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A MULTI-CAVITY KLYSTRON COMPUTER PROGRAM INCLUDING POTENTIAL DEPRESSION CORRECTION

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ABSTRACT

This report describes a computer program which may be used to investigate the characteristics of a multicavity klystron[1, 2, 3]. It is written for the IBM 7090 in "Fortran" language so that it may be intelligible to people other than the originator of the program. It is written for solid or hollow beam klystrons. For maximum flexibility it is in the form of several subroutines connected by a master control program. It is complete in the sense that it leaves nothing for the user to compute manually.

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I. Introduction

The following describes a multicavity klystron (MCK) computer program which has been written for the IBM 7090 computer at Lincoln Laboratory. It is based upon two papers[1,2] describing an improved MCK analysis and a third[3] in which a potential depression correction is derived.

It has been assumed that the reader is familiar with the above mentioned reports, and this manual is intended only as an aid to the use of the program.

The program was written in the IBM 709 "FORTRAN" language which, in addition to being a compact and efficient language, provides an excellent record of the computation which is easily understood by people other than the originator of the program. The writers have sought to achieve three qualities in the program: generality, adaptability to future changes, and completeness. The program achieves generality insofar as it is good for any solid or hollow beam klystron with from 1 to 6 (this number can be extended by altering input and output format statements) cavities of equal or unequal spacing.

The program is flexible and adaptable to future changes since it has been written in the form of several subroutines connected by a master control program. Any future change will merely require altering or adding subroutines without disturbing the rest of the program.*

The program is complete in the sense that it leaves nothing for the user to compute manually. This can be seen from the following outline in which only the most elementary parameters of the tube are required as input to the program.

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*No attempt has been made to optimize the program for the sake of brevity or economy of operation, nor is such optimization planned. The writers realize that several correctable redundancies in form do exist, and that some inefficient methods are employed. Users of the program may find it to their advantage to make several minor alterations.

II. Input

The input data are of two kinds. First, there are those which put into storage the mechanical and electrical tube parameters and associated quantities necessary to the computation. Table I lists and defines these parameters. Secondly, there are those inputs, listed in Table II, which determine the quality and quantity of the output data. Some discussion of these is necessary.

The quality of the output is determined to some degree by the number of modes considered, although it has been found for typical tubes that the effect due to modes of order higher than the fourth contribute little to the end results. The decision of the degree of accuracy desired has been left to the user in that the number of modes to be used in the calculation is an input parameter.

Since the output is generally in the form of some parameter as a function of frequency, the number of frequencies at which data is desired partially determines the amount of output data. Output data may be obtained over a 16% or smaller bandwidth for as many frequencies as are desired. The input necessary to determine the bandwidth and number of frequency points is: the fractional deviation from the center frequency of the initial (lowest) operating frequency at which data is desired, the fractional frequency increment, and the total number of points desired.

There are, in addition, three other parameters not directly used in the computation. These will have value 1 or 0 and will determine which of several options in output are to be chosen.

It might be advantageous for a particular tube to change the values of $\gamma_{\pm}$ at which the searches for solutions start and the spacing of the points used in the search. (Note $\gamma_{\pm} = (\beta_{\pm}^2 - k^2)^{1/2}$, where $\beta_{\pm}$ are the roots of the propagation equation and $k \equiv \omega/c$.) If the range is too wide or the initial spacing too fine, computer time is wasted; if the range is too narrow or the initial spacing too coarse, a root may be missed. As the program is presently set up, the search for γ_+ starts at $0.6\beta_e$ and increases, and the search for γ_- starts at $1.8\beta_e$ and decreases. This change may be effected by altering statement number 121 and the immediately following (unnumbered) statement which reads presently:

```
121        GPOS(I) =    0.6*BE(I)
           GMINUS(I) =  1.8*BE(I)
```

(Note $\beta_e = \omega/v$.) This is adequate for conventional multicavity klystrons where v/c is of the order of 0.5 and where the $\beta_{\pm}$ are spaced on the order of $\pm$ 0.1 from β_e (i.e., $\omega_q/\omega \simeq 0.1$). Similarly, the initial spacing of the points used to search for the root can be changed by altering statement number 153 which reads presently:

```
153        DDG = .001
```

Increasing the value of "DDG" widens the initial spacing.

