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MULTIWALL RADOME ANALYSIS PROGRAM

Air-to-Ground Analysis Group
Reconnaissance and Weapon Delivery Division

February 1976

TECHNICAL REPORT AFAL-TR-75-183

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This report describes a computer analysis tool for calculating the electrical transmission and reflection properties of a multiwall radome. The radome program may be used with a suitable antenna program to estimate the effects of the radome on the antenna pattern.

The analysis tool is comprised of two programs, a radome-geometry program, RADOME, and a flat-panel analysis program, WAVES2. The geometry program calculates the incidence angle for each ray (a ray represents the radiated RF power from each antenna element) at the radome wall. The output data (Contd)

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Abstract continued:

from the geometry program, RADOME, serves as input to the flat-panel program. The flat-panel program then calculates the electrical transmission and reflection parameters of the radome for each ray. These parameters may then be used with a suitable free-space antenna pattern simulation program, and the resultant antenna pattern in the presence of the radome can be computed.

FOREWORD

The computer program in this report was written for the Air Force Avionics Laboratory's Electronically Agile Radar (EAR) program. The work was performed by personnel from the Air-to-Ground Analysis Group, Mr. Richard M. Reeves, Group Leader, Analysis and Evaluation Branch, Reconnaissance and Weapon Delivery Division. Mr. Robert M. Blumgold was the principal investigator. Special acknowledgment is due Dr. James McDougal of the Air-to-Air Analysis Group, Mrs. Georgeanne Chitwood of the Air-to-Ground Analysis Group, and to Mr. Clyde Hoots of the Brunswick Corp., Marion, Va., for their valuable assistance during this study.

Publication of this report does not constitute Air Force approval of the report findings or conclusions. It is published only for the exchange and stimulation of ideas.

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LIST OF SYMBOLS

x_{at}, y_{at}, z_{at}	Antenna coordinates of point of interest
R	Magnitude of the vector from antenna phase center to point of interest
θ_e, θ_a	Antenna elevation and azimuth scan angles
λ	Wavelength
D	Antenna aperture
x_{ij}, y_{ij}, z_{ij}	Antenna coordinates of the i, j element, where i and j are the row and column number respectively
α_{ij}, β_{ij}, γ_{ij}	Are the direction cosines from each element to point of interest
R_{ij}	Vector from i, j element to point of interest
X_r, Y_r, Z_r	Coordinate system used in defining radome contour
y_i, z_i	Coordinates of radome stations
ΔYR_i	y axis location of radome station i relative to the antenna phase center
α'	Angle between the antenna phase center to point of interest and the YR axis
z_{ir}	Z coordinate of radome station i
x_a, y_a, z_a	Antenna coordinate system
θ	Rotation angle about the YR axis
θ_I	Initial rotation angle about the YR axis
$\Delta\theta$	Incremental change in the rotation angle about the YR axis
x_o, y_o, z_o	Radome coordinates of the antenna phase center
α_j, β_j, γ_j	Direction cosines of illuminated area of the radome
$X_{\theta j}$, $Y_{\theta j}$, $Z_{\theta j}$	Are the components of the vector from the antenna phase center to the radome surface
$TMAG_{\theta j}$	Magnitude of the vector from the antenna phase center to the illuminated area of the radome

X_{mn}, Y_{mn}, Z_{mn}	Coordinates of array elements
m, n	Antenna array element row and column numbers respectively
α, β, γ	Direction cosines for the point of interest relative to the antenna phase center
α_{ij}, β_{ij}, γ_{ij}	Direction cosines of the ray from each element to the illuminated area of the radome
B_i-B_n	Least squares fit coefficients for radome contour
$\underline{n}_R$	Unit normal to radome surface (radome coordinates)
$\underline{n}_A$	Unit normal to radome surface (antenna coordinates)

SECTION I

INTRODUCTION

1. GENERAL

This technical report describes a digital computer analysis program which will calculate the electrical transmission and reflection properties of a multiwall radome. The radome program may be used with a suitable antenna program to estimate the effects of the radome on the antenna pattern.

The analysis program is comprised of two programs, a radome-geometry program, RADOME, and a flat-panel analysis program, WAVES2. The radome-geometry program calculates the incidence angle for each ray (a ray represents the radiated RF power from each antenna element) at the radome wall. The output from the geometry program serves as an input to the flat-panel program. The flat-panel program, WAVES2, calculates the electrical transmission and reflection parameters of the radome for each ray, using the input from RADOME. These parameters may then be used with a suitable free-space antenna pattern simulation program, and the resultant antenna pattern in the presence of the radome can then be computed.

This technical report documents the radome-geometry program, RADOME, and the necessary modifications to the flat-panel program, WAVES2. A complete description of the flat-panel program may be found in AFAL-TR-67-191.

2. DEFINITION OF THE PROBLEM

The specific problem which generated the radome analysis program involved position fixing accuracy using an aircraft forward-looking multimode radar. For example, a position fix is to be made of a ground target at location "A" (Figure 1). The antenna electrical boresight is steered to the estimated azimuth, θ_a, and elevation, θ_e, of the target. Then by using the antenna's monopulse patterns, an accurate measurement of the target's location relative to the antenna electrical boresight may be determined. However, due to the distortion of the antenna's free-space pattern in the presence of the radome, an error exists in determining the azimuth and elevation location of the target relative to the steered direction of the antenna electrical boresight. Therefore, to minimize the measurement inaccuracies it is desirable to estimate the antenna pattern in the presence of the radome and use this information to correct the measurement of target location.

A table of correction terms may be generated by using the radome analysis program and a suitable antenna pattern simulation program. A set of azimuth and elevation scan angles can be used as inputs to the geometry program, RADOME, to generate the incidence angles for the ray from each element in the antenna array and the information stored on magnetic tape. The magnetic tape storage is required because of the large number of rays involved and the computation time required. The incidence angle information from RADOME on the magnetic tape is then input to the flat-panel program, WAVES2. In the WAVES2 program the transmission and reflection parameters are calculated for each element in the antenna array for given antenna electrical boresight azimuth and elevation angles. Transmission and reflection parameters calculated by

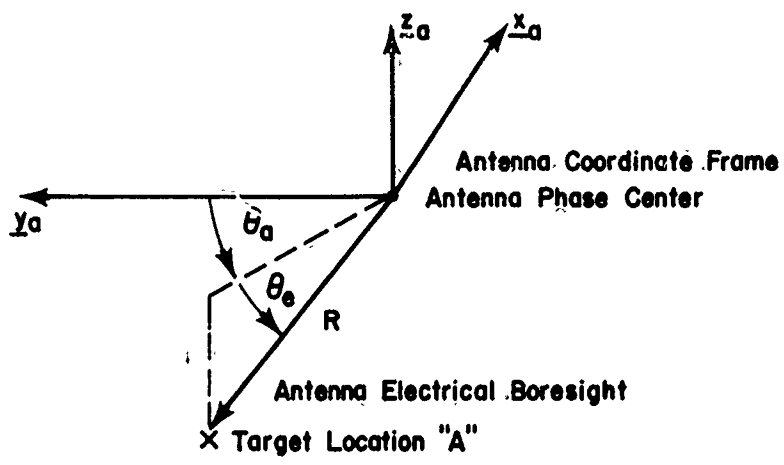

Figure 1. Position Fix

the WAVES2 program can then serve as inputs to a suitable antenna pattern simulation program, and a table of correction terms (i.e., boresight shift) can be generated and subsequently used to correct the measurement of the target's azimuth and elevation location.

3. REPORT ORGANIZATION

This technical report is divided into eight sections. Section two describes items included in the documentation, method of analysis, equations involved, geometry, input and output parameters. Section three gives the variables, common, labeled common, dimension, and data statements for the main program and all subroutines. Section four outlines the input deck structure, defines the required data, and establishes the format of the input data cards. Section five presents a sample problem with a typical set of data describing the radome, gives the user's output requirements, lists the printout, and describes the data stored on magnetic tape for later use. Flowcharts and program listings have been included. Section six describes the Flat-Panel Program and Section seven offers recommendations for best utilization of the routine.

SECTION II

DEVELOPMENT OF THE RADOME-GEOMETRY PROGRAM (RADOME)

1. METHOD

The RADOME program applies the techniques of ray tracing to an antenna array and a multiwall radome, and calculates the incidence angles of antenna radiation at the radome inner surface. The incidence angles are needed to compute reflection and transmission parameters which were accomplished by program WAVES2.

2. DERIVATION OF EQUATIONS

The rectangular coordinates of the point of interest (a point at which the antenna boresight is directed) are computed from the given scan angles of the antenna's electrical boresight. The antenna coordinate system is defined by a unit vector, $\underline{y}_a$, normal to the face of the antenna array, a unit vector $\underline{x}_a$, which is parallel to the face of the array and at a right angle to $\underline{y}_a$, and a unit vector $\underline{z}_a$, parallel to the array face and perpendicular to $\underline{x}_a$ and $\underline{z}_a$. The aximuth angle, θ_a, is defined in the plane determined by $\underline{x}_a$ and $\underline{y}_a$. The elevation angle θ_e is defined in a plane perpendicular to the one formed by $\underline{x}_a$ and $\underline{y}_a$.

The location of the antenna array elements is computed in antenna coordinates, one quadrant of the array at a time. The central elements of the array are spaced one quarter of a wavelength from the phase center of the array. The antenna aperture is assumed to be circular, with the elements arranged in a rectangular grid out to the aperture's edge. The maximum number of rows and columns is specified as a user

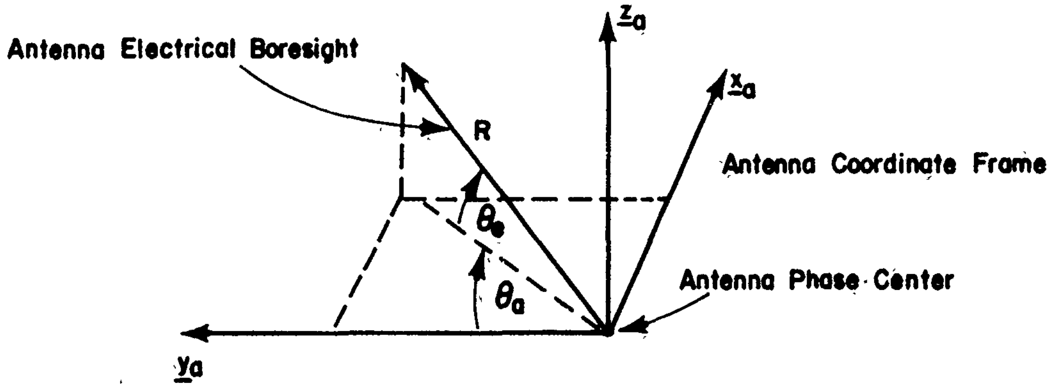

Figure 2. Antenna Scan Angles

Then,

$$x_{at} = R \cos\theta_e \sin\theta_a \quad (1)$$

$$y_{at} = R \cos\theta_e \cos\theta_a \quad (2)$$

$$z_{at} = R \sin\theta_e \quad (3)$$

input. The coordinates of those elements that are contained within a given aperture radius are stored for later use (Figure 3).

The antenna coordinate system is a rectangular coordinate system with its origin at the antenna phase center. In antenna coordinates the location of the (i,j)-element is denoted by x_{ij}, y_{ij}, z_{ij}.

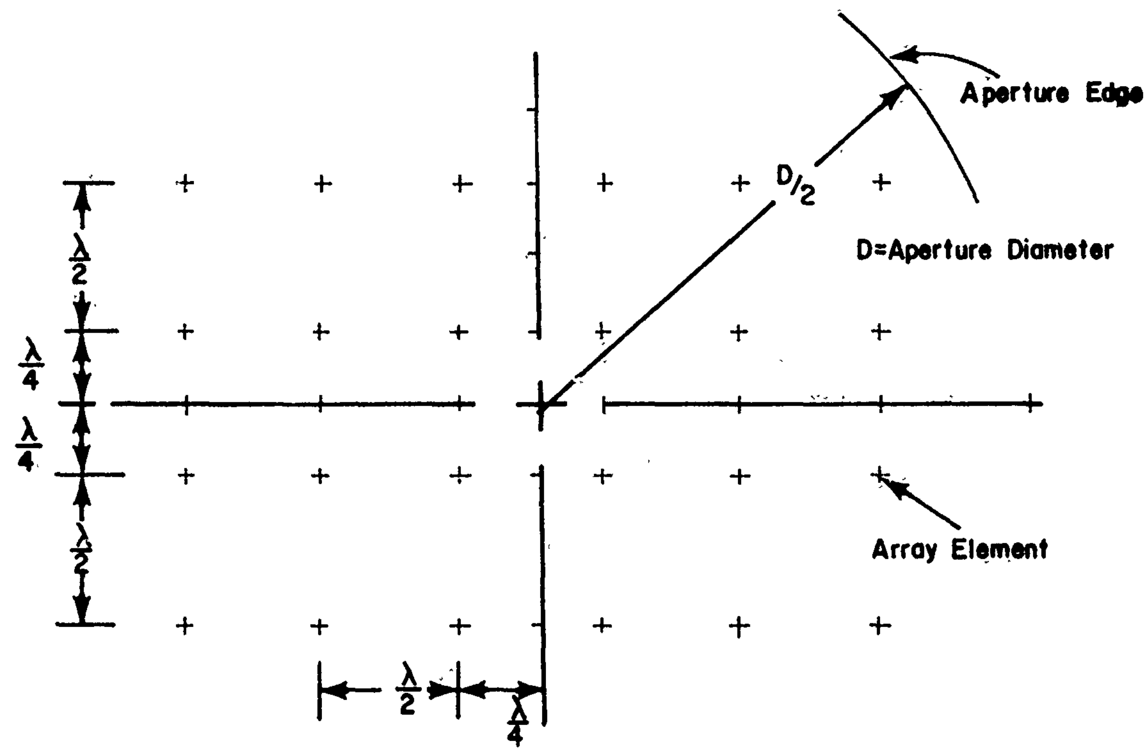

Figure 3. Array Element Geometry

The direction cosines of a ray from array element (i,j) to the point of interest are determined as follows:

$$\alpha_{ij} = \frac{(x_{at} - x_{ij})}{|R_{ij}|} \qquad (4)$$

$$\beta_{ij} = \frac{(y_{at} - y_{ij})}{|R_{ij}|} \qquad (5)$$

$$\gamma_{ij} = \frac{(z_{at} - z_{ij})}{|R_{ij}|} \qquad (6)$$

where

$$|R_{ij}| = \left[(x_{at} - x_{ij})^2 + (y_{at} - y_{ij})^2 + (z_{at} - z_{ij})^2\right]^{1/2} \qquad (7)$$

and i = row number

j = column number

The radome is a body of revolution over the complete window area. The radome contour is generated by rotating the curve (Figure 4), representing the outside mold line, about the YR axis. Coordinates of the radome contour y_i and z_i are given by the manufacturer in tabular form. Data cards containing the y_i and z_i coordinates of points on the radome contour are used as inputs to the computer program. Usually, points are spaced more closely together on the YR axis nearer the front of the radome. The radome axis, YR, and the antenna axis, $\underline{y}_a$, are assumed to be parallel. (Due to program storage limitations it is necessary to store only the coordinates of the radome surface that will encompass the projected surface area of the antenna aperture in the given scan direction.)

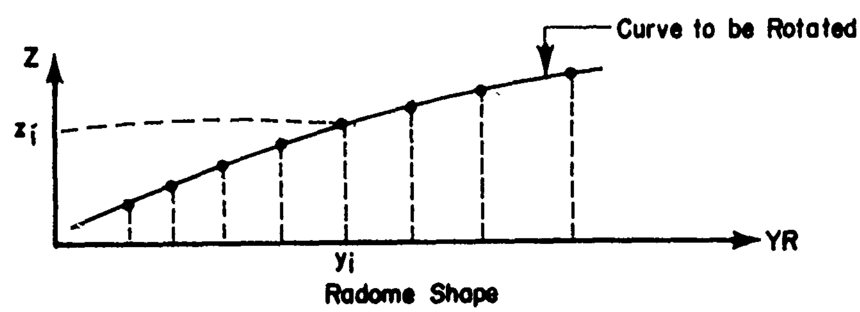

Figure 4. Radome Outside Mold Line Contour

The angle (α') between a ray from the central area of the antenna aperture and the YR axis is used to determine the region where this ray passes through the radome's surface (Figure 5). The angle (α') is determined from the following equations.

$$x = x_{at} - x_{11} \quad (8)$$

$$y = y_{at} - y_{11} \quad (9)$$

$$z = z_{at} - z_{11} \quad (10)$$

$$|R| = \left[x^2 + y^2 + z^2\right]^{1/2} \quad (11)$$

$$\alpha' = \cos^{-1}\left[\frac{y}{|R|}\right] \quad (12)$$

The interval ΔYR_i on the YR axis is obtained by subtracting the YR coordinate of the ith radome contour point from the antenna's phase center location.

$$\Delta YR = Ya - y_i \quad (13)$$

Beginning with the first point of the radome contour near the tip, points are tried until the quantity $Z = \Delta YR_i \tan(\alpha')$ is less than the Z coordinate of the ith radome contour point. Once this point is determined, i.e., $(Z_i - Z) > 0$, the sixty radome contour points that are symmetric about this central point are determined and used to encompass

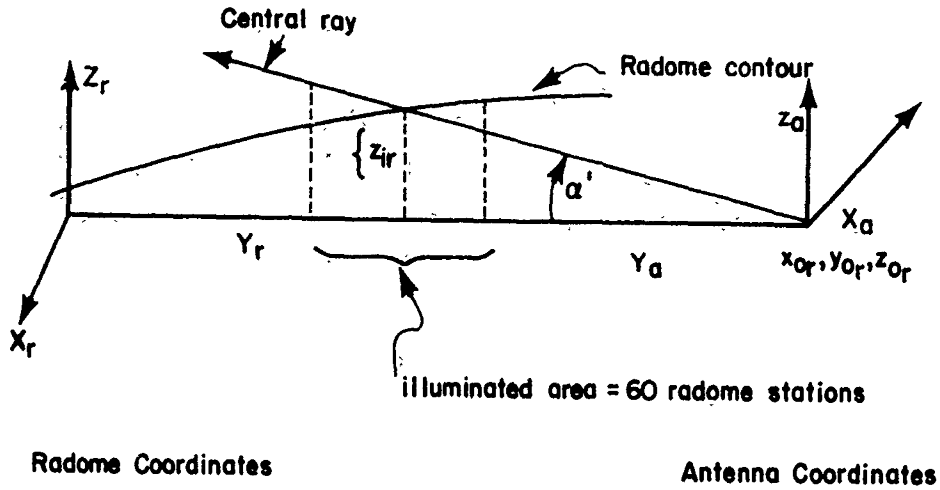

Figure 5. Radome Area Illuminated by the Antenna

the projected area of the antenna aperture. The value of sixty points was chosen from empirical results. If the points are too close to the tip of the radome, then we choose sixty points beginning with the point closest to the radome tip as we progress toward the rear of the radome. Similarly, if the points are too close to the rear, then sixty points are used beginning with the last point and working forward.

