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A USER'S MANUAL FOR THE ELECTROMAGNETIC SURFACE PATCH CODE: ESP VERSION III

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This report serves as a user's manual for Version III of the "Electromagnetic Surface Patch Code" or ESP code. ESP is a user-oriented code, based upon the method of moments (MM) for treating geometries consisting of an interconnection of thin wires and perfectly conducting polygonal plates. Wire/plate junctions must be about 0.1λ or more from any plate edge. Several plates may intersect along a common edge. Excitation may be by either a delta-gap voltage generator or by a plane wave. The thin wires may have finite conductivity and also may contain lumped loads. The code computes most of the usual quantities of interest such as current distribution, input impedance, radiation efficiency, mutual coupling, far zone gain patterns (both polarizations) and radar-cross- section (both/cross polarizations).

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Contents

List of Figures

Abstract

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Chapter 1

Introduction

This report serves as a user's manual for Version III of the "Electromagnetic Surface Patch" or ESP code. ESP is a user-oriented computer code, based on the method of moments (MM), for the analysis of antenna and scattering problems. The program can analyze geometries consisting of perfectly conducting polygonal plates, thin wires, wire/plate junctions and plate/plate junctions. Wire/plate junctions must be at least 0.1λ from the edge of the plate. Plate/plate junctions must be at the edges of the plates. The code can treat several plates which intersect along a common edge. The program is designed to provide reasonable accuracy and versatility, and also reasonable ease in describing the problem geometry (without the aid of any special graphics or geometry software). The main limitation of the method is that the required computer storage and CPU time increases as the electrical size of the antenna or scatterer increases.

The present code is referred to as Version III, and is a modification of the Version II released in May 1985 [1]. No new features were added to ESP in Version III. Basically the changes which resulted in Version III were:

- Version II contained geometry and pattern plots as an integral part of the code. However, when the code was supplied outside Ohio State Univ., it was found that the plotting software was usually not transportable. In fact, the first thing most users did upon receiving the code was to remove the plotting. In Version III we have removed all plotting from the basic ESP code. Instead ESP produces output files which contain the data to be plotted. These files are described in Chapter 4.

- The many user's of ESP in the the last two years have uncovered numerous instances of non-standard FORTRAN, programming errors, and other problems with the code [2]. We have (hopefully) corrected these problems, and I believe that Version III is a far more reliable code than Version II as it existed in May 1985. However, in answer to the question "Have all of the errors in ESP now been found?" I can answer with complete confidence "**NO!**".

When the ESP code is supplied outside Ohio State University, it will include the three FORTRAN files:

ESP3 = the main program and all required subroutines for ESP Version III, written in standard FORTRAN 77.

ESP3GM = a program using the GKS language [24] to plot the problem geometry (see Chapter 4).

ESP3PT = a program using the GKS language [24] to plot the radiation and scattering patterns (see Chapter 4).

In order to provide CPU run times, the ESP main program contains several calls to the function GETCP(I), where I is the clock time in hundredths of a second. However, since this is not standard FORTRAN 77, these line have been essentially removed by making them COMMENT lines (i.e. putting a "C" in column 1). If possible a user should replace this function by a comparable clock routine on his system. As delivered, the ESP code will print 0.0 for the CPU time.

The ESP code can compute all of the usual quantities of interest such as:

1. current distribution
2. input impedance
3. radiation efficiency
4. mutual coupling between two ports in the wires
5. far-zone radiation or gain patterns (both polarizations)

6. plane wave back or bistatic or forward scattering patterns (complete scattering matrix).

The excitation can be either a voltage generator (i.e., the antenna problem) or a plane wave (i.e., the scattering problem). Also, to aid the user who wishes to analyze a structure over an infinite perfectly conducting ground plane, the code will include the image wave. Although the plates are considered to be perfectly conducting and of zero thickness, the wires may have finite conductivity and also may contain complex lumped loads.

The early implementation of the MM into user-oriented computer programs involved the thin-wire formulation [3],[4]. These programs provided good results for most wire antennas. Also, solid surfaces could be modeled by forming wire grid models of the surfaces [5]. A disadvantage of the wire grid model of a solid surface is that many modes per square wavelength of surface area are required. Also, results are sometimes very dependent upon the specific grid geometry used.

In order to alleviate the problems associated with wire grid modeling, surface patch modeling was developed. Surface patch modeling represents a perfectly conducting surface by a vector electric current density on the surface. Surface patch models give a more accurate approximation to the currents on a surface and require less unknowns than the wire grid model. Oshiro [6] used pulse basis functions and point matching to solve the Magnetic Field Integral Equation (MFIE) for various three dimensional surfaces. Albertsen et al. [7] used pulse test modes and the MFIE formulation to model wires, plates and wire/plate attachments. Based on the MFIE formulation, the Numerical Electromagnetic Code (NEC) was developed by Burke and Poggio [8] to solve for geometries consisting of wires and surfaces. The above work was all based upon the MFIE and is thus applicable only to closed surfaces. These codes could treat such closed surfaces as a box or a sphere, but could not treat such open surfaces as a plate, a corner reflector, a fin or wing on an aircraft, a box with a hole, etc. In order to be able to treat open and closed surfaces, the ESP code, as-well-as most recent work, has been based upon the electric field integral equation (EFIE). Wang and Richmond [9] used piecewise sinusoidal (PWS) rectangular surface patches to model rectangular plates. Surface patch models using triangular patches and pulse test modes have been developed by Rao et al [10]. The ESP code incorporates the work of several researchers at the ElectroScience Lab, including E.H. Newman, D.M. Pozar, J.H. Richmond, P. Tulyathan, P. Alexandroupoulos, M.R. Schrote and R. Dilsavor [11]-[16]. It is based upon the piecewise sinusoidal reaction formulation (basically equivalent to the EFIE) for wires and surfaces.

Chapter 2 gives a brief review of the MM solution for electromagnetic scattering and radiation problems, based on the Reaction Integral Equation (RIE) [17]. The wire, plate, attachment and overlap modes used in the ESP code are defined. Chapter 3 describes the READ input statements of the main program. For every READ statement an explanation of all the parameters introduced is given. Subroutine WGEOM, for defining wire geometries, is described and two examples are given. Five example problems are described to provide for a better understanding of the input parameters and code output. A brief description of how to change the various array DIMENSIONS is also given. Finally Chapter 4 describes two output files produced by ESP which can be used to plot the wire/plate geometry and the far zone radiation and scattering patterns.

Chapter 2

Theory

2.1 The Reaction Integral Equation

This chapter gives a brief outline of the solution of the electromagnetic radiation or scattering problems by the method of moments (MM). A description of the expansion (basis) and weighting (testing) functions used in the ESP code is also given.

Figure 2.1 shows an arbitrarily shaped scatterer in a homogeneous medium. Let S represent the surface of the scatterer and $\hat{n}$ the unit outward normal to the surface. $(\mathbf{J}_i, \mathbf{M}_i)$ is an impressed source which radiates the fields $(\mathbf{E}_i, \mathbf{H}_i)$ in free space and the fields $(\mathbf{E}, \mathbf{H})$ in the presence of the scatterer. All fields and currents are time harmonic with the $e^{j\omega t}$ time dependence suppressed.

Using Schelkunoff's surface equivalence theorem [18],[19] the fields interior to the surface S will vanish without changing the exterior fields if the scatterer is replaced by the ambient medium, and the following electric and magnetic surface current densities are placed on the surface S:

$$\mathbf{J}_s = \hat{n} \times \mathbf{H} \tag{2.1}$$

$$\mathbf{M}_s = \mathbf{E} \times \hat{n} \tag{2.2}$$

where $\mathbf{E}$ and $\mathbf{H}$ are the total electric and magnetic fields, respectively, exterior to the surface S. The equivalent problem is illustrated in Figure 2.2. In the ambient medium $(\mathbf{J}_s, \mathbf{M}_s)$ radiate the scattered fields $(\mathbf{E}_s, \mathbf{H}_s)$ which are defined by:

$$\mathbf{E}_s = \mathbf{E} - \mathbf{E}_i \tag{2.3}$$

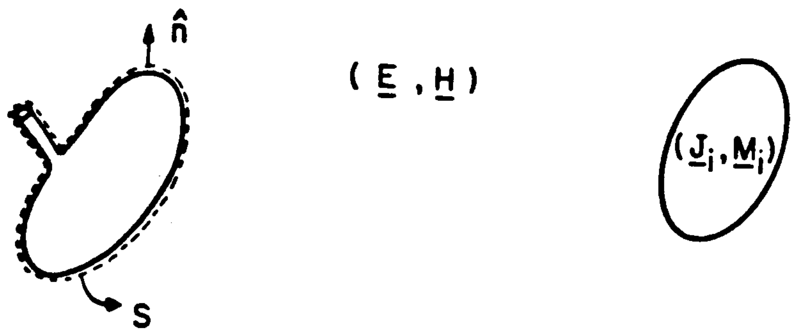


Figure 2.1: Source $(\mathbf{J}_i, \mathbf{M}_i)$ radiates fields $(\mathbf{E}, \mathbf{H})$ in the presence of the scatterer.

$$\mathbf{H}_s = \mathbf{H} - \mathbf{H}_i \tag{2.4}$$

If one places a test source $(\mathbf{J}_m, \mathbf{M}_m)$ in the volume interior to the surface S, then its reaction with the sources $(\mathbf{J}_i, \mathbf{M}_i)$ and $(\mathbf{J}_s, \mathbf{M}_s)$ will be zero since the fields interior to the surface S are zero, i.e.,

$$\iiint_m (\mathbf{J}_m \cdot \mathbf{E}_s - \mathbf{M}_m \cdot \mathbf{H}_s) dv + \iiint_m (\mathbf{J}_m \cdot \mathbf{E}_i - \mathbf{M}_m \cdot \mathbf{H}_i) dv = 0, \tag{2.5}$$

where the integrals are over the volume of the test source. Using the reciprocity, Equation 2.5 can be written as

$$-\iint_S (\mathbf{J}_s \cdot \mathbf{E}_m - \mathbf{M}_s \cdot \mathbf{H}_m) ds = \iiint_{V_i} (\mathbf{J}_i \cdot \mathbf{E}_m - \mathbf{M}_i \cdot \mathbf{H}_m) dv. \tag{2.6}$$

where V_i is the volume occupied by source $(\mathbf{J}_i, \mathbf{M}_i)$, and $(\mathbf{E}_m, \mathbf{H}_m)$ are the fields of the test source radiating in the ambient medium.

Equation 2.6 is the Reaction Integral Equation (RIE). If one uses electric test sources (i.e. $\mathbf{M}_m = 0$), the RIE is equivalent to the Electric Field

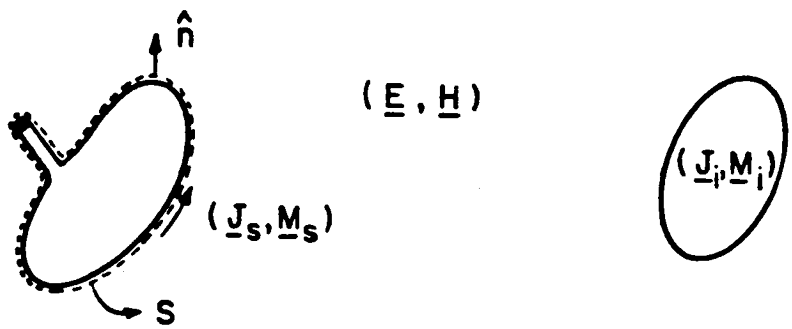


Figure 2.2: In the equivalent problem the total fields exterior to S are produced by $(\mathbf{J}_s, \mathbf{M}_s)$ and $(\mathbf{J}_i, \mathbf{M}_i)$ radiating in the ambient medium.

Integral Equation (EFIE). If magnetic test sources are used (i.e. $\mathbf{J}_m = 0$), the RIE is equivalent to the Magnetic Field Integral Equation (MFIE). Here we employ the RIE with electric test sources. As a result, this work will apply to both closed and open surfaces [12]. The RIE with magnetic test sources applies to closed surfaces only. Thus, below we take $\mathbf{M}_m = 0$. Also, for simplicity we will consider the surface to be perfectly conducting, and thus $\mathbf{M}_s = 0$. The ESP code does allow for finite conductivity of the wires, but the plates must be perfectly conducting. We note that treating open surfaces with finite conductivity is not trivial [20].

Strictly speaking the above use of Schelkunoff's surface equivalence theorem requires that the surfaces in consideration are closed. However it can be shown that the analysis is valid for open surfaces such as a plate [12]. This is very important since plate modeling is the core of the Electromagnetic Surface Patch Code (ESP). The plates used in the ESP code are idealized in the sense that they have zero thickness and are thus open surfaces. In general different currents exist on the top and bottom surfaces of a thick or a zero thickness plate. As the thickness of the plate goes to zero the fields radiated by the top and bottom currents become equivalent to the field radiated by a single current located at the center of the plate. This current, which is the $\mathbf{J}_s$ of Equation 2.6, is the vector sum of the top and bottom surface currents of the plate [12].

2.2 Moment Method Solution

The next step is to solve Equation 2.6 (with $\mathbf{M}_s = 0$) for $\mathbf{J}_s$, the current on the body. Once $\mathbf{J}_s$ is known, most quantities of engineering importance can be computed in a straight foward manner. Equation 2.6 will be solved by the numerical technique known as the method of moments (MM) [21]. The MM solution begins by expanding the unknown $\mathbf{J}_s$ in terms of N expansion (basis) functions $\mathbf{F}_n$, i.e.,

$$\mathbf{J}_s = \sum_{n=1}^{N} I_n \mathbf{F}_n. \tag{2.7}$$

Substituting $\mathbf{J}_s$ from Equation 2.7 into Equation 2.6, and enforcing Equation 2.6 for N linearly independent test modes, one obtains the $N \times N$ system of simultaneous linear algebraic equations:

$$\sum_{n=1}^{N} I_n Z_{mn} = V_m \qquad m = 1, 2, ...N \tag{2.8}$$

where, except as mentioned below, we choose test modes identical to expansion modes. Equation 2.8 is usually written more compactly as the matrix equation $[Z]I = V$, where $[Z]$ is the $N \times N$ impedance matrix, V is the length N voltage vector, and I is the length N current vector which contains the I_n of Equation 2.7. The elements of $[Z]$ and V are given by

$$Z_{mn} = -\iint_n \mathbf{E}_m \cdot \mathbf{F}_n ds, \tag{2.9}$$

$$V_m = \iiint_{V_i} (\mathbf{J}_i \cdot \mathbf{E}_m - \mathbf{M}_i \cdot \mathbf{H}_m) dv. \tag{2.10}$$

The integral in Equation 2.9 is over the surface of the n^{th} expansion mode while the integral in Equation 2.10 is over the volume occupied by the source ($\mathbf{J}_i, \mathbf{M}_i$). V_m is called the modal excitation voltage, and Z_{mn} the mutual impedance between modes m and n. The detailed evaluation of Equations 2.9 and 2.10 are described in references [11]-[16].

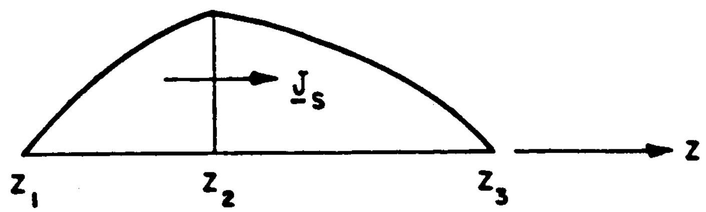


Figure 2.3: A wire PWS dipole mode.

2.2.1 Expansion Modes

Three types of basis functions (modes) are used in the moment method solution, i.e., wire, surface patch and attachment dipole modes. With these modes one can model geometries consisting of an interconnection of wires and polygonal plates or any geometry that can be approximated by wires and polygonal plates. These expansion modes will now be described.

Wire Modes

The wire mode is the piecewise sinusoidal (PWS) V-dipole consisting of two sinusoidal monopoles. Figure 2.3 shows a V-dipole with a 180° interior angle. The current on this dipole is given by

$$\mathbf{J}_s = \frac{\hat{z}}{2\pi a}\left[P_1\frac{\sin k(z-z_1)}{\sin k(z_2-z_1)} + P_2\frac{\sin k(z_3-z)}{\sin k(z_3-z_2)}\right], \tag{2.11}$$

where a = the wire radius, and $k = 2\pi/\lambda$, and the pulse functions

$$P_1 = \begin{cases} 1 & z_1 < z < z_2 \\ 0 & \text{elsewhere} \end{cases}$$

$$P_2 = \begin{cases} 1 & z_2 < z < z_3 \\ 0 & \text{elsewhere} \end{cases}$$

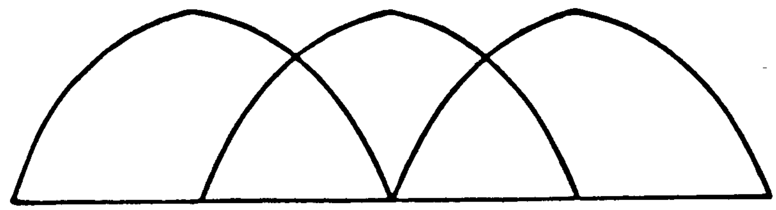


Figure 2.4: Array of overlapping PWS wire dipoles representing the current on a wire.

The wire dipole modes are placed on the wires in an overlapping array as shown in Figure 2.4. This ensures continuity of current on the wire, as well as zero current at the endpoints.

Surface Patch Modes

For rectangular plates, the surface current density is expanded in terms of the PWS rectangular surface patch dipole modes. The rectangular surface patch mode is a surface V-dipole consisting of two rectangular sinusoidal surface patch monopoles. A surface V-dipole with an interior angle of 180 degrees is shown in Figure 2.5. The current density on this dipole is given by

$$\mathbf{J}_s = \hat{z}\frac{P_1 \sin k(z - z_1)}{2w \sin k(z_2 - z_1)} + \hat{z}\frac{P_2 \sin k(z_3 - z)}{2w \sin k(z_3 - z_2)}, \tag{2.12}$$

where P_1 and P_2 are the unit pulse functions as described for the wire dipole. Two orthogonal and overlappping arrays of rectangular surface patch modes are used to represent the current density on a rectangular plate as shown in Figure 2.6. Each arrow represents a surface patch V-dipole. This modal layout allows for a vector current density, and also ensures continuity of the longitudinal component of current on the surface of the plate. Further, at plate edges, the normal component of current vanishes, while the tangential

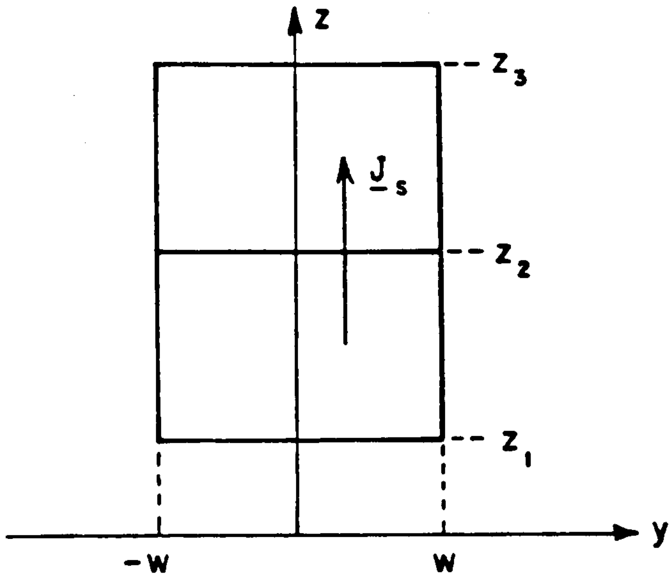


Figure 2.5: A PWS rectangular surface patch dipole mode.

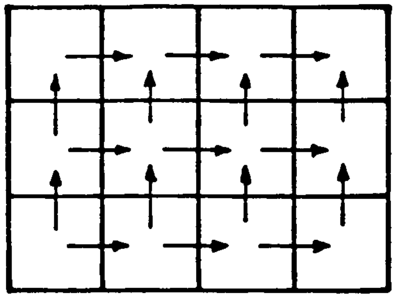


Figure 2.6: A two dimensional array of overlapping rectangular surface patch dipole modes representing the current density on a rectangular plate. The PWS modes are represented by arrows.

component is finite.

If the plate is not rectangular then PWS quadrilateral V-dipole surface patch modes are used. A typical quadrilateral surface patch mode is shown in Figure 2.7, and is a generalization of the rectangular mode. To describe the current density on the quadrilateral patch consider a point C interior to monopole A. Draw a line X through C intersecting sides a and b in such a way that u/U equals v/V. Now draw a line through C from the terminal to the end side of monopole A, such that $l/L = u/U = v/V$. L is the length of this line segment. The coordinate along segment L is l ($l = 0$ at the end and $l = L$ at the terminal) and $W(l/L)$ is the length of the line segment X between sides a and b. That is, $W(l/L)$ is the width of the monopole. Thus, $W(0)$ is the width of the end side and $W(1)$ is the width of the terminal side.

Now the current density on monopole A of the surface patch mode is

$$\mathbf{J}_{S_A} = -C\hat{l}\frac{\sin k(L-l)}{\sin kL\, W(l/L)}. \tag{2.13}$$

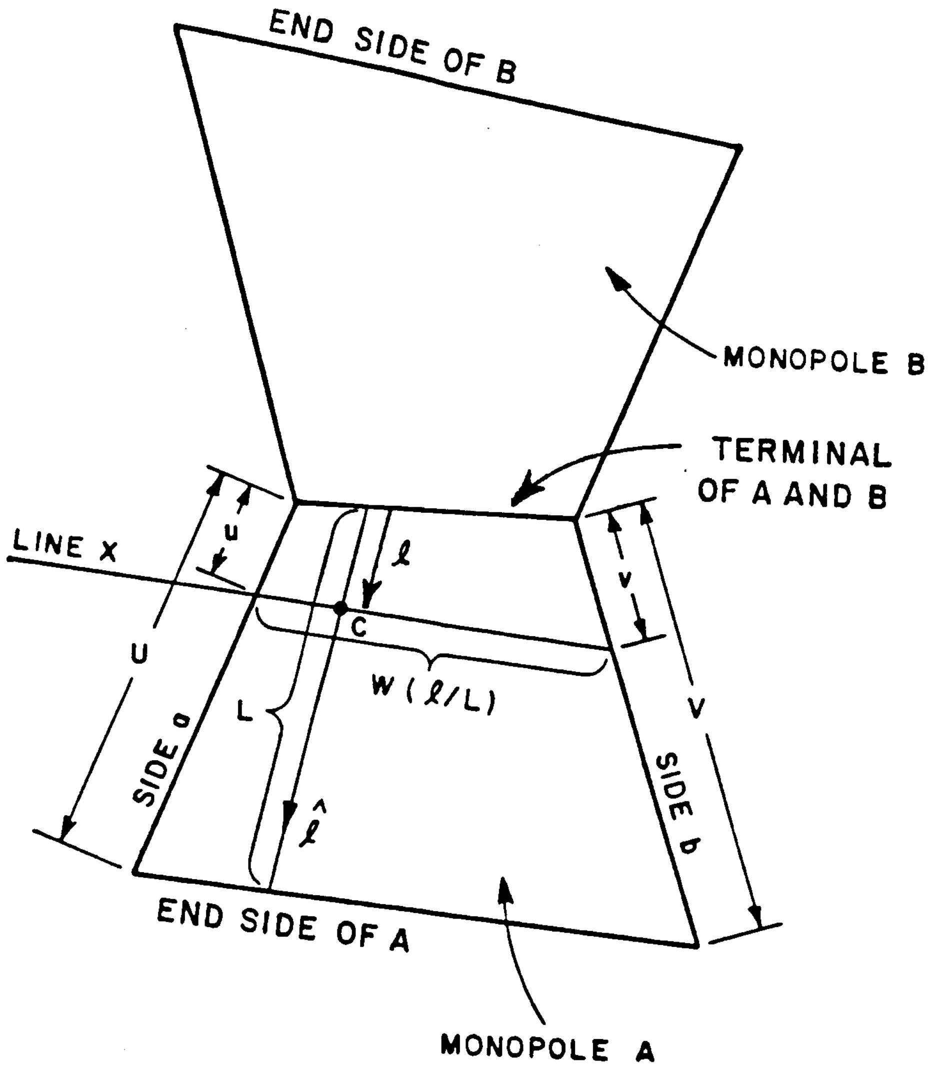


Figure 2.7: A quadrilateral surface patch dipole mode.

The constant C is chosen so that the current at the terminal side of monopole A is one ampere. The density on monopole B is obtained in a similar manner. The only difference is that the minus sign in Equation 2.13 would be omitted for monopole B. In this way, the continuous dipole current density starts at zero at the end side of A, rises to a maximum at the terminals, and drops to zero at the end side of B. Note that the quadrilateral surface patch monopole is a generalization of the rectangular surface patch monopoles in Equation 2.12.

Attachment Modes

The attachment mode, shown in Figure 2.8, is used at wire/plate junctions. The wire does not have to be perpendicular to the plate. The attachment mode serves two purposes:

1. It ensures the continuity of current at the wire/plate junction.

2. It ensures the proper $\hat{\rho}$ polarization and $1/\rho$ dependence of the plate surface current density near the junction.

Figure 2.8 illustrates an attachment mode where for simplicity the wire is perpendicular to the plate. The dipole attachment mode consists of a wire monpole and a circular disk monopole. The wire monopole is an ordinary PWS wire monopole existing on the wire segment which contacts the plate. If the wire segment is perpendicular to the plate, the current density of the wire monopole is

$$\mathbf{J}_S^W = \frac{1}{2\pi a} \frac{\sin k(z_2 - z)}{\sin k z_2} \hat{z} \qquad ; \qquad 0 \le z \le z_2. \tag{2.14}$$

The current density on the disk is

$$\mathbf{J}_S^D = -\frac{\sin k(b-\rho)}{2\pi\rho \sin k(b-a)} \hat{\rho} \qquad ; \qquad a \le \rho \le b, \tag{2.15}$$

where as illustrated in Figure 2.8, a is the radius of the wire and the inner radius of the disk, while b is the outer radius of the disk. Note that the disk current density at $\rho = a$ equals the wire current density at z=0, insuring continuity of current at the junction. Also, the current density at the

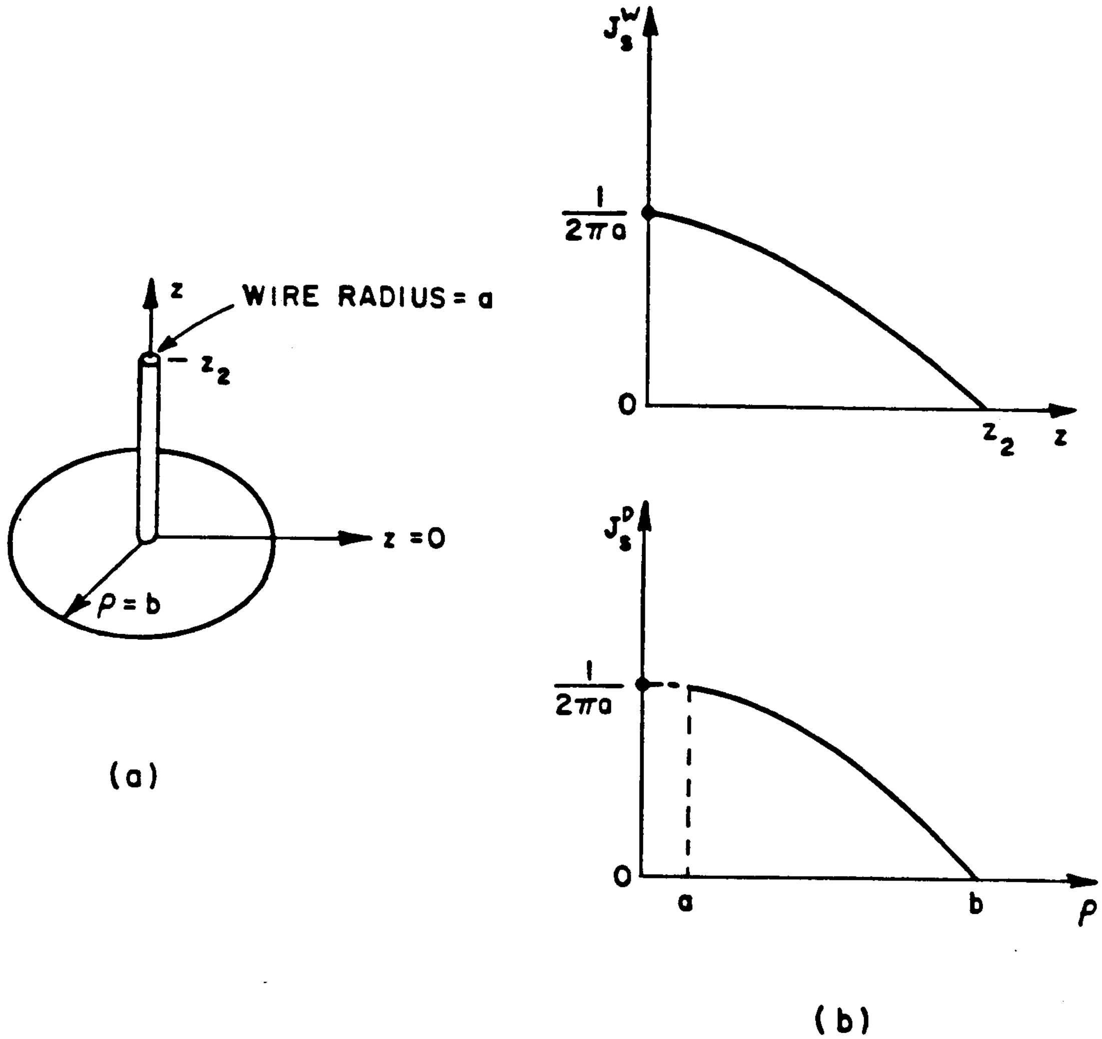


Figure 2.8: (a) Wire attachment dipole mode, and (b) Current density on the wire monopole (top) and the disk monopole (bottom).

edge of the disk ($\rho = b$) is zero to maintain continuity of the longitudinal component of current on the plate where the disk is placed.

The attachment mode is placed directly on the surface of the plate at the wire/plate junction. The attachment point does need not be at a particular location with respect to the grid of plate surface patch modes. The only restriction is that the wire/plate junction be at least 0.1λ away from all edges of the plate to which it is attached. The attachment disk must lay entirely on the plate which contacts the wire. Through numerical tests it was found that for reasonable results, $0.1\lambda \le b \le 0.25\lambda$, with a good value for b being 0.2λ.

Overlap Modes

Overlap modes are used to join two (or more) plates which intersect along a common edge. The overlap modes are identical in mathematical description to the plate PWS surface patch modes.

Figure 2.9 shows two plates which intersect along a common edge. As mentioned above, the PWS surface patch plate modes are placed on plates 1 and 2 so that the normal component of current vanishes at the plate edges. However, at the junction of plates 1 and 2 the normal component of current is continuous and not in general zero. Thus, a set of overlap modes with terminals at the common edge is needed. They enforce continuity of the normal component of current at a plate/plate intersection. The edges of the overlap modes need not coincide with the edges of the surface patch modes on either plate. However, the closer they match the better the results seem to become. The program automatically searches for plates with touching sides and inserts the corresponding overlap modes. Note that, as illustrated in Figure 2.9, the intersection need not be along an entire edge of a plate. Also, the code can treat several plates which intersect along a common edge.

2.2.2 Test Modes

The wire test modes are filamentary sinusoidal dipole modes, identical to the wire expansion modes, except that they are located along the wire center-line. The attachment test modes consist of a disk monopole, identical to Equation 2.15, and a wire monopole given by Equation 2.14 and located

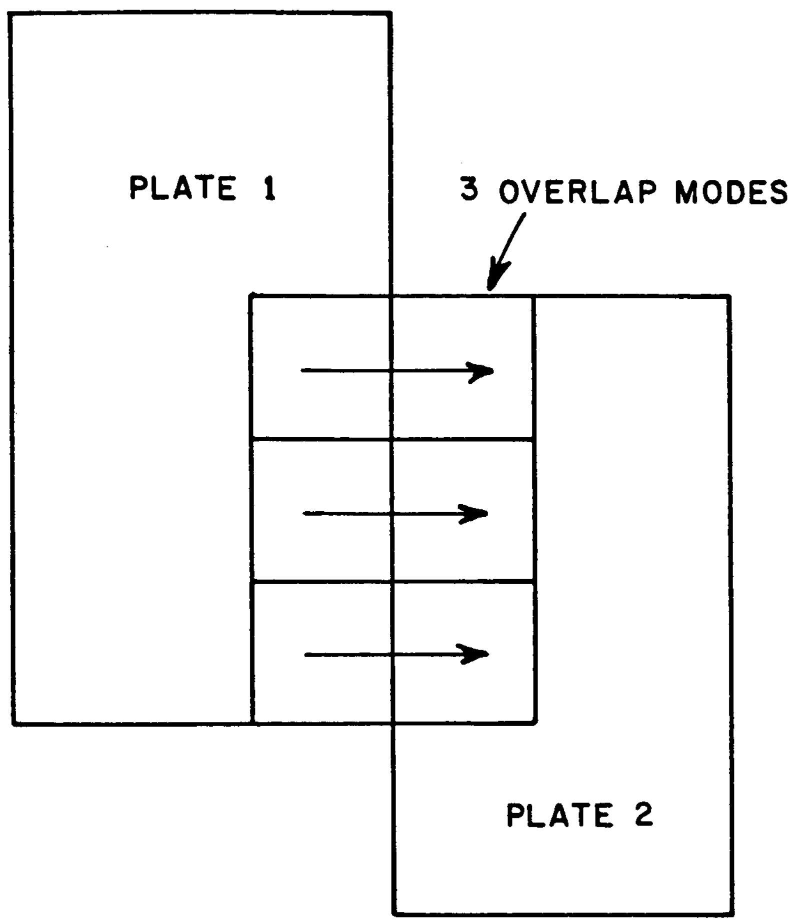


Figure 2.9: Three surface patch dipole overlap modes enforce continuity of the normal component of current at the plate/plate junction.

on the wire center-line.

The code allows for two choices of the plate test modes. One choice for the plate test or weighting modes used in the MM solution is to choose them identical to the expansion modes (Galerkin's method). This results in a symmetric impedance matrix and only its lower triangular part is evaluated. However, as seen in Equation 2.6, the mutual impedance between two surface patch dipole modes is a quadruple integration which requires a great deal of CPU time. Substantial CPU time can be saved, without significantly compromising the accuracy of the solution, by replacing the plate test modes with filaments. As seen in Figure 2.10, the endpoints of a filament are defined by the midpoints of the terminal and end sides of the surface patch mode it represents. This simplification is only possible if there are no wire/plate junctions. When filament testing is used, the mutual impedance between two surface patch dipole modes is a triple integration, however, the matrix is no longer symmetric.

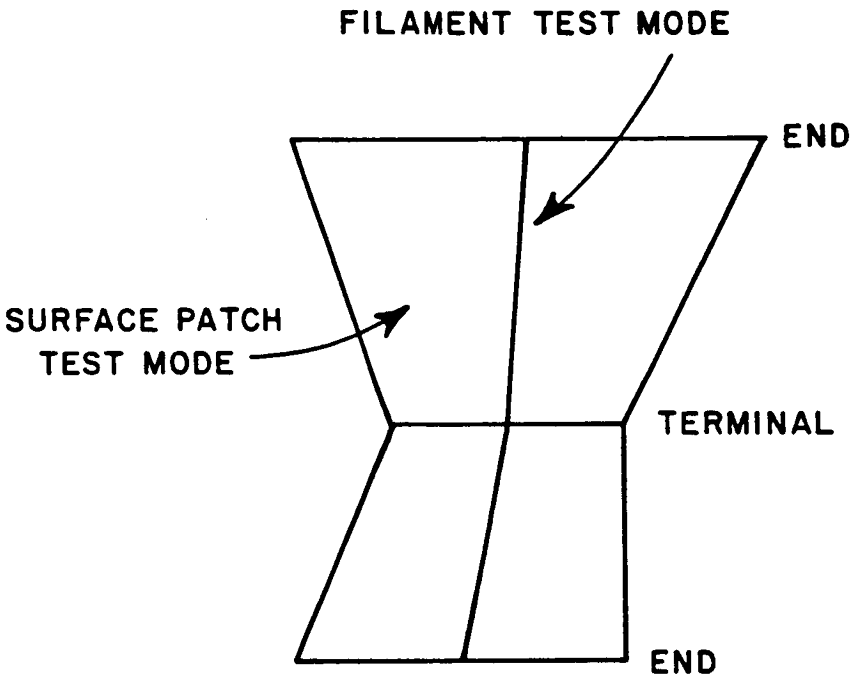


Figure 2.10: A quadrilateral surface patch dipole test mode and the corresponding filamentary test mode.

Chapter 3

Inputs and Outputs

The inputs to the Electromagnetic Surface Patch Code (ESP) are explained below. They are used to describe to the program the detailed geometry of the problem and indicate the type of calculation desired. The input data can be broken into four major groups as follows:

1. Miscellaneous input and run control parameters.

2. Type of calculation desired (i.e. radiation or scattering).

3. Plate geometry.

4. Wire and attachment geometry.

The first three of the above are always defined by an input file. The wire and attachment geometry can be defined either by an input file or by a FORTRAN subroutine called WGEOM. At first, the use of a separate subroutine for describing the wire geometry might seem an unnecessary complication. However, experience has shown that subroutine WGEOM is very useful for cases where the wire structure has a regular or periodic geometry or a shape that can be defined by an analytic expression. Examples are monopole and dipole antennas, loop antennas, helical antennas, log periodic antennas and arrays. For further explanation about the use of WGEOM see Section 3.2.

3.1 Read Input Statements

A description of every READ input statement is given below along with a definition of every parameter introduced. The fifteen READ input statements are shown in Figure 3.1. Also shown is some of the main program logic, indicating the order and number of times each READ is executed. All READ input statements use a free format input on logical unit 5.

