

1, Report No.	2. Government Accession	on No.	3. Recipi	ent's Catalog No.	
4. Title and Subtitle			5. Repor	t Date	
COMPUTER PROGRAM FOR THIN-WIRE STRUCTURES IN A HOMOGENEOUS		June	1974		
CONDUCTING MEDIUM			6. Perfor	ming Urganization Code	
7. Author(s)			8. Perfor	ming Organization Report No.	
J. H. Richmond			TR 2	2902-12	
			10, Work	Unit No.	
9. Performing Organization Name and Addres	3		502-	-33-13-02	
The Ohio State University			11. Contra	. Contract or Grant No.	
ElectroScience Laboratory			NGL	36-008-138	
Columbus, Ohio 43212			13. Type	of Report and Period Covered	
12. Sponsoring Agency Name and Address			Cont	tractor Report	
National Aeronautics and Space Washington, D.C. 20546	e Administration		14. Spons	oring Agency Code	
15. Supplementary Notes	<u></u>				
Topical report.					
16. Abstract					
A computer program is pre	sented for thin-wire	antennas	and scatterers i	n a homogeneous	
conducting medium. The analys	is is performed in t	he r <b>eal</b> or	complex frequen	cy domain. The	
and and a singulated and	bare wires with fini	te conduct	ivity and lumped	loads. The output	
program nandies insurated and			- Col al anarra d	n absorption pross	
data includes the current dist	ribution, impedance,	radiation	efficiency, gai	n, absorption cross	
section, scattering cross sect	ion, echo area and t	he polariz	ation scattering	matrix. The program	
uses sinusoidal bases and Galerkin's method.					
17. Key Words (Suggested by Author(s))		18. Distribut	ion Statement		
Antennas, Spacecraft and Airc	raft Antennas				
Applied Electromagnetic Theory	à	Unclassified - Unlimited			
				STAR Category 09	
19. Security Classif, (of this report)	20. Security Classif. (of this	page)	21. No. of Pages	22. Price"	
Unclassified	Unclassified		52	\$3.75	

\*For sale by the National Technical Information Service, Springfield, Virginia 22151

.

# CONTENTS

	Page
I. INTRODUCTION	1
II. THE THIN-WIRE COMPUTER PROGRAM	2
III. SUMMARY	17
REFERENCES	18
APPENDIX 1 Subroutine SORT	19
APPENDIX 2 Subroutine SGANT	19
APPENDIX 3 Subroutine CBES	25
APPENDIX 4 Subroutine DSHELL	25
APPENDIX 5 Subroutine GGS	25
APPENDIX 6 Subroutine GGMM	30
APPENDIX 7 Subroutine EXPJ	34
APPENDIX 8 Subroutine GANT1	37
APPENDIX 9 Subroutine SQROT	37
APPENDIX 10 Subroutine RITE	40
APPENDIX 11 Subroutine GDISS	42
APPENDIX 12 Subroutine GNFLD	42
APPENDIX 13 Subroutine GNF	42
APPENDIX 14 Subroutine GFFLD	42
APPENDIX 15 Subroutine GFF	49

.

· •

. ÷

•

#### I. INTRODUCTION

Reference 1 presents the electromagnetic theory for a thin-wire structure in a homogeneous conducting medium, and this report presents the corresponding computer program. The program performs a frequencydomain analysis of thin-wire antennas and scatterers. The wire configuration is a generalized polygon assembled from straight wire segments. The program has been tested extensively with simple structures (linear dipoles, V dipoles, coupled dipoles, square loops, octagonal loops, multiturn loops and coupled loops) and complicated configurations including wire-grid models of plates, spheres, cones, aircraft and ships. Although the air-earth or air-water interface is not considered, the program is applicable in many problems involving buried or submerged antennas or targets. It is useful in locating the poles of the admittance or scattering function for wire structures in the complex frequency domain.

A piecewise-sinusoidal expansion is used for the current distribution. The matrix equation ZI = V is generated by enforcing reaction tests with a set of sinusoidal dipoles located in the interior region of the wire. Since the test dipoles have the same current distribution as the expansion modes, this may be regarded as an application of Galerkin's method. Rumsey's reaction concept was most helpful in this development, and therefore the formulation is known as the "sinusoidal reaction technique."

The current is assumed to vanish at the endpoints (if any) of the wire, and Kirchhoff's current law is enforced everywhere on the structure. The input data specify the frequency, wire radius, wire conductivity, the parameters of the exterior medium, coordinates of points to describe the shape and size of the wire configuration, and a list of the wire segments. If some or all of the wire segments are insulated, the radius and permittivity of the insulating sleeve are indicated.

Coordinates are required for wire endpoints, corners, junctions and terminals. For accuracy, the longest wire segment should not greatly exceed one-quarter wavelength. Longer segments should be subdivided by defining additional current-sampling points. The program automatically defines a set of N sinusoidal dipole modes on the wire structure and computes the mutual impedance matrix for these modes. The elements in the matrix are generated by numerical integration when appropriate, or from closed-form expressions in terms of exponential integrals. The computer program uses certain approximations which yield a symmetric matrix even when the wire structure has finite conductivity, lumped loads and insulating sleeves.

In antenna problems, the output data includes the current distribution, impedance, radiation efficiency, gain, patterns and near-zone field. In bistatic scattering problems, the output includes the echo area and the complex elements of the polarization scattering matrix. In backscatter situations, the output includes also the absorption, scattering and extinction cross sections.

If the wire has finite conductivity or dielectric sleeves, it is assumed that the frequency is real. This restriction can readily be removed if the user will specify the surface impedance of the wire and the complex permittivities of the dielectric sleeves and the ambient medium appropriate for complex frequencies.

The user may make a tradeoff between accuracy and computation costs by specifying the input variable INT. A large value increases the accuracy and the cost. For most problems, the recommended value is INT = 4.

The program was run on an IBM 370/165 computer to determine the broadside backscatter for a wire-grid square plate with edge length L. With a five-by-five grid, there are 60 segments, 36 points and 84 simultaneous equations. With INT = 4, calculations were made for  $L/\lambda$  = 0.3, 0.4, 0.5, 0.6 and 0.7. The execution time was 100 seconds. This averages to 20 seconds for each value of  $L/\lambda$ . The wire structure was perfectly conducting, uninsulated and located in free space. No advantage was taken of the target symmetries.

The next section presents the thin-wire computer program, instructions for the user, typical input and output data and tables of the mutual impedance of sinusoidal dipoles. Appendicies list the computer subroutines and explain their functions.

#### II. THE THIN-WIRE COMPUTER PROGRAM

Fig. 1 is a Fortran listing of the thin-wire computer program. Near the beginning of this program, the DIMENSION statements reserve storage for a wire structure with up to 50 segments, 55 points and 60 dipole modes. Quantities with the same or related dimensions are grouped together on the same line or consecutive lines.

NM denotes the actual number of monopoles (segments), INM is the corresponding dimension, and the dimension for CG, VG and ZLD is twice INM. The second subscript for MD always has a dimension of 4.

N denotes the number of simultaneous linear equations and ICJ is the corresponding dimension. The dimension for C is (ICJ\*ICJ + ICJ)/2.

The DO LOOP ending at statement 15 sets ISC(J) = 0 for all the segments. This indicates that the wires are bare or uninsulated. If some or all of the segments are insulated, the user may set ISC(J) = 1 for the appropriate segment numbers J.

	COMPLEX EP2, EP3, ETA, GAM, Y11, Z11, ZS	0 00 1
	COMPLEX EPPS, EPTS, ETPS, ETTS, EX, EY, EZ	0002
	CDMPLEX C(1830),CJ(60),EP(60),ET(60),EPP(60),ETT(60)	0003
	DIMENSION I1(60),I2(60),I3(60),JA(60),JB(60)	0004
	COMPLEX CGD(50),SGD(50),CG(100),VG(100),ZLD(100)	0005
	DIMENSION D(50),1A(50),IB(50),ISC(50),MD(50,4),ND(50)	0006
	DIMENSION X(55),Y(55),Z(55)	0007
	DATA PI,TP/3.14159,6.28318/	0008
	DATA E0,U0/8.854E-12,1.2566E-6/	0009
2	FORMAT(1X,8F15.7)	0010
3	FORMAT(1X,4F15.7/)	0011
4	FORMAT(1X,115,8F14.6)	0012
5	FORMAT(1HO)	0013
6	FORMAT(1X,6F15.7/)	0014
7	FORMAT(8F10.5)	0015
8	FORMAT(1X,114,1315)	0015
9	FORMAT(3X, 'MAX = ',15,3X, 'MIN = ',15,3X, 'N = ',15)	0017
		0018
		0019
	DU 15 J=1,INM	0020
15	15(1)]=0 05(6)700 FD2 F1C2 TD2	0021
	KEAUIS, // BM JEKZ, SIGZ, IUZ	0022
	WKIIE (0,2) BM (EK2) SIG2 (102) SIG3 TO 3	0025
	KEAU12 (1)AM (CMM (EKS)SICS(1)D)	0024
	WRITE (0,27AM), UMM, ER3,3103,103 DEADLE 0,17D, ECC TEATN THE AD TECAT, THD ALCEN, NM, ND	0025
		0027
	WE THE ( $0, 6, 7$ ) FIG. ( $0, 4$ ) A TH THIS THIS THIS THE STORE THE STORE STOR	0028
	WEATE (4.2) EMC THAT THAT ALL THIS PHS. THS	0029
		0030
	BEAD (5 • 8) (A (J) • 18 (J)	0031
22	WRITE(6,8)J,IA(J),IB(J)	0032
	DO 40 I=1,NP	0033
	READ(5,7)X(I),Y(I),Z(I)	0034
40	WRITE(6,4)I,X(I),Y(I),Z(I)	0035
	READ (5,7)XP,YP,ZP	0036
	FHZ=FMC*1.E6	0037
	OMEGA=TP*FHZ	0038
	IF (SIG2.LT.0.)EP2=ER2*E0*CMPLX(1.,-TD2)	0039
	IF (TD2.LT.0.)EP2=CMPLX(ER2*E0,-S1G2/0MEGA)	0040
	IF (S1G3.LT.0.)EP3=ER3*E0*CMPLX(1.,-TD3)	0041
	IF (TD3.LT.0.)EP3=CMPLX(ER3*E0,-SIG3/OMEGA)	0042
	ETA=CSQRT(UO/EP3)	0043
	GAM=UMEGA*CSORT(-UO*EP3)	0044
	CALL SORT (IA, IB, II, I2, I3, JA, JB, MD, ND, NM, NP, N, MAX, MIN, ICJ, INM)	0045
	WRITE(6,5)	0046
	WRITE(6,9)MAX,MIN,N	0047
	WRIE(0,5) Terman of a dramatic i dramatic ico to 800	0040
	IT IMAAAGIA4 AURA MINALIAI AURA WAGIAICA/GO TO 500	0050
	1 N 1 = 4	0051
		. 0052
	VG(1) = (-0, -0)	0053
	710(J) = (.0.0)	0054
	JJ=J+NM	0055
	VG(JJ) = (.0, .0)	0056
60	Z LD (JJ) = (.0, .0)	0057
	IF (NGEN.GT.0)VG(NGEN)=(1.,0.)	0058
	CALL SGANT (IA, IB, INM, INT, ISC, 11, 12, 13, JA, JB, MD, N, ND, NM, NP	0059
	2, AM, BM, C, CGD, CMM, D, EP2, EP3, ETA, FHZ, GAM, SGD, X, Y, Z, ZLD, ZS)	0060
	IF (N.LE.0) GO TO 800	0061
	IF (NGEN.LE.O)GO TO 400	0062

•

.

Fig. 1a. The thin-wire computer program.

CALL GANTI(IA, IB, INM, IWR, II, I2, I3, I12, JA, JB, MD, N, ND, NM, AM	0063
2. C.CJ.CG.CMM.D.EFF.GAM.GG.CGD.SGD.VG.Y11.Z11.ZLD.ZS)	0064
WRITE(6,3)EFF,GG,Z11	0065
200 IF (INEAR.LE.0) GO TO 300	0066
CALL GNFLD (IA, IB, INM, I1, I2, I3, MD, N, ND, NM, AM, CGD, SGD, ETA, GAM	0067
2, CJ, D, X, Y, Z, XP, YP, ZP, EX, EY, EZ)	0068
WRITE(6,3)XP,YP,ZP	0069
WRITE(6,6)EX,EY,EZ	0070
300 IF (IGAIN .LE .0) GO TO 400	0071
IN C = 0	0072
ρη=ρηγ	0073
ΤΗ=ΤΗΔ	0074
CALL GFFLD(IA, IB, INC, INM, IWR, I1, I2, I3, I12, MD, N, ND, NM, AM	0075
2, ACSP, ACST, C, CGD, CG, CJ, CMM, D, ECSP, ECST, EP, ET, EPP, ETT, EPPS, EPTS	0076
3,ETPS,ETTS,GG,GPP,GTT,PH,SGD,SCSP,SCST,SPPM,SPTM,STPM,STTM,TH	0077
4,X,Y,Z,ZLD,ZS,ETA,GAM)	0078
WRITE(6,3)PH,TH,GPP,GTT	0079
400 IF(1SCAT.LE.0)G0 T0 600	0080
INC=1	0081
	0082
	0083
$CALL \qquad GFFLD(1A, 1B, INC, INM, IWR, II, I2, I3, I12, MD, N, ND, NM, AM$	0084
2, ACSP, ACST, C, CGD, CG, CJ, CMM, D, ECSP, ECST, EP, ET, EPP, ETT, EPPS, EPTS	0085
3, E TPS, E TTS, GG, GPP, GTT, PH, SGD, SCSP, SCST, SPPM, SPTM, STPM, STTM, TH	0086
4,X,Y,Z,ZLD,ZS,ETA,GAM)	0087
WRITE(6,6)PH,TH,SPPM,SPTM,STPM,STTM	0088
WRITE(6,6)ACSP,ACST,ECSP,ECST,SCSP,SCST	0089
500 IF(1BISC+LE+0)G0 T0 600	0090
INC=2	0091
PH=PHS	0092
TH=THS	0093
CALL GFFLD(IA, IB, INC, INM, IWR, I1, I2, I3, I12, MD, N, ND, NM, AM	0094
2, ACSP, ACST, C, CGD, CG, CJ, CMM, D, ECSP, ECST, EP, ET, EPP, ETT, EPPS, EPTS	0095
3,ETPS,ETTS,GG,GPP,GTT,PH,SGD,SCSP,SCST,SPPM,SPTM,STPM,STTM,TH	0096
4, X, Y, Z, ZLD, ZS, ETA, GAM)	0097
WRITE(6,6)PH,TH,SPPM,SPTM,STPM,STTM	0098
600 CONTINUE	0099
800 CALL EXIT	0100

END

Fig. 1b. The thin-wire computer program.

4

The first READ statement inputs the following parameters for the dielectric insulation:

BM	outer radius in meters
E R2	dielectric constant relative to free space
SIG2	conductivity in mhos per meter
TD2	loss tangent

The program will use SIG2 or TD2 but not both. The user determines which one will be used by assigning the other a negative value. For an uninsulated wire structure, the program will not use any of the data from the first READ statement.

The second READ statement inputs the following parameters for the wire and the exterior medium:

AM wire radius in meters CMM wire conductivity in megamhos per meter ER3 dielectric constant relative to free space SIG3 conductivity in mhos per meter TD3 loss tangent

The parameters ER3, SIG3 and TD3 are those of the homogeneous ambient medium. Again, the program will use SIG3 or TD3 but not both.

The third READ statement inputs the following data:

indicator for bistatic scattering calculations IBISC indicator for antenna gain calculations IGAIN indicator for near-zone field calculations INEAR indicator for backscatter calculations ISCAT indicator for writeout of current distributions TWR indicator for antenna calculations NGEN number of monopoles (segments) NM number of points NP

For each indicator, a positive value means the calculation or writeout is desired while a zero or negative value means it is not desired.

The fourth READ statement inputs the following data:

FMC frequency in megahertz PHA,THA far-field angle for antenna gain PHI,THI incidence angle for plane-wave scattering PHS,THS scattering angle for bistatic scattering

The above angles are given in degrees, and they denote values of the angular coordinates in the spherical system  $(r, \theta, \phi)$  widely used in antenna and scattering literature.

The fifth READ statement (in the DO LOOP ending with statement 22) inputs the endpoints IA(J) and IB(J) of segment J. Thus, IA and IB are the index numbers of the two points which are joined by segment J.

The sixth READ statement (in the DO LOOP ending with statement 40) inputs the coordinates X(I), Y(I) and Z(I) of point I in meters. The seventh and last READ statement inputs the coordinates XP, YP and ZP (in meters) of the observation point for near-zone field calculations.

Some of the quantities used in the program are defined as follows:

FHZ	frequency in Hertz
OMEGA	angular frequency
EP2	complex permittivity of insulation
EP3	complex permittivity of ambient medium
ETA	intrinsic impedance of ambient medium
GAM	intrinsic propagation constant of ambient medium
ZS	surface impedance of wire

For an uninsulated wire with perfect conductivity, one may specify complex values for ETA and GAM and delete the following input data and calculations: BM, ER2, SIG2, TD2, ER3, SIG3, TD3, FMC, FHZ, OEMGA, EP2 and EP3.

After reading the input data, the program calls subroutine SORT. This subroutine defines a set of dipole modes on the wire structure. N denotes the total number of dipole modes, the number of simultaneous linear equations, and the size of the impedance matrix  $Z_{ij}$ . Since this matrix is symmetric, only the upper-right triangular portion (including the entire principal diagonal) is calculated and stored in C(K). SORT calculates N, but the user may predict N as follows to reserve adequate storage. If m wire segments intersect at a point, this point is defined as a junction of order m and degree n = m - 1. There will be n dipole modes with terminals at this junction. N is determined by summing the degrees of all the junctions. For an example, an endpoint of a dipole is a junction of order m = 1 and degree n = 0. The vertex of a V dipole is a junction of order 2 and degree 1. NP denotes the number of points on the wire structure, and each of these points is considered to be a junction.

Mode I is a two-segment V dipole with a sinusoidal current distributed over the intersecting segments JA(I) and JB(I). The dipole has endpoints I1(I) and I3(I) and terminals at I2(I). The reference direction for positive current on dipole I is from I1 to I2 to I3.

A wire segment may be shared by as many as four dipole modes, or as few as one. In the output of subroutine SORT, ND(J) denotes the number of dipoles sharing segment J. The extreme values of ND(J) are MAX and MIN. If MIN is less than one, the wire structure has an unconnected segment and the computation is aborted. (An isolated wire must have at least two segments and three points.) If N exceeds ICJ, the dimensions are inadequate and the run is aborted.

INT specifies the number of intervals for calculating the elements in the impedance matrix with Simpson's-rule integration. A large value for INT improves the accuracy at the expense of greater execution time. For most problems a suitable combination of speed and accuracy is obtained with INT = 4. A larger value is recommended if one wire passes close to another as in the helix or the multiturn loop. If in doubt, one may set INT = 0 to choose the rigorous closed-form impedance expressions in terms of exponential integrals.

The DO LOOP ending with statement 60 sets all the lumped load impedances and generator voltages to zero. If the wire structure has lumped loads, one may insert a READ command after statement 60 to input a list of complex load impedances ZLD(J). For a wire antenna with just one generator, the program inserts a unit voltage generator with VG(NGEN) = (1.,0.). If the antenna or array has several generators, one may insert a READ command after statement 60 to input a list of complex voltages VG(J).

Generators or lumped loads may be inserted at either end or both ends of segment J. First consider a load impedance inserted in the middle of segment J. Now slide the load along the segment and let it approach the endpoint IA(J). This load is represented by ZLD(J). Next insert another load in segment J and slide it to approach the endpoint IB(J). This load is designated ZLD(JJ) where JJ = J + NM. The same convention is employed for the voltage generators VG(J) and VG(JJ). A generator voltage VG(J) is considered positive if it tends to force a current flow in the direction from IA(J) to IB(J).

Subroutine SGANT calculates the elements of the impedance matrix  $Z_{ij}$  and stores them in C(K) where K = (I-1)\*N - (I\*I - I)/2 + J. This subroutine will set N = 0 and the run will abort if the wire radius is zero or negative, the shortest segment length is less than the wire diameter, the wire radius is electrically large, or the longest segment is too long.

Subroutine GANT1 considers the thin-wire structure as an antenna and solves for the current distribution CG(J), radiation efficiency EFF, time-average power input GG and complex power input Y11. In the current distribution, CG(J) is the current on segment J as one approaches the endpoint IA(J) and CG(JJ) is the current at the other end IB(J). The reference direction for positive current is from IA to IB. Thus, the conventions are the same for the branch currents CG and the branch voltages VG.

If the antenna has only one voltage generator with VG(NGEN) = (1.,0.), then Y11 is the antenna admittance and Z11 is the impedance.

The radiation efficiency EFF is calculated from the time-average power input to the antenna and the time-average power dissipated in the wire and the lumped loads. If the antenna is insulated, the power dissipated in the insulation is neglected. If the wire has perfect conductivity and the loads are purely reactive, the calculated efficiency will be 100 per cent.

The near-field subroutine GNFLD calculates the electric field intensity (EX,EY,EZ) at the observation point (XP,YP,ZP). In the calling parameters, CJ denotes the current distribution on the wire. (The loop currents are stored in CJ(I) and the branch currents in CG(J)). Thus, the currents must be calculated before GNFLD is called. Fig. 1 illustrates the use of GNFLD to calculate the near-zone field in an antenna problem. This subroutine can be called again just above statement 500 to calculate the near-zone scattered field for a wire target. In the calling parameters, CJ is replaced with EP or ET to obtain the near-zone field with a phi-polarized or theta-polarized incident plane wave. Reference 1 describes the more sophisticated techniques required when the observation point is extremely close to the wire structure.