The surface region of the radome encompassing the projected area of the antenna aperture in a given scan direction is determined through the use of the following equations (Figure 6).

$$\theta = \theta_I + \Delta\theta \tag{14}$$

where θ_I is the initial rotation angle about the YR axis, and

$\Delta\theta$ is the incremental change in the rotation angle

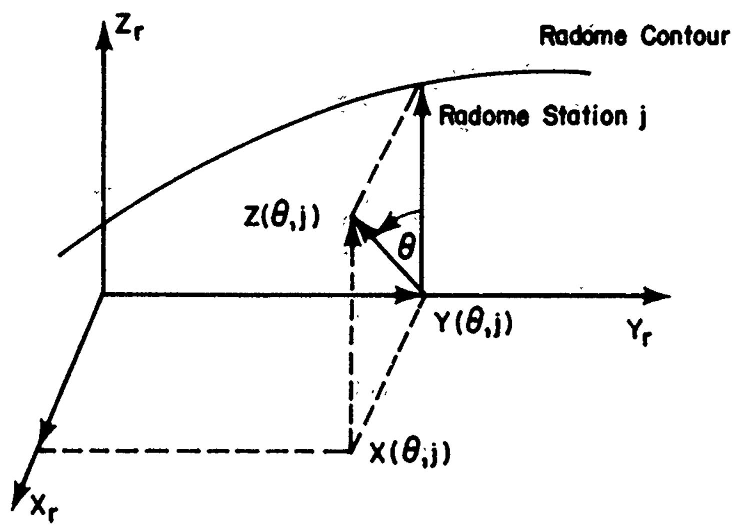

Figure 6. Radome Station Coordinates

The program allows ninety values of (θ). The incremental change (Δθ) is a user-supplied input, and a suggested value based on empirical results is two degrees. The initial value of the rotation angle (θ_I), also supplied by the user, is chosen on the basis of (Δθ) and by program results so that the determined region of the radome encompasses the projected antenna aperture area.

Thus, provision is made for as many as sixty radome surface elements (radially) and by ninety surface elements (rotationally), or 5400 possible surface elements defining the projected aperture area of the antenna on the radome's surface. In general, the projected antenna aperture will occupy less than this number of radome surface elements.

The required surface region of the radome is determined by the following equations:

$$X(\theta, j) = z_j \sin\theta \qquad (15)$$

$$Y(\theta, j) = y_j \qquad (16)$$

$$Z(\theta, j) = z_j \cos\theta \qquad (17)$$

where

y_j, z_j are the coordinates of the jth point on the radome contour

The antenna coordinates of the region of interest are determined as follows:

$$X\theta_j = -(X(\theta, j) - x_o) \qquad (18)$$

$$Y\theta_j = y_o - Y(\theta, j) \qquad (19)$$

$$Z\theta_j = Z(\theta, j) - z_o \qquad (20)$$

where

x_o, y_o, z_o are the radome coordinates of the antenna phase center

The direction cosines of the illuminated area of the radome relative to the antenna phase center are:

$$\alpha_j = \frac{X\theta_j}{TMAG\theta_j} \tag{21}$$

$$\beta_j = \frac{Y\theta_j}{TMAG\theta_j} \tag{22}$$

$$\gamma_j = \frac{Z\theta_j}{TMAG\theta_j} \tag{23}$$

$$TMAG\theta_j = \left[X^2_{\theta_j} + Y^2_{\theta_j} + Z^2_{\theta_j} \right]^{1/2} \tag{24}$$

The antenna elements to the illuminated area direction-cosines are:

$$\alpha_{m,n} = \frac{\Delta X_{m,n}}{|R_{m,n}|} \tag{25}$$

$$\beta_{m,n} = \frac{\Delta Y_{m,n}}{|R_{m,n}|} \tag{26}$$

$$\gamma_{m,n} = \frac{\Delta Z_{m,n}}{|R_{m,n}|} \tag{27}$$

where

$$\Delta X_{m,n} = X\theta_j - X_{m,n} \tag{28}$$

$$\Delta Y_{m,n} = Y\theta_j - Y_{m,n} \tag{29}$$

$$\Delta Z_{m,n} = Z\theta_j - Z_{m,n} \qquad (30)$$

$$R_{m,n} \mid = \left[\Delta X^2_{m,n} + \Delta Y^2_{m,n} + \Delta Z^2_{m,n} \right]^{1/2} \qquad (31)$$

for which $X\theta_j, Y\theta_j, Z\theta_j$ are the antenna coordinates of a subelement of the illuminated area

$X_{m,n}, Y_{m,n}, Z_{m,n}$ are the antenna coordinates of each element in the antenna array

and m,n are the row and column number of the antenna elements

The next step is to find the radome subelement intersected by a ray in the boresight direction from each antenna element. For each element in the antenna array, a search of the illuminated area of the radome surface is made, beginning with the first radome station. The direction cosines from the element to the radome surface are compared to those of the central ray. If the direction cosines are within a given tolerance, i.e., the two rays are pointing in approximately the same direction, then this point on the radome surface is used to indicate where the ray passes through the radome. The direction cosine for the angle between the ray from the element to the surface and the central ray is

$$DC = \alpha\alpha_{ij} + \beta\beta_{ij} + \gamma\gamma_{ij} \qquad (32)$$

where α,β,γ = direction cosines for the central ray, and

$\alpha_{ij},\beta_{ij},\gamma_{ij}$ = direction cosines of the ray from the element to the window area.

The ray is parallel to the antenna electrical boresight when "DC" is equal to one. The tolerance is set to slightly less than one. And, the coordinate of the radome surface that is used is the point where "DC" is greater than the given tolerance.

Next, the normal to the surface of the illuminated area is determined for each coordinate where a ray intersects the radome surface. A least squares curve fitting routine (CURFIT) is used to fit the radome outside mold contour data to a sixth degree polynomial in radome coordinates (Figure 2). A transformation is then made to antenna coordinates, so that

$$f(y) = B_n + B_1 y + B_2 y^2 + B_3 y^3 + B_4 y^4 + B_5 y^5 + B_6 y^6 \quad (33)$$

An equation in x,y,z can be found for the surface of the illuminated area of the radome, when given that the radome is a body of revolution (Figure 7). Thus,

$$R = f(y) \quad (34)$$

$$x^2 + z^2 = R^2 \quad (35)$$

$$x^2 + z^2 = f^2(y) \quad (36)$$

$$x^2 + z^2 - f^2(y) = 0 \quad (37)$$

$$F = x^2 + z^2 - f^2(y) \quad (38)$$

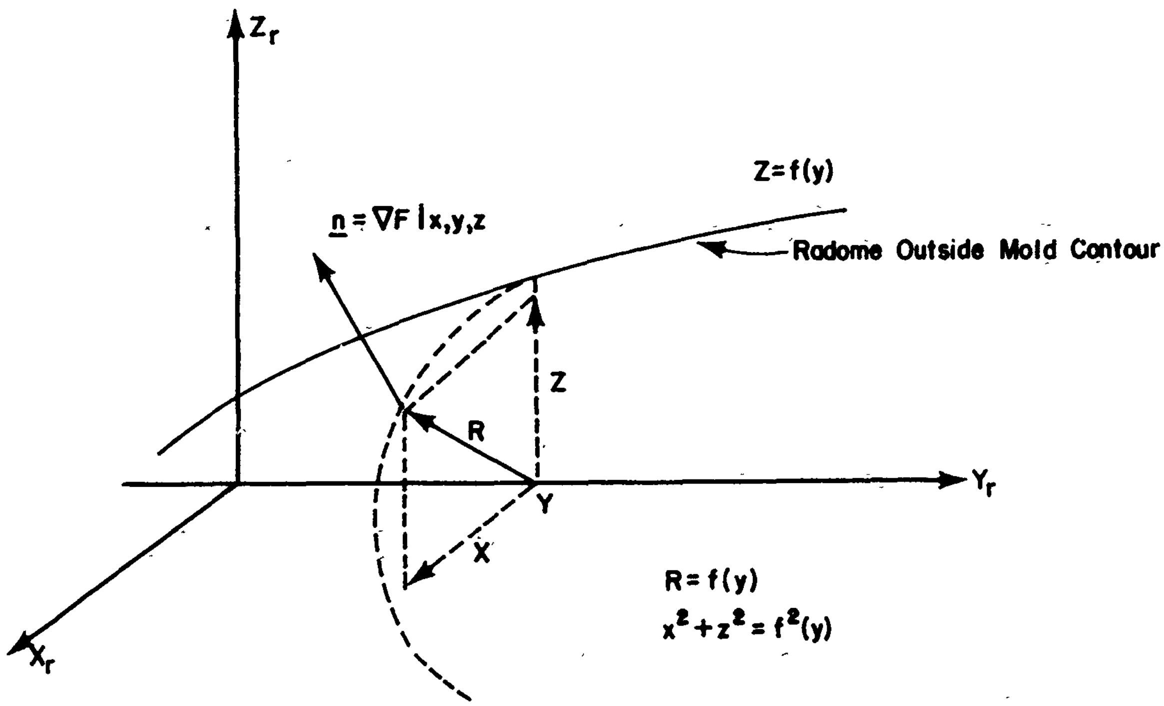

Figure 7. Determination of Normal to Radome Surface

The normal to the surface is given by

$$\underline{N} = \nabla F$$

$$\underline{N} = 2\,x\,\underline{i} + 2\,z\,\underline{k} - 2\,f(y)\left(\frac{df(y)}{dy}\right)\underline{j} \qquad (39)$$

where

$$\frac{df(y)}{dy} = B_1 + 2B_2 y + 3B_3 y^2 + 4B_4 y^3 + 5B_5 y^4 + 6B_6 y^5 \qquad (40)$$

To obtain the unit normal, first define

$$\underline{N}^{*} = 1/2\,\underline{N} = x\,\underline{i} + z\,\underline{k} - f(y)\,\frac{d\,f(y)}{dy}\,\underline{j} \qquad (41)$$

$$|N^{*}| = \left\{ x^{2} + z^{2} + \left[f(y)\,\frac{d\,f(y)}{dy} \right]^{2} \right\}^{1/2} \qquad (42)$$

Then the unit normal, in radome coordinates, is stated by

$$\underline{n}_R = \frac{N^{*}}{|N^{*}|} = \alpha_{iR} + \beta_{jR} + \gamma_{kR} \qquad (43)$$

In antenna coordinates, the unit normal is

$$\underline{n}_A - \alpha\underline{i}_A - \beta\underline{j}_A + \gamma\underline{K}_A \qquad (44)$$

The incidence angle of the ray from each element to the radome surface is determined by taking the dot product of the unit vector from the array element to the surface, and the normal to the surface at the point of intersection. Thus,

$$x_{ij} = \underline{r}_{ij} \cdot \underline{n}_A \qquad (45)$$

$$\theta_{ij} = \cos^{-1}(x_{ij}) \qquad (46)$$

where $\underline{r}_{ij}$ is the unit vector of the ray from the i, j, element to the intersection point on the surface

$\underline{n}_a$ is the unit normal curve at the point of intersection

and θ_{ij} is the incidence angle for the ray from an array element.

The sequence of events we have described in this section is programmed in RADOME. The end product is the incidence angle of each ray at the radome surface. This is used in program WAVES2 to calculate reflection and transmission properties of the radome for each ray.

3. INPUT

Program I/O (Input/Output) is described in Section III and examples are given in Section V. Briefly, the input consists of the following items:

a. Number of radome stations
b. Initial rotation angle, incremental angle, and total number of angles
c. Antenna elevation and azimuth scan angles
d. Antenna phase center location in radome coordinates
e. Number of computer runs to be made
f. Wavelength
g. Aperture radius
h. Maximum number of rows and columns in the antenna array
i. Radome outside mold station coordinates

4. OUTPUT

Program output is in the form of a tabular printout:

a. Row and column number for each array element whose ray passes through the radome wall

b. Incidence angle for each ray

c. Number of rays passing through the radome wall

d. Elevation and azimuth scan angles

e. Number of radome stations

f. Initial rotation angle, incremental angle, and number of angles

g. Antenna phase center location in radome coordinates

SECTION III

GENERAL ANALYSIS PROGRAM DESCRIPTION

1. THE MAIN PROGRAM

The analysis program is written in FORTRAN IV for a CDC 6600 CYBER 74, operating under SCOPE 3.4.1. The main program is primarily an executive routine which calls a series of subroutines. The subroutines are organized into the following functional groups:

1. Antenna element location, ARRAY
2. Element to point of interest direction cosines, DIRET
3. Window area surface coordinates, SFILE
4. Illuminated radome stations, START
5. Element to radome direction cosines, DIRER
6. Normal to window area, NORM
7. Incidence angles, INCID

The Main Program, PROGRAM RADOME (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7), is a routine which reads the following input variables:

NSEC, number of radome stations

ANGI, initial rotation angle

ANGD, incremental rotation angle

NANG, number of angular positions

THEL, elevation scan angle

THAZ, aximuth scan angle

COMMON FILE (60,90,3), NSEC,ANGI,ANGD,NANG,AX,AY,AZ

COMMON/BLK1/TGTX,TGTY,TGTZ

COMMON/BLK3/ABGET(45,45,3)

COMMON/BLK20/SW2

AX,AY,AZ antenna phase center location in radome coordinates

2. SUBROUTINES

a. ARRAY

COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN

COMMON/BLK12/RMAX

COMMON/BLK13/IMAX,JMAX

COMMON/BLK20/SW2

DATA XLAMDA/1.2/

DATA RR/18.0/

NUMM,NUMN - maximum allowable number of rows and columns in the antenna array

RMAX - radius of antenna aperture

IMAX,JMAX - actual number of rows and columns in the antenna array

XLAMDA - wavelength (inches)

RR - aperture radius (inches)

EFILE - file of element locations

b. DIRET

COMMON/BLK1/TGTX,TGTY,TGTZ

COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN

COMMON/BLK3/ABGET(45,45,3)

```
COMMON/BLK12/RMAX
COMMON/BLK13/IMAX,JMAX
```

TGTX,TGTY,TGTZ	-	antenna coordinates of point of interest
NUMM,NUMN	-	maximum allowable number of rows and columns in the array
ABGET	-	file of array element to point of interest direction cosines
RMAX	-	maximum radius of antenna aperture
IMAX,JMAX	-	maximum number of rows and columns in the array

c. SFILE

```
COMMON FILE (60,90,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ
COMMON/BLK4/XY(200),XZ(200)
COMMON/BLK5/NSTART,NFIN
COMMON/BLK20/SW2
DIMENSION FX(90),FY(90),FZ(90)
```

FILE	-	file of antenna coordinates of window area
NSEC	-	number of radome stations
ANGI	-	initial rotation angle
ANGD	-	rotation angle increment
NANG	-	number of incremental angles
AX,AY,AZ	-	radome coordinates of antenna phase center
XY,XZ	-	files of radome stations, Y and Z co-ordinates

NSTART,NFIN	-	beginning and ending window area radome station numbers
SW2	-	switch set false after first run
FX,FY,FZ	-	radome coordinates of window area

d. START

```
COMMON FILE (60,90,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ
COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
COMMON/BLK3/ABGET(45,45,3)
COMMON/BLK4/XY(200),XZ(200)
COMMON/BLK5/NSTART,NFIN
```

FILE	-	defined in SFILE
NSEC	-	"
ANGI	-	"
ANGD	-	"
NANG	-	"
AX,AY,AZ	-	"
XY,XZ	-	"
EFILE	-	defined in ARRAY
NUMM,NUMN	-	"
ABGET	-	defined in DIRET
NSTART,NFIN	-	defined in START

e. DIRER

```
COMMON FILE (60,90,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ
COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
```

```
COMMON/BLK3/ABGET(45,45,3)
COMMON/BLK5/NSTART,NFIN
COMMON/BLK6/IFILE(45,45),JFILE(45,45)
COMMON/BLK8/FILEE(45,45,3)
COMMON/BLK12/RMAX
COMMON/BLK13/IMAX,JMAX
DATA TOL/.99939/
```

FILE	-	defined in SFILE
EFILE	-	defined in ARRAY
NUMM,NUMN	-	defined in ARRAY
ABGET	-	defined in DIRET
NSTART	-	defined in START
NFIN	-	defined in START
IFILE	-	file of radome stations for ray intersections
JFILE	-	file of the number of angular increments for a given radome station ray intersection
FILEE	-	file of direction cosine, for each ray
RMAX	-	defined in ARRAY
IMAX	-	defined in ARRAY
JMAX	-	defined in ARRAY
TOL	-	if the direction cosine of the difference in the direction of the point of interest and a particular coordinate of the window area is greater than TOL then this coordinate is used to obtain the point where the ray passes through the radome surface

f. NORM

```
COMMON FILE (60,90,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ
COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
COMMON/BLK5/NSTART,NFIN
COMMON/BLK6/IFILE(45,45),JFILE(45,45)
COMMON/BLK13/IMAX,JMAX
DIMENSION FILEEN(45,45,3)
EQUIVALENCE (EFILE,FILEN)
COMMON/BLK10/LT
DATA BN/   /
DATA B1/   /
      .
      .
      .
DATA B6/   /
```

FILE	-	defined in SFILE
NSEC	-	"
ANGI	-	"
ANGD	-	"
NANG	-	"
AX	-	"
AY	-	"
AZ	-	"
NUMM	-	defined in ARRAY
NUMN	-	"
NSTART	-	defined in START

NFIN	-	defined in START
IFILE	-	defined in DIRER
JFILE	-	"

g. INCID

```
COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
COMMON/BLK4/XY(200),XZ(200)
DIMENSION FILEN(45,45,3)
EQUIVALENCE(EFILE,FILEN)
COMMON/BLK8/FILEE(45,45,3)
COMMON/BLK9/XINCID(45,45)
COMMON/BLK10/LT
COMMON/BLK13/IMAX,JMAX
```

EFILE,NUMM,NUMN	-	defined in ARRAY
XY,XZ	-	defined in SFILE
IFILE,JFILE	-	defined in DIRER
FINEN	-	defined in NORM
EFILE	-	defined in ARRAY
FILEE	-	defined in DIRER
XINCID	-	file of incidence angles for each ray passing through the radome wall
LT	-	defined in NORM
IMAX,JMAX	-	defined in ARRAY
IMAX	-	defined in ARRAY
JMAX	-	defined in ARRAY

FILEN	-	file of normals for ray/radome intersection, for those rays passing through the radome wall (in antenna coordinates)
LT	-	used to test the value of IFILE in DIRER
EFILE	-	defined in ARRAY

BN
B1
B2
B3
B4
B5
B6

} coefficients of six-degree polynomial fit of radome's outside mold line contour

SECTION IV
MAIN PROGRAM INPUT

The input deck structure is shown in Figure 8.