3.1.1 READ 1: Run Control Parameters

The first READ input statement defines the following run control and integration parameters:

NGO = run indicator.
= 0 implies input and print out problem geometry and then stop, i.e., do not make any electromagnetic computations. An NGO=0 run should precede any pattern or data calculations. It gives the user the opportunity to review the accuracy of the problem geometry as defined by the input file.
= 1 implies go through the whole program, i.e., input the geometry and calculate the required patterns or data. Also if NGO = 0, then the program will output a file on logical unit 9. As described in Section 4.1, this data file can be used to plot the wire and plate geomtery.

NPRINT = print indicator.
= 1 implies print wire and plate geometry.
= 2 implies print both the input parameters and the wire/plate geometry. Normally NPRINT=2.
= 3 implies print nothing.

NRUNS = the number of runs to be made, i.e., the limit of the DO 700 loop in Figure 3.1.

NWGS = the number of wire geometries for each run, i.e., the limit of the DO 600 loop in Figure 3.1.

IWR = indicator for writing out the induced modal currents.
= 0 implies do not print the induced modal currents.
= 1 implies print the induced modal currents plus the detailed wire

```
(1)---   READ(5,*)NGO,NPRINT,NRUNS,NWGS,IWR,IWRZT,INT,INTP,INTD,INWR,
     +   IRGM,IFIL
(2)---   READ(5,*)IFE,IPFE,NDFE,PHFE
(3)---   READ(5,*)IFA,IPFA,NDFA,THFA
(4)---   READ(5,*)ISE,IPSE,NDSE,PHSE,THIN,PHIN
(5)---   READ(5,*)ISA,IPSA,NDSA,THSA
         DO 700 NRUN=1,NRUNS
(6)---   READ(5,*)FMC,CMM,A
(7)---   READ(5,*)NPLTS
         IF(NPLTS.EQ.0) GOTO462
         DO 464 NPL=1,NPLTS
(8)---   READ(5,*)NCNRS(NPL),SEGM(NPL),IREC(NPL),IPN(NPL),IGS(NPL)
         DO 466 NCNR=1,NCNRS(NPL)
(9)---   READ(5,*)PCN(1,NCNR,NPL),PCN(2,NCNR,NPL),PCN(3,NCNR,NPL)
  466    CONTINUE
  464    CONTINUE
  462    CONTINUE
         DO 600 NWG=1,NWGS
(10)--   READ(5,*)IWRZM,IRDZM
         IF(INWR.EQ.0) GOTO 2773
         IF(IRGM.EQ.0) GOTO 2800
(11)--   READ(5,*)NM,NP,NAT,NFPT,NFS1,NFS2
         DO 2810 I=1,NP
(12)--   READ(5,*)X(I),Y(I),Z(I)
 2810    CONTINUE
         DO 2820 I=1,NM
(13)--   READ(5,*)IA(I),IB(I)
 2820    CONTINUE
         DO 2830 I=1,NFPT
(14)--   IF(NFPT.GE.1) READ(5,*)IFM,IAB,VLG,ZL
 2830    CONTINUE
         IF(NAT.EQ.0) GOTO2850
         DO 2840 I=1,NAT
(15)--   READ(5,*)NAS,IAB,NPLA(I),VGA(I),ZLDA(I),BDSK(I)
 2840    CONTINUE
         GOTO 2850
 2800    CALL WGEOM(IA,IB,X,Y,Z,NM,NP,NAT,NSA,NPLA,VGA,BDSK,
     +   ZLDA,NWG,VG,ZLD,WV,NFS1,NFS2)
 2850    CALL SORT(IA,IB,I1,I2,I3,JA,JB,MD,ND,NM,NP,NWR,MAX,MIN,ICJ,INM)
 2773    CONTINUE
                 .
                 .
                 .
   **** MAIN BODY OF PROGRAM ****
                 .
                 .
                 .
  600    CONTINUE
  700    CONTINUE
         STOP
         END
```

Figure 3.1: The 15 READ input statements.

and plate modal geometry. Note that for backscatter and forward scatter patterns, setting IWR = 1 will cause the currents to be printed at every angle, and can produce a very large output file.

IWRZT = indicator for writing the impedance matrix on the printed output file.
= 0 implies do not write the impedance matrix on the output file.
= 1 implies write the impedance matrix on the output file. Caution: this will result in N^2 lines of output where N = the total number of MM modes.

INT = the number of Simpson's rule integration intervals used for the evaluation of the wire-to-wire impedances. INT is always an even integer, typically equal to 4.
= 0 implies the wire-to-wire impedance calculations are to be done using the exact closed form expression. Self or overlapping wire impedances are always calculated by the closed form expression because it is more accurate than numerical integration. However, the closed form expression is more time consuming than the INT=4 numerical integration.

INTP = the number of Simpson's rule integration intervals used in integrating over the surface patch monopoles. INTP is always an even integer, typically chosen as 6.

INTD = the number of Simpson's rule integration intervals used in integration over the disk monopoles. INTD is always an even integer, typically chosen as 18.

INWR = wire indicator.
= 0 implies geometry does not contain any wires.
= 1 implies geometry contains wires.

IRGM = indicator for choosing the method of defining the wire geometry.
= 0 implies the wire geometry is to be defined by subroutine WGEOM.

= 1 implies the wire geometry is to be read in via the input file.

INFIL = indicator for choosing the type of plate test modes.
= 0 implies full surface patch plate test modes.

= 1 implies filamentary plate test modes. Generally filamentary testing is used to reduce run time. However, if the geometry involves a wire to plate junction then full surface testing (IFIL=0) is required.

3.1.2 READS 2-5: Pattern Specifications

READS 2-5 specify the far-zone pattern calculations desired. READS 2 and 3 specify the elevation and azimuth radiation patterns, respectively. READS 4 and 5 specify the elevation and azimuth scattering patterns, respectively. An elevation pattern means ϕ is fixed, and θ is varied. An azimuth pattern means θ is fixed and ϕ is varied. Note θ and ϕ refer to the usual spherical coordinates.

READ 2 defines the following:

IFE = indicator for calculating the far zone elevation radiation pattern.
= 0 implies do not compute far zone radiation pattern in the elevation plane.
= 1 implies compute far zone radiation pattern in the elevation plane.

IPFE = indicator to output a file on logical unit 8 which can be used to plot the far zone radiation pattern in the elevation plane (see Section 4.2)
= 0 implies do not output plot file
= 1 implies output plot file.

NDFE = angle increment in degrees for far zone radiation pattern in the elevation plane. NDFE (and all other angle increments) must be evenly divisible into 360.

PHFE = constant ϕ angle in degrees for far zone radiation pattern in the elevation plane.

READ 3 defines the following:

IFA, IPFA, NDFA = same as IFE, IPFE, NDFE but for azimuth plane radiation patterns.

THFA = constant θ angle in degrees for far zone radiation pattern in the azimuth plane.

READ 4 defines the following:

ISE = indicator for calculating the far zone elevation plane scattering pattern. Scattering implies either backscattering (ISE=1) or bistatic scattering (ISE=2) or forward scattering (ISE=3).
= 0 implies do not compute far zone scattering pattern in the elevation plane.
= 1 implies compute backscatter pattern in the elevation plane.
= 2 implies compute bistatic scattering pattern in the elevation plane.
= 3 implies compute forward scattering pattern in the elevation plane.

IPSE = indicator to output a file on logical unit 8 which can be used to plot the far zone scattering pattern in the elevation plane (see Section 4.2)
= 0 implies do not output plot file
= 1 implies output plot file.

NDSE = angle increment in degrees for far zone scattering pattern in the elevation plane.

PHSE = constant ϕ angle in degrees for far zone scattering pattern in the elevation plane.

THIN = θ angle in degrees of the incident wave for bistatic scattering calculations (i.e., ISE=2 or ISA=2).

PHIN = ϕ angle in degrees of the incident wave for bistatic scattering calculations.

READ 5 defines the following:

ISA,IPSA,NDSA = same as ISE,IPSE,NDSE but for scattering in the azimuth plane.

THSA = constant θ angle in degrees for far zone scattering pattern in the azimuth plane.

Although the ESP code is set up to analyze wires and plates in free-space, it can also be used to analyze wires and plates over an infinite and perfectly conducting ground plane. This is done with the use of image theory [19]. Basically, to use image theory one replaces the ground plane by free-space, but then adds:

- the "image" of the scatterer. If the xy plane is the ground plane then the image of the scatterer is identical to the actual scatterer except one replaces z by $-z$.
- the "image" of the impressed field. Again assuming the xy plane is the ground plane, the image of a plane wave incident from (θ_i, ϕ_i) is a plane wave incident from $(180^0 - \theta_i, \phi_i)$. If the incident wave is $\hat{\theta}$ polarized then the image wave is $\hat{\theta}$ polarized. If the incident wave is $\hat{\phi}$ polarized, then the image wave is $-\hat{\phi}$ polarized.

If ISA or ISE are set to -1 or -2 or -3, then the above applies to their absolute values. If ISA or ISE are negative, the image (into the xy plane) of the incident wave is included for the azimuth or elevation plane scattering patterns, respectively. As discussed above, this option is useful for treating problems over an infinite ground plane using image theory. The image of the structure must be defined by the user. However, the program does insert the image incident wave.

On a given run one can obtain only one type of pattern, i.e., either radiation patterns or backscatter patterns or bistatic scatter patterns or forward scatter patterns. For each type of calculation, the code provides both θ and ϕ polarizations, and cross polarization for scattering. To obtain different patterns for the same antenna or scatterer structure see READ 10 input statement.

3.1.3 READ 6: Frequency and Wire Type

READ 6 defines the following:

FMC = frequency in megahertz.

CMM = wire conductivity in megamhos/meter. CMM = -1.0 implies a perfect conductor.

A = the wire radius in meters. ESP can only treat electrically thin wires. Subroutine SGANT contains logic which will terminate a run if A $> 0.01\lambda$. The thin wire approximations will also be violated if two wire segments intersect at a small acute angle (i.e. $< 30^0$) or if two wire segments pass within a few wire diameters of each other.

3.1.4 READS 7-9: Plate Geometry

READS 7-9 define the plate geometry. In particular READ 7 defines the following:

NPLTS = the total number of plates.

READS 8 and 9 define the geometry of the NPLTS plates.

For plate NPL READ 8 is executed once, followed by READ 9 executed NCNRS(NPL) times. This is then repeated for each of the NPLTS plates, i.e., (NPL = 1,2, ...,NPLTS). For plate NPL READ 8 inputs:

NCNRS(NPL) = the number of corners on plate NPL. There is no upper limit on the number of corners, except that it should not exceed the dimension indicator ICN discussed in Section 3.3. NCNRS(NPL) must be greater than 3. Thus, the code can not directly treat a triangular plate. Triangular plates can be treated by representing them as quadrilateral plates. Figure 3.2 shows a triangular plate and two methods of modeling it as a quadrilateral plate. In Figure 3.2(b) the longest side of the triangle is split into two sides which intersect at a 180° angle, and in (c) a short fourth side is added to the triangle.

SEGM(NPL) = the maximum segment size of the surface patch monopoles on plate NPL (in wavelengths). It should not exceed 0.25 and is typically chosen 0.25. If more accuracy is needed SEGM can be chosen less than 0.25 with a substantial increase in computation time and storage since the number of modes increases. Note that the maximum segment size is specified in wavelengths. Thus, as the frequency is changed, the segmentation of the plates into surface patch modes is automatically adjusted to maintain the same segment size in wavelengths and thus comparable accuracy. This "frequency independent" method of specifying the segmentation of the plates allows the user to make runs at different frequencies by only changing the frequency (in READ 6). It also allows the user to easily increase or decrease the density of modes on different parts of the surface i.e. on different plates.

IREC(NPL) = indicator for plate NPL being rectangular or polygonal. Note that it is O.K. to specify a rectangular plate as being polygonal, but not visa versa. Identifying the rectangular plates simply allows for a reduction in CPU run time. = 0 implies plate NPL is polygonal. = 1 implies plate NPL is rectangular.

IPN(NPL) = polarization indicator. = 0 implies place no modes on plate NPL. = 1 implies modes are to be placed on plate NPL to cover polarization one only. = 2 implies modes are to be placed on plate NPL to cover polarization two only. = 3 implies both polarizations are to be placed on plate NPL and is the usual value.

As mentioned above, one normally sets IPN(NPL) = 3, which will place both polarizations of current on plate NPL. Setting IPN(NPL) to other than 3 is not recommended to the beginning user, except on four sided plates. A four-sided plate is defined by its consecutive corners 1, 2, 3 and 4. Side 1 is from corners 1 to 2. Side 2 is from corners 2 to 3. Side 3 is from corners 3 to 4. Side 4 is from corners 4 to 1. The term polarization one implies the current flowing in the direction from side 2 to 4. Polarization two implies the current flowing in the direction from side 1 to 3. Example 5 illustrates the use of the IPN array to reduce the number of modes when one has the junction of two thin rectangular plates.

IGS(NPL) = the generating side used in subroutine PLATE3. Side N on plate NPL goes from point N to point N + 1, except side NCNRS(NPL) which goes from point NCNRS(NPL) to point 1.

The generating side is the reference side subroutine PLATE3 uses to divide plate NPL into modes. It is not possible to completely describe here how PLATE3 segments plates and the meaning of the generating side [16]. We will only say that PLATE3 begins to produce a grid by drawing a set of lines which starts adjacent to the generating side and nearly parallel to it. More lines are drawn as one moves across the polygon and ends with a line adjacent and nearly parallel to the side opposite the generating side. Normally IGS(NPL) = 0 which implies that subroutine PLATE3 will use the longest side of plate NPL as the generating side. However, the ensuing modal segmentation may not be the optimal one in the sense of minimum number of modes or an accurate representation of the current flowing on the plate. In such cases the user might want to use a different generating

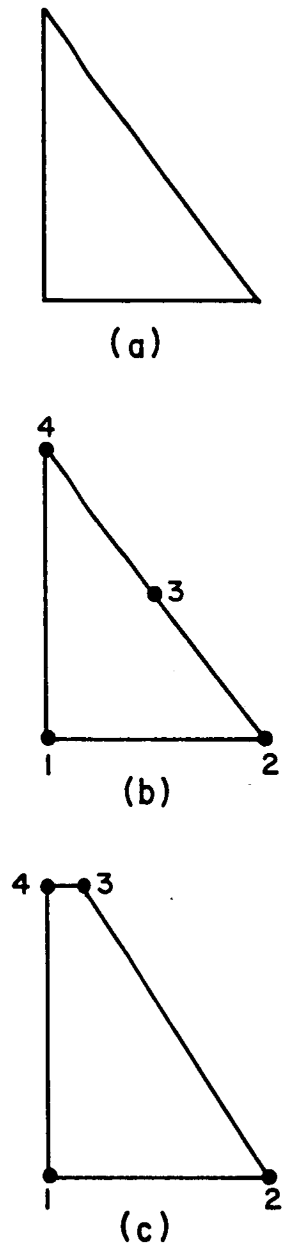


Figure 3.2: (a) A triangular plate. (b) A triangular plate represented as a four-sided plate by splitting the hypotenuse into two sides which intersect at a 180° angle. (c) A triangular plate represented by a four-sided plate by adding a short side.

side by setting IGS(NPL) = the side number of the desired reference or generating side.

READ 9 inputs the x,y,z coordinates of the corners of plate NPL. It is executed NCNRS(NPL) times for each plate and defines the following:

PCN(1,NCNR,NPL),PCN(2,NCNR,NPL), PCN(3,NCNR,NPL)
= x,y,z coordinates (in meters), respectively, of corner NCNR (1 $\leq$ NCNR $\leq$ NCNRS(NPL)) of plate NPL.

Note that plates must be planar structures, and may not contain more than one interior angle greater than 180°. If the specified corners of a plate are nearly planar, the code adjusts them so that they are exactly planar. If the specified corners of a plate are too far from being planar, an error message is printed and the run is aborted.

As an example of the use of READS 7-9 to specify a polygonal plate, Figure 3.3(a) shows a five-sided plate in the xy plane. The numbering scheme for the five points is arbitrary except that they must be consecutive (clockwise or counterclockwise) around the polygon. For this plate, READS 7-9 are shown in Figure 3.3(b). READ 8 indicates that the plate: has NCNRS(1) = 5 sides; is to be segmented into modes not to exceed SEGM(1) = 0.25λ; is polygonal; is to have modes with both polarizations; and that the generating side is to be selected by the code. READ 9 is executed five times since this is a five-sided plate. Each line defines the (x,y,z) coordinates in meters of one of the five corners of the five-sided polygon. The scattering from this plate is the subject of Example 2 below.

The program automatically checks for plates which intersect along a common edge and inserts surface patch overlap modes to ensure the continuity of the normal component of current across the common edge. If more than two plates intersect along a common edge the program finds the minimum linearly independent set of overlapping modes. Two intersecting plates may share only a single common edge. Thus, one plate may not fit into a notch in another plate.

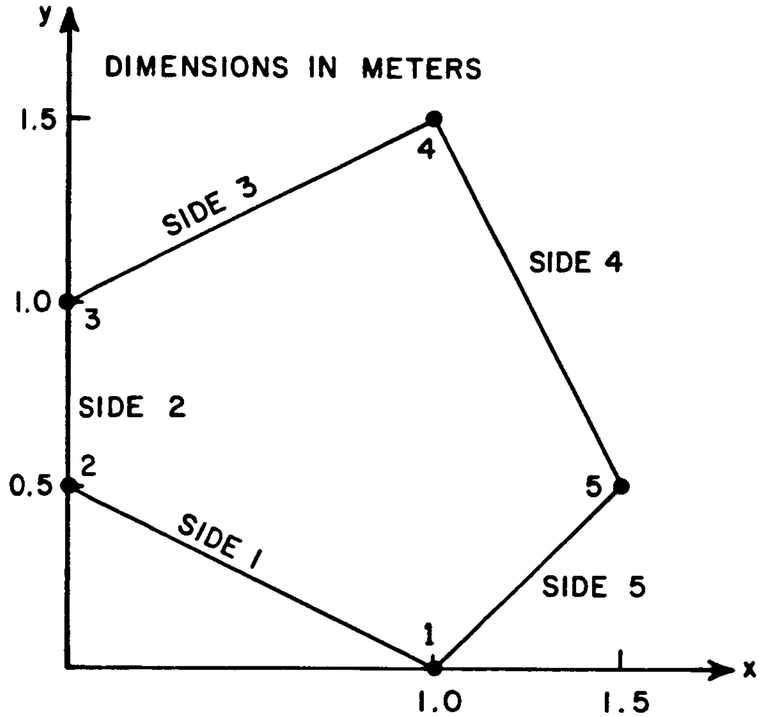
The subroutines which segment the plates into modes and define overlap modes to connect plates are a crucial part of the ESP code. This is because they permit a user to specify a complex geometry in terms of a relatively few polygonal plates, and not be responsible for specifying the hundreds or even thousands of surface patch modes on these plates. Our methods for segmenting and connecting plates have worked on a great many complex plate geometries. However, the user can be confident that eventually he will specify a geometry for which our subroutines fail. A failure is usually obvious by looking at a plot of the plate and overlap modes (see Section 4), and it is reccommended that all users obtain these plots. When a failure does occur, it usually can be fixed by breaking the complex or unusual polygonal plate into two or more (intersecting) simpler polygonal plates.

3.1.5 READ 10: Saving and Reusing the Impedance Matrix

At times a user may wish to run several consecutive problems for which the impedance matrix either does not change or only certain blocks of the matrix change. For example, the impedance matrix will not change for the following cases:

1. if different far-zone patterns are desired.
2. if different voltage excitations are used, or
3. if different angles of incidence are used in a bistatic scattering calculation.

Obviously, in these cases it would be extremely wasteful to recompute the entire impedance matrix. At other times the geometry may change only slightly from one run to the other. For example, consider the problem of locating a monopole on a ship such that a desired impedance and/or pattern is achieved. In order to solve this problem one would construct a model of the ship from several intersecting plates, possibly requiring hundreds of surface patch modes. A few wire modes would be used to model the monopole, and one attachment mode would be required where the monopole physically connects to a plate. The user would then analyze this configuration for many monopole locations in search of the optimum location. The impedance matrix of this (and in general of any) MM problem can be visualized as shown in Figure 3.4. It consists of nine blocks, corresponding to coupling between wire (W), plate (P), and attachment (A) modes. As the monopole location changes, the P/P block of the matrix does not change, since the plate geometry does not change. Thus, a considerable savings



(a)

READ 7:	1				
READ 8:	5	0.25	0	3	0
READ 9:	1.0	0.0	0.0		
READ 9:	0.0	0.5	0.0		
READ 9:	0.0	1.0	0.0		
READ 9:	1.0	1.5	0.0		
READ 9:	1.5	0.5	0.0		

(b)

Figure 3.3: (a) A five-sided plate in the xy plane. (b) READS 7-9 for the plate in (a).

in time will result if on the first run the entire matrix is stored on a disk file. On subsequent runs the stored matrix is read in and only the blocks involving wires and attachments are recomputed. The operation of storing, reading, and selecting the blocks of the impedance matrix to be recomputed is controlled by the parameters IWRZM and IRDZM. Specifically:

IWRZM = indicator for writing the impedance matrix onto logical unit 1, a disk file.
= 0 implies do not write out the impedance matrix.
= 1 implies write out the impedance matrix.

IRDZM = indicator for reading in the impedance matrix calculated during a previous run.
= 0 implies do not read in the previous matrix. Thus, the entire impedance matrix will be computed.
= 1 implies read in the previous matrix and compute the new matrix except for the W/W and A/A blocks. Use this option when the wire and attachment geometry is identical to the run on which IWRZM = 1.
= 2 implies read in the previous matrix and compute the new matrix except for the P/P block. Use this option when the plate geometry is identical to the run on which IWRZM = 1.
= 3 implies read in previous matrix and use as new matrix, i.e., do not calculate any impedance elements. Use this option when the entire wire/plate geometry is identical to the run on which IWRZM = 1.

Thus IRDZM=2 if the plate geometry is unchanged, IRDZM=1 if the wire and attachment geometry is unchanged, and IRDZM=3 if the entire geometry is unchanged. By unchanged it is meant unchanged from the run on which IWRZM=1. Whenever IRDZM > 0 the following should be true:

1. IWRZM must have been 1 on a previous or first run.

2. the number of wire, plate and wire attachment modes is identical to the IWRZM = 1 run,

3. the frequency is the same as the IWRZM = 1 run.

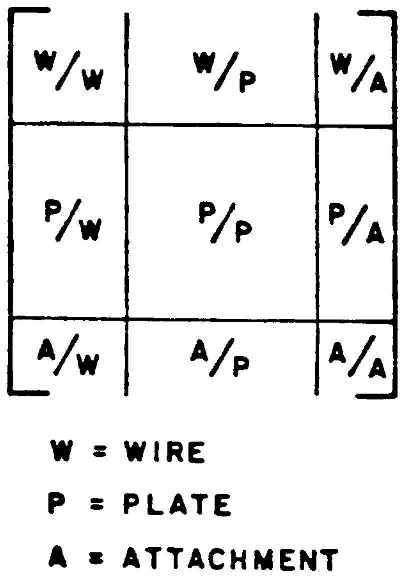


Figure 3.4: Symbolic representation of the nine blocks of the moment method impedance matrix.

The impedance matrix is written to and read from logical unit 1, which is a disk file termed ZMAT.DAT by the authors. It is suggested that any time a long and costly run is made, the user should set IWRZM = 1. If this option is not being used, simply set IRDZM=IWRZM=0.

3.1.6 READS 11-15: The Wire and Attachment Geometry

READS 11-15 define the wire and attachment geometry, including the lumped loads, voltage generators, wire-to-plate attachments, and ports for mutual coupling. These READ statements are executed only if INWR=1 and IRGM=1 (see READ 1). The wire geometry input will be described with the aid of the example shown in Figure 3.5. This geometry will be analyzed below in Example 1. The structure consists of a T-shaped wire with one load, one generator, and one wire/plate junction. The wire is defined by four points, shown as heavy black dots in Figure 3.5, and three wire segments. The wire point and segment numbering scheme shown in Figure 3.5 is arbitrary. The wire point numbers are shown adjacent to the dots and the segment numbers are shown as circled numbers next to the segments.

The following rules apply for wires:

1. The wire geometry consists of interconnected straight wire segments.
2. Each segment should not exceed a quarter wavelength in length.
3. Two intersecting segments should not form an acute angle less than 30 degrees.
4. Single or isolated wire segments are not permitted.
5. There is no limit to the number of wire segments intersecting at a given point (providing 3 above is not violated).
6. No wire segment should be smaller than two times the wire radius.
7. The wire radius should not exceed 0.01λ.

READ 11 inputs the following parameters:

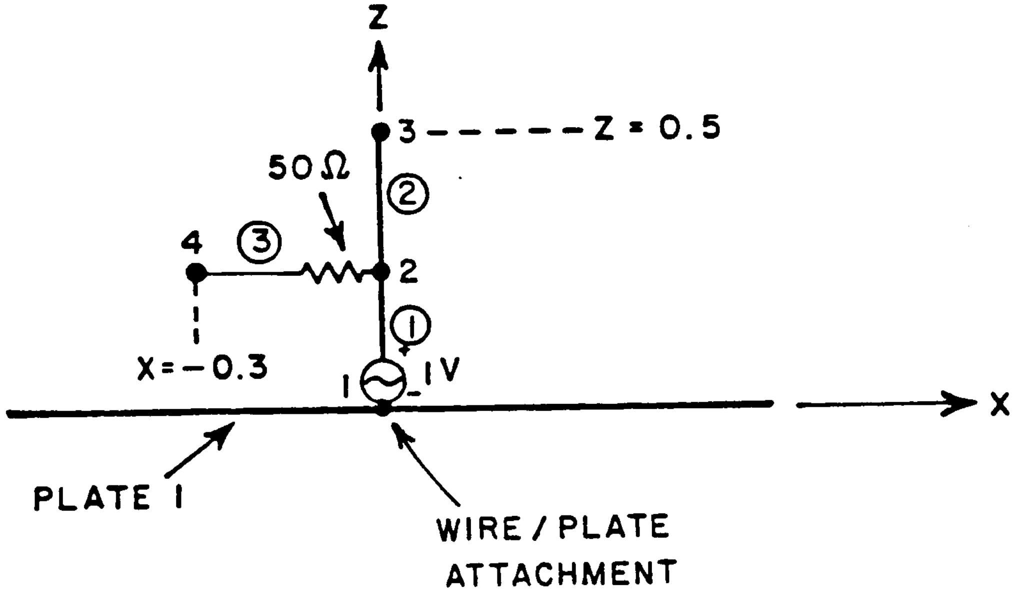


Figure 3.5: A wire geometry showing points, segments, 1 load, 1 voltage generator and 1 wire/plate attachment.

NM = total number of segments in the wire structure.

NP = total number of points in the wire structure.

NAT = total number of wire-to-plate attachment points.

NFPT = total number of feed points in the wire structure, excluding feeds at wire-to-plate attachment points. By a feed point it is meant a location where there is a genrator and/or a lumped load. Note that if a location in the wire contains a generator and load, this counts as one feed point.

NFS1 = wire "location" of the first feed port for mutual coupling computations, and

NFS2 = wire "location" of the second feed port for mutual coupling computations.

The meaning of the term wire "location" is described below. By specifying non-zero values of NFS1 and NFS2, the program will calculate the maximum coupling (i.e., source and receiver conjugate matched) between feed ports NFS1 and NFS2. Also, the two-port impedance matrix relating the two feed ports is calculated and printed. If no coupling calculations are desired then set NFS1 = NFS2 = 0. At present the feed locations for mutual coupling must be adjacent to a point in the wire which has only two segments emanating from it.

For the example of Figure 3.5 READ 11 would be:

3 4 1 1 0 0 .

That is, the wire has NM = 3 segments, NP = 4 points, NAT = 1 wire/plate junction, NFPT = 1 feed point in the wire, and no mutual coupling computation is desired.

READ 12 requires NP lines of input. Line I specifies the x,y,z coordinates of wire point I in meters. Each line of READ 12 defines:

X(I) = the x coordinate of point I in meters.

Y(I) = the y coordinate of point I in meters.

Z(I) = the z coordinate of point I in meters.

For the geometry of Figure 3.5 the NP = 4 lines of input for READ 12 are:

$$\begin{array}{rrr} 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.25 \\ 0.0 & 0.0 & 0.5 \\ -0.3 & 0.0 & 0.25. \end{array}$$

READ 13 requires NM lines of input to define the endpoints of the NM segments. Each segment has two endpoints denoted by A and B. The user can arbitrarily select which end is A and which end is B. Line J of READ 13 defines:

IA(J) = endpoint A of wire segment J.

IB(J) = endpoint B of wire segment J.

By arbitrarily choosing the endpoint with the smaller point number as A, the NM=3 lines of input for READ 13 would be:

$$\begin{array}{cc} 1 & 2 \\ 2 & 3 \\ 2 & 4. \end{array}$$

That is we specify that segment 1 goes from point 1 to point 2, segment 2 goes from point 2 to point 3, and segment 3 goes from point 2 to point 4.

We are now in a position to define the meaning of a wire "location". Following the same convention as Richmond [3] in his thin wire code, a wire "location" **DOES NOT** refer to a wire point. The term wire "location" implies either endpoint A or endpoint B of a particular segment. Specifically, wire "location" L means:

- by endpoint A of segment L if L $\leq$ NM.
- by endpoint B of segment L - NM if NM + 1 $\leq$ L $\leq$ 2 NM.

READ 14 is executed NFPT times, and defines for every feed point its wire "location" and the complex value of the generator and load at that "location". In this code one always thinks of generators and loads as being inserted into segments, either by endpoint A or B of the segment. One should not think of feeds as being at a point in the wire. For example, for the geometry of Figure 3.5 it is not sufficient to say a 50 ohm load is by point 2. There are three "locations" (although physically close, electrically very different) next to point 2, i.e., endpoint B of segment 1, endpoint A of segment 2, or endpoint A of segment 3. The last "location" is the correct "location" for the 50 ohm load. READ 14 defines the following for each of the NFPT wire feed points:

IFM = the segment number which contains the feed point.

IAB = indicator specifying by which endpoint of segment IFM the feed point is located.
= 0 implies feed point is by endpoint A of segment IFM.
= 1 implies feed point is by endpoint B of segment IFM.

VLG = complex voltage generator at the feed point (in volts). Positive polarity is from endpoint A to endpoint B of segment IFM.

ZL = complex impedance load at the feed point (ohms).

For the geometry of Figure 3.5 the NFPT =1 line of input for READ 14 would be:

3 0 (0.0, 0.0) (50.0, 0.0).

Note that there is a 50Ω load, but no voltage generator at endpoint A of segment 3.

READ 15 specifies the wire-to-plate attachment geometry along with the complex values of the generators and loads at the attachment locations. Specifically, READ 15 is executed NAT times and defines the following for each of the NAT attachments:

NAS = the number of the wire segment which is attached to the plate.

IAB = indicator specifying which endpoint of segment NAS is attached to the plate.
= 0 implies endpoint A of segment NAS.
= 1 implies endpoint B of segment NAS.

NPLA(I) = for attachment I, plate onto which segment NAS is attached.

VGA(I) = complex voltage generator at attachment point I.

ZLDA(I) = complex lumped load impedance at attachment point I.

BDSK(I) = outer disk radius in meters of the disk monopole of the I^{th} attachment mode.

See Chapter 2 for a description of the attachment mode used at wire/plate junctions. Experience has shown that for accurate impedance and pattern data the disk radius should be between 0.1λ and 0.25λ. A good average choice is 0.2λ. Also, the disk should not extend beyond the edge of the plate. Thus, the center of disk I should be at least BDSK(I) meters away from all plate edges. Also, problems may arise if two attachment points on the same plate are too close. Basically, we feel that no problem should arise if the disk of the first attachment mode overlays the disk of the second. However, problems could arise if the disk of one mode overlays the attachment point of the second. Thus, two attachment points should be separated by atleast a disk radius. The problems which arise from closely spaced attachments are not fundamental, but rather are numerical and could be cured by a more careful treatment of certain numerical integrations. Closely spaced attachments is not a problem which we have studied in any detail.

READ 15 for the geometry of Figure 3.5 would require the NAT=1 lines of input:

1 0 1 (1.0,0.0) (0.0,0.0) 0.4.

The frequency must be low enough that BDSK(1) = 0.4 meters is no more than 0.25λ. Note that there is a 1 volt generator, but no impedance load, at the attachment point.

3.2 SUBROUTINE WGEOM

If INWR=1 and IRGM=0 (see READ 1), then the wire and attachment geometry is defined by subroutine WGEOM, which be written by the user. The general form of subroutine WGEOM is:

```
SUBROUTINE WGEOM(IA,IB,X,Y,Z,NM,NP,NAT,NSA,NPLA,VGA,
BDSK,ZLDA,NWG,VG,ZLD,WV,NFS1,NFS2)
DIMENSION IA(1),IB(1),X(1),Y(1),Z(1),NSA(1),NPLA(1),BDSK(1)
COMPLEX VGA(1),ZLDA(1),VG(1),ZLD(1)
          ⋮             ⋮
"FORTRAN STATEMENTS"
          ⋮             ⋮
RETURN
END
```

The following parameters are inputs to WGEOM and are defined in the main program:

NWG = index of the DO 600 loop shown in Figure 3.1.

WV = wavelength in meters.

The following parameters are outputs defined by FORTRAN statements in WGEOM:

IA(I) = endpoint A of wire segment I (I = 1 to NM).

IB(I) = endpoint B of wire segment I (I = 1 to NM).

X(J),Y(J),Z(J) = x,y,z coordinates (meters) of wire point J (J = 1 to NP).

NM = the total number of wire segments.

NP = the total number of wire points.

NAT = the total number of attachment points.

NSA(K) = wire "location" of attachment point K (K = 1 to NAT).

NPLA(K) = the number of the plate onto which attachment point K is located.

VGA(K) = complex voltage generator (volts) at attachment point K.

BDSK(K) = outer disk radius (meters) of the disk monopole of attachment mode K.

ZLDA(K) = complex impedance load (ohms) at attachment point K.

VG(L) = complex voltage generator (volts) at wire "location" L.

ZLD(L) = complex impedance load (ohms) at wire "location" L.

NFS1 = wire "location" of the first feed point for mutual coupling.

NFS2 = wire "location" of the second feed point for mutual coupling.

As described in READ 11 above, the parameters NFS1 and NFS2 are used when the mutual coupling between two feed ports on the wire structure is required. When no two-port coupling calculation is needed then set NFS1 = NFS2 = 0. Wire "location" L means:

by endpoint A of segment L if L $\leq$ NM
by endpoint B of segment L-NM if NM + 1 $\leq$ L $\leq$ 2 NM.

All of the above outputs must be defined by the user via FORTRAN statements in subroutine WGEOM. Usually WGEOM is written on a separate file and is linked with the main program. This procedure saves compiling time when debugging or changing WGEOM.

3.2.1 WGEOM for a Dipole

Consider the problem of writing subroutine WGEOM for a center-fed dipole. If one wants to study different dipole lengths and/or segmentations, it is more convenient to write a subroutine WGEOM to generate the dipole geometry for variable length and segmentation than to define each dipole via the input file. A dipole of length H and consisting of NM segments is shown in Figure 3.6. In this figure the segment numbers are shown circled. A subroutine WGEOM describing the geometry of this dipole should define the following parameters:

1. NM = the number of segments and NP = the number of points = NM+1.

2. The segment size DH = H/NM.
3. The coordinates X(I), Y(I), Z(I) of the I^{th} point, i.e.,
   X(I) = 0.0
   Y(I) = 0.0
   Z(I) = DH*(I-1) .
4. The endpoints A and B of segment J, i.e.,
   IA(J) = J
   IB(J) = J + 1 .
5. If the dipole is to be center fed then NM must be an even number and the generator wire "location" is:
   IGN = (NM/2) + 1 or
   IGN = NM + NM/2 .
6. There are no attachments, i.e., NAT=0.
7. No coupling calculations are desired, i.e., NFS1=0, NFS2=0.

A WGEOM subroutine to describe the center-fed dipole is shown in Figure 3.7. The length of the dipole is set at H=0.5 meters and the number of segments is set at NM=4. The advantage of writing a subroutine WGEOM for this problem is that a user can obtain dipoles of different lengths and/or segmentations by simply changing the parameters H and NM. If, instead of setting NM=4, we had defined NM as NM = (H/0.125*WV) + 0.999, then the code would segment the dipole into segments of length about 0.125λ, independent of H and frequency.

3.2.2 WGEOM for a Loop

As a second example consider the problem of describing a regular polygon loop of variable radius, number of sides and segment size. Figure 3.9 shows a subroutine WGEOM to generate a polygonal loop with arbitrary R, NS, and SWX where:

R = the loop radius in meters.

NS = the number of sides in the loop.

