 + SNPS1**2 * DTOR
AA = (DC(3)**2 + DC(2)**2 + DC(2)**2) * SNPS12**2 + SNPS12**2 * DC(2) + SNPS12**2 + SNPS12**2 -
  (2 * DC(2)**2 + DC(3)**2) * SNPS12**2 + SNPS12**2 -
BB = 0.0
CC = (DC(3)**2 + DC(3)**2 + DC(3)**2) * SNPS12**2 + SNPS12**2 -
  (2 * DC(2)**2 + DC(3)**2) * SNPS12**2 + SNPS12**2 -

GO TO 100

60 AA = (DC(1)**2 + DC(2)**2) * (DC(1)**2 + DC(2)**2) + (DC(2)**2) * (DC(1)**2 + DC(2)**2 -
BB = 0.0
CC = (DC(1)**2 + DC(2)**2) * (DC(1)**2 + DC(2)**2 -

GO TO 100

100 IF (DBAS(AA) .LT. 0.0 - 10.0) RM = CC / BB
IF (DBAS(AA) .LT. 0.0 - 10.0) GO TO 110
V2 = DBBB + 0.0
IFF (V2 .LT. 0.0) V2 = 0.0
RM = 1.0 + 0.0 + SNPS12**2 + (Y0**2/BELLP2)**2 + (Z0**2/BELLP2)**2 - (Y0**2/BELLP2)**2