The far-field subroutine GFFLD calculates antenna gain if INC = 0, backscattering if INC = 1, and bistatic scattering if INC = 2. If INC = 0, PH and TH denote the spherical coordinates  $\phi$  and  $\theta$  of the distant observation point and the output from GFFLD is defined as follows. EPPS and ETTS denote the phi-polarized and theta-polarized components of the electric field intensity. For example,

(1) EPPS = 
$$re^{\gamma r}E_{\phi}$$

where r is the distance from the origin to the observation point. GPP and GTT denote the power gains associated with the phi and theta polarizations. Appendix 14 defines GPP and GTT more precisely.

If INC = 1, PH and TH denote the incidence angles  $\phi_i$  and  $\theta_i$ . These are also the spherical coordinates of the distant source. In this backscattering situation, the output data from GFFLD are defined as follows:

ACSP,ACST	absorption cross sections for $\phi$ and $\theta$ polarizations
ECSP,ECST	extinction cross sections for $\phi$ and $\theta$ polarizations
EP,ET	loop currents induced by $\phi$ and $\theta$ polarized waves
EPPS	scattered electric field E
EPTS	scattered electric field E
ETPS	scattered electric field E
ETTS	scattered electric field E
SCSP,SCST	scattering cross sections for $\phi$ and $\theta$ polarizations
SPPM	echo area or,
	ዋወ

SPTM	echo	area	JA D
STPM	echo	area	σθφ
STTM	echo	area	000

The echo areas are given in square meters. For the doubly-subscripted quantities such as  $E_{\phi\phi}$  and  $\sigma_{\phi\phi}$ , the first and second subscripts specify the polarizations of the incident and scattered waves, respectively. The complex numbers EPPS, EPTS, ETPS and ETTS are the elements of the polarization scattering matrix.

If INC = 2, PH and TH denote the scattering angles  $\phi_s$  and  $\theta_s$ . These are the spherical coordinates of the distant observer. In this bistatic scattering situation, the only outputs from GFFLD are the polarization scattering matrix and the echo areas.

To obtain antenna patterns, backscattering patterns or bistatic patterns, one may insert DO LOOPS in the program to increment the angles PH and TH. The DO LOOP will begin just above the call to GFFLD and terminate just below this call. To obtain the near-zone field distribution along a given probing path, one may insert a DO LOOP beginning just above the call to GNFLD and terminating just below this call.

When the calculations have been completed for one problem, one may GO TO a point just above CALL GANT1 if only the generator voltages are to be changed. One may GO TO a point just below CALL SORT if there is a change in the wire radius or conductivity, the insulation, ambient medium, frequency, load impedances or the coordinates (X,Y,Z). If there is a change in NM, NP, IA or IB, one should GO TO a point above CALL SORT.

Consider an array of three center-fed dipoles, and suppose we desire the 3 x 3 admittance matrix for the array. Let each dipole be divided into four segments with segments 1 through 4 on dipole 1, 5 through 8 on dipole 2 and 9 through 12 on dipole 3. The three-port admittance matrix can be obtained by inserting a DO LOOP beginning just above CALL GANT1 and terminating just below this call. GANT1 will be called three times with all the voltages VG set to zero except for a single one-volt generator. On the first, second and third calls, let NGEN = 3, 7 and 11 to represent a generator at the center of dipole 1, 2 and 3, respectively. After the first call, set Y11 = CG(3), Y12 = CG(7) and Y13 = CG(11). Set Y22 = CG(7) and Y23 = CG(11) after the second call and Y33 = CG(11) after the third call.

For extremely small antennas, quasi-static or double-precision subroutines are required.

The wire radius must exceed zero, but there is no difficulty with small radii. If the radius exceeds  $0.007\lambda$ , the thin-wire assumptions are questionable and the accuracy and convergence deteriorate. The length ratio of the longest and shortest segments should not exceed 100. It is

assumed that the <u>wire</u> length exceeds the wire diameter by a factor of at least 30. We are not aware of any lower limit on the <u>segment</u> length, however.

If a wire is bent sharply to form a small acute angle (less than 30 degrees), the thin-wire model is questionable. It is assumed that the wire conductivity greatly exceeds the conductivity of the ambient medium. For insulated wires, the dielectric layer is assumed to be electrically thin.

For each thin-wire problem, calculations should be repeated several times with the wire divided progressively into shorter segments. There is no assurance of accuracy until the output data converge. For a moderately thick wire (with radius a = 0.007  $\lambda$  or larger), the susceptance may diverge with the delta-gap model. This difficulty may be alleviated or eliminated with the magnetic-frill model and the techniques of Imbriale and Ingerson [2].

Tables 1, 2 and 3 list input and output data for three simple examples of uninsulated wire structures. Each table includes a sketch of the wire configuration with labels to indicate the numbering system for the points and segments. In these examples there are no lumped loads.

In the sinusoidal-reaction formulation, a basic function is the mutual impedance between two sinusoidal filamentary electric dipoles. One dipole is a test source located on the axis of the wire structure, and the other is an expansion mode on the wire surface. In view of the importance of this mutual impedance, short tables are presented next for a few simple cases. The data can be reproduced with the program in Fig. 1 with appropriate input data for uninsulated wires with perfect conductivity and no lumped loads in free space. The data were obtained with the closed-form expressions (INT = 0) by writing out the quantities C(K) just below the call to subroutine SGANT. Double precision was used for these calculations.

Table 4 lists the self impedance of a two-segment sinusoidal V dipole with radius  $a = 0.001 \lambda$ . Subroutine SGANT calculates this quantity by setting up one filamentary dipole on the wire axis and another identical dipole on the wire surface. These dipoles lie in parallel planes separated by a distance equal to the wire radius.

In Table 5, dipoles 1 and 2 have terminals at vertices 1 and 2, respectively, and they share the middle segment. Again these dipoles lie in parallel planes separated by a distance equal to the wire radius. For a one-turn planar polygon wire loop, subroutine SGANT would generate the data in Table 4 for the diagonal elements  $Z_{ij}$  and the data in Table 5 for the next elements.

	Input	t and Output	: Data ·	for Stratg	nt Wire		
Input Dat 0.002 0.001 1 300. 1 2 3	za 2.56 1.00 1 0. 2 3 4	-1.0 1.0 1 90.	0.000 -1.0 1 0.	5 0.0 90.	3 45.	4 45.	5
4 0. 0. 0. 0. 1.	5 0. 0. 0. 0. 1.	-0.250 -0.125 0. 0.125 0.250 1.		1 1 2	<sup>2</sup> <del>3</del> <del>3</del> <del>3</del>	4 5	
Output Da 98.18 091 0.0 0.0 0.0 45.0	ata 0.0095 0.080 90.0 90.0 0.0069 45.0	82.97 -0.091 0.0 0.0 0.0 0.0		43.26 0.080 1.615 0.0 0.377 0.0	0.224 0.0 0.0 0.0	-0.096 0.608 0.370 J.239	
	Inp	ut and Outpu	TABLE 2 ut Data	for Squar	e Loop		
Input Dat 0.002 0.001 1 300. 1	ta 2.56 1.0 1 0.0 2	-1.0 1.0 1 90.0	0.0005 -1.0 1 0.0	0.0 0 90.0	1 45.	4 45.	4
2 3 4 0.05 0.05 -0.05 -0.05 1.0	3 4 1 -0.05 0.05 0.05 -0.05 1.0	0.0 0.0 0.0 0.0 1.0		3	2		
Output Da 73.10 0078 0.0 0.0 .126E-4 45.0	ata .243E-4 .0027 90.0 90.0 0.0 45.0	62.94 .0057 .8066 .0002 .936E-4 .106E-3	1 • • • •	609.8 0029 0 0 0 265E-4	0010 .0 .810E-4 .0	0056 .0 .0 .0	

TABLE 1 Input and Output Data for Straight Win

	-						
Input Da	<u>ta</u> 2.56	-1.0	0.0005				
0.001	1.0	1.0	-1.0	0.0	_	_	_
1	1	1	1	0	2	4	5
300.	0.0	90.0	0.0	90.0	45.	45.	
1	2						
2	3					5	
3	4					-	
3	5			_	4		
0.0	-0.30	0.0	1				
0.0	-0.15	0.0	1				
0.0	0.0	0.0	-		3		
0.1	0.1	0.0				-	
-0.1	0.1	0.0				4	
1.0	1.0	1.0					
Output D	ata						
97,88	0.013	75.53	-0.572				
124	0.081	0.260	-0.064	-0.126	. 0	.070	
0.0	90.0	1.535	0.0				
0.0	90.0	0.748	0.0	0.0	0	.0	
0.0103	0.0	0.487	0.0	0.477	0	.0	
45.0	45.0	0.360	0.170	0.0	0	.0	

TABLE 3 Input and Output Data for Y Antenna

TABLE 4

Self Impedance of Two-Segment V Dipole Shown in Fig. 2 Radius:  $a = 0.001\lambda$ 

ψ	h = 0.10x	h = 0.15λ	h = 0.20λ	h = 0.25%
30°	0.59 - j 481	1.4 - j 314	3.1 - j 186	6.1 - j 61
60	2.15 - j 547	5.3 - j 337	11.0 - j 177	21.3 - j 21
90	4.22 - j 572	10.4 - j 340	21.1 - j 163	40.0 + j 9
120	6.31 - j 583	15.3 - j 338	30.9 - j 151	57.7 + j 28
150	7.81 - j 587	18.9 - j 335	37.7 - j 144	69.3 + j 39
180	8.33 - j 589	20.1 - j 335	39.9 - j 142	73.1 + j 42



Fig. 2. Symmetric center-fed V dipole.

TABLE	5
-------	---

Mutual Impedance Between Overlapping V Dipoles in Fig. 3 Radius:  $a = 0.001\lambda$ 

ψ	$h = 0.10\lambda$	h = 0.15λ	h = 0.20x	$h = 0.25\lambda$
60°	-0.96 + j 338	-2.08 + j 285	-3.45 + j 275	- 4.8 + j 298
90	0.19 + j 322	1.03 + j 276	3.57 + j 271	10.1 + j 297
120	3.29 + j 336	8.40 + j 290	17.86 + j 285	35.3 + j 309
150	6.61 + j 346	15.61 + j 299	30.00 + j 291	52.9 + j 309
180	8.01 + j 349	18.47 + j 301	34.35 + j 292	58.2 + j 308



Fig. 3. Overlapping V dipoles share the middle segment.

Tables 6, 7, and 8 list the mutual impedance for other configurations. In all these tables, the data apply to two-segment center-fed sinusoidal dipoles with identical segment lengths h.

a	h = 0.10λ	h = 0.15λ	h = 0.20λ	h = 0.25%
30°	6.74 - j 314	16.24 - j 167	32.17 - j 56	58.7 + j 49.6
60	3.16 - j 291	7.68 - j 169	15.47 - j 76	28.8 + j 14.2
90	0.06 - j 278	0.31 - j 172	1.15 - j 92	3.5 - j 12.2
120	-1.01 - j 256	-2.39 - j 168	-4.47 - j 101	-7.6 - j 35.5
150	-0.48 - j 207	-1.20 - j 146	-2.40 - j 98	-4.5 - j 50.7

TABLE 6 Mutual Impedance Between Overlapping V Dipoles in Fig. 4 Radius:  $a = 0.001\lambda$ 



Fig. 4. Overlapping V dipoles share the bottom segment in a planar Y configuration.

TABLE 7 Mutual Impedance Between the Coplanar-Skew Linear Dipoles in Fig. 5 Displacement:  $d = \lambda$ 

θ	$h = 0.10\lambda$	h = 0.15λ	$h = 0.20\lambda$	h = 0.25x
0°	0.337 + j 1.952	0.880 + j 4.759	1.932 + j 9.547	4.011 + j 17.7
15	0.322 + j 1.884	0.831 + j 4.585	1.799 + j 9.180	3.671 + j 17.0
30	0.281 + j 1.684	0.700 + j 4.082	1.448 + j 8.128	2.800 + j 15.0
45	0.220 + j 1.369	0.521 + j 3.301	1.000 + j 6.519	1.745 + j 11.9
60	0.149 + j 0.964	0.333 + j 2.310	0.579 + j 4.524	0.860 + j 8.1
75	0.075 + j 0.497	0.159 + j 1.187	0.252 + j 2.308	0.305 + j 4.1
90	0.0 + j 0.0	0.0 + j 0.0	0.0 + j 0.0	0.0 + j 0.0



Fig. 5. Center-fed coplanar-skew linear dipoles.

¢	h = 0.10λ	h = 0.15λ	h = 0.20λ	h = 0.251
0°	0.337 + j 1.952	0.880 + j 4.759	1.932 + j 9.547	4.011 + j 17.74
15	0.326 + j 1.886	0.850 + j 4.596	1.867 + j 9.222	3.877 + j 17.14
30	0.292 + j 1.691	0.762 + j 4.121	1.675 + j 8.269	3.482 + j 15.37
45	0.238 + j 1.380	0.622 + j 3.365	1.369 + j 6.752	2.850 + j 12.55
60	0.169 + j 0.976	0.440 + j 2.380	0.969 + j 4.775	2.020 + j 8.88
75	0.087 + j 0.505	0.228 + j 1.232	0.502 + j 2.472	1.047 + j 4.60
90	0.0 + j 0.0			

TABLE 8 Mutual Impedance Between the Nonplanar-Skew Linear Dipoles in Fig. 6 Displacement:  $d = \lambda$ 



Fig. 6. Center-fed nonplanar-skew linear dipoles.

III. SUMMARY

This report presents the sinusoidal-reaction computer program for thin-wire antennas and scatterers, instructions for the user, typical input and output data and mutual-impedance tables for sinusoidal dipoles. Appendices list the computer subroutines and explain their functions.

#### REFERENCES

 Richmond, J.H., "Radiation and scattering by thin-wire structures in the complex frequency domain," Report 2902-10, July, 1973, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering; prepared under Grant NGL 36-008-138 for National Aeronautics and Space Administration, Langley Research Center. (Available as NASA CR-2396, 1974.)

٠

- Imbriale, W.A., and Ingerson, P.G., "On numerical convergence of moment solutions of moderately thick wire antennas using sinusoidal basis functions," IEEE Trans., Vol. AP-21, May 1973, pp. 363-366.
- Abramowitz, M., and Stegun, I.A., "Handbook of mathematical functions with formulas, graphs, and mathematical tables," National Bureau of Standards, Applied Mathematics Series AMS-55, 1964, Chapter 5.
- Faddeev, D.K., and Faddeeva, V.N., <u>Computational Methods of Linear Algebra</u>, W. H. Freeman and Company, San Francisco, 1963, pp. 144-147.

### APPENDIX 1. Subroutine SORT

Subroutine SORT, listed in Fig. 7, defines a set of dipole mode currents on the wire structure. The input data IA, IB, NM, NP, ICJ and INM have been defined already. The output data are defined as follows:

total number of dipole modes
endpoint of dipole I
terminal point of dipole I
endpoint of dipole I
first segment of dipole I
second segment of dipole I
list of dipoles sharing segment J
total number of dipoles sharing segment 1
extreme values of ND(J)

At completion of the DO LOOP ending with statement 20, NJK denotes the number of segments intersecting at point K, and JSP is a list of these segments. In the DO LOOP ending with statement 22, the computer sets up the appropriate number MOD of dipoles modes with terminals at poink K.

## APPENDIX 2. Subroutine SGANT

Subroutine SGANT, listed in Fig. 8, calculates the mutual impedances  $Z_{ij}$  and stores them in C(K). The input data for SGANT have been defined already. The output data are defined as follows:

C(K)	open-circuit impedance matrix
CGD(J)	cosh yd for segment J
SGD(J)	sinh vd for seament J
D(J)	length of segment 1
zŚ	surface impedance of the wire

The surface impedance is calculated just above statement 12. B01 denotes  $J_0/J_1$  where  $J_0$  and  $J_1$  are the Bessel functions of order zero and one with complex argument ZARG. It is assumed that all the wire segments have the same radius, conductivity and surface impedance.

In the DO LOOP ending with statement 20, SGANT calculates the segment lengths D(J). DMIN and DMAX denote the lengths of the shortest and longest segments. If the wire radius or the segment lengths are clearly beyond the range of thin-wire theory, N is set to zero at statement 25 followed by RETURN to the main program to abort the calculation.

At statement 30, the program selects a segment K, and a few statements below this it selects another segment L. K is a segment of test dipole I, and L is a segment of expansion mode J. The mutual impedance between segments K and L is obtained by calling subroutine GGS or GGMM.