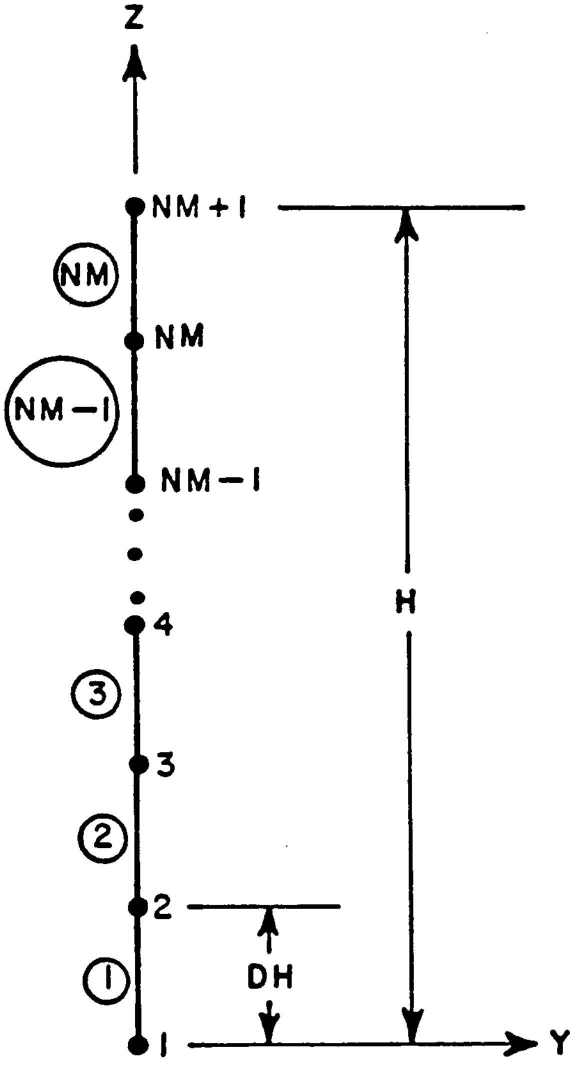


Figure 3.6: A straight wire split into NM segments and NP = NM + 1 points.

```
      SUBROUTINEWGEOM(IA,IB,X,Y,Z,NM,NP,NAT,NSA,NPLA,VGA,BDSK,
     2 ZLDA,NWG,VG,ZLD,WV,NFS1,NFS2)
      DIMENSIONIA(1),IB(1),X(1),Y(1),Z(1),NSA(1),NPLA(1),BDSK(1)
      COMPLEXVGA(1),ZLDA(1),VG(1),ZLD(1)
C
C     GEOMETRY FOR A CENTER FED DIPOLE.
C
C     SPECIFY H = WIRE LENGTH AND NM = NUMBER OF SEGMENTS.
      H=0.5
      NM=4
C     INSURE THAT NM IS AN EVEN NUMBER.
      NM=2*((NM+1)/2)
C     THE NUMBER OF POINTS IS
      NP=NM+1
C     THE SEGMENT SIZE IS
      DH=H/NM
C     DEFINE COORDINATES OF NP POINTS AND NM SEGMENTS.
      DO100I=1,NP
      X(I)=0.0
      Y(I)=0.0
      Z(I)=(I-1)*DH
      IF(I.EQ.NP)GOTO100
      IA(I)=I
      IB(I)=I+1
  100 CONTINUE
C     DEFINE GENERATOR LOCATION AND VALUE.
      IGN=NM/2+1
      VG(IGN)=(1.0,0.0)
C     INDICATE NO ATTACHMENTS.
      NAT=0
C     INDICATE NO TWO-PORT COUPLING COMPUTATION DESIRED
      NFS1=0
      NFS2=0
      RETURN
      END
```

Figure 3.7: A subroutine WGEOM to describe the center fed dipole of Figure 3.6.

SWX = the maximum segment size in λ.

Currently, it is set to an NS=6 sided loop of radius R=0.3 meters, and with a maximum segment size of SWX=0.2λ.

Subroutine WGEOM for the polygonal loop will be written with the aid of Figure 3.8 which shows a hexagon loop with two segments per side. The subroutine WGEOM in Figure 3.9 computes the following parameters:

1. The length SL of each side.

2. The number of segments per side (NMS) and the length of each segment (DSL).

3. The total number of segments (NM = NMS*NS) and the total number of points (NP=NM).

4. The x,y,z coordinates of the endpoints of side I, i.e.

   - X1 = R*COS(PH1), PH1 = (I-1)*360/NS
   - Y1 = R*SIN(PH1)
   - X2 = R*COS(PH2), PH2 = I*360/NS
   - Y2 = R*SIN(PH2) .

5. The x,y,z coordinates of wire point K which is the J^{th} point on side I, i.e.,

   - K = (I-1)*NMS + J
   - X(K) = X1 + (J-1)*DX12, where DX12 = (X2 - X1)/NMS
   - Y(K) = Y1 + (J-1)*DY12, where DY12 = (Y2 - Y1)/NMS
   - Z(K) = 0.0 .

6. The endpoints A and B of segment K are:

   IA(K) = K

   IB(K) = K + 1 except IB(NM) = 1.

7. The feed point is by endpoint A of segment 1, i.e., IGN = 1.

8. There are no attachments, i.e., NAT=0.

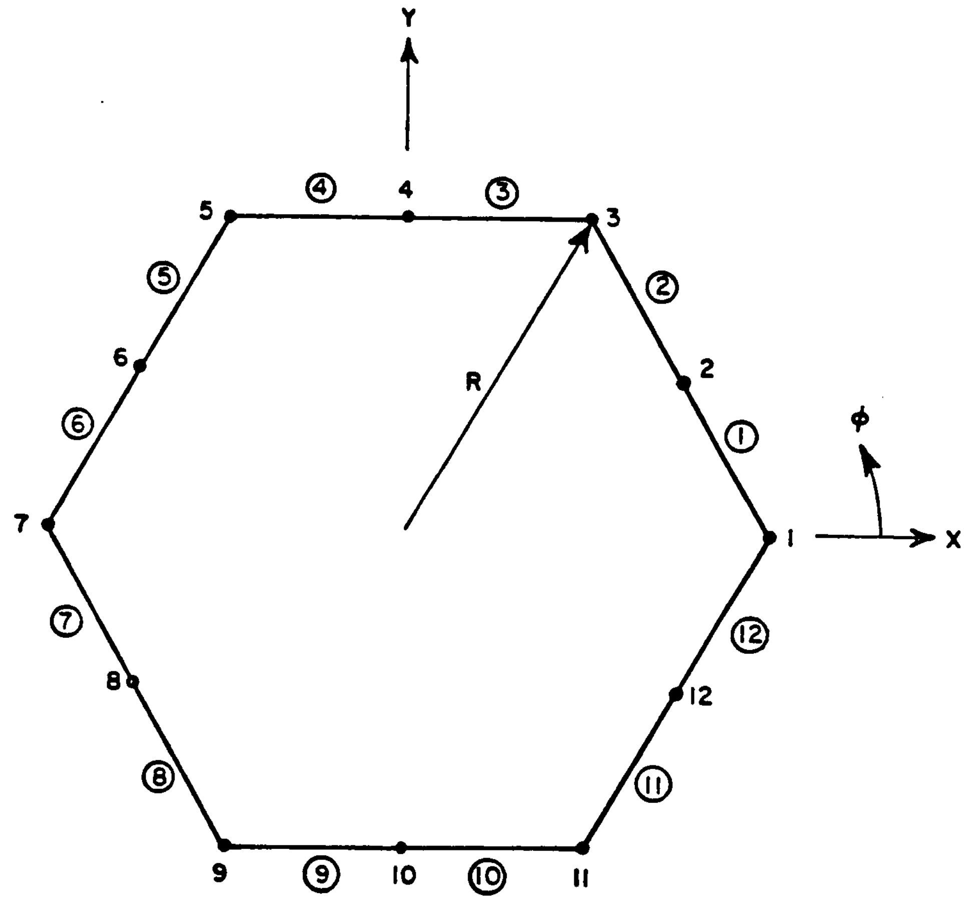


Figure 3.8: Points and segments defined on a hexagon loop.

```
      SUBROUTINE WGEOM(IA,IB,X,Y,Z,NM,NP,NAT,NSA,NPLA,VGA,BDSK,
     2 ZLDA,NWG,VG,ZLD,WV,NFS1,NFS2)
      DIMENSION IA(1),IB(1),X(1),Y(1),Z(1),NSA(1),NPLA(1),BDSK(1)
      COMPLEX VGA(1),ZLDA(1),VG(1),ZLD(1)
C
C     GEOMETRY FOR A POLYGONAL LOOP.
C
C     SPECIFY R = LOOP RADIUS IN METERS, NS = NUMBER OF SIDES IN THE
C     POLYGONAL LOOP, AND SWX = THE MAX. SEGMENT SIZE IN WAVELENGTH.
C
      R=0.3
      NS=6
      SWX=0.2
C     FIND SL = SIDE LENGTH
      PI=4.0*ATAN(1.0)
      DPH=2.0*PI/NS
      SL=2.0*R*SIN(DPH/2.0)
C     FIND NMS = NUMBER OF SEGMENTS PER SIDE AND DSL = SEGMENT LENGTH.
      DSL=SWX*WV
      NMS=0.99 + SL/DSL
      DSL=SL/NMS
C     FIND NM = TOTAL NUMBER OF SEGMENTS AND NP = TOTAL NUMBER OF POINTS.
      NM=NS*NMS
      NP=NM
C     DEFINE THE NMS POINTS AND SEGMENTS ON EACH OF THE NS SIDES.
      DO 100 I=1,NS
C     THE COORDINATES OF THE FIRST AND SECOND END OF SIDE I.
      PH1=(I-1)*DPH
      X1=R*COS(PH1)
      Y1=R*SIN(PH1)
      PH2=I*DPH
      X2=R*COS(PH2)
      Y2=R*SIN(PH2)
C     THE DELTA X AND DELTA Y BETWEEN POINTS ON SIDE I IS
      DX12=(X2-X1)/NMS
      DY12=(Y2-Y1)/NMS
      DO 200 J=1,NMS
C     DEFINE THE KTH POINT AND SEGMENT
      K=(I-1)*NMS + J
      X(K)=X1+(J-1)*DX12
      Y(K)=Y1+(J-1)*DY12
      Z(K)=0.0
      IA(K)=K
      IB(K)=K+1
      IF(K.EQ.NM)IB(K)=1
  200 CONTINUE
  100 CONTINUE
C     PLACE A 1 VOLT GENERATOR ON THE +X AXIS (BY SIDE A OF SEG. 1).
      IGN=1
      VG(IGN)=(1.0,0.0)
C     INDICATE NO ATTACHMENTS.
      NAT=0
C     INDICATE NO TWO-PORT COUPLING COMPUTATION DESIRED
      NFS1=0
      NFS2=0
      RETURN
      END
```

Figure 3.9: A subroutine WGEOM to describe a regular polygonal loop such as the hexagon loop of Figure 3.8.

9. No coupling calculations are desired, i.e., NFS1=0, NFS2=0.

The advantage of writing a subroutine WGEOM for this problem is that a user can easily define regular polygon loops with different radii, number of sides and segment sizes. This can be accomplished by changing only the parameters R, NS and SWX. Also, since SWX is specified in wavelengths the subroutine is frequency independent. This feature is especially desirable for an analyzing of a wire antenna over a broad frequency range.

3.3 Array Dimensions

The size of the problem, i.e., the number of points, segments, modes, etc., which can be treated by the ESP code is determined by the dimensions specified for various arrays. All arrays whose dimensions may change from problem to problem are dimensioned near the top of the main program. Arrays dimensioned by the same parameters are grouped together, and the dimensions are described by comment statements. The array dimensions are specified by DIMENSION and COMPLEX statements. All arrays have either fixed dimensions, independent of the geometry being run, or are dimensioned according to one of the following dimension indicators:

IDWR = maximum number of wire points, wire segments, or wire modes. Although in a complex wire geometry the number of wire points (NP), segments (NM) and modes (NWR) are in general different, they are always of comparable magnitude. Thus it is easier to dimension all arrays dealing with the wire geometry by the single dimension indicator, IDWR.

IPL = maximum number of plates.

ICN = maximum number of corners on a polygonal plate.

IAT = maximum number of wire-to-plate attachments.

ITOT = maximum number of modes (wire + plate + attachment).

IDZT = maximum length of the one dimensional array ZT which is used to store the symmetric impedance matrix for full surface testing and is used for temporary storage of the symmetric wire/wire block of the impedance matrix for filament testing. Thus, the value for IDZT is dependent upon whether filament (IFIL = 1 in READ 1) or full surface (IFIL = 0 in READ 1) testing is being used. If IFIL = 0, set IDZT $\geq$ (ITOT*ITOT + ITOT)/2. If IFIL = 1, IDZT can be reduced to (IDWR*IDWR + IDWR)/2 to save storage. IDZT must be at least 1.

IDZTF = dimension of the two dimensional array ZTF, used to store the impedance matrix when filament testing is being used, i.e., IFIL = 1 in READ 1. If IFIL=1, then set IDZTF $\geq$ ITOT. If IFIL = 0, then IDZTF can be reduced to 1 to save storage.

IDWR2 = twice the maximum number of wire points, segments or modes = 2*IDWR.

ITW2 = the larger of IDWR2 and ITOT.

IERVSR = the maximum length of the second index, NINA1, in the ERVSR(IAT,NINA1) array. This array is only used when there are wire/plate juntions. For each attachment mode, ERVSR stores an array of E_ρ versus ρ. Depending on the details of the wire/plate junction geometry, NINA1 will be between $60D_{max}/\lambda$ and $120D_{max}/\lambda$, where D_{max} is the maximum diagonal length from one corner of a plate to another corner. Subroutine ZTOT includes a check that NINA1 does not exceed IERVSR. If it does, a message is printed indicating the minimum acceptable value for IERVSR, and execution is halted.

The dimension indicators are defined in PARAMETER statements at the top of the MAIN program. In addition to the nine dimension indicators defined above, we also define the parameters IDFIL and IDSUR which indicate whether filament of full surface testing is to be used. Specifically, these parameters are defined by:

IDFIL = indicator to dimension for filament testing
= 1 implies dimension for filament testing
= 0 implies do not dimension for filament testing.

IDSUR = indicator to dimension for full surface testing
= 1 implies dimension for full surface testing
= 0 implies do not dimension for full surface testing

Either IDFIL or IDSUR must be 1. If IFIL (in READ 1) is 1, then IDFIL must be 1. If IFIL is 0, then IDSUR must be 1. It is always valid to set IDFIL and IDSUR to 1. If IDFIL and IDSUR are both 1, then the arrays will be properly dimensions for IFIL = 0 or 1, however, some storage will be wasted. It is never valid to set IDFIL and IDSUR to 0.

The ESP code stores the impedance matrix in different arrays, depending on whether full surface (IFIL=0) or filament testing (IFIL=1) is used. If IFIL=0, then the impedance matrix is stored in the one dimensional complex array ZT, while if IFIL=1 the impedance matrix is stored in the two-dimensional complex array ZTF. When full surface testing is used, the impedance matrix is symmetric. Thus, for IFIL=0, an N by N symmetric matrix would result in only (N*N + N)/2 elements in the one dimensional array ZT. When IFIL=1, the ZT array is also used as temporary storage for the symmetric wire/wire block of the impedance matrix. Clearly it is wasteful of storage to have both the ZT and ZTF arrays dimensioned large enough to hold the entire impedance matrix. If IFIL = 0, storage can be saved by setting IDFIL = 0 and IDSUR = 1. If IFIL=1, storage can be saved by setting IDSUR = 0 and IDFIL = 1.

When ESP is supplied outside Ohio St. Univ., typically the dimension indicators are set to:

IDFIL = 1

IDSUR = 1

IDWR = 100

IPL = 30

ICN = 8

IAT = 4

ITOT = 300

IDZT = MAX0((IDWR*IDWR+IDWR)/2,IDSUR*(ITOT*ITOT+ITOT)/2,1)

IDZTF = MAX0(IDFIL*ITOT,1)

IDWR2 = 2*IDWR

ITW2 = MAX0(ITOT,IDWR2)

IERVSR = 400.

The function MAX0 takes the maximum value of its arguments. In standard FORTRAN 77 one can not have a function subroutine in a PARAMETER statement. Therefore, in the ESP code we have replaced the MAX0 function by arithmetic statements which perform the same function. In the above case the code can treat filament or full surface testing problems with up to IPL = 30 polygonal plates, each having up to ICN = 8 corners, and up to IAT = 4 wire-to-plate attachments. The number of wire points, segments or modes can not exceed IDWR = 100. The total number of modes can be up to ITOT = 300. If the geometry involves wire/plate junctions, the code definitely can treat plates with diagonal lengths of 3.33λ, and possibly up to 6.66λ.

The MAIN program of ESP contain logic which compares the "size" of the current problem being run to the above dimension indicators. The only exception is IERVSR which is checked in subroutine ZTOT. If a dimension indicator is too small, a message is printed, and the run is aborted.

If it is desired to change array dimensions, then one must only change the corresponding PARAMETER statements at the top of the main program. For example, if one wished to run a problem with full surface testing involving 1000 modes (all but a few being plate modes), then one should set:

IDFIL = 0

IDSUR = 1

ITOT = 1000

Note that setting IDFIL = 0 avoids dimensioning both the ZT and ZTF arrays for ITOT = 1000 modes. Also, when changing dimensions, the user need only change the first seven of the above dimension indicators. The remaining four will automatically be adjusted.

3.4 Examples

In this section five examples will be presented illustrating the use of the computer code to analyze problems involving thin-wires, rectangular and polygonal plates, wire-to-plate attachments, and plate-to-plate junctions. These example runs are designed to:

1. illustrate the input data
2. illustrate the output data
3. provide trial or debugging runs for a new user.

Running any problem is a two step process. The first step is to insure that the problem geometry has been correctly defined. Even for relatively simple geometries, experience has shown that one is likely to make some errors in setting up the input file. Complicated geometries may require several runs before the geometry has been correctly defined. To avoid the time and expense of computing the impedance matrix and finding currents and fields when the geometry is incorrect, the parameter NGO is used in READ 1. If NGO = 0, then the code inputs the geometry and then outputs a printout of the geometry. However, no moment method or electromagnetic field calculations are made. The NGO = 0 run typically requires only a few seconds of CPU time. After the NGO = 0 run, when the user is reasonably confident that the input geometry is correct, then the actual data run is made by simply changing NGO to 1. As described in Section 4.1, when NGO = 0, the code also outputs a file on logical unit 9 which can be used to provide plots of the geometry. These include a three view plot of the wire/plate geometry and, if desired, a detailed plot of the surface patch dipole modes on each plate as well as the overlap modes connecting intersecting plates. In the examples to follow, samples of these geometry plots will be given. Although all input files are shown with NGO = 1, it should be understood that the geometry plots were obtained by an initial run with NGO = 0. We strongly urge all ESP user's to obtain these geometry plots, since on a complicated problem they are the best method of verifying that the geometry is correct. They can also be used to verify that the polygonal plates have (or have not) been properly segmented into surface patch modes. Finally, they provide a convenient pictoral documentation of the geometry.

The examples to follow were run with the ESP code as it existed in March 1987. The author intends to continually update and revise the code as errors are found, more efficient methods are found, or additional capabilities are added. When a copy of the code is supplied to a user, the user will normally get the latest (and hopefully the best) version of the code. However, as each change to the code is made, the results of running any problem, and in particular the examples below, will change. Thus, a user should not be overly concerned if the output he obtains from running the examples is slightly different from that indicated in this report. It should be mentioned that running the examples on a computer other than the VAX 11/780 used here will also produce some changes in the output.

3.4.1 Example 1

Example 1 will be to compute the input impedance and far-zone elevation pattern, in the plane $\phi = 90°$, for the geometry of Figure 3.5. The plate is 1.0 meter square with its center at the origin. The frequency is 150.0 MHz, and the wire is aluminum (conductivity = 38 megamho/meter) with radius 0.001 meter.

The input file for this problem is shown in Figure 3.10. Note that in READ 1, IFIL = 0, to obtain full surface testing. This is required whenever a problem involves a wire/plate junction. Also in READ 1, INWR = 1 and IRGM = 1, indicating that the wire geometry is to be defined by the input file (as opposed to a subroutine WGEOM). Also we set IWRZT = 1 to obtain a printout of the impedance matrix. The far-zone elevation pattern is specified in READ 2. READS 7-9 define the one rectangular plate. The surface patch mode segment size is chosen as 0.2 wavelength. In READ 11 the wire is specified as having NM = 3 segments, NP = 4 points, NAT = 1 wire/plate attachment, and NFPT = 1 feed point in the wire. READ 12 defines the (x,y,z) coordinates of the 4 points. READ 13 defines the endpoints of the 3 segments. READ 14 specifies that there is a 50.0 + j0.0 ohm load by endpoint A of segment three. READ 15 specifies that there is a 1.0 + j0.0 volt generator by endpoint A of segment 1, i.e., at the attachment point. The disk radius for the attachment mode is specified as 0.4 meters, which corresponds to 0.2λ at 150 MHz.

Figure 3.11 shows a three view plot of the wire and plate geometry. It can be obtained from the data file output on the NGO = 0 run as described

```
READ 1:    1  2  1  1  0  1  4  6  18  1  1  0
READ 2:    1  1  3  90.0
READ 3:    0  1  3  90.0
READ 4:    0  1  3  0.0  90.0  0.0
READ 5:    0  1  3  90.0
READ 6:    150.0  38.0  0.001
READ 7:    1
READ 8:    4  0.2  1  3  0
READ 9:    -0.5  -0.5  0.0
           0.5  -0.5  0.0
           0.5  0.5  0.0
           -0.5  0.5  0.0
READ 10:   0  0
READ 11:   3  4  1  1  0  0
READ 12:   0.0  0.0  0.0
           0.0  0.0  0.25
           0.0  0.0  0.5
           -0.3  0.0  0.25
READ 13:   1  2
           2  3
           2  4
READ 14:   3  0  (0.0,0.0)  (50.0,0.0)
READ 15:   1  0  1  (1.0,0.0)  (0.0,0.0)  0.4
```

Figure 3.10: The input file for Example 1.

in Section 4.1. The legend indicates that the moment solution will use 2 wire modes, 12 plate modes, and one wire/plate attachment mode, for a total of 15 modes. A scale or tick mark is shown of length 0.183λ which permits one to estimate the electrical size of the geometry. The wire points are shown as heavy dots.

The output file for Example 1 is shown in Appendix A. The initial data lists miscellaneous parameters such as the frequency, the wire radius, the integration parameters, and IFIL = 0 for full surface testing on the plates. Next the plate geometry is printed. In this case there is one plate. The plate is identified as being four sided and rectangular. It is to be broken into surface patch modes, no side of which is to exceed 0.2λ. The polarization indicator is 3, indicating that modes with both polarizations are to be placed on the plate. Next the (x,y,z) coordinates in meters of the four corners of the plates are printed. It is next indicated that the plate has been split into 12 surface patch dipole modes. If in READ 1 we had set IWR = 1, then a printout of the coordinates of each of the 12 modes would follow. These modes are plotted in Figure 3.12, with each arrow representing a surface patch dipole mode. The next output lists the (x,y,z) coordinates in meters of the NP = 4 points on the wire. Next the output shows that there are a maximum of two wire modes at any point on the wire (if this number is greater than four, there is an error in the wire geometry), a minimum of one mode at any point on the wire (if this number is less than one, there is an error in the wire geometry), and a total of two wire modes. Next the endpoints and length in meters of each wire segment is listed. The next group of output data lists the attachment point geometry. In this case, the one attachment point is by point A (since IAB = 0) of segment 1, and is attached to plate 1 with an attachment disk radius of 0.4 meters. The loads and generators are listed next. The next group of output summarizes the number of modes for the wires, plates and attachments. The modes are ordered so that the first NWR are wire modes, the next NPLTM are plate modes, and the next NAT are attachment modes. This ends the specification of the input geometry and would be the end of the output if NGO = 0.

The following output are the results of the MM analysis of the above geometry. Since IWRZT was set to 1 in READ 1, the impedance matrix (in volt-amps) is printed. Normally the impedance matrix is not printed since it can be very large, however, it was printed here simply to document

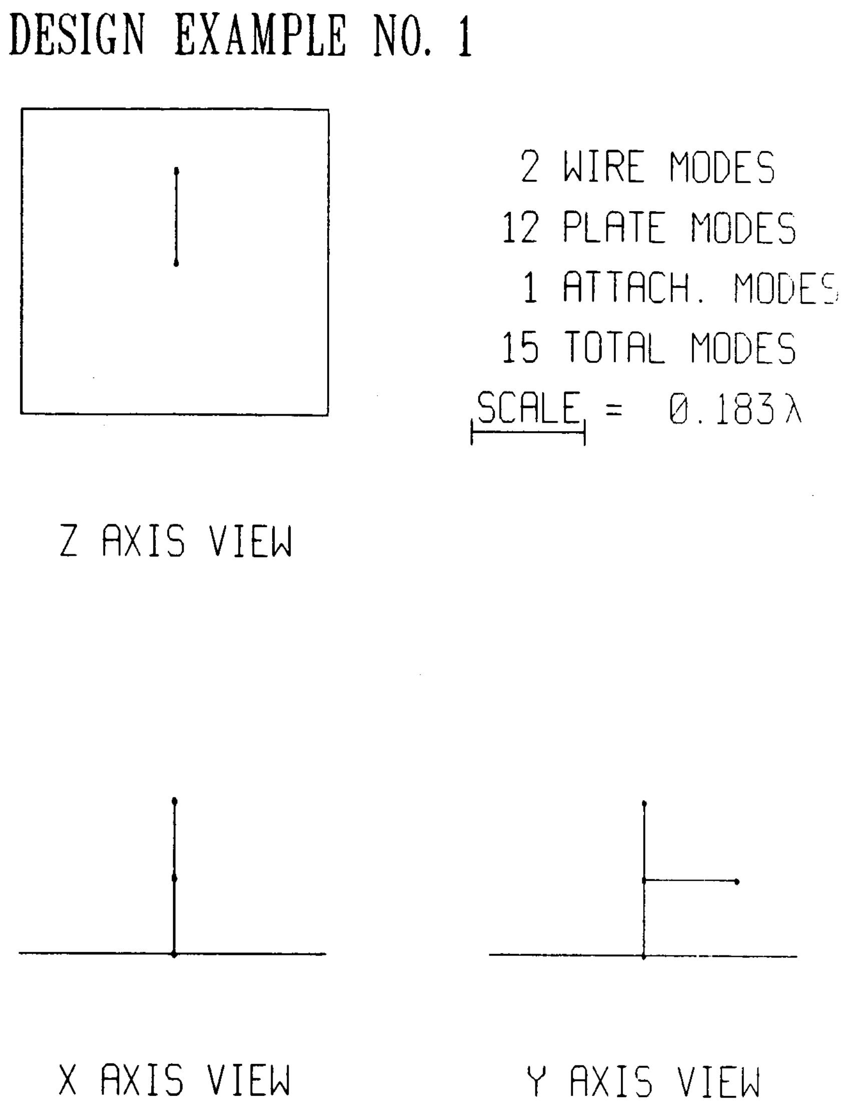


Figure 3.11: A three view sketch of the geometry for Example 1.

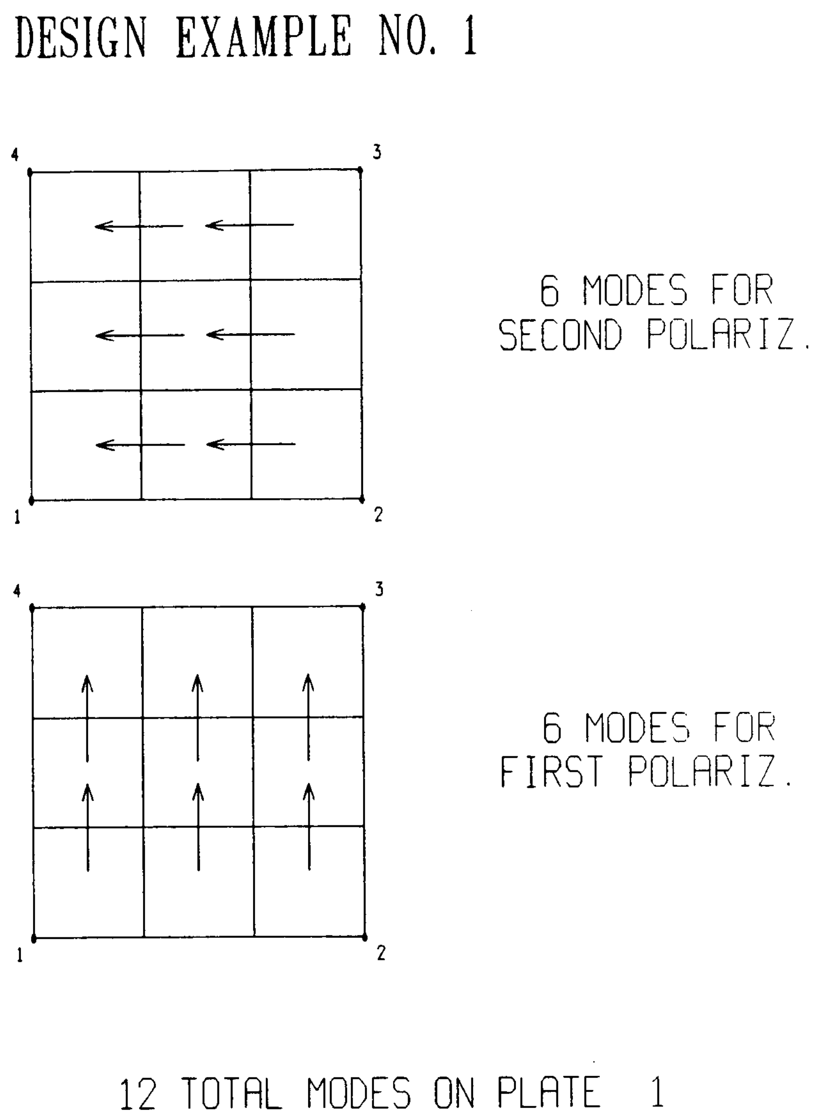


Figure 3.12: The segmentation of the square plate in Example 1 into surface patch dipole modes.

typical values. Since this is an antenna problem (as opposed to a scattering problem) the input admittance, impedance, and radiation efficiency are printed. The efficiency of 59.9% is primarily due to the 50 ohm load. Next the elevation plane pattern in the plane $\phi = 90°$ is printed. The far-zone patterns include the gain (as opposed to directive gain) for θ and ϕ polarizations in dB. Since IPFA = 1 in READ 2, the code outputs a file on logical unit 8 which can be used to plot the far-zone patterns (see Section 4.2). The elevation plane pattern gain plots for $\hat{\theta}$ and $\hat{\phi}$ polarizations are shown in Figures 3.13 and 3.14, respectively. The legend in the plots indicates that the frequency is 150.0 Mhz, the pattern is far-zone gain, and that the polarization is θ in Figure 3.13 and ϕ in Figure 3.14. The patterns are in the elevation plane plane $\phi = 90^0$. In Figure 3.13 the outer ring of the plot corresponds to -1.022 dB, and the scale is 10 dB/division. This means that the second ring is at -11.022 dB, the third at -21.022 dB, etc. The spherical angle θ is shown as zero at the top of the polar plot, and increases clockwise. The final output indicates that the CPU time for this run was about 104 sec. The CPU time is computed with the aid of the clock function GETCP(I), where I is the clock reading in hundredths of a second. Since this function is not standard FORTRAN 77, when the ESP code is delivered outside Ohio State University, the lines containg the calls to GETCP are essentially removed by making them COMMENT lines. The user can replace the calls to GETCP by a corresponding call to his clock routine. However, if this is not done, the code will print 0.0 for the CPU time.

3.4.2 Example 2

Example 2 will illustrate the computation of the backscatter from the five sided polygonal plate shown in Figure 3.3. The frequency will be 300 MHz, and the pattern will be in the elevation plane $\phi = 0°$. The input file for this example is shown in Figure 3.15. In READ 1 note that IFIL = 1, to obtain filament test modes on the plate. Filament testing is normally used to reduce CPU time, providing the problem does not involve a wire/plate junction. Figure 3.16 shows the detailed segmentation of the plate into 71 surface patch dipole modes. The arrows in this plot represent the surface patch dipole modes defined in Chapter 2. It is recommended that this plot be obtained (see Section 4.1) whenever polygonal plates are used. The

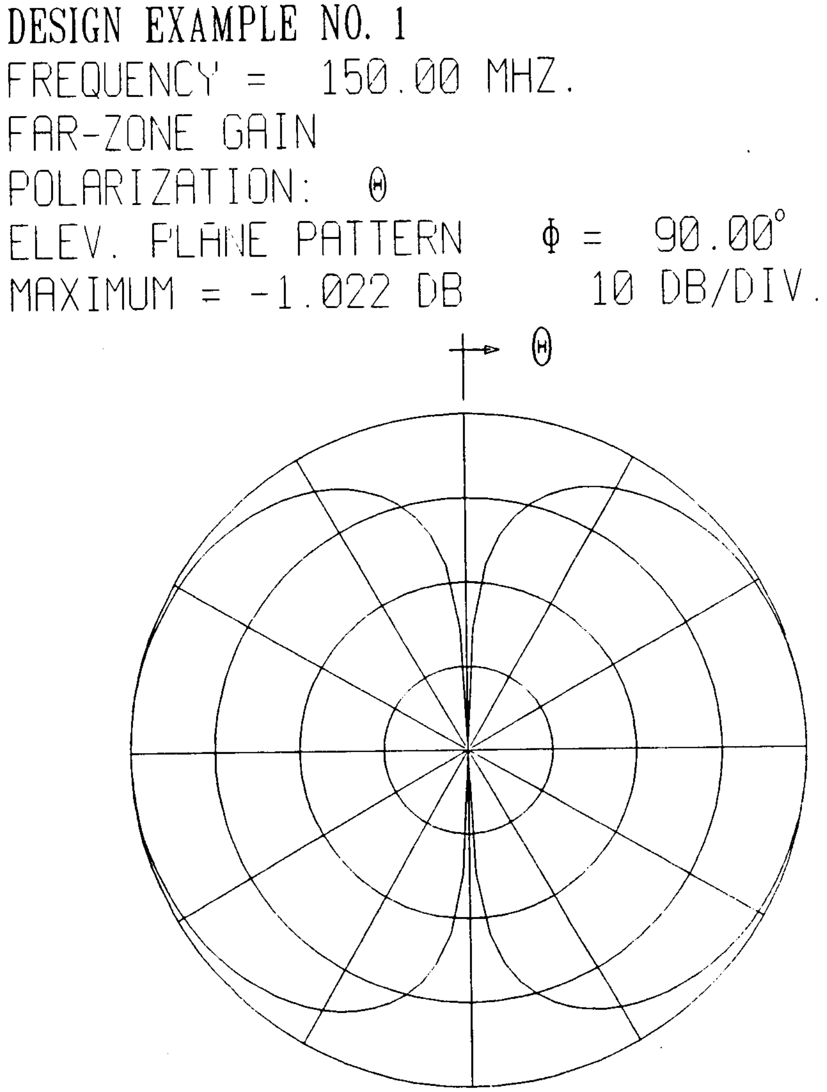


Figure 3.13: θ polarized gain in the elevation plane $\phi = 90°$ for Example 1.

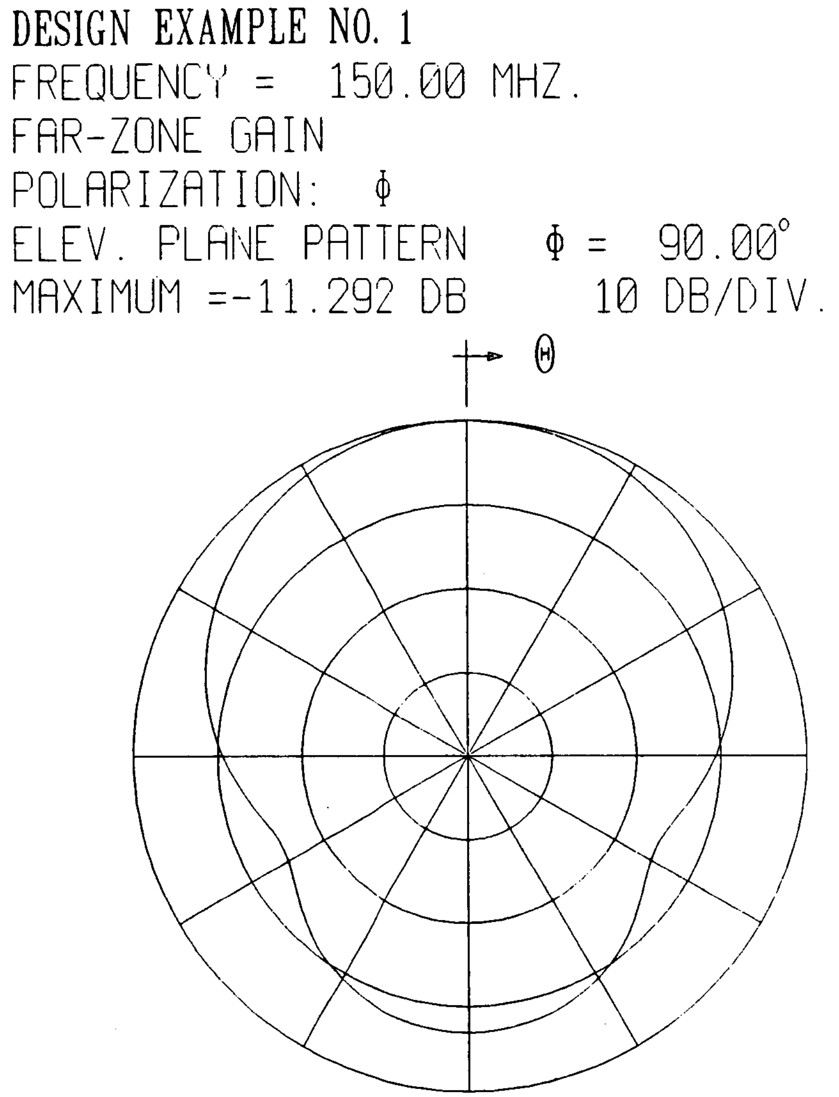


Figure 3.14: ϕ polarized gain in the elevation plane $\phi = 90°$ for Example 1.

reason is to verify that the code has done a reasonable job of segmenting the plates into the quadrilateral surface patch dipole modes, and also that it has done a reasonable job in placing overlap modes at plate/plate junctions. Although considerable effort was made in writing the computer subroutines which define the plate modal geometry, there is no doubt that geometries exist which the code cannot treat. For example, the code cannot treat a polygonal plate with more than two interior angles which are greater than 180°. The best way to recognize failures is to obtain the detailed surface patch mode geometry plots. Failures can normally be easily recognized and typically result in modes which either do not completely fill the area of the plate, or extend beyond the area of the plate. When a failure occurs it can be avoided by replacing the unusual or complex shaped polygonal plate by two intersecting simpler plates.