GO TO 100

110 COMMON X02 = X0*RM / DC(1)
Y02 = Y0*RM / DC(2)
200 \*REM OOC(3) 
GO TO (110,130,140,150,160,170), SURFC2
120 NHAT2(1)=NORM(1)
NHAT2(2)=NORM(2)
NHAT2(3)=NORM(3)
GO TO 200
130 NHAT2(1)=X02*BELLP2#12/DSORT(X02**Z02#2+Y02**Z02#2)*
\*AQROR2#4)
NHAT2(2)=Y02*AQROR2#2/DSORT(X02**Z02#2+Y02**Z02#2)*
\*AQROR2#4)
NHAT2(3)=Z02*AQROR2#2/DSORT(X02**Z02#2+Y02**Z02#2)*
\*AQROR2#4)
GO TO 200
140 NHAT2(1)=X02/AQROR2
NHAT2(2)=Y02/AQROR2
NHAT2(3)=-Z02/AQROR2
GO TO 200
150 NHAT2(1)=2.0*AQROR2/DSORT(4.0*AQROR2#2+Y02**Z02#2)
NHAT2(2)=Y02/DSORT(4.0*AQROR2#2+Y02**Z02#2)
NHAT2(3)=-Z02/DSORT(4.0*AQROR2#2+Y02**Z02#2)
GO TO 200
160 NMAAG=DSORT(4.0*AQROR2#2*AQROR2#2+Z02*CSPS12#SNPS12-
\*Y02#SNPS12#SNPS12#2+(Y02#SNPS12+CSPS12-Z02*CSPS12#SNPS12#2)
NHAT2(1)=2.0*AQROR2/NMAAG
NHAT2(2)=SNPS12#Z02*CSPS12-Y02#SNPS12)/NMAAG
NHAT2(3)=CSPS12#(Y02#SNPS12-Z02*CSPS12)/NMAAG
GO TO 200
170 DEN2=DSQR((X02+01ST2)**2/AQROR2#4)*(Y02*Y02/BELLP2#4)*
\*(Z02#Z02/CELLP2#4))
NHAT2(1)=(X02+01ST2)*(AQROR2#2)*DEN2)
NHAT2(2)=-Y02/(BELLP2#2)*DEN2)
NHAT2(3)=-Z02/(CELLP2#2)*DEN2)
200 SCALA2=2.0*(DC(1)+NHAT2(1)+DC(2)*NHAT2(2)+DC(3)*NHAT2(3))
DO 250 L=1,3
250 SR2(L)*DC(L)-SCALA2*NHAT2(L)
E12(N)=0.0
DO 300 N=1,3
300 E12(N)=ER(N)/RHM
DO 350 K=1,3
SCALA3=2.0*(E12(1)+NHAT2(1)+E12(2)+NHAT2(2)+E12(3)+NHAT2(3))
350 LH(K)=SCALA3*NHAT2(K)-E12(K)
IF(DABS(SR2(1))<LT1.0D-5) SR2(1)=1.0D-5
Y=Y02*+X02)*SR2(2)/SR2(1)
Z=Z02+(X02)*SR2(3)/SR2(1)
U=DSORT((X-X02)**2+(Y-Y02)**2+(Z-Z02)**2)
RETURN
END
SUBROUTINE APRIN(P,NCALL)
IMPLICIT REAL*8 (A-H,O-Z)
REAL*8 NORM
INTEGER SURFC1,SURFC2
COMMON/APPRIM/NPTPL,NPERIM
COMMON/PARAMS/AORURF,BELLP,CELLP,DIST,PSI,PLNPNT(3),PLNORM(3),
* FEED(3),ALPHA,BETA,GAMMA,XLAM,XC,AOROR2,BELL2,CELL2,
* PSI2,DISTZ,POINT(3),NORM(3),SURFC1,NPML,NPOINT,SURFC2
COMMON/FEED/EP(9),ET(91),NP,NT,XS,YS,ZS
COMMON/CURL//NoPT(3),NLST,ICPT,ICASS,ILIST(100)
DIMENSION P(3,2750)
READ(1,10) NPERIM,SURFC1,NPTPL
10 FORMAT(3I5)
IF (NPERIM.LE.2) GO TO 250
IF (NPERIM.GT.40) GO TO 260
IF (SURFC1.GT.6) GO TO 270
IF (NPTPL.GT.2500) GO TO 270
IF ((NPERIM+SURFC1).LE.0) GO TO 250
READ(1,20) ((P(I,J),I=1,3),J=1,NPERIM)
20 FORMAT(3F10.6)
N=1
DO 2 I=2,NPERIM
IF(P(3,N).NE.P(3,1)) N=2
2 CONTINUE
IF(N.NE.1) N=1
READ(1,10) NPERIM
READ(1,10) P(3,1)
DO 2 I=2,NPERIM
READ(1,10) P(3,N)
40 CONTINUE
READ(1,55) AORURF,BELLF
55 FORMAT(F10.3)
GO TO 100
READ(1,55) AORURF
GO TO 100
READ(1,55) AORURF,PSI
GO TO 100
READ(1,55) AORURF,BELLF,CELLP,DIST
GO TO 100
CONTINUE
199 IF(ID(I1,ICALL).EQ.0) RETURN
200 PRINT 200, ICALL
201 FORMAT('I1',35X,'REFLECTOR PANEL NUMBER', 14)
202 GO TO (320, 330, 340, 350, 360, 370), SURF:
250 PRINT 252, ICALL
252 FORMAT(/'************ INPUT ERROR ON CARD ONE FOR PANEL NUMBER*,
     * 14, * EXECUTION TERMINATING *************)
     STOP
260 PRINT 262, ICALL
262 FORMAT(/'************ STORAGE DOES NOT EXIT FOR NUMBER OF*,
     * PERIMETER POINTS SPECIFIED - PANEL', 14, * *************)
     STOP
270 PRINT 272, ICALL
272 FORMAT(/'************ MAXIMUM ILLUMINATION REQUEST IS 2500*,
     * RAYS - PANEL', 14, * *************/)
     NPTPPL=2500
     GO TO 28
320 PRINT 401, PLNPNT, PLNORM, NPERIM
     RETURN
330 PRINT 402, AURORF, BELLP, NPERIM
     RETURN
340 PRINT 403, AURORF, NPERIM
     RETURN
350 PRINT 404, AURORF, PSI, NPERIM
     RETURN
360 PRINT 405, AURORF, PSI, NPERIM
     RETURN
370 PRINT 406, AURORF, BELLP, CELLP, DIST, NPERIM
     RETURN
401 FORMAT(/'IOX,' PANEL IS A PLANAR SURFACE', */
     * A POINT ON THE REFLECTOR SURFACE (X,Y,Z)..........,/F7.2
     * COMPONENTS OF UNIT NORMAL TO SURFACE (X,Y,Z).........,/F7.2
     * NUMBER OF USER-SUPPLIED EDGE POINTS................../17)
402 FORMAT(/'IOX,' PANEL IS AN ELLIPTICAL SECTION', */
     * MAJOR AXIS OF ELLIPTICAL REFLECTOR..................,/F7.2
     * MINOR AXIS OF ELLIPTICAL REFLECTOR..................,/F7.2
     * NUMBER OF USER-SUPPLIED EDGE POINTS................../17)
403 FORMAT(/'IOX,' PANEL IS A SPHERICAL SECTION', */
     * RADIUS OF REFLECTOR SPHERE........................../F7.2
     * NUMBER OF USER-SUPPLIED EDGE POINTS................../17)
404 FORMAT(/'IOX,' PANEL IS A PARABOLIC SECTION', */
     * FOCAL LENGTH OF THE PARABOLA........................../F7.2
     * NUMBER OF USER-SUPPLIED EDGE POINTS................../17)
405 FORMAT(/'IOX,' PANEL IS A SECTION OF A PARABOLIC CYLINDER', */
     * FOCAL LENGTH OF THE PARABOLA........................../F7.2
     * FOCAL LINE ROTATION FROM Y-AXIS (PSI)................./F8.3
     * NUMBER OF USER-SUPPLIED EDGE POINTS................../17)
406 FORMAT(/'IOX,' PANEL IS A HYPERBOLIC SECTION', */
     * MAJOR AXIS OF REFLECT IN X DIRECTION................./F8.3
     * AXIS OF REFLECTOR IN Y DIRECTION....................../F8.3
     * AXIS OF REFLECTOR IN Z DIRECTION....................../F8.3
     * NUMBER OF USER-SUPPLIED EDGE POINTS................../17)
END
SUBROUTINE FINDXC(P,B)
IMPLICIT REAL*8 (A-H,O-Z)
COMMON/COLOR/DELTA,XC,ANGINC,PM(3,4),RS,MAX,DX,SYM,YM
COMMON/NAT/NPI,IP2,IP12,DP2,DTOR,RTOD
COMMON/CTRL/NOPT(3),NLIST,IOPT,ICASS,ILLST(100)
DIMENSION P(5,2750),B(3,2)
IF(ICASS.NE.1) GO TO 15
N=1
DO 2 I=2,4
IF(PM(3,I).LT.PM(3,1)) 3,2,2
3 N=1
2 CONTINUE
RSMOSTRT(PM(1,N)*8+PM(2,N)*8+PM(3,N)*8)+1.0
THTXACT=DATAN(-PM(3,N)/PM(1,N))
THTWG=THTXACT*0.5*ANGINC
XC=-RS0CUSTH(THTAUG)
RETURN
15 RSMOSTRT(I;MAX+O(I,2))=0+(YM+O(B,2))=0+(ZM+O(3,2))=0)+1.5
THTXACT=DATAN(-(ZM+O(B,I,2))/(XMAX+O(B,I,2)))
THTWG=THTXACT*0.5*ANGINC*0.9
ZM=-(RSM0CUSTH(THTAUG)+B(I,2))
RETURN
END

FUNCTION IU1(INTENT,ITER)
IMPLICIT REAL*8 (A-H,O-Z)
INTEGER SURFC1,SURFC2
COMMON/CTRL/NOPT(3),NLIST,IOPT,ICASS,ILLST(100)
GO TO (20,30,40,50,60),INTENT
20 IF (NUOPT(1).LT.0) GO TO 90
IF (NUOPT(1).EQ.2) GO TO 91
22 DO 25 I=1,NLIST
 IF (I+O(I),EQ,ITER) GO TO 91
25 CONTINUE
GO TO 90
30 IF (NUOPT(2).GT.0) GO TO 91
GO TO 90
40 IF (NUOPT(2).LE.0) GO TO 90
IF (NUOPT(2).EQ.2) GO TO 91
GO TO 22
50 IF (NUOPT(3).GE.1) GO TO 91
GO TO 90
60 IF (NUOPT(3).EQ.2) GO TO 91
90 101=0
RETURN
91 101=1
RETURN
END
INTEGER

SUBROUTINE INTG(P, MAJOR, MINOR, FIELD, FIELD2)

IMPLICIT REAL*(8) (A-H, O-Z)

REAL*8 MAJOR, MINOR
REAL*8 NORM

COMPLEX*16 CTEMP, CCL2, CY1, CY2, TSZ, TSY, D1, DT1, ZI, ZIUD, ZIOLD.