SUBRUUTINE SONT(TATIONICATURE ATTAINICATURATURA ATTAINICATURA ATTAINICATUU ATTAINITATAUTUATURA ATTAINICATURA ATTAINICATURA ATTAINICATURA ATT		THE REPORT OF THE TRANSPORT OF THE TRANSPORT	0001
2, 1(J,1(AM)         0003           DIMENSION JSP(20)         0004           DIMENSION JA(J), TS(1), JA(1), JB(1)         0004           DIMENSION JA(J), TS(1), AD(1), MD(1),		SUBROUTINE SURTIA, ID, II, IZ, ID, SA, SUTIDA UD, ID, ID, ID, ID, ID, ID, ID, ID, ID, I	0002
D MENSIGN JSA (L) (1) (12 (1) (13 (1) (14 (1) (15 (1) (14 (1) (15 (1) (14 (14 (14 (14 (14 (14 (14 (14 (14 (14		2, ICJ, INMJ	0003
D INENSION IA11), IB(I), ND(I), MD(I)M, 4) D INENSION IA11), IB(I), ND(I), MD(INM, 4) 100 DU 24 K=1, NP NJK=0 DU 20 J=1, NM ND=(IA(J)K) + (IB(J)-K) IF(IND, K=, 0)E0 TO 20 NJK=NJK=1 OOT JS(IL)K) - J CONTINUE ND0=NJK=1, OF TO 22 IF(IND, K=, 0)E0 TO 24 IF(IND, K=, 0)E0 TO 22 IF(IND, K=, 0)E0 TO 22 IF(IND, K=, 0)E0 TO 22 IF(IND, K=, 0)E0 TO 22 IF(IND) IF(I) + IND IF(I) + IND		DIMENSION $J_{J}(1), I_{J}(1), I_{J}(1), J_{J}(1), J_{J}(1), J_{J}(1), J_{J}(1)$	0004
100         100 <td></td> <td>DIMENSION IA(1), IB(1), ND(1), MD(INM, 4)</td> <td>0005</td>		DIMENSION IA(1), IB(1), ND(1), MD(INM, 4)	0005
DD 24 K=1,NP         0007           NJK=0         0008           DD 20 J=1,MM         0008           IND=(IA(J)-K)*(IB(J)-K)         0010           IF (IND-NE_0)GO TO 20         0011           NJK=N         0012           JSP(NJK)=J         0013           20 CONTINUE         0015           MDD=NJK=1         0015           IF (MDD-KE_0)GO TO 24         0016           DC 22 IMD=1,MOD         0017           I=1+1         0013           JA[I=JA]         0012           JA[I=JA]         0020           JA[I=JA]         0021           JA[I=JA]         0022           JB[I=JSP(IMD)         0022           JA[I=JA]         0022           JB[I=JSP(IMD)         0022           JA[I]=JA[         0026           If (IA(JAL)=K),K)1(I)=IB(JAL)         0026           If (IA(JAL)=K),K)1(I)=IB(JAL)         0022           IS (I)=IA(JAL)         0023           IS (I)=IA(JAL)         0023           IS (I)=IA(JAL)         0030           IS (I)=IA(JAL)         0023           IS (I)=IA(JAL)         0030           IS (I)=IA(JAL)         0030           IS (I		I=0	0006
NJK-0         00000           D0 20 J=1,NM         00000           IND=(IA(J)-K)*(IB(J)-K)         0010           NJK:N.NE.016 TO 20         0011           NJK:N.NE.016 TO 20         0011           NJK:N.NE.016 TO 20         0011           NJK:N.NE.016 TO 20         0012           JSP(INX)EJ         0013           JSP(INX)EJ         0014           MODENJK-1         0015           IF(IND)+LE.0160 TO 24         0017           D0 22 IMD=1,MOD         0017           JAI=JSP(IMD)         0021           JAI=JSP(IMD)         0022           JAI=JSP(IMD)         0022           JB(I)=JBI         0022           JB(I)=JSP(IMD)         0022           JSP(INTNUE         0028           JSP(INTNUE         0027           JSP(INUNE         0032		DU 24 K=1,NP	0007
D0         20         J=1,NM         00010           IND=(IA(J)-K)*(IB(J)-K)         0011         0011           IF (IND,NE.0)GO TO 20         0013         0013           JSP(IAJK)=J         0014         0015           CONTINUE         0015         0016           MODENJK-1         0016         0016           DC (DNTINUE         0017         0017           DC 22 IMD=1,MOD         0019         0019           I=1-1         0018         0021           JAT=JSP(IND)         0022         JAT=JSP(IND)         0022           JAT=JSP(IND)         0022         JBT=JSP(IPD)         0022           JBT=JSP(IPD)         0025         IF (IATJAT)=IA(JAT)         0026           IT (I=IA(JAT)=IA(JAT))         0026         IF (IATJAT)=IA(JBT)         0027           JST=JSP(IPD)         0022         0027         0019         0027           JST(I=A(JAT)=IA(JBT))         0026         IF (IATJAT)         0026         0027           JST(I=A(JAT)=IA(JBT))         0026         0027         0027         0027           JST(I=A(JAT))         0026         0027         0027         0027         0027           JST(I=A(JAT))         0028         0		NJK=0	0000
INUSTIALUTER (MIDELATER)       0011         IF (IND. NE. 0.160 TO 20       0012         NJKENJKH       0013         JSP(INK)E       0014         0 CONTINUE       0015         MOBENJK-1       0016         IF (MUD. LE. 0.160 TO 24       0016         DD 22 IMDE1.MOD       0018         IF (I. CT. ICJJGO TO 22       0020         JAT ISP(IMD)       0021         JAT ISP(IMD)       0022         JAT ISP(IMD)       0023         JBE ISP(IMD)       0023         JBE ISP(IMD)       0024         JBE ISP(IMD)       0025         JBE ISP(IMD)       0026         IF (IALJBI).EO.K)11(I)=IB(JAI)       0026         IF (IALJBI).EO.K)11(I)=IB(JAI)       0027         IS (I)=IALUAT)       0027         IS (I)=IALUAT)       0027         IS (I)=IALUAT)       0026         IS (I)=IALUAT)       0027         IS (I)=IALUAT)       0028         IS (I)=IALUAT)       0027         IS (I)=IALUAT)       0028     <		DO = 2O = J = 1, NM	0010
NJK*NJK+1       0013         JSP(NJK+1=J)       0014         OCNTINUE       0015         MODENJK-1       0016         DO 22 IM0-1,MCD       0017         DO 22 IM0-1,MCD       0018         I=1+1       0018         JAT=JSP(IMO)       0020         JAT=JSP(IMO)       0022         JAT=JSP(IMO)       0022         JAT=JSP(IMO)       0022         JAT=JSP(IMO)       0022         JAT=JSP(IMO)       0022         JAT=JSP(IMO)       0022         JB(I)=JAT       0026         I(1)=IA(JAT)       0026         I(1)=IA(JAT)       0026         I(1)=IA(JAT)       0027         JS(I)=JAT       0027         JS(I)=JAT       0027         JS(I)=JAT       0027         JS(I)=JS(IA)       0026         I(1)=K       0027         JS(I)=JAT       0027         JS(I)=JAT       0026         IS(I)=JAT       0027         JS(I)=JAT       0028         JS(I)=JAT       0028         JS(I)=JAT       0030         OD 30 J=1,NM       0033         DO 40 I=1,II       0035		INU = (IA(J) - K) + (IB(J) - K)	0011
3GP (HJK + J)         0013           20 CONTINUE         0016           HODENJK-1         0016           1F (HUD) LE 0160 TO 24         0017           DD 22 IMD-1 HADD         0018           1=11         0020           1K (L, GT, LCJ)GO TO 22         0020           1A1-3P(IMO)         0021           JA1-3P(IMO)         0022           JA1-3P(IMO)         0025           IF (IA(JA1)+EQ-K)TI1(I)=IB(JA1)         0026           IZ (I)=K         0027           JZ (I)=K         0028           GONTINUE         0030           OO 30 J=1,MM         0023           D0 30 J=1,MM         0033           D0 30 J=1,MM         0035           D0 30 J=1,MM         0036           D0 30 J=1,MM         0037           D0 30 J=1,MM		N K=N K+1	0012
20         CONTINUE         0015           MDD=NJK=1         0016         0015           MDD=NJK=1         0016         0017           D0 22 IM01.4K 0)K00 T0 22         0019         0019           IP0=IM0+1         0020         0021           JA1=JSP(IM0)         0022         JA1=JSP(IM0)         0022           JA1=JSP(IM0)         0022         JA1=JSP(IM0)         0022           JA1=JSP(IM0)         0024         0024         0025           JA1=JSP(IM0)         0025         0026         0027           JA1=JSP(IM0)         0026         0027         0027           JA1=JSP(IM0)         0026         0027         0027           JA1=JSP(IM0)         0026         0027         0027           JA1=JSP(IM0)         0026         0027         0027           JC(I)=K         0027         0027         0027           IS(I)=IA(JA1)         0026         0027         0027           JA1=JSP(IM0)         0026         0027         0027           I=I=N         0027         0027         0028           I=I=N         0028         0028         0030         0030           I=I=N         0028		JSP (NJK)=J	0013
MOD=NJK-1         0016           DF (MUD).LE.0160 T0 24         0017           D0 22 IMD=1.MOD         0018           IF (I.GT.ICJ)60 T0 22         0019           PD=HD=1.MOD         0020           JAI=JSP(IMD)         0021           JAI=JSP(IMD)         0022           JAI=JSP(IMD)         0023           JAI=JSP(IMD)         0024           JB(I)=JAI         0025           JB(I)=JSP(IMD)         0025           JB(I)=JSP(IMD)         0025           JB(I)=JSP(IMD)         0025           JB(I)=JSP(IMD)         0025           JB(I)=JSP(IMD)         0026           JSI=JSP(IMD)         0025           JSI=JSP(IMD)         0025           JSI=JSP(IMD)         0026           JSI=JSP(IMD)         0027           JSI=JSP(IMD)         0028           JSI=JSI         0027           DSI	20	CONTINUE	0014
IF (M0): LE : 0.000 T0 24       0017         D0 22 INDE1, MOD       0019         I=1:1       0019         IF (I.CT.ICJ)GO TO 22       0020         JAI=JSP(IMO)       0021         JA(1)=JAI       0022         JBI=JSP(IMO)       0024         JA(1)=JAI       0025         JB(1)=JBI       0024         JA(1)=JAI       0025         JB(1)=JBI       0026         JA(1)=JAI       0026         JS(1)=JSP(IMO)       0026         JS(1)=JSI       0027         JB(1)=JBI       0026         I(1)=IA(JAI)       0026         I(1)=LA(JAI)       0026         I(1)=LA(JAI)       0026         I(1)=LA(JAI)       0027         I(1)=LA(JAI)       0027         I(1)=LA(JAI)       0028         IF(IA(JAI)=CO.K)III(I)=IB(JBI)       0028         IF(IA(JAI)=CO.K)III(I)=IB(JBI)       0030         22 CONTINUE       0031         NO(J)=D       0033         NO(J)=CO.K)IIII=ICJ       0033         NO(J)=CO       0037         III=N       0037         III=N       0040         NO (J)=ND(J)+II       0042      <		MOD=NJK-1	0016
D0         22         10:1-1:NOD         0018           I=1+1         0019           IPD=IMD+1         0020           JAI=JSP(IMD)         0021           JAI=JSP(IMD)         0022           JBI=JSP(IPD)         0022           JBI=JSP(IPD)         0022           JBI=JSP(IPD)         0025           JBI=JSP(IPD)         0026           JBI=JSP(IPD)         0027           JBI=JSP(IPD)         0026           JBI=JSP(IPD)         0027           JBI=JSP(IPD)         0026           JBI=JSP(IPD)         0027           JBI=JSP(IPD)         0027           JBI=JSP(IPD)         0027           JBI=JSP(IPD)         0027           JSII=AN         0027           JSII=IA         0027           JSII=SUB         0027           JSII=SUB         0027           JSII=SUB         0027           JSII=SUB         0027           JSII=SUB         0027           JSII=SUB         0028           JSII=SUB         0027           JSII=SUB         0031           JSII=SUB         0032           JSII=SUB         0031 <tr< td=""><td></td><td>IF (MQI).LE.0160 10 24</td><td>0017</td></tr<>		IF (MQI).LE.0160 10 24	0017
iFileT.T.ICJ GO TO 22       0019         iPD=IMD+1       0021         JAI=JSP(IMD)       0023         JAI=JSP(IMD)       0023         JBI=JSP(IPD)       0024         JB(I)=JAI       0025         JB(I)=JSP(IPD)       0026         JB(I)=JSP(IPD)       0027         JB(I)=JSP(IPD)       0027         JB(I)=JSP(IPD)       0027         JB(I)=JSP(IPD)       0026         If(IAJAI)=CO.K)II1(I)=IB(JAI)       0027         If(I)=K       0027         If(I)=LA(JAI)       0027         If(I)=LA(JAI)       0027         If(I)=LA(JAI)       0027         If(I)=LA(JAI)       0027         If(I)=LA(JAI)       0027         If(I)=LA(JAI)       0028         If(I)=LA(JAI)       0038         If(I)=LA(JAI)       0030         If(I)=LA(JAI)       0031         If(I)=LA(JAI)       0033         NO(J)=LA(JA)       0035         If(I)=LA(JAI)       0035         If(I)=LA(JAI)       0035         If(I)=LA(JAI)       0036         If(I)=LA(JAI)       0037         If(I)=LA(JAI)       0046         ND (J)=ND(J)+I       00		1=1+1	0018
iPp=IM0+1       0020         JAI=JSP(IM0)       0021         JAI=JSP(IPD)       0023         JBI=JSP(IPD)       0024         JBI=JSP(IPD)       0025         II(I)=JAI       0026         JBI=JSP(IPD)       0026         JBI=JSP(IPD)       0027         JBI=JSP(IPD)       0026         II(I)=IA(JAI)_EO.K)II(I)=IB(JAI)       0026         IZ(I)=K       0028         IA(I)=JAI)_EO.K)II(I)=IB(JBI)       0029         CONTINUE       0031         No       0031         DO 30 J=1,NM       0033         NO (J)=O       0034         DO 30 K=1,4       00335         30 MO(J,K)=O       0035         30 MO(J,K)=O       0038         DO 40 I=1,1II       0038         D0 40 I=1,1II       0040         Nd(J)=ND(J)+1       0042         MC       0042         MS=0       0044         MC       0045         IF (MJ,K)=I       0045         Ma(J,K)=I       0046         MC (J,K)=I       0045         Ma = 0       0052         OD 38 L=1,2       0051         MD (J,K)=I       0045 <td></td> <td>IF (1.GT.ICJ)GO TO 22</td> <td>0019</td>		IF (1.GT.ICJ)GO TO 22	0019
JA[=JSP(IMD)         0021           JA[1=JA[         0022           JB[1=JSP(IPD)         0024           JB[1=JSP(IPD)         0025           JB[1]=JA[         0025           II(I]=JA[]         0026           II(I]=LA[JA[]         0027           II(I]=LA[JA[]         0027           II(I]=LA[JA[]         0027           II(I]=LA[JA[]         0027           II(I]=LA[JA[]         0027           II(I]=LA[JA[]         0027           II(I]=LA[JB]         0030           II(I]=LA[JB]         0031           ND(J]=D         0033           ND(J]=ND(J)         0035           II(I]=NM         0037           ND(J]=ND(J)+I         0038           DD 30 L=1,2         0041           ND(J]=ND(J)+I         0042           K=1         0043           M=0         0044           M=1         0045		IPD = IMD + 1	0020
JA[1]=JA[ JA[1]=JA[ JB[1]=JA[ JB[1]=JB] JB[1]=JB] JB[1]=JB] JB[1]=JB] JB[1]=JB] JA[2] JA[1]=JB] JA[2] JA		JAI=JSP(IMD)	0021
JB I = JSP ( PD ) JB I = JSP ( PD ) JB I = JB I I + [ JA ( JA I ) = C = K   I ( I ) = IB ( JA I ) IF ( IA ( JA I ) = C = K ) I ( I ) = IB ( JA I ) IF ( IA ( JA I ) = C = K ) I 3 ( I ) = IB ( JA I ) IF ( IA ( JB I ) = C = K ) I 3 ( I ) = IB ( JB I ) 22 CONTINUE 22 CONTINUE 23 CONTINUE 24 CONTINUE 25 CONTINUE 26 CONTINUE 27 ON 30 J = 1, MM ND ( J) = 0 28 ON 30 K = 1, 4 30 MD ( J, K I = 0 11 I = N 16 N = 1, IC ) III = IC J 29 ON 30 L = 1, 1II 20 30 J = 1, 1II 20 30 J = 1, 1II = CJ 20 0040 I = 1, III = CJ 20 0040 I = 1, III = CJ 20 0040 I = 1, 1II = CJ 20 0040 I = 0, 0, 1 = 1, 1II = CJ 20 0041 D0 0042 21 MJ K = MD ( J) + 1 22 MJ K = MD ( J) + 1 23 MJ K = MD ( J) + 1 24 MJ K = MD ( J) + 1 25 MJ K = MD ( J) + 1 26 MJ K = 1 27 MJ K = MD ( J, K ) = 1 28 J = B ( I ) 29 ON 20 TO 32 20 ON 20 CONT INUE 20 ON 20 TO 32 20 ON 20 CONT INUE 20 ON 20 TO 32 20 ON 20 CONT INUE 20 ON 20 CONT 20		JA(I)=JAI	0023
JB(1)=1A(JAI)         0025           If (IA(JAI),E0,K)II(I)=IB(JAI)         0027           I2(I)=K         0028           If (IA(JBI),E0,K)I3(I)=IB(JBI)         0028           If (IA(JBI),E0,K)I3(I)=IB(JBI)         0030           22         CONTINUE         0031           N=I         0032           00 30 J=1,NM         0033           N0 (J)=0         0036           01 30 K=1,4         0035           00 30 (K)=0         0036           11I=N         0037           16 (N, CT, IC, J) III=ICJ         0038           00 40 [=1,1II         0040           00 38 (=1,2         0041           ND (J)=ND (J)+1         0042           ND (J)=ND (J)+1         0043           M=0         0044           32         MJK=MD (J,K)         0044           M=1         0044           MD (J,K)=1         0043           34         K=K+1         0043           35         J=JR(1)         0043           40         K=K+1         0043           38         J=JR(1)         0044           44         K=K+1         0045           45         K=K+1         00		JBI=JSP(IPD)	0024
If (IA(JAI):E0.K)I1(I)=IB(JAI)       0027         I2(I)=K       0027         I3(I)=IA(JBI)       0028         IF (IA(JBI):E0.K)I3(I)=IB(JBI)       0030         22       CONTINUE       0031         00 30       J=1,NM       0033         N=I       003       0034         00 30       J=1,NM       0035         00 30       State       0035         00 30       State       0035         00 30       State       0035         00 30       State       0036         01 30       K=1,4       0035         00 30       State       0036         01 30       K=1,4       0036         00 40       IIIIEN       0037         JE (IN,K)=State       0037         JE (IN,K)=State       0037         JE (IN,GT,ICJ)III=ICJ       0038         DD 40       IIII       0038         DD 38       L=1,2       0041         ND (J)=ND (J)+1       0042       0043         M=0       0044       0047         M=1       0044       0047         MD (J,K)=I       0048       0047         MD (J,K)=I       0048		JB(1) - JB(1)	0025
12(1)=K       0027         13(1)=1A(JBI)       0028         14(1)=1A(JBI)       0032         22       CONTINUE       0031         N=1       0032         D0 30 J=1,NM       0033         N0(J)=0       0034         00 30 K=1,4       0035         30       M0(J,K)=0       0035         11=N       0037         15((N,GT,ICJ)III=ICJ       0038         D0 40 1=1,111       0044         D0 38 L=1,2       0042         ND(J)=ND(J)+1       0042         ND(J)=ND(J)+1       0044         M=0       0044         M=0       0044         M=1       0045         M=1       0051         MO(J,K)=1 </td <td></td> <td><math>IF(IA(JAI) \cdot EQ \cdot K)II(I) = IB(JAI)</math></td> <td>0026</td>		$IF(IA(JAI) \cdot EQ \cdot K)II(I) = IB(JAI)$	0026
13(1)=1A(JB1)       0028         1F(1A(JB1),EQ,K)13(1)=1B(JB1)       0030         22       CONTINUE       0031         N=1       0032         D0 30 J=1,NM       0033         N0 (J)=0       0034         D0 30 K=1.4       0035         30       M0 (J,K)=0       0037         111=N       0037         JF(N,GT,ICJ)III=ICJ       0037         JG(1)       0037         JJ(1)       0037         JJ(1)       0037         JJ(1)       0037         JJ=A(1)       0037         JG(1)       0038         JJ=A(1)       0041         D0 30 L=1,2       0041         ND (J)=ND(J)+1       0042         K=1       0043         M=0       0044         M=1       0043         M=2       0044         M=3       0045         IF(MJ,K)=1       0046         M=1       0047         M0(J,K)=1       0046         M1       0050         IF(MJ,GT,A)       0051         IF(M,Eco,0)GO TO 32       0051         JB J=B(1)       0052         MIN=100		I2(I)=K	0027
IF (1A(JB1)-EQ.K)13(1)=18(JB1)       0022         22 CONTINUE       0031         N=I       0032         D0 30 J=1,NM       0033         NO(J)=0       0035         D0 30 K=1,4       0035         30 M0(J)=0       0036         D0 30 K=1,4       0035         D0 40 1=1,III       0037         J=JA(1)       0040         D0 38 L=1,2       0041         ND(J)=ND(J)+1       0042         MD(J)=ND(J)+1       0042         K=1       0043         M=0       0044         K=1       0043         M0(J,K)=1       0044         32 MJK=MD(J,K)       0045         IF (MJK,NE,0)GO TD 34       0046         M=1       0047         MD(J,K)=1       0050         IF (K,GT,4)GO TO 38       0050         IF (MJK,NE,0)GO TO 32       0051         J=JB(1)       0052         40 CONTINUE       0052         MD (J,K)=1       0052         34 K=K+1       0050         IF (MJK,NE,0)GO TO 32       0051         36 J=JB(1)       0052         40 CONTINUE       0055         MIN=100       0055 <td></td> <td>13(1)=IA(JBI)</td> <td>0028</td>		13(1)=IA(JBI)	0028
22       CONTINUE       0031         24       CONTINUE       0032         N=I       0033         00       30       J=1,NM         N0(J)=0       0034         00       30       K=1,4         30       M0(J,K)=0       0035         11       IF       0037         30       M0(J,K)=0       0038         D0       40       I=1,111       0038         J=JA(1)       0040       0041         D0       38       L=1,2       0041         ND(J)=ND(J)+1       0042       0042         M=0       0044       0044         32       MJK=MD(J,K)       0046         M=1       0047       0046         M=1       0048       0047         M0(J,K)=1       0048       0047         M0(J,K)=1       0048       0051         JF (M,SC.4)GO TO 38       0051       0051         IF (K.6T.4)GO TO 38       0053       0051         JB =JB(1)       0053       0052         40       CONTINUE       0053         MAX=0       0055       0054         MAX=0       0055       0056 <td>_</td> <td><math>IF(IA(JBI) \cdot EQ \cdot K)I3(I) = IB(JBI)</math></td> <td>0029</td>	_	$IF(IA(JBI) \cdot EQ \cdot K)I3(I) = IB(JBI)$	0029
24       CUNTINUE       0032         N=I       0033         D0 30 J=1,NM       0033         N0 (J)=0       0035         D0 30 K=1,4       0035         30       M0 (J,K)=0       0036         III=N       0037         J0 30 K=1,4       0036         J1I=N       0037         J0 30 K=1,4       0038         D0 40 I=1,1II       0037         J=JA(1)       0040         D0 38 L=1,2       0041         ND (J)=ND (J)+1       0043         K=1       0043         M0 (J,K)=NE.0)GO TD 34       0044         Me 0       0045         JK=MD (J,K)       0046         M=1       0048         M0 (J,K)=1       0048         34       K=K+1         MD (J,K)=1       0051         J=JB(1)       0052         00 CONTINUE       0051         M1 =100       0053         MAx=0       0055         00 46 J=1,NM       0056         ND J=ND (J)       0058         IF (ND J.CT.MIN MAX=ND J       0058         40       IF (ND J.CT.MIN JMAX=ND J       0056         ND J=ND (J) </td <td>22</td> <td></td> <td>0031</td>	22		0031
No 1       003         No (J)=0       003         OD 30 K=1,4       0036         30 M0 (J,K)=0       0037         II I=N       0037         IF (N.GT.ICJ) III=ICJ       0038         D0 40 I=1,III       0040         J=JA(1)       0040         D0 38 L=1,2       0041         ND (J)=ND (J)+1       0042         M=0       0043         M=0       0044         M=1       0044         M0 (J,K) =1       0046         Mo (J,K) =1       0046         M=1       0047         M0 (J,K)=1       0048         34 K=K+1       0049         IF (M.F.GT.GT D 38       0050         IF (M.EQ.O)GO TO 32       0051         38 J=JB(1)       0053         40 CONTINUE       0053         MAX=0       0054         MAX=0       00554         MAX=0       00554         MAX=0       00557         IF (NDJ.GT.MAX)MAX=NDJ       0058         KE TURN       0050         RE TURN       0050         RE TURN       0060	24		0032
ND(J)=0         0034           D0 30 K=1,4         0035           30 M0(J,K)=0         0037           III=N         0038           D0 40 I=1,III         0039           J=JA(I)         0040           D0 38 L=1,2         0041           ND(J,K)=ND(J)+1         0042           NJ=ND(J)+ND(J)+1         0043           M=0         00443           M=0         0045           IF (MJK,NE=0)GO TD 34         00445           M=1         0047           MD(J,K)=1         0048           34 K=x+1         0050           IF (M.EQ.O)GO TO 34         0050           IF (M.EQ.O)GO TO 32         0051           J=JB(I)         0052           40 CONTINUE         0053           MAx=0         0054           MAX=0         0055           DD 46 J=1,NM         0057           MIN=100         0058           40 F (NDJ.GT.MAX)MAX=NDJ         0058           40 IF (NDJ.LT.MIN MIN=NDJ         0056           RETURN         0056           DI 40 J=1.T.MIN MIN=NDJ         0056           RETURN         0056           END         00661		DO 30 J=1+NM	0033
DO 30 K=1,4 00035 MO (J,K)=0 0037 III=N 0038 DO 40 I=1,III 0038 DO 40 I=1,III 0040 DO 38 L=1,2 0041 ND (J)=ND (J)+1 0041 M=0 0042 K=1 0044 32 MJK=MD (J,K) 0045 IF (MJK,NE.0)GO TO 34 0045 ME (J,K)=1 0046 34 K=K+1 0047 MD (J,K)=1 0049 IF (K.GT.4)GO TO 38 0050 IF (M.GT.4)GO TO 38 0050 IF (M.GT.4)GO TO 32 0050 AK=1 0053 MIN=100 0055 MIN=100 0055 MI		ND(J) = 0	0034
30       MO (J,K)=0       0037         II I=N       0038         D0 40 I=1,III       0040         J=JA(I)       0040         D0 38 L=1,2       0041         ND (J)=ND (J)+1       0043         K=1       0043         M=0       00443         M=1       00443         MD (J,K)       0045         IF (MJK+NE+0)GO TD 34       00443         M=1       0047         MD (J,K)=1       0048         34       K=K+1       0049         IF (M,EQ.O)GO TO 34       0046         MD (J,K)=1       0049         38       J=JB(I)       0052         39       IF (M,EQ.O)GO TO 32       0051         38       J=JB(I)       0052         40       CONTINUE       0053         MAX=0       0055       0054         MAX=0       00557       0056         ND J=ND (J)       0057       0057         IF (NDJ.GT.MAX)MAX=NDJ       0058         6       IF (NDJ.LT.MIN MIN=NDJ       0050         RETURN       0050       0054         END       0051       0057		DO 30 K=1,4	0035
IIII=N       0038         IF (N.GT.ICJ)III=ICJ       0039         DD 40 I=1,III       0040         J=JA(1)       0041         DO 38 L=1,2       0041         ND (J)=ND (J)+1       0043         K=1       0043         M=0       0044         32 MJK=MD (J,K)       0045         IF (MJK.NE.0)GO TD 34       0047         M=1       0047         MD (J,K)=I       0049         IF (K.GT.4)GO TO 38       0051         IF (M.EQ.0)GO TO 32       0051         38 J=JB(1)       0052         40 CONTINUE       0055         MIN=100       0054         MAX=0       0055         0D 46 J=1,NM       0057         0F (NDJ.GT.MAX)MAX=NDJ       0058         46 IF (NDJ.T.T.MIN)MIN=NDJ       0059         RETURN       0059         RETURN       0050         END       0061	30	MD ( J , K )=0	0037
D1 (40) i=1,0111       0039         D0 40 i=1,111       0040         D0 38 L=1,2       0041         ND (J)=ND(J)+1       0043         M=0       0044         32 MJK=MD(J,K)       0045         IF (MJK+NE+0)GO TO 34       0046         M=1       0047         MD (J,K)=1       0048         34 K=K+1       0049         IF (K.GT.4)GO TO 38       0050         IF (M.EQ.0)GO TO 32       0051         38 J=JB(1)       0052         40 CONTINUE       0053         MIN=100       0054         MAX=0       0055         DD 46 J=1,NM       0058         46 IF (NDJ-LT.MIN )MIN=NDJ       0058         46 IF (NDJ-LT.MIN )MIN=NDJ       0059         RE TURN       0060         END       0061		III=N 1E (N CT ICI)III=ICJ	0038
J=JA(I)       0040         D0 38 L=1,2       0041         ND(J)=ND(J)+1       0043         M=0       0044         32 MJK=MD(J,K)       0045         IF (MJK.NE.0)GO TD 34       0046         M=1       0047         MD(J,K)=I       0049         34 K=K+1       0049         IF (K.GT.4)GO TO 38       0050         IF (M.EQ.0)GO TO 32       0051         38 J=JB(I)       0053         40 CONTINUE       0053         MIN=100       0055         MAX=0       0056         DD 46 J=1,NM       0056         ND J=ND(J)       0057         IF (ND J.CT.MAX)MAX=ND J       0058         40 IF (ND J.LT.MIN MIN=ND J       0059         RETURN       0060         END       0061			0039
D0 38 L=1,2       0041         ND(J)=ND(J)+1       0043         K=1       0043         M=0       0044         32 MJK=MD(J,K)       0045         IF (MJK.NE.0)GO TD 34       0046         M=1       0047         MD(J,K)=I       0048         34 K=K+1       0049         IF (K.GT.4)GO TO 38       0050         IF (M.EQ.0)GO TO 32       0051         38 J=JB(1)       0052         40 CONTINUE       0053         MIN=100       0054         MAX=0       00554         DD 46 J=1,NM       0057         DF (NDJ.GT.MAX)MAX=NDJ       0058         46 IF (NDJ.LT.MIN MIN=NDJ       0059         RETURN       0059         O060       0061		J = JA(1)	0040
ND (J) = ND (J) + 1         0042           K = 1         0043           M = 0         0044           32         MJK = MD (J, K)         0045           IF (MJK • NE • 0) GO TD 34         0046           M = 1         0047           MD (J, K) = 1         0048           34         K = K + 1         0049           IF (M.EQ.0) GO TO 38         0051           IF (M.EQ.0) GO TO 32         0051           38         J = JB (I)         0052           40         CONTINUE         0053           MIN = 100         0054           MIN = 100         0055           MIN = 100         0054           MAX = 0         0055           DD 46 J = 1 , NM         0056           ND J = ND (J)         0058           46         IF (NDJ.CT.MIN )M IN = ND J         0059           RETURN         0060           END         0061		DO 38 L=1,2	0041
K=1       00/44         M=0       00/45         32       MJK=MD(J,K)       00/45         IF (MJK,NE.0)GO TD 34       00/46         M=1       00/47         MD(J,K)=I       00/48         34       K=K+1         IF (K.GT.4)GO TO 38       00/50         IF (M.EQ.0)GO TO 32       00/51         38       J=JB(I)       00/52         40       CONTINUE       00/53         MIN=100       00/54         MAX=0       00/57         DO 46       J=1,NM       00/57         ND J=ND (J)       00/58         46       IF (NDJ.LT.MIN)MIN=ND J       00/59         RETURN       00/60       00/61		ND(J)=ND(J)+1	0042
M=0       0045         32       MJK=MD(J+K)       0046         IF (MJK+NE+0)GO TD 34       0047         M=1       0048         MD(J,K)=I       0049         34       K=K+1       0049         IF (K.GT+4)GO TO 38       0050         IF (M-EQ+0)GO TO 32       0051         38       J=JB(I)       0053         40       CONTINUE       0053         MIN=100       0054       0054         MAX=0       0055       0054         DO 46       J=1,NM       0055         ND J=ND(J)       0057       0057         IF (NDJ+LT+MIN)MIN=NDJ       0059         RETURN       0060         END       0061		K=1	0044
32       M3(k+M) (3(k))       0046         IF (MJK, NE • 0) GO TO 34       0047         M=1       0048         MO (J,K) = I       0049         34       K=K+1       0049         IF (K.GT.4) GO TO 38       0050         IF (M.EQ.0) GD TO 32       0051         38       J=JB(I)       0053         40       CONT INUE       0053         MIN=100       0054         MAX=0       0055         DO 46       J=1,NM       0057         ND J=ND (J)       0058         46       IF (ND J.CT.MIN )M IN =ND J       0059         RE TURN       0060         END       0061	22		0045
M=1       0047         MD (J,K)=I       0048         34       K=K+1       0049         IF (K.GT.4)GO TO 38       0050         IF (M.EQ.0)GD TO 32       0051         38       J=JB(I)       0053         40       CONTINUE       0053         MIN=100       0054       0054         MAX=0       0055       0054         DD 46 J=1,NM       0056       0055         ND J=ND (J)       0058       0059         46       IF (ND J.LT.MIN )M IN =ND J       0059         RE TURN       0060       0061	22	IE (MJK NE O)GO TO 34	0046
MD (J,K)=I       0048         34       K=K+1       0049         IF (K.GT.4)GO TO 38       0050         IF (M.EQ.0)GO TO 32       0051         38       J=JB(I)       0052         40       CONTINUE       0053         MIN=100       0054         MAX=0       0056         DD 46 J=1,NM       0057         ND J=ND (J)       0058         46       IF (ND J.LT.MIN )M IN =ND J       0059         RETURN       0060         ND       0061		M=1	0047
34       K=K+1       0049         IF (K.GT.4)GO TO 38       0050         IF (M.EQ.0)GO TO 32       0051         38       J=JB(I)       0053         40       CONTINUE       0053         MIN=100       0054         MAX=0       0056         DD 46 J=1,NM       0057         ND J=ND(J)       0058         46       IF (NDJ.CT.MIN)MIN=NDJ       0059         RETURN       0060         ND       0061		MD(J,K)=1	0048
IF (K.GT.4)GO TO 38       0051         IF (M.EQ.0)GO TO 32       0051         38 J=JB(I)       0052         40 CONTINUE       0053         MIN=100       0054         MAX=0       0056         DD 46 J=1,NM       0057         ND J=ND(J)       0058         46 IF (NDJ.LT.MIN)MIN=NDJ       0059         RETURN       0060         ND       0061	34	K = K + 1	0049
IF (M.EQ.0) GU 10 32       0052         38 J=JB(I)       0053         40 CONTINUE       0054         MIN=100       0054         MAX=0       0055         DD 46 J=1,NM       0056         ND J=ND(J)       0057         IF (NDJ.GT.MAX)MAX=NDJ       0058         46 IF (NDJ.LT.MIN)MIN=NDJ       0059         RETURN       0060         END       0061		IF (K.GT.4)GO TO 38	0050
36       J-JNT //       0053         40       CONTINUE       0054         MIN=100       0054         MAX=0       0055         DD       46       J=1,NM         NDJ=ND(J)       0057         IF       (NDJ.GT.MAX)MAX=NDJ       0058         46       IF (NDJ.LT.MIN)MIN=NDJ       0059         RETURN       0060         END       0061	20	IF (M.EQ.0)GU 1U 32	0052
40       0054         MIN=100       0055         MAX=0       0056         DD       46       J=1,NM       0056         ND J=ND (J)       0057       0058         IF (ND J.GT.MAX)MAX=ND J       0059       0059         RE TURN       0060       0061         END       0061       0061	20		0053
MAX=0       0055         DD       46       J=1,NM       0056         NDJ=ND(J)       0057       0058         IF (NDJ.GT.MAX)MAX=NDJ       0059         46       IF (NDJ.LT.MIN)MIN=NDJ       0059         RETURN       0060         END       0061	7 V	MIN=100	0054
DD         46         J=1,NM         0056           NDJ=ND(J)         0057         0058           IF (NDJ.GT.MAX)MAX=NDJ         0059           46         IF (NDJ.LT.MIN)MIN=NDJ         0050           RETURN         0060           END         0061		M A X = 0	0055
ND J=ND (J)         0057           IF (ND J.GT.MAX)MAX=NDJ         0058           46         IF (ND J.LT.MIN)MIN=NDJ         0059           RE TURN         0060           END         0061		DD 46 J=1,NM	0056
IF (NDJ.G[.MAX]MAX=NDJ       0050         46       IF (NDJ.LT.MIN)MIN=NDJ       0059         RETURN       0060         END       0061		ND J=ND (J)	0057
46         1F INDJELTEM IN JM IN = NOJ         0060           RETURN         0061		IF (NDJ.GI.MAX)MAX=NDJ	0059
END 0061	46		0060
		END	0061

