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IMPROVED PROGRAMS FOR ANALYSIS OF RADIATION AND SCATTERING BY CONFIGURATIONS OF ARBITRARILY BENT THIN WIRES

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ABSTRACT

Improved user-oriented computer programs are presented and described for analyzing the electromagnetic behavior of arbitrarily bent thin-wire antennas and scatterers. A given problem can involve several wires of different shapes and radii and the wires can be excited or loaded at arbitrary points along their lengths. Matrix methods are used with the method of moments to compute various quantities of engineering interest. For radiation problems these include current distributions, input impedances, and specified far-field patterns and near-field distributions. For scattering problems the current is again calculated along with specified scattered field and bistatic radar cross-section patterns. Particular emphasis is given to required data input, and illustrative examples are included.

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I. INTRODUCTION

Computer programs are presented for analysis of the electromagnetic behavior of arbitrarily bent, thin-wire antennas and scatterers. Brief instructions for using the programs are given and examples are included to illustrate data input requirements. For radiation problems the current distributions on the wires are determined along with appropriate near and far field patterns and input admittances corresponding to feed points. For plane-wave scattering problems the current distributions are again computed along with appropriate scattered fields and bistatic radar cross-section patterns. A given problem geometry can involve more than one wire and it is not necessary that all the wires have the same shape or even the same radius. The wires can be loaded discretely at arbitrary points and for radiation problems they can be excited or fed at any arbitrary point or points along their lengths. Finally, it is possible to include wire junctions in the problem geometry enabling treatment of certain special configurations of practical interest such as wire crosses, supporting wires for long antennas, and so on.

The programs presented here represent improved versions of programs provided in two earlier research reports [1,2]. The advantage here is that computing time requirements have been reduced to about one-half those of the earlier programs. Computations are performed using the matrix methods suggested by Harrington [3,4] as specialized for thin-wire problems where each wire length L and radius a are such that $L/a \gg 1$ and $a \ll \lambda$, the wavelength. In applying these methods each wire in the problem geometry is thought of as a number of short subsections or segments connected together. Normally at least

20 subsections are used per wavelength of wire subject to the condition that each subsection length should be at least five times the radius of the corresponding wire. Accurate results have already been obtained using these programs for a variety of problems of engineering interest. Computations for near field distributions are valid (within the approximations used) up to (but not closer than) a distance equalling the largest segment or subsection length from the nearest wire surface.

All wires are assumed to be perfect conductors with wire losses treated as a special case of wire loading. Within Harrington's general procedure a piecewise linear current approximation is used together with the subsections referred to above. The current approximation is the result of using triangle current expansion functions where each function is non-zero only over a small portion of a wire. Triangle functions are also used for testing functions resulting in a Galerkin solution which is characterized by relatively fast convergence with respect to the number of expansion functions used. Feed voltages and load impedances can only be applied at wire positions corresponding to the peaks of the triangle expansion functions. However, this does not detract from the generality of the programs since the exact locations of points defining the individual segments and triangles can be chosen arbitrarily.

The computer programs presented in this report are intended to handle general wire configurations. Hence, when problems are encountered that are characterized by certain symmetries these programs may require more time for solutions than required by specialized programs written specifically to handle such problems and that incorporate the symmetries at hand. A linear array of parallel identical wires is one such problem. It should be noted that several specialized programs already exist to handle the linear array and certain other special configurations containing symmetry [5-7].

II. PROGRAM DESCRIPTIONS

In this section information is given that should enable the reader to apply the radiation and scattering programs included in the Appendix to specific problems of interest. Particular attention is given to required data input and also to the necessary dimensions of the matrices involved. The latter, of course, enables the user to conserve memory space wherever possible. The program for radiation problems is described first, followed by a description of its counterpart for scattering. Examples of their use are included in Section III. The programs are written in Fortran IV and have been applied with an IBM 360/50 computer.

2-1. Current Approximation

Before proceeding with the program descriptions some further comments regarding the current approximation used may be helpful. As indicated earlier the wires of a given configuration are thought of as being divided into a number of short subsections or segments connected together. This is illustrated in Fig. 1 where it is seen that each segment is defined by its two axial end points. The complete set of points (together with the wire radii) essentially defines the geometry of the wire structure, and individual points are numbered consecutively from the first point of the first wire to the final point of the last wire. The spatial coordinates of these points are normally part of the required data input although they can be provided more easily for certain common configurations by using generating functions. In the programs of the Appendix the total number of points must be less than 100. With this limitation the resulting program can be handled by most medium size computers. Of course, if a large computer is available this number can be increased.

The current is expanded in triangles (such as the triangle in Fig. 2a) resulting in a piecewise linear current approximation (as in Fig. 2b). Each triangle extends over four adjacent segments and is defined by five consecutively

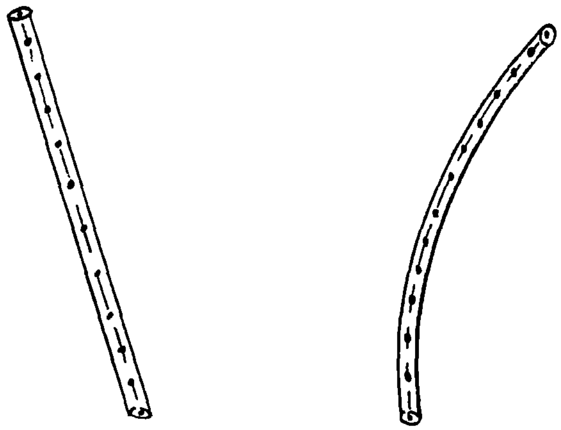

Fig. 1. Problem geometry specified by a sequence of points together with wire radii.

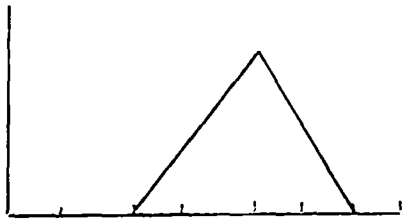

Fig. 2a. Triangle function.

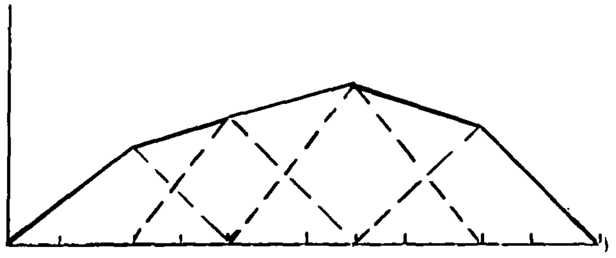

Fig. 2b. Piecewise linear approximation.

numbered points. It is evident that an odd number of points is required to specify the geometry of each wire, although the total number of points for the entire problem may be even. Feed voltages and load impedances can only be applied at wire positions corresponding to the peaks of triangles. However, as mentioned earlier this does not detract from the program generality in any way because the points (and hence, the segments) can always be specified such as to locate feeds and loads at any desired wire positions. Thus, if there are NP points defining the geometry of a single wire then there are (NP-1) segments and $(\frac{NP-1}{2} - 1)$ expansion functions. Finally, either feed voltages or load impedances can be applied at any of the $(\frac{NP-1}{2} - 1)$ triangle peaks.

2-2. Data Input - Radiation Program

The first data statement reads in quantities NW, NP, NR, and BK where NW is the total number of different wires in the problem geometry and where NP is the total number of points needed to specify the problem geometry as described in Section 2-1. As indicated earlier, in the program shown the dimensions are such that NP should be less than 100. NR is the total number of different wire radii encountered in considering the segments consecutively, one-by-one. For example, for a single straight wire of constant radius, NR = 1. On the other hand if a problem consists of two different wires, each with a different radius, then NR = 2. Or, if a single wire has abrupt changes in radius as in Fig. 3 then NR = 3. Note again that NR is the number of changes in radius that occur as segments are considered one-by-one beginning with the first and ending with the last. Finally, BK equals the factor 2π divided by the wavelength in meters.

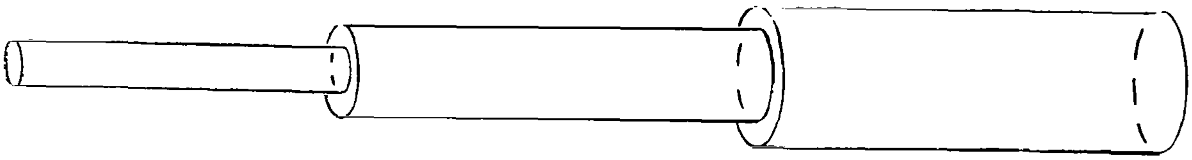

Fig. 3. A single wire with abrupt changes in radius.

The next step is to read in the x,y,z-coordinates of the points defining the problem geometry. For a typical point, say the ith point, these are labeled PX(I), PY(I), and PZ(I), respectively in the program, and these entries are in meters. These coordinates can be read in as data input, or they can be computed automatically in some cases using appropriate generating functions. In the radiation program of the Appendix DO LOOP 50 is used to generate the coordinates of points defining the straight-wire problem included as a first example in Section III. Useful generating functions for specifying other common configurations can be found in an earlier report [1].

The next data statement reads in the elements of a column matrix [LL] of dimension (NW+1). The first element LL(1) denotes the number of the first point on the first wire (normally LL(1) = 1), LL(2) denotes the number of the first point on the second wire, and so on. Finally, LL(NW) denotes the number of the first point on the NWth (and last) wire. It is only necessary to read in NW numbers for the [LL] matrix as LL(NW+1) = 200 is written explicitly in the program and places another limit on the total number of points that can be specified. This statement must be changed along with the dimensions of most matrices if a problem requires use of a larger number of points.

The next read statement provides a column matrix [LR] of dimension (NR+1) containing the numbers of the segments at which changes in radius occur. (These numbers are identical with the numbers of points at which radius changes occur if the problem involves only one wire.) Again referring to Fig. 3, if segments one through ten are of radius R_1, segments 11 through 15 of radius R_2, and segments 16 through 21 of radius R_1 then LR(1) = 1, LR(2) = 11, and LR(3) = 16. Finally, as was the case of the matrix [LL] the program automatically completes the LR matrix with the statement LR(NR+1) = 200.

The various wire radii are read in next (in meters), using a column matrix [RAD] of dimension NR. With reference to the example of the preceeding paragraph it is evident that RAD(1) = R_1, RAD(2) = R_2, and RAD(3) = R_1. In the computer program of the Appendix a matrix [RAD2] is also defined where RAD2(i) = R_i^2.

For radiation problems it is necessary to provide data relating to both wire excitation and loading. Hence, the next data card reads in a number NL which equals the number of discrete load impedances to be applied to the wire structure. This number, of course, cannot exceed the number of current expansion functions (triangles) used. If no loads are to be applied then NL = 0. If NL $\geq$ 1 then DO LOOP 43 executes a total of NL times with an integer LP and a corresponding complex number ZL read in using a single data card with each execution. Recall that loads can be applied only at wire positions corresponding to the peaks of triangles. Hence, LP signifies the number of the particular triangle whose peak marks the position of the first load impedance and ZL is the value of that load impedance in ohms. (Note, the first triangle begins at the first point and terminates at point five, while the second begins at point three and terminates at point seven, and so on.) Thus, following the data statement providing NL, the next NL data cards read in load positions (corresponding to the numbers of specific triangles) and load values for each of the discrete loads to be applied.