INTEGER SURFC1, SURFC2

COMMON/CONT/NOPT(3), NLIST, OPT, ICASS, ICASH, ICASS(1), ICASH(1),


PSI1, PSI2, PSI3, PSI4, PSI5, PSI6, PSI7, PSI8, PSI9, PSI10, PSI11, PSI12,

PRINT/(31, NPER(3), PLUFL(3), PLUFL(3), PLUFL(3), PLUFL(3), PLUFL(3),

DIMENSION AMINOR(3), P(5, 2750)

DATA NPHI, MTHA, /NPHI, MTHA/

NPHI = 990.0

NPT = 7

RPT = 1.0 / NPARTS

ZLAM = PLZ/XLAM

CALL SETM(SEN, P(1, NPOINT + 1), 0)

DEG = MAJOR

DEG* = DEG + 1

DUX = AMINOR(1) / OPT

DJH = AMINOR(2) / OPT

DSTOR = AMINOR(3) / OPT

DICR = 0.5

NTH = 0

DLOL

IF (MAJOR .NE. NPHI) GO TO 3400

400

COSP = COS(SIN(DERG))

COST = COS(DERG)

CUST = COS(SIN(DERG))

SINT = SIN(DERG)

GO TO 3425

J400

COSP = COS(DERG)

SINT = SIN(DERG)

GO TO 3425

J425

NTH = NTH + 1

COSP = COS(SINP)

ZK = 2LAM * CUST

YK = 2LAM * SINP * SINT

IOLD = 1

INE = 2

FLDT = (0.0, 0.0)

FLDZ = (0.0, 0.0)

IOLD = SEN

YI = (0.0, 0.0)

ZI = (0.0, 0.0)

3450

CONTINUE

IF (P(I, IOLD) .NE. P(I, INEW)) GO TO 4000

Z = P(I, IOLD)

EY = P(J, IOLD)

ER = P(N, IOLD)

ZH = P(I, IOLD)

PHE = P(J, IOLD)

Z = P(2, INEW) - Z * RPT

VHE = P(3, INEW) - EY * RPT

VHR = P(4, INEW) - ER * RPT
DPH=(P(S,1,NE1)-PH)*RPAR
CTEMP=CEXP(DCMPLX(0.000,YK+0.000)-PH))
CZ1=ERZ*COSPT*CTEMP
CY1=ERE*SINT*ERZ*CTSP)*CTEMP
TSY=(0.000,0.000)
TSZ=(0.000,0.000)
DO 3700 N=1,NPARTS
Zt=ZD2
ET=ERE*ELY
ERZ=ERZ*ERZ
PH=PH+DPH
CTEMP=CEXP(DCMPLX(0.000,ZK+Z-PH))
CZ2=ERZ*COSPT*CTEMP
CY2=ERE*SINT*ERZ*CTSP)*CTEMP
TSY+TSZ+Z1+CY2
TSZ=TSY+CY1+CY2
CZ1=CY2
CY1=CY2
3700 CONTINUE
Z1=Z1+TSZ*(0.5*D2)
Y1V=TSY*(0.5*D2)
3900 YLD=YLD+1
IN=IN+1
GO TO 3450
4000 CONTINUE
YNEW=(1.10L0)
IF (YLD+EQ+SEN) GO TO 4400
4200 DZ1=(Z1-I*YNEW)*RPAR
DY1=(Y1-I*YNEW)*RPAR
Y=(YNEW-YULD)*RPAR
CTEMP=CEXP(DCMPLX(0.000,YK+YOLD))
CZ1=ZIULD+1
CY1=YZULD+1
TSY=(0.000,0.000)
TSZ=(0.000,0.000)
DO 4300 N=1,NPARTS
YULD=YULD+DY
ZULD=ZIULD+DZ1
YULD=YZULD+DY1
CTEMP=CEXP(DCMPLX(0.000,YK+YOLD))
CZ2=ZIULD+1
CY2=ZIULD+1
TSY+TSZ+Z1+CY2
TSY=TSY+CY1+CY2
CZ1=CY2
CY1=CY2
4300 CONTINUE
FLO2=FLO2+TSY*(0.5*DY)
FLO4=FLO4+TSY*(0.5*DY)
4400 CONTINUE
YULD=YNEW
ZULD=Z1
YULD=Y1
Y1=(0.000,0.000)
Z1=(0.000,0.000)
IF (P(S,1,NE1),NE,SEN) GO TO 3900
FIELDY(NTH)=FLDY
FIELDZ(NTH)=FLDZ
D=D+DICR
IF (D=.EQ.DSTOPR) GO TO 5000
IF (MAJOR.EQ.MPH1) GO TO 400
GO TO 3400
5000 CONTINUE
RETURN
END

FILLP

SUBROUTINE FILLP(P,NPT)
IMPLICIT REAL*8 (A-Z)
COMMON/FEED/EP(91),ET(91),NP,NM,XS,YS,ZS
COMMON/MATH/PI,PI2,PID2,070R,RT02
COMMON/CONTRL/NOPT(3),NLIST,IOPT,ICASS,ILIST(100)
DIMENSION P(5,NPT)
DO 100 I=1,NPT
   PROJX=DABS(P(1,I))*COS(P(2,I))
   PROJX=0.000
5   IF (DABS(P(2,I)-PI)>.GT.1.0D-5)
      PROJX=DABS(DATAN(DCOS(P(1,I)))/DSIN(P(1,I))/DSIN(P(2,I)))
   10  ANGLX=DARCOS(DABS(PROJX))*RT02
   LO=ANGLX+1.000
   IFI=LO+1
   TPFLD=(ANGLX-DFLOAT(LO-1))*(ET(IFI)-ET(LO))*ET(LO)
   SINE2=PROJX*PROJX
   COSE2=1.000-SINE2
   P(3,I)=PPFLD*TPFLD/(DSQR(TPFLD*TPFLD*COSE2*
                              PPFLD*PPFLD*SINE2))
   P(4,I)=0.000
   P(5,I)=0.000
100 CONTINUE
RETURN
END
SUBROUTINE QUANTZ(P,NPERIM,ICALL)