-

Fig. 7. Subroutine SORT

20

	SUBROUTINE SGANT (IA, IB, INM, INT, ISC, II, I2, I3, JA, JB, MD, N, ND, NM, NP	0001
	2, AM, BM, C, CGD, CMM, D, EP2, EP3, ETA, FHZ, GAM, SGD, X, Y, Z, ZLD, ZS)	0002
	COMPLEX ZG,ZH,ZS,EGD,GD,CGDS,SGDS,SGDT,B01	0003
	CUMPLEX P11,P12,P21,P22,Q11,Q12,Q21,Q22,EP2,EP,ETA,GAM,EP3	0004
	COMPLEX EPSILA, CWEA, BETA, ZARG	0005
	COMPLEX P(2,2),Q(2,2),CGD(1),SGD(1),C(1),ZLD(1)	0006
	DIMENSION_X(1),Y(1),Z(1),D(1),IA(1),IB(1),MD(INM,4)	0007
	DIMENSION 11(1),12(1),13(1),JA(1),JB(1),ND(1),ISC(1)	0008
	DATA E0,TP,U0/8.854E-12,6.28318,1.2566E-6/	0009
2	FURMAT(3X, AM = ', E10.3, 3X, 'DMAX = ', E10.3, 3X, 'DMIN = ', E10.3)	0010
2	E P = E P 3	0011
	ICC=(N *N+N )/2	0012
	DO 10 $I=1,ICC$	0013
10	C(I) = (.0, .0)	0014
	Z S = (•0+•0)	0015
	IF (CMM.LE.0.)GO TO 12	0017
	OMEGA=TP*FHZ	0018
	EPSILA=CMPLX(E0,-CMM#1.E8/UMEGA)	0019
	$CWEA = \{0, 1, 0\} * OMEGA * EPSILA$	0020
	BETA=OMEGA+SQRT(UO)*CSQRT(EPSICA-EP)	0021
	ZARG=BETA#AM	0022
	CALL CBES(ZARG, BOI)	0023
	ZS=BETA*BOI/CWEA	0024
12	ZH=ZS/(TP*AM*GAM)	0025
	DM IN = 1 • E 30	0026
		0027
	DD 20 J=1,NM	0028
		0029
	L=18(J) o ( + + - c opt / / y / y ) - y / ( ) ) ** 2 + ( Y ( Y ) - Y (   ) ) ** 2 + ( 7 ( K ) - Z ( L ) ) ** 2 }	0030
	D(J) = SQRT((A(K) - A(C)) + 2 + (A(K) - A(K) - A(K)) + 2 + (A(K) - A(K)) + (A(K) - A(K)) + 2 + (A(K) - A(K)) + 2 + (A(K) - A(K)) + 2 + (A(K) - A(K)) + (A(K) - A	0031
		0032
		0033
		0034
20	(GU(J)) = (CGU(J) + (CGU(J)) =	0035
20	$S_{0}(3) = (-1)^{-1} + (-1)^$	0036
	$F (CARS(CAM \pm aM), GT_0, 0.06) GD_TD_25$	0037
	1 = (CABS(GAM * DMAX), GT, 3) GD TO 25	0038
	$\mathbf{F} = \{\mathbf{A} \mathbf{M}_{1}, \mathbf{G} \mathbf{T}_{2}, \mathbf{O}_{2}\} = \{\mathbf{G} \mathbf{M}_{1}, \mathbf{G} \mathbf{M}_{2}, \mathbf{G} \mathbf{M}_{2}\}$	0039
25	N=0	0040
25	HRITE (6.2) AM +DMAX+DM IN	0041
	RETURN	0042
30	DD 200 K=1.NM	0045
00	NDK=ND(K)	0044
	<b>ΚΑΞΙΑ(Κ)</b>	0045
	KB=IB(K)	0040
	DK=N(K)	0048
	CGDS=CGD(K)	0049
	SGD S= SGD (K)	0050
	DO 200 L=1,NM	0051
	NDL=ND(L)	0052
		0053
		0054
	$D = D \left( L \right)$	0055
		0056
		0057
		0058
		0059
	MM = (1 - 1) *N + (1 + 1 - 1)/2	0060
	ri=1	0061
	$\frac{1}{100} = \frac{1}{100} = \frac{1}$	0062
	IF (ND+EW+11(1))F1=-1+	

,

Fia.	8a.	Subroutine	SGANT

		I S= 1	0063'
		GO TU 40	0064
	36	IF (KA.EQ.I3(I))FI=-1.	0065
		I S=2	0066
	40	DD 200 JJ=1,NDL	0067
			0068
		IE(I,GT,I)GO,TO,200	0009
		F.I=1.	0070
		IF(LB.EQ.12(J))GD TO 46	0072
		IF(L8.EQ.I1(J))FJ=-1.	0073
		J S = 1	0074
		GO TO 50	0075
	46	IF (LA, EQ. 13(J))F J=-1.	0076
	50		0077
	50	NTI=1	0078
		IF (K.EQ.L)GD TO 120	0080
		IND=(LA-KA)*(LB-KA)*(LA-KB)*(LB-KB)	0081
		1E (IND .EQ.0)GD TO 80	00 82
	С	SEGMENTS K AND L SHARE NO POINTS	0083
		CALL GGS(X(KA),Y(KA),Z(KA),X(KB),Y(KB),Z(KB),X(LA),Y(LA),Z(LA)	0084
		Z;X(LD);Y(LD);Z(LD);AM;UK;UUD);SUD);UL;SUD;JN1;E1A;UAM 3. P(1,1), P(1,2), P(2,1), P(2,2))	0085
		G(1) 168	0080
	с	SEGMENTS K AND L SHARE ONE POINT (THEY INTERSECT)	0088
	80	KG=0	0089
		JM=KB	0090
		JC=KA	0091
			0092
		INU=(ND-LA)+(NO-LD) IE(IND_NE_0)CO_TO_87	0093
		.IC=KB	0094
		KF = -1	0096
		JM=KA	0097
		KG=3	0098
	82	LG=3	0099
		JP=LA	0100
		TE ( I B E () I C ) CO TO 83	0101
			0102
		1F=1	0105
		LG=O	0105
	83	SGN=KF ≠LF	0106
		CPSI=((X(JP)-X(JC))*(X(JM)-X(JC))+(Y(JP)-Y(JC))*(Y(JM)-Y(JC))	0107
		2+(Z(JP)-Z(JC))*(Z(JM)-Z(JC)))/(DK*DL)	0108
		CALL GGMM(.0,DK,.0,DL,AM,CGDS,SGDS,SGDT,CPSI,ETA,GAM	0109
		2 + 0(1 + 1) + 0(1 + 2) + 0(2 + 1) + 0(2 + 2))	0110
		KP=TARS(KK-KG)	0112
		DU 98 LL=1.2	0113
		LP=IABS(LL+LG)	0114
-		P(KP,LP)=SGN≠Q(KK,LL)	0115
	98	CONTINUE	0116
,	~	GUTU 168	0117
. (	ט 1 זי	N-L ISELF KEALIIUN UF SEGMENI K)	0118
	120	012=(.00)	0120
		IF (CMM.LE.0.)GD TO 150	0121
		GD = GAM #DK	0122
		2G=2H/(SGDS**2)	0123
		Q11=ZG*(SGDS*CGDS-GD)/2.	0124

Fig. 8b. Subroutine SGANT

22

•**[**],

Q12=ZG*(GD*CGDS-SGDS)/2.	0125
150 ISCK=ISC(K)	0126
P11=(.0,.0)	0127
P12=(.0,.0)	0128
IF (ISCK-EQ-0)GO TO 155	0129
IF (BM.LE.AM)GO TO 155	0130
CALL DSHELL (AM, BM, DK, CGD S, SGD S, EP2, EP, ETA, GAM, P11, P12)	0131
155 Q11=P11+Q11	0132
Q12=P12+Q12	0133
CALL GGMM (.0, DK, .0, DK, AM, CGDS, SGDS, SGDS, 1.	0134
2 • E T A • G AM • P 1 1 • P 1 2 • P 2 1 • P 2 2 )	0135
Q11=P11+Q11	0136
Q12=P12+012	0137
P(1,1)=Q11	0138
P(1,2)=Q12	0139
P(2,1) = Q12	0140
P(2,2)=Q11	0141
IF (KA.NE.LA)GO TO 160	0142
GD TO 168	0143
160 P(1,1) = -Q12	0144
P(1,2) = -Q11	0145
P(2,1) = -Q11	0146
P(2,2) = -012	0147
$168 C(MMM) = C(MMM) + FI \neq FJ \neq P(IS, JS)$	0148
200 CONTINUE	0149
D0 220 I=1.N	0150
$I_{J=}(1-1) \neq N - (I \neq I - 1)/2 + I$	0151
J1=JA(I)	0152
IF(I2(I).EQ.IB(J1))J1=J1+NM	0153
J2=JB(I)	0154
IF(I2(I).EQ.IB(J2))J2=J2+NM	0155
220 C(IJ)=C(IJ)+ZLD(J1)+ZLD(J2)	0156
RETURN	0157
END	0158

Fig. 8c. Subroutine SGANT

In statement 168, this impedance is lumped into C(MMM). The mutual impedance  $Z_{ij}$  between dipoles I and J is the sum of four segment-segment impedances.

In SGANT, segment K has endpoints KA and KB, and segment L has endpoints LA and LB. It is convenient to think of KA and KB as points 1 and 2 on segment K, and LA and LB as points 1 and 2 on L. Now we define four segment-segment impedances P(IS,JS). The first subscript IS refers to the terminal point on segment K, and the second subscript JS refers to the terminal point on L. Thus IS = 1 or 2 if dipole I has its terminal point I2(I) at KA (point 1) or KB (point 2), respectively. Similarly, JS = 1 or 2 if mode J has its terminal point I2(J) at LA or LB. The impedances P(IS,JS) are defined with the following reference directions for current flow: from point 1 toward point 2 on each segment. If dipole I has this same reference direction on segment K, we set FI = 1; otherwise FI = -1. Similarly FJ = 1 or -1 in accordance with the reference direction for mode J on segment L. In statement 168, P(IS,JS) is multiplied by FI and FJ before its contribution is added to Z<sub>ij</sub>.

Subroutine GGMM calculates the impedances Q(KK,LL) which are like the P(IS,JS) but have different conventions for reference directions and subscript meaning. The transformation from the Q impedances to the P impedances is accomplished in the DO LOOP ending with statement 98.

If the wire has finite conductivity, the appropriate modification is applied to the impedance matrix just above statement 150. (See Eqs. 27 through 29 in Reference 1.) The terms arising from the dielectric shell on an insulated segment are obtained from subroutine DSHELL just above statement 155. Finally, the lumped loads ZLD are added to the diagonal elements of the impedance matrix in statement 220.

The impedance matrix could be calculated in a different order as follows. Select modes I and J, calculate ZIJ, and then increment I or J. Instead, SGANT selects segments K and L, calculates ZKL, adds ZKL to all the appropriate elements ZIJ, and then increments K or L. This minimizes the calls to GGS and GGMM and presumably improves the computational efficiency.

K is a segment of test dipole I, and L is a segment of expansion mode J. When the segment numbers K and L are equal, SGANT calls GGMM to obtain the mutual impedance between two filamentary electric monopoles. These monopoles are parallel and have the same length. Monopole K is positioned on the axis of the wire segment, and monopole L is on the surface of the same wire segment. Thus, the displacement is equal to the wire radius. The two monopoles are side-by-side with no stagger.