Referring to Figure 3.16, each dipole mode consists of two quadrilateral monopoles or patches. Since in READ 8 we set SEGM(1) = 0.25, the sides of these quadrilateral patches do not exceed 0.25λ in length. Note that the plate current density includes modes with both polarizations. Actually the modes with the first and second polarizations are not in general orthogonal. However, they do include orthogonal components, and are therefore suitable for expanding a vector current density on the plate surface. The modes are also set up so that at the edge of a plate the normal component of the current density vanishes and the tangential component of the current is finite. Note that in READ 10 IWRZM = 1, and thus the impedance matrix will be output on logical unit 1, which is a disk file termed ZMAT.DAT by the authors. This matrix will be reused in Example 3. Figure 3.17 shows a three view plot of the five sided plate.

The output for Example 2 is shown in Appendix B. The backscatter pattern in the plane $\phi = 0°$ is shown. The backscatter cross section magnitudes are given in dB over a square meter. We caution that in the previous version of ESP, the cross sections were given in dB over a square wavelength. Also the phase in degrees of the far-zone scattered electric field is given, with the usual e^{-jkr} factor removed. The notation for the polarization of the incident and scattered wave is:

STTM = cross section for θ incident and θ scattered

SPPM = cross section for ϕ incident and ϕ scattered

```
READ 1:    1  2  1  1  0  0  4  6  18  0  1  1
READ 2:    0  1  3  0.0
READ 3:    0  1  3  90.0
READ 4:    1  1  3  0.0  90.0  90.0
READ 5:    0  1  3  45.0
READ 6:    300.0  -1.0  0.001
READ 7:    1
READ 8:    5  0.25  0  3  0
READ 9:    1.0  0.0  0.0
           0.0  0.5  0.0
           0.0  1.0  0.0
           1.0  1.5  0.0
           1.5  0.5  0.0
READ 10:   1  0
```

Figure 3.15: The input file for Example 2.

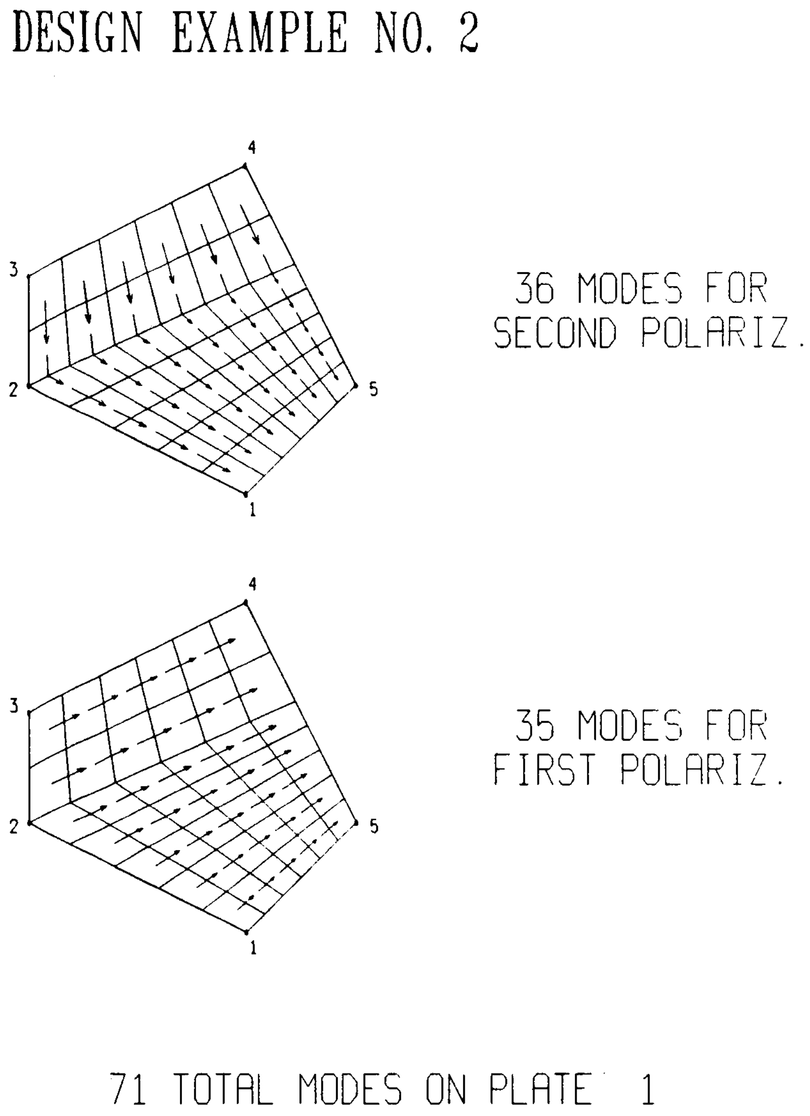


Figure 3.16: Surface patch modal layout for the five sided plate in Example 2.

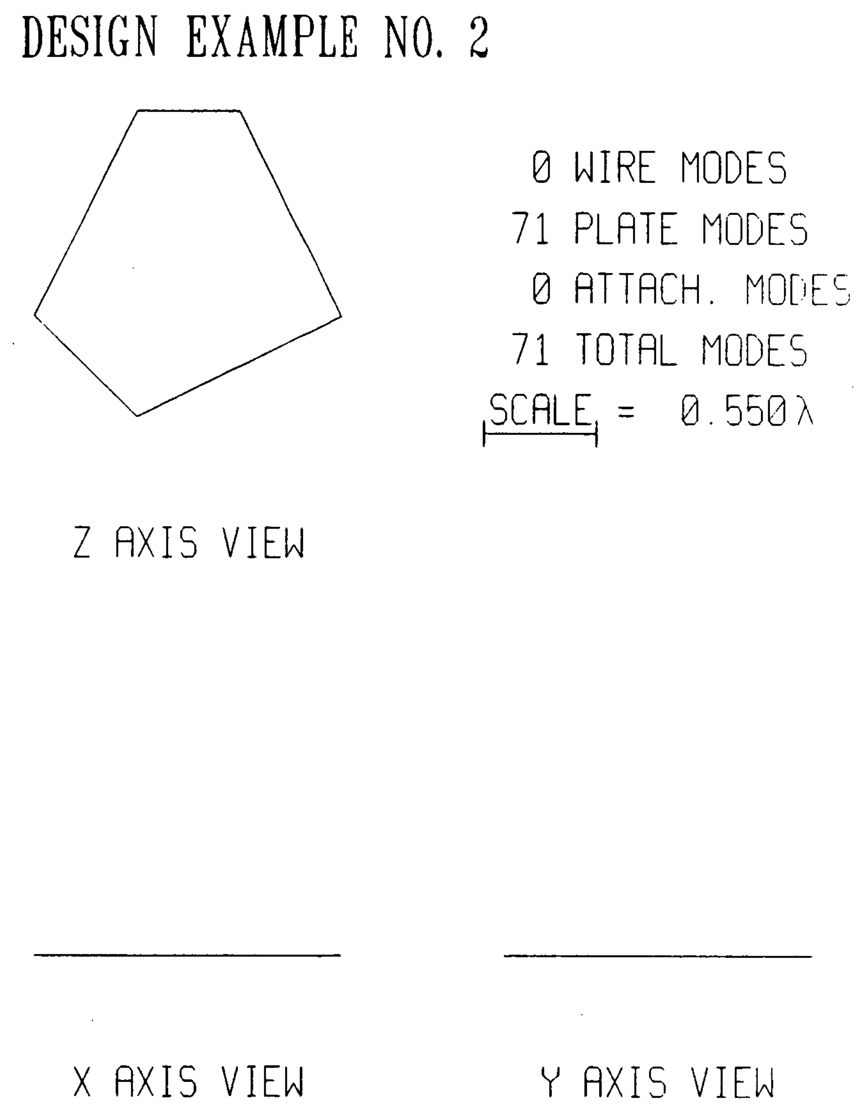


Figure 3.17: A three view sketch of the geometry for Example 2.

STPM = cross section for θ incident and ϕ scattered

SPTM = cross section for ϕ incident and θ scattered

These four patterns are plotted in Figure 3.18 through 3.21. For backscatter patterns STPM should be identical to SPTM. However, due to numerical errors there is always some difference in the computed patterns. However, if STPM is not reasonably close to SPTM (for backscatter) a severe problem is indicated. Again we note that Section 4.2 describes the data necessary to obtain these pattern plots.

3.4.3 Example 3

Example 3 involves the computation of the bistatic cross section of the same plate studied in Example 2 and at the same frequency of 300 MHz. The incident wave will be broadside to the plate, i.e., from $\theta = \phi = 0°$. The bistatic pattern will be in the plane $\phi = 0°$. The input file for this example is shown in Figure 3.22. The bistatic elevation plane pattern is specified in READ 4 by setting ISE = 2 (to obtain a bistatic pattern), PHSE = 0.0 (to obtain a pattern in the plane $\phi = 0.0°$) and THIN = PHIN = 0.0° to obtain the incident wave from $\theta = \phi = 0.0°$. The impedance matrix for this problem is identical to that previously generated and stored in disk file ZMAT.DAT in Example 2 (by setting IWRZM = 1 in READ 10 of Example 2). Thus, we now set IRDZM = 3 in READ 10. The result will be that the impedance matrix will be read from the disk file ZMAT.DAT and used for this bistatic calculation. No elements of the impedance matrix need be recomputed.

The output for this problem is in Appendix C. This output is identical to that of Example 2, except that the far-zone pattern is a bistatic scattering pattern in the plane $\phi = 0°$. These patterns are plotted in Figure 3.23 through 3.26. Note that STPM is not equal to SPTM, since this is a bistatic calculation. The CPU run time is shown as 303 seconds, as opposed to Example 2 which required 1538 seconds. The main reason for the savings in CPU time is that Example 3 did not compute the impedance matrix, but rather used the impedance matrix computed in Example 2.

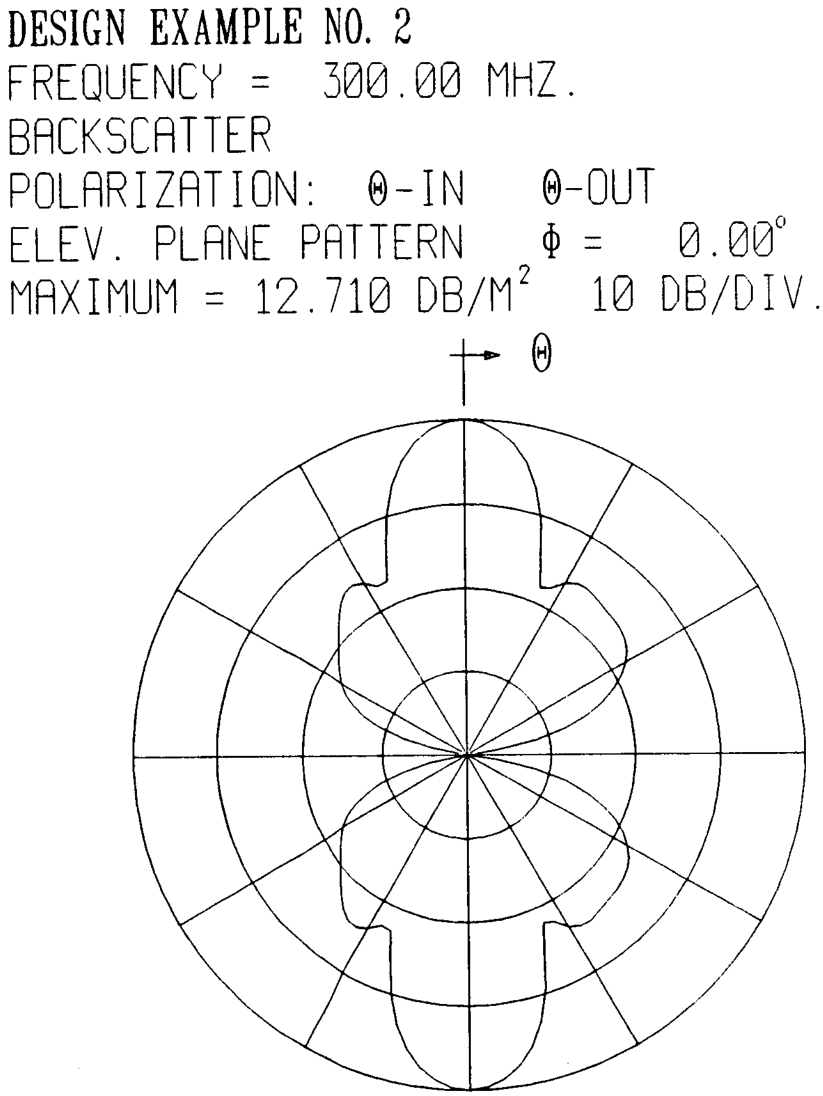


Figure 3.18: Backscatter pattern for Example 2 in the elevation plane $\phi = 0°$ and for polarization θ incident and θ scattered.

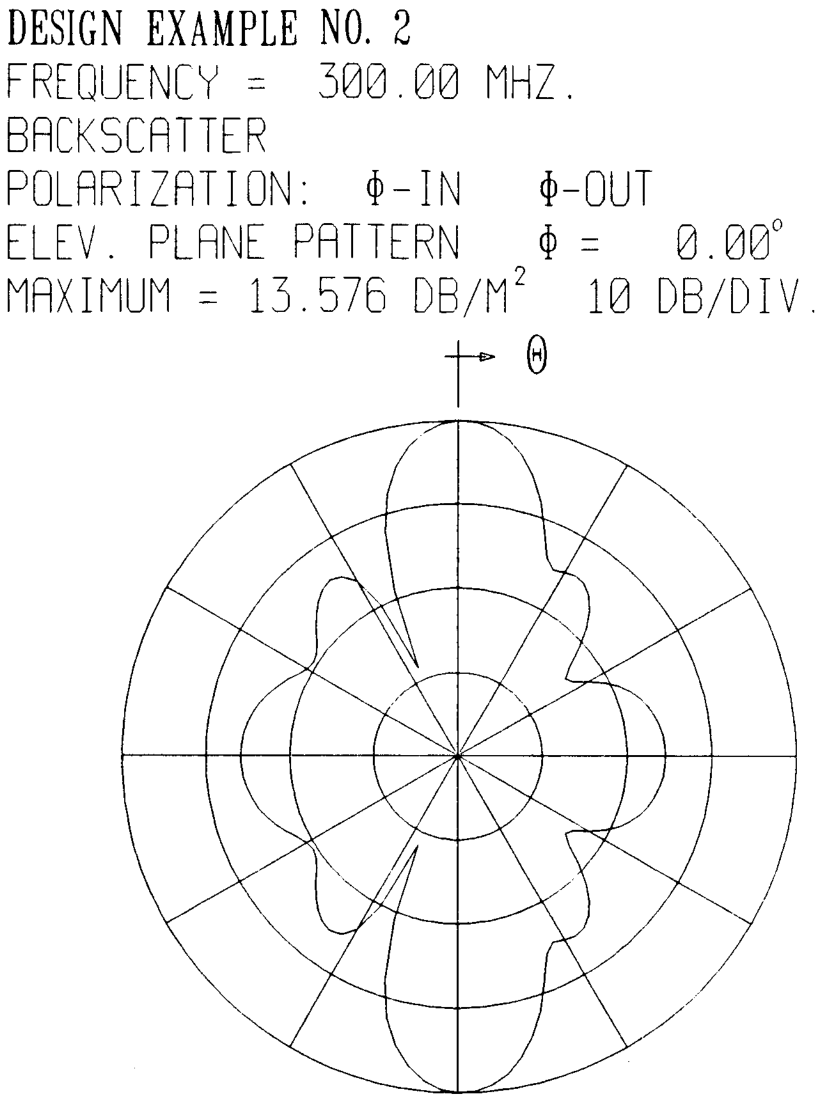


Figure 3.19: Backscatter pattern for Example 2 in the elevation plane $\phi = 0°$ and for polarization ϕ incident and ϕ scattered.

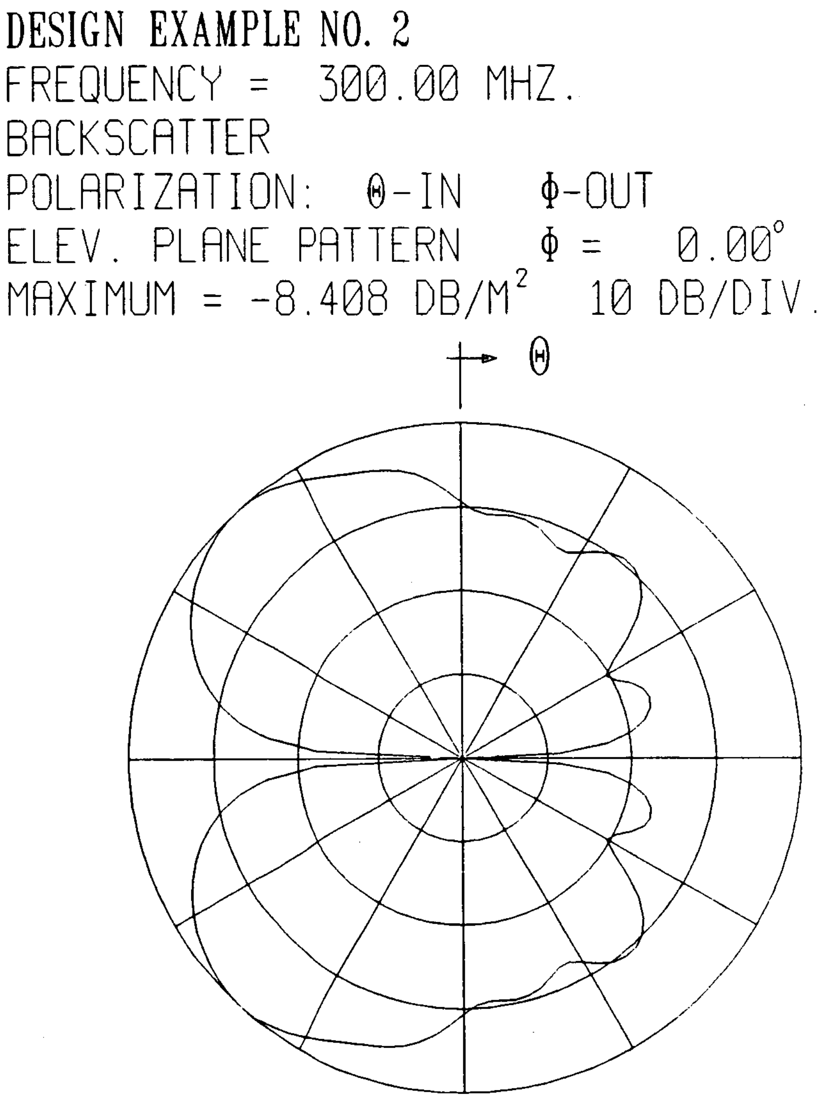


Figure 3.20: Backscatter pattern for Example 2 in the elevation plane $\phi = 0°$ and for polarization θ incident and ϕ scattered.

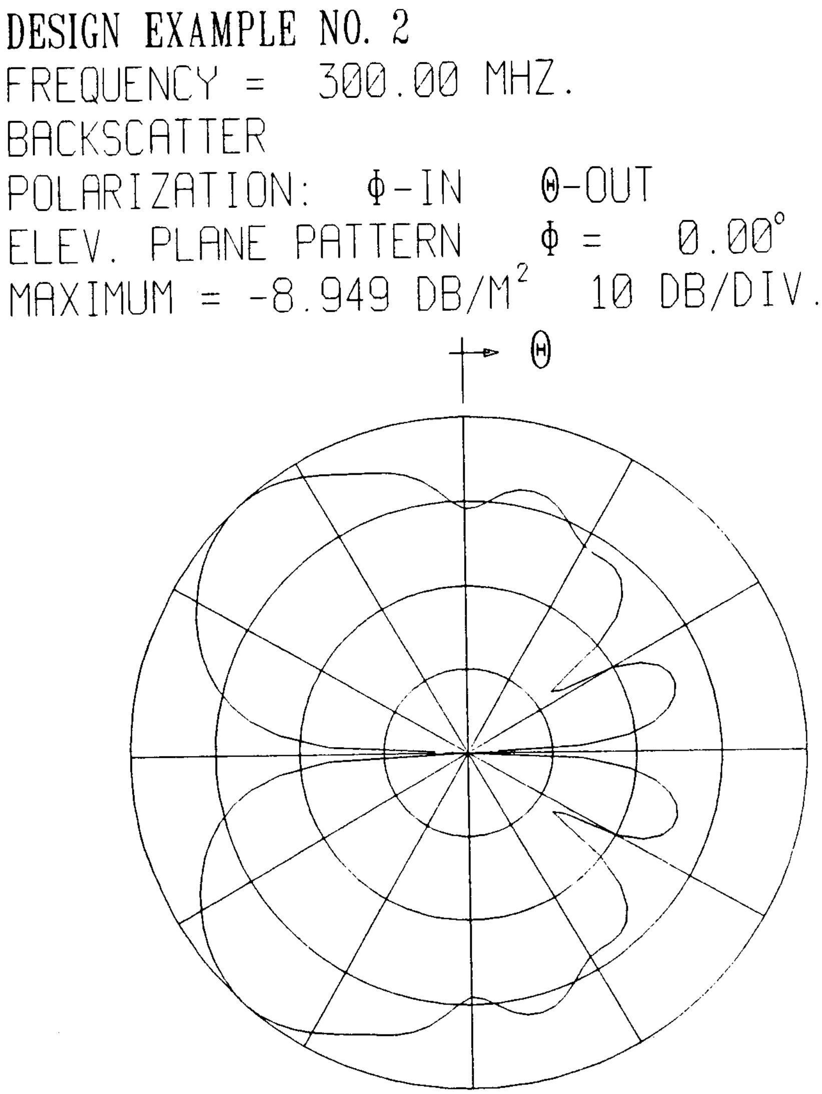


Figure 3.21: Backscatter pattern for Example 2 in the elevation plane $\phi = 0°$ and for polarization ϕ incident and θ scattered.

```
READ 1:    1  2  1  1  0  0  4  6  18  0  1  1
READ 2:    0  1  3  0.0
READ 3:    0  1  3  90.0
READ 4:    2  1  3  0.0  0.0  0.0
READ 5:    0  1  3  45.0
READ 6:    300.0  -1.0  0.001
READ 7:    1
READ 8:    5  0.25  0  3  0
READ 9:    1.0  0.0  0.0
           0.0  0.5  0.0
           0.0  1.0  0.0
           1.0  1.5  0.0
           1.5  0.5  0.0
READ 10:   0  3
```

Figure 3.22: The input file for Example 3.

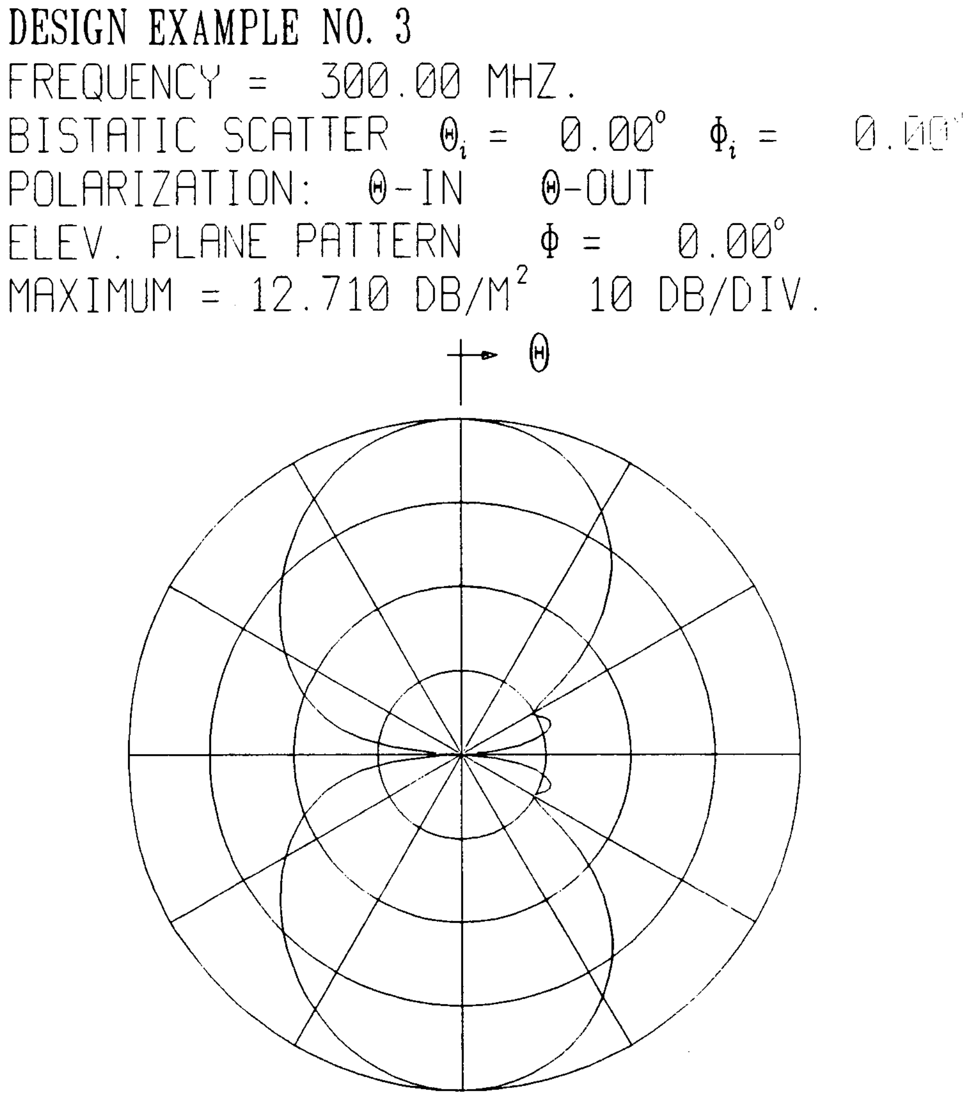


Figure 3.23: Bistatic pattern for Example 3 in the elevation plane $\phi = 0°$ and for polarization θ incident and θ scattered.

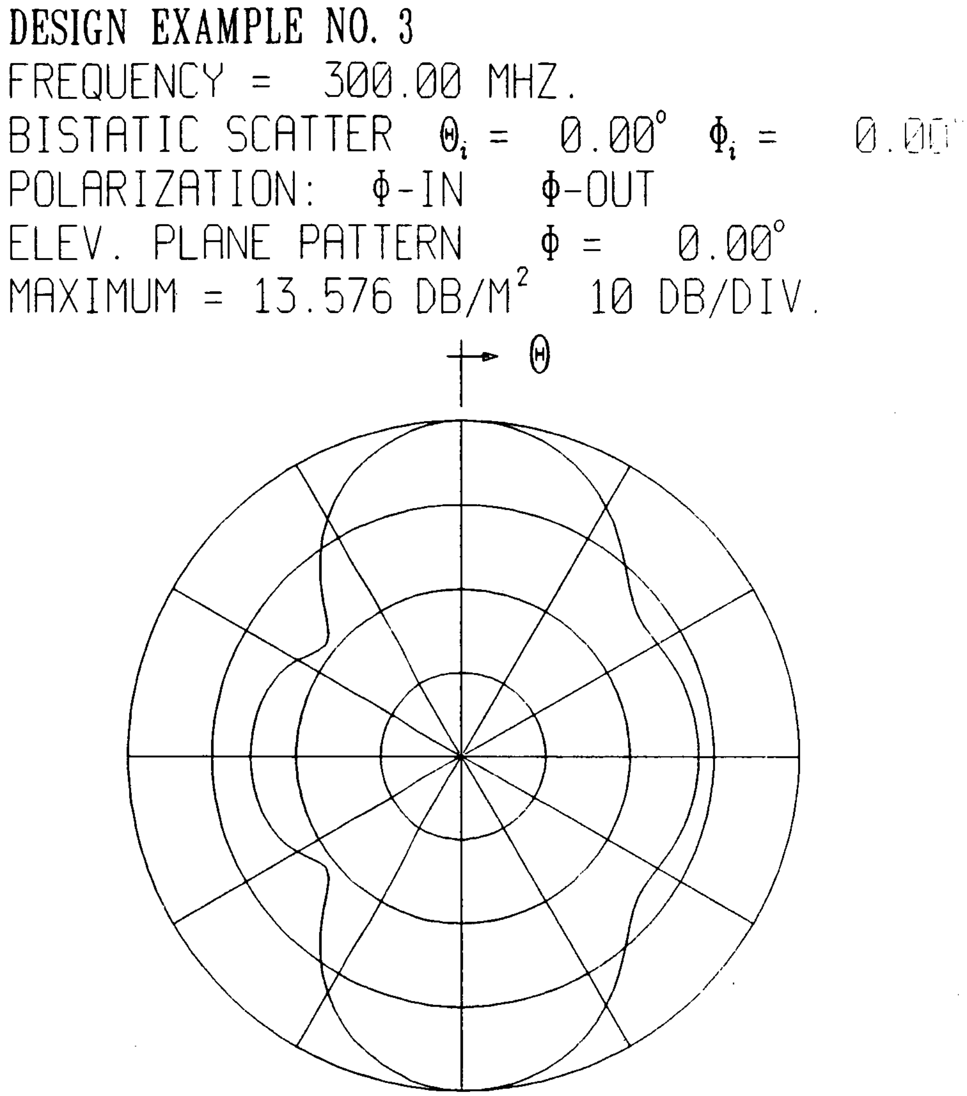


Figure 3.24: Bistatic pattern for Example 3 in the elevation plane $\phi = 0°$ and for polarization ϕ incident and ϕ scattered.

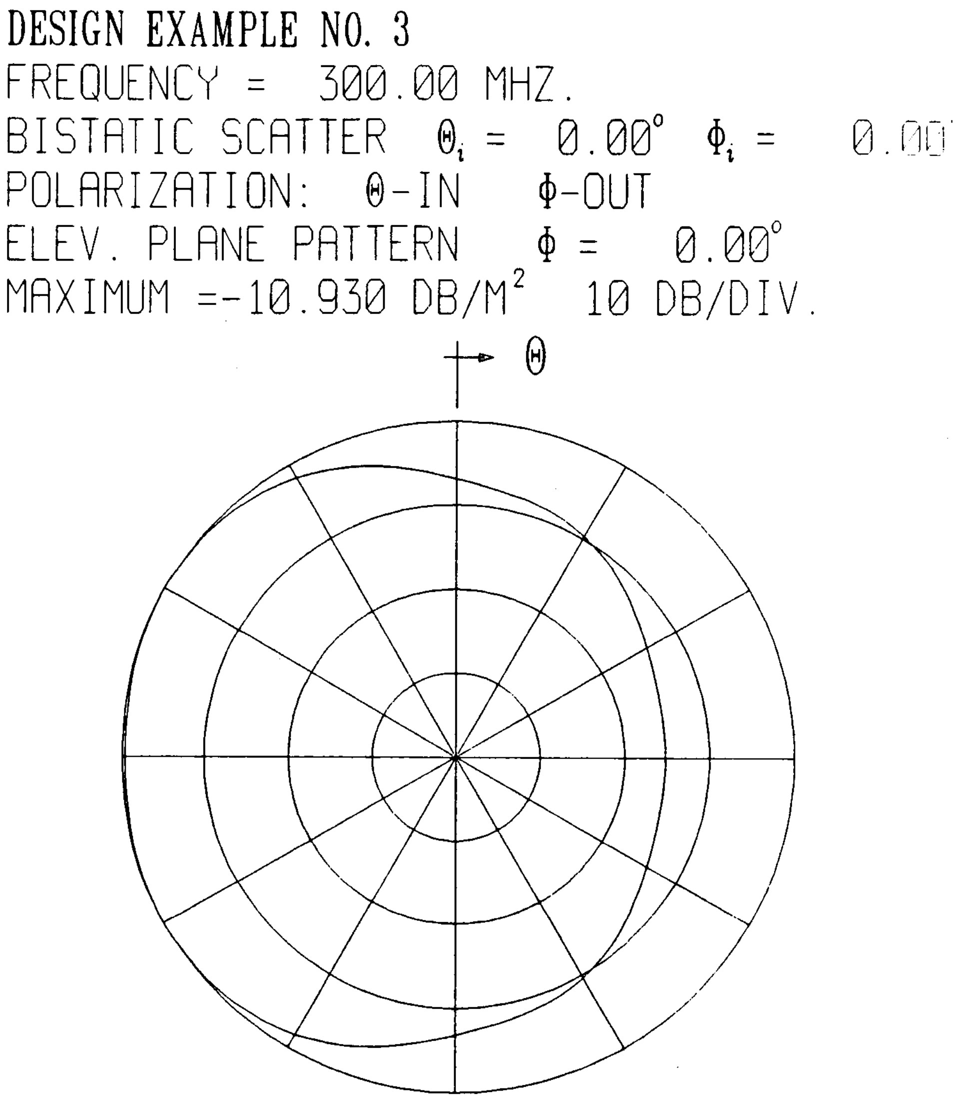


Figure 3.25: Bistatic pattern for Example 3 in the elevation plane $\phi = 0°$ and for polarization θ incident and ϕ scattered.

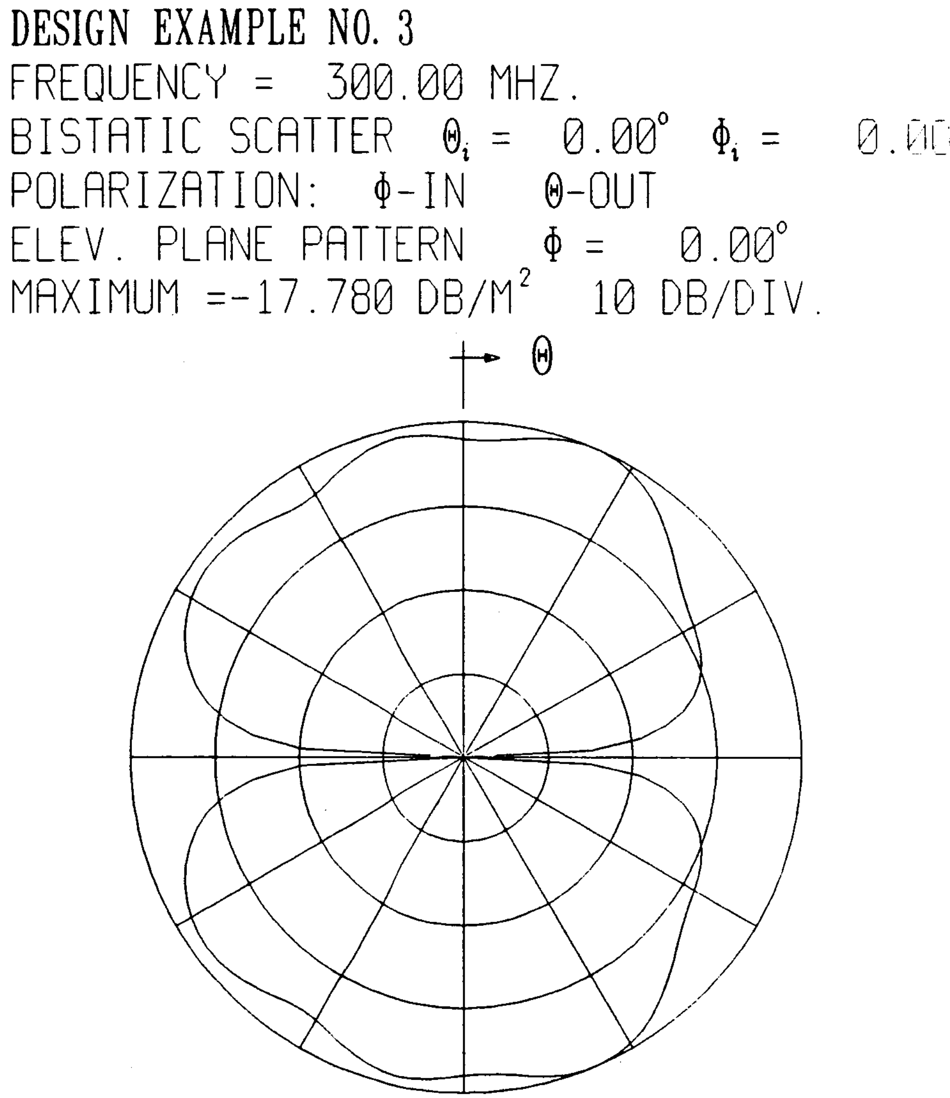


Figure 3.26: Bistatic pattern for Example 3 in the elevation plane $\phi = 0°$ and for polarization ϕ incident and θ scattered.

3.4.4 Example 4

Example 4 involves the computation of the backscatter from the two intersecting plates shown in Figure 3.27. The pattern is to be a backscatter pattern in the plane $\theta = 45°$ and at 300 MHz. Plate 1 is a triangular plate in the yz plane. This creates a problem since the code cannot treat three sided plates. In this case the problem is solved by adding a corner in the center of the hypotenuse. Thus, the triangular plate is represented as a four sided plate which happens to have two sides which intersect at a 180° angle. Plate 2 is a quadrilateral plate in the xy plane. Plates 1 and 2 intersect along the y axis. The (x,y,z) coordinates in meters of the endpoints of plates 1 and 2 are shown in Figure 3.27.

The input file for Example 4 is shown in Figure 3.28. The backscatter azimuth pattern in the plane $\theta = 45°$ is specified in READ 5. Plate 1 is specified by the top READS 8 and 9, and Plate 2 by the bottom READS 8 and 9. Figures 3.29-3.31 show the detailed surface patch model layout on the two plates. Figure 3.29 shows Plate 1 segmented into 4 modes, and 3.30 shows Plate 2 segmented into 17 modes. The code recognizes that side 1 of Plate 1 contacts side 4 of Plate 2, and Figure 3.31 shows three overlap modes which connect Plates 1 and 2 by enforcing continuity of the normal component of current at the plate/plate junction. Note that when we show the overlap modes on intersecting plates we unfold the plates (using the intersecting edge as a hinge) until the two plates are planar. A three view sketch of the geometry is shown in Figure 3.32.