REAL*8 NORM
INTEGER SURFC1,SURFC2
COMMUN/BLKGL/YBGL,ZBGL,MF2ABL,MF1B1L
COMMUN/DIM(5,YIN,ZIN,YCT,ZCT
COMMUN/EEXTNT/YMIN,YMAX,ZMIN,ZMAX
COMMUN/CUNTRLS/NPUT(5),NLST,OPT1,ICASS1,LST(100)
COMMUN/FED/FN1,FN2,NP,KT,AS,YS,ZS
COMMUN/P8M/ASURF,BELLP,CELP,DIST,PSI,PLNPNT(3),PLNORM(3),
* FEED(3),ALPHA,BETA,GM,ALN,XX,ADQR2,BELLP2,CELP2,
P12,DISTZ,POINT(3),NORM(3),SURFC1,NP8NT,SPRTC2
DIMENSION P5,NP8NT,PINT(5),POLD(5),PBLK(5),P(5,41),Z2(2,101)
IF(ICASS.EQ.1) NPERIM=4
NBARS=NP-2
YM IN=1.00+1O
YMAX=1.0D+10
ZMIN=1.0D+10
ZMAX=1.0D+10
NUS=2*NBARS
CALL SETMN(1.0D+20.2,NS0)
DO 20 =1,NPERIM
IF (P(l.1).GT,YMAX) YMAX=P(l.1)
IF (P(l.1).LT.YMIN) YMIN=P(l.1)
IF (P(l.1).GT.ZMAX) ZMAX=P(l.1)
IF (P(l.1).LT.ZMIN) ZMIN=P(l.1)
20 CALL MOVLM(P(l.1),P1511.1,5)
YDIN=YMAX-YMIN
YCT=(YMAX+YMIN)/2.
ZDIN=ZMIN-ZMAX
ZCT=(ZMAX+ZMIN)/2.
GRID=(YMAX-YMIN)/(DFLOAT(NBARS)-0.6)
GRID=GRID/(GRID+0.0)
GRID=YMAX-GRID*GRID
31 IBGN=NPERIM+1
NUEX=NPERIM
GO TO 100
100 IBGN=NPERIM
NUEX=NPERIM
GO TO 100
IF (P(l.1).GT.YMAX) GO TO 98
IF (P(l.1).LT.YMIN) GO TO 98
GRID=(P(l.1)-GRID)/GRID+0.5
P(l.1)=GRID+DFLOAT(GRID-GRID)*GRID
IF (NPUT.EQ.1) GO TO 222
CALL MOVEM(P11.1),P(1.1-NDEX),5)
GO TO 100
98 NUEX=NUEX+1
100 CONTINUE
NP8NT=NP8NT-NUEX
CALL PTJRT(P5,NP8NT)
IF (LJPT.EQ.1) GO TO 422
CALL MOVEM(PH5(1.1),PS5(1,NPERIM+1),5)
KDEX=2
Y2=PS5(1.1)
Z2=PS5(2.1)
200 Y1=PH5(1,KDEX)
Z1=PS5(2,KDEX)
IF (DBSL((Y1-Y2)-LT.1.00-5) GO TO 400
SLOPE=(Z1-Z2)/(Y1-Y2)
B=2-SLOPE#Y2
IF (Y1-Y2) Z20+Z30=Z30
220 Y1=Y2
YLD=1
GO TO 240
230 Y1=Y2
YLD=Y2
240 INDEX=(YLU-GRIDLO)/GRID+1.0
250 INDEX=INDEX+1
YU=GRIDLU+FLAT(INDEX-1)*GRID
IF (YU+GT.YH1) GO TO 400
YLOAD=1
ZEE=SLOPE#YQ+B
IF (Z1.INDEX).LT.1.00+10) ILLOAD=2
Z(1)LOAD+INDEX=ZEE
GO TO 250
400 Y2=Y1
Z2=Z1
KDEX=KDEX+1
IF (KDEX=LE.NPERIM+1) GO TO 200
DO 420 I=1,NBARS
420 IF (((Z(1,1)+Z(2,1))=GT.1.00+10) GO TO 1009
IF (((Z(2,1)-Z(1,1)))=410.420.420
430 ZZ=Z(2,1)
Z(2,1)=Z(1,1)
Z(1,1)=ZZ
440 CONTINUE
GO TO 444
490 HPMAEX=Z01M/2.000
HPMAEX=Z01M/2.000
DO 430 I=1,NBARS
430 YGRIDLO=FLAT((-1)*GRID
Y3=1.000-(Y-YCT)/HPMAEX) #2
IF (Y3.GT.0.0) W3=0.0
ZZ=HPMAEX#SORT(Y3)
Z(1,1)=ZZ+ZCT
Z(2,1)=Z3+ZCT
450 CONTINUE
490 L=0
N=1
CALL SLIM(0.0,PBLK,5)
YQ=P(1,1)
INDEX=INT((YQ-GRIDLO)/GRID+1.001)
DO 900 I=1,NPOINT
900 IF (P(1,1).EQ.YQ) GO TO 490
IF (L.GT.2) GO TO 470
N=N-L
470 L=0
YQ=P(1,1)
INDEX=INT((YQ-GRIDLO)/GRID+1.001)
490 PBLK(1)=P(1,1)
PBLK(2)=P(2,1)
TEST=1.0
IF ((Z(2,1).EQ.Z(1,1).AND.P(2,1).EQ.Z(2,1).AND.P(2,1).LE.Z(2,1))) TEST=0.0
IF (P(2,1).LT.Z(1,1).AND.P(2,1).LT.Z(2,1)) TEST=1.0
TESTUL=#MFMLH1*#MFMLH1*#MFMLH1*#MFMLH1*#MFMLH1
* - HFMABL*HFMABL*(P(2,1)-ZCBL)*(P(2,1)-ZCBL)
  * - HFMIBL*HFMIBL*(P(1,1)-YCBL)*(P(1,1)-YCBL)