When segments K and L intersect, SGANT again calls GGMM for the mutual impedance between the two filamentary monopoles. Monopole K is

situated on the axis of wire segment K, and monopole L is on the surface of wire segment L. The axes of segments K and L define a plane P, and monopole K lies in this plane. Monopole L is parallel with plane P and is displaced from it by a distance equal to the wire radius.

APPENDIX 3. Subroutine CBES

Subroutine CBES, listed in Fig. 9, calculates the quantity BO1 =  $J_0(z)/J_1(z)$  where z is complex and  $J_0$  and  $J_1$  denote the Bessel functions of order zero and one.

APPENDIX 4. Subroutine DSHELL

Subroutine DSHELL, listed in Fig. 10, calculates the mutual impedance term contributed by the dielectric insulation on the surface of a thin wire. This subroutine uses Eq. 35 of Reference 1.

APPENDIX 5. Subroutine GGS

Subroutine GGS, listed in Fig. 11, calculates the mutual impedance between two filamentary monopoles with sinusoidal current distributions. (The dipole-dipole mutual impedance in Eq. 20 of Reference 1 is the sum of four monopole-monopole mutual impedances.) The endpoints of the axial test monopole s are (XA,YA,ZA) and (XB,YB,ZB), and the endpoints of the expansion monopole t are (X1,Y1,Z1) and (X2,Y2,Z2). DS and DT denote the lengths of monopoles s and t, respectively. CAS, CBS and CGS are the direction cosines of monopole s, and CA, CB and CG are the direction cosines of monopole t.

If INT = 0, GGS calls GGMM for the closed-form impedance calculations. Otherwise GGS calculates the mutual impedance via Simpson'srule integration with the following number of sample points: IP = INT + 1. If the monopoles are parallel with small displacement, GGS calls GGMM to avoid the difficulties of numerical integration.

For the fields of the test monopole, GGS uses Eqs. 75 and 76 of Reference 1. The current distribution on the expansion monopole is given by Eq. 74 of Reference 1. With an origin at (X1,Y1,Z1), the coordinate T measures distance along the expansion monopole. Thus T is the integration variable.

Let the coordinate s measure distance along the test monopole with origin at (XA,YA,ZA). From any point T on monopole t, construct a line to the test monopole such that the line is perpendicular to the test monopole. SZ denotes the s coordinate of the intersection of this line with the test monopole. The length of the line is the radial coordinate  $\rho$ , and RS denotes  $\rho^2$ . R1 and R2 are the distances from (XA,YA,ZA) and (XB,YB,ZB) to the point T. C1 is the current at T for the mode with terminals at (X1,Y1,Z1), and C2 is the current at T for the other mode with terminals at (X2,Y2,Z2). C denotes the Simpson'srule weighting coefficient.

	SUBROUTINE CBES(Z,BO1)	0001
	COMPLEX ARG,CC,CS,EX	0002
	COMPLEX BO1,Z,TERMJ,TERMN,MZZ4,JN(2)	0003
	DATA PI/3.14159/	0004
	IF (CABS( Z ).GE.12.0) GO TO 10	0005
	FACTOR=0.0	0006
	TERMN=(0,,0,)	0007
	M724=-0,25*7*7	0008
	TERM.J=[1.0.0.0]	0009
	DO = 1 NP = 1.2	0010
	N=NP-1	0011
	JN (NP)=TFRMJ	0012
	M=0	0013
2	M=M+1	0014
	TERMJ=TERMJ*MZ24/FLOAT(M*(N+M))	0015
	JN (NP)=JN (NP)+TERMJ	0016
	IF (NP.NE.1) GO TO 3	0017
	FACTOR=FACTOR+1.0/FLOAT(M)	0018
	TERMN = TERMN + TERM J + FACTOR	0019
3	ERROR=CABS(TERMJ)	0020
	IF (ERROR.GT.1.0E-10) GO TO Z	0021
1	TERMJ=0.5*Z	0022
	B01=JN(1)/JN(2)	0023
	RETURN	0024
10	Y=AIMAG(Z)	0025
	IF (ABS(Y).GT.20.)GO TO 20	0026
	ARG=(.0,1.)*Z	0027
	EX=CEXP(ARG)	0028
	CC=EX+1./EX	0029
	CS=(.0,-1.)*(EX-1./EX)	0030
	BO1=(CS+CC)/(CS-CC)	0031
	RETURN	0032
20	B01=(.0,-1.)	0033
	IF(Y.LT.0.)B01=(.0,1.)	0034
	RETURN	0035
	END	0036

;

# Fig. 9. Subroutine CBES

,

SUBROUTINE DSHELL(AM, BM, DK, CGDS, SGDS, EP2, EP, ETA, GAM, P11, P12)	0001
COMPLEX CGDS,SGDS,EP2,EP,ETA,GAM,P11,P12,GD,CST	0002
DATA PI/3.14159/	0003
GD=GAM +DK	0004
CS1=(EP2-EP) *ETA*ALOG(BM/AM)/(4 *PI*EP2*SGDS*SGDS)	0005
$P I I = -(S I + (G) + SG) S \neq (G) S $	0006
$P12=CS1=(GD \times CGD S+SGD S)$	0007
RETURN	0008
ENU	0009

\_

# Fig. 10. Subroutine DSHELL.

.

	CURRONTING CCS (YA, VA, 7A, XB, YB, 7B, X1, Y1, Z1, X2, Y2, Z2, AM	0001
	SUBRUUTINE OUSTAATATERT OF DATA DID DID DID DID	0002
2	DS,CGDS,SGUS,DT,SGDT, INI,EIA,GAM,PII,PIZ,PZI,PZZ	0002
	COMPLEX P11, P12, P21, P22, EJA, EJB, EJ1, EJ2, ETA, GAM, C1, C2, CST	0003
	COMPLEY FOR CODS. SODS. SODT. FRI. FR2. ET1. ET2	0004
		0005
	DATA FP/12.566377	0006
	CA=(X2-X1)/DT	0000
	CB={Y2-Y1}/DT	0007
		0008
		0009
	CAS=(XB-XA)/DS	0010
	CBS = (YB - YA)/DS	0010
	$(GS = (7B - 7\Delta)/DS$	0011
		0012
		0013
	IF (ABS(CC).G1997)GD 10 200	0014
20	SZ=(X1-XA)*CAS+(Y1-YA)*CBS+(Z1-ZA)*CGS	0014
	1F(INT_1F_0)G0 T0 300	0015
		0016
		0017
	IF (INS + LI + 2 ) INS = 2	0018
	I P = I N S + 1	0010
	DELT=DT/INS	0019
	T=_0	0020
		0021
		0022
	P11=(.0,.0)	0000
	$P_{12}=(.0.0)$	0023
		0024
		0025
	P22=(•0,•0)	00.26
	AM S = AM * AM	0020
	SGN = -1 -	0021
	DO 100 IN=1.IP	0028
		0029
	ZZ1=SZ	0030
	222=S2-DS	0030
	xxz=x1+T+CA-xA-SZ+CAS	0031
	VY7-V1+T+CR-VA-S7+CRS	0032
		0033
		0034
	R S = X X Z **2+YYZ **2+ZZZ **2	0035
	R1=SQRT(RS+ZZ1**2)	0035
	E.IA=CEXP(-GAM*R1)	0036
		0037
		0038
	R2=SQRT(RS+ZZZ##Z)	0030
	EJB=CEXP(-GAM*R2)	0039
	F.12=F.18/R2	0040
		0041
		0042
	ER2=-EJB#SGDS+222#EJ2#CGDS=221#EJ1	0043
	FAC=•0	0045
	1F(RS.GT.AMS)FAC=(CA*XXZ+CB*YYZ+CG*ZZZ)/RS	0044
	$ET1 = CC + (E_1) - E_1 + CGDS + EAC + ER1$	0045
		0046
	$E \uparrow 2 = CC \neq (EJI = EJZ \neq CGDS) + FAC \neq ERZ$	0047
	C=3.+SGN	0047
	IF (IN_FO_] _OR_ IN_EQ.IP)C=1.	0048
	$E_{C}(-C_{C} \times D / C \wedge M \times (D T - T))$	0049
		0050
	$C1 = C * (EGD - 1 \cdot / EGD) / 2 \cdot$	0051
	E GD = CE X P ( GAM *T )	0051
	$C_2 = C * (F_{CD} - 1_{a}/F_{CD})/2_{a}$	0052
		0053
		0054
	P12=P12+E11+62	0055
	P <u>21</u> =P21+ET <b>2*C1</b>	0000
	P22=P22+FT2 #C2	0056
		0057
		0058
	5Z=5Z+U5Z	0050
100	S GN =– S GN	0009
	CST=-ETA*DELT/(3,*FP*SGDS*SGDT)	0060
		0061
		0062
	F12+6317F14	