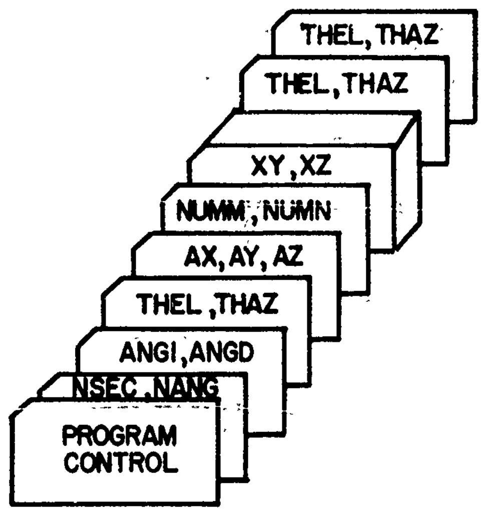

Figure 8. Input Deck Structure

Data Definitions are as follows:

VARIABLE	-	DESCRIPTION	FORMAT
NSEC	-	number of radome stations	2I5
NANG	-	number of circumferential radome divisions	2I5
ANGI	-	initial rotation angle in degrees	2F10.5
ANGD	-	angular increment	
THEL	-	antenna elevation scan angle in degrees	2F10.4
THAZ	-	antenna azimith scan angle in degrees	
AX,AY,AZ	-	radome coordinates of antenna phase center	3F10.4

NUMM	-	maximum allowable antenna row number	2I2
NUMN	-	maximum allowable antenna column number	
XY,XZ	-	radome contour coordinates in radome coordinates	2F10.4

SECTION V

USER'S GUIDE

1. PROGRAM CONTROL

To use the radome analysis program for a given problem, the user must set up the input deck and control cards.

A sample problem is presented in this section. Also shown is how specific sections of that problem are related to the sample input. The printed output of the sample program is included.

The following control card deck structure is presented as a guide to the user. The control card structure is applicable to CDC 6600 CYBER 74 SCOPE 3.4.1.

The radome program has been previously stored on a permanent file. The ATTACH card requests the program. A LABEL card is used to make available a magnetic tape for data storage. The data is first written onto a permanent file that has been requested by a REQUEST card. The source decks are transferred to a program library by the UPDATE card. The program is then compiled (FTN), loaded (LGO), and finally cataloged. The cataloged file is rewound and then copied to magnetic tape (Figure 9a).

On subsequent runs there is a difference in the control cards to allow extending the data on the magnetic tape. The radome program is attached along with the permanent file containing the old data. The tape label is read and the program transferred to the library file by the UPDATE card. The first set of information on the permanent file is skipped, the program compiled, loaded, and executed. The data on the permanent file is extended, the file rewound, and then the entire file copied onto magnetic tape (Figure 9b).

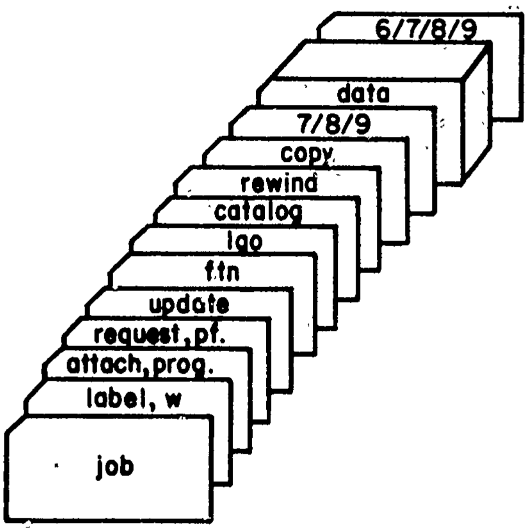

Figure 9a. First Update Deck in Program Control

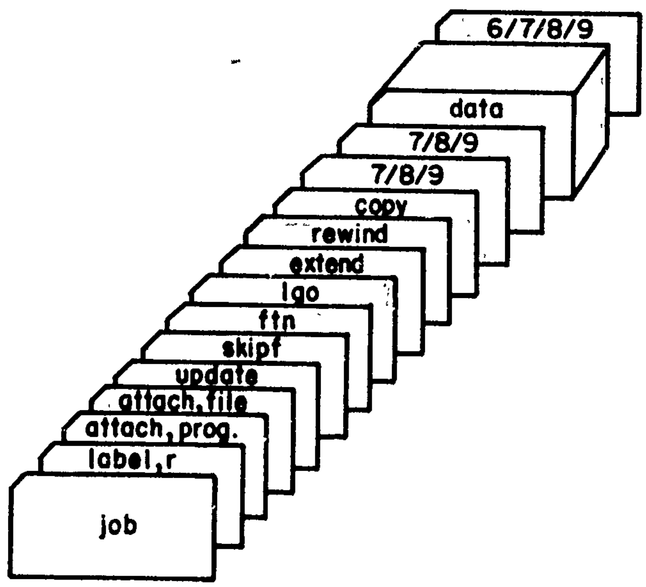

Figure 9b. Second Update Deck in Program Control

2. SAMPLE PROBLEM

A cut is to be made in the azimuth plane. The first step consists of using the Main Program routine, in which the following variable values are used:

1. Number of radome stations equals 117 (NSEC=117)
2. Initial rotation angle equals 0.0 (ANGI=0.0)
3. Number of angular intervals about radome equals 90 (NANG=90)
4. Angular interval equals -4.0 degrees (ANGD=-4.0)

The number of computer runs, i.e., sets of azimuth and elevation scan angles has been set at 3 (NRUN=3). Elevation, and azimuth scan angles (THEL,THAZ) are inputs, one set per card, three cards per run.

3. SAMPLE INPUT

Proceeding to the subroutines, we will have inputs as outlined in the following.

a. ARRAY

Wavelength of interest in inches, XLAMDA

DATA XLAMDA/1.2/

Maximum aperture radius in inches, RR

DATA RR/18.0/

Maximum allowable number of rows and columns in the array, respectively (45,45)

NUMM = 45

NUMN = 45

b. SFILE

Coordinates of the radome contour for radome station I=1, 117

XY(1) = Y1

XZ(1) = Z1

.

.

.

.

.

XY(117) = Y117

XZ(117) = Z117

c. Data Input Format

Card No.	Variable(s)	Format
1	NSEC,NANG	2I5
2	ANGI,ANGD	2F10.5
3	THEL,THAZ	2F10.5
4	AX,AY,AZ	3F10.4

5	NUMM,NUMN	2I2
6-122	XY(I),XZ(I)	2F10.4
123	THEL,THAZ	2F10.5
124	THEL,THAZ	2F10.5

d. The steps given in Section V are shown as flowcharts in Figures 10, 11, and 12. Final printout from our example problem follow the flowcharts.

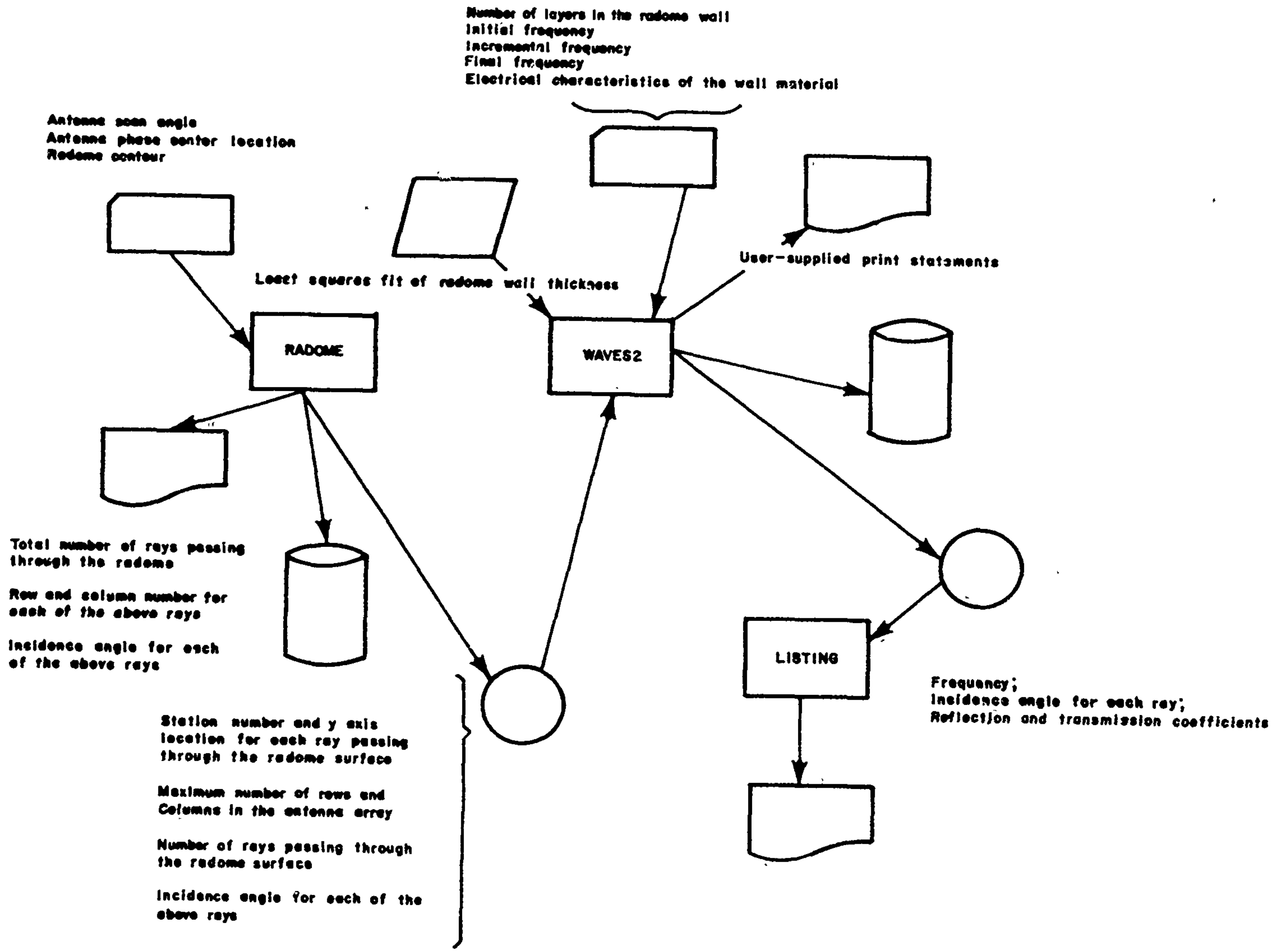

Figure 10. System Flow Chart.