Data relating to feed or excitation voltages are provided in the same way. The next card reads in a number NF which equals the number of independent feed voltages to be applied to the wire structure. For radiation problems it is assumed NF $\geq$ 1, and DO LOOP 44 executes a total of NF times with an integer J1 and a complex number V read in using a single data card with each execution. Feed voltages must also be applied at wire positions corresponding to the peaks of triangles. Hence J1 is the number of the particular triangle whose peak marks the desired position of the first excitation voltage and V in the desired excitation in volts. Thus, following the data statement providing NF, the next NF data cards read in feed positions (corresponding to the numbers of specific triangles) and excitation voltages for each of the feed points of the wire structure.

Far-field patterns are calculated and printed out using DO LOOP 17. Here, of course, it is necessary to provide the polar and azimuthal angles of observation desired. In the radiation program included in the Appendix the instructions

```
PHI = 90.
DO 17 ITH = 1,91,10
```

result in a pattern corresponding to the $\phi = 90°$ plane with θ varying from zero to 90° in 10° steps. These instructions can be changed easily, of course, to provide whatever patterns are desired. The printed output includes real and imaginary parts, magnitude, and phase of both the θ and ϕ components of the far-zone electric field vector. These components are labeled E(1) and E(2), respectively in DO LOOP 17.

Near-field distributions are calculated and printed out using DO LOOP 18. Here it is necessary to specify the x,y,z-coordinates of points when the near field is to be calculated. These coordinates are denoted by X1, X2, X3 in the program. These points can be specified individually as data input or they can be computed automatically using a generating function. In the particular radiation program included in the Appendix the instructions

```
DO 18 M = 1,3
XM = M
DO 18 K = 1,7,2
XK = K
X1 = 0
X2 = .2*XK
X3 = (XM-1.)*.5
```

specify the points (0.0, 0.6, 0.0), (0.0, 1.0, 0.0), (0.0, 1.4, 0.0), (0.0, 0.2, 0.5), (0.0, 0.6, 0.5), ..., (0.0, 1.4, 1.0), as shown in the printed output. Subroutine ENEAR is then used to calculate the real and imaginary parts, magnitude, and phase of the x,y,z-components of the electric field vector at each point specified. These components are labeled E(1), E(2), and E(3) in DO LOOP 18 and this information is all included, of course, in the printed output.

This completes the discussion of required data input for the radiation program shown in the Appendix. The printed output includes all data input, the current distribution (complex triangle amplitudes), input impedances calculated at all feed points, total power input, and the far- and near-field patterns and distributions as described above.

2-3. Radiation Program Description

As mentioned earlier the programs presented in this report are derived from the matrix methods suggested by Harrington [3,4] as specialized for thin-wire problems. Within Harrington's general procedure triangle expansion functions are used resulting in a piecewise linear current approximation. Triangles are also used for testing functions, and this choice is known as Galerkin's Method. In some instances triangles are approximated by sequences of pulse functions in order to simplify certain required integrations.

Once the geometry of a given problem has been specified DO LOOP 2 is used to locate the centers of the individual segments and also to calculate the segment lengths. The x,y,z-coordinates of the centerpoints are arranged as column matrices [XX],[XY] and [XZ], respectively. The column matrix of segment lengths is denoted by [AL] in the program and the x,y,z-components of these lengths are normalized and labeled [TX], [TY], and [TZ], respectively.

The generalized impedance matrix [Z] is computed using subroutine CALZ. This matrix is a function only of the problem geometry and is a square matrix of dimension equal to the number of expansion functions used. The effects of loading are included in the impedance matrix by using DO LOOP 43, and subsequently [Z] is inverted using subroutine LINEQ. The result $[Z]^{-1}$ is known as the generalized admittance matrix, but because $[Z]^{-1}$ occupies the same storage locations previously held by [Z] the admittance matrix is also denoted by [Z] in the program. It should also be noted that [Z] is manipulated in this program as a column matrix of N^2 complex numbers where $N = (\frac{NP-1}{2} - 1)$, the number of expansion functions used.

DO LOOPS 45 and 44 are used to calculate the generalized voltage matrix [U] and this is premultiplied by $[Z]^{-1}$ resulting in the generalized current matrix [C]. Both are column matrices of dimension equal to the number of expansion functions used. Each element of [U] equals the complex excitation voltage applied at the wire position of the peak of the corresponding triangle. Obviously, many elements of [U] are normally zero. Each element of [C] equals the corresponding complex current amplitude. Input impedances are calculated in DO LOOP 23 along with the total power input for the radiating structure. Finally, the far-field patterns of interest are computed using DO LOOP 17 with subroutine ROW, and the near-field distributions are calculated as described earlier using DO LOOP 18 which includes subroutine ENEAR.

Matrices which have not been discussed in either this section or the last include a column matrix [L] which has as its elements the numbers of the first triangles of each wire in the problem. For example, if the first triangle of the first wire is triangle No. 1 and if the first triangle of the second wire in triangle No. 6, then the first two elements of [L] are the numbers one and six, and so on. Also, a column matrix [IFP] is defined with elements specifying the numbers of triangles where excitations are actually applied. For example, if excitation voltages are applied at wire positions corresponding to the peaks of triangles 5, 11, and 15, then the elements of [IFP] are simply 5, 11, and 15. Finally, the matrices [EI] and [UV] shown in the main program pertain only to scattering and are not involved in the radiation program.

2-4. Data Input - Scattering Program

Data input for the scattering program are identical with the required data input for the radiation program as described in Section 2-2 up to the point where the number of excitation voltagesis specified along with the values and locations of those voltages. For the scattering problem NF is not required and DO LOOP 44 of the radiation program is not included. Instead, following DO LOOP 43 (which pertains to loading as described earlier) information is provided concerning the propagation and orientation of the incoming plane wave. In fact, the program is set up to allow calculations for several different incoming waves. This is accomplished by first specifying a number NSET which is simply the number of different problems or incoming plane waves to be treated. For example, if computations are to be made for the scattering by a wire structure due to an x-polarized plane wave propagating in the +z-direction and also for a z-polarized wave propagating in the +y-direction then NSET = 2.

Following the specification of NSET the next read statement provides the numbers THE, PHI, EI(1), and EI(2) which completely specify the incoming plane wave. THE and PHI denote angles θ_i and ϕ_i in degrees respectively which designate the direction of propagation of the incident wave as shown in Fig. 4.

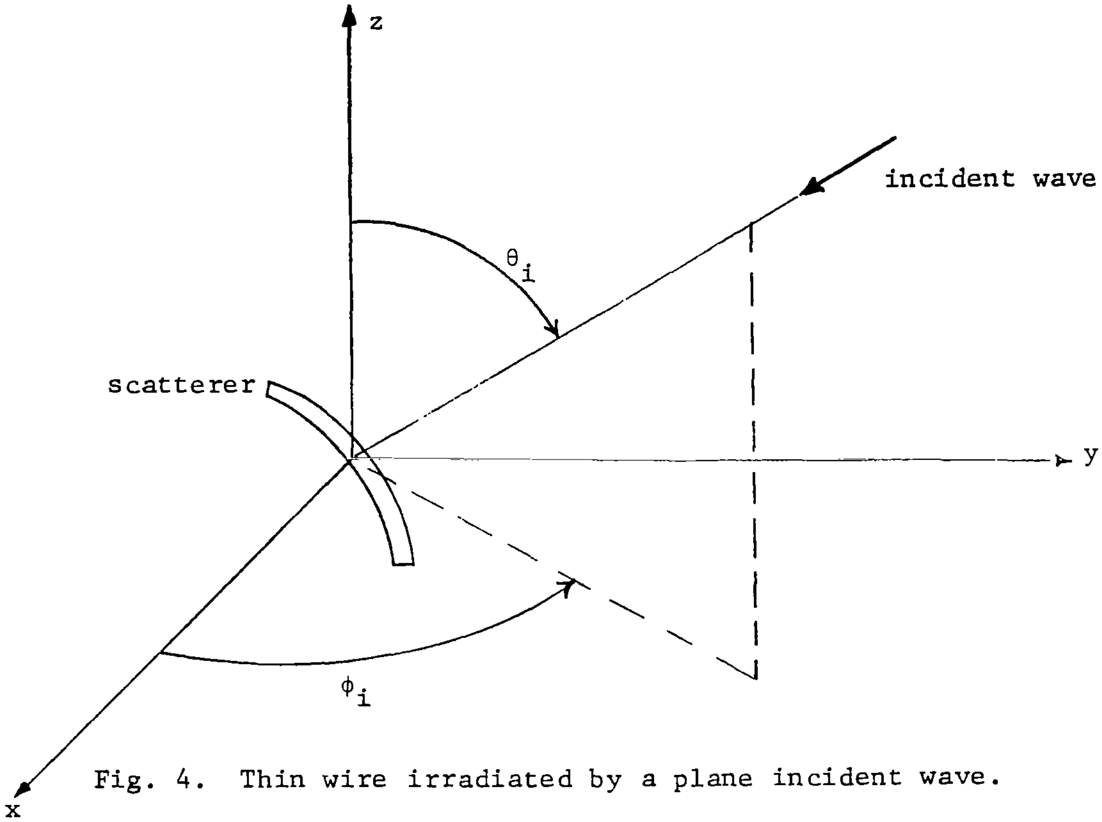

Fig. 4. Thin wire irradiated by a plane incident wave.

Then, EI(1) and EI(2) (in volts/meter) are the θ and ϕ components of the incident electric field where phase is with respect to the coordinate origin. As mentioned earlier the program is set up to handle scattering by a given structure due to several different incoming waves. Thus, a data card providing THE, PHI, EI(1), and EI(2) is needed for each wave. (The number of these statements equals NSET.)

Scattered field patterns are calculated and printed out using DO LOOP 17 just as the far-field patterns were treated in the radiation program. In the scattering program included in the Appendix the instructions

```
PHI = 90.
DO 17 ITH = 1,91,5
```

result in a pattern corresponding to the $\phi = 90°$ plane with θ varying from zero to 90° in 5° steps. The printed output includes real and imaginary parts, magnitude, and phase of both the θ and ϕ components of the electric vector of the scattered field. Also included are the bistatic radar cross-section patterns corresponding to the two scattered field components. These are labeled SIGMA in the program. These computations are all included in DO LOOP 26 which executes a total of NSET times, once for each incoming wave treated.

2-5. Scattering Program Description

The operation of the scattering program is the same as the radiation program through the specification of loading and the inversion of the impedance matrix using subroutine LINEQ. It's at this point that NSET is read in and computations of the current distributions and scattered fields are performed using DO LOOP 26. An equivalent generalized voltage matrix [U] is computed from knowledge of the incident wave, and this is premultiplied by $[Z]^{-1}$ resulting in the current matrix [C] as before. Once the current is known DO LOOP 17 executes, providing the scattered fields and bistatic radar cross-section patterns requested. Obviously, computations of the current distribution and desired scattering patterns are performed once for each incoming wave treated, and hence, are included in DO LOOP 26.

The only matrices that are different from those described with the radiation program are [EI] and [UV]. The former has components EI(1) and EI(2) which are provided as input data as described in Section 2-4. The latter is used only as a tool in performing the necessary calculations.