IF (TEST) 701, 501, 501
501 IF (TESTBL.LE.0.0) GO TO 510
   CALL MOVEMPBLK(P1,N), 5
   GO TO 515
510 CALL MOVEMP(1,1), P1, N), 5
515 N=N+1
   L=L+1
   IF (TEST.EQ.0.0) GO TO 800
701 IF (L.EQ.0.0) GO TO 800
   IF (TEST*TEST) 704, 800, 800
704 CALL INTLP(g, oD, P1, P1, Z(I, IDEX))
   NCMP = 0
   IF (TEST.EQ.0.0) GO TO 711
   CALL MOVLMP(I, N-1), P1, N, 5)
   NCMP = 1
711 CALL MOVLMP(P, P1, P1, 2)
   TESTL = HFMABL*HFMABL*HFMIBL*HFMIBL
   * - HFMABL*HFMABL*(P(2,1)-ZCBL)*(P(2,1)-ZCBL)
   * - HFMIBL*HFMIBL*(P(1,1)-YCBL)*(P(1,1)-YCBL)
   IF (TEST.EQ.0.0) GO TO 720
   CALL MOVLMPBLK(P1, N-NCMP+1, 5)
   GO TO 725
720 CALL MOVLMP(PI, N-NCMP), 5)
725 N=N+1
   L=L+1
600 CALL MOVLMP(1,1), P1, N)
   TEST = TEST
900 CONTINUE
   INPU1 = I N-1
   NCMP = NCPHIM
   CALL MOVLMP(PI, N-1, N-LUC)
   IF(J(J=1, L)=0.0) WRITE(7, 301) NPOINT, CALL
   IF(J(J=1, L)=0.0) WRITE(7, 301) NPOINT, CALL
   IF(J(J=1, L)=0.0) RETURN
   PRINT 950, YMIN, YMAX, ZMIN, ZMAX, GRIDL, GRIDM, GRIDN, NPARS, NPOINT
950 FORMAT(/"QUANTIFICATION DATA."/
   * POINT PATTERN EXTENTS ON APERTURE PLANE............YMIN=*.F7.2/
   * .........YMAX=*.F7.2/
   * ...........ZMIN=*.F7.2/
   * ...........ZMAX=*.F7.2/
   * GRID RANGES FROM................................*.F3,* Tu
   * .F3,*
   * SPACING BETWEEN GRID BARS IS................................*.F8.4/
   * THE NUMBER OF GRID BARS................................*.F8.4/
   * NUMBER OF POINTS SUPPLIED TO RADPAT........................*.F8.4/
   * 951 FORMAT("ID")
952 FORMAT("ID",101)
   RETURN
1000 PRINT , 000
1000 FORMAT/"
   * ************* ( ARRAY FOR POINT RESIDENCE NOT FILLED CORRECTLY
   * *************.I/10A,** STOP EXECUTION **)
   STOP
   END
8.7. APPENDIX G

OUTPUT FOR TEST CASES A AND B
**FARFIELD RADIATION PATTERN CALCULATION**

**CASE STUDY: ANTENNA EXAMPLE**

A PARABOLOID-HYPERBOLOID COMBINATION

FEED: HYBRID

**INPUT PARAMETERS:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength of Electric Field</td>
<td>4.7340</td>
</tr>
<tr>
<td>Location of Feed Origin in Feed Plane ((x, y, z))</td>
<td>(-1, 0, 0)</td>
</tr>
<tr>
<td>Feed Rotation Angles ((\alpha, \beta, \gamma))</td>
<td>(0, 0, -180, 000)</td>
</tr>
<tr>
<td>Aperture Plane Location ((x, y, z))</td>
<td>(0, 0)</td>
</tr>
<tr>
<td>Sub-Dish Shadow Center Coordinates in Aperture Plane</td>
<td>(0, 0)</td>
</tr>
<tr>
<td>Half-Minor Axis of Sub-Dish Shadow</td>
<td>(0, 0)</td>
</tr>
<tr>
<td>Number of Panels in Reflector</td>
<td>0</td>
</tr>
</tbody>
</table>

**MAIN DISH DESCRIPTION AND ITS PARAMETERS:**

- It is a parabolic reflector.
- Focal Length of the Reflector | 100, 000 |
- Number of Panels in Single Panel Model | 100 |
- Minimum-Y Point on the Reflector \((x, y, z)\) | (-65, 600 - 117, 304, 0) |
- Maximum-Y Point on the Reflector \((x, y, z)\) | (-65, 600 117, 304, 0) |
- Minimum-Z Point on the Reflector \((x, y, z)\) | (-65, 600, 0, 0) |
- Maximum-Z Point on the Reflector \((x, y, z)\) | (-65, 600, 0, 0) |

**ORIGINAL PAGE IS OF POOR QUALITY**
SUBLISH DESCRIPTION AND ITS PARAMETERS:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>IT IS A HYPERBOLIC REFLECTOR</td>
<td></td>
</tr>
<tr>
<td>MAJOR AXIS REFLECT IN X DIRECTION</td>
<td>70° 26'</td>
</tr>
<tr>
<td>AXIS OF REFLECTOR IN Y DIRECTION</td>
<td>33° 95'</td>
</tr>
<tr>
<td>AXIS OF REFLECTOR IN Z DIRECTION</td>
<td>73° 90'</td>
</tr>
<tr>
<td>DISTANCE USED FOR TRANSLATION OF ORIG. OF AXES</td>
<td>45° 50'</td>
</tr>
</tbody>
</table>

**MINIMUM-Y POINT ON THE REFLECTOR (X,Y,Z)**
-10° 712 -19° 156 0° 0

**MAXIMUM-Y POINT ON THE REFLECTOR (X,Y,Z)**
-10° 712 19° 156 0° 0

**MINIMUM-Z POINT ON THE REFLECTOR (X,Y,Z)**
-10° 712 0° 0 -19° 156

**MAXIMUM-Z POINT ON THE REFLECTOR (X,Y,Z)**
-10° 712 0° 0 19° 156

**NUMBERS OF PATTERN GROUP REQUESTED**
- 2

**THETA** = 90° 00' 00"
**PHI** = 0° 00' 00"
**THETA FROM** = 38° 00' 00"
**THETA TO** = 51° 00' 00"
**THETA BY** = 0° 25' 00"
**PHI FROM** = -4° 00' 00"
**PHI TO** = 4° 00' 00"
**PHI BY** = 0° 25' 00"