Fig. 11a. Subroutine GGS

p22=cST*P22         0064           RETURN         0065           200         SZ1=(X1-XA)*CAS+(Y1-YA)*CBS+(Z1-ZA)*CGS         0066           RH1=SQRT((X1-XA-SZ1*CAS)**2+(Y1-YA-SZ1*CBS)**2+(Z1-ZA-SZ1*CGS)**2)         0067           SZ2=SZ1+DT*CC         0068           RH2=SQRT((X2-XA-SZ2*CAS)**2+(Y2-YA-SZ2*CBS)**2+(Z2-ZA-SZ2*CGS)**2)         0067           DDD=(RH1+RH2)/2.         0070           IF (DDD.str.20.*AM.AND.INT.GT.0)GO TO 20         0071           IF (DDD.str.AN)DDD=AM         0073           CALL GGMM(.0,DS,SZ1,SZ2,DDD,CGDS,SGDS,SGDT,1.         00773           2. FTA,GAM,P11,P12,P21,P22)         0076           RETURN         00776           SS=SQRT(1CC*CC)         00776           CBD=(CAS*CB-CBS*CG)/SS         0077           CBD=(CAS*CACAS*CB)/SS         0077           DK=(AS*CACAS*CB)/SS         0077           DK=(AS*CACAS*CB)/SS         0078           CGD=(CBS*CACACAS*CB)/SS         0081           IF (DK.LT.AM)*DK=AM         0082           XZ=XA+SZ*CGS         0086           XZ=XA+SZ*CGS         0085           XP1=X1-DK*CAD         0086           CAP=CBS*CGD-CGS*CBD         0086           CAP=CGS*CAD-CAS*CBD         0088           CAP=CGS*CAD		P21=CST#P21	0063
RETURN       0065         200       SZ1=(X1-XA)*CAS+(Y1-YA)*CBS+(Z1-ZA)*CGS       0066         RH1=SQRT((X1-XA-SZ1*CAS)**2+(Y1-YA-SZ1*CBS)**2+(Z1-ZA-SZ1*CGS)**2)       0067         SZ2=SZ1+DT*CC       0068         RH2=SQRT((X2-XA-SZ2*CAS)**2+(Y2-YA-SZ2*CBS)**2+(Z2-ZA-SZ2*CGS)**2)       0069         DDD=(RH1+RH2)/2.       0071         IF (DDD.GT.20.*AM .AND. INT.GT.0)GO TO 20       0071         IF (DDD.LT.AM)DDD=AM       0072         CALL GGM(.0,DS,SZ1,SZ2,DDD,CGDS,SGDS,SGDT,1.       0073         2.ETA,GAM,P11,P12,P21,P22)       0074         RETURN       0075         300       SS=SQRT(1CC*CC)       0076         CAD=(CGS*CB-CBS*CC)/SS       0077         CBD=(CAS*CA-CAS*CB)/SS       0077         DK=ABSIDK)       0080         DK=XBSLCK)       0081         IF (DK.LT.*A)*CAD + (Y1-YA)*CBD + (Z1-ZA)*CGD       0088         XZ=XA+SZ*CAS       0085         XZ=XA+SZ*CAS       0086         XZ=XA+SZ*CAS       0086         YA + SZ*CAS       0086         XZ=XA+SZ*CAS       0086         YA + SZ*CAS       0086         XZ=XA+SZ*CAS       0086         XY + YA + SZ*CAS       0086         YA + SZ*CAS       0086 <td></td> <td>P22=CST*P22</td> <td>0064</td>		P22=CST*P22	0064
200       SI = (XI - XA) *CAS + (Y1 - YA) *CBS + (Z1 - ZA) *CGS       0066         RH = SQRT ((X1 - XA - SZ 1 *CAS) **2 + (Y1 - YA - SZ 1 *CBS) **2 + (Z1 - ZA - SZ 1 *CGS) **2)       0067         SZ = SZ 1 + DT *CC       0068         RH = SQRT ((X2 - XA - SZ 2 *CAS) **2 + (Y2 - YA - SZ 2 *CBS) **2 + (Z2 - ZA - SZ 2 *CGS) **2)       0069         DDD = (RH1 + RH2) / 2.       0070         IF (DDD ± GC - ZO *AM *AND * INT •GT • 0) GO TO 20       0071         IF (DDD ± GC + ZA + SZ 2 *CGS) **2 + (Y2 - YA - SZ 2 *CGS) **2)       0073         2, ETA, GAM , P11 *P12 *P21 *P21       0075         300       CAS ± CG + CGS *CG + CS *CD + CS *CG + CS *CB + CS *CG + CS *CD + CS *CG + CS *CG + CS *CD + CS *CG + CS		RETURN	0065
200 RH = SQRT((X1-XA-SZ1*CAS)**2+(Y1-YA-SZ1*CBS)**2+(Z1-ZA-SZ1*CGS)**2) 0067 SZ2=SZ1+DT*CC 0068 RH2=SQRT((X2-XA-SZ2*CAS)**2+(Y2-YA-SZ2*CBS)**2+(Z2-ZA-SZ2*CGS)**2) 0069 DDD=(RH1+RH2)/2. 0071 IF (DDD.GT.20.*AM .AND. INT.GT.0)GD TD 20 0071 IF (DDD.GT.20.*AM .AND. INT.GT.0)GD TD 20 0077 CALL GGMM(0.0)DS;SZ1,SZ2,DDD,CGDS,SGDS,SGDT,1. 0077 2,ETA,GAM,P11,P12,P21,P22) 0076 CAD=(CGS*CB-CBS*CG)/SS 0077 CAD=(CGS*CB-CBS*CG)/SS 0077 CAD=(CGS*CA-CAS*CG)/SS 0077 DK=(X1-XA)*CAD+(Y1-YA)*CBD+(Z1-ZA)*CGD 0080 DK=ABS(DK) 0077 CAD=(CGS*CAD-CAS*CGS 2000) XZ=XA+SZ*CAS 0083 YZ=YA+SZ*CAS 0083 YZ=YA+SZ*CAS 0083 YZ=YA+SZ*CAS 0083 CGP=CBS*CAD-CAS*CGD 0080 CAP=CBS*CAD-CAS*CCD 0080 CAP=CBS*CAD-CAS*CCD 0080 CAP=CBS*CAD-CAS*CCD 0080 CAP=CBS*CAD-CAS*CCD 0080 CAP=CBS*CAD-CAS*CAD 0080 CAP=CBS*CAD-CAS*CAD 0080 CAP=CBS*CAD-CAS*CAD 0080 CAP=CBS*CAD-CAS*CAD 0080 CAP=CBS*CAD-CAS*CAD 0087 CAP=CBS*CAD-CAS*CAD 0087 CAP=CBS*CAD-CAS*CAD 0087 CAP=CBS*CAD-CAS*CAD 0087 CAP=CBS*CAD-CAS*CAD 0087 CAP=CBS*CAD-CAS*CAD 0087 CAP=CBS*CAD-CAS*CAD 0097 CAP=CAS*CBD-CBS*CAD 0097 CAP=CAS*CBD-C	200	S71=(X1-XA)*CAS+(Y1-YA)*CBS+(Z1-ZA)*CGS	0066
NIA SOLA DIA CONTRACTOR OF A CO	200	BH1 = SOBT ((X1 - XA - S7)*CAS)**2 + (Y1 - YA - S7)*CBS)**2 + (Z1 - ZA - S7)*CBS)**2)	0067
RH2=SQRT(1X2=XA=SZ2*CAS)**2+(Y2=YA=SZ2*CBS)**2+(Z2=ZA=SZ2*CGS)**2)       0069         DDD=(RH]+RH2)/2.       0070         IF (DDD,GT=Z0.*AM = AND. INT.GT.0)GD TD 20       0071         IF (DDD,LT=AM)DDD=AM       0072         CALL GGMM(.0,DS,SZ1,SZ2,DDD,CGDS,SGDS,SGDT,1.       0073         2.E TA,GAM,P11,P12,P21,P22)       0076         RE TURN       0075         300       SS=SQRT(1=-CC*CC)       0077         CBD=(CBS*CA=CBS*CG)/SS       0077         CBD=(CBS*CA=CAS*CB)/SS       0077         DK=(A1=XA)*CAD+(Y1=YA)*CBD+(Z1=ZA)*CGD       0080         DK=(X1=XA)*CAD+(Y1=YA)*CBD+(Z1=ZA)*CGD       0082         XZ=XA+SZ*CAS       0083         YZ=YA+SZ*CAS       0085         XP1=X1=DK*CAD       0086         YZ=YA+SZ*CAS       0086         YZ=YA+SZ*CAS       0086         YZ=YA+SZ*CAS       0086         CAP=CBS*CCD-CGS*CBD       0088         CAP=CBS*CCD-CGS*CAD       0088         CAP=CBS*CAD-CAS*CCD       0090         CGP=CAS*CDD-CBS*CAD       0092         T1=P1/SS       0093         S1=T1*CC=SZ       0094         CALL GGM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDS,SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0096			006B
DDD=(RH1+RH2)/2.       0070         IF (DDD.GT.20.*AM .AND. INT.GT.0)GD TD 20       0071         IF (DDD.LT.AM )DDD=AM       0072         CALL GGMM(.0,DS,SZ1,SZ2,DDD,CGDS,SGDS,SGDT,1.       0073         2.ETA,GAM,P11,P12,P21,P22)       0074         RETURN       0075         300       SS=SQRT(1CC*CC)       0076         CAD=(CGS*CB-CBS*CG)/SS       0077         CB=(CAS*CG-CCS*CA)/SS       0078         CGD=(CBS*CA-CAS*CB)/SS       0078         CGD=(CBS*CA-CAS*CB)/SS       0078         CGD=(CS*CA-CAS*CB)/SS       0078         CGD=(CAS*CGS       0079         DK = (X1-XA)*CAD+(Y1-YA)*CBD+(Z1-ZA)*CGD       0080         DK = ABS(DK)       0081         IF (DK.LT.AM)DK = AM       0082         XZ = XA+SZ *CGS       0085         XZ = XA+SZ *CGS       0085         XZ = XA+SZ *CGS       0086         CAP = CB \$*CCD - CS *CBD       0087         CBP = CAS *CD - CAS *CCD       0091         P1 = Z1 = DK *CGD       0092         CBP = CG \$*CAD - CAS *CCD       0091         CBP = CAS *CD - CG \$*CAD       0092         CBP = CAS *CD - CAS *CCD       0091         P1 = CAP*(XP1 - XZ) + CBP *(YP1 - YZ) + CGP *(ZP1 - ZZ)       009		RH2=SQRT((X2-XA-SZ2*CAS)**2+(Y2-YA-SZ2*CBS)**2+(Z2-ZA-SZ2*CGS)**2)	0069
IF (DDD.GT.20.*AM .AND. INT.GT.0)G0 T0 20       0071         IF (DDD.LT.AM)DDD=AM       0072         CALL GGMM(.0,DS,SZ1,SZ2,DDD,CGDS,SGDS,SGDT,1.       0073         2,E TA,GAM,P11,P12,P21,P22)       0074         RETURN       0075         300       SS=SQRT(1CC*CC)       0076         CAD=(C6S*CB-CBS*CG)/SS       0077         CBD=(CAS*CG-CGS*CA)/SS       0077         CBD=(CAS*CA-CAS*CB)/SS       0078         CGD=(CBS*CA-CAS*CB)/SS       0079         DK=(X1-XA)*CAD+(Y1-YA)*CBD+(Z1-ZA)*CGD       0080         DK=ABSIDK)       0081         IF (DK.LT.AM)DK=AM       0082         XZ=XA+SZ*CAS       0085         YZ=YA+SZ*CAS       0086         YP1=X1-DK*CAD       0086         YP1=X1-DK*CAD       0087         CBP=CAS*CD-CGS*CBD       0088         CAP=CBS*CCD-CGS*CBD       0090         CBP=CAS*CBD-CBS*CAD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDS,SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0096         RETURN       0097         O098		DDD=(RH1+RH2)/2.	0070
IF (DDD.T.AM)DDD=AM       0072         CALL GGMM(.0,DS,SZ1,SZ2,DDD,CGDS,SGDS,SGDT,1.       0073         2,ETA,GAM,P11,P12,P21,P22)       0074         RETURN       0075         300       SS=SQRT(1CC*CC)       0076         CAD=(CGS*CB-CBS*CG)/SS       0077         CBD=(CAS*CG-CGS*CA)/SS       0077         CBD=(CAS*CG-CGS*CA)/SS       0079         DK=(X1-XA)*CAD+(Y1-YA)*CBD+(Z1-ZA)*CGD       0080         DK=ABS(DK)       0081         IF (DK.LT.AM)DK=AM       0082         XZ=XA+SZ*CAS       0083         YZ=YA+SZ*CBS       0084         ZI=ZA+SZ*CGS       0085         XP1=X1-DK*CGD       0086         CAP=CBS*CGD-CGS*CBD       0087         CBP=CGS*CAD-CAS*CED       0089         CBP=CBS*CAD-CS*CBD       0090         CGP=CAS*CBD-CBS*CAD       0091         P1=Z1-DK*CGD       0092         T1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM (S1,S1+DS,T1,T1+DT,DK,CGD S, SGDS, SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0096         RETURN       0097         END       0097		IE (DDD GT 20 * AM AND INT GT 0) GO TO 20	0071
CALL GGMM (.0, DS, SZ1, SZ2, DDD, CGD S, SGD S, SGD T, 1.       0073         2, ETA, GAM, P11, P12, P21, P22)       0074         RETURN       0075         300       SS=SQRT(1CC*CC)       0076         CAD=(CGS*CB-CBS*CG)/SS       0077         CB=(CAS*CG-CSS*CA)/SS       0078         CGD=(CBS*CA-CAS*CB)/SS       0079         DK=(X1-XA)*CAD+(Y1-YA)*CBD+(Z1-ZA)*CGD       0080         DK=ABS(DK)       0081         IF (DK, LT - AM )DK = AM       0082         XZ = XA + SZ * CAS       0083         YZ = YA + SZ * CGS       0084         ZZ = XA + SZ * CGS       0085         XP 1 = X1 - DK * CAD       0086         YP 1 = Y1 - DK * CGD       0088         CAP = CBS * CAD - CAS * CGD       0089         CBP = CGS * CAD - CAS * CGD       0091         P1 = CAP * (XP1 - XZ) + CBP * (YP1 - YZ) + CGP * (ZP1 - ZZ)       0092         T1 = P1 / SS       0093         S1 = T1 * CC - SZ       0094         CALL GGMM (S1, S1 + D S, T1, T1 + DT, DK, CGD S, SGDS, SGDT, CC, ETA, GAM       0095         2, P11, P12, P21, P22)       0096         RE TURN       0097         RE TURN       0097         CALL GGMM (S1, S1 + D S, T1, T1 + DT, DK, CGD S, SGDS, SGDT, CC, ETA, GAM		IE (DDD - IT - AM )DDD = AM	0072
2,ETA,GAM,P11,P12,P21,P22) RETURN 0075 300 SS=SQRT(1CC*CC) 0077 CAD=(CGS*CB-CBS*CG)/SS 0077 CBD=(CAS*CG-CGS*CA)/SS 0077 CBD=(CAS*CG-CGS*CA)/SS 0079 DK=(X1-XA)*CAD+(Y1-YA)*CBD+(Z1-ZA)*CGD 0080 DK=ABS(DK) 0081 IF(DK.LT.AM)DK=AM 0082 XZ=XA+SZ*CAS 0083 YZ=YA+SZ*CBS 0084 ZZ=ZA+SZ*CGS 0085 XP1=X1-DK*CAD 0085 XP1=X1-DK*CAD 0085 CAP=CDS*CAD-CAS*CBD 0087 CP1=Z1-DK*CGD 0087 CP=CAS*CBD-CBS*CAD 0089 CGP=CAS*CBD-CBS*CAD 0099 CGP=CAS*CBD-CBS*CAD 0099 CGP=CAS*CBD-CBS*CAD 0099 S1=T1*CC-SZ 0094 CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDS,SGDT,CC,ETA,GAM 0095 2,P11,P12,P21,P22) 0098		CALL GGMM (+0+DS+SZ1+SZ2+DD+CGDS+SGDS+SGDT+1+	0073
RETURN       0075         300       SS=SQRT(1CC*CC)       0076         CAD=(CGS*CB-CBS*CG)/SS       0077         CBD=(CAS*CG-CGS*CA)/SS       0078         CGO=(CBS*CA-CAS*CB)/SS       0079         DK=(X1-XA)*CAD+(Y1-YA)*CBD+(Z1-ZA)*CGD       0080         DK=ABS(DK)       0081         IF (DK+LT+AM)DK=AM       0082         XZ=XA+SZ*CAS       0083         YZ=YA+SZ*CBS       0086         Y1=Y1-DK*CAD       0086         Y1=Y1-DK*CAD       0087         Y1=X1-DK*CAD       0087         QP1=Z1-DK*CAD       0087         QP1=Z1-DK*CAD       0088         CAP=CBS*CAD-CAS*CAD       0090         CGP=CAS*CAD-CAS*CCD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDS,SGDT,CC,ETA,GAM       0096         RETURN       0097         RETURN       0097         RETURN       0097         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDS,SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0098		2.FIA.GAM.P11.P12.P21.P22)	0074
300       SS=SQRT(1CC*CC)       0076         CAD=(CGS*CB-CBS*CG)/SS       0077         CBD=(CAS*CG-CGS*CA)/SS       0078         CGD=(CBS*CA-CAS*CB)/SS       0079         DK=(X1-XA)*CAD+(Y1-YA)*CBD+(Z1-ZA)*CGD       0080         DK=ABS(DK)       0081         IF (DK.LT.AM)DK=AM       0082         XZ=XA+SZ*CAS       0084         ZZ=ZA+SZ*CGS       0085         XP1=X1-DK*CAD       0086         YP1=Y1-DK*CGD       0087         CBP=CGS*CAD-CAS*CGD       0087         CBP=CGS*CAD-CAS*CGD       0089         CBP=CGS*CAD-CAS*CGD       0091         P1=CAP*(XP1-XZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDS,SGDT,CC,ETA,GAM       0095         RETURN       0097         RETURN       0098		RETURN	0075
000       CAD = (CGS*CB-CBS*CG)/SS       0077         CBD = (CAS*CG-CGS*CA)/SS       0078         CGD = (CBS*CA-CAS*CB)/SS       0079         DK = (X1-XA)*CAD + (Y1-YA)*CBD + (Z1-ZA)*CGD       0080         DK = (X1-XA)*CAD + (Y1-YA)*CBD + (Z1-ZA)*CGD       0081         DF = (X1-XA)*CAD + (Y1-YA)*CBD + (Z1-ZA)*CGD       0081         DK = (X1-XA)*CAD + (Y1-YA)*CBD + (Z1-ZA)*CGD       0081         DK = (X1-XA)*CAD + (Y1-YA)*CBD + (Z1-ZA)*CGD       0081         DF = (X1-XA)*CAD + (Y1-YA)*CBD + (Z1-ZA)*CGD       0082         XZ = XA+SZ*CAS       0083         YZ = YA+SZ*CBS       0083         YZ = YA+SZ*CBS       0083         YZ = YA+SZ*CBS       0085         XZ = XA+SZ*CAS       0085         YZ = YA+SZ*CBS       0085         YZ = YA+SZ*CBS       0086         QZ = ZA+SZ*CGS       0086         Y1 = X1-DK*CAD       0087         CP = CB S*CCD       0088         CAP = CB S*CCBD - CG S*CBD       0089         CBP = CG S*CAD - CAS*CGD       0090         CGP = CAS*CBD - CB S*CAD       0092         T1 = P1/SS       0093         S1 = T1*CC-SZ       0094         CALL GGMM (S1, S1+D S, T1, T1+DT, DK, CGD S, SGDS, SGDT, CC, ETA, GAM       0095	300	SS = SORT(1 - CC + CC)	0076
CBD = (CAS*CG-CGS*CA)/SS       0078         CGD = (CBS*CA-CAS*CB)/SS       0079         DK = (X1-XA)*CAD + (Y1-YA)*CBD + (Z1-ZA)*CGD       0080         DK = ABS(DK)       0081         IF (DK.LT.AM)DK = AM       0082         XZ = XA + SZ * CAS       0083         YZ = YA + SZ * CGS       0085         XP = X + SZ * CGS       0086         YP = X1-DK * CAD       0086         YP = X1-DK * CGD       0088         CAP = CB S* CGD - CG S * CBD       0087         CBP = CG S * CAD - CAS * CGD       0090         CGP = CAS * CBD - CB S * CAD       0091         P1 = CAP*(XP1-XZ) + CBP*(YP1-YZ) + CGP*(ZP1-ZZ)       0092         T1 = P1/SS       0093         S1 = T1 * CC - SZ       0094         CALL GGMM (S1, S1 + D S, T1, T1 + DT, DK, CGD S, SG DS, SG DT, CC, ETA, GAM       0096         R = TURN       0097         R = TURN       0097         NE ND       0098	500	CAD = (CGS * CB - CB S * CG)/SS	0077
CGD = (CBS*CA-CAS*CB)/SS       0079         DK = (X1-XA)*CAD + (Y1-YA)*CBD + (Z1-ZA)*CGD       0080         DK = ABS(DK)       0081         IF (DK.LT.AM)DK = AM       0082         XZ = XA + SZ * CAS       0083         YZ = YA + SZ * CBS       0084         ZZ = ZA + SZ * CGS       0085         XP = Y + SZ * CBS       0086         YP = Y1 - DK * CAD       0086         YP = Y1 - DK * CGD       0087         CBP = CG S * CGD - CG S * CBD       0088         CAP = CB S * CGD - CG S * CBD       0089         CBP = CG S * CAD - CAS * CGD       0090         CGP = CA S * CBD - CB S * CAD       0091         P1 = CAP * (XP1 - XZ) + CBP * (YP1 - YZ) + CGP * (ZP1 - ZZ)       0092         T1 = P1 / SS       0093         S1 = T1 * CC - SZ       0094         CALL GGMM (S1 , S1 + D S , T1 , T1 + D T , D K , C GD S , SG D S , SG D T , CC , ET A , GAM       0095         2 + P11 + P12 , P21 , P22 )       0097         RE TURN       0097         END       0098		CBD = (CAS*CG-CGS*CA)/SS	0078
DK = (X1-XA) *CAD + (Y1-YA) *CBD + (Z1-ZA) *CGD       0080         DK = ABS(DK)       0081         IF (DK .LT .AM )D K=AM       0082         XZ = XA + SZ *CAS       0083         YZ = YA + SZ *CGS       0084         ZZ = ZA + SZ *CGS       0085         ZZ = XA + SZ *CGS       0086         YP = X1-DK *CAD       0086         YP = Y1-DK *CBD       0087         ZP = Z + SZ *CGD       0088         CAP = CB S *C GD - CG S * CBD       0089         CBP = CG S * CAD - CAS *C GD       0090         CGP = CAS *C GD - CG S * CAD       0091         P 1 = CAP * (XP 1 - XZ) + CBP * (YP 1 - YZ) + CGP * (ZP 1 - ZZ)       0092         T1 = P1 / SS       0094         CALL GGMM (S1 , S1 + D S , T1 , T1 + DT , DK , C GD S , SG DS , SG DT , CC , ETA , GAM       0096         2, P11 , P12 , P21 , P22 )       0097         RE TURN       0097         END       0098		CGD = (CBS + CA - CAS + CB) / SS	0079
DK=ABS(DK)       0081         IF (DK+LT+AM)DK=AM       0082         XZ=XA+SZ*CAS       0083         YZ=YA+SZ*CBS       0084         ZZ=ZA+SZ*CGS       0085         XP1=X1-DK*CAD       0086         YP1=Y1-DK*CBD       0087         ZP1=Z1-DK*CGD       0088         CAP=CBS*CGD-CGS*CBD       0089         CBP=CGS*CAD-CAS*CGD       0090         CGP=CAS*CBD-CBS*CAD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1+S1+DS,T1,T1+DT,DK+CGDS,SGDT,CC,ETA,GAM       0096         0097       RETURN       0097         RETURN       0098		DK = (X1 - XA) * CAD + (Y1 - YA) * CBD + (Z1 - ZA) * CGD	0080
IF (DK.LT.AM )D K=AM       0082         XZ=XA+SZ*CAS       0083         YZ=YA+SZ*CBS       0084         ZZ=ZA+SZ*CGS       0085         XP1=X1-DK*CAD       0086         YP1=Y1-DK*CBD       0087         ZP1=Z1-DK*CGD       0088         CAP=CBS*CGD-CGS*CBD       0089         CBP=CGS*CAD-CAS*CGD       0090         CGP=CAS*CBD-CBS*CAD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1+S1+DS,T1,T1+DT,DK+CGDS,SGDT,CC,ETA,GAM       0096         0096       RE TURN       0097         RE TURN       0098		DK = ABS(DK)	0081
XZ=XA+SZ*CAS       0083         YZ=YA+SZ*CBS       0084         ZZ=ZA+SZ*CGS       0085         XP1=X1+DK*CAD       0086         YP1=Y1-DK*CBD       0087         ZP1=Z1+DK*CGD       0088         CAP=CBS*CGD-CGS*CBD       0089         CBP=CGS*CAD-CAS*CGD       0090         CGP=CAS*CBD-CBS*CAD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0096         RETURN       0097         END       0098		IF (DK.LT.AM)DK=AM	0082
YZ=YA+SZ*CBS       0084         ZZ=ZA+SZ*CGS       0085         XP1=X1-DK*CAD       0086         YP1=Y1-DK*CBD       0087         ZP1=Z1-DK*CGD       0088         CAP=CBS*CGD-CGS*CBD       0089         CBP=CGS*CAD-CAS*CGD       0090         CGP=CAS*CBD-CBS*CAD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0096         RETURN       0097         END       0098		XZ = XA + SZ + CAS	0083
ZZ=ZA+SZ*CGS       0085         XP1=X1-DK*CAD       0086         YP1=Y1-DK*CBD       0087         ZP1=Z1-DK*CGD       0088         CAP=CBS*CGD-CGS*CBD       0089         CBP=CGS*CAD-CAS*CGD       0090         CGP=CAS*CBD-CBS*CAD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0097         RETURN       0098		YZ=YA+SZ*CBS	0084
XP1=X1-DK*CAD       0086         YP1=Y1-DK*CBD       0087         ZP1=Z1-DK*CGD       0088         CAP=CBS*CGD-CGS*CBD       0089         CBP=CGS*CAD-CAS*CGD       0090         CGP=CAS*CBD-CBS*CAD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0097         RETURN       0097         END       0098		7 = 7 A + S Z * C G S	0085
YP1=Y1-DK*CBD       0087         ZP1=Z1-DK*CGD       0088         CAP=CBS*CGD-CGS*CBD       0089         CBP=CGS*CAD-CAS*CGD       0090         CGP=CAS*CBD-CBS*CAD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0097         RETURN       0098		XP1=X1-DK*CAD	0086
ZP1=Z1-DK*CGD       0088         CAP=CBS*CGD-CGS*CBD       0089         CBP=CGS*CAD-CAS*CGD       0090         CGP=CAS*CBD-CBS*CAD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0093         RETURN       0097         END       0098		YP1=Y1-DK*CBD	0087
CAP=CBS*CGD-CGS*CBD       0089         CBP=CGS*CAD-CAS*CGD       0090         CGP=CAS*CBD-CBS*CAD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0095         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDT,CC,ETA,GAM       0096         0097       RETURN       0097         END       0098       0098		7P1=71-DK*CGD	0088
CBP=CGS*CAD-CAS*CGD       0090         CGP=CAS*CBD-CBS*CAD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0096         RETURN       0097         END       0098		CAP = CBS + CGD - CGS + CBD	0089
CGP=CAS*CBD-CBS*CAD       0091         P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ)       0092         T1=P1/SS       0093         S1=T1*CC-SZ       0094         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0096         RETURN       0097         END       0098		CBP=CGS*CAD-CAS*CGD	0090
P1=CAP*(XP1-XZ)+CBP*(YP1-YZ)+CGP*(ZP1-ZZ) T1=P1/SS S1=T1*CC-SZ CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDT,CC,ETA,GAM 0095 2,P11,P12,P21,P22) RETURN END 0098		$CGP = CAS \neq CBD - CBS \neq CAD$	0091
T1=P1/SS 0093 S1=T1*CC-SZ 0094 CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDT,CC,ETA,GAM 0095 2,P11,P12,P21,P22) 0096 RETURN 0097 END 0098		P1 = CAP * (XP1 - XZ) + CBP * (YP1 - YZ) + CGP * (ZP1 - ZZ)	009 <b>2</b>
S1=T1*CC-SZ       0094         CALL GGMM(S1,S1+DS,T1,T1+DT,DK,CGDS,SGDT,CC,ETA,GAM       0095         2,P11,P12,P21,P22)       0096         RETURN       0097         END       0098		T1=P1/SS	0093
CALL GGMM (S1,S1+DS,T1,T1+DT,DK,CGDS,SGDS,SGDT,CC,ETA,GAM 0095 2,P11,P12,P21,P22) 0096 RETURN 0097 END 0098		S1=T1*CC-SZ	0094
2,P11,P12,P21,P22) 0096 RETURN 0097 END 0098		CALL GGMM (S1,S1+DS,T1,T1+DT,DK,CGDS,SGDS,SGDT,CC,ETA,GAM	0095
RE TURN 0097 END 0098		2.P11.P12.P21.P22)	0096
END 009B		RETURN	009 <b>7</b>
		END	009B

Fig. 11b. Subroutine GGS

Below statement 300, GGS performs some analytic geometry in preparation for calling GGMM. The remaining part of this Appendix concerns this last part of subroutine GGS.

Let  $\hat{s}$  denote a unit vector in the direction from (XA,YA,ZA) toward (XB,YB,ZB). Also let  $\hat{t}$  denote a unit vector from (X1,Y1,Z1) toward (X2,Y2,Z2). Then  $\hat{s} \cdot \hat{t} = \cos \theta = CC$  where  $\theta$  is the angle formed by the axes of the two monopoles. Let monopole s lie in one plane P, and monopole t lie in another parallel plane P<sub>t</sub>. CAD, CBD and CGD are the direction cosines of the unit vector  $\hat{d} = \hat{t} \times \hat{s} / \sin \theta$  which is perpendicular to both planes. To obtain the distance DK between the two planes, we construct a vector  $\underline{R}_{11}$  from (XA,YA,ZA) to (X1,Y1,Z1) and take DK =  $\underline{R}_{11} \cdot \hat{d}$ .

Construct a line from (X1,Y1,Z1) to the test monopole, such that the line is perpendicular to the test monopole. SZ denotes the s coordinate of the intersection of this line with the test monopole, and the cartesian coordinates of this intersection are XZ, YZ and ZZ. The direction cosines of  $\hat{s} \times \hat{d}$  are CAP, CBP and CGP.

From the point (X1,Y1,Z1) in plane  $P_t$ , construct a perpendicular line to the point (XP1,YP1,ZP1) in the plane  $P_s$ . This line is parallel with  $\hat{d}$  and has length DK. Let <u>R</u> represent a vector from (XZ,YZ,ZZ) to (XP1,YP1,ZP1). P1 denotes <u>R</u>  $\cdot$  ( $\hat{s} \times \hat{d}$ ). S1 and T1 are defined in the next Appendix.

#### APPENDIX 6. Subroutine GGMM

Subroutine GGMM calculates the mutual impedance between two filamentary monopoles with sinusoidal current distributions. The dipoledipole mutual impedance in Eq. 20 of Reference 1 is the sum of four monopole-monopole mutual impedances. The monopole impedances are calculated by GGS with Simpson's rule or by GGMM with closed-form expressions in terms of exponential integrals.

To explain the input data for GGMM, reference is made to Fig. 12. Subroutine GGMM is listed in Fig. 13. If the monopoles are parallel, let the z axis be parallel with both monopoles. The coordinate origin may be selected arbitrarily. S1 and S2 denote the z coordinates of the endpoints of the test monopole, T1 and T2 are the z coordinates of the endpoints of the expansion monopole, and D is the perpendicular distance (displacement) between the monopoles. The mutual impedance of parallel monopoles is calculated in the last part of GGMM below statement 110.

For skew monopoles, let the test monopole s lie in the xy plane and the expansion monopole t in the plane z = D. (D is the perpendicular distance between the parallel planes.) If the monopoles are viewed along a line of sight parallel with the z axis as in Fig. 12, the extended axes of the two monopoles will appear to intersect at a point on the xy plane. Let s measure the distance along the axis of



Fig. 12. Coordinates for parallel and skew monopoles in subroutine GGMM.