2-6. Dimensions

The required dimensions of most matrices are related either to NP, the number of points specifying the problem geometry, or to NW, the total number of wires, or to NR, the number of wire radii encountered as the segments are considered one-by-one from the first to the last. Table 1 lists the matrices that must be dimensioned and indicates how the dimensions relate to these quantities. First, however, note that the total number of segments (denoted by NS) is given by

$$NS = NP - NW$$

and the total number of triangle expansion functions (denoted by N) is

$$N = (NP - 3NW)/2$$

Table 1

a. Main Program

Matrix	Dimension
PX, PY, PZ	NP
XX, XY, XZ, TX, TY, TZ, AL	NS
T, TP	2NS
Z	N × N
U, C, IFP	N
LL, L	NW + 1
LR, RAD, RAD2	NR + 1

b. Subroutine CALZ

Matrix	Dimension
PSI, DC	4NS

c. Subroutine ROW

Matrix	Dimension
BKR, DT, DP	NS

d. Subroutine ENEAR

Matrix	Dimension
P, PS, DX, DY, DZ	NS

e. Subroutine LINEQ

Matrix	Dimension
LA	N

III. EXAMPLES

3-1. Radiation Problem

Consider a z-directed straight wire antenna that is $\lambda/2$ in length and centered at $z=0$. The wire radius is constant at 0.00337λ and the wavelength is one meter. The wire is excited with a unit voltage at $z=-\lambda/8$ and is loaded reactively at the centerpoint ($z=0$) with $Z_\ell = j100$ ohms. The radiation program of Appendix A is applied in this case to determine the current distribution and input impedance along with the far-field patterns and near-field distributions of interest.

Since there is only one short wire in this problem a relatively large number of segments per wavelength can be used conveniently. Choosing a total of 25 equally spaced points (NP = 25) beginning at $z = -0.25$ meter and extending to $z = 0.25$ meter there are 24 equal segments of length $\lambda/48$, or about six times the wire radius. There are 11 triangle expansion functions with the first beginning at $z = -0.25$m and the last ending at $z = 0.25$m. The excitation at $z = -0.125\lambda$ corresponds to the peak of the third triangle, while the load at $z=0$ corresponds to the peak of the sixth triangle. Data input are as follows:

NW = 1 (number of wires)
NP = 25 (number of points)
NR = 1 (number of wire radii encountered
BK = 6.283184 (2π/wavelength in meters)

1st statement

PX, PY, PZ (Coordinates of points - see printout - in this example these points are <u>not</u> included in data input - they are specified instead using the generating function in DO LOOP 50)

LL(1) = 1 (first point on the first wire) — 2nd statement

LR(1) = 1 (the first radius encountered begins with the first segment - there is no change in radius) — 3rd statement

RAD(1) = 0.00337 (wire radius in meters) 4th statement
NL = 1 (number of loads) 5th statement
LP = 6 (load position)
ZL = 0.0 + j100.0 (corresponding load) 6th statement
NF = 1 (number of feed points) 7th statement
FP = 3 (feed position)
V = 1.0 + j0.0 (corresponding feed voltage) 8th statement

As noted above, the rectangular coordinates of the points defining the problem geometry that are stored in matrices PX, PY, and PZ are not part of the input data in this particular case. Instead, they are calculated in the program using the generating function of DO LOOP 50. Generating functions are useful and can be written easily for simple configurations such as straight wires and loops. (It was mentioned earlier that some generating functions are available in earlier reports [1,2].) When a generating function is not used the elements of PX, PY, and PZ must be part of the input data.

The printed output for this problem is presented in Appendix A and includes all data input. Note that the only far-field calculations are for the $\phi = 90°$ plane and for 10° steps in θ. More extensive data for this problem are available and are plotted elsewhere [1,8]. Near-field computations are included here for isolated points in the yz-plane as shown.

3-2. Scattering Problem

As a second example consider the wire cross of Fig. 5 irradiated by the uniform plane wave denoted by $\vec{E} = E_o e^{-jky} \hat{u}_z$. A similar problem was treated earlier by Taylor and McAdams [9,10] and by Chao and Strait [1,10]. The only difference here is that the vertical and horizontal sections of the cross are of different radii. The cross is treated as a junction of four open-ended wires as shown in Fig. 5. The details of treating wire junctions are included in an earlier report [1]. In this example the scattering characteristics are computed

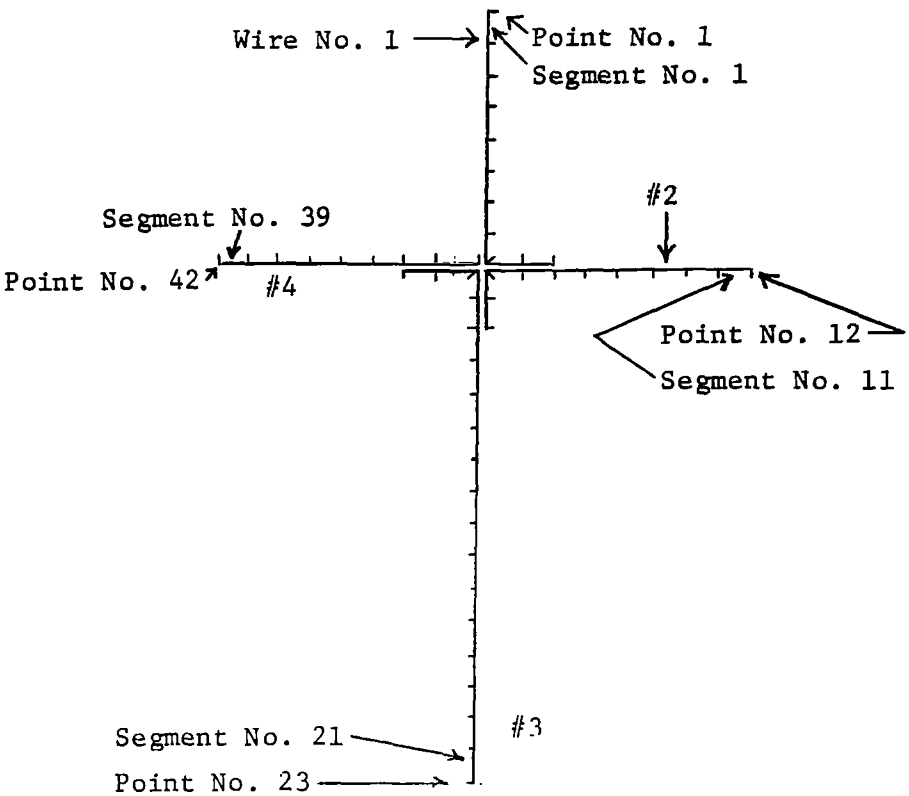

Fig. 5. Thin wire cross treated as four open-ended wires.

for the plane wave given above and also for two additional incident waves denoted by $\vec{E} = E_o e^{-jk(\frac{\sqrt{3}}{2} y + \frac{1}{2} z)} \hat{u}_z$ and by $\vec{E} = E_o e^{-jk(\frac{1}{2} y + \frac{\sqrt{3}}{2} z)} \hat{u}_z$.

The first wire is shown to be defined by 11 points as is the second. Wire No. 3 is characterized by 19 points while wire No. 4 requires 9. Thus, NP = 50 and NW = 4. The vertical section has a total length of 0.33 meters while the horizontal section is of length 0.22 meters. The segment lengths are all equal at about 0.0137m. Segments one through 10 make up the first wire, segments 11-20 the second wire, segments 21-38 the third, and segments 39-46 make up the fourth wire. All segments directed vertically are of one radius and all those directed horizontally are of another radius. Hence, with reference to Fig. 5, segments 1-8 and 19-36 are of radius 0.00222m, while segments 9-18 and 37-46 are of radius 0.00111m. The number of radii that are encountered in considering the segments one-by-one is denoted by NR = 4, and segments corresponding to changes in radius are Nos. 1, 9, 19, and 37. Data input for this problem are as follows:

NW = 4 (number of wires)
NP = 50 (number of points)
NR = 4 (number of radii encountered)
BK = 6.283184 (2π/wavelength in meters, λ = 1 meter)

PX, PY, PZ (coordinates of points defining the geometry - in this case these are treated as data input - see printout)

LL(1) = 1 (first point on wire No. 1)
LL(2) = 12 (first point on wire No. 2)
LL(3) = 23 (first point on wire No. 3)
LL(4) = 42 (first point on wire No. 4)

LR(1) = 1 (segment where first radius begins)
LR(2) = 9 (segment where second radius begins)
LR(3) = 19 (segment where third radius begins)
LR(4) = 37 (segment where fourth radius begins)

RAD(1) = 0.00222 (first radius in meters)
RAD(2) = 0.00111 (second radius in meters)
RAD(3) = 0.00222 (third radius in meters)
RAD(4) = 0.00111 (fourth radius in meters)

NSET = 3 (three incident waves are to be considered)

THETA = 90
PHI = 90
EI(1) = -1.0 + j0.0
EI(2) = 0

$$\vec{E}_{inc.} = e^{-jky}\ \hat{u}_z$$

THETA = 60
PHI = 90
EI(1) = -1.0 + j0.0
EI(2) = 0

$$\vec{E}_{inc.} = e^{-jk(\frac{\sqrt{3}}{2} y + \frac{1}{2} z)}\ \hat{u}_z$$

$$\left\{\begin{array}{l}\text{THETA} = 30\\ \text{PHI} = 90\\ \text{EI}(1) = -1.0 + j0.0\\ \text{EI}(2) = 0\end{array}\right\} \quad \vec{E}_{inc.} = e^{-jk(\frac{1}{2}y + \frac{\sqrt{3}}{2}z)}\,\hat{u}_z$$

Scattered field patterns are computed for $\phi = 90°$ and 5° steps in θ for each incident wave considered. More detailed information on this particular problem is available elsewhere [1].

IV. CONCLUSION

User-oriented computer programs have been presented and described for analyzing the electromagnetic behavior of arbitrarily bent, thin-wire antennas and scatterers. These programs are improved versions of some presented in two earlier reports [1,2] and can be applied to problems involving several wires of different radii that can be bent in different shapes and that can include wire junctions. For radiation problems the wires can be excited or loaded at any arbitrary points along their lengths. Computed output includes all input data, the current distribution of each wire, input impedances corresponding to feed points, and total power input, as well as specified far-field patterns and near-field distributions of interest. For plane-wave scattering problems the wires can also be loaded arbitrarily, and the computed output again includes all input data and wire current distributions, as well as specified scattered field patterns and bistatic radar cross-section patterns. Mutual coupling is taken completely into account in the analysis procedure and no unrealistic assumptions are necessary regarding the wire currents.

Detailed instructions for using these programs were given with particular attention devoted to required data input. Two examples are included to illustrate their use.