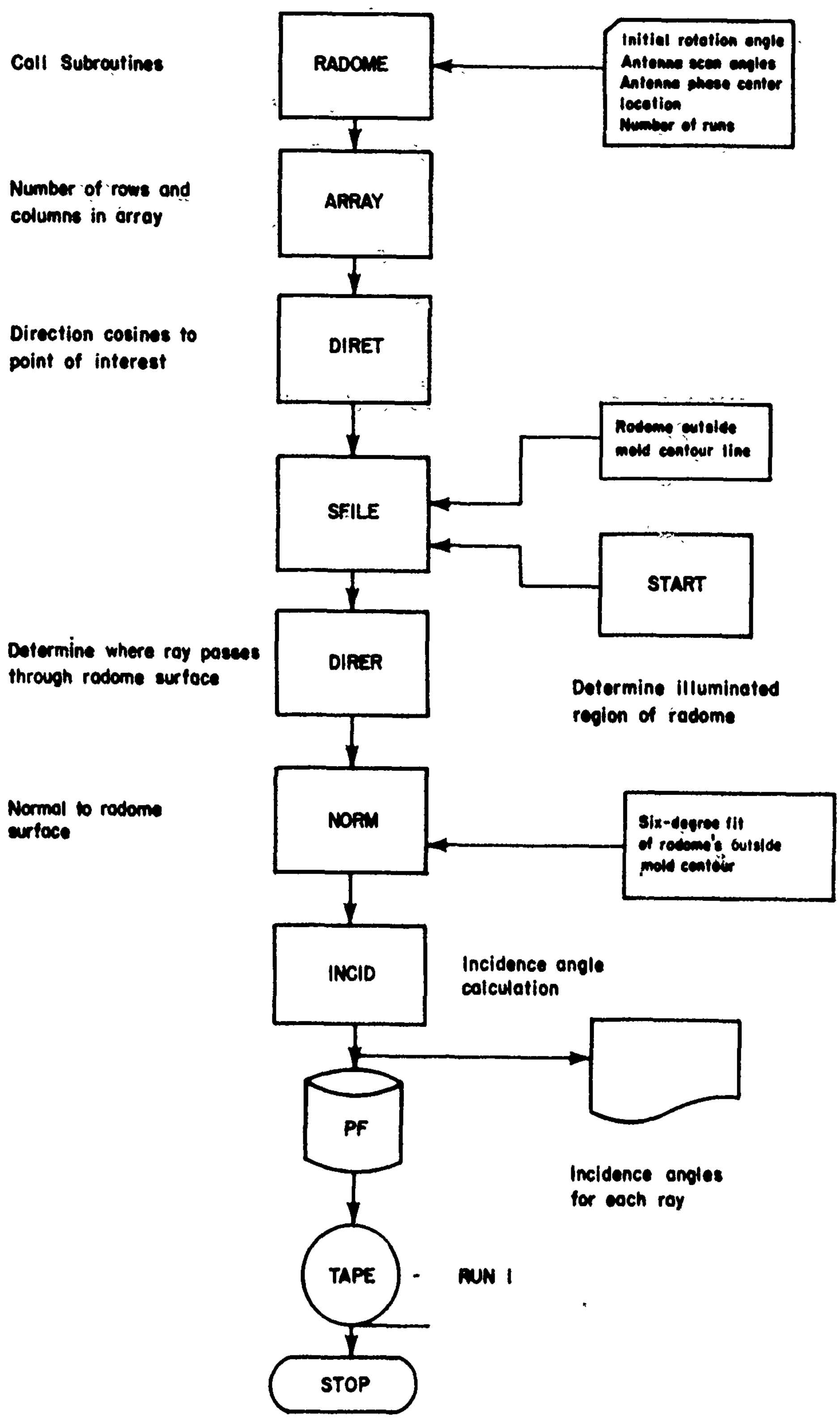

Figure 11. Radome-Geometry Program Flow Chart

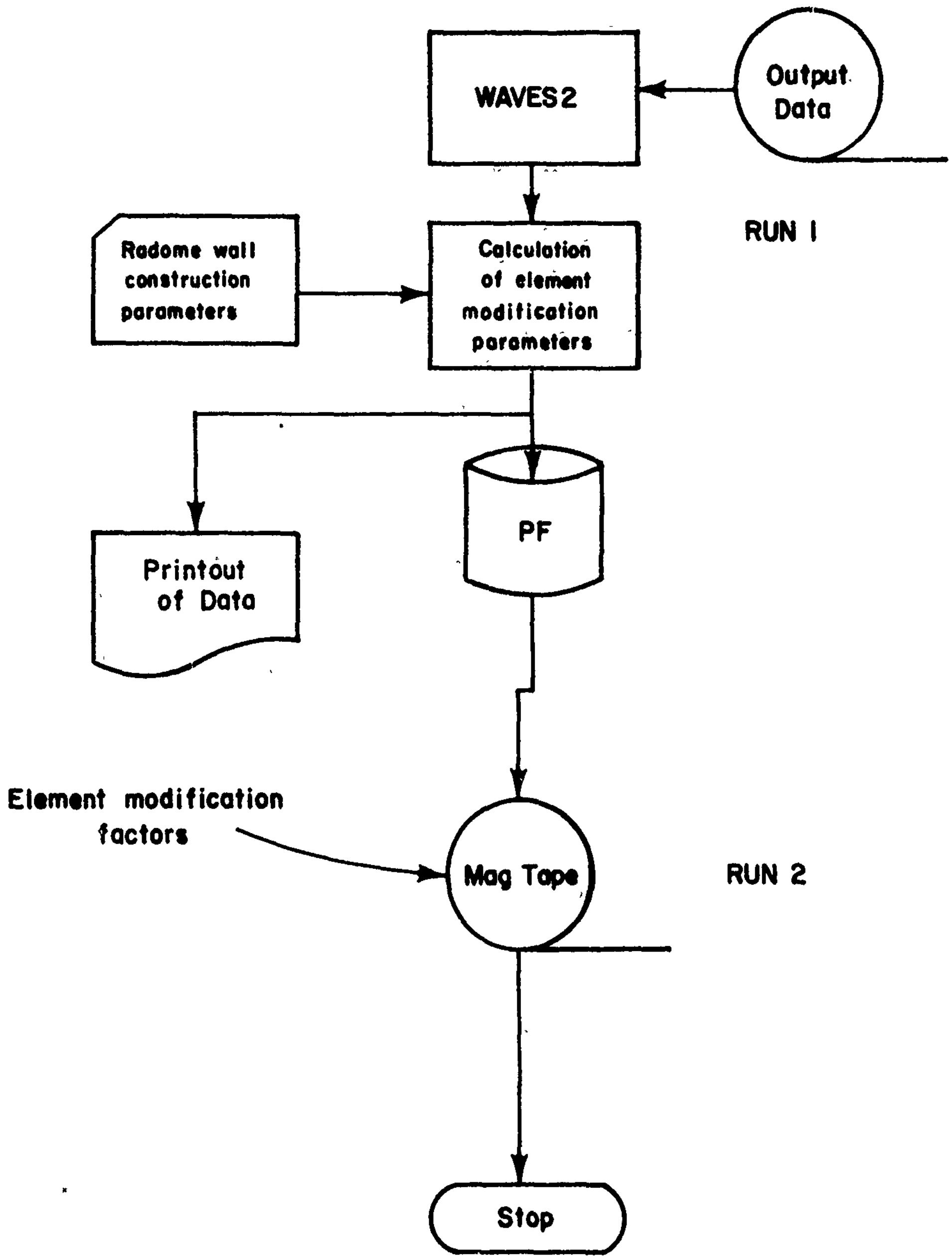

Figure 12. WAVES2 Program Flow Chart

4. SAMPLE OUTPUT

```
PROGRAM RADOME      74/74    OPT=2                          FTN 4.2+P380     03/27/75   11.06.06.      PAGE

      PROGRAM RADOME(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)           RADOME     2
      COMMON FILE(45,45,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ                    RADOME     3
      COMMON/BLK1/TGTX,TGTY,TGTZ                                           RADOME     4
      COMMON/BLK3/ARGET(45,45,3)                                           RADOME     5
      COMMON/BLK20/SW2                                                     RADOME     6
C READ INPUT PARAMETERS                                                     RADOME     7
C NSEC=TOTAL NUMBER OF RADOME SECTIONS                                      RADOME     8
C ANGI= INITIAL ROTATION ANGLE                                              RADOME     9
C ANGD=INCREMENTAL ANGLE ROTATION                                           RADOME    10
C NANG= NUMBER OF ANGULAR  POSITIONS                                        RADOME    11
C R,THEL,THAZ ARE TGT RANGE,EL AND AZ ANGLES                                RADOME    12
C AX,AY,AZ ARE THE ANTENNA PHASE CENTER LOCATIONS IN RADOME COORDINATES     RADOME    13
C                                                                           RADOME    14
      LOGICAL SW2                                                          RADOME    15
      NRUN=0                                                               RADOME    16
      SW2=.TRUE.                                                           RADOME    17
      READ (5,100)NSEC,NANG                                                RADOME    19
  100 FORMAT(2I5)                                                          RADOME    20
      READ(5,200)ANGI,ANGD                                                 RADOME    21
  200 FORMAT(2F10.5)                                                       RADOME    22
    1 CONTINUE                                                             RADOME    23
      NRUN=NRUN+1                                                          RADOME    24
      READ(5,210)THEL,THAZ                                                 RADOME    25
  210 FORMAT(2F10.4)                                                       RADOME    26
      R=1.E+06                                                             RADOME    27
      WRITE(7)THEL,THAZ                                                    RADOME    28
      PRINT(6,130)NSEC,NANG,ANGI,ANGD,R,THEL,THAZ                          RADOME    29
  130 FORMAT(1H0,*NSEC=*,I3,2X,*NANG=*,I3,2X,*ANGI=*,                      RADOME    30
     1F10.4,2X,*ANGD=*,F10.4,2X,*R=*,F10.2,2X,*THEL=*,F10.4,2X,            RADOME    31
     1*THAZ=*,F10.4)                                                       RADOME    32
      IF(.NOT.SW2) GO TO 141                                               RADOME    33
      READ(5,110)AX,AY,AZ                                                  RADOME    34
  110 FORMAT(3F10.4)                                                       RADOME    35
  141 CONTINUE                                                             RADOME    36
      PRINT  140                                                           RADOME    37
  140 FORMAT(1X,/1X,*      AX          AY         AZ        *)             RADOME    38
      PRINT(6,150)AX,AY,AZ                                                 RADOME    39
  150 FORMAT(3F10.4)                                                       RADOME    40
C     COMPUTE TGT LOCATION IN ANTENNA COORDINATES                           RADOME    41
      THELR=THEL*(3.14159/180.)                                            RADOME    42
      THAZR=THAZ*(3.14159/180.)                                            RADOME    43
      TGTX=R*COS(THELR)*SIN(THAZR)                                         RADOME    44
      TGTY=R*COS(THELR)*COS(THAZR)                                         RADOME    45
      TGTZ=R*SIN(THELR)                                                    RADOME    46
      PRINT(6,160)TGTX,TGTY,TGTZ                                           RADOME    47
  160 FORMAT(1X,*  TGTX=*,E10.4,*. TGTY=*,E10.4,*  TGTZ=*,E10.4)           RADOME    48
C     INPUT ANTENNA ELEMENT SPACING IN ANTENNA COORDINATES                  RADOME    52
      CALL ARRAY                                                           RADOME    53
      CALL DIRET                                                           RADOME    54
C SUBROUTINE SFILE GENERATES THE XYZ COORDINATES OF THE SURFACE IN ANT.     RADOME    55
      CALL SFILE                                                           RADOME    56
      CALL DIREP                                                           RADOME    57
      CALL NORM                                                            RADOME    58
      CALL INCID                                                           RADOME    59
      SW2=.FALSE.                                                          RADOME    60
      IF(NRUN.NE.3) GO TO 1                                                RADOME    61
      STOP                                                                 RADOME    62
```

```
SUBROUTINE ARRAY       74/74   OPT=2                    FTN 4.2+P380     03/27/75  11.05.08.     PAGE

      SUBROUTINE ARRAY
      COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
      COMMON/BLK12/RMAX
      COMMON/BLK13/IMAX,JMAX
      COMMON/BLK20/SW2
      LOGICAL SW2
      DATA XLAMDA/1.20/
      DATA RR/18.0/
      RMAX=RR
      IF(.NOT.SW2) GO TO 101
      READ(5,100)NUMM,NUMN
  100 FORMAT(2I2)
  101 CONTINUE
      PRINT(6,110)NUMM,NUMN
  110 FORMAT(1H0,*NUMM=*,I2,*NUMN=*,I2)
      PRINT(6,800)RMAX,XLAMDA
  800 FORMAT(1H0,*RMAX=*,F11.3,*XLAMDA=*,F11.5)
      XX=XLAMDA/4.
      DO 120 II=2,NUMM,2
      IF(XX.GT.RMAX) GO TO 130
      XX=XX+XLAMDA/2.
  120 CONTINUE
  130 IMAX=II-2
      JMAX=II-2
      PRINT (6,600)IMAX,JMAX
  600 FORMAT(1H0,*IMAX=*,I2,*JMAX=*,I2)
      DO 1000 I=1,IMAX
      DO 1001 J=1,JMAX
      EFILE(I,J,1)=1000.
      EFILE(I,J,2)=1000.
      EFILE(I,J,3)=1000.
 1001 CONTINUE
 1000 CONTINUE
      XX=XLAMDA/4.
      XZ=XLAMDA/4.
      L=0
      DO 140 I=2,IMAX,2
      DO 150 J=2,JMAX,2
      EFILE(I,J,1)=XX
      EFILE(I,J,2)=0.0
      EFILE(I,J,3)=XZ
      X=EFILE(I,J,1)
      Y=EFILE(I,J,2)
      Z=EFILE(I,J,3)
      R=SQRT(X**2+Z**2)
      IF(R.GT.RMAX) GO TO 170
      XX=XX+(XLAMDA/2.)
      L=L+1
  150 CONTINUE
  170 XZ=XZ+(XLAMDA/2.)
      XX=XLAMDA/4.
  140 CONTINUE
      LL=4*L
      PRINT(6,900)LL
  900 FORMAT(1H0,*TOTAL NUMBER OF ELEMENTS =*,I4)
C     DO UPPER RIGHT QUAD.
      JMAX=JMAX-1
```

```
      SUBROUTINE ARRAY      74/74   OPT=2                    FTN 4.2+P380       03/27/75  11.05.38.        PAGE

                      DO 200 I=2,IMAX,2                                                     ARRAY      60
                      DO 210 J=1,JMAX,2                                                     ARRAY      61
 60                   EFILE(I,J,1)=-EFILE(I,J+1,1)                                          ARRAY      62
                      EFILE(I,J,2)=0.0                                                      ARRAY      63
                      EFILE(I,J,3)=EFILE(I,J+1,3)                                           ARRAY      64
                210   CONTINUE                                                              ARRAY      65
                200   CONTINUE                                                              ARRAY      66
 65             C     DO LOWER LEFT QUAD                                                    ARRAY      67
                      JMAX=JMAX+1                                                           ARRAY      68
                      IMAX=IMAX-1                                                           ARRAY      69
                      DO 300 I=1,IMAX,2                                                     ARRAY      70
                      DO 310 J=2,JMAX,2                                                     ARRAY      71
 70                   EFILE(I,J,1)=EFILE(I+1,J,1)                                           ARRAY      72
                      EFILE(I,J,2)=0.0                                                      ARRAY      73
                      EFILE(I,J,3)=-EFILE(I+1,J,3)                                          ARRAY      74
                310   CONTINUE                                                              ARRAY      75
                300   CONTINUE                                                              ARRAY      76
 75             C     DO LOWER RIGHT QUAD.                                                  ARRAY      77
                      JMAX=JMAX-1                                                           ARRAY      78
                      DO 400 I=1,IMAX,2                                                     ARRAY      79
                      DO 410 J=1,JMAX,2                                                     ARRAY      80
                      EFILE(I,J,1)=-EFILE(I,J+1,1)                                          ARRAY      81
 80                   EFILE(I,J,2)=0.0                                                      ARRAY      82
                      EFILE(I,J,3)=EFILE(I,J+1,3)                                           ARRAY      83
                410   CONTINUE                                                              ARRAY      84
                400   CONTINUE                                                              ARRAY      85
                      IMAX=IMAX+1                                                           ARRAY      86
 85                   JMAX=JMAX+1                                                           ARRAY      87
                      DO 500 I=1,IMAX,5                                                     ARRAY      88
                      DO 510 J=1,JMAX,5                                                     ARRAY      89
                      X1=EFILE(I,J,1)                                                       ARRAY      90
                      Z1=EFILE(I,J,3)                                                       ARRAY      91
 90                   R1=SQRT(X1**2+Z1**2)                                                  ARRAY      92
                      IF(R1.GT.RMAX) GO TO 500                                              ARRAY      93
                      PRINT(6,700)I,J,EFILE(I,J,1),EFILE(I,J,2),EFILE(I,J,3)                ARRAY      94
                700   FORMAT(1H0,1X,I2,3X,I2,3F11.5)                                        ARRAY      95
                510   CONTINUE                                                              ARRAY      96
 95             500   CONTINUE                                                              ARRAY      97
                      RETURN                                                                ARRAY     101
                      END                                                                   ARRAY     102

REGISTER ALLOCATION
1. REGISTERS ASSIGNED OVER THE LOOP BEGINNING AT LINE 28
```

```
SUBROUTINE DIRET       74/74    OPT=2                        FTN 4.2+P380        03/27/75  11.06.15.        PAGE

               SUBROUTINE DIRET                                                          DIRET        2
               COMMON/BLK1/TGTX,TGTY,TGTZ                                                DIRET        3
               COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN                                      DIRET        4
               COMMON/BLK3/ABGET(45,45,3)                                                DIRET        5
               COMMON/BLK12/RMAX                                                         DIRET        6
               COMMON/BLK13/IMAX,JMAX                                                    DIRET        7
         C     THIS SUBROUTINE CALCULATES THE DIRECTION COSINES FROM EACH                DIRET        8
         C     ELEMENT TO THE TARGET                                                     DIRET        9
               PRINT 130                                                                 DIRET       11
         130   FORMAT(1X,/1X,*  DIRECTION COSINES FROM I,J, ELEMENT TO TGT   */)        DIRET       12
               DO 100 I=1,IMAX                                                           DIRET       13
               DO 110 J=1,JMAX                                                           DIRET       14
               X=EFILE(I,J,1)                                                            DIRET       15
               Z=EFILE(I,J,3)                                                            DIRET       16
               R=SQRT(X**2+Z**2)                                                         DIRET       17
               IF(R.GT.RMAX) GO TO 100                                                   DIRET       18
               XTX=TGTX-EFILE(I,J,1)                                                     DIRET       19
               XTY=TGTY-EFILE(I,J,2)                                                     DIRET       20
               XTZ=TGTZ-EFILE(I,J,3)                                                     DIRET       21
               XMAG=SQRT(XTX**2+XTY**2+XTZ**2)                                           DIRET       22
               ABGET(I,J,1)=XTX/XMAG                                                     DIRET       23
               ABGET(I,J,2)=XTY/XMAG                                                     DIRET       24
               ABGET(I,J,3)=XTZ/XMAG                                                     DIRET       25
         110   CONTINUE                                                                  DIRET       26
         100   CONTINUE                                                                  DIRET       27
               DO 300 I=1,IMAX,5                                                         DIRET       28
               DO 400 J=1,JMAX,5                                                         DIRET       29
               X1=EFILE(I,J,1)                                                           DIRET       30
               Z1=EFILE(I,J,3)                                                           DIRET       31
               R1=SQRT(X1**2+Z1**2)                                                      DIRET       32
               IF(R1.GT.RMAX) GO TO 300                                                  DIRET       33
               PRINT(6,120)I,J,ABGET(I,J,1),ABGET(I,J,2),ABGET(I,J,3)                    DIRET       34
         120   FORMAT(1X,/1X,*  ABGET(*,2I2,*)=*,1X,F10.4,3X,F10.4,3X,F10.4)            DIRET       35
         400   CONTINUE                                                                  DIRET       36
         300   CONTINUE                                                                  DIRET       37
               RETURN                                                                    DIRET       41
               END                                                                       DIRET       42
```

```
SUBROUTINE SFILE        74/74   OPT=2                FTN 4.2+P380        03/27/75  11.06.19.      PAGE

          SUBROUTINE SFILE                                                 SFILE      2
          COMMON FILE(60,90,3),NSEC,ANGI,ANGO,NANG,AX,AY,AZ                SFILE      3
          COMMON/BLK4/XY(200),XZ(200)                                      SFILE      4
          COMMON/BLK5/NSTART,NFIN                                          SFILE      5
          COMMON/BLK20/SW2                                                 SFILE      6
          DIMENSION FX(90),FY(90),FZ(90)                                   SFILE      7
C READ CONTOUR LINE XYZ                                                    SFILE      8
          LOGICAL SW2                                                      SFILE      9
          IF(.NOT.SW2) GO TO 101                                           SFILE     11
          DO 100 I=1,NSEC                                                  SFILE     12
          READ(5,110)XY(I),XZ(I)                                           SFILE     13
    110   FORMAT(2F10.4)                                                   SFILE     14
    100   CONTINUE                                                         SFILE     15
    101   CONTINUE                                                         SFILE     16
          CALL START                                                       SFILE     17
C GENERATE IN RADOME COORDINATES,SURFACE XYZ                               SFILE     18
          ANGII=ANGI                                                       SFILE     19
          L=1                                                              SFILE     20
          DO 120 I=NSTART,NFIN                                             SFILE     21
          DO 130 J=1,NANG                                                  SFILE     22
          ANGR=ANGII*(3.14159/180.)                                        SFILE     23
          FZ(J)=XZ(I)*COS(ANGR)                                            SFILE     24
          FX(J)=XZ(I)*SIN(ANGR)                                            SFILE     25
          FILE(L,J,1)=FX(J)                                                SFILE     26
          FILE(L,J,2)=XY(I)                                                SFILE     27
          FILE(L,J,3)=FZ(J)                                                SFILE     28
          ANGII=ANGII+ANGO                                                 SFILE     29
    130   CONTINUE                                                         SFILE     30
          ANGII=ANGI                                                       SFILE     31
          L=L+1                                                            SFILE     32
    120   CONTINUE                                                         SFILE     33
          DO 200 I=1,60,10                                                 SFILE     34
          DO 210 J=1,90,10                                                 SFILE     35
          PRINT (6,300) FILE(I,J,1),FILE(I,J,2),FILE(I,J,3)                SFILE     36
    300   FORMAT(1X,3E10.4)                                                SFILE     37
    210   CONTINUE                                                         SFILE     38
    200   CONTINUE                                                         SFILE     39
C TRANSFORM THE DATA TO ANTENNA COORDINATES                                SFILE     40
          DO 150 I=1,60                                                    SFILE     41
          DO 140 J=1,NANG                                                  SFILE     42
          FILE(I,J,1)=-(FILE(I,J,1)-AX)                                    SFILE     43
          FILE(I,J,2)=AY-FILE(I,J,2)                                       SFILE     44
          FILE(I,J,3)=FILE(I,J,3)-AZ                                       SFILE     45
    140   CONTINUE                                                         SFILE     46
    150   CONTINUE                                                         SFILE     47
          PRINT 450                                                        SFILE     48
    450   FORMAT(1X,/1X,*    XYZ OF SURFACE IN ANTENNA COORDINATES     *)  SFILE     49
          DO 320 I=1,60,5                                                  SFILE     50
          DO 310 J=1,90,10                                                 SFILE     51
          TX=FILE(I,J,1)                                                   SFILE     52
          TY=FILE(I,J,2)                                                   SFILE     53
          TZ=FILE(I,J,3)                                                   SFILE     54
          TMAG=SQRT(TX**2+TY**2+TZ**2)                                     SFILE     55
          A=TX/TMAG                                                        SFILE     56
          B=TY/TMAG                                                        SFILE     57
          G=TZ/TMAG                                                        SFILE     58
          PRINT(6,400)FILE(I,J,1),FILE(I,J,2),FILE(I,J,3),A,B,G            SFILE     59
```

```
      SUBROUTINE SFILE       74/74    OPT=2                         FTN 4.2+P380       03/27/75  11.06.19.       PAGE

                  400  FORMAT(1X,3F10.4,3X,3F10.5)                                        SFILE        60
                  310  CONTINUE                                                           SFILE        61
    60            320  CONTINUE                                                           SFILE        62
                       RETURN                                                             SFILE        66
                       END                                                                SFILE        67

REGISTER ALLOCATION
3 REGISTERS ASSIGNED OVER THE LOOP BEGINNING AT LINE 40
```

```
SUBROUTINE START      74/74   OPT=2                         FTN 4.2+P380      03/27/75  11.06.22.      PAGE

              SUBROUTINE START                                                 START       2
      C       THIS SUBROUTINE DETERMINES THE GENERAL REGION TO BEGIN THESEARCH START       3
              COMMON FILE(60,90,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ                START       4
              COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN                             START       5
              COMMON/BLK3/ABGET(45,45,3)                                       START       6
              COMMON/BLK4/XY(200),XZ(200)                                      START       7
              COMMON/BLK5/NSTART,NFIN                                          START       8
              A=ACOS(ABGET(2,2,2))                                             START      10
              PRINT(6,200)ABGET(2,2,2)                                         START      11
          200 FORMAT(1H0,*ABGET=*,F11.5)                                       START      12
              DO 100 I=1,NSEC                                                  START      13
              XYX=AY-XY(I)                                                     START      14
              Z=XYX*TAN(A)                                                     START      15
              IF(Z.LT.XZ(I))GO TO 110                                          START      16
          100 CONTINUE                                                         START      17
          110 NSTART=I                                                         START      18
              PRINT(6,210)I                                                    START      19
          210 FORMAT(1H0,*I=*,I3)                                              START      20
              DO 130 J=1,30                                                    START      21
              NSTART=NSTART-1                                                  START      22
              IF(NSTART.LT.1)GO TO 140                                         START      23
          130 CONTINUE                                                         START      24
              NFIN=NSTART+59                                                   START      25
              IF(NFIN.LT.NSEC) GO TO 150                                       START      26
              NFIN=NSEC                                                        START      27
              NSTART=NSEC-59                                                   START      28
              GO TO 150                                                        START      29
          140 NSTART=NSTART+1                                                  START      30
              NFIN=NSTART+59                                                   START      31
          150 CONTINUE                                                         START      32
              PRINT(6,120)NSTART,NFIN                                          START      33
          120 FORMAT(1X/1X,*NSTART=*,I3,*NFIN=*,I3)                            START      34
              RETURN                                                           START      38
              END                                                              START      39
```

```
      SUBROUTINE DIRER
C
C     THIS SUBROUTINE CALCULATES THE DIRECTION COSINES FROM EACH
C     ELEMENT TO THE SURFACE AND COMPARES THIS NUMBER TO
C     THAT OF THE GIVEN ELEMENT TO THE TGT
      COMMON FILE(60,90,3),NSEG,ANGI,ANGO,NANG,AX,AY,AZ
      COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
      COMMON/BLK3/ABGET(45,45,3)
      COMMON/BLK5/NSTART,NFIN
      COMMON/BLK6/IFILE(45,45),JFILE(45,45)
      COMMON/BLK8/FILEE(45,45,3)
      COMMON /BLK12/RMAX
      COMMON /BLK13/IMAX,JMAX
      DATA TOL/.99939/
      CALL SECOND(T1)
      PRINT(6,180) TOL
  180 FORMAT(1H0,* TOL = *,F10.6)
      L=0
      DO 100 M=1,IMAX
      DO 110 N=1,JMAX
      X=EFILE(M,N,1)
      Z=EFILE(M,N,3)
      R=SQRT(X**2+Z**2)
      IF(R.GT.RMAX) IFILE(M,N)=1000
      IF(R.GT.RMAX)GO TO 110
      DO 120 I=1,60
      DO 130 J=1,NANG
      ESX=FILE(I,J,1)-EFILE(M,N,1)
      ESY=FILE(I,J,2)-EFILE(M,N,2)
      ESZ=FILE(I,J,3)-EFILE(M,N,3)
      XMAGES=SQRT(ESX**2+ESY**2+ESZ**2)
      ALPHA=ESX/XMAGES
      BETTA=ESY/XMAGES
      GAMMA=ESZ/XMAGES
      FILEE(M,N,1)=ALPHA
      FILEE(M,N,2)=BETTA
      FILEE(M,N,3)=GAMMA
      DC=ABGET(M,N,1)*ALPHA+ABGET(M,N,2)*BETTA+ABGET(M,N,3)*GAMMA
      IF(DC .LT. TOL ) GO TO 170
      II=NSTART+I-1
      L=L+1
      LL=MOD(L,5)
      IF(LL.NE.0)GO TO 500
  140 PRINT(6,160)M,N,II,J,DC
  160 FORMAT(1H0,* RAY(*,I2,*,*,I2,*) INTERSECTS SECTION(*,I3,*,*,I3,
     1*) DC= *,F8.5)
  500 IFILE(M,N)=II
      JFILE(M,N)=J
      GO TO 110
  170 CONTINUE
C     THIS IS A TEST FOR INTERSECTION WITH THE SURFACE
      IFILE(M,N)=1000
  130 CONTINUE
  120 CONTINUE
      PRINT (6,150)M,N,TOL
  150 FORMAT(1X,*RAY(*,I2,*,*,I2,*)DOES NOT INTERSECT WITH THE SURF.
     1GIVEN TOL  *,F11.5)
```

```
SUBROUTINE DIPER       74/74    OPT=2                          FTN 4.2+P380      03/27/75  11.06.24.        PAGE

        110  CONTINUE
        100  CONTINUE                                                              DIRER      59
             CALL SECOND(T2)                                                       DIRER      60
             DELT=T2-T1                                                            DIRER      61
             PRINT*,DELT                                                           DIRER      62
             RETURN                                                                DIRER      63
             END                                                                   DIRER      64
                                                                                   DIRER      65
```

```
SUBROUTINE NORM      74/74    OPT=?                    FTN 4.2+P380      03/22/75  11.05.29.      PAGE

      SUBROUTINE NORM
      COMMON FILE(45,31,3),NSEG,ANGI,ANGD,NANG,AX,AY,AZ
      COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
      COMMON/BLK5/NSTART,NFIN
      COMMON/BLK6/IFILE(45,45),JFILE(45,45)
      COMMON/BLK13/IMAX,JMAX
      DIMENSION FILEN(45,45,3)
      EQUIVALENCE (EFILE,FILEN)
      COMMON/BLK18/LT
      DATA B0/-.51754939E-01/
      DATA B1/.34291929E+00/
      DATA B2/-.17442715E-02/
      DATA B3/.23997697E-04/
      DATA B4/0.0/
      DATA B5/-.25443686E-08/
      DATA B6/.12667666E-10/
      PRINT 200
  200 FORMAT(1H0,*  X,Y,Z    IN RADOME COORD. AND F(Y) *)
      K=0
      DO 100 M=1,IMAX
      DO 110 N=1,JMAX
      LT=998
      IF(IFILE(M,N).GT.LT) GO TO 110
      I=IFILE(M,N)
      I=I-NSTART+1
      J=JFILE(M,N)
C     THE ORIGINAL CURVEFIT WAS DONE IN RADOME COORDINATES
      XX=-FILE(I,J,1)+AX
      XY=AY-FILE(I,J,2)
      XZ=FILE(I,J,3)+AZ
      XY1=XY
      XY2=XY**2
      XY3=XY**3
      XY4=XY**4
      XY5=XY**5
      XY6=XY**6
      F=B0+B1*XY1+B2*XY2+B3*XY3+B4*XY4+B5*XY5+B6*XY6
      K=K+1
      KK=MOD(K,10)
      IF(KK.NE.0) GO TO 131
      PRINT(6,130)XX,XY,XZ,F
  130 FORMAT(1H0,4F10.5)
  131 DFY=B1+2*B2*XY1+3*B3*XY2+4*B4*XY3+5*B5*XY4+6*B6*XY5
      XNX=XX
      XNZ=XZ
      XNY=-F*DFY
      XMAGN=SQRT(XNX**2+XNY**2+XNZ**2)
      XAN=XNX/XMAGN
      XBN=XNY/XMAGN
C     TRANSFORM THE DATA TO ANT. COORD.
      XAN=-XAN
      XBN=-XBN
      XGN=XNZ/XMAGN
C     FILEN CONTAINS THE DIRECTION COSINES OF THE NORMALS FOR EL M,N
      FILEN(M,N,1)=XAN
      FILEN(M,N,2)=XBN
      FILEN(M,N,3)=XGN
```

```
SUBROUTINE NORM        74/74    OPT=2                         FTN 4.2+P380      03/27/75  11.06.29        PAGE

        110   CONTINUF                                                           NORM          60
        100   CONTINUF                                                           NOPM          61
              PRINT 140                                                          NOPM          62
        140 . FORMAT(1H0,*FILE OF DIRECTION COSINES FOR NORMAL OF EL. M,N*,/)    NOPM          63
              K1=0                                                               NORM          64
              DO 150 M=1,IMAX                                                    NORM          65
              DO 160 N=1,JMAX                                                    NORM          66
              IF(IFILF(M,N).GT.LT) GO TO 160                                     NOPM          67
              K1=K1+1                                                            NORM          68
              K2=MOD(K1,10)                                                      NORM          69
              IF(K2.GT.0) GO TO 160                                              NORM          70
              PRINT(6,170)M,N,FILEN(M,N,1),FILEN(M,N,2),FILEN(M,N,3)             NORM          71
        170   FORMAT(1X,*ELEMENT(*,I2,*,*,I2,*)   *,3E11.5)                      NOPM          72
        160   CONTINUE                                                           NORM          73
        150   CONTINUE                                                           NORM          74
              RETURN                                                             NORM          78
              END                                                                NORM          79
```

```
SUBROUTINE INCID      74/74    OPT=2                          FTN 4.2+P380      03/27/75  11.07.38.       PAGE

          SUBROUTINE INCID                                                     INCID       2
          COMMON/BLK2/FFILE(45,45,3),NUMM,NUMN                                 INCID       3
          COMMON/BLK4/XY(200),XZ(200)                                          INCID       4
          COMMON/BLK6/IFILE(45,45),JFILE(45,45)                                INCID       5
          DIMENSION FILEN(45,45,3)                                             INCID       6
          EQUIVALENCE (EFILE,FILEN)                                            INCID       7
          COMMON/BLK8/FILEE(45,45,3)                                           INCID       8
          COMMON/BLK9/XINCID(45,45)                                            INCID       9
          COMMON/BLK10/LT                                                      INCID      10
          COMMON/BLK13/IMAX,JMAX                                               INCID      11
C         FILEN CONTAINS THE DIR COSINES FOR THE NORMAL OF EA. EL.             INCID      12
C         FILEE CONTAINS THE DIR COSINES FOR THE EL TO RADOME VECTOR           INCID      13
          PRINT 300                                                            INCID      15
    300   FORMAT (1H0,* INCIDENT ANGLE DIRECTION COSINE AND ANGLE (DEG)*)      INCID      15
          K3=0                                                                 INCID      17
          DO 100 M=1,IMAX                                                      INCID      18
          DO 110 N=1,JMAX                                                      INCID      19
          IF(IFILE(M,N).GT.LT)XINCID(M,N)=1000..                               INCID      20
          IF(IFILE(M,N).GT.LT) GO TO 200                                       INCID      21
          XINCID(M,N)=FILEE(M,N,1)*FILEN(M,N,1)+FILEE(M,N,2)*FILEN(M,N,2)+     INCID      22
         1FILEE(M,N,3)*FILEN(M,N,3)                                            INCID      23
          XDEGR=ACOS(XINCID(M,N))                                              INCID      24
          XDEG=XDEGR*(180./3.14159)                                            INCID      25
          K3=K3+1                                                              INCID      26
          K4=MOD(K3,5)                                                         INCID      27
          IF(K4.GT.0) GO TO 200                                                INCID      28
          PRINT(6,120)M,N,XINCID(M,N),XDEG                                     INCID      29
    120   FORMAT(1H0,*INCID(*,I2,*,*,I2,*)=*,F11.5,1X,E11.5)                   INCID      30
    200   CONTINUE                                                             INCID      31
    110   CONTINUE                                                             INCID      32
    100   CONTINUE                                                             INCID      33
          PRINT(6,400)K3                                                       INCID      34
    400   FORMAT(1H0,*NUMBER OF BISTATIC ANGLES =*,I4)                         INCID      35
          WRITE(7)IMAX,JMAX,K3,XINCID,IFILE,XY                                 INCID      36
          RETURN                                                               INCID      40
          END                                                                  INCID      41
```