The output for Example 4 is shown in Appendix D. After listing the geometries of Plates 1 and 2, the code outputs a message indicating that three overlap modes are used to connect Plates 1 and 2. This message assures the user that the code did recognize that Plates 1 and 2 are touching. Note that the code can only treat plates which intersect along edges (see Example 5 for the treatment of plates which intersect, but not along edges). The backscatter pattern in the azimuth plane $\theta = 45°$ is shown in Appendix D, and is plotted in Figure 3.33-3.36

3.4.5 Example 5

Example 5 involves the analysis of the two intersecting plates shown in Figure 3.37(a) at 300 MHz. The problem is to compute the foward scattering

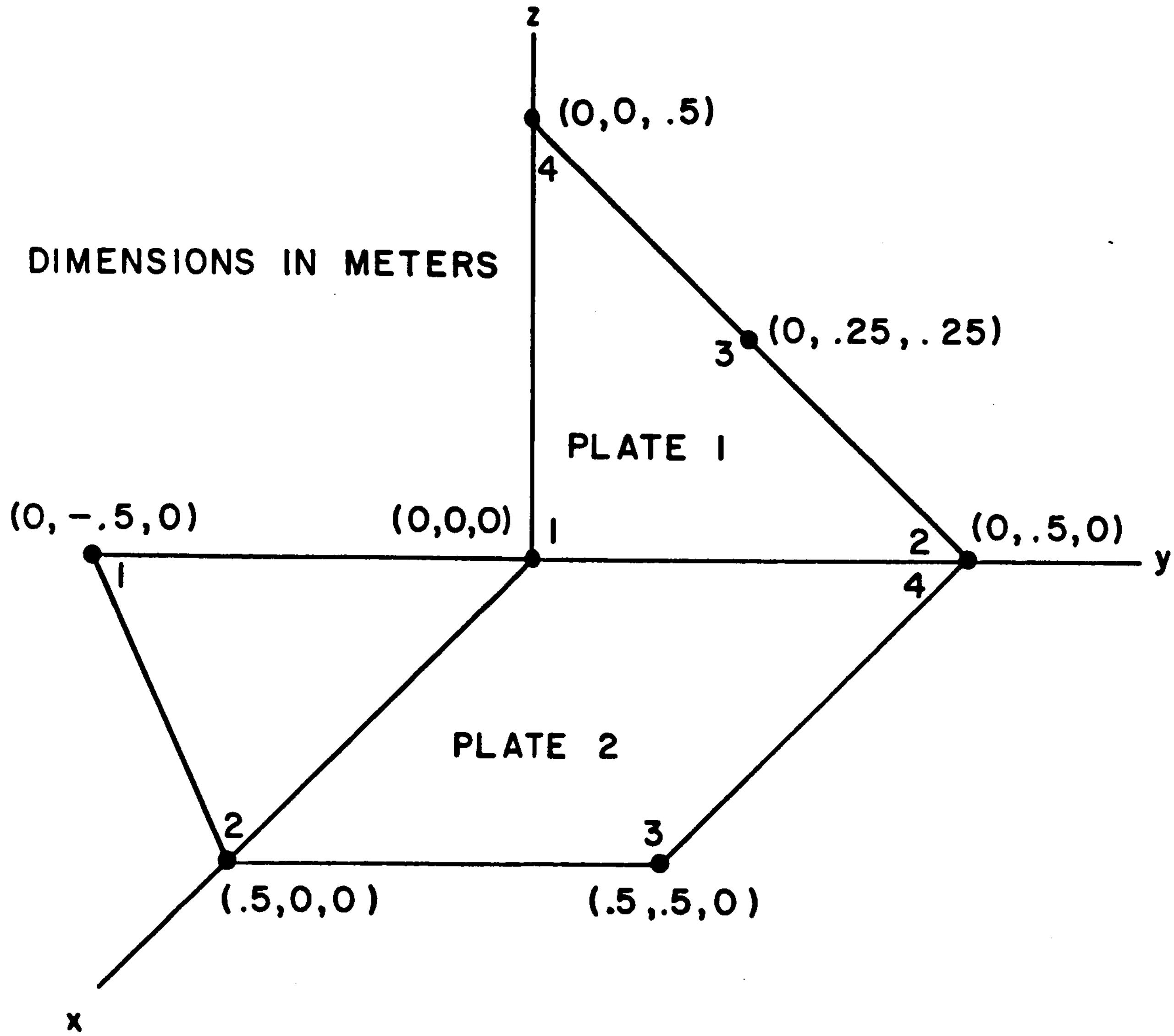


Figure 3.27: The geometry for Example 4 is the intersection of a triangular plate and a quadrilateral plate.

```
READ 1:    1  2  1  1  0  0  4  6  18  0  1  1
READ 2:    0  1  3  0.0
READ 3:    0  1  3  90.0
READ 4:    0  1  5  0.0  90.0  90.0
READ 5:    1  1  3  45.0
READ 6:    300.0  -1.0  0.001
READ 7:    2
READ 8:    4  0.25  0  3  0
READ 9:    0.0  0.0  0.0
           0.0  0.5  0.0
           0.0  0.25  0.25
           0.0  0.0  0.5
READ 8:    4  0.25  0  3  0
READ 9:    0.0  -0.5  0.0
           0.5  0.0  0.0
           0.5  0.5  0.0
           0.0  0.5  0.0
READ 10:   0  0
```

Figure 3.28: The input file for Example 4.

DESIGN EXAMPLE NO. 4

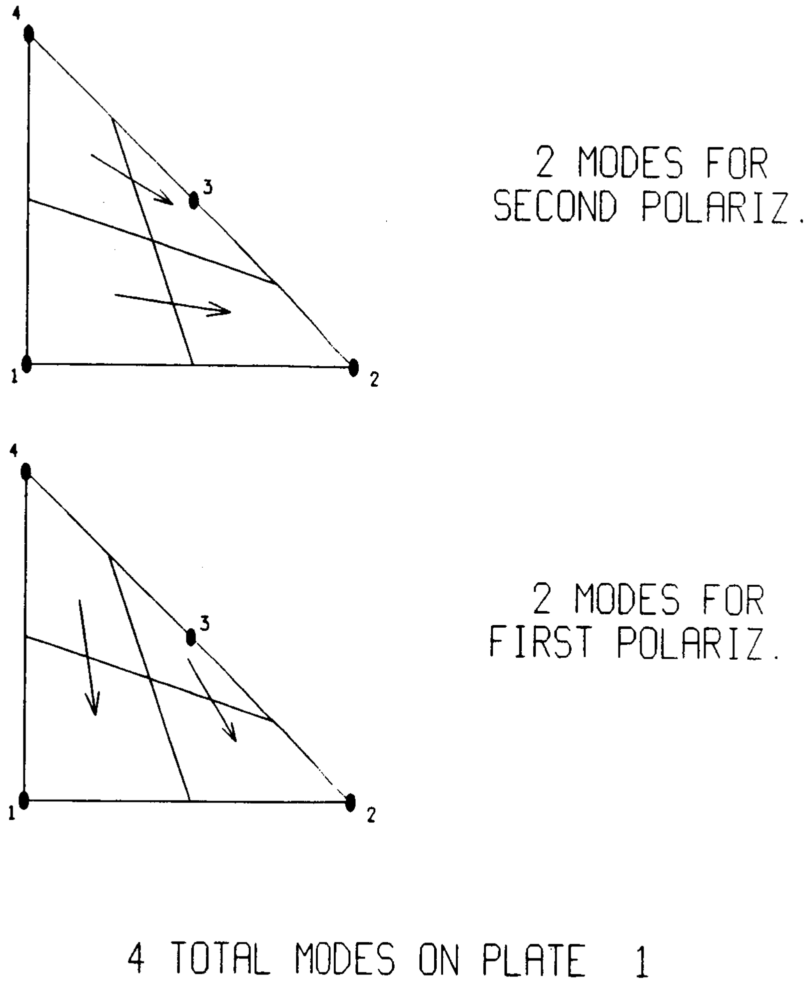


Figure 3.29: The detailed surface patch modal layout for Plate 1 of Example 4.

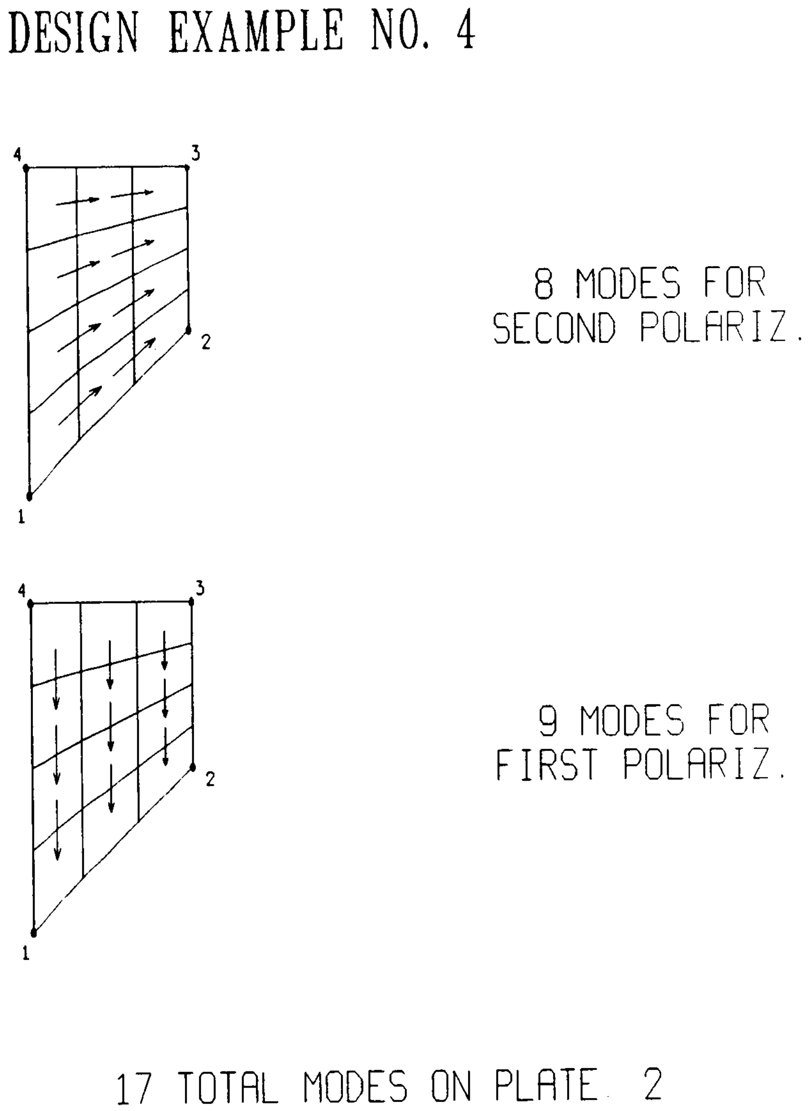


Figure 3.30: The detailed surface patch modal layout for Plate 2 of Example 4.

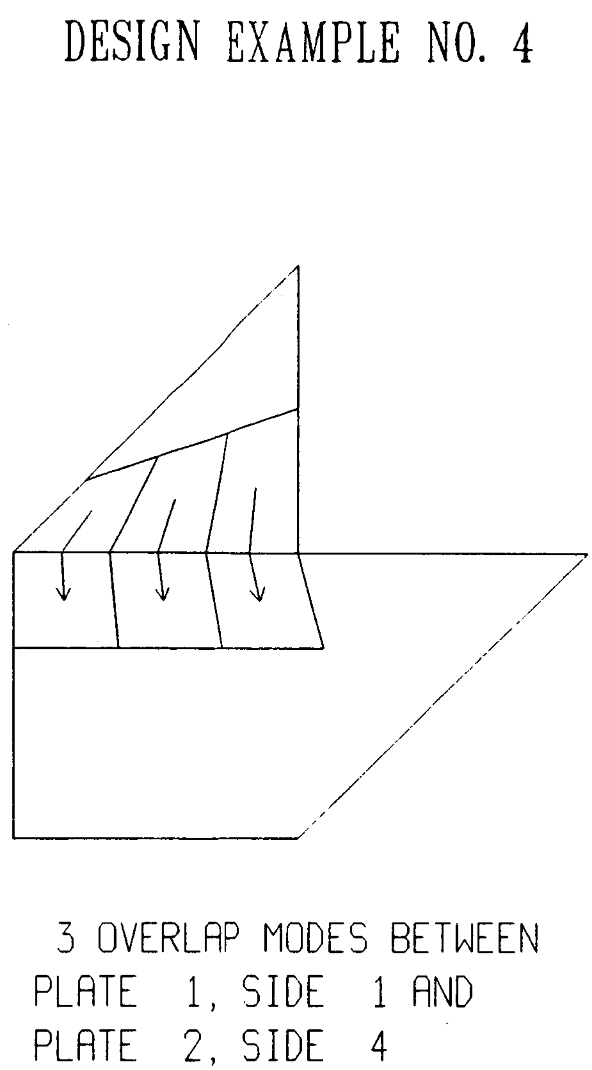


Figure 3.31: The detailed surface patch modal layout for the overlap modes connecting Plates 1 and 2 in Example 4.

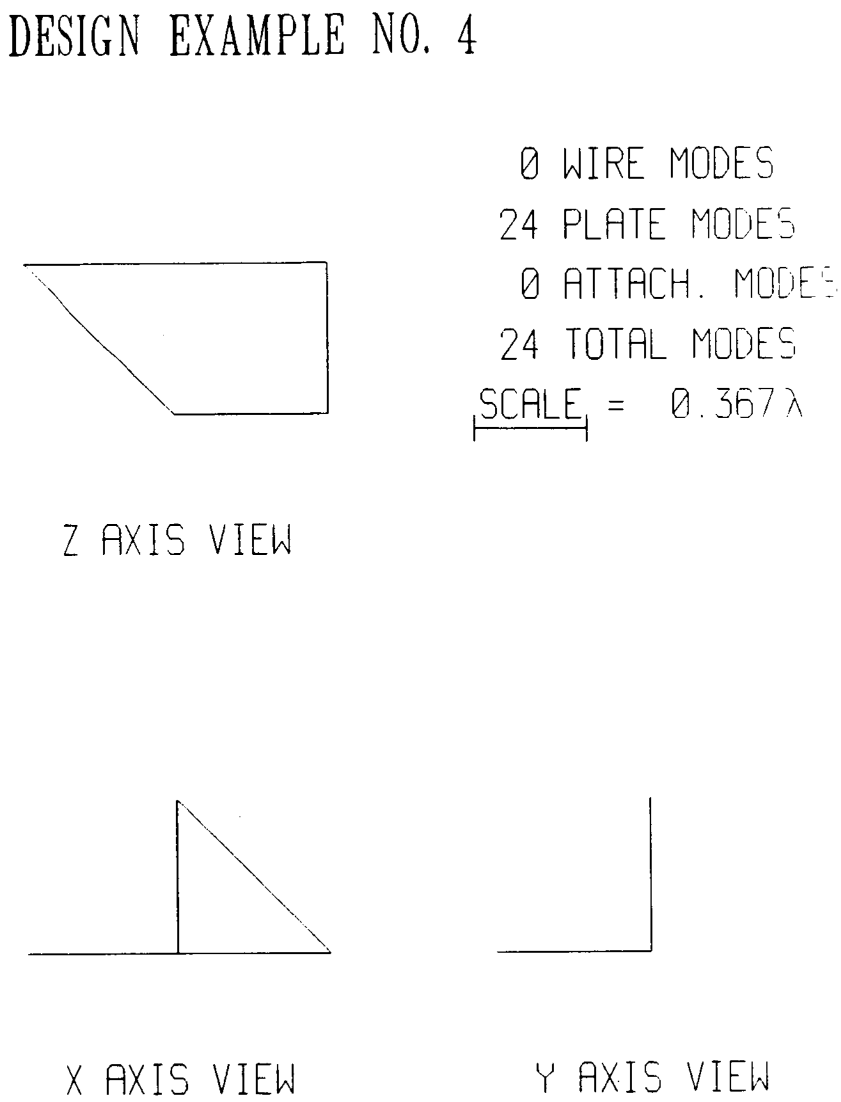


Figure 3.32: A three view plot of the geometry of Example 4

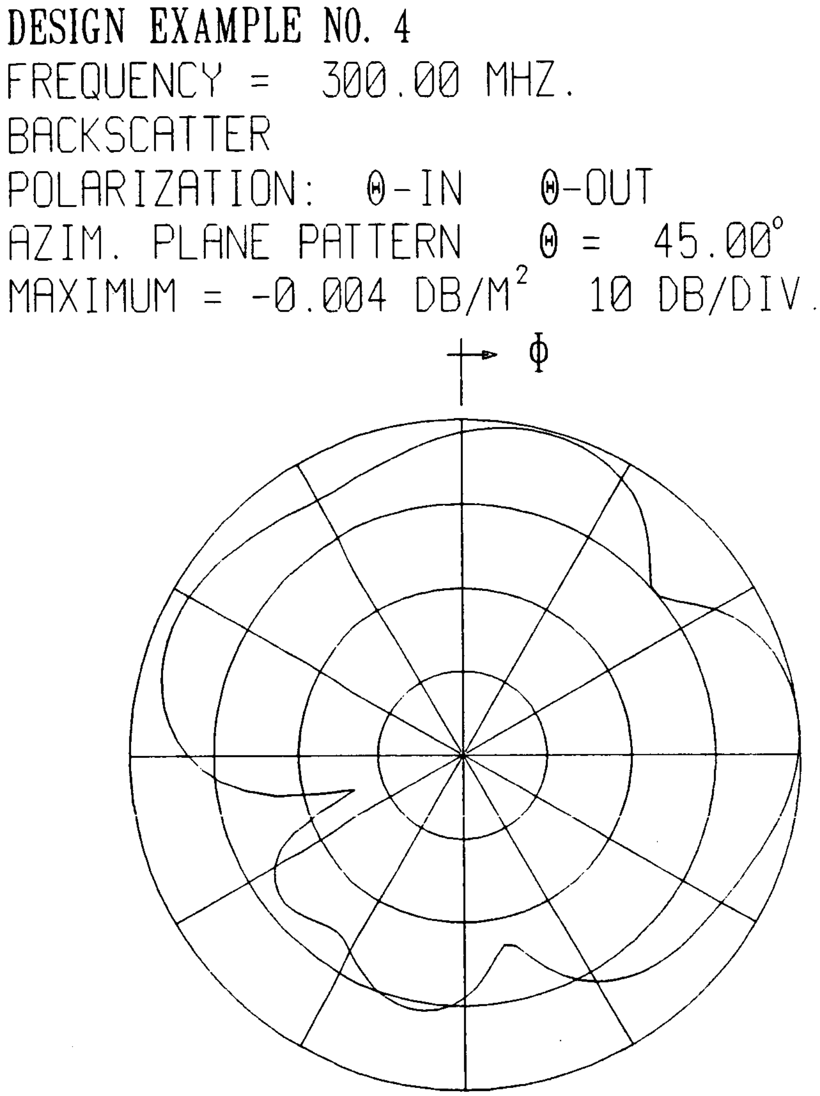


Figure 3.33: Backscatter pattern for Example 4 in the azimuth plane $\theta = 45°$ and for polarization θ incident and θ scattered.

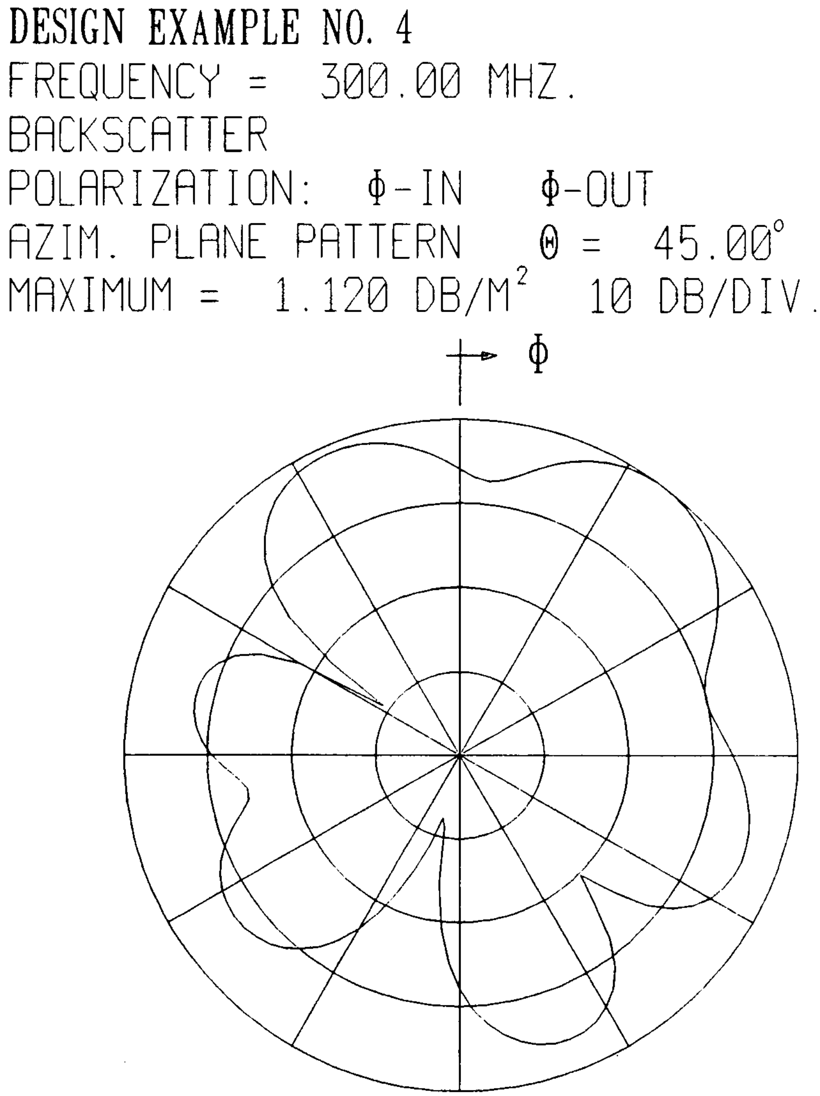


Figure 3.34: Backscatter pattern for Example 4 in the azimuth plane $\theta = 45°$ and for polarization ϕ incident and ϕ scattered.

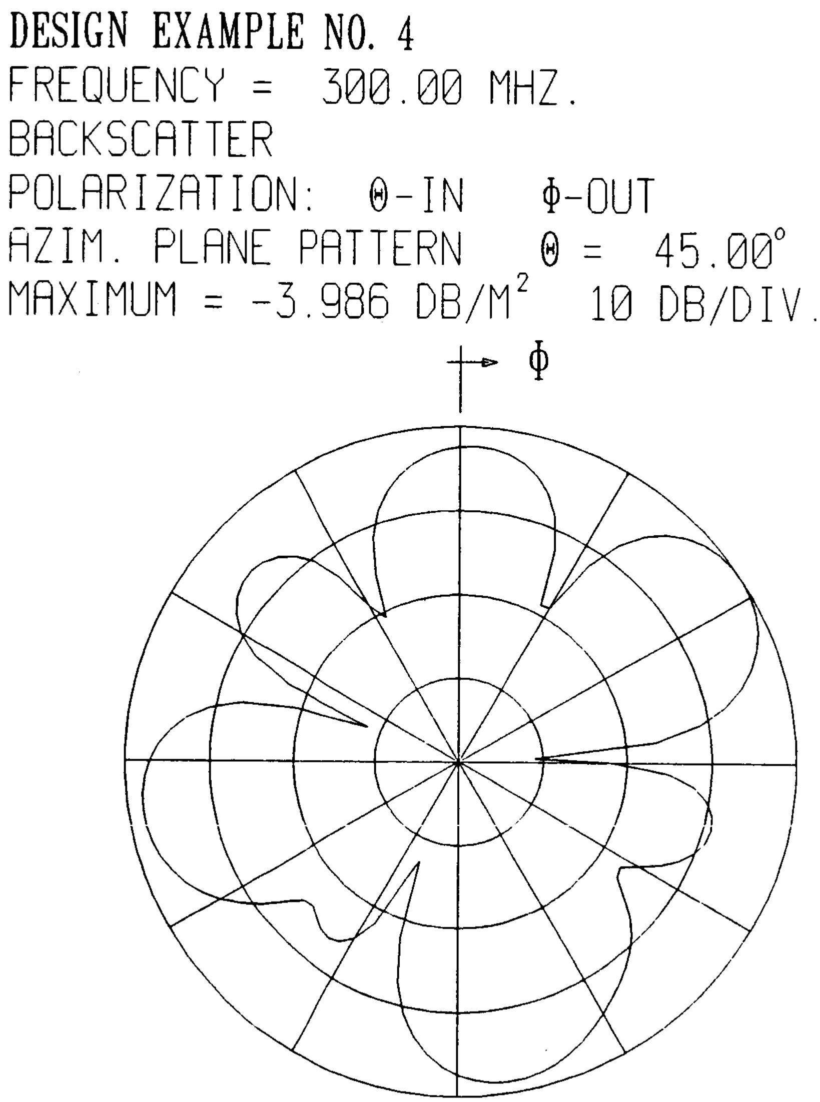


Figure 3.35: Backscatter pattern for Example 4 in the azimuth plane $\theta = 45°$ and for polarization θ incident and ϕ scattered.

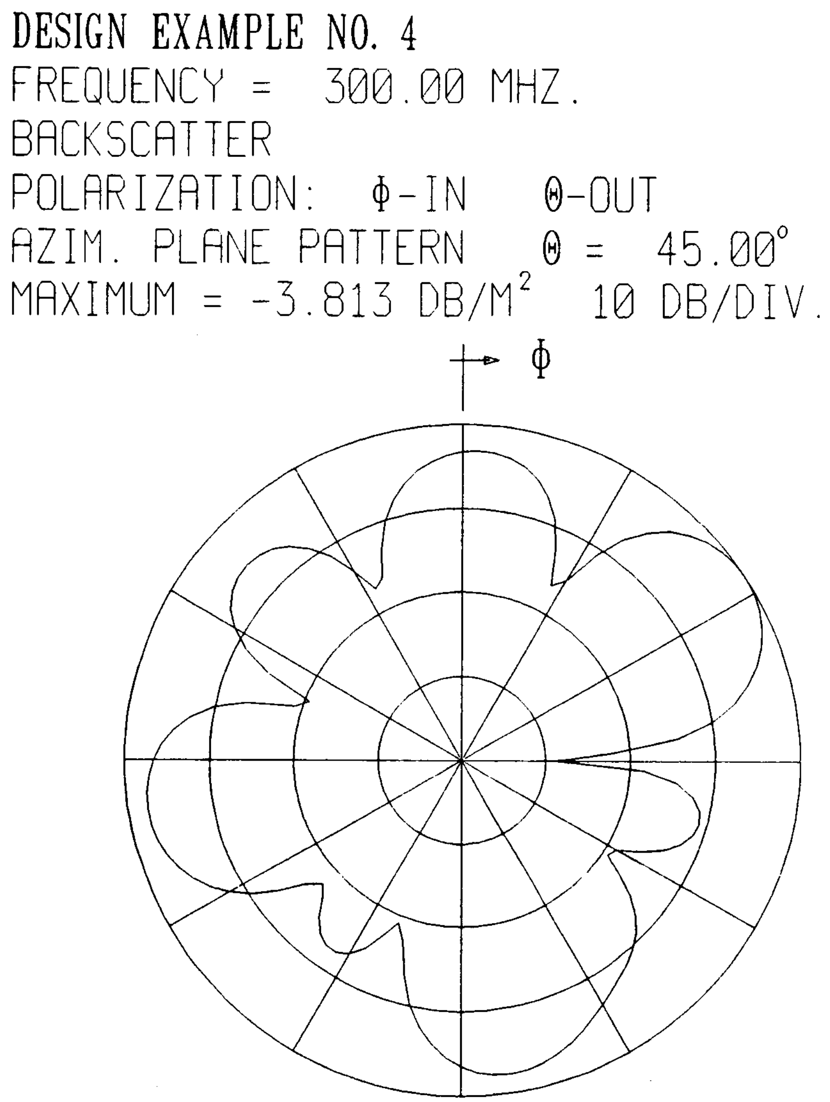


Figure 3.36: Backscatter pattern for Example 4 in the azimuth plane $\theta = 45°$ and for polarization ϕ incident and θ scattered.

pattern in the azimuth plane at $\theta = 90°$. Note the edge of Plate A, which is along the z axis, contacts the surface of Plate B, which is in the xz plane. The code cannot directly treat this type of plate/plate junction. In this code, plates must intersect along edges only. The code can treat several plates which intersect along a common edge. Thus, to treat the geometry of Figure 3.37(a), we must split Plate B into two plates, so as to create an edge along the z-axis. Figure 3.37(b) shows the geometry of Figure 3.37(a) represented by three plates which intersect and have a common edge along the z-axis.

In analyzing the three plates of Figure 3.37(b), one can use the IPN array of READ 8 to reduce the number of required surface patch modes. IPN(I) controls which polarization of current modes will be placed on Plate I. Consider Plate 1. It is of electrical length 0.5 λ (in the 1 to 2 direction) and width 0.25 λ (in the 2 to 3 direction). Assume that a surface patch segment size of 0.25 λ is acceptable. Then Plate 1 would only need to be split into two segments along its length and one segment along its width. This would result in one $\hat{z}$ polarized mode on Plate 1. If Plate 1 were isolated (i.e., did not contact another plate), this segmentation would not be satisfactory. The reason is that there are no $\hat{x}$ polarized modes. In order to obtain $\hat{x}$ polarized modes on an isolated Plate 1, there must be at least two segments in the 2 to 3 direction. If Plate 1 were segmented with two segments in the 1 to 2 direction and two segments in the 2 to 3 direction, this would result in 2 $\hat{z}$ polarized modes and 2 $\hat{x}$ polarized modes, for a total of four modes on Plate 1. The use of the IPN array to reduce the number of modes is possible here since two conditions are met. The first condition is that only one segment is required across the width of Plate 1, i.e., the width of Plate 1 is less than or equal to SEGM(1)*λ (see READ 8). That is the width of Plate 1 is less than or equal to the maximum allowable segment size. The second condition is that Plate 1 intersects another plate (i.e., Plates 2 or 3) along its entire length. Since these two conditions are met for Plate 1 it is permissable to set IPN(1) = 1. As mentioned above, the Plate 1 modes will be $\hat{z}$ polarized only. However, the overlap modes, which connect Plate 1 to Plates 2 or 3 will properly account for the $\hat{x}$ polarized currents on Plate 1. Note that it is never wrong to set IPN(I) = 3. When appropriate, setting IPN(I) = 1 or 2 can simply reduce the number of required modes.

The input file for Example 5 is shown in Figure 3.38. Note that ISA in

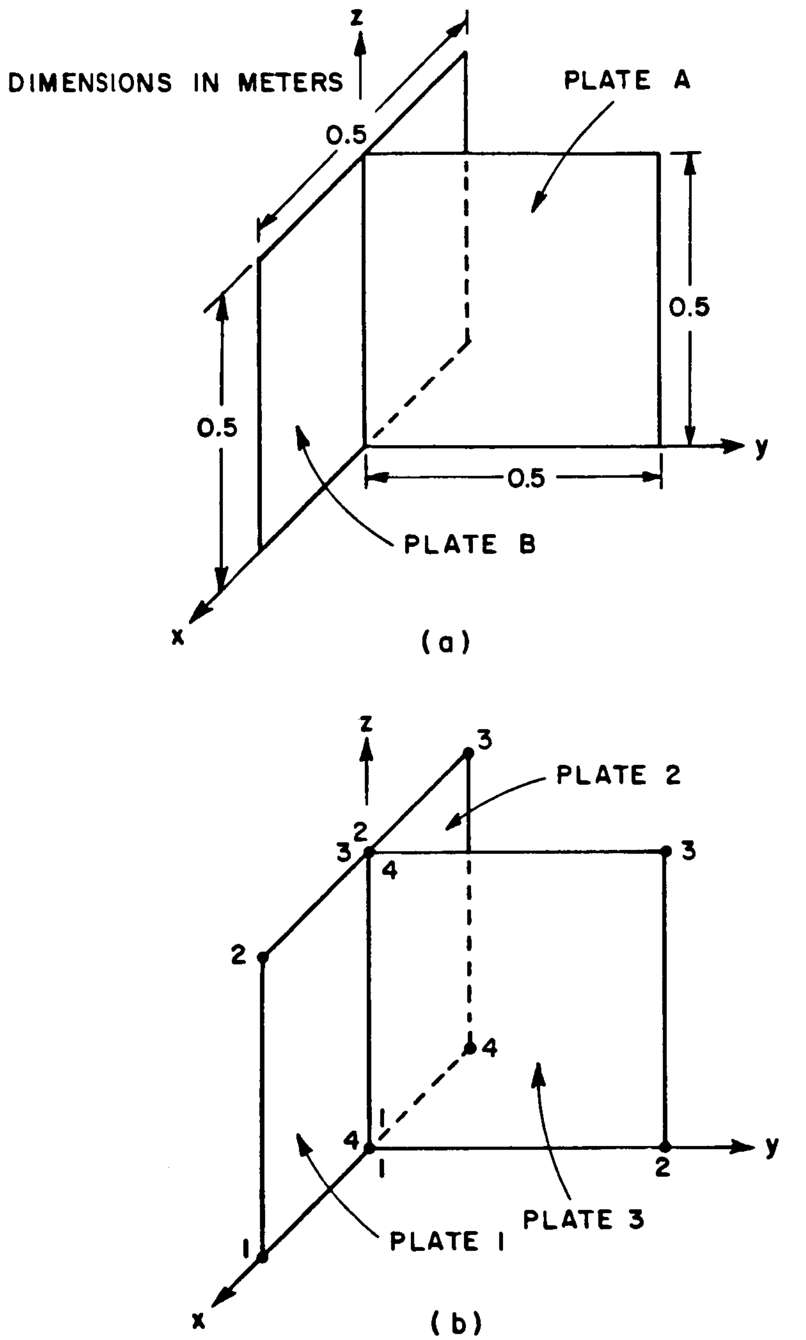


Figure 3.37: (a) The geometry for Example 5 involves Plate A intersecting the surface or face of Plate B. (b) The intersection of Plates A and B in (a) modeled by the intersection of Plates 1, 2 and 3 which intersect along a common edge (the z axis).

READ 5 is set to 3 to obtain a foward scattering pattern in the azimuth plane. Also, IPN(1) and IPN(2) are both set to 1, while IPN(3) = 3. The detailed modal layout on the three plates is shown in Figure 3.39 - 3.43. Note that Plates 1 and 2 only have one mode each in the 1 to 2 or $\hat{z}$ direction, while Plate 3 has modes with $\hat{y}$ and $\hat{z}$ polarizations. However, note also that $\hat{x}$ polarized overlap modes are properly placed on Plate 1 and 2. A three view sketch of the three plate intersection is shown in Figure 3.44.

The output for Example 5 is shown in Appendix E. Following the output of the geometry of the three plates is a summary of the overlap modes. The messages printed indicate that:

1. The code recognized that Plate 1 contacted Plate 2, and that two overlap modes were used to connect the plates.

2. The code recognized that Plate 1 contacted Plate 3, and that two overlap modes were used to connect the plates.

3. The code recognized that Plate 2 contacted Plate 3, and that 0 overlap modes were used to connect the plates. The fact that 0 overlap modes were used in this case does not mean that Plates 2 and 3 are not connected. It simply means that overlap modes connecting Plates 2 and 3 would be linearly dependent with the overlap modes used to connect Plates 1 and 2, and Plates 1 and 3. Thus, no additional overlap modes are needed to connect Plates 2 and 3.

The forward scatter pattern is printed in Appendix E, and also plotted in Figure 3.45 - 3.46. The cross polarized patterns are not plotted, since they are zero. For foward scatter patterns, the (θ, ϕ) shown in the output file or in the pattern plots is the angle of the scattered wave.

C-2

```
READ 1:    1  2  1  1  0  0  4  6  18  0  1  1
READ 2:    0  1  3  0.0
READ 3:    0  1  3  90.0
READ 4:    0  1  5  0.0  90.0  90.0
READ 5:    3  1  5  90.0
READ 6:    300.0  -1.0  0.001
READ 7:    3
READ 8:    4  0.25  1  1  0
READ 9:    0.25  0.0  0.0
           0.25  0.0  0.5
           0.0  0.0  0.5
           0.0  0.0  0.0
READ 8:    4  0.25  1  1  0
READ 9:    0.0  0.0  0.0
           0.0  0.0  0.5
           -0.25  0.0  0.5
           -0.25  0.0  0.0
READ 8:    4  0.25  1  3  0
READ 9:    0.0  0.0  0.0
           0.0  0.0  0.5
           0.0  0.5  0.5
           0.0  0.5  0.0
READ 10:   0  0
```

Figure 3.38: The input for Example 5.