INPUT

TABLE I

TUBE PARAMETERS

Fortran Symbol	Parameter	Definition
NCVS	r	Number of cavities
VO	V_o	DC voltage
FIO	I_o	DC current
FO	f_o	Center frequency
A	a	Drift tube inside radius (inches)
B	b	*Beam outside radius (inches)
C	c	*Beam inside radius (inches)
DGAP	d	Gap half length (inches)
RQ(I)	$(R/Q)^{(i)}$	(R/Q) value for each cavity
QO(I)	$Q_o^{(i)}$	Circuit loading for each cavity
QEXT(I)	$Q_{ext}^{(i)}$	External loading for each cavity
S(I)	$\ell^{(i+1)} - \ell^{(i)}$	Center gap to center gap distance for each gap pair
THETA	θ_{ext}	Phase shift in external circuits
FNU(I)	$\upsilon^{(i)}$	Fractional detuning for each cavity

*In this treatment, infinite magnetic field is assumed, so that there is no variation of beam dimensions.

TABLE II

OUTPUT OPTIONS

Fortran Symbol	Parameter	Definition
N	n	Number of modes
SFRIQ	$\delta_o = \frac{f-f_o}{f_o}$	Fractional deviation of input frequency (f) from center frequency (f_o) (SFRIQ $\geq$ -.08)
FFDEL	$\frac{\Delta f}{f_o}$	Fractional frequency increment
NKK		Number of frequencies at which information is desired (Note: SFRIQ + NKK * FFDEL must be less than or equal to +.08)
POTD		= 0 do potential depression $\neq$ 0 omit potential depression
SKIP		= 0 do complete computation thru gain and phase as a function of frequency $\neq$ 0 do all calculations except gain and phase as a function of frequency
WOT		$\neq$ 0 print all output parameters = 0 print only gain and phase information

III. Output

The heading or the first nineteen lines of the printed output which are always printed verify some of the input parameters and serve to identify the tube and conditions being examined. Each of these lines has a label. The contents of these lines are:

1. The contents of identification input card number 1
2. Number of cavities
3. Number of modes
4. DC voltage
5. DC current
6. Center frequency
7. A -
8. B -
9. C -

Lines 10 through 16 give the following parameters for each of the cavities considered and the drift tube.

10. Cavity numbers*
11. DC cavity voltage (depressed potential)
12. D
13. R/Q
14. QO
15. QEXT
16. S

---

* The information for the beam in the drift tube is presented with the cavity data in the last column (i.e., as cavity number NCVS + 1).

The heading is completed by printing out the three input parameters:

17. NKK

18. FREQ = (SFRIQ)

19. DEL = (FFDEL)

The second portion of the output is controlled by the WOT input option parameter. It will be printed out if WOT $\neq$ 0. It consists of major groupings for each frequency and minor groups for each mode at each particular frequency. The major group is denoted by the printed line:

"FDEL = "xyz.... " where "xyz" is (frequency - $f_o)/f_o$. This will be followed by as many groups of the following twenty-eight parameters, as there are modes to be considered. Each minor group is headed by the line "M = x" where x is the mode number. Each parameter is given in tabular form for each cavity. The parameters again have a label. They are:

Fortran Symbol	Parameter	Definition
BE	β_e	
B+	β_{+n}	Fast wave longitudinal plasma wave number
B-	β_{-n}	Slow wave longitudinal plasma wave number
G+	γ_{+n}	Fast wave transverse E.M. wave number
G-	γ_{-n}	Slow wave transverse E.M. wave number
T+	T_{+n}	Fast wave transverse plasma wave number
T-	T_{-n}	Slow wave transverse plasma wave number
BQPOS	β_{q+n}	
BQMIN	β_{q-n}	