SECTION VI
FLAT-PANEL ANALYSIS PROGRAM (WAVES2)

1. ADAPTING THE RADOME PROGRAM

Thus far, the radome analysis program has been one of geometry, i.e., determining the incidence angles for rays passing through the radome wall; there remains the task of determining how the radome wall modifies the electrical parameters of each ray. To accomplish this, first, a flat-panel analysis program (Krueger, AFAL-TR-67-191, Sep 67) is used to calculate the following:

Power reflection coefficient
Electrical angle after reflection
Insertion loss
Insertion phase delay

Our original flat-panel program required input via data cards containing incidence angles and material thickness. But, due to the increasing number of rays considered, input via data cards became prohibitive, and modification of the flat-panel program was required. The program was modified to read the required input data from magnetic tape. Such inputs consisted of the following:

Coefficients of the six-degree polynominal fit of the radome
The radome's outside mold line contour
Maximum number of row and column elements in the array
Incidence angles and their total number
Radome station number where each ray passes through
Coordinate of radome surface where each ray passes through the surface

A printout of these inputs follows.

2. WAVES2 PRINTOUT

```
PROGRAM WAVES2      74/74    OPT=1                              FTN 4.2+P380        03/27/75  18.17.02.        PAGE

          PROGRAM WAVES2(INPUT,OUTPUT,T    5=INPUT,TAPE6=OUTPUT,TAPE8,          WAVES2     2
         1TAPE9,TAPE10)                                                         WAVES2     3
          COMPLEX KM,KE,K,TEZ,THZ,PHI,RTE,RTM,TTE,TTM,IM,TMZSC,TEZSC,           WAVES2     4
         1RTESC,RTMSC,TTMSC,TTESC,EMT,EPI,TAN,R1,R2,R3,R4,AE,AM,AES,AMS,CE,C    WAVES2     5
         2M,CES,CMS,BE,BM,BES,BMS,PHIK                                          WAVES2     6
          COMPLEX KA(31),KU(31),KE1,KM1,CET,CMT,Y(30),YN,ADMSRD(30),ZN          WAVES2     7
          DIMENSION BETA(2025),THETA(2025),D(20),KM(20,30),KE(20,30),F(         WAVES2     8
         120,30),                                                               WAVES2     9
         1TEZ(30),THZ(30),PHI(30),RTE(30),RTM(30),TTE(30),TTM(30),TMZSC(30),    WAVES2    10
         2RTESC(30),RTMSC(30),TTMSC(30),TTESC(30),AE(2,2),AM(2,2),AES(2,2),     WAVES2    11
         3CE(2,2),CM(2,2),CES(2,2),CMS(2,2),BE(2,2),BM(2,2),BES(2,2),BMS(2,2    WAVES2    12
         4),INT(20),MA(20),K(30),TEZSC(30),AMS(2,2),FSTRIP(30)                  WAVES2    13
          DIMENSION XINCID(45,45)                                               WAVES2    14
          DIMENSION IFILE(45,45),XY(200),T(2025)                                JAN28      1
          INTEGER CAEXIT                                                        WAVES2    15
          LOGICAL SW1                                                           JAN23      1
          DATA PI/3.141592/                                                     WAVES2    16
          DATA BN/.39476003E+03/                                                JAN23      2
          DATA B2/-.22388918E-02/                                               JAN23      3
          DATA B3/-.16308283E-04/                                               JAN23      4
          SW1=.TRUE.                                                            JAN23      5
      777 CONTINUE                                                              MAR5       1
          JD=0                                                                  WAVES2    18
          CAEXIT=0                                                              WAVES2    19
          IM=CMPLX(0.0,1.0)                                                     WAVES2    20
      807 FORMAT(1H1)                                                           WAVES2    22
          READ(8)THEL,THAZ                                                      JAN23      6
          IF(EOF(8).NE.0.)CALL EXIT                                             MAR6       1
          READ(8)IMAX,JMAX,K3,XINCID,IFILE,XY                                   JAN28      2
          WRITE(10)THEL,THAZ                                                    JAN23      7
          WRITE(10)IMAX,JMAX,K3,XINCID                                          WAVES2    29
          PRINT(6,903)THEL,THAZ                                                 JAN23      8
      903 FORMAT(1H0,*THEL=*,F10.4,1X,*THAZ=*,F10.4)                            JAN23      9
          MM=0                                                                  WAVES2    30
          JJ=K3                                                                 FEB4       1
          DO 900 I1=1,IMAX                                                      WAVES2    31
          DO 910 J1=1,JMAX                                                      WAVES2    32
          IF(XINCID(I1,J1).GT.999.) GO TO 910                                   WAVES2    33
          MM=MM+1                                                               WAVES2    34
          BETA(MM)=ACOS(XINCID(I1,J1))                                          WAVES2    35
          BETA(MM)=BETA(MM)*(180./3.14159)                                      WAVES2    36
          T(MM)=XY(IFILE(I1,J1))                                                FEB4       2
      910 CONTINUE                                                              WAVES2    37
      900 CONTINUE                                                              WAVES2    38
          LCNT=0                                                                FEB4       3
      621 CONTINUE                                                              FEB4       4
          LCNT=LCNT+1                                                           FEB4       5
          IF(JD.EQ.JJ)GO TO 777                                                 MAR6       2
          IF(.NOT.SW1) GO TO 958                                                FEB4       7
          READ(5,500)NL,NB,FINC,FINT,FFIN                                       FEB4       8
      958 CONTINUE                                                              FEB4       9
          BETA(1)=BETA(LCNT)                                                    FEB4      10
          MA(1)=0                                                               FEB4      11
          MA(2)=0                                                               FEB4      12
          T2=T(LCNT)**2                                                         FEB4      13
          T3=T(LCNT)**3                                                         FEB4      14
          D(1)=(BN+B2*T2+B3*T3)*.001*2.54                                       FEB4      15
```

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PROGRAM WAVES2     74/74    OPT=1                          FTN 4.2+P380        03/27/75  18.17.07.      PAGE

                 D(2)=.0280                                                      FEB4      16
                 J0=J0+1                                                         WAVES2    41
                 L=1                                                             WAVES2    42
             300 CONTINUE                                                        WAVES2    43
                 LL=MA(L)                                                        WAVES2    44
                 DLS=D(L)                                                        WAVES2    45
              11 CONTINUE                                                        WAVES2    56
               4 CONTINUE                                                        WAVES2    70
                 IF(.NOT.SW1) GO TO 310                                          FEB4      17
                 IF(LL.EQ.0)READ(5,504)NF                                        WAVES2    71
             504 FORMAT(2I5)                                                     FEB7       8
                 IF(LL.EQ.0)READ(5,8)(M,F(L,J),KH(L,J),KE(L,J),AI01,AI02,AI03,J=1,- WAVES2 72
                2NF)                                                             WAVES2    73
             310 CONTINUE                                                        FEB4      18
               8 FORMAT(I5,5F10.4,2A10,A5)                                       WAVES2    74
             631 CONTINUE                                                        WAVES2   103
             622 FORMAT(1X,*LAYER NO.*,1X,I5,2X,*MATERIAL*,1X,I5,2X,2A10,A5)     WAVES2   105
             623 FORMAT(1X,5F10.3)                                               WAVES2   106
             625 CONTINUE                                                        WAVES2   107
                 IF(L.EQ.NL)GO TO 645                                            WAVES2   108
                 L=L+1                                                           WAVES2   109
                 GO TO 300                                                       WAVES2   110
             500 FORMAT(2I5,3F10.4)                                              WAVES2   111
             501 FORMAT(13F6.2)                                                  WAVES2   112
             502 FORMAT(5(F10.4,I5))                                             WAVES2   113
             645 CONTINUE                                                        WAVES2   114
                 GOTO030                                                         WAVES2   119
                 GO TO 30                                                        WAVES2   121
              30 CONTINUE                                                        WAVES2   123
                 DT=0.0                                                          WAVES2   124
                 DO 629 I=1,NL                                                   WAVES2   125
                 DTOT=DT+D(I)                                                    WAVES2   126
                 DT=DTOT                                                         WAVES2   127
             629 CONTINUE                                                        WAVES2   128
             626 FORMAT(1X,*TOTAL DESIGN THICKNESS=*,F10.4,*CMS*)                WAVES2   129
                 F1=FINT                                                         WAVES2   132
              28 CONTINUE                                                        WAVES2   133
                 DO 611 IL=1,NL                                                  WAVES2   134
                 II=1                                                            WAVES2   135
             612 CONTINUE                                                        WAVES2   136
                 IF(ABS(F1-F(IL,II)).LE..001)GO TO 613                           WAVES2   137
                 IF(F1.LE.F(IL,II))GOTO613                                       WAVES2   138
                 II=II+1                                                         WAVES2   139
                 GOTO612                                                         WAVES2   140
             613 INT(IL)=II                                                      WAVES2   141
             611 CONTINUE                                                        WAVES2   142
                 DO 29 NN=1,NL                                                   WAVES2   143
                 NJ=INT(NN)                                                      WAVES2   144
                 IF(ABS(F1-F(IL,II)).LE..001)GO TO 619                           WAVES2   145
                 FJJ=F(NN,NJ-1)                                                  WAVES2   146
                 GO TO 620                                                       WAVES2   147
             619 CONTINUE                                                        WAVES2   148
                 FJJ=F(NN,NJ)                                                    WAVES2   149
             620 CONTINUE                                                        WAVES2   150
                 IF(NJ.EQ.1)NJ1=NJ                                               WAVES2   151
                 IF(NJ.NE.1)NJ1=NJ-1                                             WAVES2   152
                 CALL INTERP(F1,FJJ,F(NN,NJ),KE(NN,NJ1),KE(NN,NJ),KH(NN,NJ1),KH(NN, WAVES2 153
```