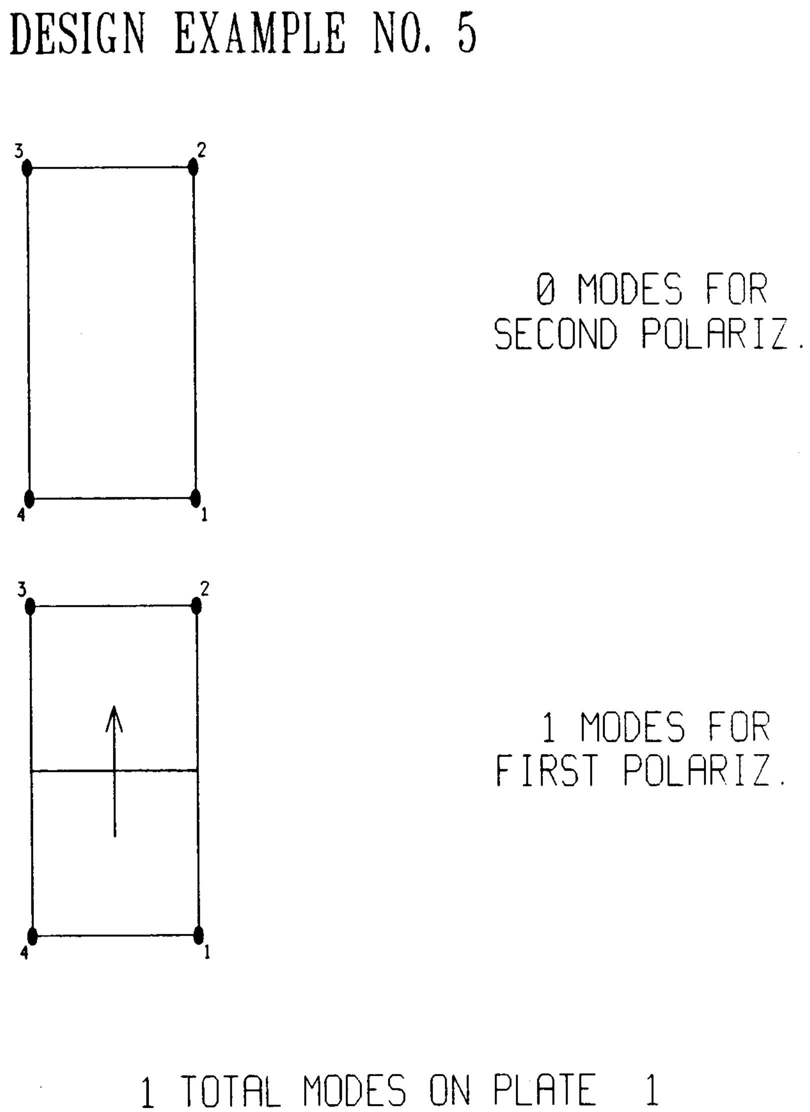


Figure 3.39: The detailed surface patch modal layout for Plate 1 of Example 5.

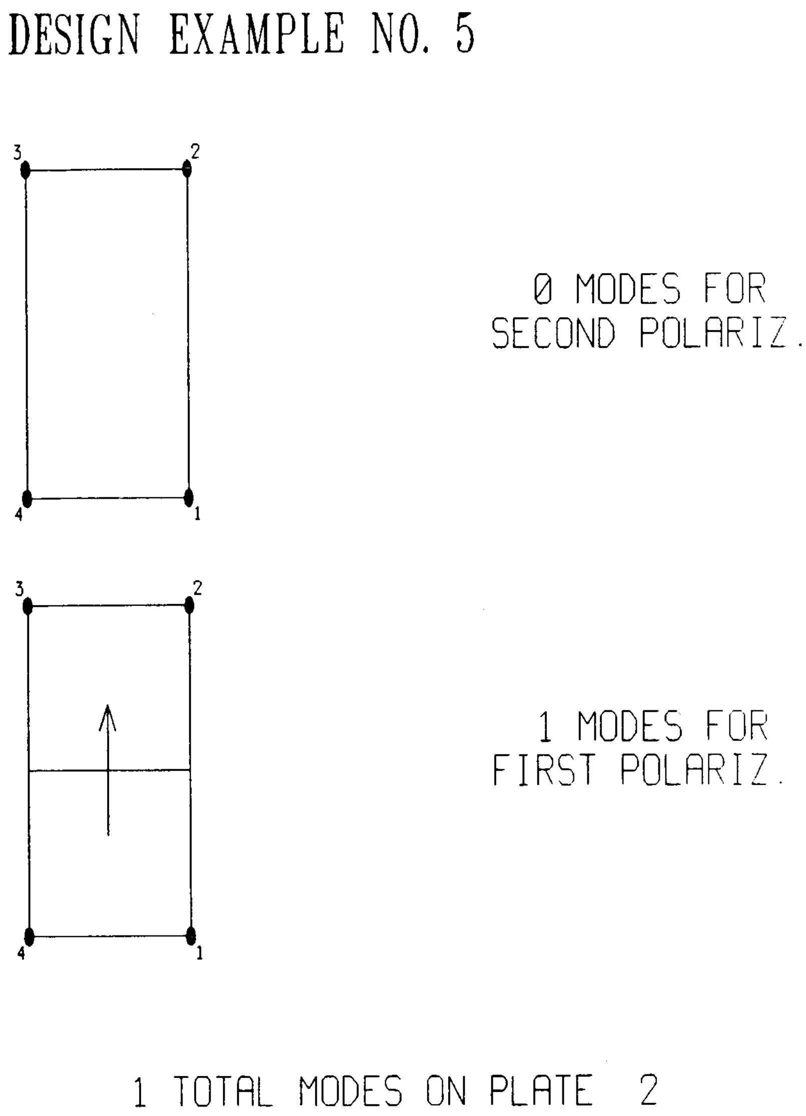


Figure 3.40: The detailed surface patch modal layout for Plate 2 of Example 5.

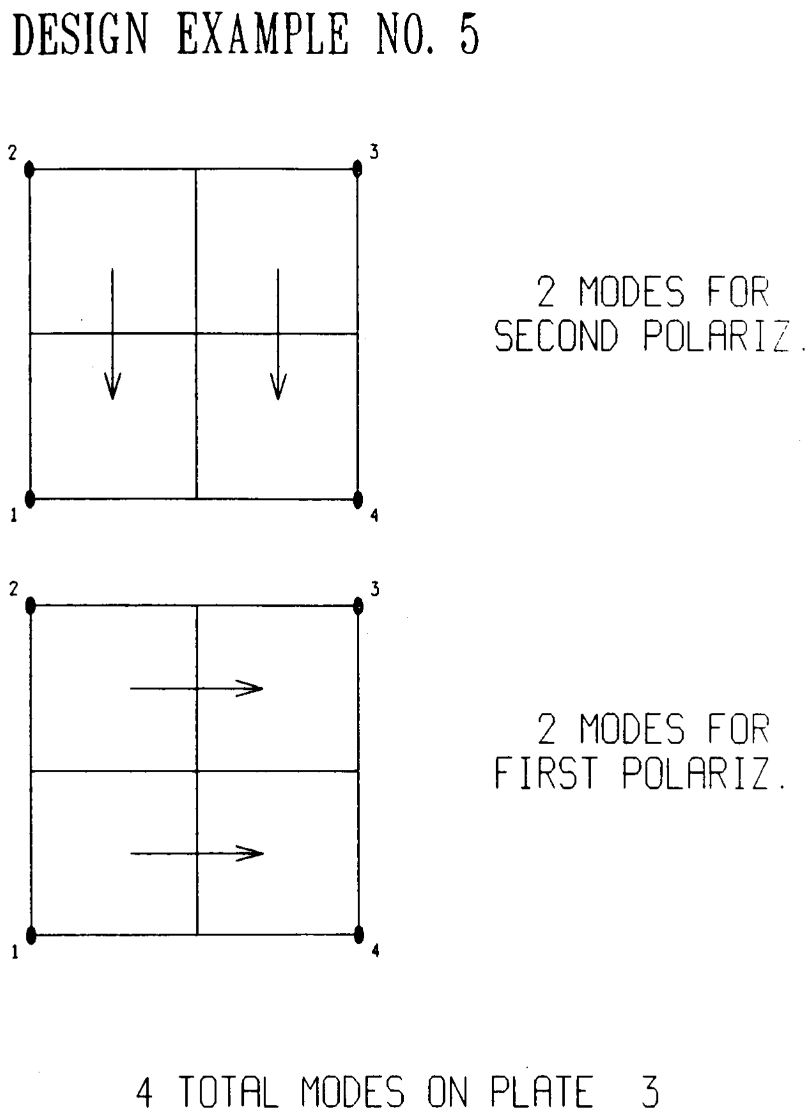


Figure 3.41: The detailed surface patch modal layout for Plate 3 of Example 5.

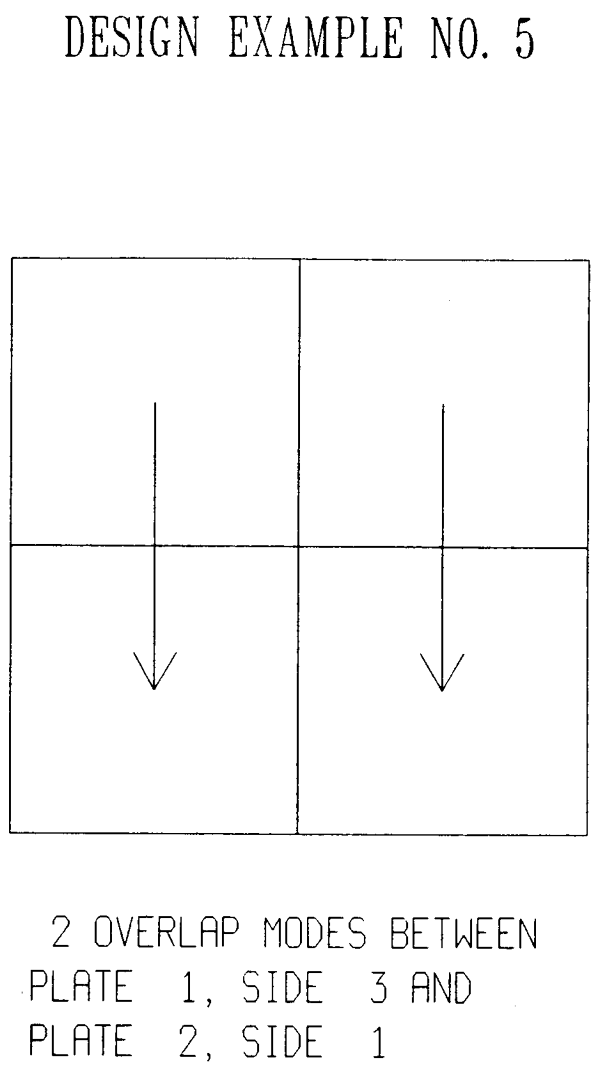


Figure 3.42: The detailed modal layout for the overlap modes connecting Plates 1 and 2 in Example 5.

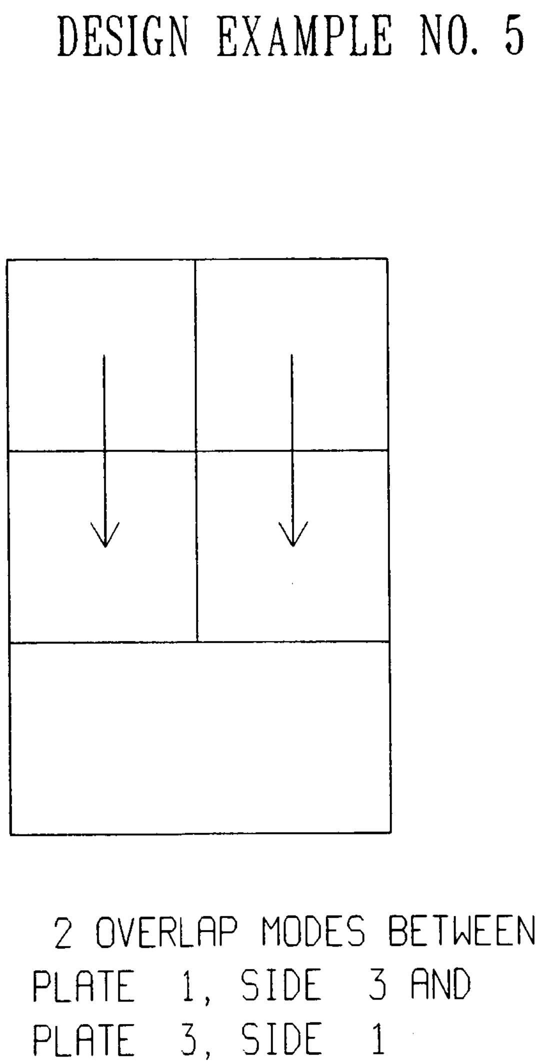


Figure 3.43: The detailed modal layout for the overlap modes connecting Plates 1 and 3 in Example 5.

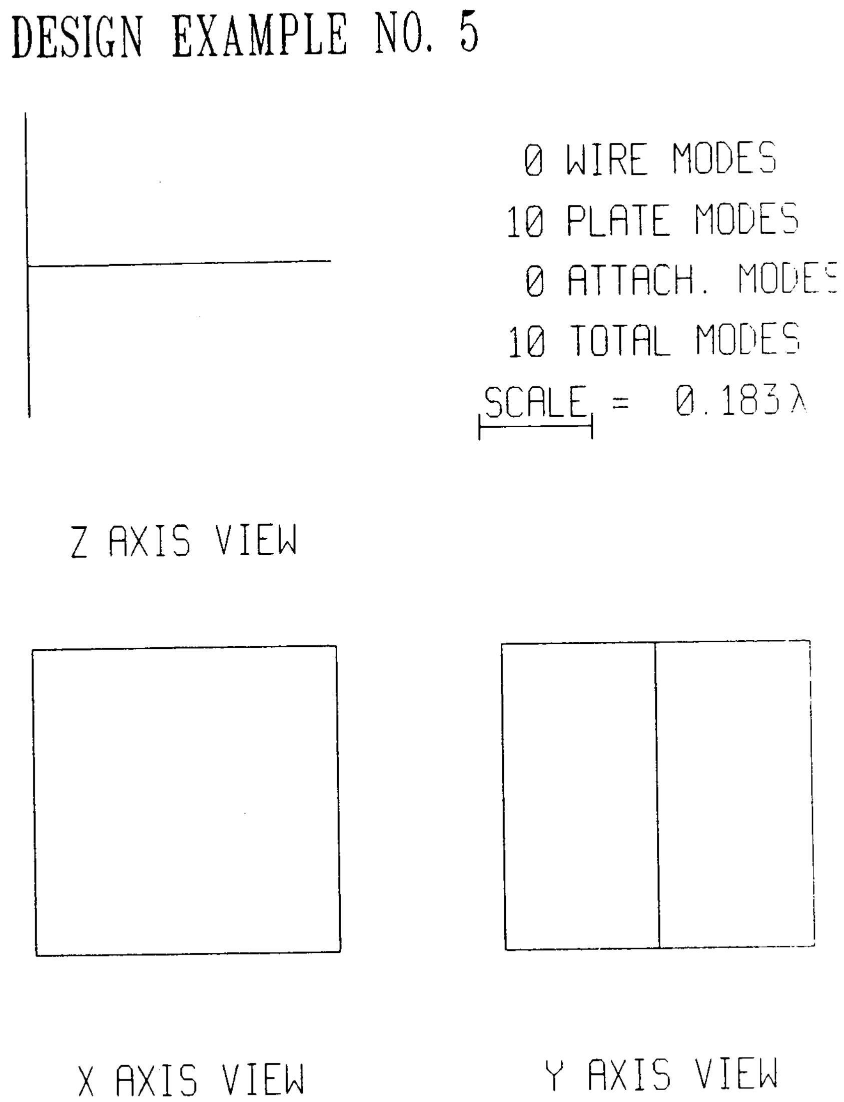


Figure 3.44: A three view sketch of the geometry of Example 5.

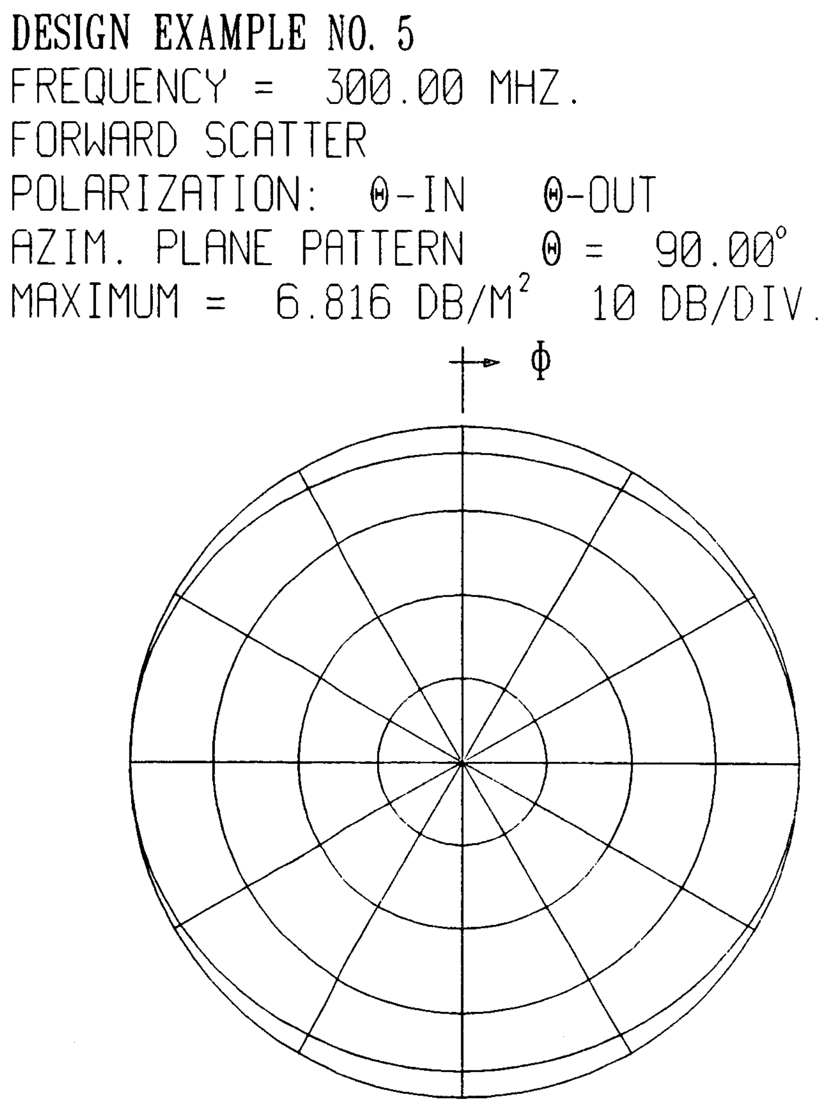


Figure 3.45: Backscatter pattern for Example 5 in the azimuth plane $\theta = 90°$ and for polarization θ incident and θ scattered.

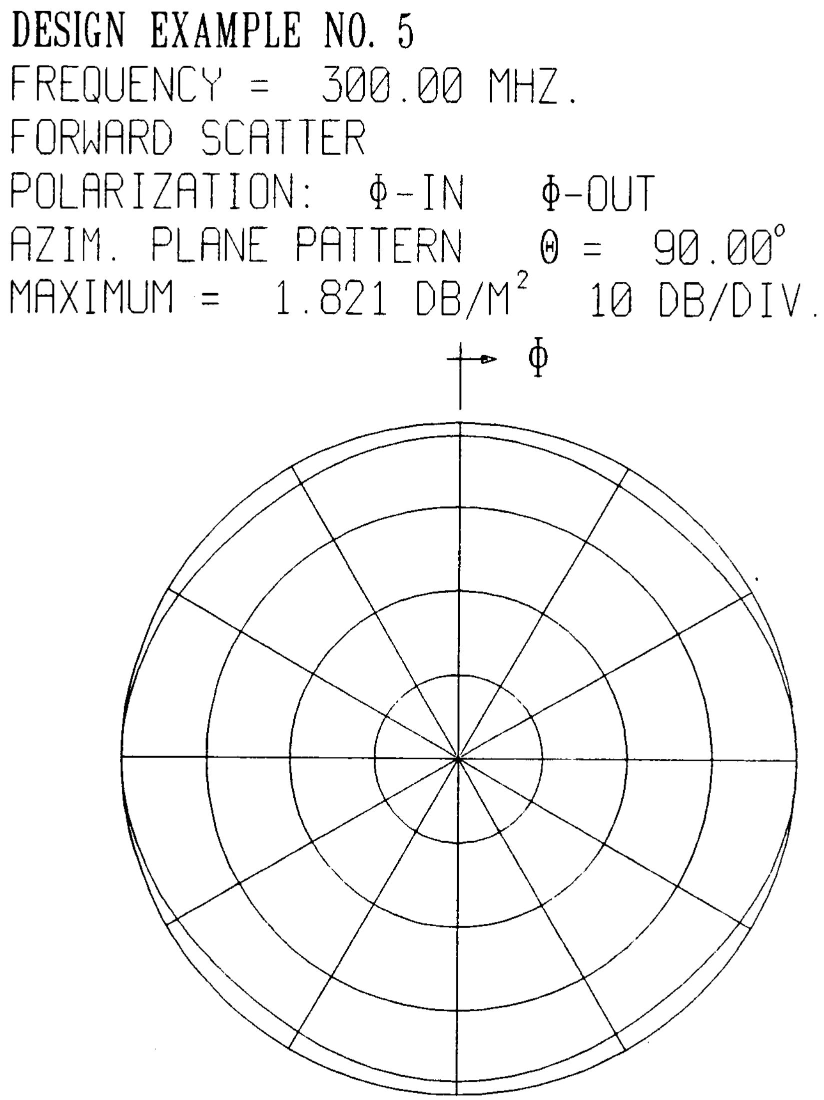


Figure 3.46: Backscatter pattern for Example 5 in the aximuth plane $\theta = 90°$ and for polarization ϕ incident and ϕ scattered.

Chapter 4

Data for Plotting

The amount of data generated by the ESP code is so large that in most cases it can be best understood when it is properly plotted, rather than printed in tabular fashion. In particular this data includes the wire/plate geometry, the detailed layout of surface patch modes on the plates and far zone radiation and scattering patterns. The previous Version II of the ESP code included plots of these data as an integral part of the code. This plotting capability has proven to be extremely valuable to the authors. However, when ESP was supplied to an outside user it was usually found that the plotting software was not transportable and thus would not work on the outside user's system. In fact the first thing many outside users did when they received ESP was to remove all plotting capabilities. In order to make ESP more transportable we decided to separate the plotting from the main ESP code. Basically what we did was to remove all plotting from the ESP code, and instead, have ESP output two data files which could be used to generate the plots. The two data files generated by ESP are; one containing geometry data and the other radiation/scattering pattern data. With knowledge of the contents and format of these data files one can use any available graphics software to write programs which display the data. This chapter describes the contents and format of these two data files.

We have written two plotting codes to accompany the ESP code. The first (ESP3GM) reads in the geometry data file and plots the geometry (see Figure 3.29-3.32), while the second (ESP3PT) reads in the pattern data file and plots the patterns (see Figures 3.33-3.36. These two plotting codes are written in FORTRAN and use the "Graphical Kernel System

(GKS)" plotting software. When ESP is supplied outside Ohio St. Univ., these two plotting programs are normally supplied as separate files. The plotting codes were written to be used interactively, and provide prompts which hopefully make their use self explanatory. If a user does not have GKS on his system then we strongly urge that he write his own plotting software which reads in and then plots the data files produced by ESP. This chapter will provide a description of the data files produced by the ESP code.

4.1 Geometry Data

Setting NGO=0 in READ 1 of the input file will result in ESP writing a data file on logical unit 9 which contains the wire/plate geometry and the detailed layout of surface patch modes on the plates. Let GMDAT be the name of the file assigned to unit 9. The geometry data mainly consists of

1. the coordinates of the corners of the plates,
2. the coordinates of the endpoints of the wire segments,
3. the coordinates of the corners of all quadrilateral surface patch monopoles.

The coordinates are in the x, y, z rectangular system in meters. File GMDAT contains all the data necessary to draw the three view plot of the wire/plate geometry, the surface patch modal layout on each plate, and the overlap surface patch modal layout of intersecting plates. The plots can be used to check the accuracy of the input geometry and also serve as an excellent record of the problem geometry.

Appendix F provides the code that reads in and stores all the geometry data contained in file GMDAT. The IF-THEN blocks are included to test whether the data arrays are of sufficient lengths to store all the data contained in file GMDAT. If an array is too small the program ends after telling the user how to redimension that array. The following list defines all geometry variable names whose values are read from GMDAT via the code of Appendix F .

NPLTS = the total number of plates

NPLTM = the total number of surface patch modes including overlap modes

NM = the total number of wire segments

NP = the total number of wire points

NWR = the total number of wire modes

NAT = the total number of wire/plate attachment points or modes

WV = the wavelength in meters

NOPL = the total number of overlap plate pairs; an overlap plate pair is a set of 2 plates that share a common edge and are connected by overlap modes

NOVT = the total number of overlap modes

X(I),Y(I),Z(I) = the x, y, z coordinates in meters of I^{th} wire endpoint, where I$\in \{1,2, \ldots, \mathrm{NP}\}$

IA(I),IB(I) = the endpoints A and B, respectively, of wire segment I where I $\in \{1,2, \ldots, \mathrm{NM}\}$ and IA, IB $\in \{1,2, \ldots, \mathrm{NP}\}$.

NCNRS(NPL) = the number of corners on plate NPL

NPL11(NPL) = the total number of surface patch modes covering the first current polarization on plate NPL (does not count overlap modes)

NPL22(NPL) = the total number of surface patch modes on plate NPL (does not count overlap modes)

NDNPLT(NPL) = the total number of surface patch modes covering plates 1 through and including NPL, i.e., the number of the last surface patch mode on plate NPL. (does not include overlap modes)

IPN(NPL) = the polarization indicator for plate NPL
IPN=1 $\Rightarrow$ 1^{st} polarization only
IPN=2 $\Rightarrow$ 2^{nd} polarization only
IPN=3 $\Rightarrow$ both polarizations are present
IPN=0 $\Rightarrow$ no polarizations

PA(I, J, K) = x, y, z coordinates (K=1,2,3) in meters of the J^{th} corner of monopole A of the I^{th} surface patch mode. J $\in$ { 1,2,3,4 } , I$\in$ { 1, 2, ..., NPLTM }.

PB(I, J, K) is analogous to PA(I, J, K) but for monopole B.

PCN(K, NC, NPL) = x, y, z coordinates (K=1,2,3) in meters of the NC^{th} corner of plate NPL where NC $\in$ {1,2, ..., NCNRS(NPL) } and NPL $\in$ {1,2, ..., NPLTS }

IOVT(I, J) specifies the 2 plates and the common side which define overlap plate pair I where I $\in$ { 1,2, ..., NOPL }.
IOVT(I,1) = plate A of pair I
IOVT(I,2) = junction side of plate A of pair I
IOVT(I,3) = plate B of pair I
IOVT(I,4) = junction side of plate B of pair I
where IOVT(I,1), IOVT(I,3) $\in$ { 1,2, ..., NPLTS }
and IOVT(I,1) $\neq$ IOVT(I,3),
IOVT(I,2) $\in$ { 1,2, ..., NCNRS[IOVT(I,1)] }, and
IOVT(I,4) $\in$ { 1,2, ..., NCNRS[IOVT(I,3)] }.
By "junction side" of plate A it is meant that side of plate A which contacts a side of plate B. Side 1 connects corners 1 and 2, side 2 connects corners 2 and 3, ..., and side NCNRS(NPL) connects corners NCNRS(NPL) and 1.

ITK(I) = the number of overlap modes in overlap plate pair I

The data variables NPLTS, NM, NP, NAT, WV, X, Y, Z, IA, IB, PCN, and NCNRS are exactly the same as those specified in the input file of the main program. See Chapter 3 for further description of these variables. All other variables contained in GMDAT describe the detailed surface patch modal layout and are described below.

A surface patch dipole mode is made up of two surface patch monopoles, termed A and B. The geometry of the A and B monopoles are contained in the PA and PB arrays, respectively. We will describe these arrays with the help of Figure 4.1, which shows the PA or PB array for a geometry consisting of 3 plates among which there are 2 overlap plate pairs. In this figure the vertical dimension represents the index I, which (see above) corresponds to the mode number. The following observations may be helpful to the user.

- There are NPL22(N) modes on plate N. Of these NPL11(N) are for polarization one and NPL22(N) - NPL11(N) for polarization two.
- The last mode on plate N is mode number NDNPLT(N) = NDNPLT(N-1) + NPL22(N).
- If there are NPLTS plates, then the first overlap mode is NDNPLT(NPLTS) + 1. The first overlap pair of plates involves modes NDNPLT(NPLTS) + 1 through NDNPLT(NPLTS) + ITK(1). The second overlap pair involves modes NDNPLT(NPLTS) + ITK(1) + 1 through NDNPLT(NPLTS) + ITK(1) + ITK(2).
- The last overlap mode is mode number NPLTM = NDNPLT(NPLTS) + NOVT.
- Overlap pair P involves side IOVT(P,2) of plate IOVT(P,1) contacting side IOVT(P,4) of plate IOVT(P,3).

A typical surface patch dipole mode (or overlap mode) is shown in Figure 4.2 in which corner numbers are circled. The corner and side numbering scheme of a monopole is shown. The arrow indicates that the current of a dipole is always referenced as positive in the direction from monopole A to monopole B. Note also that corner number 1 of monopole A always coincides with corner number 1 of monopole B, and corner number 4 of monopole A always coincides with corner number 4 of monopole B. In other words monopoles A and B of surface patch mode I share side 4. The x, y, z coordinates of each of the four corners are contained in the PA and PB arrays. For example the x, y, z coordinates of PA1, which is the same as PB1 is given by:

$$\begin{aligned} \text{PA1} = \text{PB1} &= (\ \text{PA(I,1,1), PA(I,1,2), PA(I,1,3)}\ ) \\ &= (\ \text{PB(I,1,1), PB(I,1,2), PB(I,1,3)}\ ). \end{aligned}$$

Similarily, the coordinates of PB3 are:

$$\text{PB3} = (\ \text{PB(I,3,1), PB(I,3,2), PB(I,3,3)}\ ).$$

The above information should be sufficient to allow a user to obtain geometry plots similar to those shown in the previous chapter.

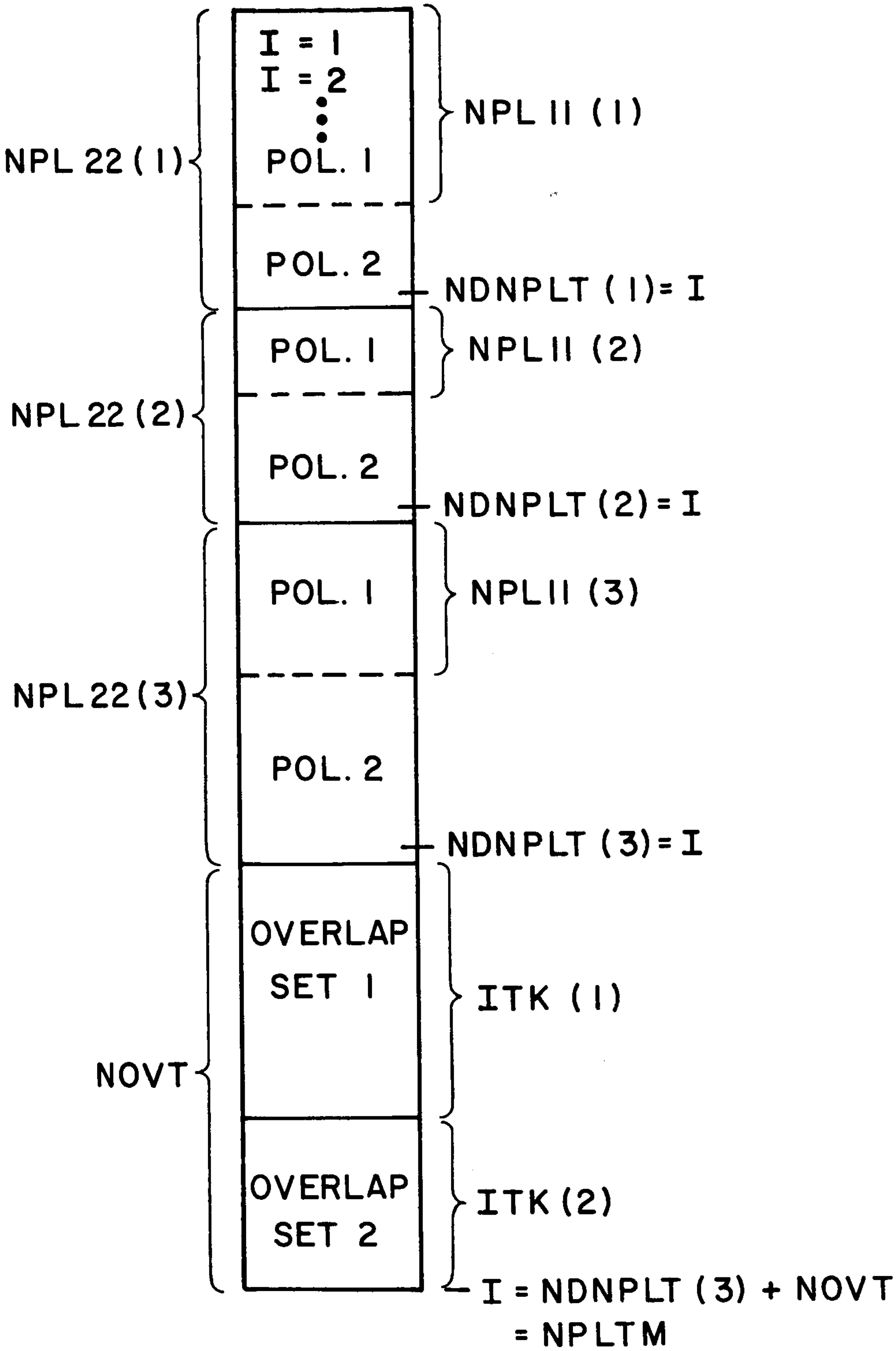


Figure 4.1: Monopole corner coordinate array PA or PB for a geometry with NPLTS=3 and NOPL=2.

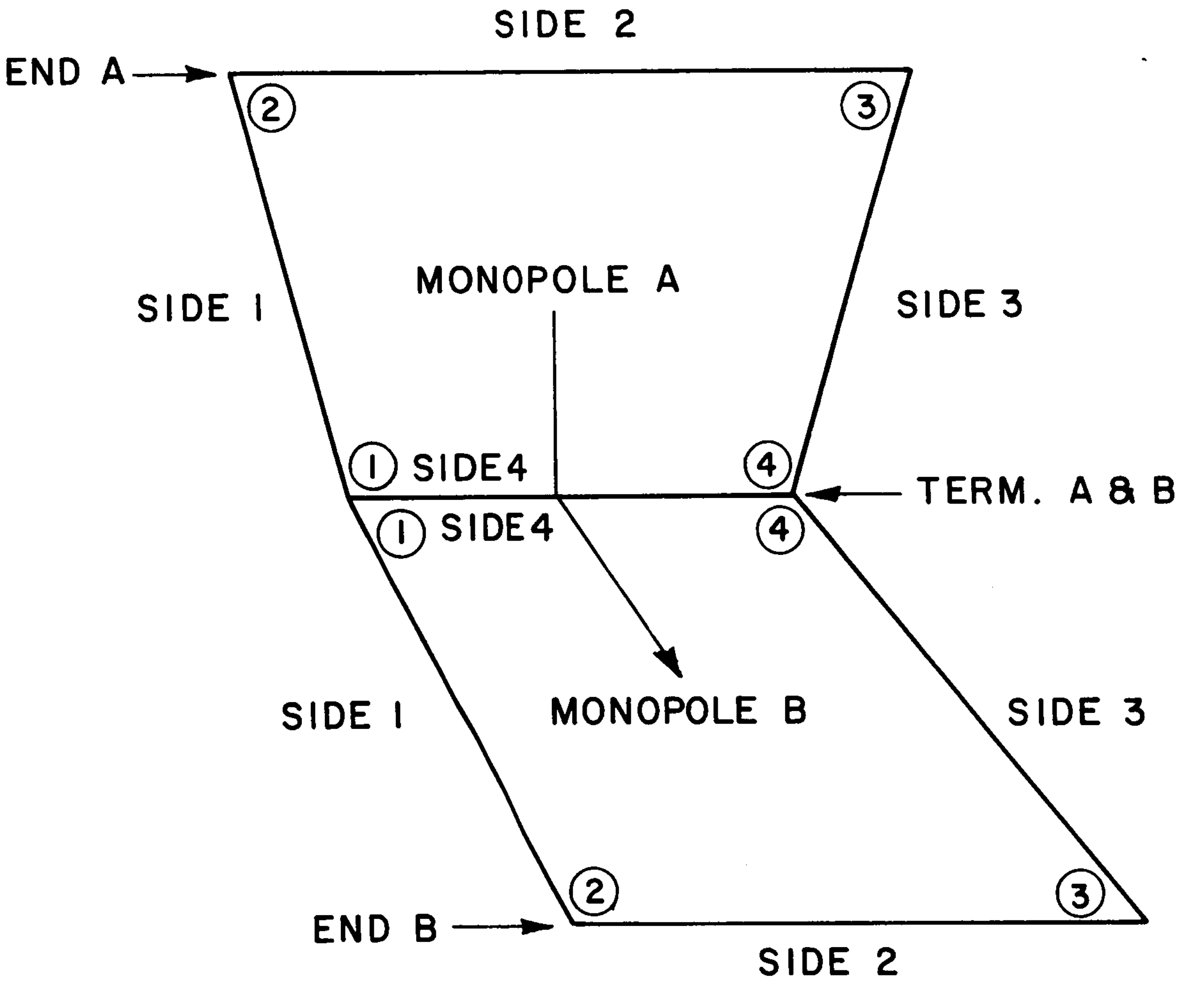


Figure 4.2: A typical dipole surface patch mode or overlap mode.

4.2 Pattern Data

If in READ 1 NGO = 1, and in READ 2 IFE and IPFE are set to 1, the ESP will produce an output file on logical unit 8, which contains the far zone radiation pattern in the elevation plane. Similarily, if in READS 3-5 the first two parameters are nonzero, the code will produce an output file on logical unit 8 which contains the far zone pattern data. This section will describe this data file. This information should allow a user to write a simple code to plot the patterns.

Let PTDAT be the name of the file assigned to unit 8. The data sent to PTDAT consists of the radiated or scattered field magnitude in dB, its phase in degrees, as well as other miscellaneous parameters descibing the pattern. Appendix G shows code to read and store the pattern data of file PTDAT. The IF-THEN blocks are included to test whether the data arrays are of sufficient lengths to store all the data contained in file PTDAT. If an array is too small the program ends after telling the user how to redimension that array. The following list defines all pattern variable names whose values are read from PTDAT via the code of Appendix G .

NPATS = the number of pattern cuts. The different polarizations computed on a single pattern cut do not count as additional patterns in specifying NPATS.