	SUBRUHTINE GGMM(S1.S2.T1.T2.D.CGDS,SGD1,SGD2,CPSI,ETA,GAM	0001
		0002
	ZIPILI, PIZIPZZI (PZZ)	0003
	DOUBLE PRECISION RITE, DOUBLE PRECISION RITE, DECEMBER OF THE	0004
ē	2, TL1, TL2, TD1, TD2, S01, DP31, DD , 2D	0005
	COMPLEX CGDS, SGDS, SGDI, SGDI, SGDI, SGDI, EIA, GAM, FILLFILLFILLFLE	0006
	COMPLEX CST, EB, EC, EK, EL, EKL, EGZI, ESI, ESI, ESI, ESI, ESI, ESI, ESI, ES	0007
	COMPLEX E (2,2),F(2,2)	0007
	COMPLEX EGZ(2,2),GM(2),GP(2)	0008
	DATA PI/3.14159/	0009
	0 S Q = D *D	0010
	SGD S = SGD 1	0011
	$E(S_2 + I_2 + S_1) S_{GD} S_{=} - S_{GD} I$	0012
	SCDT = SCD2	0013
	SOUT = SOUZ	0014
	17(12.01.113001-3002)	0015
		0016
		0017
	$E S Z \approx C E X P (GAM \Rightarrow S Z)$	0018
		0019
	ET2 = CEXP(GAM = 12)	0020
	DD=D	0021
	DPSI=CPSI	0022
	TD1=T1	0023
	TD2=T2	0025
	CPSS=DPSI*DPSI	0024
	CD=DD/DSQRT(1.DO-CPSS)	0025
	C=CD	0020
	BD=CD *D PS I	0027
	B=BD	0028
	$FB = CE XP (GAM * CM PLX ( \bullet 0 \bullet B))$	0029
	FC = CEXP(GAM * CMPLX(.0, C))	0030
		0031
		0032
10		0033
10	C(N)L)-(+0)+0)+	0034
		0035
	132-102-102	0036
		0037
	51=51	0038
		0039
	FI=(-1)**I	0040
	SD I = S I	0040
	S I S = SD I * SD I	0041
	ST1=2.*SD1*TD1*DPSI	0042
	ST2=2.+	0043
	$R_{1} = D_{SORT} (D_{PO+SIS+TS1-ST1})$	0044
	$R_2 = D SOBT (DPO+SIS+TS2-ST2)$	0045
	EK = E B	0046
		0047
		0048
		0049
	24-56	0050
		0051
		0052
		0053
	EKL=EK#EL	0054
	XX=FK+BD+FL+CD	0055
	TL1=FL*TD1	0055
	TL2=FL*TD2	0050
	RR1=R1+SK+TL1	0057
	RR2=R2+SK+TL2	0058
	CALL EXPJ (GAM * CMPLX (RR1, -XX), GAM * CMPLX (RR2, -XX), EXPA)	0059
	CALL EXPJ(GAM +CMPLX(RR1,XX),GAM +CMPLX(RR2,XX),EXPB)	0060
	F(K-L)=F(K-L)+FI*(EXPA*EKL+EXPB/EKL)	0061
4 ۸		0062
<b>TU</b>	L L = 477 - 4	

Fig. 13a. Subroutine GGMM

32

50	FK=1./FB	0063
20		0064
		0065
	GZI=CEXP(GAM *ZC)	0066
	BR1 = R1 + ZO - TD1	0067
	RR2 = R2 + ZD - TD2	0068
	CALL EXPJ(GAM*RR1,GAM*RR2,EXPB)	0069
	RR1=R1-ZD+TD1	0070
	RR2 = R2 - ZD + TD2	0071
	CALL EXPJ(GAM*RR1,GAM*RR2,EXPA)	0072
	F(I,1)=2.*SGDS*EXPA/EGZI	0073
	F(I,2)=2.*SGDS*EXPB*EGZI	0074
100	S I = S2	0075
	CST=ETA/(16.*PI*SGDS*SGDT)	0076
	P11=CST*(( F(1,1)+E(2,2)*ES2-E(1,2)/ES2)*E12	0078
	A + (-+(1,2)-+(2,1)*+(2++(1,1))*(2+2)+(1,2)	0078
	P12=CS   *((-+(1,1)-+(2,2))*(-S2++(1,2))*(-S2)*(-1)	0019
	b + (F(1)/2) + E(2)/1 + E(2)/2 + E(1)/2 + E(1)/2 + E(2)/2 + E(2)	0081
	P(2) = (S) + ((-F)(2), (-F)(2), (-F)(	0082
4	b = + ( + (2)(2) + (2)(1) + (2)(2) + (2)(2)(2)(2)(2)(2)(2)(2)(2)(2)(2)(2)(2)(	0083
,	YZZ≅USI*(( F(Z ; 1)+E(Z ; 2)+E(3)+E(1);Z(+U);S(+U);Z(	0084
1		0085
110		0086
110		0087
		0088
	G TO 130	0089
120		0090
	TB=-T2	0091
	SGDT=-SGDT	0092
130	SI=S1	0093
	DO 150 I=1,2	0094
	TJ=TA	0095
	D0 140 J=1,2	0098
		0097
	R = SQRT(DSQ+ZIJ + ZIJ)	0098
		0100
		0101
	V = K = 2 I S I E ( 7 I I = GT = 0 = ) V = D S Q / ( R + 7 I J )	0102
		0103
		0104
	$EGZ(I \cdot J) = CEXP(GAM \neq ZIJ)$	0105
140	TJ=TB	0106
	CALL EXPJ (GAM *V1, GAM *V, GP(I))	0107
	CALL EXPJ(GAM #W1,GAM #W,GM(I))	0108
150	SI=S2	0109
	CST=-ETA/(8.*PI*SGDS*SGDT)	0110
	P11=CST*(GM(2)*EGZ(2,2)+GP(2)/EGZ(2,2)	0111
	$2-CGD S \neq (GM(1) \neq GZ(1,2)+GP(1)/EGZ(1,2))$	0112
	Y12=631#1-6M(2)#E62(291)=6Y12)/E62(291) 3.5505#10M(1)#E62(1, 1)#60(1)/E62(1, 1))	0114
	2+60/3*10/11/*E02(11/1/E02(11/1//	0115
	2_1~CDS*(CM(2)*FG7(2.2)+GP(2)/FG7(2.2))	0116
	$p_{2} = (T_{1} + (T$	0117
	2+CGDS*(GM(2)*EGZ(2+1)+GP(2)/EGZ(2+1)))	0118
	RETURN	0119
	END	0120

Fig. 13b. Subroutine GGMM

-

33

the test monopole with origin at the apparent intersection. S1 and S2 denote the s coordinates of the endpoints of the test monopole. Similarly, let t measure distance along the axis of the expansion monopole with origin at the apparent intersection. T1 and T2 denote the t coordinates of the endpoints of the expansion monopole. Let  $\hat{s}$  and  $\hat{t}$  be unit vectors parallel with the positive s and t axes, respectively. Then CPSI =  $\hat{s} \cdot \hat{t} = \cos \psi$ . The monopole lengths are d<sub>s</sub> and d<sub>t</sub>, and the remaining input data are defined as follows:

CGDS	cosh	γds
SGD1	sinh	yde.
S GD2	sinh	γdt

GGMM calls EXPJ for the exponential integrals.

The output data from GGMM are the impedances P11, P12, P21, and P22. In defining these impedances, the reference direction is from S1 to S2 for the current on monopole s, and from T1 to T2 for the current on monopole t. In the impedance  $P_{ij}$ , the first subscript is 1 or 2 if the test dipole has terminals at S1 or S2 on monopole s. The second subscript is 1 or 2 if the expansion dipole has terminals at T1 or T2 on monopole t. The endpoint coordinates S1, S2, T1 and T2 may be positive or negative. The monopole lengths d<sub>s</sub> and d<sub>t</sub> are assumed positive in defining the input data CGDS, SGD1 and SGD2.

For parallel monopoles, CPSI = 1 or -1. S1, S2, T1 and T2 are cartesian coordinates for parallel monopoles and spherical coordinates for skew monopoles. For skew monopoles, the radial coordinates S1, S2, T1 and T2 tend to infinity as the angle  $\psi$  tends to zero or  $\pi$ . Therefore, if the monopoles are within 4.5° of being parallel, they are approximated by parallel dipoles.

#### APPENDIX 7. Subroutine EXPJ

1/0

Subroutine EXPJ, listed in Fig. 14, evaluates the exponential integral defined as follows:

(2) 
$$W12 = \int_{V1}^{V2} \frac{e^{-V} dV}{V} = E_1(V1) - E_1(V2) + j 2n\pi$$

where the integration path is the straight line from V1 to V2 on the complex v plane and

(3) 
$$E_1(z) = \int_z^{\infty} \frac{e^{-t} dt}{t}$$

SUBROUTINE EXPJ(V1,V2,W12) 0001 COMPLEX EC, E15, S, T, UC, VC, V1, V2, W12,Z 0002 DIMENSION V(21), W(21), D(16), E(16) 0003 DATA V/ 0.22284667E 00, 0004 20.11889321E 01,0.29927363E 01,0.57751436E 01,0.98374674E 01, 0005 20.15982874E 02.0.93307812E-01.0.49269174E 00.0.12155954E 01, 0006 20.22699495E 01,0.36676227E 01,0.54253366E 01,0.75659162E 01, 0007 20.10120228E 02.0.13130282E 02.0.16654408E 02.0.20776479E 02. 0008 20.25623894E 02,0.31407519E 02,0.38530683E 02,0.48026086E 02/ 0009 DATA W/ 0.45896460E 00, 0010 20.41700083E 00,0.11337338E 00,0.10399197E-01,0.26101720E-03, 20.89854791E-06,0.21823487E 00,0.34221017E 00,0.26302758E 00, 0011 0012 20.12642582E 00.0.40206865E-01.0.85638778E-02.0.12124361E-02. 0013 20.11167440E-03,0.64599267E-05,0.22263169E-06,0.42274304E-08, 0014 20.39218973E-10,0.14565152E-12,0.14830270E-15,0.16005949E-19/ 0015 DATA D/ 0.22495842E 02, 0016 2 0.74411568E 02,-0.41431576E 03,-0.78754339E 02, 0.11254744E 02, 0017 2 0.16021761E 03,-0.23862195E 03,-0.50094687E 03,-0.68487854E 02, 0018 2 0.12254778E 02,-0.10161976E 02,-0.47219591E 01, 0.79729681E 01, 0019 2-0.21069574E 02, 0.22046490E 01, 0.89728244E 01/ 0020 0.21103107E 02, DATA E/ 0021 2-0.37959787E 03,-0.97489220E 02, 0.12900672E 03, 0.17949226E 02, 0022 2-0.12910931E 03,-0.55705574E 03, 0.13524801E 02, 0.14696721E 03, 0023 2 0.17949528E 02,-0.32981014E 00, 0.31028836E 02, 0.81657657E 01, 0024 2 0.22236961E 02, 0.39124892E 02, 0.81636799E 01/ 0025 Z=V1 0026 DO 100 JIM=1,2 0027 X=REAL(Z) 0028 Y=AIMAG(Z) 0029 E15=(.0,.0) 0030 AB=CABS(Z) 0031 IF (AB.EQ.0.)GO TO 90 0032 IF (X.GE.O. . AND. AB.GT.10.)GO TO 80 0033 YA = ABS(Y)0034 IF (X.LE.O. . AND. YA.GT.10.)GO TO 80 0035 IF (YA-X.GE.17.5.OR.YA.GE.6.5.OR.X+YA.GE.5.5.OR.X.GE.3.)GO TO 20 0036 IF (X.LE.-9.)GO TO 40 0037 IF (YA-X.GE.2.5)GO TO 50 0038 IF (X+YA.GE.1.5)GO TO 30 0039 10 N=6.+3.\*AB 0040 E15=1./(N-1.)-Z/N\*\*2 0041 15 N=N-1 0042 E15=1./(N-1.)-Z\*E15/N 0043 IF (N.GE.3)GO TO 15 0044 E15=Z\*E15-CMPLX(.577216+ALOG(AB),ATAN2(Y,X)) 0045 GO TO 90 0046 20 .11=1 0047 J2 = 60048 GO TO 31 0049 30 J1=7 0050 J2=21 0051 31 5=(.0,.0) 0052 YS=Y\*Y 0053 DO 32 I=J1,J2 0054  $XI = V \{I\} + X$ 0055 CF = W(I)/(XI \* XI + YS)0056 32 S=S+CMPLX(XI\*CF,-YA\*CF) 0057 GO TO 54 0058 40 T3=X\*X-Y\*Y 0059 T4=2.\*X\*YA 0060 T5=X \*T3-YA \*T4 0061 T6=X#T4+YA#T3 0062

Fig. 14a. Subroutine EXPJ

	UC=CMPLX(D(11)+D(12)*X+D(13)*T3+T5-E(12)*YA-E(13)*T4,	0063
	$c_{11} + c_{12} + c_{12} + c_{13} + c$	0064
	$Z = C_{HD} \times (16) + 0(15) + (16) + (16) + (13) + (15) + (16) + $	0065
	$v_{1} = (1 + 1) + (1 + 1$	0066
		0067
50		0068
50		0069
	$1 \forall = 2 \bullet \pi \wedge \pi + 1 A$ $\pi = - 2 \bullet \pi \wedge \pi + 1 A$	0070
	1 = 7 + 1 = 7 + 1 + 7 + 7 + 7 + 7 + 7 + 7 + 7 + 7 +	0071
		0072
		0073
		0074
		0075
	1/C=CMP1 X (D(1))+D(2)*X+D(3)+T3+D(4)*T5+D(5)*T7+T9-(E(2)*YA+E(3)*T4	0076
	2+E (4) *T(4+E (5) *T(8) *E (1) +E (2) *X+E (3) *T3+E (4) *T5+E(5) *T7+T10+	0077
	$3(p(2) + y_{A+p}(3) + 14 + p(4) + 16 + p(5) + 18))$	0078
	VC=CMPIX(D(6)+D(7)*X+D(8)*T3+D(9)*T5+D(10)*T7+T9-(E(7)*YA+E(8)*T4	0079
	2+E(9)*T6+E(10)*T8),E(6)+E(7)*X+E(8)*T3+E(9)*T5+E(10)*T7+T10+	0800
	3(D(7) * YA+D(8) * T4+D(9) * T6+D(10) * T8))	0081
52	EC=UC/VC	00.82
	S=EC/CMPLX(X,YA)	0083
54	E X=E XP(-X)	0084
-	T=EX*CMPLX(COS(YA),-SIN(YA))	0085
	E 15 = S * T	0086
56	IF (Y.LT.0.)E15=CONJG(E15)	0087
-	GQ TU 90	0088
80	$F_{15}=.409319/(2+.193044)+.421831/(2+1.02666)+.147126/(2+2.56788)+$	0089
	2.206335E-1/(Z+4.90035)+.107401E-2/(Z+8.18215)+.158654E-4/(Z+	0090
	$312 \cdot 7342 + 317031E + 7/(2 + 19 \cdot 3957)$	0091
	E 15 = E 15 * CE XP (-Z)	0092
90	IF (JIM.EQ.1)W12=E15	0093
10	0 Z=V2	0094
	2 = V 2 / V 1	0095
	TH=ATAN2(AIMAG(Z),REAL(Z))-ATAN2(AIMAG(V2),REAL(V2))	0096
	2+ATAN2(AIMAG(V1),REAL(V1))	0097
	AB=ABS(TH)	0098
	IF (AB.LT.1.)TH=.0	0099
	IF (TH.GT.1.)TH=6.2831853	0100
	IF (TH.LT1.)TH=-6.2831853	0101
	W12=W12-E15+CMPLX(.0,TH)	0102
	RETURN	0103
	END	0104

Fig. 14b. Subroutine EXPJ

The exponential integral  $E_1(z)$  is defined in Reference 3. To generate W12, subroutine EXPJ calculates  $E_1(V1)$ , subtracts  $E_1(V2)$  and adds  $j2n\pi$ . The term  $j2n\pi$  is determined by the requirement that W12 vanish in the limit as V1 approaches V2. The integer n may assume values of -1, 0 or +1. If the integration path does not cross the negative real axis in the v plane, n is zero. The term  $j2n\pi$  is calculated below statement 100.

### APPENDIX 8. Subroutine GANT1

Subroutine GANT1, listed in Fig. 15, considers the wire structure as an antenna. In the input data, VG(J) is the voltage of a generator at point IA(J) of segment J. VG(JJ) is the voltage of a generator at point IB(J) of segment J. The DO LOOP ending with statement 50 uses the delta-gap model to determine the excitation voltages CJ(I) for all the dipole modes. These are also stored temporarily in CG(I). Then subroutine SQROT is called to obtain a solution of the simultaneous linear equations. SQROT stores the solution (the loop currents) in CJ(I).

In the DO LOOP ending at statement 80, the complex power input is calculated and stored in Y11. GG denotes the time-average power input and is the real part of Y11. If the antenna has only one voltage generator (with unit voltage and zero phase angle), then Y11 also denotes the antenna admittance and Z11 is the antenna impedance at that port.

Subroutine RITE is called to make the transformation from the loop currents CJ(I) to the branch currents CG(J). If IWR is a positive integer, RITE will write out the list of branch currents.

Finally, GANT1 calculates the radiation efficiency EFF. PIN denotes the time-average power input. Subroutine GDISS is called to obtain the time-average power dissipated. DISS is the total power dissipated in the lumped loads and the imperfectly-conducting wire. PRAD is the time-average power radiated, defined by the difference between PIN and DISS. If the antenna has perfect conductivity and purely reactive loads, the radiation efficiency is considered to be 100 per cent.

#### APPENDIX 9. Subroutine SQROT

Subroutine SQROT is listed in Fig. 16. This subroutine considers the matrix equation ZI = V which represents a system of simultaneous linear equations. If the square matrix Z is symmetric, SQROT is useful for obtaining the solution I with V given. NEQ denotes the number of simultaneous equations and the size of the matrix Z.

On entry to SQROT, S is the excitation column V. On exit, the solution I is stored in S. Let Z(I,J) denote the symmetric square

	SUBROUTINE GANTI(IA, IB, INM, IWR, II, I2, I3, I12, JA, JB, MD, N, ND, NM, AM	0001
	2, C, CJ, CG, CMM, D, EFF, GAM, GG, CGD, SGD, VG, Y11, Z11, ZLD, ZS)	0002
	COMPLEX C(1),CJ(1),CGD(1),SGD(1),VG(1),ZLD(1),Y11,Z11,ZS,GAM,CG(1)	0003
	DIMENSION D(1), IA(1), IB(1), JA(1), JB(1)	0004
	DIMENSION I1(1),12(1),13(1),MD(1NM,4),ND(1)	0005
2	FORMAT(1X,115,8F10,2)	0006
5	FORMAT(1HO)	0007
	DO 50 I=1.N	8000
	CJ(I) = (aO + aO)	0009
	K=JA(I)	0010
	DD 40 KK=1.2	0011
	KA = IA(K)	0012
	κβ=[β(κ)	0013
	JJ=K	0014
	F I = 1 •	0015
	IF(K8.EQ.12(I))GO TO 36	0016
	IF(KB.EQ.I1(I))FI=-1.	0017
	CJ(I)=CJ(I)+FI*VG(JJ)	0018
	GD TO 40	0019
36	IF (KA.EQ.I3(I))FI=-1.	0020
	JJ=K+NM	0021
	CJ(I)=CJ(I)+FI*VG(JJ)	0022
40	K=JB(I)	0023
50	CONTINUE	0024
	DO 55 I=1,N	0025
55	CG(I)=CJ(I)	0026
	CALL SQROT(C,CJ,0,I12,N)	0027
	112=2	0028
	Y11=(.0,.0)	0029
	DO 80 I=1,N	0030
80	Y11=Y11+CJ(I)*CONJG(CG(I))	0031
	CALL RITE(IA, IB, INM, IWR, II, 12, I3, MD, ND, NM, CJ, CG)	0032
	GG=REAL(Y11)	0033
	Z11=1./Y11	0034
	P IN = GG	0035
	CALL GDISS(AM,CG,CMM,D,DISS,GAM,NM,SGD,ZLD,ZS)	0036
	PRAD=PIN-DISS	0037
	EFF=100.*PRAD/PIN	0038
	RETURN	0039
	END	0040

# Fig. 15. Subroutine GANT1

38

	SUBROUTINE SQROT(C,S,IWR,I12,NEQ)	0001
	COMPLEX C(1),S(1),SS	0002
2	FORMAT(1X,115,1F10.3,1F15.7,1F10.0,2F15.6)	0003
3	FORMAT(1HO)	0004
	N=NEQ	0005
	IF(112.EQ.2)GU 10 20	0006
		0007
,	$\frac{1}{2} \frac{1}{2} \frac{1}$	0008
4		0010
		0011
	IP() = I + 1	0012
	ID = (I-1) * N - (I * I - I)/2	0013
	II=ID+I	0014
	DO 5 L=1,IMO	0015
	LI = (L-1) * N - (L * L - L) / 2 + I	0016
5	C(II)=C(II)-C(LI)*C(LI)	0017
	C(II) = CSQRI(C(II))	0018
		(0.20
		0021
	$DD = 6 M = 1 \cdot IMO$	0022
	MD = (M-1) * N - (M * M - M) / 2	0023
	MI=MD+I	0024
	MJ=MD+J	0025
6	C(IJ)=C(IJ)-C(MJ)*C(MI)	0026
8	C(IJ)=C(IJ)/C(II)	0027
10	CONTINUE	0028
20	S(1) = S(1)/C(1)	0029
	DO 30 1=2,N	0030
	IMU=1-1 DD 25 (+), IMO	0031
	$I I = (1 - 1) \times N - (1 \times 1 - 1) / 2 + 1$	0033
25	S(1) = S(1) + C(1) + S(1)	0034
.,	II = (I-1) * N - (I * I - I) / 2 + I	0035
30	S(1) = S(1)/C(11)	0036
	$NN = ((N+1) \neq N)/2$	0037
	S(N) = S(N)/C(NN)	0038
	NM() = N - 1	0039
	DO 40 I=1,NMO	0040
		0041
	KD=(K=1)*N=(K*K=K)/2	0042
	NO = (N - 1) + N - (N + N - N)/2	0044
	KI = KD+1	0045
35	S(K) = S(K) - C(KL) + S(L)	0046
	KK=KD+K	0047
40	S(K) = S(K)/C(KK)	0048
	IF(IWR.LE.O) GO TO 100	0049
		0050
	$UU = 50  I = I_{9}N$	0051
50	54+0405151177 TE/SA GT (NOD)(NOD=SA	0052
50	$1F(CNOR_{-} F_{-}O_{-})CNOR=1$	0054
	DD = 60 I = 1 + N	0055
	SS=S(1)	0056
	SA=CABS(SS)	0057
	SNOR = SA/CNOR	0058
	PH=.0	0059
	1F(SA.GT.0.)PH=57.29578*ATAN2(AIMAG(SS),REAL(SS))	0060
60	WRITE(6,2)I, SNOR, SA, PH, SS	0061
	WRITE(6,3)	0062
100	RETUKN	0083
	END	0064

-

-

Fig. 16. Subroutine SQROT

matrix. On entry to SQROT, the upper-right triangular portion of Z(I,J) is stored by rows in C(K) with

(4) 
$$K = (I - 1) * NEQ - (I * I - I) / 2 + J$$

If I12 = 1, SQROT will transform the symmetric matrix into the auxiliary matrix (implicit inverse), store the result in C(K) and use the auxiliary matrix to solve the simultaneous equations. If I12 = 2, this indicates that C(K) already contains the auxiliary matrix.

The transformation from the symmetric matrix to the auxiliary matrix is programmed above statement 10, and the solution of the simultaneous equations is programmed in statements 20 to 40. If IWR is positive, the program below statement 40 will write the solution.

SQROT uses the square root method described in Reference 4. The original symmetric matrix Z and the upper triangular auxiliary matrix A are related by

(5) Z = A' A

1

where A' is the transpose of A.

In the thin-wire application, SQROT must be called with I12 = 1 before it is called with I12 = 2. With a large matrix, the execution time in SQROT is much smaller with I12 = 2 than with I12 = 1.