Fortran Symbol	Parameter
WQ+/WP	ω_{q+n}/ω_p
WQ-/WP	ω_{q-n}/ω_p
WQ+/W	ω_{q+n}/ω
WQ-/W	ω_{q-n}/ω
ZETA +	ζ_{+n}
ZETA -	ζ_{-n}
Yϕ+ /Gϕ	Y_{o+n}/G_o
Yϕ- /Gϕ	Y_{o-n}/G_o
E+	E_{+n}
E-	E_{-n}
F+	F_{+n}
F-	F_{-n}
C+	C_{+n}
C-	C_{-n}
M+	M_{+n}
M-	M_{-n}
H+	H_{+n}
H-	H_{-n}
GELGO	$(G_{el}/G_o)_n$

At the end of each frequency group, there are printed out (if WOT $\neq 0$) the following:

Fortran Symbol	Parameter	Definition
GELGOP	$G_{el}/G_o = \sum_n (G_{el}/G_o)_n$	
QEL	Q_{el}	Q of electronic load
Q	Q	total Q
QOEL	Q_{oel}	Q of cavity and electronic load
GEL	G_{el}	electronic conductance
REL	R_{el}	$1/G_{el}$
if WOT $\neq 0$ and SKIP = 0		
Y	$y^{(i)}$	$Q^{(i)}/Q^{(i)}_{el}$
ZGR	$Re(Z^{(i)}_g)$	Real part of gap impedance
ZGI	$Im(Z^{(i)}_g)$	Imaginary part of gap impedance
FIVR		Real part of over-all trans-admittance
FIVI		Imaginary part of over-all transadmittance
GVR	$Re(G_v)$	Real part of over-all voltage gain
GVI	$Im(G_v)$	Imaginary part of over-all voltage gain

After all of the major (frequency) groupings are printed out, the cavity detunings are given. These are labeled NU and given for each cavity. Finally, the numerical gain, gain in db, and phase are given as a function of frequency. These quantities are unlabeled but appear in three distinct groups in which frequency increases from left to right in steps according to the frequency increment chosen. These quantities (gain, phase) are calculated only if SKIP = 0.

IV. The Mechanics of Using the Program

The mechanics of using the program are very simple. They consist essentially of knowing how to get the input parameters into the computer. This is accomplished by punching the values of the input parameters on a set of cards in the format* and sequence indicated below, placing these at the end of the program deck, and instructing the operator to clear the core and load the cards. The card format for input parameters is as follows:

Card Format for Input Parameters

Card 1

Column 1 requires a "1" punch if it is desired to skip to a new page for each tube. Columns 2-72 may contain any identifying information for the printed output such as tube name and date.

Card 2

Parameter	N	NCVS	VO	FIO	FO	A	B	C
Columns	1-5	6-10	11-18	19-26	27-34	35-41	42-48	49-55
Type Conversion	I	I	E	E	E	F	F	F
Decimal Places			0	0	0	4	4	4

Card 3

Parameter	NKK	SFRIQ	FFDEL
Columns	1-5	6-15	16-25
Type Conversion	I	F	F
Decimal Places		4	4

* See FORTRAN manual for an explanation of conversion types.

Card 4

Parameter	DGAP(1)	DGAP(2)	DGAP(3)	DGAP(4)	DGAP(5)	DGAP(6)
Columns	1-8	9-16	17-24	25-32	33-40	41-48
Type Conversion	F	F	F	F	F	F
Decimal Places	4	4	4	4	4	4

Card 5

Parameter	RQ(1)	RQ(2)	RQ(3)	RQ(4)	RQ(5)	RQ(6)
Columns	1-10	11-20	21-30	31-40	41-50	51-60
Type Conversion	F	F	F	F	F	F
Decimal Places	2	2	2	2	2	2

Card 6

Parameter	QO(1)	QO(2)	QO(3)	QO(4)	QO(5)	QO(6)
Columns	1-10	11-20	21-30	31-40	41-50	51-60
Type Conversion	F	F	F	F	F	F
Decimal Places	2	2	2	2	2	2

Card 7

Parameter	QEXT(1)	QEXT(2)	QEXT(3)	QEXT(4)	QEXT(5)	QEXT(6)
Columns	1-10	11-20	21-30	31-40	41-50	51-60
Type Conversion	F	F	F	F	F	F
Decimal Places	2	2	2	2	2	2