```
      PROGRAM WAVES2      74/74    OPT=1                    FTN 4.2+P380      03/27/75  18.17.02.      PAGE

     2NJ),K' 1,KM1)
      KA(NN)=KE1
      KU(NN)=KM1
   29 CONTINUE
      FJJ=F1
   27 F1=FJJ+FINC
      IF(F1.GT.FFIN)CAEXIT=CAEXIT+1
      OLAM=29.9776/FJJ
      TEZ(NL+1)=1.
      TMZ(NL+1)=1.
      TEZSC(NL+1)=0.
      TMZSC(NL+1)=0.
      PHI(NL+1)=0.
      DO 1 L=1,NB
      THETA(L)=PI*BETA(L)/180.
      DO 2 J=1,NL
      ER=REAL(KA(J))
      IF(MA(J).EQ.-1)GOTO33
      IF(ER.LE.0.)CALL RLC(KA(J),KU(J),D(J),OLAM)
   33 CONTINUE
      K(J)=KU(J)*KA(J)
      TMZ(J)=CSQRT(K(J)-SIN(THETA(L))*SIN(THETA(L)))/(KA(J)*COS(THETA(L)
     *))
      TEZ(J)=KU(J)*COS(THETA(L))/CSQRT(K(J)-SIN(THETA(L))*SIN(THETA(L)))
      TMZSC(J)=TMZ(J)
      TEZSC(J)=TEZ(J)
      PHI(J)=2.0*PI*D(J)*CSQRT(K(J)-SIN(THETA(L))*SIN(THETA(L)))/OLAM
      IF(J.NE.1)GOTO3
      RTE(J)=(TEZ(J)-1.0)/(TEZ(J)+1.0)
      RTM(J)=(TMZ(J)-1.0)/(TMZ(J)+1.0)
      IF(J.EQ.NL)GOTO51
      RTESC(J)=(TEZSC(J)-1.0)/(TEZSC(J)+1.0)
      RTMSC(J)=(TMZSC(J)-1.0)/(TMZSC(J)+1.0)
      GOTO6
    3 CONTINUE
      RTE(J)=(TEZ(J)-TEZ(J-1))/(TEZ(J)+TEZ(J-1))
      RTM(J)=(TMZ(J)-TMZ(J-1))/(TMZ(J)+TMZ(J-1))
      IF(J.EQ.NL)GOTO5
      RTESC(J)=(TEZSC(J)-TEZSC(J-1))/(TEZSC(J)+TEZSC(J-1))
      RTMSC(J)=(TMZSC(J)-TMZSC(J-1))/(TMZSC(J)+TMZSC(J-1))
      GOTO6
   51 EMI=CEXP(-IM*PHI(J))
      EPI=CEXP(IM*PHI(J))
      TAN=(EPI-EMI)/(EPI+EMI)
      RTESC(J)=(TEZSC(J)*TAN-1.0)/(TEZSC(J)*TAN+1.0)
      RTMSC(J)=(TMZSC(J)*TAN-1.0)/(TMZSC(J)*TAN+1.0)
      GOTO6
    5 EMI=CEXP(-IM*PHI(J))
      EPI=CEXP(IM*PHI(J))
      TAN=(EPI-EMI)/(EPI+EMI)
      RTESC(J)=(TEZSC(J)*TAN-TEZSC(J-1))/(TEZSC(J)*TAN+TEZSC(J-1))
      RTMSC(J)=(TMZSC(J)*TAN-TMZSC(J-1))/(TMZSC(J)*TAN+TMZSC(J-1))
    6 CONTINUE
      TTM(J)=RTM(J)+1.0
      TTE(J)=RTE(J)+1.0
      TTMSC(J)=RTMSC(J)+1.0
      TTESC(J)=RTESC(J)+1.0
```

```
      PROGRAM WAVES2      74/74    OPT=1                    FTN 4.2+P380        03/27/75  18.17.02.        PAGE

    2 CONTINUE
      RTM(NL+1)=(TMZ(NL+1)-TMZ(NL))/(TMZ(NL+1)+TMZ(NL))
      RTE(NL+1)=(TEZ(NL+1)-TEZ(NL))/(TEZ(NL+1)+TEZ(NL))
      RTMSC(NL+1)=0.
      RTESC(NL+1)=0.
      TTMSC(NL+1)=RTMSC(NL+1)+1.0
      TTESC(NL+1)=RTESC(NL+1)+1.0
      TTM(NL+1)=RTM(NL+1)+1.0
      TTE(NL+1)=RTE(NL+1)+1.0
      NP1=NL+1
      DO 40 K1=1,NP1
      DO 20 J=1,2
      DO 20 I=1,2
      R1=CMPLX(1.0,0.)
      R2=R1
      R3=R1
      R4=R1
      IF(I.NE.J)R1=RTE(K1)
      IF(I.NE.J)R2=RTM(K1)
      IF(I.NE.J)R3=RTESC(K1)
      IF(I.NE.J)R4=RTMSC(K1)
      S=1.0
      IF(J.EQ.2)S=-1.0
      AE(I,J)=1.0
      AM(I,J)=1.0
      AES(I,J)=1.0
      AMS(I,J)=1.0
      IF(I.NE.J)AE(I,J)=0.
      IF(I.NE.J)AM(I,J)=0.
      IF(I.NE.J)AES(I,J)=0.
      IF(I.NE.J)AMS(I,J)=0.
      IF(K1.NE.1)AES(I,J)=CES(I,J)
      IF(K1.NE.1)AMS(I,J)=CMS(I,J)
      IF(K1.NE.1)AE(I,J)=CE(I,J)
      IF(K1.NE.1)AM(I,J)=CM(I,J)
      CES(I,J)=0.
      CMS(I,J)=0.
      CE(I,J)=0.
      CM(I,J)=0.
      BE(I,J)=R1*CEXP(S*IM*PHI(K1))
      BM(I,J)=R2*CEXP(S*IM*PHI(K1))
      PHIK=PHI(K1)
      IF(K1.EQ.NL)PHIK=0.
      BES(I,J)=R3*CEXP(S*IM*PHIK)
   20 BMS(I,J)=R4*CEXP(S*IM*PHIK)
      DO 50 M=1,2
      DO 50 L1=1,2
      DO 50 N1=1,2
      CE(L1,M)=CE(L1,M)+(AE(L1,N1)*BE(N1,M))/TTE(K1)
      CM(L1,M)=CM(L1,M)+(AM(L1,N1)*BM(N1,M))/TTM(K1)
      CES(L1,M)=CES(L1,M)+(AES(L1,N1)*BES(N1,M))/TTESC(K1)
   50 CMS(L1,M)=CMS(L1,M)+(AMS(L1,N1)*BMS(N1,M))/TTMSC(K1)
   40 CONTINUE
      A=CABS(CE(2,1)/CE(1,1))
      B=CABS(CM(2,1)/CM(1,1))
      C=CABS(CES(2,1)/CES(1,1))
      E=CABS(CMS(2,1)/CMS(1,1))
```

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PROGRAM WAVES2    74/74   OPT=1                    FTN 4.2+P380      03/27/75  18.17.02.      PAGE

          TE=-20.0*ALOG10(CABS(1.0/CE(1,.)))                              WAVES2   258
          PHIF=-(ATAN2(AIMAG(CE(1,1)),REAL(CE(1,1)))*180.0/PI)+360.0*DTOT* WAVES2   259
         1COS(THETA(L))/OLAM                                               WAVES2   270
          IF(PHIF.GT.0.0)PHIF=PHIF-360.0                                   WAVES2   271
          TM=-20.0*ALOG10(CABS(1.0/CM(1,1)))                               WAVES2   272
          PHIM=-(ATAN2(AIMAG(CM(1,1)),REAL(CM(1,1)))*180.0/PI)+360.0*DTOT* WAVES2   273
         1COS(THETA(L))/OLAM                                               WAVES2   274
          IF(PHIM.GT.0.0)PHIM=PHIM-360.0                                   WAVES2   275
          IF(A.EQ.0.)GO TO 45                                              WAVES2   276
          RE=-20.0*ALOG10(CABS(CE(2,1)/CE(1,1)))                           WAVES2   277
          CET=CE(2,1)/CE(1,1)                                              WAVES2   278
          PHIET=ATAN2(AIMAG(CET),REAL(CET))*180.0/PI                       WAVES2   279
          IF(PHIET.LT.0.0)PHIET=360.0+PHIET                                WAVES2   280
   48     IF(9.EQ.0.)GO TO 46                                              WAVES2   281
          RM=-20.0*ALOG10(CABS(CM(2,1)/CM(1,1)))                           WAVES2   282
          CMT=CM(2,1)/CM(1,1)                                              WAVES2   283
          PHIMT=ATAN2(AIMAG(CMT),REAL(CMT))*180.0/PI                       WAVES2   284
          IF(PHIMT.LT.0.0)PHIMT=360.0+PHIMT                                WAVES2   285
          GO TO 47                                                         WAVES2   286
   45     RE=-10.0**38                                                     WAVES2   287
          GO TO 48                                                         WAVES2   288
   46     RM=-10.0**38                                                     WAVES2   289
   47     IF(C.EQ.0.)GOTO41                                                WAVES2   290
          RESC=-20.0*ALOG10(CABS(CES(2,1)/CES(1,1)))                       WAVES2   291
          YN=(CFS(1,1)-CES(2,1))Y(CES(1,1)+CES(2,1))                       WAVES2   292
          ZN=1.0/YN                                                        WAVES2   293
          ZNM=CABS(ZN)                                                     WAVES2   294
          ZNP=ATAN2(AIMAG(ZN),REAL(ZN))*180./PI                            WAVES2   295
   44     IF(E.EQ.0.)GOTO42                                                WAVES2   296
          RMSC=-20.0*ALOG10(CABS(CMS(2,1)/CMS(1,1)))                       WAVES2   297
          GOTO43                                                           WAVES2   298
   41     PESC=-10.0**38                                                   WAVES2   299
          GOTO44                                                           WAVES2   300
   42     RMSC=-10.0**38                                                   WAVES2   301
   43     CONTINUE                                                         WAVES2   302
          WRITE(10)FJJ,BETA(L),RE,PHIET,TE,PHIE,RM,PHIMT,TM,PHIM           WAVES2   303
    1     CONTINUE                                                         WAVES2   309
  601     FORMAT(1X)                                                       WAVES2   311
          IF(CAEXIT.EQ.JD)GO TO 621                                        WAVES2   312
          SH1=.FALSE.                                                      FEB4      19
          GOTO28                                                           WAVES2   313
  602     FORMAT(1X/2X,11HFRONT LAYER,3X,1HD,I2,1H=,F8.4,3HCMS)            WAVES2   314
  603     FORMAT(2X,9HLAYER NO.,I2,3X,1HD,I2,1H=,F8.4,3HCMS)               WAVES2   315
  604     FORMAT(2X,10HBACK LAYER,4X,1HD,I2,1H=,F8.4,3HCMS)                WAVES2   316
  605     FORMAT(1X/1X/3X,21HFREQUENCY     INCIDENT,4X,3HRTE,4X,*ANGLE*,6X, WAVES2   317
         13HTTE,4X,*ANGLE*,6X,3HRTM,5X,*ANGLE*,8X,3HTTM,4X,*ANGLE*,3X,     WAVES2   318
         25HRSCTE,2X,5HRSCTM,5X,13HIMPEDANCE(TE)/5X,5H(GHZ),6X,10HANGLE(DEG) WAVES2   319
         A,2X,4H(DB),                                                      WAVES2   320
         34X,*DEG*,7X,4H(DB),5X,*DEG*,6X,4H(DB),5X,*DEG*,6X,4H(DB),7X,     WAVES2   321
         4*DEG*,4X,4H(DB),4X,4H(DB),5X,3HAMP,5X,5HPHASE/1X)                WAVES2   322
  610     FORMAT(2X,F7.2,4X,F8.3,5X,10(F7.2,2X),F6.2,F8.2)                 WAVES2   323
          END                                                              WAVES2   324
```

```
SUBROUTINE RLC        74/74    OPT=1                    FTN 4.2+P380      03/27/75  10.17.48.       PAGE

      SUBROUTINE RLC(KE,KM,D,OLAM)                                  RLC      2
      COMPLEX KE,KM,IM,Y                                            RLC      3
      FR=AIMAG(KE)                                                  RLC      4
      B=REAL(KE)                                                    RLC      5
      D=REAL(KM)                                                    RLC      6
      G=AIMAG(KM)                                                   RLC      7
      IM=CMPLX(0.,1.)                                               RLC      8
      P=3.14159265                                                  RLC      9
      F=(29977.6/OLAM)/1000.                                        RLC     10
      A=F/FR                                                        RLC     11
      YII=B*A                                                       RLC     12
      A=(A*A-1.)/A                                                  RLC     13
      YDEN=1.+Q*Q*A*A                                               RLC     14
      YR=G/YDEN                                                     RLC     15
      YI=G*Q*A/YDEN                                                 RLC     16
      YI=YII+YI                                                     RLC     17
      Y=CMPLX(YR,-YI)                                               RLC     18
      KE=Y*OLAM/(IM*2.*P*D)                                         RLC     19
      KM=CMPLX(1.0,0.0)                                             RLC     20
      RETURN                                                        RLC     21
      END                                                           RLC     22
```

SUBROUTINE INTERP   74/74   OPT=1   FTN 4.2+P380   03/27/75   18.17.52.   PAGE

```
      SUBROUTINE INTERP(F1,B,B1,C1,C,D1,D,KE1,KM1)
      COMPLEX KE1,KM1,C,C1,D,D1
      ERMAX=REAL(C1)
      ERMIN=REAL(C)
      EIMAX=AIMAG(C1)
      EIMIN=AIMAG(C)
      URMAX=REAL(D1)
      URMIN=REAL(D)
      UIMAX=AIMAG(D1)
      UIMIN=AIMAG(D)
      IF(ABS(B-B1).LE..001)GO TO30
      FRAC=(B1-F1)/(B1-B)
      GO TO 31
   30 FRAC=0.0
   31 CONTINUE
      ERMED=FRAC*(ERMAX-ERMIN)
      EIMED=FRAC*(EIMAX-EIMIN)
      URMED=FRAC*(URMAX-URMIN)
      UIMED=FRAC*(UIMAX-UIMIN)
      ER=ERMIN+ERMED
      EI=EIMIN+EIMED
      UR=URMIN+URMED
      UI=UIMIN+UIMED
      KE1=CMPLX(ER,EI)
      KM1=CMPLX(UR,UI)
      RETURN
      END
```

```
SUBROUTINE STRIPS      74/74    OPT=1                    FTN 4.2+P380       03/27/75

      SUBROUTINE STRIPS(YLN,F1,NFS)
C  NSETS  NUMBER OF DATA SETS INCLUDED WITH THIS RUN
C  FMIN   LOWER FREQUENCY LIMIT IN GHZ.
C  FMAX   UPPER FREQUENCY LIMIT IN GHZ.
C  DELF   FREQUENCY INCREMENT IN GHZ.
C  DX     STRIP SPACING IN CM.
C  W      STRIP WIDTH IN CM.
C  G      RELATIVE SHEET CONDUCTANCE IN MHO PER SQUARE
C  TH     STRIP THICKNESS IN CM.
C  DZ     SPACING BETWEEN CUTS IN CM.
C  ESUB   RELATIVE DIELECTRIC CONSTANT OF SUBSTRATE
C  TSUB   SUBSTRATE THICKNESS IN CM.
C  GW     CUT WIDTH IN CM.
C  CSS    SHUNT CAP. ACROSS R AND L DUE TO SUBSTRATE IN PICOFARADS
C  CSC    SHUNT CAP.ACROSS ZL DUE TO X-POL. DIELECTRIC STRIPS IN PICOFAR
C  CF     CONSTRUCTION FACTOR       =0 IF NO ORTHOGONAL ARRAY PRESENT
C                                   =1 IF ONE LAYER WITH ORTHOGONAL ARRAY
C                                   =2 IF TWO LAYERS WITH ORTHOGONAL ARRAY
      INTEGER PHI,CF
      COMPLEX FM,FMK,B,SUM1,SUM2,SUM3,SUM4,SUM5,RS,ZL,E,TERM1,TERM2,TERM
     *M3,TERM4,R,T,ZS,REFLC,ZOC,ZCSC,YL,YLN(30)
      DIMENSION REFLR(90),REFLI(90),F1(30)
      NSETS=1
      NFS=1
      DO 40 NSET=1,NSETS
      READ(5,1) FMIN, FMAX,DELF,DX,W,G,TH,DZ,ESUB,TSUB,GW,CF
    1 FORMAT(6F10.6,/3F10.6,1X,I1)
      IF(DELF.GT.0.0)GO TO 210
      WRITE(6,205)
  205 FORMAT(51H FREQUENCY INCREMENT MUST BE A POSITIVE REAL NUMBER)
      GO TO 40
  210 IF(W.GT.0.0.AND.(DX-W).GT.0.0)GO TO 220
      WRITE(6,215)
  215 FORMAT(81H STRIP SPACING MUST BE GREATER THAN STRIP WIDTH AND BOTH
     H MUST BE POSITIVE NUMBERS)
      GO TO 40
  220 IF(TH.GT.0.0)GO TO 230
      WRITE(6,225)
  225 FORMAT(42H STRIP THICKNESS MUST BE A POSITIVE NUMBER)
      GO TO 40
  230 FPI2=2.0*3.14159265
      SIGMA= 100.*G/(377.0*TH)
      IF((DZ-GW).GT.0.0.OR.GW.EQ.0.0)GO TO 232
      WRITE(6,231)
  231 FORMAT(43H CUT SPACING MUST BE GREATER THAN CUT WIDTH)
      GO TO 40
  232 IF(GW)235,237,240
  235 WRITE(6,236)
  236 FORMAT(29H GAP WIDTH CANNOT BE NEGATIVE)
      GO TO 40
  237 DZ=1.0
      C=0.25
      A=W/4.0
      CSQ=0.0
      ESUBE=1.0
      GO TO 245
  240 CALL CSQARE(ESUB,TSUB,DZ,GW,W,DX,ESUBE,CSQ,A,C,TH)
```