APPENDIX 10. Subroutine RITE

Subroutine RITE is listed in Fig. 17. Given the list of loop currents CJ(I), this subroutine generates a list of branch currents CG(J). CG(J) and CG(JJ) denote the currents at IA(J) and IB(J), respectively, on the wire segment J, where JJ = J + NM. If IWR is a positive integer, the program below statement 110 writes a list of the branch currents. The symbols in this list are defined as follows:

K	the segment number
ACJ	normalized current magnitude at IA(K)
BCJ	normalized current magnitude at IB(K)
PA	phase of current at IA(K)
PB	phase of current at IB(K)
CJA	complex current at IA(K)
CJB	complex current at IB(K)

The phase angles PA and PB are in degrees. Even if IWR is negative, RITE generates the branch-current list for use in subroutine GDISS.

40

	SUBRUUTINE RITE(IA, IB, INM, IWR, I1, I2, I3, MD, ND, NM, CJ, CG)	0001
	COMPLEX CULLI.CG(1).CJA.CJB	0002
	DIMENSION IA(1), IB(1), I1(1), I2(1), I3(1), MD(INM, 4), ND(1)	0003
2	FORMAT(1X+115+2F10-3+2F10-0+4F15+6)	0004
5	FURMAT(1HO)	0005
-	AMAX=.0	0006
	DO 100 K=1,NM	0007
	KA=1A(K)	0008
	KB=1B(K)	0009
	CJA = (.0, .0)	0010
	CJB=(.0,.0)	0011
	NDK=ND(K)	0012
	DO 40 II=1,NDK	0013
	I=MD(K,11)	0014
	FI=1.	0015
	IF(KB.EQ.12(I))GO TO 36	0016
	IF(KB.EQ.I1(I))FI=-1.	0017
	CJA=CJA+FI*CJ(1)	0018
	GO TO 40	0019
36	$IF(KA \cdot EQ \cdot I3(I))FI = -1 \cdot$	0020
	CJB=CJB+FI <b>*CJ(I)</b>	0021
40	CONTINUE	0022
	CG(K)=CJA	0023
	KK=K+NM	0024
	CG(KK)=CJB	0025
	ACJ=CABS(CJA)	0026
	BCJ=CABS(CJB)	0027
	IF (ACJ.GT.AMAX)AMAX=ACJ	0028
	IF (BCJ.GT.AMAX)AMAX=BCJ	0029
100	CONTINUE	0030
	IF (IWR.GT.0)GD TO 110	0031
	RETURN	0032
110	IF (AMAX.LE.O.)AMAX=1.	0033
	DO 200 K=1,NM	0034
	CJA=CG(K)	0035
	KK=K+NM	0036
	CJB=CG(KK)	0037
	ACJ=CABS(CJA)/AMAX	0038
	BCJ=CABS(CJB)/AMAX	0039
	PA=57.29578*ATAN2(AIMAG(CJA), REAL(CJA))	0040
	PB=57.29578*ATAN2(AIMAG(CJB),REAL(CJB))	0041
200	WRITE(6,2)K,ACJ,BCJ,PA,PB,CJA,CJB	0042
	WK11E(0,5)	0043
	RETURN	0044
	END	0045

Fig. 17. Subroutine RITE

ŝ

### APPENDIX 11. Subroutine GDISS

Subroutine GDISS is listed in Fig. 18. This subroutine uses Eq. 50 of Reference 1 to calculate the time-average power dissipated in the imperfectly conducting wire. This is accomplished in the DO LOOP terminating at statement 100. The power dissipated in the lumped loads is calculated in the DO LOOP terminating with statement 140. DISS denotes the time-average power dissipated in the wire and the loads.

## APPENDIX 12. Subroutine GNFLD

Subroutine GNFLD, listed in Fig. 19, inputs the loop currents CJ(I), calls GNF for the near-zone field of each wire segment, and sums over all the segments to obtain the near-zone field of the wire antenna or the near-zone scattered field of the wire scatterer. EX, EY and EZ denote the cartesian components of this field at the observation point (XP,YP,ZP). This calculated field does not include the incident fields of the magnetic frills or loops associated with generators on the antenna. It also does not include the radiation from the polarization currents in the dielectric insulation.

This subroutine could be simplified and speeded by inputting the branch currents CG(J) instead of the loop currents CJ(I). However, this would increase the storage requirements because the far-field subroutine GFFLD would have to store the branch currents induced by the phi-polarized and theta-polarized incident waves.

#### APPENDIX 13. Subroutine GNF

Subroutine GNF, listed in Fig. 20, uses Eqs. 75 and 76 of Reference 1 to calculate the near-zone electric field of a sinusoidal electric monopole with endpoints at (XA,YA,ZA) and (XB,YB,ZB). The observation point is at (X,Y,Z). EX1, EY1 and EZ1 are the components of the field generated by the mode with unit current at (XA,YA,ZA). EX2, EY2 and EZ2 denote the field generated by the mode with unit current at (XB,YB,ZB). GNF is similar to GGS, and Appendix 5 defines many of the symbols used in both subroutines.

### APPENDIX 14. Subroutine GFFLD

The far-field subroutine GFFLD, listed in Fig. 21, is discussed in section II. In antenna gain calculations with INC = 0, the loop currents CJ(I) are employed by GFFLD to calculate the far-zone field. The field of each segment is obtained by calling GFF, and a summation over all the segments yields the field of the antenna.

In a bistatic scattering situation with INC = 2, the input data include the loop currents EP and ET induced by phi-polarized and theta-polarized incident waves. These currents were calculated by GFFLD in a

SUBROUTINE GDISS(AM,CG,CMM,D,DISS,GAM,NM,SGD,ZLD,ZS)	0001
COMPLEX CG(1).SGD(1).ZLD(1).CJA.CJB.GAM.ZS	0002
DIMENSION D(1)	0003
DATA P1/3.14159/	0004
DISS=0	0005
IF (CMM .LE .0.)GO TO 120	0006
ALPH=REAL(GAM)	0007
BETA=AIMAG(GAM)	0008
RH=RFAL(ZS)/(4.*PI*AM)	0009
DO 100 K=1.NM	0010
DK = D(K)	0011
DEN=CABS(SGD(K))**2	0012
EAD = EXP(ALPH*DK)	0013
$CAD = (EAD + 1 \cdot / EAD)/2 \cdot$	0014
CBD=COS(BETA*DK)	0015
SAD = DK	0016
IF $(ALPH_{0}E_{0})$ SAD = $(EAD - 1 \cdot / EAD) / (2 \cdot * ALPH)$	0017
SBD=DK	0018
IF(BETA。NE •O • ) SBD = SIN(BETA ≠DK)/BETA	0019
FA=RH*(SAD*CAD-SBD*CBD)/DEN	0020
FB=2•*RH*(CAD*SBD-SAD*CBD)/DEN	0021
CJA=CG(K)	0022
L=K+NM	0023
CJB=CG(L)	0024
100 DISS=DISS+FA*(CABS(CJA)**2+CABS(CJB)**2)	0025
2+FB*(REAL(CJA)*REAL(CJB)+AIMAG(CJA)*AIMAG(CJB))	0026
120 DO 140 J=1,NM	0027
K=J+NM	0028
140 DISS=DISS+REAL(ZLD(J))*(CABS(CG(J))**2)	0029
2+REAL(ZLD(K))*(CABS(CG(K))**2)	0030
RETURN	1600
END	0052

Fig. 18. Subroutine GDISS

-

	SUBROUTINE GNELD (IA, IB, INM, I1, I2, I3, MD, N, ND, NM, AM, CGD, SGD, ETA, GAM	0001
-	- (1 - 0) + (1 - 2) + (1	0002
~	CONDICY EY EY EY EY EFT - FY1 - F71 - F72 - FY2 - F72 - F74 - GAM	0003
		0004
•	$C_{1}$ $C_{2}$ $C_{1}$ $C_{1$	0005
	D IMENSION IA(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(	0006
	U IMENSION MOVING THE THOUSE	0007
		0008
		0009
		0010
		0011
		0012
		0013
	KB=1B(K)	0014
	[ALL GNF (X KA], T(KA), Z(KA), A(KB), T(KB), Z(KB), A(KB), A(KB	0015
4	2, COURN , SOURN , ETA , GAM , EXI ; ETI ; ETI ; EXI ; ETI ; E	0016
		0017
	DU 140 II=I,NDK	0018
	1=MD(K,11)	0019
		0020
	IF (KB.EQ.12(1))GU 10 136	0021
	IF(KB - EQ - II(I)) + I = -I -	0022
	E X = E X + F I * E X 1 * C J ( 1 )	0023
	EY=EY+FI*EY1*CJ(I)	0024
	E Z = E Z + F I + E Z 1 + C J ( I )	0024
	GO TO 140	0025
136	IF (KA.EQ.I3(1))FI=-1.	0020
	E X = E X + F I + E X 2 + C J ( I )	0021
	EY=EY+FI*EY2*CJ(I)	0028
	E Z=E Z+F I *E Z2 *CJ(I)	0029
140	CONTINUE	0031
	RETURN	0032
	END	0032

# Fig. 19. Subroutine GNFLD

	SURFOLTINE GNF (XA,YA,ZA,XB,YB,ZB,X,Y,Z,AM,DS,CGDS,SGDS,ETA,GAM	0001
	2,EX1,EY1,EZ1,EX2,EY2,EZ2)	0002
	COMPLEX EJA, EJB, EJ1, EJ2, ER1, ER2, ES1, ES2, SGDS, GAM, CST, CGDS, ETA	0003
	COMPLEX EX1, EX1, EX2, EX2, EX2, EX2, EX2, EX2	0004
	DATA PI/3.14159/	0005
	CAS=(XB-XA)/DS	0006
	CBS=(YB-YA)/DS	0007
	CGS = (ZB - ZA)/DS	0008
	SZ = (X - XA) + CAS + (Y - YA) + CBS + (Z - ZA) + CGS	0009
	Z Z 1 = S Z	0010
	ZZ 2 = SZ – D S	0011
	XXZ=X-XA-SZ*CAS	0012
	YYZ=Y-YA-SZ*CBS	0013
	ZZZ=Z-ZA-SZ*CGS	0014
	RS=XXZ**2+YYZ**2+ <b>ZZZ**2</b>	0015
	R1=SQRT(R5+ZZ1**2)	0016
	EJA=CEXP(-GAM*R1)	0017
	EJ1=EJA/R1	0018
	R2=SQRT(RS+ZZ2**2)	0019
	EJB=CEXP(-GAM*R2)	0020
	EJ2=EJB/R2	0021
	E S 1 = E J 2 - E J 1 * C GD S	0022
	E S2=E J1-E J2 *CGD S	0023
	ER1=(.0,.0)	0024
	ER2=(•0••0)	0025
	AM S=AM *AM	0026
	IF (RS.LT.AMS)GO TO 80	0027
	CTH1=ZZ1/R1	0028
	CTH2=ZZ2/R2	0029
	ER1=( EJA*SGDS+EJA*CGDS*CTHI-EJB*CTH2)/RS	0030
	ERZ=(-EJB*SGDS+EJB*CGDS*C HZ-EJA*C HI)/RS	0031
80	CSI = ETA/(4 + PI + SGUS)	0032
		0033
	EY1=CST*(ES1*CBS+ER1*YYZ)	0034
	EZI=CST*(ESI*CGS+ERI*ZZZ)	0035
		0030
		0031
		0030
		0039
	ENU	0040

Fig. 20. Subroutine GNF

	SUBROUTINE GFFLD(IA, IB, INC, INM, IWR, 11, 12, 13, 112, MD, N, ND, NM, AM	0001
;	ACSP.ACST.C.CGD.CG.CJ.CMM.D.ECSP.ECST.EP.ET.EPP.ETT.EPPS.EPTS	0002
	.FTPS.FTTS.GG.GPP.GTT.PH.SQD.SCSP.SCST.SPPM, SPTM, STPM, STTM, TH	0003
4	• X • Y • Z • Z LD • Z S • E TA • GAM )	0004
	COMPLEX CJI, ET1, ET2, EP1, EP2, EPPS, ETTS, EPTS, ETPS, ZS, VP, VT	0005
	COMPLEX C(1),CJ(1),EP(1),ET(1),EPP(1),ETT(1),ZLD(1)	0006
	COMPLEX ETA, GAM, CGD(1), SGD(1), CG(1)	0007
	DIMENSION IA(1), IB(1), I1(1), I2(1), I3(1), ND(1), MD(INM, 4)	0008
	DIMENSION $D(1), X(1), Y(1), Z(1)$	0009
	DATA PI,TP/3.14159,6.28318/	0010
	CJI=-4.*PI/(ETA*GAM)	0011
	GGG=REAL(1./ETA)	0012
	THR=+01745337TH	0013
		0015
	318-318(188) 540 - 117633±04	0016
		0017
	SPH=SIN(PHR)	0018
	DO 130 I=1,N	0019
	ETT(1)=(.0,.0)	0020
130	EPP(I) = (.0,.0)	0021
	DO 140 K=1,NM	0022
	KA=IA(K)	0023
	KB=IB(K)	0024
	CALL GFF(X(KA),Y(KA),Z(KA),X(KB),Y(KB),Z(KB),D(K)	0025
2	$P_{1}$ CGD (K), SGD (K), CTH, STH, CPH, SPH, GAM, E TA, E T1, E 12, EP1, EP2	0020
		0021
		0020
	1=MU(K + 11)	0029
	FI-1+ 16/KB 60.12/11/00 TO 136	0031
	IF(KB,EQ,II)(I) FI=-I.	0032
	FPP(I) = FPP(I) + FI + FP	0033
	ETT(I)=ETT(I)+FI*ET1	0034
	GU TO 140	0035
136	IF (KA.EQ.13(I))FI=-1.	0036
	EPP(1)=EPP(1)+F1*EP2	0037
	ETT(1)=ETT(1)+FI*ET2	0038
140	CONTINUE	0039
	EPPS=(.0,.0)	0040
	ETTS=(.0,.0)	0041
	IF (INC.EQ.0)GU IU 200	0042
	$1 + (1 \times 1 + 2 \times 1 + 2 \times 1 + 1 \times 1 + 1 \times 1 + 2 \times 1 + 1 \times 1 \times$	0045
	DU 100 1-19N	0045
150	EP(T)=EPP(T)+CJT	0046
100	$CALL SOROT(C_FP_0_1)2.N)$	0047
	112=2	0048
	CALL SOROT (C.ET.O.112.N)	0049
	CALL RITE (IA . IB . INM . IWR , 11, 12, 13, MD , ND , NM , EP , CG)	0050
	CALL GDISS(AM,CG,CMM,D,PDIS,GAM,NM,SGD,ZLD,ZS)	0051
	CALL RITE (IA, IB, INM, IWR, I1, 12, I3, MD, ND, NM, ET, CG)	0052
	CALL GDISS (AM, CG, CMM, D, TOIS, GAM, NM, SGD, ZLD, ZS)	0053
	ACSP=PD IS/GGG	0054
	ACST=TD15/GGG	0055
	PIN=.0	0056
	T IN=.0	0057
	DO 164 I=1,N	0058
	VP=CJ1=EPP(1)	0039
	VI-001*CII117	0061
144	FIN-FINTREALLYFTUNNULEFLIIII TIN-TINTREALLYFTUNNULEFLIIII	0062
1 04	111-111-1CAF141-COMPOLE 111111	

.

7

.

Fig. 21a. Subroutine GFFLD

46

	ECSP=PIN/GGG	0063
	ECST=TIN/GGG	0064
	SCSP=ECSP-ACSP	0065
	SCST=ECST-ACST	0066
170	EPTS = (.0, .0)	0067
170	ETPS = (.0, .0)	0068
	DO 180 I=1,N	0069
	EPPS=EPPS+EP(I)*EPP(I)	0070
	EPTS=EPTS+EP(I) *ETT(I)	0071
	ETTS=ETTS+ET(I)*ETT(I)	0072
180	ETPS=ETPS+ET(I)*EPP(I)	0073
100	SPPM=2.*TP*(CABS(EPPS)**2)	0074
	SPTM=2.*TP*(CABS(EPTS)**2)	0075
	STPM=2.*TP*(CABS(ETPS)**2)	0076
	STTM=2.*TP*(CABS(ETTS)**2)	0077
	RETURN	0078
200	DO 260 I=1,N	0079
	ETTS=ETTS+CJ(I)*ETT(I)	0080
260	EPPS=EPPS+CJ(1)*EPP(I)	0081
	APP=CABS(EPPS)	0082
	ATT=CABS(ETTS)	0083
	GPP=4.*PI*APP*APP*GGG/GG	0084
	GTT=4.*PI*ATT*ATT*GGG/GG	0085
	RETURN	0086
	END	0087

# Fig. 21b. Subroutine GFFLD

-

previous call for the backscattering situation with INC = 1. Thus, a bistatic call must be preceded by a backscatter call.

EPP(I) and ETT(I) denote the phi-polarized and theta-polarized far-zone fields of dipole mode I with unit terminal current. In a backscattering situation, the excitation voltages EP(I) and ET(I) are obtained by multiplying EPP and ETT by the constant CJI. (See Eqs. 38, 39 and 40 in Reference 1.) Then calls are made to SQROT which stores the solution (the induced loop currents) in EP(I) and ET(I). RITE is called for the branch currents CG(J), and GDISS is called for the time-average power dissipated in the imperfectly conducting wire and the lumped loads. This power is denoted PDIS and TDIS for phi-polarized and theta-polarized incident waves, respectively.

In scattering problems, the incident plane wave has unit electric field intensity at the coordinate origin. GGG denotes the time-average power density of the incident wave at the origin. ACSP and ACST denote the absorption cross sections for the phi and theta polarizations.

PIN and TIN denote the time-average power input to the wire structure, delivered by the equivalent voltage generators VP and VT at the terminals. PIN and TIN apply for the phi and theta polarizations, respectively. The time-average power input is regarded as the sum of the time-average power dissipated (in the wire and the lumped loads) and the time-average power radiated or scattered by the wire. ECSP and ECST denote the extinction cross sections and SCSP and SCST are the scattering cross sections.

The distant field is calculated in the DO LOOP ending with statement 180 for scattering situations, and in the DO LOOP ending with statement 260 for the antenna situation. In these fields, the range dependence is suppressed as in Eq. (1).

The radar cross sections (echo areas) SPPM, SPTM, STPM and STTM are defined as in Eq. 72 of Reference 1 with the incident power density  $(S_i \text{ or } GGG)$  evaluated at the coordinate origin. The user selects the location of the origin when supplying the input data for the coordinates of all the points on the wire.

For an antenna, the following definition is employed for the power gain:

(6)  $G_p(\theta,\phi) = \lim_{r \to \infty} 4\pi r^2 e^{2\alpha r} S(r,\theta,\phi) / P_i$ 

where  $P_i$  (or GG in the program) denotes the time-average power input and  $S(r, \theta, \phi)$  is the time-average power density in the radiated field. For an antenna in a lossless medium,  $\alpha$  vanishes and Eq. (6) reduces to the standard definition of power gain. Without the factor  $e^{2\alpha r}$  in Eq. (6), the power gain would vanish for a finite antenna in a conducting medium. GPP and GTT denote the power gains associated with the phipolarized and theta-polarized components of the field, respectively.

### APPENDIX 15. Subroutine GFF

Subroutine GFF, listed in Fig. 22, uses the equations in Appendix 2 of Reference 1 to calculate the far-zone field of a sinusoidal electric monopole. The monopole has endpoints (XA,YA,ZA) and (XB,YB,ZB). EP1 and ET1 denote E, and E, for the mode with unit current at (XA,YA,ZA). EP2 and ET2 denote the fields for the mode with unit current at (XB,YB,ZB). The range dependence is suppressed as in Eq. (1). The far field vanishes in the endfire direction where GK = 0.

	SUBRUUTINE GFF (XA, YA, ZA, XB, YB, ZB, D,	0001
	2CGD . SGD . CTH. STH. CPH. SPH.	0002
	2GAM • FTA • FT1 • FT2 • EP1 • EP2 )	0003
	COMPLEX ET1, ET2, EP1, EP2, GAM, ETA	0004
	COMPLEX GD + CGD + SGD + EGD	0005
	COMPLEX EGFA, EGFB, EGGD, ESA, ESB	0006
	COMPLEX CST	0007
	FP=12.56637	0008
	XΔB=XB-XΔ	0009
	$Y \Delta B = Y B - Y \Delta$	0010
	7 Δ B = 7 B - 7 Δ	0011
	CA=XAB/D	0012
	CB=YAB/D	0013
	CG=7AB/D	0014
	G=(CA*CPH+CB*SPH)*STH+CG*CTH	0015
	GK = 1 - G * G	0016
	FT1=(.0,.0)	0017
	ET2=(.0,.0)	0018
	FP1 = (.0.0)	0019
	FP2=(.0.0)	0020
	IF (GK-LT-001)G0 T0 200	0021
	$FA = (XA \neq CPH + YA \neq SPH) \neq STH + 7 A \neq CTH$	0022
	FB=(XB+CPH+YB+SPH)+STH+7B+CTH	0023
	$FGEA = (F \times P (GAM \neq EA))$	0024
	$EGEB=CEXP(GAM \neq EB)$	0025
	EGGD = CE XP (GAM * G * D)	0026
	$CST = ETA / (GK \neq SG) \neq EP$	0027
	$E SA = CST \neq E GEA \neq (E GGD - G \neq SGD - CGD)$	0028
	ESH=CST *EGEB * (1 . /EGGD + G * SGD - CGD )	0029
	T=(CA+CPH+CB+SPH)+CTH-CG+STH	0030
	P=-CA*SPH+CB*CPH	0031
	ET1=T*ESA	0032
	ET2=T*ES8	0033
	EP1=P*ESA	0034
	EP2≃P≈ES8	0035
200	CONTINUE	0036
	RETURN	0037
	END	0038

Fig. 22. Subroutine GFF

50

C.S. GOVERNMENT PRINTING OFFICE: 1974-737-724/91 REGION NO. 3-11

-

•

· .

Ŧ