V. REFERENCES

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VI. APPENDIX

A. Radiation Program

This program is suitable for radiation problems involving thin wires with excitation and loading represented by voltage sources and lumped loads located at wire positions corresponding to the peaks of triangle expansion functions. The maximum number of points specifying the problem geometry that can be accommodated here is 100. Subroutines are listed first. The input-output data listed correspond to the example of Section 3-1.

```
  SUBROUTINE CALZ (N,N1,Z)
  COMPLEX Z( 400),PSI(200),U,U1,U2,U3,U4,U5,U6
  COMMON XX(50),XY(50),XZ(50),TX(50),TY(50),TZ(50),AL(50)
  COMMON T(100),TP(100),BK,RAD2(10),L(5),LR(10)
  DIMENSION DC(200)
  U=(0.,1.)
  PI=3.141593
  ETA=376.7307
  C1=.125/PI
  C2=.25/PI
  J1=1
  J2=-2
  DO 1 J=1,N
  IF(L(J1)-J) 3,4,3
4 J2=J2+2
  J1=J1+1
3 J3=(J-1)*4
  J4=J3+1
  J5=J4+1
  J6=J5+1
  J7=J6+1
  K4=J2+1
  K5=K4+1
  K6=K5+1
  K7=K6+1
  S1=AL(K4)+AL(K5)
  S2=AL(K6)+AL(K7)
  T(J4)=AL(K4)*.5*AL(K4)/S1
  T(J5)=AL(K5)*(AL(K4)+.5*AL(K5))/S1
  T(J6)=AL(K6)*(AL(K7)+.5*AL(K6))/S2
  T(J7)=AL(K7)*.5*AL(K7)/S2
  TP(J4)=AL(K4)/S1
  TP(J5)=AL(K5)/S1
  TP(J6)=-AL(K6)/S2
  TP(J7)=-AL(K7)/S2
```

```
      J2=J2+2
    1 CONTINUE
      U3=U*BK*ETA
      U4=-U/BK*ETA
      BK2=BK*BK/2.
      BK3=BK2*BK/3.
      N9=0
      N2=1
      NO=1
      N3=-2
      DO 10 NS=1,N
      IF(L(N2)-NS) 12,11,12
   11 KK=1
      N3=N3+2
      N2=N2+1
      GO TO 13
   12 KK=3
      DO 14 NF=1,N1
      N4=NF+N1
      N5=N4+N1
      N6=N5+N1
      DC(NF)=DC(N5)
      DC(N4)=DC(N6)
      PSI(NF)=PSI(N5)
      PSI(N4)=PSI(N6)
   14 CONTINUE
   13 IF (N3+1-LR(NO)) 5,6,5
    6 AA=RAD2(NO)
      NO=NO+1
    5 CONTINUE
      DO 15 K=KK,4
      N7=N3+K
      K1=(K-1)*N1
      DO 16 NF=1,N1
      N8=NF+K1
      S1=XX(N7)-XX(NF)
      S2=XY(N7)-XY(NF)
      S3=XZ(N7)-XZ(NF)
      R2=S1*S1+S2*S2+S3*S3+AA
      R=SQRT(R2)
      RT=ABS(S1*TX(N7)+S2*TY(N7)+S3*TZ(N7))
      RT2=RT*RT
      RH=(R2-RT2)
      ALP=.5*AL(N7)
      AR=ALP/R
      S1=BK*R
      U2=COS(S1)-U*SIN(S1)
      IF(AR-.1) 22,22,21
   21 U2=U2*C1/ALP
      S1=RT-ALP
      S2=RT+ALP
      S3=SQRT(S1*S1+RH)
      S4=SQRT(S2*S2+RH)
      IF(S1) 18,18,19
   18 AI1=ALOG((S2+S4)*(-S1+S3)/RH)
```

```
    GO TO 20
 19 AI1=ALOG((S2+S4)/(S1+S3))
 20 AI2=AL(N7)
    AI3=(S2*S4-S1*S3+RH*AI1)/2.
    AI4=AI2*(RH+ALP*ALP/3.+RT2)
    S3=AI1*R
    S1=AI1-BK2*(AI3-R*(2.*AI2-S3))
    S2=-BK*(AI2-S3)+BK3*(AI4-3.*AI3*R+R2*(3.*AI2-S3))
    GO TO 28
 22 U2=U2*C2/R
    BA=BK*ALP
    BA2=BA*BA
    AR2=AR*AR
    AR3=AR2*AR
    ZR=RT/R
    ZR2=ZR*ZR
    ZR3=ZR2*ZR
    ZR4=ZR3*ZR
    H1=(3.-30.*ZR2+35.*ZR4)*AR3/40.
    A1=AR*(-1.+3.*ZR2)/6.+(3.-30.*ZR2+35.*ZR4)*AR3/40.
    A0=1.+AR*A1
    A2=-ZR2/6.-AR2*(1.-12.*ZR2+15.*ZR4)/40.
    A3=AR*(3.*ZR2-5.*ZR4)/60.
    A4=ZR4/120.
    S1=A0+BA2*(A2+BA2*A4)
    S2=BA*(A1+BA2*A3)
 28 PSI(N8)=U2*(S1+U*S2)
    DC(N8)=TX(NF)*TX(N7)+TY(NF)*TY(N7)+TZ(NF)*TZ(N7)
 16 CONTINUE

 15 CONTINUE
    N3=N3+2
    J3=(NS-1)*4
    J7=-2
    J9=1
    DO 25 NF=1,N
    J1=(NF-1)*4
    IF(L(J9)-NF) 26,27,26
 27 J9=J9+1
    J7=J7+2
 26 N9=N9+1
    U5=0.
    U6=0.
    J5=0
    DO 23 JS=1,4
    J4=J3+JS
    J8=J5+J7
    DO 24 JF=1,4
    J6=J8+JF
    J2=J1+JF
    U5=T(J2)*T(J4)*DC(J6)*PSI(J6)+U5
    U6=TP(J2)*TP(J4)*PSI(J6)+U6
 24 CONTINUE
    J5=J5+N1
 23 CONTINUE
```

```
      Z(N9)=U5*U3+U6*U4
      J7=J7+2
   25 CONTINUE
   10 CONTINUE
      RETURN
      END


      SUBROUTINE ROW(N,TH,PH,E)
      COMPLEX C(20),E(2),U,U1,U2,U3,U4,U5
      COMMON XX(50),XY(50),XZ(50),TX(50),TY(50),TZ(50),AL(50)
      COMMON T(100),TP(100),BK,RAD2(10),L(5),LR(10) /COA/C
      DIMENSION BKR( 50),DT( 50),DP( 50)
      U=(0.,1.)
      ETA=376.7307
      CT=COS(TH)
      ST=SIN(TH)
      CP=COS(PH)
      SP=SIN(PH)
      S1=CT*CP
      S2=CT*SP
      BK1=BK*ST*CP
      BK2=BK*ST*SP
      BK3=BK*CT
      N2=1
      N3=-2
      DO 1 NS=1,N
      IF (L(N2)-NS) 2,3,2
    3 KK=1
      N3=N3+2
      N2=N2+1
      GO TO 4
    2 KK=3
    4 DO 5 K=KK,4
      N7=N3+K
      BKR(N7)=XX(N7)*BK1+XY(N7)*BK2+XZ(N7)*BK3

      DT(N7)=TX(N7)*S1+TY(N7)*S2-TZ(N7)*ST
      DP(N7)=-TX(N7)*SP+TY(N7)*CP
    5 CONTINUE
      N3=N3+2
    1 CONTINUE
      N2=1
      N3=-2
      U3=0.
      U4=0.
      DO 6 NS=1,N
      IF (L(N2)-NS) 7,8,7
    8 N3=N3+2
      N2=N2+1
    7 J1=(NS-1)*4
      U1=0.
      U2=0.
      DO 9 JS=1,4
```

```
      J2=J1+JS
      J3=N3+JS
      S1=BKR(J3)
      U5=T(J2)*(COS(S1)+U*SIN(S1))
      U1=U1+U5*DT(J3)
      U2=U2+U5*DP(J3)
    9 CONTINUE
      U3=U3+U1*C(NS)
      U4=U4+U2*C(NS)
      N3=N3+2
    6 CONTINUE
      S1=.0795774*ETA*BK
      E(1)=-U*S1*U3
      E(2)=-U*S1*U4
      RETURN
      END



      SUBROUTINE ENEAR (N,N1,PX,PY,PZ,E)
      COMPLEX C(20),P( 50),PS( 50),U,U1,U2,U3,U4,U5,UA,UB,UC,UU,E(3)
      COMMON XX(50),XY(50),XZ(50),TX(50),TY(50),TZ(50),AL(50)
      COMMON T(100),TP(100),BK,RAD2(10),L(5),LR(10) /COA/C
      DIMENSION DX( 50),DY( 50),DZ( 50)
      U=(0.,1.)
      PI=3.141593
      ETA=376.7307
      C1=.125/PI
      C2=.25/PI
      U4=-U*BK*ETA
      U5=-U*ETA/BK
      BK2=BK*BK/2.
      BK3=BK2*BK/3.
      BK4=BK3*BK/4.
      N2=1
      N3=-2
      DO 1 NS=1,N
      IF (L(N2)-NS) 2,3,2
    3 KK=1
      N3=N3+2
      N2=N2+1
      GO TO 4
    2 KK=3
    4 N4=N2-1
      DO 5 K=KK,4
      N7=N3+K
      S1=XX(N7)-PX
      S2=XY(N7)-PY
      S3=XZ(N7)-PZ
      R2=S1*S1+S2*S2+S3*S3
      R=SQRT(R2)
```

```
      DX(N7)=S1/R
      DY(N7)=S2/R
      DZ(N7)=S3/R
      RT=S1*TX(N7)+S2*TY(N7)+S3*TZ(N7)
      RT2=RT*RT
      RH=R2-RT2
      ALP=.5*AL(N7)
      AR=ALP/R
      S1=BK*R
      U2=COS(S1)-U*SIN(S1)
      IF(AR-.1) 11,11,6
    6 U2=U2*C1/ALP
      U3=U2
      S1=RT-ALP
      S2=RT+ALP
      S3=SQRT(S1*S1+RH)
      S4=SQRT(S2*S2+RH)
      IF (S1) 7,7,8
    7 AI1=ALOG((S2+S4)*(-S1+S3)/RH)
      GO TO 9
    8 AI1=ALOG((S2+S4)/(S1+S3))
    9 AI2=AL(N7)
      AI3=(S2*S4-S1*S3+RH*AI1)/2.
      AI4=AI2*(RH+ALP*ALP/3.+RT2)
      S3=AI1*R
      S1=AI1-BK2*(AI3-R*(2.*AI2-S3))
      S2=-BK*(AI2-S3)+BK3*(AI4-3.*AI3*R+R2*(3.*AI2-S3))
      RHH=SQRT(ABS(RH))
      S3=4.*RHH*AI2/(4.*R2-AI2*AI2)
      AI0=ATAN(S3)/RHH
      S5=AI0*R
      S3=AI0-BK2*(AI2-R*(2.*AI1-S5))+BK4*(AI4-4.*R*AI3+6.*R2*AI2-R2*R*
     1(4.*AI1-S5))
      S4=-BK*(AI1-S5)+BK3*(AI3-3.*R*AI2+R2*(3.*AI1-S5))
      GO TO 10
   11 U2=U2*C2/R
      U3=U2/R
      BA=BK*ALP
      BA2=BA*BA
      AR2=AR*AR
      AR3=AR2*AR
      AR4=AR3*AR
      ZR=RT/R
      ZR2=ZR*ZR
      ZR3=ZR2*ZR
      ZR4=ZR3*ZR
      H1=(3.-30.*ZR2+35.*ZR4)*AR3/40.
      A1=AR*(-1.+3.*ZR2)/6.
      A0=1.+AR*(A1+H1)
      A1=A1+H1