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SUBROUTINE STRIPS      74/74    OPT=1                       FTN 4.2+P380        03/27/75  10.17.54.        PAGE

  245 IF(CF.NE.0)A=A/(1.0-0.31*W, .)
      CSS= (ESUB-1.0)*TSUB/(1.80*FPI2)
      CSC= X*W/(14.4*DX)
      WRITE(6,2)FMIN, FMAX,DELF,DX,W,G,TH,DZ,SIGMA,GW,CSQ,CSS,TSUB,ESUB,
     ZESUBE
    2 FORMAT (20H FREQUENCY SCAN FROM,F10.3,7H GHZ TO,F10.3,21H GHZ IN I
     2NCREMENTS OF,F10.3,4H GHZ,/24H SPACING BETWEEN STRIPS=,F10.6,3H CM
     3,/13H STRIP WIDTH=,F10.6,3H CM,/23H REL SHEET CONDUCTANCE=,F10.6
     4,16H MHOS PER SQUARE,/ 17H STRIP THICKNESS=,F10.6,3H CM,/ 13H CUT
     5SPACING=,F10.6,3H CM,/ 7H SIGMA=,E12.6,14H MHO PER METER,/
     "11H GAP WIDTH=,F10.6,3H CM/
     620H SERIES CAPACITANCE=,F10.6,11H PICOFARADS,/36H SHUNT CAPACITANC
     7E DUE TO SUBSTRATE=,F10.6,11H PICOFARADS,/21H SUBSTRATE THICKNESS=
     8,F10.6,3H CM,/35H SUBSTRATE REL DIELECTRIC CONSTANT=,F10.6/
     931H EFFECTIVE DIELECTRIC CONSTANT=,F10.6)
      IF (CF.EQ.0) WRITE(6,5)
      IF (CF.EQ.1) WRITE(6,6)
      IF (CF.EQ.2) WRITE(6,7)
    5 FORMAT(43H LAYER CONSTRUCTED WITH NO ORTHOGONAL ARRAY)
    6 FORMAT(45H ORTHOGONAL ARRAY IN SAME PLANE AS BASE ARRAY)
    7 FORMAT(45H ORTHOGONAL ARRAY PLACED ON TOP OF BASE ARRAY)
      FPHI=0.0
      SPHI=SIN(FPI2*SPHI/360.)
      CPHI=COS(FPI2*FPHI/360.)
      F=FMIN
   41 CONTINUE
      FLAM=30./F
      BETA=FPI2/FLAM
      BDX=BETA*DX
      SUM1=(0.0,0.0)
      N=0
    8 N=N+1
      FN=FLOAT(N)
      DEN1=BDX*BDX-(BDX*SPHI+FPI2*FN)**2
      IF (DEN1) 10,10,9
    9 DEN1=SQRT(DEN1)
      TERM1=2.0/DEN1
      SUM1=SUM1+TERM1
      GO TO 8
   10 N1=N-1
      SUM2=(0.0,0.0)
      N=0
   11 N=N+1
      FN=FLOAT(N)
      DEN2=BDX*BDX-(BDX*SPHI-FPI2*FN)**2
      IF(DEN2) 13,13,12
   12 DEN2=SQRT(DEN2)
      TERM2=2.0/DEN2
      SUM2=SUM2+TERM2
      GO TO 11
   13 N2=N-1
      SUM3=(0.0,0.0)
      N=N1
   14 N=N+1
      FN=FLOAT(N)
      DEN3=SQRT((BDX*SPHI+FPI2*FN)**2-BDX*BDX)
      TERM3=CMPLX(0.0,2.0*EXP(-A*DEN3/DX)/DEN3)
```

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SUBROUTINE STRIPS      74/74    OPT=1                    FTN 4.2+P380       03/27/75  18.17.54.        PAGE

          IF(CABS(TERM3).LT.1.0E-6) G   O 15                                STRIPS    116
          SUM3=SUM3+TERM3                                                   STRIPS    117
          GO TO 14                                                          STRIPS    118
      15  N3=N-N1                                                           STRIPS    119
          SUM4=(0.0,0.0)                                                    STRIPS    120
          N=N2                                                              STRIPS    121
      16  N=N+1                                                             STRIPS    122
          FN=FLOAT(N)                                                       STRIPS    123
          DEN4=SQRT((BDX*SPHI-FPI2*FN)**2-BDX*BDX)                          STRIPS    124
          TERM4=CMPLX(0.0,2.0*EXP(-A*DEN4/DX)/DEN4)                         STRIPS    125
          IF(CABS(TERM4).LT.1.0E-6) GO TO 17                                STRIPS    126
          SUM4=SUM4+TERM4                                                   STRIPS    127
          GO TO 16                                                          STRIPS    128
      17  N4=N-N2                                                           STRIPS    129
          SUM5=2.0*(CEXP(CMPLX(0.0,-BETA*A*CPHI)))/(BDX*CPHI)               STRIPS    130
          FM=-(SUM1+SUM2+SUM3+SUM4+SUM5)                                    STRIPS    131
          E=CMPLX ( 1.0, -SIGMA/(FPI2*F*8.852E-03))                         STRIPS    132
          FM=(0.0,8.)/(FPI2*E*A*A*BETA*BETA)+FM                             STRIPS    133
          FMK=(1.0,0.0)                                                     STRIPS    134
          B=FMK/FM                                                          STRIPS    135
          BMAG=CABS(B)                                                      STRIPS    136
          BPH=(360./FPI2)*ATAN2(AIMAG(B),REAL(B))                           STRIPS    137
          R=-B/((FPI2/2.0)*DX*CPHI/FLAM)                                    STRIPS    138
          RPH=(360.0/FPI2)*ATAN2(AIMAG(R),REAL(R))                          STRIPS    139
          RMAG=CABS(R)                                                      STRIPS    140
      89  RDB=-20.0*ALOG10(RMAG)                                            STRIPS    141
          T=1.-R                                                            STRIPS    142
          TMAG=CABS(T)                                                      STRIPS    143
          TPH=(360.0/FPI2)*ATAN2(AIMAG(T),REAL(T))                          STRIPS    144
          TDB=-20.0*ALOG10(TMAG)                                            STRIPS    145
          FLOSS=1.0-RMAG*RMAG-TMAG*TMAG                                     STRIPS    146
          ZS=30.*FPI2*(1.-R)/(R*CPHI)                                       STRIPS    147
          XL=AIMAG(ZS)                                                      STRIPS    148
          XL=XL*4.0*C/DZ                                                    STRIPS    149
          FLL=XL/(FPI2*F)                                                   STRIPS    150
          Y0=60.*FPI2/XL                                                    STRIPS    151
          SCR=10.0                                                          STRIPS    152
          I2F=IFIX(F*2.0)                                                   STRIPS    153
          ZOC= CMPLX( 60.0*FPI2 /CPHI , 0.0)                                STRIPS    154
          RL= 60.0*FPI2*DX/(W*G)                                            STRIPS    155
          RL=RL*DZ/(4.0*C)                                                  STRIPS    156
          IF (CF.EQ.1) RL=RL*(1.0-0.31*W/DX)                                STRIPS    157
          IF (CF.EQ.2) RL=RL*(1.0-0.592*W/DX)                               STRIPS    158
          IF((N1.NE.0).OR.(N2.NE.0))  RL=2.0*FLOAT(N1+N2)*RL                STRIPS    159
          Q=XL/RL                                                           STRIPS    160
          IF(GW.EQ.0.0)GO TO 260                                            STRIPS    161
          XCSQ=  1.0E+03/(FPI2*F*CSQ)                                       STRIPS    162
          GO TO 265                                                         STRIPS    163
     260  XCSQ=0.0                                                          STRIPS    164
     265  IF(CSS.EQ.0.0)GO TO 270                                           STRIPS    165
          XCSS= 1.0E+03/(FPI2*F*CSS)                                        STRIPS    166
          ZDEN= RL*RL+(XL-XCSS)*(XL-XCSS)                                   STRIPS    167
          ZL=CMPLX(RL*XCSS*XCSS/ZDEN,-XCSQ-XCSS*(RL*RL+XL*XL-XL*XCSS)/ZDEN) STRIPS    168
          GO TO 275                                                         STRIPS    169
     270  ZL=CMPLX(RL,-XCSQ+XL)                                             STRIPS    170
     275  IF(CF.NE.0) GO TO 100                                             STRIPS    171
          REFLC=-(ZL-ZOC)/(ZL+ZOC)                                          STRIPS    172
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SUBROUTINE STRIPS      74/74    OPT=1                    FTN 4.2+P380        03/27/75  18.17.54.        PAGE

          GO TO 101                                                        STRIPS    173
      100 ZCSC=CMPLX(0.0,-1.0E+3/(FPI2*F*CSC*CPHI))                        STRIPS    174
          ZL = ZL*ZCSC/(ZL+ZCSC)                                           STRIPS    175
          REFLC=-(ZL-ZOC)/(ZL+ZOC)                                         STRIPS    176
      101 CONTINUE                                                         STRIPS    177
          REFLR(I2F)= REAL(REFLC)*SCR                                      STRIPS    178
          REFLI(I2F)= AIMAG(REFLC)*SCR                                     STRIPS    179
          YL=1.0/ZL                                                        STRIPS    180
          YLN(NFS)=YL*ZOC                                                  STRIPS    181
          F1(NFS)=F                                                        STRIPS    182
          NFS=NFS+1                                                        STRIPS    183
          F=F+DELF                                                         STRIPS    184
          IF(F.LE.FMAX) GO TO 41                                           STRIPS    185
          NFS=NFS-1                                                        STRIPS    186
       40 CONTINUE                                                         STRIPS    187
          RETURN                                                           STRIPS    188
          END                                                              STRIPS    189
```

```
SUBROUTINE CSQARE      74/74    OPT=1                    FTN 4.2+P380       03/27/75  18.18.10.       PAGE

       SUBROUTINE CSQARE(ESUB,TSUB,DZ,GW,W,DX,ESUBE,CSQ,RHO,C,TH)       CSQARE   2
       INTEGER CFP                                                      CSQARE   3
       RSQ=W*W/16.0                                                     CSQARE   4
       H=(DZ+GW)/4.0                                                    CSQARE   5
       X1=GW/2.0                                                        CSQARE   6
       X2=DZ/2.0                                                        CSQARE   7
    10 C=SQRT(((H*H+H*X1-X1*X1)*H-X2*X2*X1)/(H-X1))                     CSQARE   8
       A=(C+SQRT(C*C+RSQ))*(2.0*H-C+SQRT((2.0*H-C)*(2.0*H-C)+RSQ))/((-C+S CSQARE   9
      *SQRT(C*C+RSQ))*(2.0*H+C+SQRT((2.0*H+C)*(2.0*H+C)+RSQ)))          CSQARE  10
       X2C=SQRT(((H-C)*(H-C)-A*(H+C)*(H+C))/(1.0-A))                    CSQARE  11
       T=X2/X2C                                                         CSQARE  12
       IF(ABS(T-1.0).LT.1.0E-6)GO TO 20                                 CSQARE  13
       H=H*T                                                            CSQARE  14
       GO TO 10                                                         CSQARE  15
    20 F=C*(1.0+A)/(1.0-A)                                              CSQARE  16
       X1C=F+SQRT(F*F+H*H-C*C)                                          CSQARE  17
       PH1=ALOG(A)                                                      CSQARE  18
       B=(ESUB-1.0)/(ESUB+1.0)                                          CSQARE  19
       BS=B*B                                                           CSQARE  20
       BN=B*(1.0-BS)                                                    CSQARE  21
       PHN=(1.0-B)*PH1                                                  CSQARE  22
       RHO=W/4.0                                                        CSQARE  23
       XX2=2.0*H+C                                                      CSQARE  24
       XX3=2.0*H-C                                                      CSQARE  25
       X2S=XX2*XX2                                                      CSQARE  26
       X3S=XX3*XX3                                                      CSQARE  27
       Z=2.0*TSUB+RHO                                                   CSQARE  28
    30 ZS=Z*Z                                                           CSQARE  29
       R1=SQRT(ZS+C*C)                                                  CSQARE  30
       R2=SQRT(ZS+X2S)                                                  CSQARE  31
       R3=SQRT(ZS+X3S)                                                  CSQARE  32
       PHP=BN*ALOG((R1+C)*(XX3+R3)/((R1-C)*(XX2+R2)))+PHN               CSQARE  33
       U=PHN/PHP                                                        CSQARE  34
       PHN=PHP                                                          CSQARE  35
       IF(ABS(U-1.0).LT.1.0E-6)GO TO 40                                 CSQARE  36
       BN=BN*BS                                                         CSQARE  37
       Z=Z+2.0*TSUB                                                     CSQARE  38
       GO TO 30                                                         CSQARE  39
    40 ESUBE=PH1/PHN                                                    CSQARE  40
       READ(5,1)CFP                                                     CSQARE  41
     1 FORMAT(I2)                                                       CSQARE  42
       IF(CFP.EQ.1)GO TO 45                                             CSQARE  43
       ESUBE=2.0*ESUBE-1.0                                              CSQARE  44
       PHN=PH1/ESUBE                                                    CSQARE  45
    45 CSQ=(DZ*C)/(8.90*DX*PHN)                                         CSQARE  46
       CSQ=CSQ+0.085*W*TH/GW                                            CSQARE  47
    50 CONTINUE                                                         CSQARE  48
       RETURN                                                           CSQARE  49
       END                                                              CSQARE  50
```

3. THE LISTING PROGRAM

The "listing" program will read the magnetic tape containing the flat-panel program outputs, and print out the electrical parameters required for each array element. The program list consists of the following for a given antenna array row or column:

(I,J)	-	array row and column numbers, respectively
—	-	incidence angle in degrees
RTE	-	reflection loss in dB for vertical polarization (power)
ANGLE	-	electrical angle after reflection
TTT	-	transmission loss for vertical polarization in dB (power)
Angle	-	insertion phase delay (Deg)
RTM	-	reflection loss for horizontal polarization dB (power)
ANGLE	-	phase angle in electrical degrees after reflection
TTM	-	insertion loss for horizontal polarization in dB (power)
ANGLE	-	insertion phase delay in electrical degrees for horizontal polarization

a. WAVES2 INPUTS

The required data cards are:

1. Input magnetic tape from flat-panel program
2. One data card, on which will be entered:

In column 5: 1 = row output
2 = column output

and in columns 9 and 10: array row or column desired

Final printout of the array element modification parameters follows.

b. WAVES2 OUTPUT

```
PROGRAM MAIN        74/74    OPT 1                    FTN 4.2+P380     04/01/75  09.15.27.        PAGE

             PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE8)
             DIMENSION XINCID(45,45)
C            1,2 IN COL 5 = ROW,COL AND 9 AND 10 ARE ROW OR COL NUM.
             READ(5,500)KOP,NUM
             PRINT(6,510)
       90    READ(5)THEL,THAZ
             IF(EOF(5).NE.0.)CALL EXIT
             PRINT(6,200)THEL,THAZ
             READ(5)IMAX,JMAX,K3,XINCID
             PRINT(6,530)IMAX,JMAX,K3
             PRINT(6,540)
             PRINT(6,541)
             DO 230 I=1,IMAX
             DO 210 J=1,JMAX
             IF(XINCID(I,J).GT.900.)GO TO 210
             DO 220 K=1,2
             READ(8)FJJ,DUMMY,RE,PHIET,TE,PHIE,RM,PHIMT,TM,PHIM
             IF(KOP.NE.1)GO TO 310
             IF(I.NE.NUM)GO TO 300
             GO TO 320
      310    IF(J.NE.NUM)GO TO 300
      320    CONTINUE
             PRINT(6,400)I,J,FJJ,DUMMY,RE,PHIET,TE,PHIE,RM,PHIMT,TM,PHIM
      300    CONTINUE
      220    CONTINUE
      210    CONTINUE
      230    CONTINUE
             GO TO 90
      200    FORMAT(1H0,*THEL=*,F10.4,1X,*THAZ=*,F10.4)
      400    FORMAT(1X,I2,*,*,I2,2X,F7.2,4X,F8.3,5X,8(F7.2,2X))
      500    FORMAT(2I5)
      510    FORMAT(1H1)
      530    FORMAT(1H0,*NUM OF ROWS=*,I2,3X,*NUM OF COLS=*,I2,3X,
            1*NUM OF VISIBLE RAYS =*,I4/)
      540    FORMAT(1X,*ELEMENT*,1X,*FREQUENCY*,1X,*INCIDENCE*,5X,*RTE*,5X,
            1*ANGLE*,7X,*TTE*,3X,*ANGLE*,6X,*RTM*,5X,*ANGLE*,7X,*TTM*,3X,*ANGLE
            1*)
      541    FORMAT(1X,*ROW,COL*,1X,*(GHZ)*,5X,*ANGLE(DEG)*,4X,*(DB)*,4X,
            1*(DEG)*,7X,*(DB)*,3X,*(DEG)*,5X,*(DB)*,4X,*(DEG)*,7X,*(DB)*,2X,
            1*(DEG)*/)
             END
```