IRS12 = the pattern type indicator
= 1 for a radiation pattern
= 2 for a scattering pattern

FMC = frequency in megahertz

IEA(I) pattern plane indicator for pattern I
where I ∈ { 1, 2, ... , NPATS }
IEA(I) = 1 for an elevation plane pattern
IEA(I) = 2 for an azimuth plane pattern

NPTS(I) = the number of pattern data points in pattern I
where I ∈ { 1, 2, ... , NPATS },

CANG(I) = constant or fixed angle for pattern I
= fixed angle ϕ (°) if IEA(I) = 1
= fixed angle θ (°) if IEA(I) = 2

ISCAT(I) = the pattern type for pattern I
= 0 for radiation pattern
= 1 for backscatter pattern
= 2 for bistatic scatter pattern
= 3 for forward scatter pattern

THIN(I), PHIN(I) = θ and ϕ angles in degrees specifying the bistatic incident wave direction for pattern I. As seen in Appendix G, these values are only written to PTDAT for scatter patterns.

PATS(I,J,K,1), PATS(I,J,K,2) = the magnitude in dB and angle in degrees, respectively, of polarization K of pattern point J of pattern I where
I $\in$ { 1, 2, ... , NPATS },
J $\in$ { 1, 2, ... , NPTS(I) },
and for IRS12 = 1:
K = 1 $\Rightarrow$ θ polarization
K = 2 $\Rightarrow$ ϕ polarization
for IRS12 = 2:
K = 1 $\Rightarrow$ θ-in θ-out polarization
K = 2 $\Rightarrow$ ϕ-in ϕ-out polarization
K = 3 $\Rightarrow$ θ-in ϕ-out polarization
K = 4 $\Rightarrow$ ϕ-in θ-out polarization

The contents of pattern data file PTDAT have been described. Appendix G shows a code which will read PTDAT and store the values in the above described variables and arrays. Simple programs can then be written using this information to draw the desired patterns with any available graphics software.

Chapter 5

Summary

This report serves as a user's manual for the Electromagnetic Surface Patch (ESP) Code: Version II – Polygon Plates and Wires. ESP is a general purpose computer code based on the method of moments (MM) solution for electromagnetic radiation and scattering. The MM formulation, as implemented by the program, was discussed in brief. The program inputs were described and several examples illustrating their use were given.

The program can handle geometries consisting of thin wires, polygonal plates, wire/plate junctions and multiple plate junctions. The computation time and storage requirements are proportional to the square of the number of MM modes. The number of modes is proportional to the electrical length of the wires and the electrical area of the plates. Thus, the program is limited to treating bodies which are not too large electrically. The major advantages of the program are accuracy, flexibility and the simplicity of the input format.

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Appendix A

Output for Example 1

```
       INPUT DATA

 FREQ.(MHZ)=    150.000   WAVE(M)=       2.000   WIRE RAD(M)=  0.001000
 INTP=    6   INTD=  18   INT =     4    IFIL= 0


 WIRE CONDUCTIVITY = 38.00 MEGAMHOS/M



 GEOMETRY FOR THE    1 PLATES



                      PLATE NUMBER    1  (RECTANGULAR)
 NUMBER OF CORNERS =    4
 MAXIMUM SEGMENT SIZE  (WAVELENGTH) =     0.20000
 POLARIZATION INDICATOR =    3
 GENERATING SIDE INDICATOR =    0

X,Y,Z COOR.(METERS) OF CORNER  1 =    -0.50000     -0.50000      0.00000
X,Y,Z COOR.(METERS) OF CORNER  2 =     0.50000     -0.50000      0.00000
X,Y,Z COOR.(METERS) OF CORNER  3 =     0.50000      0.50000      0.00000
X,Y,Z COOR.(METERS) OF CORNER  4 =    -0.50000      0.50000      0.00000


 THERE ARE  12 MODES ON PLATE    1
```

```
  4 POINTS ON THE WIRE
 I         X (I)          Y (I)          Z (I)

 1   0.0000E+00     0.0000E+00     0.0000E+00
 2   0.0000E+00     0.0000E+00     0.2500E+00
 3   0.0000E+00     0.0000E+00     0.5000E+00
 4  -0.3000E+00     0.0000E+00     0.2500E+00


 MODES ON THE WIRE STRUCTURE

 MAXIMUM NUMBER OF MODES AT ONE POINT =  2
 MINIMUM NUMBER OF MODES AT ONE POINT =  1
 NUMBER OF WIRE MODES =   2


  3 SEGMENTS ON THE WIRE
 J    IA(J)   IB(J)    D(J)(M)

 1      1       2     0.25000E+00
 2      2       3     0.25000E+00
 3      2       4     0.30000E+00


GEOMETRY FOR THE  1 ATTACHMENT POINTS

I  SEGMENT  END  PLATE      B(M)

1      1     0      1      0.40000
```

LISTING OF LOADS AND GENERATORS

0.5000E+02 0.0000E+00 OHMS BY PT. A OF SEGMENT 3
0.1000E+01 0.0000E+00 VOLTS AT ATTACHMENT 1

NWR = NUMBER OF WIRE MODES = 2
NPLTM = NUMBER OF PLATE MODES = 12
NAT = NUMBER OF ATTACHMENT MODES = 1

LOWER TRIANGULAR PART OF SYMMETRIC IMPEDANCE MATRIX

I	J	Z(I,J)	
1	1	0.13544E+02	-0.53039E+03
2	1	-0.67718E+01	0.26520E+03
3	1	0.62850E+00	0.66951E+01
4	1	-0.62851E+00	-0.66951E+01
5	1	0.68693E+00	0.34919E+02
6	1	-0.68693E+00	-0.34919E+02
7	1	0.62850E+00	0.66951E+01
8	1	-0.62850E+00	-0.66951E+01
9	1	0.62850E+00	0.66951E+01
10	1	-0.62851E+00	-0.66951E+01
11	1	0.68693E+00	0.34919E+02
12	1	-0.68693E+00	-0.34919E+02
13	1	0.62850E+00	0.66951E+01
14	1	-0.62850E+00	-0.66951E+01
15	1	0.69633E+01	0.38143E+03
2	2	0.58741E+02	-0.46394E+03
3	2	0.22498E+00	0.79425E+00
4	2	-0.22498E+00	-0.79425E+00
5	2	-0.27889E+00	-0.44345E+01
6	2	0.27888E+00	0.44345E+01
7	2	-0.78922E+00	-0.84120E+01
8	2	0.78922E+00	0.84120E+01
9	2	0.67352E+01	-0.49264E+01
10	2	0.81140E+01	-0.22329E+01
11	2	0.87477E+01	-0.48153E+01
12	2	0.10313E+02	0.18874E+01
13	2	0.67352E+01	-0.49264E+01

14	2	0.81140E+01	-0.22329E+01
15	2	-0.34260E+01	-0.76975E+01
3	3	0.24726E+02	-0.50460E+02
4	3	0.22204E+02	0.65659E+02
5	3	0.19673E+02	-0.13370E+02
6	3	0.17511E+02	0.74029E+01
7	3	0.77809E+01	-0.12877E+02
8	3	0.66041E+01	-0.97975E+01
9	3	-0.62153E+00	-0.48584E+02
10	3	-0.15735E+01	-0.14611E+02
11	3	0.62153E+00	0.48584E+02
12	3	0.15735E+01	0.14611E+02
13	3	0.15829E+01	0.14639E+02
14	3	0.40238E+01	0.12022E+02
15	3	0.27531E+00	0.53959E+01
4	4	0.24726E+02	-0.50460E+02
5	4	0.17511E+02	0.74029E+01
6	4	0.19673E+02	-0.13370E+02
7	4	0.66041E+01	-0.97975E+01
8	4	0.77809E+01	-0.12877E+02
9	4	-0.15829E+01	-0.14639E+02
10	4	-0.40238E+01	-0.12022E+02
11	4	-0.62153E+00	-0.48584E+02
12	4	-0.15735E+01	-0.14611E+02
13	4	0.62153E+00	0.48584E+02
14	4	0.15735E+01	0.14611E+02
15	4	-0.27530E+00	-0.53959E+01
5	5	0.24726E+02	-0.50460E+02
6	5	0.22204E+02	0.65659E+02
7	5	0.19673E+02	-0.13370E+02
8	5	0.17511E+02	0.74029E+01
9	5	0.62153E+00	0.48584E+02
10	5	-0.62153E+00	-0.48584E+02
11	5	-0.62153E+00	-0.48584E+02
12	5	0.62153E+00	0.48584E+02
13	5	-0.15829E+01	-0.14639E+02
14	5	0.15829E+01	0.14639E+02
15	5	0.29802E+00	-0.45973E+01
6	6	0.24726E+02	-0.50460E+02
7	6	0.17511E+02	0.74029E+01
8	6	0.19673E+02	-0.13370E+02
9	6	0.15829E+01	0.14639E+02
10	6	-0.15829E+01	-0.14639E+02
11	6	0.62153E+00	0.48584E+02

12	6	-0.62153E+00	-0.48584E+02
13	6	-0.62153E+00	-0.48584E+02
14	6	0.62153E+00	0.48584E+02
15	6	-0.29802E+00	0.45973E+01
7	7	0.24726E+02	-0.50460E+02
8	7	0.22204E+02	0.65659E+02
9	7	0.15735E+01	0.14611E+02
10	7	0.62153E+00	0.48584E+02
11	7	-0.15735E+01	-0.14611E+02
12	7	-0.62153E+00	-0.48584E+02
13	7	-0.40238E+01	-0.12022E+02
14	7	-0.15829E+01	-0.14639E+02
15	7	0.27531E+00	0.53959E+01
8	8	0.24726E+02	-0.50460E+02
9	8	0.40238E+01	0.12022E+02
10	8	0.15829E+01	0.14639E+02
11	8	0.15735E+01	0.14611E+02
12	8	0.62153E+00	0.48584E+02
13	8	-0.15735E+01	-0.14611E+02
14	8	-0.62153E+00	-0.48584E+02
15	8	-0.27531E+00	-0.53959E+01
9	9	0.24726E+02	-0.50460E+02
10	9	0.22204E+02	0.65659E+02
11	9	0.19673E+02	-0.13370E+02
12	9	0.17511E+02	0.74029E+01
13	9	0.77809E+01	-0.12877E+02
14	9	0.66041E+01	-0.97975E+01
15	9	0.27531E+00	0.53959E+01
10	10	0.24726E+02	-0.50460E+02
11	10	0.17511E+02	0.74029E+01
12	10	0.19673E+02	-0.13370E+02
13	10	0.66041E+01	-0.97975E+01
14	10	0.77809E+01	-0.12877E+02
15	10	-0.27530E+00	-0.53959E+01
11	11	0.24726E+02	-0.50460E+02
12	11	0.22204E+02	0.65659E+02
13	11	0.19673E+02	-0.13370E+02
14	11	0.17511E+02	0.74029E+01
15	11	0.29802E+00	-0.45973E+01
12	12	0.24726E+02	-0.50460E+02
13	12	0.17511E+02	0.74029E+01
14	12	0.19673E+02	-0.13370E+02
15	12	-0.29802E+00	0.45973E+01
13	13	0.24726E+02	-0.50460E+02

14	13	0.22204E+02	0.65659E+02
15	13	0.27531E+00	0.53959E+01
14	14	0.24726E+02	-0.50460E+02
15	14	-0.27531E+00	-0.53959E+01
15	15	0.36942E+01	-0.27189E+03

INPUT ADMITTANCE(MHOS) = 0.002412 J -0.007197
INPUT IMPEDANCE(OHMS) = 41.865 J 124.917
EFFICIENCY(PERCENT) = 59.902

ANTENNA PROBLEM, ISCAT = 0

ELEVATION PATTERN. PHI = 90.0 DEG.

THETA(DEG)	GTHETA(DB)	GPHI(DB)
0	-99.900	-11.292
3	-26.442	-11.366
6	-18.909	-11.405
9	-15.160	-11.469
12	-12.629	-11.560
15	-10.727	-11.676
18	-9.217	-11.817
21	-7.978	-11.984
24	-6.939	-12.175
27	-6.056	-12.390
30	-5.299	-12.630
33	-4.645	-12.893
36	-4.078	-13.179
39	-3.586	-13.487
42	-3.159	-13.818
45	-2.789	-14.170
48	-2.470	-14.543
51	-2.195	-14.937
54	-1.959	-15.351
57	-1.760	-15.784
60	-1.591	-16.237
63	-1.451	-16.709
66	-1.335	-17.200
69	-1.242	-17.710
72	-1.168	-18.240

75	-1.111	-18.789
78	-1.070	-19.358
81	-1.042	-19.948
84	-1.027	-20.559
87	-1.022	-21.191
90	-1.028	-21.825
93	-1.044	-22.512
96	-1.070	-23.192
99	-1.107	-23.876
102	-1.155	-24.546
105	-1.215	-25.175
108	-1.290	-25.728
111	-1.380	-26.157
114	-1.489	-26.416
117	-1.618	-26.468
120	-1.770	-26.304
123	-1.950	-25.945
126	-2.159	-25.438
129	-2.402	-24.833
132	-2.684	-24.177
135	-3.009	-23.507
138	-3.384	-22.847
141	-3.815	-22.214
144	-4.309	-21.619
147	-4.878	-21.067
150	-5.534	-20.561
153	-6.292	-20.104
156	-7.175	-19.696
159	-8.213	-19.337
162	-9.451	-19.026
165	-10.958	-18.764
168	-12.853	-18.551
171	-15.369	-18.385
174	-19.076	-18.267
177	-26.337	-18.196
180	-54.416	-18.186
183	-26.337	-18.196
186	-19.076	-18.267
189	-15.369	-18.385
192	-12.853	-18.551
195	-10.958	-18.764
198	-9.451	-19.026
201	-8.213	-19.337
204	-7.175	-19.696

207	-6.292	-20.104
210	-5.534	-20.561
213	-4.878	-21.067
216	-4.309	-21.619
219	-3.815	-22.214
222	-3.384	-22.847
225	-3.009	-23.507
228	-2.684	-24.177
231	-2.402	-24.833
234	-2.159	-25.438
237	-1.950	-25.945
240	-1.770	-26.304
243	-1.618	-26.468
246	-1.489	-26.416
249	-1.380	-26.157
252	-1.290	-25.728
255	-1.215	-25.175
258	-1.155	-24.546
261	-1.107	-23.876
264	-1.070	-23.193
267	-1.044	-22.512
270	-1.028	-21.866
273	-1.022	-21.191
276	-1.027	-20.559
279	-1.042	-19.948
282	-1.070	-19.358
285	-1.111	-18.789
288	-1.168	-18.240
291	-1.242	-17.710
294	-1.335	-17.200
297	-1.451	-16.709
300	-1.591	-16.237
303	-1.760	-15.784
306	-1.959	-15.351
309	-2.195	-14.937
312	-2.470	-14.543
315	-2.789	-14.170
318	-3.159	-13.818
321	-3.586	-13.487
324	-4.078	-13.179
327	-4.645	-12.893
330	-5.299	-12.630
333	-6.056	-12.390
336	-6.939	-12.175

339	-7.978	-11.984
342	-9.217	-11.817
345	-10.727	-11.676
348	-12.629	-11.560
351	-15.160	-11.469
354	-18.909	-11.405
357	-26.442	-11.366
360	-54.333	-11.348

CPU RUN TIME FOR RUN 1 GEOMETRY 1 = 103.28 SECONDS

TOTAL CPU RUN TIME = 103.70 SECONDS

Appendix B

Output for Example 2

```
        INPUT DATA

   FREQ.(MHZ)=   300.000   WAVE(M)=      1.000   WIRE RAD(M)=  0.001000
   INTP=    6   INTD=  18   INT =    4   IFIL= 1


   WIRE CONDUCTIVITY = -1.00 MEGAMHOS/M



   GEOMETRY FOR THE   1 PLATES



                         PLATE NUMBER   1  (POLYGONAL)
   NUMBER OF CORNERS =   5
   MAXIMUM SEGMENT SIZE  (WAVELENGTH) =    0.25000
   POLARIZATION INDICATOR =   3
   GENERATING SIDE INDICATOR =   0

  X,Y,Z COOR.(METERS) OF CORNER  1 =     1.00000     0.00000     0.00000
  X,Y,Z COOR.(METERS) OF CORNER  2 =     0.00000     0.50000     0.00000
  X,Y,Z COOR.(METERS) OF CORNER  3 =     0.00000     1.00000     0.00000
  X,Y,Z COOR.(METERS) OF CORNER  4 =     1.00000     1.50000     0.00000
  X,Y,Z COOR.(METERS) OF CORNER  5 =     1.50000     0.50000     0.00000
```

THERE ARE 71 MODES ON PLATE 1

LISTING OF LOADS AND GENERATORS

NWR = NUMBER OF WIRE MODES = 0
NPLTM = NUMBER OF PLATE MODES = 71
NAT = NUMBER OF ATTACHMENT MODES = 0

BACKSCATTERING, ISCAT = 1

*(DEG)**		** CROSS SECTION	(DB/M**2) **			******	PHASE	(DEG)	******
TH	PHI	STTM	SPPM	STPM	SPTM	STTM	SPPM	STPM	SPTM
0	0	12.71	13.58	-17.79	-19.84	-90.0	-89.9	-140.1	-119.5
3	0	12.44	13.47	-18.78	-19.62	-61.7	-62.8	-94.8	-69.9
6	0	11.65	12.89	-19.14	-18.65	-33.5	-35.3	-49.2	-25.7
9	0	10.31	11.81	-19.02	-17.67	-5.4	-7.3	-6.3	12.4
12	0	8.36	10.22	-18.85	-17.02	23.2	21.6	33.0	46.7
15	0	5.69	8.07	-18.94	-16.84	52.9	52.1	70.3	79.1
18	0	2.17	5.34	-19.41	-17.12	85.8	85.7	107.5	111.2
21	0	-2.12	2.18	-20.17	-17.83	127.6	125.3	146.6	144.2
24	0	-5.34	-0.59	-20.86	-18.87	-174.4	174.0	-170.6	179.6
27	0	-4.88	-1.57	-20.90	-19.96	-119.4	-133.8	-125.6	-141.9
30	0	-3.53	-1.19	-20.14	-20.69	-84.2	-90.0	-83.2	-101.0
33	0	-2.84	-0.85	-19.07	-20.85	-61.1	-55.7	-46.8	-61.2
36	0	-2.73	-1.04	-18.21	-20.74	-45.0	-27.0	-15.9	-25.4
39	0	-2.92	-1.80	-17.79	-20.81	-33.6	-1.4	10.5	5.4
42	0	-3.14	-3.12	-17.89	-21.38	-25.3	22.7	33.5	31.9
45	0	-3.28	-4.95	-18.53	-22.68	-18.3	47.1	53.5	54.8
48	0	-3.39	-7.18	-19.76	-25.04	-11.5	73.8	70.3	73.8
51	0	-3.56	-9.45	-21.63	-29.12	-4.1	106.0	83.1	86.8
54	0	-3.91	-10.70	-24.15	-36.71	3.9	144.4	89.8	75.4
57	0	-4.50	-10.13	-27.02	-35.44	12.1	-178.8	86.1	-1.5
60	0	-5.37	-8.59	-28.75	-29.05	20.3	-151.1	69.4	-8.3
63	0	-6.56	-7.01	-28.03	-25.78	28.2	-131.3	52.9	-0.5
66	0	-8.08	-5.68	-26.52	-24.02	35.5	-116.6	47.0	9.2
69	0	-9.97	-4.61	-25.47	-23.18	42.3	-105.1	47.9	18.6

72	0	-12.32	-3.78	-25.08	-23.04	48.2	-95.9	51.5	27.2
75	0	-15.24	-3.14	-25.35	-23.52	53.4	-88.4	55.8	34.6
78	0	-18.92	-2.65	-26.31	-24.63	57.6	-82.6	60.0	40.8
81	0	-23.78	-2.29	-28.10	-26.53	61.0	-78.1	63.5	45.7
84	0	-30.73	-2.05	-31.14	-29.65	63.4	-74.9	66.2	49.2
87	0	-42.72	-1.91	-36.89	-35.44	64.8	-73.0	67.8	51.3
90	0	-99.90	-1.86	-99.90	-99.90	65.3	-72.3	-111.6	-128.0
93	0	-42.72	-1.91	-36.89	-35.44	64.8	-73.0	-112.2	-128.7
96	0	-30.73	-2.05	-31.14	-29.65	63.4	-74.9	-113.8	-130.8
99	0	-23.78	-2.29	-28.10	-26.53	61.0	-78.1	-116.5	-134.3
102	0	-18.92	-2.65	-26.31	-24.63	57.6	-82.6	-120.0	-139.2
105	0	-15.24	-3.14	-25.35	-23.52	53.4	-88.4	-124.2	-145.4
108	0	-12.32	-3.78	-25.08	-23.04	48.2	-95.9	-128.5	-152.8
111	0	-9.97	-4.61	-25.47	-23.18	42.3	-105.1	-132.1	-161.4
114	0	-8.08	-5.68	-26.52	-24.02	35.5	-116.6	-133.0	-170.8
117	0	-6.56	-7.01	-28.03	-25.78	28.2	-131.3	-127.1	179.5
120	0	-5.37	-8.59	-28.75	-29.05	20.3	-151.1	-110.6	171.7
123	0	-4.50	-10.13	-27.02	-35.44	12.1	-178.8	-93.9	178.5
126	0	-3.91	-10.70	-24.15	-36.71	3.9	144.4	-90.2	-104.6
129	0	-3.56	-9.45	-21.63	-29.12	-4.1	106.0	-96.9	-93.2
132	0	-3.39	-7.18	-19.76	-25.04	-11.5	73.8	-109.7	-106.2
135	0	-3.28	-4.95	-18.53	-22.68	-18.3	47.1	-126.5	-125.2
138	0	-3.14	-3.12	-17.89	-21.38	-25.3	22.7	-146.5	-148.1
141	0	-2.92	-1.80	-17.79	-20.81	-33.6	-1.4	-169.5	-174.6
144	0	-2.73	-1.04	-18.21	-20.74	-45.0	-27.0	164.1	154.6
147	0	-2.84	-0.85	-19.07	-20.85	-61.1	-55.7	133.2	118.8
150	0	-3.53	-1.19	-20.14	-20.69	-84.2	-90.0	96.8	79.0
153	0	-4.88	-1.57	-20.90	-19.96	-119.4	-133.8	54.4	38.1
156	0	-5.34	-0.59	-20.86	-18.87	-174.4	174.0	9.4	-0.4
159	0	-2.12	2.18	-20.17	-17.83	127.6	125.3	-33.4	-35.8
162	0	2.17	5.34	-19.41	-17.12	85.8	85.7	-72.5	-68.8
165	0	5.69	8.07	-18.94	-16.84	52.9	52.1	-109.7	-100.9
168	0	8.36	10.22	-18.85	-17.02	23.2	21.6	-147.0	-133.3
171	0	10.31	11.81	-19.02	-17.67	-5.4	-7.3	173.7	-167.6
174	0	11.65	12.89	-19.14	-18.65	-33.5	-35.3	130.8	154.3
177	0	12.44	13.47	-18.78	-19.62	-61.7	-62.8	85.2	110.1
180	0	12.71	13.58	-17.79	-19.84	-90.0	-89.9	39.9	60.5
183	0	12.48	13.21	-16.44	-18.93	-118.5	-116.6	-2.8	10.7
186	0	11.73	12.33	-15.12	-17.48	-147.5	-143.1	-42.7	-34.6
189	0	10.45	10.91	-14.06	-16.11	-176.9	-169.4	-81.0	-76.0
192	0	8.57	8.82	-13.29	-15.07	152.7	164.4	-118.9	-115.6
195	0	6.03	5.88	-12.77	-14.33	120.6	138.0	-157.5	-155.2
198	0	2.71	1.61	-12.38	-13.77	84.8	110.5	162.9	164.4
201	0	-1.25	-5.41	-11.97	-13.20	40.8	76.3	122.5	123.3

204	0	-4.40	-14.93	-11.42	-12.49	-17.5	-33.6	82.0	82.4
207	0	-4.49	-6.18	-10.74	-11.64	-76.3	-109.8	42.8	42.9
210	0	-3.44	-2.52	-10.02	-10.77	-119.1	-138.6	5.4	5.7
213	0	-2.93	-1.05	-9.36	-10.00	-150.7	-161.5	-29.6	-29.0
216	0	-3.08	-0.66	-8.85	-9.42	-176.1	177.7	-62.6	-61.4
219	0	-3.76	-0.93	-8.53	-9.07	163.0	158.3	-93.8	-91.9
222	0	-4.75	-1.64	-8.41	-8.95	145.7	139.5	-123.3	-120.8
225	0	-5.86	-2.64	-8.47	-9.05	131.7	120.7	-151.4	-148.4
228	0	-6.91	-3.77	-8.70	-9.35	120.2	101.2	-178.1	-174.6
231	0	-7.80	-4.85	-9.09	-9.83	110.0	80.3	156.5	160.3
234	0	-8.57	-5.66	-9.60	-10.45	99.9	57.7	132.5	136.5
237	0	-9.33	-5.96	-10.24	-11.20	89.6	34.2	109.9	114.0
240	0	-10.20	-5.70	-10.98	-12.06	78.8	11.8	88.9	92.8
243	0	-11.29	-5.03	-11.84	-13.03	68.0	-7.9	69.6	73.2
246	0	-12.68	-4.18	-12.82	-14.11	57.4	-24.5	52.1	55.3
249	0	-14.43	-3.32	-13.95	-15.32	47.5	-38.0	36.4	39.2
252	0	-16.63	-2.56	-15.27	-16.70	38.5	-48.9	22.7	25.0
255	0	-19.41	-1.92	-16.84	-18.32	30.7	-57.7	11.1	12.9
258	0	-22.98	-1.40	-18.77	-20.28	24.0	-64.7	1.5	2.9
261	0	-27.75	-1.02	-21.26	-22.79	18.8	-69.9	-6.1	-4.9
264	0	-34.63	-0.75	-24.78	-26.32	15.0	-73.6	-11.4	-10.5
267	0	-46.58	-0.59	-30.80	-32.35	12.7	-75.8	-14.7	-13.9
270	0	-99.90	-0.54	-99.90	-99.90	11.9	-76.5	164.3	165.0
273	0	-46.58	-0.59	-30.80	-32.35	12.7	-75.8	165.3	166.1
276	0	-34.63	-0.75	-24.78	-26.32	15.0	-73.6	168.6	169.5
279	0	-27.75	-1.02	-21.26	-22.79	18.8	-69.9	173.9	175.1
282	0	-22.98	-1.40	-18.77	-20.28	24.0	-64.7	-178.5	-177.1
285	0	-19.41	-1.92	-16.84	-18.32	30.7	-57.7	-168.9	-167.1
288	0	-16.63	-2.56	-15.27	-16.70	38.5	-48.9	-157.3	-155.0
291	0	-14.43	-3.32	-13.95	-15.32	47.5	-38.0	-143.6	-140.8
294	0	-12.68	-4.18	-12.82	-14.11	57.4	-24.5	-127.9	-124.7
297	0	-11.29	-5.03	-11.84	-13.03	68.0	-7.9	-110.4	-106.8
300	0	-10.20	-5.70	-10.98	-12.06	78.8	11.8	-91.1	-87.2
303	0	-9.33	-5.96	-10.24	-11.20	89.6	34.2	-70.1	-66.0
306	0	-8.57	-5.66	-9.60	-10.45	99.9	57.7	-47.5	-43.5
309	0	-7.80	-4.85	-9.09	-9.83	110.0	80.3	-23.5	-19.7
312	0	-6.91	-3.77	-8.70	-9.35	120.2	101.2	1.9	5.4
315	0	-5.86	-2.64	-8.47	-9.05	131.7	120.7	28.6	31.6
318	0	-4.75	-1.64	-8.41	-8.95	145.7	139.5	56.7	59.2
321	0	-3.76	-0.93	-8.53	-9.07	163.0	158.3	86.2	88.1
324	0	-3.08	-0.66	-8.85	-9.42	-176.1	177.7	117.4	118.6
327	0	-2.93	-1.05	-9.36	-10.00	-150.7	-161.5	150.4	151.0
330	0	-3.44	-2.52	-10.02	-10.77	-119.1	-138.6	-174.6	-174.3
333	0	-4.49	-6.18	-10.74	-11.64	-76.3	-109.8	-137.2	-137.1

336	0	-4.40	-14.93	-11.42	-12.49	-17.5	-33.6	-98.0	-97.6
339	0	-1.25	-5.41	-11.97	-13.20	40.8	76.3	-57.5	-56.7
342	0	2.71	1.61	-12.38	-13.77	84.8	110.5	-17.1	-15.6
345	0	6.03	5.88	-12.77	-14.33	120.6	138.0	22.5	24.8
348	0	8.57	8.82	-13.29	-15.07	152.7	164.4	61.1	64.4
351	0	10.45	10.91	-14.06	-16.11	-176.9	-169.4	99.0	104.0
354	0	11.73	12.33	-15.12	-17.48	-147.5	-143.1	137.3	145.4
357	0	12.48	13.21	-16.44	-18.93	-118.5	-116.6	177.2	-169.3
360	0	12.71	13.58	-17.79	-19.84	-90.0	-89.9	-140.1	-119.5

CPU RUN TIME FOR RUN 1 GEOMETRY 1 = 1537.99 SECONDS

TOTAL CPU RUN TIME = 1538.42 SECONDS

Appendix C

Output for Example 3

```
       INPUT DATA

  FREQ.(MHZ)=    300.000   WAVE(M)=      1.000   WIRE RAD(M)=  0.001000
  INTP=    6   INTD=  18   INT =     4   IFIL= 1


  WIRE CONDUCTIVITY = -1.00 MEGAMHOS/M



  GEOMETRY FOR THE    1 PLATES



                        PLATE NUMBER    1  (POLYGONAL)
  NUMBER OF CORNERS =    5
  MAXIMUM SEGMENT SIZE  (WAVELENGTH) =     0.25000
  POLARIZATION INDICATOR =    3
  GENERATING SIDE INDICATOR =    0

 X,Y,Z COOR.(METERS) OF CORNER  1 =     1.00000     0.00000     0.00000
 X,Y,Z COOR.(METERS) OF CORNER  2 =     0.00000     0.50000     0.00000
 X,Y,Z COOR.(METERS) OF CORNER  3 =     0.00000     1.00000     0.00000
 X,Y,Z COOR.(METERS) OF CORNER  4 =     1.00000     1.50000     0.00000
 X,Y,Z COOR.(METERS) OF CORNER  5 =     1.50000     0.50000     0.00000
```

THERE ARE 71 MODES ON PLATE 1

LISTING OF LOADS AND GENERATORS

NWR = NUMBER OF WIRE MODES = 0
NPLTM = NUMBER OF PLATE MODES = 71
NAT = NUMBER OF ATTACHMENT MODES = 0

BISTATIC SCATTERING, ISCAT = 2
THETA INC.(DEG.) = 0.0
PHI INC.(DEG.) = 0.0

*(DEG)**		** CROSS SECTION	(DB/M**2) **		******	PHASE	(DEG)	******
TH	PHI	STTM	SPPM	STPM	SPTM	STTM	SPPM	STPM	SPTM
0	0	12.71	13.58	-17.79	-19.84	-90.0	-89.9	-140.1	-119.5
3	0	12.63	13.57	-18.18	-19.95	-75.8	-76.4	-120.9	-90.8
6	0	12.43	13.44	-18.51	-19.80	-61.8	-62.9	-101.5	-61.8
9	0	12.11	13.18	-18.79	-19.42	-47.9	-49.3	-82.1	-33.9
12	0	11.66	12.80	-19.02	-18.91	-34.3	-35.8	-63.1	-7.7
15	0	11.08	12.30	-19.24	-18.41	-21.0	-22.2	-44.4	16.5
18	0	10.37	11.67	-19.45	-18.02	-8.0	-8.5	-26.2	39.0
21	0	9.53	10.92	-19.68	-17.80	4.7	5.3	-8.6	60.1
24	0	8.53	10.05	-19.94	-17.78	17.0	19.3	8.6	80.2
27	0	7.39	9.06	-20.23	-17.96	28.8	33.5	25.2	99.5
30	0	6.08	7.95	-20.57	-18.35	40.1	48.1	41.2	118.3
33	0	4.60	6.75	-20.94	-18.94	50.7	63.1	56.8	136.9
36	0	2.94	5.48	-21.36	-19.72	60.6	79.0	71.9	155.5
39	0	1.05	4.18	-21.80	-20.66	69.6	95.8	86.4	174.4
42	0	-1.08	2.94	-22.27	-21.71	77.6	113.6	100.4	-166.1
45	0	-3.50	1.84	-22.74	-22.80	83.9	132.6	113.9	-145.9
48	0	-6.27	1.00	-23.21	-23.84	88.1	152.1	126.9	-125.0
51	0	-9.43	0.49	-23.66	-24.73	88.6	171.4	139.2	-103.7
54	0	-12.92	0.29	-24.08	-25.41	82.9	-170.5	150.8	-82.8
57	0	-16.12	0.32	-24.47	-25.88	67.1	-154.3	161.7	-63.2

60	0	-17.55	0.49	-24.82	-26.23	43.9	-140.2	171.7	-45.6
63	0	-17.15	0.72	-25.12	-26.58	26.3	-128.2	-179.1	-30.4
66	0	-16.42	0.94	-25.37	-27.01	17.6	-118.0	-170.8	-17.3
69	0	-16.06	1.15	-25.58	-27.61	14.4	-109.5	-163.5	-6.3
72	0	-16.21	1.32	-25.75	-28.45	13.6	-102.4	-157.1	2.8
75	0	-16.90	1.45	-25.88	-29.62	14.1	-96.7	-151.8	10.2
78	0	-18.17	1.55	-25.98	-31.21	15.0	-92.1	-147.4	16.1
81	0	-20.18	1.63	-26.06	-33.45	15.9	-88.5	-144.0	20.7
84	0	-23.38	1.68	-26.10	-36.78	16.7	-86.1	-141.6	23.8
87	0	-29.21	1.70	-26.13	-42.69	17.2	-84.6	-140.2	25.7
90	0	-99.90	1.71	-26.14	-99.90	-162.6	-84.1	-139.7	-153.7
93	0	-29.21	1.70	-26.13	-42.69	-162.8	-84.6	-140.2	-154.3
96	0	-23.38	1.68	-26.10	-36.78	-163.3	-86.1	-141.6	-156.2
99	0	-20.18	1.63	-26.06	-33.45	-164.1	-88.5	-144.0	-159.3
102	0	-18.17	1.55	-25.98	-31.21	-165.0	-92.1	-147.4	-163.9
105	0	-16.90	1.45	-25.88	-29.61	-165.9	-96.7	-151.8	-169.8
108	0	-16.21	1.32	-25.75	-28.45	-166.4	-102.4	-157.1	-177.2
111	0	-16.06	1.15	-25.58	-27.61	-165.6	-109.5	-163.5	173.7
114	0	-16.42	0.94	-25.37	-27.01	-162.4	-118.0	-170.8	162.7
117	0	-17.15	0.72	-25.12	-26.58	-153.7	-128.2	-179.1	149.6
120	0	-17.55	0.49	-24.82	-26.23	-136.1	-140.2	171.7	134.4
123	0	-16.12	0.32	-24.47	-25.88	-112.9	-154.3	161.7	116.8
126	0	-12.92	0.29	-24.08	-25.41	-97.1	-170.5	150.8	97.2
129	0	-9.43	0.49	-23.66	-24.73	-91.4	171.4	139.2	76.3
132	0	-6.27	1.00	-23.21	-23.84	-91.9	152.1	126.9	55.0
135	0	-3.50	1.84	-22.74	-22.80	-96.1	132.6	113.9	34.1
138	0	-1.08	2.94	-22.27	-21.71	-102.4	113.6	100.4	13.9
141	0	1.05	4.18	-21.80	-20.66	-110.4	95.8	86.4	-5.6
144	0	2.94	5.48	-21.36	-19.72	-119.4	79.0	71.9	-24.5
147	0	4.60	6.75	-20.94	-18.94	-129.3	63.1	56.8	-43.1
150	0	6.08	7.95	-20.57	-18.35	-139.9	48.1	41.2	-61.7
153	0	7.39	9.06	-20.23	-17.96	-151.2	33.5	25.2	-80.5
156	0	8.53	10.05	-19.94	-17.78	-163.0	19.3	8.6	-99.8
159	0	9.53	10.92	-19.68	-17.80	-175.3	5.3	-8.6	-119.9
162	0	10.37	11.67	-19.45	-18.02	172.0	-8.5	-26.2	-141.0
165	0	11.08	12.30	-19.24	-18.41	159.0	-22.2	-44.4	-163.5
168	0	11.66	12.80	-19.02	-18.91	145.7	-35.8	-63.1	172.3
171	0	12.11	13.18	-18.79	-19.42	132.1	-49.3	-82.1	146.1
174	0	12.43	13.44	-18.51	-19.80	118.2	-62.9	-101.5	118.2
177	0	12.63	13.57	-18.18	-19.95	104.2	-76.4	-120.9	89.2
180	0	12.71	13.58	-17.79	-19.84	90.0	-89.9	-140.1	60.5
183	0	12.67	13.45	-17.33	-19.55	75.7	-103.3	-159.1	32.9
186	0	12.52	13.20	-16.82	-19.22	61.3	-116.7	-177.6	6.9
189	0	12.27	12.83	-16.28	-18.97	46.9	-130.0	164.6	-17.6