      A2=-ZR2/6.-AR2*(1.-12.*ZR2+15.*ZR4)/40.
      A3=AR*(3.*ZR2-5.*ZR4)/60.
      A4=ZR4/120.
      S1=A0+BA2*(A2+BA2*A4)
      S2=BA*(A1+BA2*A3)
```

```
      A0=1.+AR2*(-1.+4.*ZR2)/3.+  AR4*(1.-12.*ZR2+16.*ZR4)/5.
      A1=AR*(-1.+5.*ZR2)/6.+AR3*(5.-66.*ZR2+93.*ZR4)/40.
      A2=-ZR2/6.-AR2*(1.-18.*ZR2+29.*ZR4)/40.
      A3=AR*(3.*ZR2-7.*ZR4)/60.
      S3=A0+BA2*(A2+BA2*A4)
      S4=BA*(A1+BA2*A3)
   10 P(N7)=U2*(S1+U*S2)
      PS(N7)=U3*(S3+U*S4)+U*BK*P(N7)
    5 CONTINUE
      N3=N3+2
    1 CONTINUE
      E(1)=0.
      E(2)=0.
      E(3)=0.
      N2=1
      N3=-2
      DO 12 NS=1,N
      IF (L(N2)-NS) 13,14,13
   14 N3=N3+2
      N2=N2+1
   13 J1=(NS-1)*4
      U1=0.
      U2=0.
      U3=0.
      UA=0.
      UB=0.
      UC=0.
      DO 15 JS=1,4
      J2=J1+JS
      J3=N3+JS
      UU=T(J2)*P(J3)
      U1=U1+UU*TX(J3)
      U2=U2+UU*TY(J3)
      U3=U3+UU*TZ(J3)
      UU=TP(J2)*PS(J3)
      UA=UA+UU*DX(J3)
      UB=UB+UU*DY(J3)
      UC=UC+UU*DZ(J3)
   15 CONTINUE
      N3=N3+2
      E(1)=E(1)+(U4*U1+U5*UA)*C(NS)
      E(2)=E(2)+(U4*U2+U5*UB)*C(NS)
      E(3)=E(3)+(U4*U3+U5*UC)*C(NS)
   12 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LINEQ (N,Z)
      COMPLEX Z(400),STOR,STO,ST,S
      DIMENSION LA(20)
      DO 20 I=1,N
```

```
      LA(I)=I
   20 CONTINUE
      M1=0
      DO 18 M=1,N
      K=M
      DO 2 I=M,N
      K1=M1+I
      K2=M1+K
      IF (CABS(Z(K1))-CABS(Z(K2))) 2,2,6
    6 K=I
    2 CONTINUE
      LS=LA(M)
      LA(M)=LA(K)
      LA(K)=LS
      K2=M1+K
      STOR=Z(K2)
      J1=0
      DO 7 J=1,N
      K1=J1+K
      K2=J1+M
      STO=Z(K1)
      Z(K1)=Z(K2)
      Z(K2)=STO/STOR
      J1=J1+N
    7 CONTINUE
      K1=M1+M
      Z(K1)=1./STOR
      DO 11 I=1,N
      IF(I-M) 12,11,12
   12 K1=M1+I
      ST=Z(K1)
      Z(K1)=0.
      J1=0
      DO 10 J=1,N
      K2=J1+M
      K1=J1+I
      Z(K1)=Z(K1)-Z(K2)*ST
      J1=J1+N
   10 CONTINUE
   11 CONTINUE
      M1=M1+N
   18 CONTINUE
      J1=0
      DO 9 J=1,N
      IF (J-LA(J)) 14,8,14
   14 LAJ=LA(J)
      J2=(LAJ-1)*N
   31 DO 13 I=1,N
      K2=J2+I
      K1=J1+I
      S=Z(K2)
      Z(K2)=Z(K1)
      Z(K1)=S
   13 CONTINUE
```

```
      LA(J)=LA(LAJ)
      LA(LAJ) =LAJ
      IF (J-LA(J)) 14,8,14
    8 J1=J1+N
    9 CONTINUE
      RETURN
      END




C     MAIN PROGRAM  MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
      COMPLEX Z( 400),U(20),C(20),E(3),EI(2),UV(4),U1,ZL,ZIN,YIN,V
      COMMON XX(50),XY(50),XZ(50),TX(50),TY(50),TZ(50),AL(50)
      COMMON T(100),TP(100),BK,RAD2(10),L(5), LR(10) /COA/C
      DIMENSION PX(100),PY(100),PZ(100),LL(5),RAD(10),IFP(20)
    1 READ (1,101,END=500) NW,NP,NR,BK
  101 FORMAT (3I3,E14.7)
      WRITE (3,102) NW,NP,NR,BK
  102 FORMAT ('0NW NP NR    BK'/3I3,E14.7)

      S1=1./48.
      DO 50 I=1,25
      XI=I
      PX(I)=0.
      PY(I)=0.
      PZ(I)=(XI-13.)*S1
   50 CONTINUE
      WRITE (3,104) (PX(I),I=1,NP)
      WRITE (3,105) (PY(I),I=1,NP)
      WRITE (3,106) (PZ(I),I=1,NP)
  104 FORMAT ('0PX'/(1X,8F8.4))
  105 FORMAT ('0PY'/(1X,8F8.4))
  106 FORMAT ('0PZ'/(1X,8F8.4))
      READ (1,107) (LL(I),I=1,NW)
  107 FORMAT (20I3)
      WRITE (3,108) (LL(I),I=1,NW)
  108 FORMAT ('0LL'/(1X,10I4))
      LL(NW+1)=200
      READ (1,107) (LR(I),I=1,NR)
      WRITE (3,103) (LR(I),I=1,NR)
  103 FORMAT ('0LR'/(1X,10I4))
      WRITE (3,110)(RAD(I),I=1,NR)
  110 FORMAT ('0RAD'/(1X,8E14.7))
      DO 46 I=1,NR
      RAD2(I)=RAD(I)*RAD(I)
   46 CONTINUE
      J1=1
      J2=2
      N1=0
      DO 2 J=1,NP
      IF (LL(J1)-J) 3,4,3
    4 J2=J2-1
```

```
      L(J1)=J2
      J1=J1+1
      GO TO 2
    3 N1=N1+1
      J3=J-1
      IF((N1/2*2-N1).EQ.0)  J2=J2+1
      XX(N1)=.5*(PX(J)+PX(J3))
      XY(N1)=.5*(PY(J)+PY(J3))
      XZ(N1)=.5*(PZ(J)+PZ(J3))
      S1=PX(J)-PX(J3)
      S2=PY(J)-PY(J3)
      S3=PZ(J)-PZ(J3)
      S4=SQRT(S1*S1+S2*S2+S3*S3)
      TX(N1)=S1/S4
      TY(N1)=S2/S4
      TZ(N1)=S3/S4
      AL(N1)=S4
    2 CONTINUE
      L(J1)=J2
      N=J2-2
      CALL CALZ (N,N1,Z)
      READ (1,107) NL
      IF (NL) 42,42,41
   41 WRITE (3,118) NL
  118 FORMAT ('ONL'/I3/'OLP                    LOAD')
      DO 43 I=1,NL
      READ (1,119) LP,ZL
  119 FORMAT (I3,2E13.6)

      WRITE (3,120) LP,ZL
  120 FORMAT (I3,5X,2E13.6)
      J2=(LP-1)*N+LP
      Z(J2)=Z(J2)+ZL
   43 CONTINUE
   42 CALL LINEQ(N,Z)
      DO 45 I=1,N
      U(I)=0.
   45 CONTINUE
      READ (1,107) NF
      WRITE (3,121) NF
  121 FORMAT ('ONF'/I3/'OFP                 VOLTAGE')
      DO 44 I=1,NF
      READ (1,119) J1,V
      WRITE (3,120) J1,V
      U(J1)=V
      IFP(I)=J1
   44 CONTINUE
      WRITE (3,111)
  111 FORMAT ('OCURRENT'/'     I      REAL          IMAG             MAGNITUDE
     1    PHASE')
      J3=0
      J1=0
    5 J1=J1+1
      U1=0.
      J2=0
```

```
  6 J2=J2+1
    J3=J3+1
    U1=U1+Z(J3)*U(J2)
    IF (J2-N) 6,7,7
  7 C(J1)=U1
    IF (J1-N) 5,8,8
  8 CONTINUE
    DO 9 I=1,N
    U1=C(I)
    CM=CABS(U1)
    IF (CM) 11,12,11
 11 CP=ATAN2(AIMAG(U1),REAL(U1))*57.2858
    GO TO 10
 12 CP=0.
 10 CONTINUE
    WRITE (3,112) I,C(I),CM,CP
112 FORMAT (I5,3E14.6,F10.3)
  9 CONTINUE
    POWER=0.
    DO 23 I=1,NF
    J1=IFP(I)
    ZIN=U(J1)/C(J1)
    WRITE (3,122) J1,ZIN
122 FORMAT ('0INPUT IMPEDANCE AT POSITION',I3,' = (',2E14.7,' )')
    GM=CABS(ZIN)
    IF (GM-.1E-6) 24,24,25
 25 YIN=1./ZIN
    WRITE (3,123)J1,YIN
123 FORMAT ('0INPUT ADMITTANCE AT POSITION',I3,' = (',2E14.7,' )')
 24 S1=REAL(ZIN)
    S2=CABS(C(J1))
    POWER=POWER+.5*S2*S2*S1
 23 CONTINUE
    WRITE (3,124) POWER

124 FORMAT ('0TOTAL POWER INPUT =',E14.7)
    WRITE (3,113)
113 FORMAT ('0FIELD PATTERN'/'    K=1 FOR THETA COMPONENT    K=2 FOR PHI
   1 COMPONENT'/'0 THETA PHI   K       REAL              IMAG          MAGNITUD
   2E       PHASE')
    PHI=90.
    PH=PHI*.0174533
    DO 17 ITH=1,91,10
    THE=ITH-1
    TH=THE*.0174533
    CALL ROW (N,TH,PH,E)
    DO 16 K=1,2
    U1=E(K)
    GM=CABS(U1)
    IF (GM)13,13,14
 14 EP=ATAN2 (AIMAG(U1),REAL(U1))
    GO TO 15
 13 EP=0.
 15 GP=EP*57.2858
    WRITE (3,114) THE,PHI,K,U1,GM,GP
```

```
114 FORMAT(F6.0,F5.0,I3,3E14.7,F10.3)
 16 CONTINUE
 17 CONTINUE
    WRITE (3,115)
115 FORMAT ('ONEAR FIELD')
    DO 18 M=1,3
    XM=M
    DO 18 K=1,7,2
    XK=K
    X1=0.
    X2=.2*XK
    X3=(XM-1.)*.5
    CALL ENEAR(N,N1,X1,X2,X3,E)
    WRITE (3,116) X1,X2,X3
116 FORMAT ('0  X=',F8.5,'  Y=',F8.5,'  Z=',F8.5/'     J              E(J
   1)                 MAGNITUDE      PHASE')
    DO 19 J=1,3
    U1=E(J)
    GM=CABS(U1)
    IF (GM) 20,20,21
 21 EP=ATAN2(AIMAG(U1),REAL(U1))
    GO TO 22
 20 EP=0.
 22 GP=EP*57.2858
    WRITE (3,117) J,U1,GM,GP
117 FORMAT (I5,3E14.7,F10.3)
 19 CONTINUE
 18 CONTINUE
    GO TO 1
500 STOP
    END
```