THEL= 0.0000 THAZ= 5.0000

NUM OF ROWS=44 NUM OF COLS=44 NUM OF VISIBLE RAYS =19

ELEMENT ROW,COL	FREQUENCY (GHZ)	INCIDENCE ANGLE(DEG)	RTE (DB)	ANGLE (DEG)	TTE (DB)	ANGLE (DEG)	RTM (DB)	ANGLE (DEG)	TTM (DB)	ANGLE (DEG)
44, 1	9.70	73.331	14.32	119.48	.70	-135.22	27.14	292.16	.25	-140.87
44, 1	9.80	73.331	18.77	127.39	.63	-139.35	30.79	299.61	.25	-142.55
44, 2	9.70	73.252	15.11	119.49	.73	-135.17	27.27	292.22	.25	-140.76
44, 2	9.80	73.252	18.89	127.62	.62	-139.30	30.95	299.80	.25	-142.43
44, 3	9.70	73.423	14.81	119.47	.71	-135.26	26.99	292.11	.25	-141.00
44, 3	9.80	73.423	18.53	127.14	.63	-139.43	30.62	299.40	.25	-142.69
44, 4	9.70	72.888	14.83	118.93	.69	-134.20	27.29	291.67	.25	-139.92
44, 4	9.80	72.888	18.55	125.87	.62	-138.24	30.81	298.32	.25	-141.57
44, 5	9.70	73.559	15.22	120.09	.70	-136.06	27.31	292.79	.25	-141.49
44, 5	9.80	73.559	19.25	129.55	.63	-140.28	31.14	301.41	.25	-143.19
44, 6	9.70	72.842	14.88	118.93	.69	-134.18	27.37	291.70	.25	-139.86
44, 6	9.80	72.842	18.62	125.98	.62	-138.21	30.90	298.42	.25	-141.50
44, 7	9.70	73.695	15.06	120.05	.71	-136.14	27.08	292.69	.26	-141.68
44, 7	9.80	73.695	19.05	129.11	.64	-140.39	30.88	301.05	.25	-143.39
44, 8	9.70	72.805	14.93	118.93	.69	-134.16	27.43	291.72	.25	-139.80
44, 8	9.80	72.805	18.67	126.07	.61	-138.18	30.98	298.50	.25	-141.45
44, 9	9.70	73.845	14.83	120.02	.72	-136.22	26.84	292.59	.26	-141.90
44, 9	9.80	73.845	18.52	128.64	.64	-140.49	30.59	300.67	.25	-143.62
44,10	9.70	72.700	14.42	118.40	.70	-133.28	27.00	291.05	.25	-139.32
44,10	9.80	72.700	17.31	123.84	.62	-137.26	30.32	296.58	.25	-140.95
44,11	9.70	74.009	14.69	120.00	.73	-136.31	26.57	292.48	.26	-142.13
44,11	9.80	74.009	18.53	128.17	.65	-140.62	30.27	300.28	.26	-143.86
44,12	9.70	72.708	14.41	118.40	.70	-133.24	26.99	291.05	.25	-139.33
44,12	9.80	72.708	17.90	123.87	.62	-137.26	30.30	296.57	.25	-140.96
44,13	9.70	74.032	15.40	120.87	.71	-137.20	27.26	293.51	.26	-142.49
44,13	9.80	74.032	19.61	132.01	.64	-141.54	31.27	303.45	.25	-144.22
44,14	9.70	72.528	14.39	118.22	.70	-132.89	27.07	290.89	.25	-138.95
44,14	9.80	72.528	17.83	123.36	.62	-136.82	30.33	296.18	.24	-140.57
44,15	9.70	74.263	15.14	120.84	.73	-137.41	26.87	293.38	.26	-142.89
44,15	9.80	74.263	19.28	131.33	.65	-141.81	30.83	302.92	.26	-144.65
44,16	9.70	72.430	14.08	117.94	.70	-132.27	26.83	290.52	.25	-138.57
44,16	9.80	72.430	17.37	122.19	.62	-136.17	29.96	295.13	.24	-140.19
44,17	9.70	74.775	14.53	120.73	.76	-137.68	26.04	293.01	.27	-143.62
44,17	9.80	74.775	18.51	129.65	.68	-142.19	29.85	301.54	.26	-145.42
44,18	9.70	72.437	13.77	117.80	.72	-131.85	26.53	290.25	.25	-139.41
44,18	9.80	72.437	16.95	121.33	.63	-135.74	29.54	294.34	.24	-140.02
44,19	9.70	74.733	14.58	120.74	.76	-137.66	26.11	293.04	.27	-143.56
44,19	9.80	74.733	18.57	129.78	.68	-142.16	29.93	301.64	.26	-145.36
44,20	9.70	72.421	13.46	117.67	.73	-131.35	26.23	289.97	.25	-138.18
44,20	9.80	72.421	16.48	120.52	.64	-135.22	29.12	293.59	.24	-139.79
44,21	9.70	74.939	14.28	120.72	.78	-137.78	25.70	292.88	.27	-143.93
44,21	9.80	74.939	18.19	129.05	.69	-142.35	29.45	301.02	.26	-145.74
44,22	9.70	72.196	13.31	117.47	.73	-130.68	26.22	289.74	.25	-137.63
44,22	9.80	72.196	16.24	119.88	.64	-134.50	29.02	292.96	.24	-139.22
44,23	9.70	75.259	13.97	120.74	.80	-137.90	25.28	292.73	.27	-144.31
44,23	9.80	75.259	17.80	128.37	.71	-142.54	28.95	300.41	.27	-146.15
44,24	9.70	72.282	12.97	117.48	.75	-130.32	25.83	289.55	.25	-137.58
44,24	9.80	72.232	15.77	119.34	.65	-134.14	28.53	292.36	.24	-139.18
44,25	9.70	75.265	13.96	120.74	.80	-137.91	25.27	292.73	.27	-144.32
44,25	9.80	75.255	17.79	128.36	.71	-142.54	28.94	300.40	.27	-146.16
44,26	9.70	72.231	12.59	117.45	.77	-129.60	25.49	289.30	.25	-137.21
44,26	9.80	72.231	15.23	118.66	.66	-133.38	28.04	291.61	.24	-138.80
44,27	9.70	75.272	13.95	120.74	.80	-137.91	25.25	292.72	.27	-144.33
44,27	9.80	75.272	17.73	128.34	.71	-142.55	28.93	300.38	.27	-146.17
44,28	9.70	72.361	12.46	117.54	.78	-129.65	25.29	289.29	.25	-137.39

44.29	9.54	75.272	17.79	129.34	.71	-142.55	28.93	300.38	.27	-146.17
44.29	9.70	72.361	12.46	117.44	.7[illegible]	-129.65	25.23	299.29	.25	-137.39
.28	9.90	77.361	15.79	119.64	.6[illegible]	-133.45	27.82	291.54	.24	-138.99
.29	9.70	75.289	13.34	120.74	.80	-137.91	25.24	292.72	.27	-144.34
44.29	9.90	75.293	17.77	129.32	.71	-142.55	28.92	300.37	.27	-146.18
44.30	9.70	72.161	11.97	117.53	.87	-128.43	24.93	299.99	.25	-136.63
44.29	9.80	72.151	14.37	117.71	.69	-132.15	27.29	299.64	.24	-138.21
44.31	9.70	75.288	13.33	120.74	.93	-137.92	25.23	292.71	.27	-144.35
44.31	9.88	75.233	17.75	129.30	.71	-142.56	28.90	300.35	.27	-146.19
44.32	9.70	72.307	11.35	117.66	.91	-128.49	24.71	299.00	.25	-136.82
44.32	9.80	72.307	14.23	117.73	.70	-132.24	27.04	290.58	.25	-138.41
44.33	9.70	75.297	13.92	120.75	.81	-137.92	25.22	292.71	.27	-144.37
44.33	9.80	75.297	17.74	128.28	.71	-142.57	28.89	300.33	.27	-146.20
44.34	9.70	72.362	11.18	118.04	.86	-127.33	24.00	288.82	.25	-136.39
44.34	9.80	72.362	13.33	117.60	.73	-131.04	26.13	289.84	.25	-137.97
44.35	9.70	75.307	13.91	120.75	.81	-137.92	25.20	292.70	.27	-144.38
44.35	9.80	75.307	17.73	128.26	.71	-142.57	28.87	300.31	.27	-146.22
44.36	9.70	72.558	11.92	118.25	.88	-127.39	23.71	288.85	.25	-136.65
44.36	9.80	72.558	13.13	117.70	.75	-131.13	25.83	289.80	.25	-138.24
44.37	9.70	76.995	12.05	121.53	.97	-138.49	22.66	292.15	.30	-146.71
44.37	9.80	76.995	15.41	125.68	.83	-143.60	25.94	297.54	.29	-148.72
44.38	9.70	72.518	10.50	118.65	.92	-126.24	23.21	288.78	.26	-136.09
44.38	9.80	72.518	12.44	117.65	.73	-129.92	25.17	289.35	.25	-137.67
44.39	9.70	77.119	11.92	121.63	.99	-138.52	22.48	292.13	.31	-146.88
44.39	9.80	77.119	15.25	125.57	.84	-143.66	25.74	297.39	.29	-148.90
44.40	9.70	72.529	9.99	119.19	.97	-125.17	22.67	288.81	.26	-135.63
44.40	9.80	72.529	11.78	117.83	.82	-128.79	24.50	289.05	.25	-137.22
44.41	9.70	77.242	11.79	121.74	1.00	-138.54	22.30	292.12	.31	-147.04
44.41	9.80	77.242	15.08	125.40	.85	-143.73	25.53	297.25	.30	-149.08
44.42	9.73	72.762	9.81	119.49	1.00	-125.22	22.35	288.87	.26	-135.93
44.42	9.80	72.762	11.57	118.05	.84	-128.87	24.16	289.07	.25	-137.53

THFL= 0.0000 THAZ= 5.0000

NUM OF ROWS=44 NUM OF COLS=44 NUM OF VISIBLE PAYS = :2

L _MENT ROW,COL	FREQUENCY (GHZ)	INCIDENCE ANGLE(DEG)	RTE (DB)	ANGLE (DEG)	TTE (DB)	ANGLE (DEG)	RTM (DB)	ANGLE (DEG)	TTM (DB)	ANGLE (DEG)
1,44	9.70	71.008	13.78	116.74	.68	-129.04	27.43	289.46	.24	-135.54
1,44	9.80	71.008	16.70	119.23	.50	-132.64	30.20	292.54	.24	-137.07
2,44	9.70	71.008	13.78	116.74	.68	-129.04	27.43	289.46	.24	-135.54
2,44	9.80	71.008	16.70	119.23	.50	-132.64	30.20	292.54	.24	-137.07
3,44	9.70	71.024	13.77	116.75	.68	-129.05	27.41	289.46	.24	-135.56
3,44	9.80	71.024	16.68	119.22	.60	-132.65	30.17	292.52	.24	-137.09
4,44	9.70	71.024	13.77	116.75	.68	-129.05	27.41	289.46	.24	-135.56
4,44	9.80	71.024	16.68	119.22	.60	-132.65	30.17	292.52	.24	-137.09
5,44	9.70	71.071	13.72	116.77	.68	-129.07	27.33	289.45	.24	-135.63
5,44	9.80	71.071	16.62	119.18	.60	-132.68	30.09	292.48	.24	-137.16
6,44	9.70	71.071	13.72	116.77	.68	-129.07	27.33	289.45	.24	-135.63
6,44	9.80	71.071	16.62	119.18	.60	-132.68	30.09	292.48	.24	-137.16
7,44	9.70	71.120	13.67	116.79	.69	-129.10	27.25	289.44	.24	-135.69
7,44	9.80	71.120	16.56	119.15	.60	-132.71	30.00	292.44	.24	-137.23
8,44	9.70	71.120	13.67	116.79	.69	-129.10	27.25	289.44	.24	-135.69
8,44	9.80	71.120	16.56	119.15	.60	-132.71	30.00	292.44	.24	-137.23
9,44	9.70	71.012	13.59	116.70	.69	-128.75	27.24	289.33	.24	-135.43
9,44	9.80	71.012	16.42	118.84	.60	-132.35	29.94	292.15	.24	-136.95
10,44	9.70	71.056	13.54	116.72	.59	-128.78	27.17	289.32	.24	-135.49
10,44	9.80	71.056	16.37	118.81	.60	-132.39	29.86	292.12	.24	-137.01
11,44	9.70	71.137	13.46	116.76	.70	-128.82	27.03	289.31	.24	-135.60
11,44	9.80	71.137	16.27	118.77	.61	-132.43	29.71	292.05	.24	-137.13
12,44	9.70	71.137	13.46	116.76	.70	-128.82	27.03	289.31	.24	-135.60
12,44	9.80	71.137	16.27	118.77	.61	-132.43	29.71	292.05	.24	-137.13
13,44	9.70	70.788	13.27	116.53	.70	-127.85	27.08	289.04	.24	-134.77
13,44	9.80	70.788	15.95	118.03	.61	-131.38	29.64	291.36	.23	-136.29
14,44	9.70	70.846	13.21	116.57	.70	-127.88	26.99	289.04	.24	-134.85
14,44	9.80	70.846	15.88	118.01	.61	-131.42	29.54	291.32	.23	-136.37
15,44	9.70	70.874	13.19	116.58	.70	-127.89	26.94	289.03	.24	-134.89
15,44	9.80	70.874	15.85	118.00	.61	-131.43	29.49	291.30	.23	-136.41
16,44	9.70	71.002	13.06	116.66	.71	-127.95	26.74	289.02	.24	-135.06
16,44	9.80	71.002	15.70	117.96	.62	-131.51	29.26	291.22	.24	-136.59
17,44	9.70	71.080	12.99	116.71	.72	-127.98	26.61	289.01	.24	-135.17
17,44	9.80	71.080	15.60	117.94	.62	-131.56	29.12	291.18	.24	-136.70
18,44	9.70	71.149	12.92	116.76	.72	-128.02	26.50	289.01	.24	-135.26
18,44	9.80	71.149	15.52	117.93	.63	-131.60	29.00	291.13	.24	-136.79
19,44	9.70	71.199	12.88	116.79	.72	-128.04	26.42	289.01	.24	-135.33
19,44	9.80	71.199	15.47	117.92	.63	-131.63	28.91	291.11	.24	-136.86
20,44	9.70	71.298	12.78	116.86	.73	-128.08	26.26	289.00	.24	-135.46
20,44	9.80	71.298	15.35	117.90	.63	-131.68	28.74	291.05	.24	-137.00
21,44	9.70	71.448	12.64	116.96	.74	-128.15	26.03	288.99	.24	-135.67
21,44	9.80	71.448	15.18	117.88	.64	-131.77	28.48	290.97	.24	-137.21
22,44	9.70	71.448	12.64	116.96	.74	-128.15	26.03	288.99	.24	-135.67
22,44	9.80	71.448	15.18	117.88	.64	-131.77	28.48	290.97	.24	-137.21
23,44	9.70	71.055	12.33	116.82	.75	-126.85	25.97	288.72	.24	-134.65
23,44	9.80	71.055	14.83	117.18	.65	-130.38	28.27	290.22	.24	-136.17
24,44	9.70	71.165	12.23	116.91	.76	-126.90	25.80	288.73	.24	-134.79
24,44	9.80	71.165	14.58	117.20	.65	-130.44	28.09	290.17	.24	-136.32
25,44	9.70	71.213	12.18	116.95	.76	-126.92	25.73	288.73	.24	-134.86
25,44	9.80	71.213	14.52	117.21	.66	-130.46	28.00	290.16	.24	-136.39
26,44	9.70	71.439	11.98	117.15	.78	-127.01	25.33	288.74	.24	-135.16
26,44	9.80	71.439	14.29	117.25	.67	-130.58	27.63	290.08	.24	-136.70
27,44	9.70	71.543	11.89	117.24	.79	-127.05	25.22	288.74	.24	-136.30
27,44	9.80	71.543	14.17	117.28	.68	-130.64	27.45	290.05	.24	-136.84
28,44	9.70	71.657	11.79	117.34	.80	-127.09	25.04	288.75	.24	-135.45
28,44	9.80	71.657	14.05	117.31	.68	-130.70	27.26	290.01	.24	-137.00
29,44	9.70	71.877	11.60	117.55	.82	-127.17	24.71	288.77	.25	-135.75
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SECTION VII

RECOMMENDATIONS FOR FURTHER REFINING THE PROGRAM

The following are suggested as subsequent tasks:

1. Verify the radome analysis program by using detailed design and measured data on an existing radome.

2. Obtain a suitable antenna simulation program and interface it with the radome program. Use the radome and antenna simulation programs to estimate the distortion of the antenna pattern due to the radome interference.

3. Verify the results from (2) above using measured data.

4. Perfect the radome simulation program with regard to core storage requirements and central processor time.

5. Document the radome/antenna simulation program as obtained using the foregoing steps.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26.31	[illegible]	.24	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	117.47	[illegible]	[illegible]	24.75	[illegible]	.24	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.24	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.31	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.35	[illegible]	.24	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.85	[illegible]	24.14	288.66	.25	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25.17	[illegible]	.24	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.87	[illegible]	23.93	[illegible]	.25	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.74	[illegible]	25.94	[illegible]	.24	[illegible]
[illegible]	[illegible]	72.274	[illegible]	[illegible]	[illegible]	-125.13	23.55	288.74	.25	-135.78
35.44	[illegible]	72.274	12.57	[illegible]	.76	[illegible]	25.53	289.36	.25	-137.35
35.44	9.70	72.274	10.69	118.37	.93	-126.18	23.55	288.74	.25	-135.78
36.44	9.80	72.274	12.67	117.48	.76	-129.82	25.53	289.36	.25	-137.35
37.44	9.70	72.143	10.29	118.70	.93	-125.07	23.21	288.71	.25	-135.13
37.44	9.85	72.143	12.13	117.49	.79	-128.65	25.08	289.04	.25	-136.78
38.44	9.70	72.249	10.18	118.88	.95	-125.11	23.01	288.75	.25	-135.32
38.44	9.85	72.289	12.00	117.61	.90	-129.70	24.86	289.04	.25	-136.89
39.44	9.70	72.416	10.08	119.04	.96	-125.14	22.83	288.78	.26	-135.49
39.44	9.80	72.416	11.35	117.72	.81	-128.75	24.67	289.05	.25	-137.06
40.44	9.70	72.591	9.94	119.27	.98	-125.18	22.59	288.82	.26	-135.71
40.44	9.85	72.591	11.72	117.88	.83	-128.81	24.41	289.05	.25	-137.39
41.44	9.70	72.838	9.68	119.69	1.02	-125.04	22.17	288.91	.26	-135.93
41.44	9.80	72.838	11.40	118.16	.86	-128.69	23.95	289.04	.26	-137.53
42.44	9.78	72.830	9.68	119.69	1.02	-125.04	22.17	288.91	.26	-135.93
42.44	9.80	72.838	11.40	118.16	.86	-128.69	23.95	289.04	.26	-137.53