192	0	11.90	12.31	-15.71	-18.89	32.4	-143.3	147.4	-41.1
195	0	11.44	11.66	-15.15	-19.01	17.9	-156.5	131.0	-63.9
198	0	10.88	10.88	-14.59	-19.33	3.5	-169.7	115.2	-86.7
201	0	10.24	9.94	-14.06	-19.84	-10.8	177.1	100.2	-110.0
204	0	9.51	8.86	-13.56	-20.47	-25.1	163.9	85.9	-134.1
207	0	8.71	7.61	-13.09	-21.11	-39.2	150.5	72.1	-159.7
210	0	7.84	6.19	-12.67	-21.60	-53.1	136.9	59.0	173.6
213	0	6.91	4.58	-12.30	-21.77	-66.8	122.7	46.4	146.4
216	0	5.93	2.79	-11.97	-21.59	-80.3	107.7	34.4	120.3
219	0	4.91	0.82	-11.70	-21.15	-93.4	91.1	23.0	96.5
222	0	3.86	-1.26	-11.46	-20.61	-106.0	72.0	12.0	75.4
225	0	2.77	-3.23	-11.28	-20.12	-118.3	49.5	1.6	56.9
228	0	1.66	-4.70	-11.14	-19.74	-129.9	23.4	-8.2	40.8
231	0	0.53	-5.24	-11.03	-19.51	-141.0	-3.7	-17.5	26.5
234	0	-0.63	-4.94	-10.97	-19.45	-151.4	-27.7	-26.2	13.9
237	0	-1.82	-4.25	-10.94	-19.56	-161.1	-46.8	-34.3	2.6
240	0	-3.05	-3.50	-10.93	-19.85	-170.0	-61.6	-41.8	-7.4
243	0	-4.33	-2.85	-10.95	-20.32	-178.0	-73.2	-48.7	-16.2
246	0	-5.69	-2.33	-10.98	-20.98	174.7	-82.5	-54.9	-24.0
249	0	-7.14	-1.92	-11.03	-21.85	168.4	-90.0	-60.4	-30.8
252	0	-8.73	-1.62	-11.08	-22.96	162.9	-96.1	-65.3	-36.7
255	0	-10.53	-1.40	-11.13	-24.36	158.2	-101.0	-69.4	-41.6
258	0	-12.65	-1.25	-11.19	-26.16	154.4	-104.9	-72.8	-45.6
261	0	-15.28	-1.14	-11.23	-28.56	151.5	-107.8	-75.5	-48.7
264	0	-18.90	-1.07	-11.26	-32.01	149.4	-109.8	-77.4	-50.9
267	0	-24.98	-1.03	-11.29	-37.99	148.1	-111.0	-78.5	-52.2
270	0	-99.90	-1.02	-11.29	-99.90	-32.3	-111.4	-78.9	127.4
273	0	-24.98	-1.03	-11.29	-37.99	-31.9	-111.0	-78.5	127.8
276	0	-18.90	-1.07	-11.26	-32.01	-30.6	-109.8	-77.4	129.1
279	0	-15.28	-1.14	-11.23	-28.56	-28.5	-107.8	-75.5	131.3
282	0	-12.65	-1.25	-11.19	-26.16	-25.6	-104.9	-72.8	134.4
285	0	-10.53	-1.40	-11.13	-24.36	-21.8	-101.0	-69.4	138.4
288	0	-8.73	-1.62	-11.08	-22.96	-17.1	-96.1	-65.3	143.3
291	0	-7.14	-1.92	-11.03	-21.85	-11.6	-90.0	-60.4	149.2
294	0	-5.69	-2.33	-10.98	-20.98	-5.3	-82.5	-54.9	156.0
297	0	-4.33	-2.85	-10.95	-20.32	2.0	-73.2	-48.7	163.8
300	0	-3.05	-3.50	-10.93	-19.85	10.0	-61.6	-41.8	172.6
303	0	-1.82	-4.25	-10.94	-19.56	18.9	-46.8	-34.3	-177.4
306	0	-0.63	-4.94	-10.97	-19.45	28.6	-27.7	-26.2	-166.1
309	0	0.53	-5.24	-11.03	-19.51	39.0	-3.7	-17.5	-153.5
312	0	1.66	-4.70	-11.14	-19.74	50.1	23.4	-8.2	-139.2
315	0	2.77	-3.23	-11.28	-20.12	61.7	49.5	1.6	-123.1
318	0	3.86	-1.26	-11.46	-20.62	74.0	72.0	12.0	-104.6
321	0	4.91	0.82	-11.70	-21.15	86.6	91.1	23.0	-83.5

324	0	5.93	2.79	-11.97	-21.59	99.7	107.7	34.4	-59.7
327	0	6.91	4.58	-12.30	-21.77	113.2	122.7	46.4	-33.6
330	0	7.84	6.19	-12.67	-21.60	126.9	136.9	59.0	-6.4
333	0	8.71	7.61	-13.09	-21.11	140.8	150.5	72.1	20.3
336	0	9.51	8.86	-13.56	-20.47	154.9	163.9	85.9	45.9
339	0	10.24	9.94	-14.06	-19.84	169.2	177.1	100.2	70.0
342	0	10.88	10.88	-14.59	-19.33	-176.5	-169.7	115.2	93.3
345	0	11.44	11.66	-15.15	-19.01	-162.1	-156.5	131.0	116.1
348	0	11.90	12.31	-15.71	-18.89	-147.6	-143.3	147.4	138.9
351	0	12.27	12.83	-16.28	-18.97	-133.1	-130.0	164.6	162.4
354	0	12.52	13.20	-16.82	-19.22	-118.7	-116.7	-177.6	-173.1
357	0	12.67	13.45	-17.33	-19.55	-104.3	-103.3	-159.1	-147.1
360	0	12.71	13.58	-17.79	-19.84	-90.0	-89.9	-140.1	-119.5

CPU RUN TIME FOR RUN 1 GEOMETRY 1 = 302.18 SECONDS

TOTAL CPU RUN TIME = 302.62 SECONDS

Appendix D

Output for Example 4

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      INPUT DATA

FREQ.(MHZ)=    300.000   WAVE(M)=      1.000   WIRE RAD(M)=  0.001000
INTP=    6    INTD=  18    INT =    4    IFIL= 1


WIRE CONDUCTIVITY = -1.00 MEGAMHOS/M


GEOMETRY FOR THE   2 PLATES


                      PLATE NUMBER    1  (POLYGONAL)
NUMBER OF CORNERS =    4
MAXIMUM SEGMENT SIZE  (WAVELENGTH) =     0.25000
POLARIZATION INDICATOR =    3
GENERATING SIDE INDICATOR =   0

X,Y,Z COOR.(METERS) OF CORNER  1 =     0.00000     0.00000     0.00000
X,Y,Z COOR.(METERS) OF CORNER  2 =     0.00000     0.50000     0.00000
X,Y,Z COOR.(METERS) OF CORNER  3 =     0.00000     0.25000     0.25000
X,Y,Z COOR.(METERS) OF CORNER  4 =     0.00000     0.00000     0.50000


THERE ARE   4 MODES ON PLATE   1
```

PLATE NUMBER 2 (POLYGONAL)

NUMBER OF CORNERS = 4
MAXIMUM SEGMENT SIZE (WAVELENGTH) = 0.25000
POLARIZATION INDICATOR = 3
GENERATING SIDE INDICATOR = 0

X,Y,Z COOR.(METERS) OF CORNER 1 =	0.00000	-0.50000	0.00000
X,Y,Z COOR.(METERS) OF CORNER 2 =	0.50000	0.00000	0.00000
X,Y,Z COOR.(METERS) OF CORNER 3 =	0.50000	0.50000	0.00000
X,Y,Z COOR.(METERS) OF CORNER 4 =	0.00000	0.50000	0.00000

THERE ARE 17 MODES ON PLATE 2

THERE ARE 3 OVERLAP MODES BETWEEN
PLATE 1, SIDE 1 AND PLATE 2, SIDE 4

LISTING OF LOADS AND GENERATORS

NWR = NUMBER OF WIRE MODES = 0
NPLTM = NUMBER OF PLATE MODES = 24
NAT = NUMBER OF ATTACHMENT MODES = 0

BACKSCATTERING, ISCAT = 1

*(DEG)**		** CROSS SECTION	(DB/M**2) **			****** PHASE	(DEG)		******
TH	PHI	STTM	SPPM	STPM	SPTM	STTM	SPPM	STPM	SPTM
45	0	-1.49	-4.85	-6.36	-7.11	-19.8	30.4	-37.6	-43.1
45	3	-1.09	-5.74	-6.28	-6.97	-17.7	42.9	-38.7	-44.3
45	6	-0.77	-6.13	-6.43	-7.08	-16.1	58.1	-40.2	-46.0

45	9	-0.53	-5.81	-6.83	-7.44	-15.0	73.7	-42.0	-48.1
45	12	-0.38	-4.89	-7.53	-8.11	-14.2	87.0	-44.1	-50.8
45	15	-0.33	-3.71	-8.61	-9.16	-13.6	97.0	-46.6	-54.2
45	18	-0.39	-2.53	-10.21	-10.72	-13.3	103.9	-49.9	-59.0
45	21	-0.57	-1.46	-12.59	-13.01	-13.0	108.5	-54.8	-66.4
45	24	-0.89	-0.57	-16.34	-16.39	-12.7	111.5	-63.8	-80.8
45	27	-1.36	0.13	-22.81	-20.46	-12.2	113.4	-92.6	-117.2
45	30	-2.00	0.64	-22.70	-19.12	-11.4	114.4	180.0	-174.2
45	33	-2.84	0.97	-15.92	-14.60	-10.0	114.8	150.8	158.5
45	36	-3.91	1.12	-11.86	-11.21	-7.7	114.8	141.4	146.7
45	39	-5.23	1.10	-9.19	-8.80	-3.6	114.3	136.1	139.8
45	42	-6.80	0.91	-7.32	-7.04	3.2	113.6	132.1	134.8
45	45	-8.49	0.56	-5.97	-5.76	14.6	112.7	128.7	130.7
45	48	-9.79	0.05	-5.03	-4.85	32.4	111.7	125.5	127.0
45	51	-9.89	-0.63	-4.41	-4.24	54.2	110.6	122.4	123.4
45	54	-8.68	-1.47	-4.07	-3.90	72.7	109.5	119.2	120.0
45	57	-6.96	-2.45	-3.99	-3.81	84.7	108.7	116.0	116.4
45	60	-5.31	-3.58	-4.15	-3.96	91.4	108.4	112.6	112.8
45	63	-3.89	-4.81	-4.57	-4.35	94.8	108.8	109.2	109.1
45	66	-2.74	-6.09	-5.26	-4.99	96.2	110.3	105.5	105.2
45	69	-1.83	-7.30	-6.23	-5.90	96.3	113.2	101.7	101.1
45	72	-1.13	-8.28	-7.56	-7.13	95.4	117.3	97.7	96.7
45	75	-0.61	-8.86	-9.32	-8.75	94.0	121.9	93.5	92.1
45	78	-0.26	-8.96	-11.69	-10.88	92.1	125.8	89.2	87.1
45	81	-0.07	-8.64	-15.05	-13.78	89.9	127.6	84.6	81.4
45	84	0.00	-8.04	-20.44	-18.06	87.6	126.9	79.8	74.2
45	87	-0.07	-7.31	-34.91	-25.85	85.1	123.8	73.2	59.9
45	90	-0.25	-6.53	-25.72	-32.64	82.7	119.0	-108.7	-73.3
45	93	-0.54	-5.76	-19.04	-22.13	80.3	112.9	-114.1	-104.5
45	96	-0.91	-5.04	-15.93	-18.10	78.1	106.1	-119.3	-113.4
45	99	-1.37	-4.40	-14.21	-16.03	76.2	98.9	-124.4	-120.0
45	102	-1.89	-3.87	-13.32	-15.01	74.6	91.5	-129.4	-125.7
45	105	-2.44	-3.48	-13.04	-14.71	73.4	84.1	-134.2	-130.8
45	108	-2.99	-3.25	-13.28	-15.04	72.6	76.9	-138.6	-135.2
45	111	-3.52	-3.22	-14.01	-15.99	72.1	70.0	-142.1	-138.3
45	114	-3.99	-3.41	-15.27	-17.61	71.7	63.3	-144.1	-139.1
45	117	-4.39	-3.87	-17.07	-19.95	71.3	57.1	-142.9	-134.6
45	120	-4.71	-4.67	-19.29	-22.61	70.7	51.4	-135.5	-118.4
45	123	-4.95	-5.89	-21.05	-23.18	69.5	46.6	-117.8	-88.7
45	126	-5.16	-7.69	-20.68	-20.77	67.6	43.2	-95.6	-67.7
45	129	-5.35	-10.38	-18.67	-18.09	64.9	43.1	-83.1	-62.0
45	132	-5.56	-14.45	-16.57	-16.03	61.5	52.2	-81.0	-64.4
45	135	-5.81	-18.62	-14.85	-14.53	57.5	93.1	-85.1	-71.1
45	138	-6.13	-15.08	-13.48	-13.44	53.1	140.6	-93.0	-80.6

45	141	-6.55	-10.60	-12.34	-12.59	48.3	153.0	-103.2	-92.2
45	144	-7.09	-7.59	-11.32	-11.85	43.6	154.4	-115.0	-105.5
45	147	-7.78	-5.55	-10.34	-11.10	39.0	152.3	-127.5	-119.7
45	150	-8.65	-4.16	-9.37	-10.28	35.0	148.9	-140.1	-134.2
45	153	-9.75	-3.25	-8.42	-9.41	32.0	144.8	-152.1	-148.0
45	156	-11.12	-2.75	-7.52	-8.52	30.8	140.4	-163.2	-160.8
45	159	-12.79	-2.59	-6.73	-7.70	32.4	135.8	-173.2	-172.2
45	162	-14.69	-2.76	-6.09	-7.01	39.1	131.1	177.8	177.6
45	165	-16.35	-3.23	-5.62	-6.49	53.2	126.2	169.7	168.6
45	168	-16.77	-4.03	-5.35	-6.17	73.6	121.2	162.4	160.5
45	171	-15.62	-5.15	-5.29	-6.08	91.4	116.0	155.8	153.2
45	174	-13.86	-6.64	-5.46	-6.22	101.8	110.5	149.9	146.6
45	177	-12.24	-8.55	-5.87	-6.63	106.6	104.4	144.5	140.3
45	180	-10.95	-10.96	-6.56	-7.32	108.0	97.5	139.5	134.4
45	183	-10.01	-14.02	-7.56	-8.34	107.6	88.9	134.8	128.5
45	186	-9.39	-17.98	-8.91	-9.73	105.9	77.3	130.4	122.4
45	189	-9.06	-23.30	-10.72	-11.58	103.5	58.1	126.1	115.4
45	192	-9.01	-30.06	-13.13	-14.03	100.5	14.9	121.6	106.6
45	195	-9.20	-31.12	-16.48	-17.24	96.7	-62.9	116.2	93.1
45	198	-9.64	-27.53	-21.59	-21.06	92.2	-110.1	107.4	67.6
45	201	-10.29	-24.31	-31.30	-22.91	86.7	-142.8	73.9	23.4
45	204	-11.13	-21.00	-28.40	-20.86	79.9	-168.1	-35.5	-12.8
45	207	-12.08	-17.76	-22.23	-18.53	71.1	174.2	-54.1	-30.9
45	210	-13.00	-14.91	-19.43	-17.05	60.1	162.6	-61.4	-40.9
45	213	-13.69	-12.54	-18.12	-16.38	47.0	154.8	-67.0	-47.8
45	216	-13.95	-10.62	-17.73	-16.39	33.1	149.7	-73.1	-53.9
45	219	-13.76	-9.08	-18.02	-17.08	20.2	146.3	-81.2	-60.6
45	222	-13.30	-7.88	-18.75	-18.44	10.0	144.1	-93.4	-70.1
45	225	-12.78	-6.98	-19.40	-20.34	2.6	142.9	-112.0	-86.8
45	228	-12.39	-6.36	-19.00	-21.59	-2.1	142.3	-135.3	-116.1
45	231	-12.21	-5.99	-17.23	-20.09	-4.6	142.2	-155.8	-148.7
45	234	-12.32	-5.86	-14.94	-17.06	-5.4	142.5	-168.8	-168.1
45	237	-12.79	-5.97	-12.76	-14.26	-4.7	142.9	-175.8	-177.2
45	240	-13.68	-6.33	-10.91	-12.01	-2.4	143.4	-179.1	179.1
45	243	-15.17	-6.94	-9.40	-10.23	1.7	143.5	-179.9	178.2
45	246	-17.55	-7.83	-8.19	-8.85	8.9	142.9	-179.2	178.9
45	249	-21.45	-9.00	-7.24	-7.78	24.1	141.0	-177.4	-179.2
45	252	-26.66	-10.43	-6.53	-7.00	72.9	136.5	-174.7	-176.4
45	255	-22.54	-11.98	-6.05	-6.45	141.0	127.9	-171.4	-173.1
45	258	-17.01	-13.19	-5.78	-6.14	163.7	113.8	-167.5	-169.3
45	261	-13.28	-13.33	-5.72	-6.05	174.6	96.3	-163.2	-165.1
45	264	-10.59	-12.31	-5.87	-6.18	-177.7	81.6	-158.5	-160.6
45	267	-8.53	-10.81	-6.24	-6.54	-171.1	73.0	-153.6	-155.9
45	270	-6.90	-9.38	-6.87	-7.17	-165.0	69.6	-148.4	-151.1

45	273	-5.60	-8.22	-7.78	-8.10	-159.2	69.6	-143.1	-146.4
45	276	-4.55	-7.37	-9.05	-9.39	-153.5	71.7	-137.7	-141.8
45	279	-3.72	-6.84	-10.80	-11.18	-147.8	75.2	-132.4	-137.9
45	282	-3.07	-6.62	-13.24	-13.68	-142.2	79.6	-127.6	-135.6
45	285	-2.57	-6.74	-16.88	-17.37	-136.7	84.8	-124.3	-137.5
45	288	-2.23	-7.23	-23.34	-22.99	-131.3	90.6	-127.6	-156.4
45	291	-2.01	-8.18	-32.35	-24.35	-126.1	96.8	139.0	138.9
45	294	-1.92	-9.74	-21.27	-18.73	-120.9	103.6	97.8	111.7
45	297	-1.93	-12.28	-16.41	-14.98	-116.0	111.3	98.0	108.1
45	300	-2.04	-16.80	-13.64	-12.58	-111.3	121.9	102.1	110.2
45	303	-2.24	-28.14	-11.91	-11.01	-106.8	160.9	107.4	114.2
45	306	-2.50	-20.00	-10.85	-10.00	-102.5	-72.5	113.0	119.2
45	309	-2.82	-12.79	-10.29	-9.45	-98.5	-57.6	118.8	124.5
45	312	-3.17	-8.80	-10.18	-9.29	-94.6	-49.4	124.7	130.2
45	315	-3.54	-6.11	-10.49	-9.51	-90.9	-42.7	130.7	136.1
45	318	-3.90	-4.15	-11.25	-10.11	-87.1	-36.7	136.9	142.3
45	321	-4.24	-2.68	-12.55	-11.15	-83.3	-31.3	143.6	149.1
45	324	-4.53	-1.58	-14.57	-12.70	-79.1	-26.2	151.6	157.1
45	327	-4.76	-0.78	-17.66	-14.93	-74.5	-21.5	163.2	167.8
45	330	-4.89	-0.23	-22.40	-17.96	-69.5	-17.2	-171.5	-174.7
45	333	-4.93	0.10	-24.66	-20.98	-63.9	-13.2	-106.5	-140.3
45	336	-4.85	0.23	-19.44	-20.19	-58.0	-9.4	-64.3	-94.1
45	339	-4.65	0.16	-15.32	-16.80	-51.8	-5.9	-50.0	-67.3
45	342	-4.33	-0.08	-12.52	-13.90	-45.7	-2.5	-43.4	-54.8
45	345	-3.93	-0.49	-10.53	-11.74	-39.9	1.0	-39.7	-48.3
45	348	-3.45	-1.08	-9.07	-10.14	-34.5	4.6	-37.6	-44.7
45	351	-2.94	-1.84	-7.99	-8.94	-29.8	8.9	-36.7	-42.9
45	354	-2.43	-2.75	-7.20	-8.07	-25.8	14.1	-36.4	-42.2
45	357	-1.94	-3.79	-6.67	-7.47	-22.4	21.0	-36.8	-42.3
45	360	-1.49	-4.85	-6.36	-7.11	-19.8	30.4	-37.6	-43.1

CPU RUN TIME FOR RUN 1 GEOMETRY 1 = 399.62 SECONDS

TOTAL CPU RUN TIME = 400.15 SECONDS

Appendix E

Output for Example 5

```
        INPUT DATA

 FREQ.(MHZ)=   300.000   WAVE(M)=      1.000   WIRE RAD(M)=  0.001000
 INTP=   6   INTD=  18   INT =    4    IFIL= 1


 WIRE CONDUCTIVITY = -1.00 MEGAMHOS/M



 GEOMETRY FOR THE   3 PLATES



                        PLATE NUMBER   1  (RECTANGULAR)
 NUMBER OF CORNERS =   4
 MAXIMUM SEGMENT SIZE  (WAVELENGTH) =    0.25000
 POLARIZATION INDICATOR =   1
 GENERATING SIDE INDICATOR =   0

X,Y,Z COOR.(METERS) OF CORNER  1 =     0.25000     0.00000     0.00000
X,Y,Z COOR.(METERS) OF CORNER  2 =     0.25000     0.00000     0.50000
X,Y,Z COOR.(METERS) OF CORNER  3 =     0.00000     0.00000     0.50000
X,Y,Z COOR.(METERS) OF CORNER  4 =     0.00000     0.00000     0.00000


 THERE ARE   1 MODES ON PLATE   1
```

```
                    PLATE NUMBER   2  (RECTANGULAR)
 NUMBER OF CORNERS =   4
 MAXIMUM SEGMENT SIZE  (WAVELENGTH) =     0.25000
 POLARIZATION INDICATOR =   1
 GENERATING SIDE INDICATOR =   0

X,Y,Z COOR.(METERS) OF CORNER  1 =     0.00000     0.00000     0.00000
X,Y,Z COOR.(METERS) OF CORNER  2 =     0.00000     0.00000     0.50000
X,Y,Z COOR.(METERS) OF CORNER  3 =    -0.25000     0.00000     0.50000
X,Y,Z COOR.(METERS) OF CORNER  4 =    -0.25000     0.00000     0.00000


 THERE ARE   1 MODES ON PLATE   2



                    PLATE NUMBER   3  (RECTANGULAR)
 NUMBER OF CORNERS =   4
 MAXIMUM SEGMENT SIZE  (WAVELENGTH) =     0.25000
 POLARIZATION INDICATOR =   3
 GENERATING SIDE INDICATOR =   0

X,Y,Z COOR.(METERS) OF CORNER  1 =     0.00000     0.00000     0.00000
X,Y,Z COOR.(METERS) OF CORNER  2 =     0.00000     0.00000     0.50000
X,Y,Z COOR.(METERS) OF CORNER  3 =     0.00000     0.50000     0.50000
X,Y,Z COOR.(METERS) OF CORNER  4 =     0.00000     0.50000     0.00000


 THERE ARE   4 MODES ON PLATE   3



 THERE ARE   2 OVERLAP MODES BETWEEN
 PLATE  1, SIDE 3 AND PLATE  2, SIDE 1



 THERE ARE   2 OVERLAP MODES BETWEEN
 PLATE  1, SIDE 3 AND PLATE  3, SIDE 1
```

THERE ARE 0 OVERLAP MODES BETWEEN
PLATE 2, SIDE 1 AND PLATE 3, SIDE 1

LISTING OF LOADS AND GENERATORS

NWR = NUMBER OF WIRE MODES = 0
NPLTM = NUMBER OF PLATE MODES = 10
NAT = NUMBER OF ATTACHMENT MODES = 0

FORWARD SCATTERING, ISCAT = 3

*(DEG)**		** CROSS SECTION	(DB/M**2) **			******	PHASE	(DEG)	******
TH	PHI	STTM	SPPM	STPM	SPTM	STTM	SPPM	STPM	SPTM
90	0	3.67	0.26	-99.90	-99.90	116.6	-118.5	50.6	-116.7
90	5	3.69	0.23	-99.90	-99.90	116.6	-118.3	-170.1	-65.1
90	10	3.75	0.15	-99.90	-99.90	116.2	-117.7	-23.2	-42.1
90	15	3.84	0.03	-99.90	-99.90	115.5	-116.7	-53.1	-99.6
90	20	3.97	-0.13	-99.90	-99.90	114.4	-115.2	-35.8	-79.4
90	25	4.14	-0.29	-99.90	-99.90	113.0	-113.2	90.0	-124.8
90	30	4.35	-0.44	-99.90	-99.90	111.5	-110.6	81.3	-70.3
90	35	4.59	-0.53	-99.90	-99.90	109.8	-107.6	29.1	-108.6
90	40	4.85	-0.54	-99.90	-99.90	108.0	-104.3	32.0	-75.7
90	45	5.12	-0.45	-99.90	-99.90	106.3	-100.9	123.7	-94.1
90	50	5.40	-0.26	-99.90	-99.90	104.6	-97.6	17.4	-86.6
90	55	5.67	0.03	-99.90	-99.90	103.0	-94.8	138.8	-40.0
90	60	5.93	0.37	-99.90	-99.90	101.5	-92.4	66.0	-94.4
90	65	6.16	0.73	-99.90	-99.90	100.3	-90.6	170.5	-165.5
90	70	6.36	1.08	-99.90	-99.90	99.2	-89.3	90.0	-3.5
90	75	6.52	1.39	-99.90	-99.90	98.3	-88.5	135.0	64.4
90	80	6.64	1.62	-99.90	-99.90	97.7	-87.9	-135.0	167.5
90	85	6.71	1.77	-99.90	-99.90	97.3	-87.6	135.0	34.7
90	90	6.73	1.82	-99.90	-99.90	97.2	-87.5	135.0	-29.5
90	95	6.71	1.77	-99.90	-99.90	97.3	-87.6	153.4	82.0

90	100	6.64	1.62	-99.90	-99.90	97.7	-87.9	135.0	83.7
90	105	6.52	1.39	-99.90	-99.90	98.3	-88.5	-116.6	119.4
90	110	6.36	1.08	-99.90	-99.90	99.2	-89.3	-146.3	86.2
90	115	6.16	0.73	-99.90	-99.90	100.3	-90.6	63.4	102.4
90	120	5.93	0.37	-99.90	-99.90	101.5	-92.4	-85.2	-140.1
90	125	5.67	0.03	-99.90	-99.90	103.0	-94.8	-90.0	114.7
90	130	5.40	-0.26	-99.90	-99.90	104.6	-97.6	-140.4	68.5
90	135	5.12	-0.45	-99.90	-99.90	106.3	-100.9	-100.4	61.6
90	140	4.85	-0.54	-99.90	-99.90	108.0	-104.3	-171.6	90.9
90	145	4.59	-0.53	-99.90	-99.90	109.8	-107.6	-96.1	101.7
90	150	4.35	-0.44	-99.90	-99.90	111.5	-110.6	-172.4	98.6
90	155	4.14	-0.29	-99.90	-99.90	113.0	-113.2	-71.6	130.7
90	160	3.97	-0.13	-99.90	-99.90	114.4	-115.2	-25.5	166.4
90	165	3.84	0.03	-99.90	-99.90	115.5	-116.7	-45.0	104.1
90	170	3.75	0.15	-99.90	-99.90	116.2	-117.7	-73.3	52.3
90	175	3.69	0.23	-99.90	-99.90	116.6	-118.3	-108.1	9.9
90	180	3.67	0.26	-99.90	-99.90	116.6	-118.5	45.0	-11.6
90	185	3.69	0.23	-99.90	-99.90	116.2	-118.3	-37.6	62.1
90	190	3.75	0.15	-99.90	-99.90	115.5	-117.7	-33.7	-4.1
90	195	3.85	0.03	-99.90	-99.90	114.4	-116.7	-138.0	59.2
90	200	3.99	-0.13	-99.90	-99.90	113.1	-115.2	-30.3	18.9
90	205	4.17	-0.29	-99.90	-99.90	111.5	-113.1	47.3	-46.3
90	210	4.39	-0.44	-99.90	-99.90	109.9	-110.6	41.2	-56.6
90	215	4.64	-0.53	-99.90	-99.90	108.1	-107.6	90.0	-4.2
90	220	4.91	-0.54	-99.90	-99.90	106.4	-104.2	-8.5	-31.3
90	225	5.19	-0.45	-99.90	-99.90	104.7	-100.8	-135.0	-37.5
90	230	5.48	-0.25	-99.90	-99.90	103.1	-97.6	143.1	7.8
90	235	5.75	0.03	-99.90	-99.90	101.6	-94.7	74.1	-20.4
90	240	6.01	0.37	-99.90	-99.90	100.3	-92.4	71.6	-35.2
90	245	6.24	0.74	-99.90	-99.90	99.1	-90.6	180.0	-6.1
90	250	6.44	1.09	-99.90	-99.90	98.2	-89.3	-108.4	-19.1
90	255	6.60	1.39	-99.90	-99.90	97.4	-88.5	153.4	-3.6
90	260	6.72	1.62	-99.90	-99.90	96.9	-87.9	90.0	13.1
90	265	6.79	1.77	-99.90	-99.90	96.5	-87.6	-104.0	-24.2
90	270	6.82	1.82	-99.90	-99.90	96.4	-87.5	148.4	-38.5
90	275	6.79	1.77	-99.90	-99.90	96.5	-87.6	180.0	-51.4
90	280	6.72	1.62	-99.90	-99.90	96.9	-87.9	53.1	-51.0
90	285	6.60	1.39	-99.90	-99.90	97.4	-88.5	-82.9	53.4
90	290	6.44	1.09	-99.90	-99.90	98.2	-89.3	-170.9	46.6
90	295	6.24	0.74	-99.90	-99.90	99.1	-90.6	-63.4	-9.0
90	300	6.01	0.37	-99.90	-99.90	100.3	-92.4	-143.1	13.8
90	305	5.75	0.03	-99.90	-99.90	101.6	-94.7	-104.0	-4.4
90	310	5.48	-0.25	-99.90	-99.90	103.1	-97.6	-123.7	65.9
90	315	5.19	-0.45	-99.90	-99.90	104.7	-100.8	-155.0	19.1

90	320	4.91	-0.54	-99.90	-99.90	106.4	-104.2	-90.0	9.1
90	325	4.64	-0.53	-99.90	-99.90	108.1	-107.6	-132.5	2.5
90	330	4.39	-0.44	-99.90	-99.90	109.9	-110.6	123.7	18.8
90	335	4.17	-0.29	-99.90	-99.90	111.5	-113.1	8.1	74.5
90	340	3.99	-0.13	-99.90	-99.90	113.1	-115.2	-74.6	50.0
90	345	3.85	0.03	-99.90	-99.90	114.4	-116.7	33.2	24.9
90	350	3.75	0.15	-99.90	-99.90	115.5	-117.7	-161.6	-78.0
90	355	3.69	0.23	-99.90	-99.90	116.2	-118.3	171.9	113.7
90	360	3.67	0.26	-99.90	-99.90	116.6	-118.5	-167.5	165.0

CPU RUN TIME FOR RUN 1 GEOMETRY 1 = 76.40 SECONDS

TOTAL CPU RUN TIME = 76.89 SECONDS

Appendix F

Code to Read Geometry Data

```
C-------DIMENSION INDICATOR ASSIGNMENTS
        PARAMETER (IPL=30)
        PARAMETER (ICN=8)
        PARAMETER (IPLM=500)
        PARAMETER (IWS=100)
        PARAMETER (IWP=100)
        PARAMETER (IOPP=100)

C-------DIMENSIONED BY IWP, THE MAX NUMBER OF WIRE POINTS
        DIMENSION X(IWP),Y(IWP),Z(IWP)

C-------DIMENSIONED BY IWS, THE MAX NUMBER OF WIRE SEGMENTS
        DIMENSION IA(IWS),IB(IWS)

C-------DIMENSIONED BY IPL
        DIMENSION NCNRS(IPL),NPL11(IPL),NPL22(IPL),NDNPLT(IPL),IPN(IPL)

C-------DIMENSIONED BY IPLM
        DIMENSION PA(IPLM,4,3),PB(IPLM,4,3)

C-------DIMENSIONED BY IOPP, THE MAX NUMBER OF OVERLAP PLATE PAIRS
        DIMENSION ITK(IOPP),IOVT(IOPP,4)

C-------DIMENSIONED BY ICN AND IPL
```

```
      DIMENSION PCN(3,ICN,IPL)
          .
          .
          .
          .

 10   FORMAT(' INCREASE PARAMETER IPL  TO ',I3,'  OR GREATER')
 20   FORMAT(' INCREASE PARAMETER IPLM TO ',I4,' OR GREATER')
 30   FORMAT(' INCREASE PARAMETER IWS  TO ',I3,'  OR GREATER')
 40   FORMAT(' INCREASE PARAMETER IWP  TO ',I3,'  OR GREATER')
 60   FORMAT(' INCREASE PARAMETER IOPP TO ',I3,'  OR GREATER')
 80   FORMAT(' INCREASE PARAMETER ICN  TO ',I3,'  OR GREATER')


C-------READ IN WIRE/PLATE/OVERLAP GEOMETRY FOR GKS PLOTTING
C       MAKE SURE STORAGE ARRAYS ARE OF ADEQUATE SIZE FOR THIS
DATA SET.
C       IF NOT TELL THE USER WHICH DIMENSIONS TO INCREASE AND END.
C
      READ(9,*)NPLTS,NPLTM,NM,NP,NWR,NAT,WV,NOPL,NOVT
      IFLAG=0
      IF(NPLTS.GT.IPL)THEN
              WRITE(5,10)NPLTS
              IFLAG=1
      ENDIF
      IF(NPLTM.GT.IPLM)THEN
              WRITE(5,20)NPLTM
              IFLAG=1
      ENDIF
      IF(NM.GT.IWS)THEN
              WRITE(5,30)NM
              IFLAG=1
      ENDIF
      IF(NP.GT.IWP)THEN
              WRITE(5,40)NP
              IFLAG=1
      ENDIF
```

```
      IF(NOPL.GT.IOPP)THEN
              WRITE(5,60)NOPL
              IFLAG=1
      ENDIF

      IF(IFLAG.EQ.1)STOP

      DO 158 I=1,NP
      READ(9,*)X(I),Y(I),Z(I)
158   CONTINUE
      DO 159 I=1,NM
      READ(9,*)IA(I),IB(I)
159   CONTINUE
      NCMAX=0
      DO 151 NPL=1,NPLTS
      READ(9,*)NCNRS(NPL),NPL11(NPL),NPL22(NPL),NDNPLT(NPL),IPN(NPL)
      IF(NCNRS(NPL).GT.NCMAX)NCMAX=NCNRS(NPL)
151   CONTINUE
      IF(NCMAX.GT.ICN)THEN
              WRITE(5,80)NCMAX
              STOP
      ENDIF
      DO 152 I=1,NPLTM
      DO 153 J=1,4
      READ(9,*)PA(I,J,1),PA(I,J,2),PA(I,J,3),PB(I,J,1),PB(I,J,2),
     2 PB(I,J,3)
153   CONTINUE
152   CONTINUE
      DO 156 NPL=1,NPLTS
      NCNR=NCNRS(NPL)
      DO 157 NC=1,NCNR
      READ(9,*)PCN(1,NC,NPL),PCN(2,NC,NPL),PCN(3,NC,NPL)
157   CONTINUE
156   CONTINUE
      DO 166 I=1,NOPL
      READ(9,*)IOVT(I,1),IOVT(I,2),IOVT(I,3),IOVT(I,4),ITK(I)
166   CONTINUE
```

```
C-------END GEOMETRY DATA INPUT
```

Appendix G

Code to Read Pattern Data

```
C-------DIMENSION INDICATOR ASSIGNMENTS
C       IPATS = MAXIMUM NUMBER OF PATTERNS
C       IPNTS = MAXIMUM NUMBER OF DATA POINTS FOR A PATTERN
        PARAMETER (IPATS = 5)
        PARAMETER (IPNTS = 361)


C-------DIMENSIONED BY IPATS ONLY
        DIMENSION NPTS(IPATS),ISCAT(IPATS),IEA(IPATS),CANG(IPATS)
     +            ,THIN(IPATS),PHIN(IPATS)

C-------DIMENSIONED BY IPATS AND IPNTS: PATS(IPATS,IPNTS,2*IRS12,2)
        DIMENSION PATS(IPATS,IPNTS,4,2)
              .
              .
              .
              .
 31     FORMAT(' INCREASE PARAMETER IPATS TO ',I3,' OR GREATER')
 32     FORMAT(' INCREASE PARAMETER IPNTS TO ',I3,' OR GREATER')

C-------BEGIN READING AND STORING INPUT DATA FILE INFO.
C       IF THE IPATS OR IPNTS DIMENSIONS ARE TOO SMALL
C       THEN INSTRUCT USER AND STOP
```

```
      READ(8,*) NPATS,IRS12,FMC

      IF(NPATS.GT.IPATS) THEN
              WRITE(5,31)NPATS
              STOP
      ENDIF

      IF(IRS12.EQ.1)THEN
              DO 10 I=1,NPATS

              READ(8,*)IEA(I),NPTS(I),CANG(I)
              IF(NPTS(I).GT.IPNTS) THEN
                      WRITE(5,32)NPTS(I)
                      STOP
              ENDIF
              DO 20 J=1,NPTS(I)
                      READ(8,*)PATS(I,J,1,1),PATS(I,J,1,2),
     +                         PATS(I,J,2,1),PATS(I,J,2,2)
20            CONTINUE
10            CONTINUE
      ELSEIF(IRS12.EQ.2)THEN
              DO 30 I=1,NPATS
              READ(8,*)IEA(I),NPTS(I),ISCAT(I),CANG(I),THIN(I)
     +        ,PHIN(I)
              IF(NPTS(I).GT.IPNTS) THEN
                      WRITE(5,32)NPTS(I)
                      STOP
              ENDIF
              DO 40 J=1,NPTS(I)
              READ(8,*)PATS(I,J,1,1),PATS(I,J,1,2),
     +                 PATS(I,J,2,1),PATS(I,J,2,2),
     +                 PATS(I,J,3,1),PATS(I,J,3,2),
     +                 PATS(I,J,4,1),PATS(I,J,4,2)
40            CONTINUE
30            CONTINUE
      ENDIF
C-------FINISHED READING PATTERN DATA FILE
```