DATA

```
  1 25  1+0.6283185E+01
  1
  1
+0.0033700E+00
  1
  6+0.000000E+00+0.100000E+03
  1

  3+0.100000E+01+0.000000E+00
```

Output

```
NW NP NR     BK
 1 25  1 0.6283184E 01

PX
  0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
  0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
  0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
  0.0

PY
  0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
  0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
  0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
  0.0

PZ
 -0.2500  -0.2292  -0.2083  -0.1875  -0.1667  -0.1458  -0.1250  -0.1042
 -0.0833  -0.0625  -0.0417  -0.0208   0.0      0.0208   0.0417   0.0625
  0.0833   0.1042   0.1250   0.1458   0.1667   0.1875   0.2083   0.2292
  0.2500

LL
   1

LR
   1

RAD
 0.3370000E-02

NL
 1

LP                    LOAD
 6       0.0     .         0.100000E 03

NF
 1

FP                VOLTAGE
 3       0.100000E 01 0.0

CURRENT
   I      REAL          IMAG           MAGNITUDE       PHASE
   1  0.476289E-03 -0.454587E-03  0.658407E-03     -43.657
   2  0.852013E-03 -0.706959E-03  0.110712E-02     -39.677
   3  0.119497E-02 -0.453587E-03  0.127816E-02     -20.782
   4  0.149155E-02 -0.221919E-02  0.267386E-02     -56.085
```

```
  5  0.173052E-02 -0.340200E-02  0.381684E-02    -63.028
  6  0.197636E-02 -0.449359E-02  0.490901E-02    -66.248
  7  0.172074E-02 -0.431462E-02  0.464510E-02    -68.245
  8  0.147368E-02 -0.401158E-02  0.427369E-02    -69.817
  9  0.117227E-02 -0.342939E-02  0.362421E-02    -71.116
 10  0.829212E-03 -0.258997E-02  0.271948E-02    -72.234
 11  0.459263E-03 -0.152876E-02  0.159625E-02    -73.266

INPUT IMPEDANCE AT POSITION  3 = ( 0.7314531E 03 0.2776448E 03 )

INPUT ADMITTANCE AT POSITION  3 = ( 0.1194970E-02-0.4535860E-03 )

TOTAL POWER INPUT = 0.5974849E-03

FIELD PATTERN
  K=1 FOR THETA COMPONENT   K=2 FOR PHI COMPONENT

 THETA PHI   K        REAL              IMAG            MAGNITUE          PHASE
   0.   90.  1 0.0             0.0             0.0                0.0
   0.   90.  2 0.0             0.0             0.0                0.0
  10.   90.  1 0.3042287E-01 0.2242029E-01 0.3779180E-01    36.382
  10.   90.  2 0.0             0.0             0.0                0.0
  20.   90.  1 0.6110083E-01 0.4426436E-01 0.7544959E-01    35.915
  20.   90.  2 0.0             0.0             0.0                0.0
  30.   90.  1 0.9201711E-01 0.6481171E-01 0.1125509E 00    35.153
  30.   90.  2 0.0             0.0             0.0                0.0
  40.   90.  1 0.1226543E 00 0.8311367E-01 0.1481619E 00    34.117
  40.   90.  2 0.0             0.0             0.0                0.0
  50.   90.  1 0.1518637E 00 0.9802002E-01 0.1807498E 00    32.834
  50.   90.  2 0.0             0.0             0.0                0.0
  60.   90.  1 0.1778987E 00 0.1083387E 00 0.2082912E 00    31.336
  60.   90.  2 0.0             0.0             0.0                0.0
  70.   90.  1 0.1986504E 00 0.1131066E 00 0.2285937E 00    29.651
  70.   90.  2 0.0             0.0             0.0                0.0
  80.   90.  1 0.2120675E 00 0.1118883E 00 0.2397741E 00    27.812
  80.   90.  2 0.0             0.0             0.0                0.0
  90.   90.  1 0.2166525E 00 0.1049888E 00 0.2407508E 00    25.850
  90.   90.  2 0.0             0.0             0.0                0.0

NEAR FIELD

  X= 0.0       Y= 0.20000  Z= 0.0
   J              E(J)                MAGNITUDE       PHASE
   1 0.0              0.0             0.0                0.0
   2 0.2322360E 00-0.2613037E-01 0.2337013E 00     -6.419
   3 0.2580132E-01 0.7595674E 00 0.7600056E 00     88.039

  X= 0.0       Y= 0.60000  Z= 0.0
   J              E(J)                MAGNITUDE       PHASE
   1 0.0              0.0             0.0                0.0
   2 0.1115810E-02-0.2415482E-01 0.2418058E-01    -87.340
   3 0.3280250E 00-0.1750230E 00 0.3717976E 00    -28.078
```

```
X= 0.0        Y= 1.00000  Z= 0.0
 J              E(J)                MAGNITUDE      PHASE
 1 0.0             0.0             0.0                0.0
 2-0.7329639E-02 0.4557341E-02 0.8630931E-02   148.102
 3-0.2261472E 00-0.6000340E-01 0.2339721E 00  -165.111

X= 0.0        Y= 1.40000  Z= 0.0
 J              E(J)                MAGNITUDE      PHASE
 1 0.0             0.0             0.0                0.0
 2 0.4285965E-02 0.9817230E-03 0.4396960E-02    12.899
 3 0.9972203E-01 0.1370197E 00 0.1694664E 00    53.944

X= 0.0        Y= 0.20000  Z= 0.50000
 J              E(J)                MAGNITUDE      PHASE
 1 0.0             0.0             0.0                0.0
 2-0.1953840E 00 0.9723461E-01 0.2182417E 00   153.516
 3 0.2916744E-01 0.2735693E 00 0.2751198E 00    83.900

X= 0.0        Y= 0.60000  Z= 0.50000
 J              E(J)                MAGNITUDE      PHASE
 1 0.0             0.0             0.0                0.0
 2 0.4238715E-01 0.1534653E 00 0.1592113E 00    74.547
 3 0.8403653E-01-0.1846061E 00 0.2028338E 00   -65.513

X= 0.0        Y= 1.00000  Z= 0.50000
 J              E(J)                MAGNITUDE      PHASE
 1 0.0             0.0             0.0                0.0
 2 0.6660056E-01-0.5298038E-01 0.8510315E-01   -38.495
 3-0.1705838E 00 0.5272150E-01 0.1785451E 00   162.797

X= 0.0        Y= 1.40000  Z= 0.50000
 J              E(J)                MAGNITUDE      PHASE
 1 0.0             0.0             0.0                0.0
 2-0.4826183E-01-0.1229450E-01 0.4980320E-01  -165.679
 3 0.1292080E 00 0.7032120E-01 0.1471046E 00    28.552

X= 0.0        Y= 0.20000  Z= 1.00000
 J              E(J)                MAGNITUDE      PHASE
 1 0.0             0.0             0.0                0.0
 2 0.4744947E-01 0.5352162E-02 0.4775037E-01     6.434
 3 0.2216408E-01-0.6867552E-01 0.7216346E-01   -72.101

X= 0.0        Y= 0.60000  Z= 1.00000
 J              E(J)                MAGNITUDE      PHASE
 1 0.0             0.0             0.0                0.0
 2 0.6399012E-01-0.6781060E-01 0.9323627E-01   -46.652
 3-0.7027382E-01-0.8141335E-02 0.7074380E-01  -173.361

X= 0.0        Y= 1.00000  Z= 1.00000
 J              E(J)                MAGNITUDE      PHASE
 1 0.0             0.0             0.0                0.0
 2-0.6079457E-01-0.6035373E-01 0.8566535E-01  -135.185
 3 0.2846730E-01 0.8501339E-01 0.8965296E-01    71.474

X= 0.0        Y= 1.40000  Z= 1.00000
 J              E(J)                MAGNITUDE      PHASE
 1 0.0             0.0             0.0                0.0
 2-0.2894978E-01 0.5947838E-01 0.6614953E-01   115.933
 3 0.6489414E-01-0.6970632E-01 0.9523767E-01   -47.039
```

B. Scattering Program

This program is suitable for scattering problems involving thin wires with loading represented by lumped loads located at wire positions corresponding to the peaks of triangle expansion functions. The maximum number of points specifying the problem geometry that can be accommodated here is 100. Required subroutines CALZ, ROW, and LINEQ are exactly the same as those of Appendix A and hence are not repeated here. The input-output data listed correspond to the example of Section 3-2.

```
C       MAIN PROGRAM  MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
        COMPLEX Z( 400),U(20),C(20),E(3),EI(2),UV(4),U1,ZL
        COMMON XX(50),XY(50),XZ(50),TX(50),TY(50),TZ(50),AL(50)
        COMMON T(100),TP(100),BK,RAD2(10),L(5),LR(10) /COA/C
        DIMENSION PX( 88),PY( 88),PZ( 88),LL(5),RAD(10)
    1   READ (1,101,END=500) NW,NP,NR,BK
  101   FORMAT (3I3,E14.7)
        WRITE (3,102) NW,NP,NR,BK
  102   FORMAT ('ONW NP NR    BK'/3I3,E14.7)
        READ (1,130) (PX(I),I=1,NP)
        READ (1,130) (PY(I),I=1,NP)
        READ (1,130) (PZ(I),I=1,NP)
  130   FORMAT (10F8.4)
        WRITE (3,104) (PX(I),I=1,NP)
        WRITE (3,105) (PY(I),I=1,NP)
        WRITE (3,106) (PZ(I),I=1,NP)
  104   FORMAT ('OPX'/(1X,8F8.4))
  105   FORMAT ('OPY'/(1X,8F8.4))
  106   FORMAT ('OPZ'/(1X,8F8.4))
        READ (1,107) (LL(I),I=1,NW)
  107   FORMAT (20I3)
        WRITE (3,108) (LL(I),I=1,NW)
  108   FORMAT ('OLL'/(1X,10I4))
        LL(NW+1)=200
        READ (1,107) (LR(I),I=1,NR)
        WRITE (3,103) (LR(I),I=1,NR)
  103   FORMAT ('OLR'/(1X,10I4))
        LR(NR+1)=200
        READ (1,109) (RAD(I),I=1,NR)
  109   FORMAT (5E14.7)
        WRITE (3,110)(RAD(I),I=1,NR)
  110   FORMAT ('ORAD'/(1X,8E14.7))
        DO 46 I=1,NR
        RAD2(I)=RAD(I)*RAD(I)
```

```
   46 CONTINUE
      J1=1
      J2=2
      N1=0
      DO 2 J=1,NP
      IF (LL(J1)-J) 3,4,3
    4 J2=J2-1
      L(J1)=J2
      J1=J1+1
      GO TO 2
    3 N1=N1+1
      J3=J-1
      IF((N1/2*2-N1).EQ.0)  J2=J2+1
      XX(N1)=.5*(PX(J)+PX(J3))
      XY(N1)=.5*(PY(J)+PY(J3))
      XZ(N1)=.5*(PZ(J)+PZ(J3))
      S1=PX(J)-PX(J3)
      S2=PY(J)-PY(J3)
      S3=PZ(J)-PZ(J3)
      S4=SQRT(S1*S1+S2*S2+S3*S3)
      TX(N1)=S1/S4
      TY(N1)=S2/S4
      TZ(N1)=S3/S4
      AL(N1)=S4
    2 CONTINUE
      L(J1)=J2
      N=J2-2
      CALL CALZ (N,N1,Z)
      READ (1,107) NL
      IF (NL) 42,42,41

   41 WRITE (3,118) NL
  118 FORMAT ('ONL'/I3/'OLP               LOAD')
      DO 43 I=1,NL
      READ (1,119) LP,ZL
  119 FORMAT (I3,2E13.6)
      WRITE (3,120) LP,ZL
  120 FORMAT (I3,5X,2E13.6)
      J2=(LP-1)*N+LP
      Z(J2)=Z(J2)+ZL
   43 CONTINUE
   42 CALL LINEQ(N,Z)
      READ (1,107) NSET
      WRITE (3,127) NSET
  127 FORMAT ('ONSET'/I4)
      IF (NSET) 33,33,32
   32 DO 26 III=1,NSET
      U1=(0.,1.)
      READ (1,126) THE,PHI,EI(1),EI(2)
```

```
126 FORMAT (2F5.0,4E13.6)
    WRITE (3,125) THE,PHI,EI(1),EI(2)
125 FORMAT ('0********'/'OTHETA   PHI          EI(1)                 EI
   1(2)'/2F6.0,4E11.4)
    A1=CABS(EI(1))**2+CABS(EI(2))**2
    A2=BK*BK
    TH=THE*.0174533
    PH=PHI*.0174533
    CT=COS(TH)
    ST=SIN(TH)
    CP=COS(PH)
    SP=SIN(PH)
    S1=CT*CP
    S2=CT*SP
    BK1=BK*ST*CP
    BK2=BK*ST*SP
    BK3=BK*CT
    J1=1
    J2=-2
    DO 27 J=1,N
    IF (L(J1)-J) 29,28,29
 28 J2=J2+2
    J1=J1+1
    KK=1
    GO TO 30
 29 UV(1)=UV(3)
    UV(2)=UV(4)
    KK=3
 30 DO 31 M=KK,4
    J3=J2+M
    XDT=TX(J3)*S1+TY(J3)*S2-TZ(J3)*ST
    XDP=-TX(J3)*SP+TY(J3)*CP
    BKR=XX(J3)*BK1+XY(J3)*BK2+XZ(J3)*BK3
    UV(M)=(XDT*EI(1)+XDP*EI(2))*(COS(BKR)+U1*SIN(BKR))
 31 CONTINUE
    J3=(J-1)*4
    J4=J3+1
    J5=J4+1
    J6=J5+1
    J7=J6+1
    U(J)=T(J4)*UV(1)+T(J5)*UV(2)+T(J6)*UV(3)+T(J7)*UV(4)
    J2=J2+2
 27 CONTINUE
    WRITE (3,111)
111 FORMAT ('OCURRENT'/'     I     REAL          IMAG         MAGNITUDE
   1     PHASE')
    J3=0
    J1=0
  5 J1=J1+1
    U1=0.
    J2=0
  6 J2=J2+1
    J3=J3+1
    U1=U1+Z(J3)*U(J2)
    IF (J2-N) 6,7,7
  7 C(J1)=U1
    IF (J1-N) 5,8,8
```

```
  8 CONTINUE
    DO 9 I=1,N
    U1=C(I)
    CM=CABS(U1)
    IF (CM) 11,12,11
 11 CP=ATAN2(AIMAG(U1),REAL(U1))*57.2858
    GO TO 10
 12 CP=0.
 10 CONTINUE
    WRITE (3,112) I,C(I),CM,CP
112 FORMAT (I5,3E14.6,F10.3)
  9 CONTINUE
    WRITE (3,113)
113 FORMAT ('OFIELD PATTERN'/'    K=1 FOR THETA COMPONENT   K=2 FOR PHI
   1 COMPONENT'/'0 THETA PHI  K        REAL              IMAG          MAGNITUD
   2E        PHASE            SIGMA')
    PHI=90.
    PH=PHI*.0174533
    DO 17 ITH=1,91,5
    THE=ITH-1
    TH=THE*.0174533
    CALL ROW (N,TH,PH,E)
    DO 16 K=1,2
    U1=E(K)
    GM=CABS(U1)
    IF (GM)13,13,14
 14 EP=ATAN2 (AIMAG(U1),REAL(U1))
    GO TO 15
 13 EP=0.
 15 GP=EP*57.2858
    SIGMA=GM*GM*A2*.3183099/A1
    WRITE (3,114) THE,PHI,K,U1,GM,GP,SIGMA
114 FORMAT(F6.0,F5.0,I3,3E14.7,F10.3,5X,E14.7)
 16 CONTINUE
 17 CONTINUE
 26 CONTINUE
 33 CONTINUE
    GO TO 1
500 STOP
    END
```