**ILLUMINATION DATA**

<table>
<thead>
<tr>
<th>THETA ILLUMINATION FROM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>76° 07' 00&quot; TO 103° 02' 00&quot;</td>
</tr>
<tr>
<td>PHI ILLUMINATION FROM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>166° 07' 00&quot; TO 193° 02' 00&quot;</td>
</tr>
</tbody>
</table>

**INCREMENTAL ANGLE (DEG)**
- 0° 52' 00"

**TOTAL NUMBER OF GENERATED POINTS**
- 2025

FINISHED APERTURE
# Table of Principal Stress Intensities (201)

Principal Plane of Cut is Theta = 90,000 Deg

<table>
<thead>
<tr>
<th>PHI</th>
<th>\theta (Z/Y)</th>
<th>\phi (Y/Y)</th>
<th>\sigma (Z/Y)</th>
<th>\phi (Y/Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.250</td>
<td>-21,45000</td>
<td>152,9000</td>
<td>121,41615</td>
<td>0,0</td>
</tr>
<tr>
<td>-1,750</td>
<td>-31,27216</td>
<td>152,9000</td>
<td>121,41615</td>
<td>0,0</td>
</tr>
<tr>
<td>-2,500</td>
<td>-31,27216</td>
<td>152,9000</td>
<td>121,41615</td>
<td>0,0</td>
</tr>
<tr>
<td>-3,250</td>
<td>-24,31747</td>
<td>152,9000</td>
<td>128,37283</td>
<td>0,0</td>
</tr>
<tr>
<td>-2,750</td>
<td>-24,31747</td>
<td>152,9000</td>
<td>128,37283</td>
<td>0,0</td>
</tr>
<tr>
<td>-2,500</td>
<td>-24,31747</td>
<td>152,9000</td>
<td>128,37283</td>
<td>0,0</td>
</tr>
<tr>
<td>-2,250</td>
<td>-24,31747</td>
<td>152,9000</td>
<td>128,37283</td>
<td>0,0</td>
</tr>
<tr>
<td>-2,000</td>
<td>-24,31747</td>
<td>152,9000</td>
<td>128,37283</td>
<td>0,0</td>
</tr>
<tr>
<td>-1,750</td>
<td>-24,31747</td>
<td>152,9000</td>
<td>128,37283</td>
<td>0,0</td>
</tr>
<tr>
<td>-1,500</td>
<td>-24,31747</td>
<td>152,9000</td>
<td>128,37283</td>
<td>0,0</td>
</tr>
<tr>
<td>-1,250</td>
<td>-24,31747</td>
<td>152,9000</td>
<td>128,37283</td>
<td>0,0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>1.750</td>
<td>18.26170</td>
<td>-152.69030</td>
<td>134.40860</td>
<td>0.0</td>
</tr>
<tr>
<td>2.50</td>
<td>21.42020</td>
<td>-152.69030</td>
<td>131.28530</td>
<td>0.0</td>
</tr>
<tr>
<td>3.750</td>
<td>29.65977</td>
<td>-152.69030</td>
<td>127.03053</td>
<td>0.0</td>
</tr>
<tr>
<td>5.25</td>
<td>31.747</td>
<td>-152.69030</td>
<td>128.77283</td>
<td>0.0</td>
</tr>
<tr>
<td>7.750</td>
<td>56.65126</td>
<td>-152.69030</td>
<td>96.027604</td>
<td>0.0</td>
</tr>
<tr>
<td>10.0</td>
<td>71.2725</td>
<td>-152.69030</td>
<td>121.44151</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**MAXIMUM FIELD VALUES:**

\[
\text{20LOG}(\text{MAX(FIELD-7)})=20\text{LOG}(4.3103777)\text{ = 92.6502594}
\]

\[
\text{20LOG}(\text{MAX(FIELD-Y)})=20\text{LOG}(1.1314110-13)\text{ = -60.0000000}
\]

**INTERPOLATION NUMBER USED FOR INTEGRATION IS:**
<table>
<thead>
<tr>
<th>THETA</th>
<th>DP(°/°)</th>
<th>DY(°/°)</th>
<th>DP(D°/°)</th>
<th>DY(Y/°)</th>
<th>DREF</th>
</tr>
</thead>
<tbody>
<tr>
<td>60.60</td>
<td>-70.777</td>
<td>-152.693</td>
<td>0.000</td>
<td>0.000</td>
<td>-30.777</td>
</tr>
<tr>
<td>60.50</td>
<td>-70.684</td>
<td>-152.690</td>
<td>0.000</td>
<td>0.000</td>
<td>-30.684</td>
</tr>
<tr>
<td>60.40</td>
<td>-70.581</td>
<td>-152.687</td>
<td>0.000</td>
<td>0.000</td>
<td>-30.581</td>
</tr>
<tr>
<td>60.30</td>
<td>-70.478</td>
<td>-152.684</td>
<td>0.000</td>
<td>0.000</td>
<td>-30.478</td>
</tr>
<tr>
<td>60.20</td>
<td>-70.375</td>
<td>-152.681</td>
<td>0.000</td>
<td>0.000</td>
<td>-30.375</td>
</tr>
<tr>
<td>60.10</td>
<td>-70.272</td>
<td>-152.678</td>
<td>0.000</td>
<td>0.000</td>
<td>-30.272</td>
</tr>
<tr>
<td>60.00</td>
<td>-70.168</td>
<td>-152.675</td>
<td>0.000</td>
<td>0.000</td>
<td>-30.168</td>
</tr>
<tr>
<td>59.90</td>
<td>-70.065</td>
<td>-152.672</td>
<td>0.000</td>
<td>0.000</td>
<td>-30.065</td>
</tr>
<tr>
<td>59.80</td>
<td>-69.962</td>
<td>-152.669</td>
<td>0.000</td>
<td>0.000</td>
<td>-29.962</td>
</tr>
<tr>
<td>59.70</td>
<td>-69.858</td>
<td>-152.666</td>
<td>0.000</td>
<td>0.000</td>
<td>-29.858</td>
</tr>
<tr>
<td>59.60</td>
<td>-69.755</td>
<td>-152.663</td>
<td>0.000</td>
<td>0.000</td>
<td>-29.755</td>
</tr>
<tr>
<td>59.50</td>
<td>-69.652</td>
<td>-152.660</td>
<td>0.000</td>
<td>0.000</td>
<td>-29.652</td>
</tr>
<tr>
<td>59.40</td>
<td>-69.549</td>
<td>-152.657</td>
<td>0.000</td>
<td>0.000</td>
<td>-29.549</td>
</tr>
<tr>
<td>59.30</td>
<td>-69.446</td>
<td>-152.654</td>
<td>0.000</td>
<td>0.000</td>
<td>-29.446</td>
</tr>
<tr>
<td>59.20</td>
<td>-69.342</td>
<td>-152.651</td>
<td>0.000</td>
<td>0.000</td>
<td>-29.342</td>
</tr>
<tr>
<td>59.10</td>
<td>-69.239</td>
<td>-152.648</td>
<td>0.000</td>
<td>0.000</td>
<td>-29.239</td>
</tr>
<tr>
<td>59.00</td>
<td>-69.135</td>
<td>-152.645</td>
<td>0.000</td>
<td>0.000</td>
<td>-29.135</td>
</tr>
</tbody>
</table>
APERTURE PLANE AFTER QUANTIZING
OFFSET CASSEGRAIN ANTENNA EXAMPLE...
A PARABOLOID- HYPERBOLOID COMBINATION
MARCH 27 1981
TICKA AP/3