DATA

```
 4 50  4+0.6283185E+01
 .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .01375
 .02750  .11000  .09625  .08250  .06875  .05500  .04125  .02750  .01375  .00000
 .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
 .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000-0.01375
-0.02750-0.11000-0.09625-0.08250-0.06875-0.05500-0.04125-0.02750-0.01375-0.00000
 .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
 .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
 .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
```

```
  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
  .11000  .09625  .08250  .06875  .05500  .04125  .02750  .01375  .00000  .00000
  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
 -.01375 -.02750 -.22000 -.20625 -.19250 -.17875 -.16500 -.15125 -.13750 -.12375
 -.11000 -.09625 -.08250 -.06875 -.05500 -.04125 -.02750 -.01375  .00000  .00000
  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
  1 12 23 42
  1  9 19 37
+0.0022200E+00+0.0011100E+00+0.0022200E+00+0.0011100E+00
  0
  3
  90.   90.-0.100000E+01+0.000000E+00+0.000000E+00+0.000000E+00
  60.   90.-0.100000E+01+0.000000E+00+0.000000E+00+0.000000E+00
  30.   90.-0.100000E+01+0.000000E+00+0.000000E+00+0.000000E+00
```

Output

```
NW NP NR      BK
 4 50  4 0.6283184E 01

PX
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
 0.0      0.0137   0.0275   0.1100   0.0962   0.0825   0.0687   0.0550
 0.0412   0.0275   0.0137   0.0      0.0      0.0      0.0      0.0
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
 0.0      0.0      0.0      0.0      0.0      0.0      0.0     -0.0137
-0.0275  -0.1100  -0.0962  -0.0825  -0.0687  -0.0550  -0.0412  -0.0275
-0.0137   0.0

PY
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
 0.0      0.0

PZ
 0.1100   0.0962   0.0825   0.0687   0.0550   0.0412   0.0275   0.0137
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
 0.0      0.0      0.0      0.0     -0.0137  -0.0275  -0.2200  -0.2062

-0.1925  -0.1787  -0.1650  -0.1512  -0.1375  -0.1237  -0.1100  -0.0962
-0.0825  -0.0687  -0.0550  -0.0412  -0.0275  -0.0137   0.0      0.0
 0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
 0.0      0.0
```

```
LL
   1  12  23  42

LR
   1   9  19  37

RAD
 0.2220000E-02 0.1110000E-02 0.2220000E-02 0.1110000E-02

NSET
  3

********

THETA    PHI          EI(1)                     EI(2)
  90.    90.-0.1000E 01 0.0          0.0          0.0

CURRENT
    I       REAL          IMAG          MAGNITUDE       PHASE
    1 -0.501472E-04 -0.266968E-03  0.271637E-03   -100.621
    2 -0.820176E-04 -0.435063E-03  0.442726E-03   -100.659
    3 -0.105347E-03 -0.557393E-03  0.567261E-03   -100.685
    4 -0.116468E-03 -0.615480E-03  0.626403E-03   -100.698
    5 -0.226121E-04 -0.115846E-03  0.118032E-03   -101.027
    6 -0.388146E-04 -0.199475E-03  0.203217E-03   -100.994
    7 -0.525300E-04 -0.270573E-03  0.275625E-03   -100.969
    8 -0.177100E-03 -0.928125E-03  0.944870E-03   -100.786
    9  0.744535E-04  0.390656E-03  0.397688E-03     79.196
   10  0.125331E-03  0.656225E-03  0.668086E-03     79.174
   11  0.167142E-03  0.873862E-03  0.889702E-03     79.158
   12  0.199533E-03  0.104218E-02  0.106110E-02     79.148
   13  0.222429E-03  0.116109E-02  0.118220E-02     79.141
   14  0.235779E-03  0.123047E-02  0.125286E-02     79.139
   15  0.239758E-03  0.125125E-02  0.127401E-02     79.139
   16  0.606309E-04  0.312641E-03  0.318465E-03     79.011
   17 -0.226117E-04 -0.115844E-03  0.118030E-03   -101.027
   18 -0.388141E-04 -0.199473E-03  0.203214E-03   -100.994
   19 -0.525292E-04 -0.270569E-03  0.275621E-03   -100.969
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FIELD PATTERN
  K=1 FOR THETA COMPONENT   K=2 FOR PHI COMPONENT

 THETA PHI   K        REAL              IMAG          MAGNITUE          PHASE        SIGMA
   0.   90.   1 0.1568453E-13-0.3359512E-14 0.1604028E-13     -12.088 0.3233205E-26
   0.   90.   2-0.4796873E-07 0.1113560E-07 0.4924430E-07     166.902 0.3047343E-13
   5.   90.   1-0.3050491E-02 0.2030153E-02 0.3664289E-02     146.330 0.1687287E-03
   5.   90.   2-0.4796873E-07 0.1113560E-07 0.4924430E-07     166.902 0.3047343E-13
  10.   90.   1-0.6109960E-02 0.4026003E-02 0.7317122E-02     146.593 0.6728063E-03
  10.   90.   2-0.4796873E-07 0.1045033E-07 0.4909387E-07     167.680 0.3028753E-13
  15.   90.   1-0.9185735E-02 0.5953122E-02 0.1094611E-01     147.028 0.1505667E-02
  15.   90.   2-0.4796873E-07 0.1027901E-07 0.4905769E-07     167.876 0.3024291E-13
  20.   90.   1-0.1228188E-01 0.7776942E-02 0.1453704E-01     147.632 0.2655591E-02
  20.   90.   2-0.4796873E-07 0.1045033E-07 0.4909387E-07     167.680 0.3028753E-13
  25.   90.   1-0.1539776E-01 0.9462882E-02 0.1807310E-01     148.401 0.4104637E-02
  25.   90.   2-0.4796873E-07 0.1045033E-07 0.4909387E-07     167.680 0.3028753E-13

  30.   90.   1-0.1852670E-01 0.1097682E-01 0.2153437E-01     149.328 0.5827382E-02
  30.   90.   2-0.4814005E-07 0.1045033E-07 0.4926128E-07     167.723 0.3049444E-13
  35.   90.   1-0.2165498E-01 0.1228579E-01 0.2489736E-01     150.406 0.7789612E-02
  35.   90.   2-0.4831136E-07 0.1045033E-07 0.4942871E-07     167.765 0.3070208E-13
  40.   90.   1-0.2476117E-01 0.1335901E-01 0.2813500E-01     151.626 0.9947255E-02
  40.   90.   2-0.4831136E-07 0.1045033E-07 0.4942871E-07     167.765 0.3070208E-13
  45.   90.   1-0.2781589E-01 0.1416922E-01 0.3121683E-01     152.979 0.1224580E-01
  45.   90.   2-0.4831136E-07 0.1045033E-07 0.4942871E-07     167.765 0.3070208E-13
  50.   90.   1-0.3078216E-01 0.1469421E-01 0.3410954E-01     154.455 0.1462046E-01
  50.   90.   2-0.4848268E-07 0.1045033E-07 0.4959617E-07     167.807 0.3091048E-13
  55.   90.   1-0.3361617E-01 0.1491842E-01 0.3677779E-01     156.042 0.1699733E-01
  55.   90.   2-0.4848268E-07 0.1045033E-07 0.4959617E-07     167.807 0.3091048E-13
  60.   90.   1-0.3626888E-01 0.1483444E-01 0.3918536E-01     157.727 0.1929555E-01
  60.   90.   2-0.4848268E-07 0.1045033E-07 0.4959617E-07     167.807 0.3091048E-13
  65.   90.   1-0.3868801E-01 0.1444435E-01 0.4129650E-01     159.499 0.2143068E-01
  65.   90.   2-0.4848268E-07 0.1045033E-07 0.4959617E-07     167.807 0.3091048E-13
  70.   90.   1-0.4082039E-01 0.1376058E-01 0.4307735E-01     161.343 0.2331885E-01
  70.   90.   2-0.4848268E-07 0.1045033E-07 0.4959617E-07     167.807 0.3091048E-13
  75.   90.   1-0.4261498E-01 0.1280620E-01 0.4449759E-01     163.246 0.2488182E-01
  75.   90.   2-0.4848268E-07 0.1045033E-07 0.4959617E-07     167.807 0.3091048E-13
  80.   90.   1-0.4402545E-01 0.1161461E-01 0.4553174E-01     165.192 0.2605182E-01
  80.   90.   2-0.4848268E-07 0.1045033E-07 0.4959617E-07     167.807 0.3091048E-13
  85.   90.   1-0.4501317E-01 0.1022834E-01 0.4616063E-01     167.169 0.2677644E-01
  85.   90.   2-0.4848268E-07 0.1045033E-07 0.4959617E-07     167.807 0.3091048E-13
  90.   90.   1-0.4554938E-01 0.8697454E-02 0.4637232E-01     169.160 0.2702259E-01
  90.   90.   2-0.4848268E-07 0.1045033E-07 0.4959617E-07     167.807 0.3091048E-13

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          THETA    PHI           EI(1)                    EI(2)
            60.    90.-0.1000E 01 0.0          0.0          0.0

          CURRENT
             I        REAL          IMAG          MAGNITUDE       PHASE
             1 -0.550140E-04  -0.215371E-03   0.222286E-03   -104.311
             2 -0.969811E-04  -0.351208E-03   0.364352E-03   -105.418
             3 -0.132468E-03  -0.449862E-03   0.468960E-03   -106.389
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  4 -0.151937E-03 -0.496478E-03  0.519206E-03  -106.997
  5 -0.460975E-04 -0.916642E-04  0.102603E-03  -116.677
  6 -0.794873E-04 -0.157871E-03  0.176752E-03  -116.705
  7 -0.108105E-03 -0.214174E-03  0.239911E-03  -116.762
  8 -0.277273E-03 -0.743972E-03  0.793961E-03  -110.421
  9  0.150203E-03  0.305218E-03  0.340174E-03    63.786
 10  0.244820E-03  0.515807E-03  0.570958E-03    64.598
 11  0.316896E-03  0.690181E-03  0.759456E-03    65.326
 12  0.367680E-03  0.826353E-03  0.904460E-03    66.002
 13  0.398976E-03  0.923521E-03  0.100602E-02    66.623