INPUT PARAMETERS-
WAVELENGTH OF ELECTRIC FIELD
LOCATION OF COORDINATE ORIGIN FOR FIELD (X,Y,Z)
FIELD ROTATION ANGLES (ALPHA,BETA,GAMMA)
APERTURE PLANE LOCATION (X,Y,Z)
SIDE DISH SHADOW CENTER COORDINATES IN APERTURE PLANE
HALF MAJOR AXIS OF SUB DISH SHADOW
HALF MINOR AXIS OF SUB DISH SHADOW
NUMBER OF PANELS IN REFLECTOR

0.9843
-3.726 0 0 -163.69
9.331
0.0 0.0
0.0 0.0 0.0
0.5
0.5
0.0
0
<table>
<thead>
<tr>
<th>Description and Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paraboloid Description and Its Parameters</strong></td>
<td></td>
</tr>
<tr>
<td>It is a parabolic reflector</td>
<td></td>
</tr>
<tr>
<td>Focal length of the reflector</td>
<td>0.83</td>
</tr>
<tr>
<td>Minimum point on the reflector (x,y,z)</td>
<td>-37.19, -31.93, 89.04</td>
</tr>
<tr>
<td>Maximum point on the reflector (x,y,z)</td>
<td>85.02, -0.00, 81.547</td>
</tr>
<tr>
<td>Minimum-z point on the reflector (x,y,z)</td>
<td>-65.55, -0.00, 17.773</td>
</tr>
</tbody>
</table>

| **Spherical Description and Its Parameters** |        |
| It is a hyperbolic reflector |        |
| Major axis of reflector in x direction | 0.99  |
| Axis of reflector in y direction | 15.12 |
| Axis of reflector in z direction | 15.44 |
| Distance used for translation of origin of axes | 19.63 |
| Minimum point on the reflector (x,y,z) | -8.74, -4.87, 7.59 |
| Maximum point on the reflector (x,y,z) | -8.74, 9.07, 7.59 |
| Maximum-z point on the reflector (x,y,z) | -7.57, -0.00, 13.47 |
| Minimum-z point on the reflector (x,y,z) | -7.74, -0.00, 2.927 |

*Subdish Description and Its Parameters*
PATTERN OF FIELDS IN ONE-DEG INCREMENT OFF-AXIS:

**E-PLANE**

<table>
<thead>
<tr>
<th>PHI</th>
<th>THETA</th>
<th>FIELD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>90.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.78530600000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.36617100000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.11756000000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

NUMBER OF PATTERN GROUNDS REQUESTED: 2

PHI FROM -90.000 TO 90.000 BY 0.500
THETA FROM 0.000 TO 90.000 BY 0.500
ILLUMINATION DATA

THETA ILLUMINATION FROM: 79.379 TO 101.848
PHI ILLUMINATION FROM: 106.789 TO 191.935
INCREMENTAL ANGLE (DEG): 0.5167

THEREFORE TOTAL NUMBER OF GENERATED RAYS: 2325
TOTAL NUMBER OF APERTURE PLANE POINTS: 2029

------------------ FINISHED APERTURE ------------------

QUANTIZING DATA

POINT PATTERN EXTENTS ON APERTURE PLANE:

YMIN = -3.01
YMAX = 3.01
ZMIN = 1.77
ZMAX = 81.53

GRID RANGES FROM:

-31.506 TO 31.068

SPACING BETWEEN GRID BARS: 0.004

THEREFORE NUMBER OF GRID BARS: 43

NUMBER OF POINTS SUPPLIED TO RAPID: 1479

------------------ FINISHED QUANTIZE ------------------

------------------ FINISHED INTOUT ------------------

------------------ FINISHED INTOUT ------------------

------------------ PATTERN COMPUTATIONS COMPLETE ------------------
<table>
<thead>
<tr>
<th>Theta</th>
<th>U0 (L/2)</th>
<th>U0 (L/C)</th>
<th>U0 (L/Y)</th>
<th>U0 (L/Y)</th>
<th>Purity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>-0.9393</td>
<td>-0.9393</td>
<td>-2.0423</td>
<td>-2.0423</td>
<td>-3.46142</td>
</tr>
<tr>
<td>0.15</td>
<td>-2.67029</td>
<td>-2.67029</td>
<td>-2.1069</td>
<td>-2.1069</td>
<td>-2.98389</td>
</tr>
<tr>
<td>0.2</td>
<td>-2.1047</td>
<td>-2.1047</td>
<td>-0.7937</td>
<td>-0.7937</td>
<td>-0.94876</td>
</tr>
<tr>
<td>0.25</td>
<td>-1.6403</td>
<td>-1.6403</td>
<td>-0.3977</td>
<td>-0.3977</td>
<td>-0.62678</td>
</tr>
<tr>
<td>0.3</td>
<td>-1.2759</td>
<td>-1.2759</td>
<td>-0.1982</td>
<td>-0.1982</td>
<td>-0.38778</td>
</tr>
<tr>
<td>0.35</td>
<td>-0.9115</td>
<td>-0.9115</td>
<td>-0.0994</td>
<td>-0.0994</td>
<td>-0.2183</td>
</tr>
<tr>
<td>0.4</td>
<td>-0.5471</td>
<td>-0.5471</td>
<td>-0.0011</td>
<td>-0.0011</td>
<td>-0.1164</td>
</tr>
<tr>
<td>0.45</td>
<td>-0.1827</td>
<td>-0.1827</td>
<td>0.097</td>
<td>0.097</td>
<td>0.0507</td>
</tr>
<tr>
<td>0.5</td>
<td>0.1827</td>
<td>0.1827</td>
<td>0.097</td>
<td>0.097</td>
<td>0.1494</td>
</tr>
<tr>
<td>0.55</td>
<td>0.5471</td>
<td>0.5471</td>
<td>0.0994</td>
<td>0.0994</td>
<td>0.38778</td>
</tr>
<tr>
<td>0.6</td>
<td>0.9115</td>
<td>0.9115</td>
<td>0.0994</td>
<td>0.0994</td>
<td>0.62678</td>
</tr>
<tr>
<td>0.65</td>
<td>1.2759</td>
<td>1.2759</td>
<td>0.097</td>
<td>0.097</td>
<td>0.94876</td>
</tr>
<tr>
<td>0.7</td>
<td>1.6403</td>
<td>1.6403</td>
<td>0.0994</td>
<td>0.0994</td>
<td>2.1069</td>
</tr>
<tr>
<td>0.75</td>
<td>2.0423</td>
<td>2.0423</td>
<td>0.0994</td>
<td>0.0994</td>
<td>2.67029</td>
</tr>
<tr>
<td>0.8</td>
<td>2.67029</td>
<td>2.67029</td>
<td>0.0994</td>
<td>0.0994</td>
<td>3.46142</td>
</tr>
</tbody>
</table>

This table contains the principal plane data for various values of theta. The angles range from 0.1 to 0.8 in increments of 0.1. The purity values are calculated and listed for each angle.
Table of Electrical Field Dimensions (cm)

**Principal plane of cut is Theta = 90.0° Deg**

**Angle Phi from -2.000 to 2.000 by 0.080 Deg**

<table>
<thead>
<tr>
<th>Phi</th>
<th>Du(x/2)</th>
<th>Du(y/z)</th>
<th>Du(x/2)</th>
<th>Du(y/z)</th>
<th>Percd</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.00</td>
<td>10.4846</td>
<td>4.5598</td>
<td>-8.03507</td>
<td>-37.46504</td>
<td>-37.42345</td>
</tr>
<tr>
<td>-1.84</td>
<td>10.6874</td>
<td>4.7170</td>
<td>1.33000</td>
<td>-37.97777</td>
<td>-38.60200</td>
</tr>
<tr>
<td>-1.60</td>
<td>10.9893</td>
<td>4.9513</td>
<td>-7.39436</td>
<td>-24.36599</td>
<td>-29.58626</td>
</tr>
<tr>
<td>-1.52</td>
<td>11.0896</td>
<td>5.0287</td>
<td>-2.84923</td>
<td>-25.33793</td>
<td>-35.33712</td>
</tr>
<tr>
<td>-1.44</td>
<td>11.1899</td>
<td>5.1061</td>
<td>3.01736</td>
<td>-27.68959</td>
<td>-27.68822</td>
</tr>
<tr>
<td>-1.36</td>
<td>11.2802</td>
<td>5.1835</td>
<td>6.09414</td>
<td>-34.32964</td>
<td>-37.91264</td>
</tr>
<tr>
<td>-1.28</td>
<td>11.3705</td>
<td>5.2609</td>
<td>9.35827</td>
<td>-35.33200</td>
<td>-25.55227</td>
</tr>
<tr>
<td>-1.12</td>
<td>11.5511</td>
<td>5.4157</td>
<td>15.66903</td>
<td>-25.51058</td>
<td>-15.42473</td>
</tr>
<tr>
<td>-1.04</td>
<td>11.6414</td>
<td>5.4931</td>
<td>18.82390</td>
<td>-12.47549</td>
<td>-12.47193</td>
</tr>
<tr>
<td>0.00</td>
<td>11.7317</td>
<td>5.5705</td>
<td>21.97876</td>
<td>-7.99246</td>
<td>-7.99114</td>
</tr>
<tr>
<td>0.08</td>
<td>11.8220</td>
<td>5.6479</td>
<td>25.13363</td>
<td>-7.02071</td>
<td>-6.46774</td>
</tr>
<tr>
<td>0.16</td>
<td>11.9123</td>
<td>5.7253</td>
<td>28.28859</td>
<td>-4.85125</td>
<td>-4.85125</td>
</tr>
<tr>
<td>0.24</td>
<td>12.0026</td>
<td>5.8027</td>
<td>31.44355</td>
<td>-3.04924</td>
<td>-3.04924</td>
</tr>
<tr>
<td>0.32</td>
<td>12.0929</td>
<td>5.8801</td>
<td>34.59860</td>
<td>-2.03363</td>
<td>-2.03363</td>
</tr>
<tr>
<td>0.40</td>
<td>12.1832</td>
<td>5.9575</td>
<td>37.75365</td>
<td>-1.01793</td>
<td>-1.01793</td>
</tr>
<tr>
<td>0.48</td>
<td>12.2735</td>
<td>6.0349</td>
<td>40.90870</td>
<td>-0.00232</td>
<td>-0.00232</td>
</tr>
<tr>
<td>0.56</td>
<td>12.3638</td>
<td>6.1123</td>
<td>44.06375</td>
<td>0.000426</td>
<td>0.000426</td>
</tr>
<tr>
<td>0.64</td>
<td>12.4541</td>
<td>6.1897</td>
<td>47.21880</td>
<td>0.000936</td>
<td>0.000936</td>
</tr>
<tr>
<td>0.72</td>
<td>12.5444</td>
<td>6.2671</td>
<td>50.37385</td>
<td>0.001446</td>
<td>0.001446</td>
</tr>
</tbody>
</table>

Original page is of poor quality.
PRINCIPAL PLANE = IHETA 90.0 DEGREES

NORMALIZED POWER PATTERN (DB)

<table>
<thead>
<tr>
<th>PHI (DEG)</th>
<th>-30</th>
<th>-50</th>
<th>-40</th>
<th>-30</th>
<th>-20</th>
<th>-10</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>