 14  0.412606E-03  0.981021E-03  0.106426E-02    67.177
 15  0.410821E-03  0.999173E-03  0.108033E-02    67.638
 16  0.125334E-03  0.247492E-03  0.277418E-03    63.131
 17 -0.460968E-04 -0.916630E-04  0.102601E-03  -116.677
 18 -0.794862E-04 -0.157869E-03  0.176750E-03  -116.705
 19 -0.108104E-03 -0.214171E-03  0.239908E-03  -116.762

FIELD PATTERN
  K=1 FOR THETA COMPONENT   K=2 FOR PHI COMPONENT

 THETA  PHI   K        REAL            IMAG          MAGNITUE          PHASE       SIGMA
   0.   90.   1 0.1160001E-13-0.6698601E-14 0.1339520E-13      -30.000 0.2254799E-26
   0.   90.   2-0.3392075E-07 0.2227119E-07 0.4057860E-07      146.687 0.2069205E-13

   5.   90.   1-0.2125504E-02 0.2163451E-02 0.3032868E-02      134.470 0.1155890E-03
   5.   90.   2-0.3392075E-07 0.2227119E-07 0.4057860E-07      146.687 0.2069205E-13
  10.   90.   1-0.4265614E-02 0.4301164E-02 0.6057676E-02      134.739 0.4611278E-03
  10.   90.   2-0.3392075E-07 0.2192856E-07 0.4039156E-07      147.093 0.2050173E-13
  15.   90.   1-0.6433595E-02 0.6386969E-02 0.9065561E-02      135.185 0.1032759E-02
  15.   90.   2-0.3409206E-07 0.2175724E-07 0.4044312E-07      147.429 0.2055410E-13
  20.   90.   1-0.8640025E-02 0.8393940E-02 0.1204608E-01      135.804 0.1823481E-02
  20.   90.   2-0.3426338E-07 0.2158593E-07 0.4049607E-07      147.763 0.2060796E-13
  25.   90.   1-0.1089160E-01 0.1029421E-01 0.1498658E-01      136.591 0.2822375E-02
  25.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  30.   90.   1-0.1318984E-01 0.1205910E-01 0.1787159E-01      137.540 0.4013613E-02
  30.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  35.   90.   1-0.1553026E-01 0.1365945E-01 0.2068259E-01      138.643 0.5375501E-02
  35.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  40.   90.   1-0.1790142E-01 0.1506638E-01 0.2339780E-01      139.891 0.6879538E-02
  40.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  45.   90.   1-0.2028460E-01 0.1625232E-01 0.2599236E-01      141.273 0.8489866E-02
  45.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  50.   90.   1-0.2265364E-01 0.1719229E-01 0.2843875E-01      142.780 0.1016320E-01
  50.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  55.   90.   1-0.2497537E-01 0.1786542E-01 0.3070736E-01      144.398 0.1184934E-01
  55.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  60.   90.   1-0.2721047E-01 0.1825645E-01 0.3276747E-01      146.115 0.1349259E-01
  60.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  65.   90.   1-0.2931497E-01 0.1835725E-01 0.3458837E-01      147.919 0.1503383E-01
  65.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  70.   90.   1-0.3124199E-01 0.1816800E-01 0.3614053E-01      149.795 0.1641340E-01
  70.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  75.   90.   1-0.3294411E-01 0.1769797E-01 0.3739695E-01      151.728 0.1757445E-01
  75.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  80.   90.   1-0.3437567E-01 0.1696585E-01 0.3833441E-01      153.705 0.1846660E-01
  80.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  85.   90.   1-0.3549547E-01 0.1599935E-01 0.3893466E-01      155.710 0.1904944E-01
  85.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
  90.   90.   1-0.3626891E-01 0.1483424E-01 0.3918531E-01      157.728 0.1929550E-01
  90.   90.   2-0.3443470E-07 0.2175724E-07 0.4073237E-07      147.688 0.2084916E-13
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THETA    PHI          EI(1)                     EI(2)
  30.    90.-0.1000E 01 0.0          0.0          0.0

CURRENT
   I        REAL          IMAG          MAGNITUDE      PHASE
   1 -0.340822E-04 -0.113050E-03   0.118076E-03   -106.758
   2 -0.624874E-04 -0.184688E-03   0.194973E-03   -108.674
   3 -0.879138E-04 -0.236519E-03   0.252329E-03   -110.371
   4 -0.102511E-03 -0.260758E-03   0.280184E-03   -111.442
   5 -0.358644E-04 -0.462348E-04   0.585142E-04   -127.779
   6 -0.619153E-04 -0.796483E-04   0.100883E-03   -127.838
   7 -0.843169E-04 -0.108075E-03   0.137075E-03   -127.938
   8 -0.200385E-03 -0.385659E-03   0.434611E-03   -117.436
   9  0.114835E-03  0.149373E-03   0.188413E-03     52.439
  10  0.186703E-03  0.255905E-03   0.316774E-03     53.877
  11  0.240766E-03  0.346165E-03   0.421661E-03     55.171
  12  0.278019E-03  0.418166E-03   0.502153E-03     56.372
  13  0.300019E-03  0.470655E-03   0.558146E-03     57.474
  14  0.308443E-03  0.502629E-03   0.589723E-03     58.454
  15  0.305377E-03  0.513762E-03   0.597667E-03     59.263
  16  0.978727E-04  0.124900E-03   0.158679E-03     51.908

  17 -0.358639E-04 -0.462343E-04   0.585135E-04   -127.778
  18 -0.619144E-04 -0.796476E-04   0.100882E-03   -127.838
  19 -0.843156E-04 -0.108074E-03   0.137073E-03   -127.938

FIELD PATTERN
  K=1 FOR THETA COMPONENT   K=2 FOR PHI COMPONENT

 THETA PHI   K        REAL            IMAG          MAGNITUE         PHASE       SIGMA
   0.  90.   1 0.4411273E-14-0.5350711E-14 0.6934652E-14     -50.488 0.6043085E-27
   0.  90.   2-0.1524720E-07 0.1850222E-07 0.2397518E-07     129.468 0.7223260E-14
   5.  90.   1-0.9580271E-03 0.1333911E-02 0.1642296E-02     125.664 0.3389316E-04
   5.  90.   2-0.1524720E-07 0.1850222E-07 0.2397518E-07     129.468 0.7223260E-14
  10.  90.   1-0.1926597E-02 0.2655490E-02 0.3280762E-02     125.940 0.1352567E-03
  10.  90.   2-0.1524720E-07 0.1850222E-07 0.2397518E-07     129.468 0.7223260E-14
  15.  90.   1-0.2915550E-02 0.3952034E-02 0.4911110E-02     126.395 0.3030880E-03
  15.  90.   2-0.1524720E-07 0.1833091E-07 0.2384322E-07     129.730 0.7143964E-14
  20.  90.   1-0.3933340E-02 0.5210191E-02 0.6528188E-02     127.028 0.5355431E-03
  20.  90.   2-0.1541852E-07 0.1815959E-07 0.2382229E-07     130.310 0.7131424E-14
  25.  90.   1-0.4986383E-02 0.6415732E-02 0.8125611E-02     127.833 0.8297006E-03
  25.  90.   2-0.1558984E-07 0.1798827E-07 0.2380380E-07     130.892 0.7120359E-14
  30.  90.   1-0.6078355E-02 0.7553488E-02 0.9695441E-02     128.801 0.1181257E-02
  30.  90.   2-0.1576115E-07 0.1798827E-07 0.2391635E-07     131.222 0.7187850E-14
  35.  90.   1-0.7209651E-02 0.8607462E-02 0.1122797E-01     129.947 0.1584207E-02
  35.  90.   2-0.1576115E-07 0.1781696E-07 0.2378776E-07     131.474 0.7110770E-14
  40.  90.   1-0.8376870E-02 0.9561166E-02 0.1271172E-01     131.200 0.2030570E-02
  40.  90.   2-0.1576115E-07 0.1781696E-07 0.2378776E-07     131.474 0.7110770E-14
  45.  90.   1-0.9572465E-02 0.1039810E-01 0.1413339E-01     132.609 0.2510163E-02
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45.   90.   2-0.1576115E-07 0.1781696E-07 0.2378776E-07     131.474 0.7110770E-14
50.   90.   1-0.1078458E-01 0.1110248E-01 0.1547812E-01     134.144 0.3010550E-02
50.   90.   2-0.1576115E-07 0.1781696E-07 0.2378776E-07     131.474 0.7110770E-14
55.   90.   1-0.1199705E-01 0.1166005E-01 0.1672979E-01     135.792 0.3517145E-02
55.   90.   2-0.1576115E-07 0.1798827E-07 0.2391635E-07     131.202 0.7187850E-14
60.   90.   1-0.1318986E-01 0.1205903E-01 0.1787155E-01     137.540 0.4013594E-02
60.   90.   2-0.1576115E-07 0.1798827E-07 0.2391635E-07     131.202 0.7187850E-14
65.   90.   1-0.1433966E-01 0.1229102E-01 0.1888636E-01     139.375 0.4482351E-02
65.   90.   2-0.1576115E-07 0.1798827E-07 0.2391635E-07     131.202 0.7187850E-14
70.   90.   1-0.1542068E-01 0.1235186E-01 0.1975768E-01     141.281 0.4905473E-02
70.   90.   2-0.1576115E-07 0.1798827E-07 0.2391635E-07     131.202 0.7187850E-14
75.   90.   1-0.1640597E-01 0.1224226E-01 0.2047019E-01     143.244 0.5265661E-02
75.   90.   2-0.1576115E-07 0.1798827E-07 0.2391635E-07     131.202 0.7187850E-14
80.   90.   1-0.1726855E-01 0.1196819E-01 0.2101048E-01     145.250 0.5547296E-02
80.   90.   2-0.1576115E-07 0.1798827E-07 0.2391635E-07     131.202 0.7187850E-14
85.   90.   1-0.1798302E-01 0.1154088E-01 0.2136775E-01     147.283 0.5737554E-02
85.   90.   2-0.1576115E-07 0.1798827E-07 0.2391635E-07     131.202 0.7187850E-14
90.   90.   1-0.1852674E-01 0.1097662E-01 0.2153430E-01     149.328 0.5827345E-02
90.   90.   2-0.1576115E-07 0.1798827E-07 0.2391635E-07     131.202 0.7187850E-14
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