Card 8

Parameter	S(1)	S(2)	S(3)	S(4)	S(5)
Columns	1-8	9-16	17-24	25-32	33-40
Type Conversion	F	F	F	F	F
Decimal Places	4	4	4	4	4

Card 9

Parameter	THETA
Columns	1 - 10
Type Conversion	F
Decimal Places	4

Card 10

Parameter	POTD	WOT	SKIP
Columns	1 - 10	11 - 20	21 - 30
Type Conversion	F	F	F
Decimal Places	2	2	2

The input should end with card 10 if tunings are not to be included. If there is another tube to be analyzed, the next card will be of the same format as Card 1 above, etc. The program stops when it runs out of cards. In this case, the value of SKIP must be nonzero. Cards 11 and 12 are to be included if, and only if, SKIP = 0.

Card 11

Parameter	FNU(1)	FNU(2)	FNU(3)	FNU(4)	FNU(5)	FNU(6)
Columns	1 - 10	11 - 20	21 - 30	31 - 40	41 - 50	51 - 60
Type Conversion	F	F	F	F	F	F
Decimal Places	5	5	5	5	5	5

This card may be followed by as many cards of the same format as there are sets of tunings to be investigated.

Card 12

Punching "999. 99999" in columns 1 - 10 indicates to the program that there are no more sets of tunings to be investigated for this particular tube and to proceed to the next tube.

MASTER CONTROL PROGRAM

```
C                       REVISED MCK PROGRAM
C                       PART 1
      DIMENSION DBGAIN(200),REL(10)
      DIMENSION DGAP(10),RQ(10),QO(10),QEXT(10),S(10),VI(10),VOC(10),VS(
     110),RHO(10),BP(10),VBAR(10),BE(10),FK(10),BQPOS(10,10),WQWPP(10),W
     2QWP(10),GPOS(10),BPOS(10),TPOS(10),ZETAP(10,10),YOGOP(10,10),BMINU
     3S(10),GMINUS(10),TMINUS(10),BQMIN(10,10),WQWPM(10),WQWM(10),ZETAM(
     410,10),YOGOM(10,10),EPOS(10),FPOS(10),CKP(10,10),FMP(10,10),FHP(10
     5,10),EMIN(10),FMIN(10),CKM(10,10),FMM(10,10),FHM(10,10),GELGO(10),
     6GELGOP(10),QEL(10),G(10),GO(10),GP(10),GM(10),D(10),QOEL(10),GPST(
     710),GMST(10),GAIN(200),PHASE(200),VPTR(10),VSUBD(10),FFO(200)
      DIMENSION FNU(10),FREAL(10,10),FIMAG(10,10),Y(10),GEL(10),ZGR(10),
     1ZGI(10),PPLUSR(20,20),PPLUSI(20,20),COLMR(20,20),COLMI(20,20),FLMP
     2R(20,20),FLMPI(20,20),DR(20,20),DI(20,20),FIR(20,20),FII(20,20),FM
     3ULTR(20,20),FMULTI(20,20),SUMR(20,20),SUMI(20,20),CR(20,20),CI(20,
     420),ZGGLR(20,20),ZGGLI(20,20)
      DIMENSION BEE(3,10,10),FKKKK(3,10,10),GPOSS(3,10,10),BPOSS(3,10,10
     1),TPOSS(3,10,10),BQPOSS(3,10,10),WQWPPP(3,10,10),WQWPW(3,10,10),ZE
     2TAPP(3,10,10),YOGOPP(3,10,10),GMINSS(3,10,10),BMINSS(3,10,10),TMIN
     3SS(3,10,10),BQMINN(3,10,10),WQWPMM(3,10,10),WQWMW(3,10,10),ZETAMM(
     43,10,10),YOGOMM(3,10,10),GELGPP(3,10,10),EPOSS(3,10,10),FPOSS(3,10
     5,10),CKPP(3,10,10),FMPP(3,10,10),FHPP(3,10,10),EMINN(3,10,10),FMIN
     6N(3,10,10),CKMM(3,10,10),FMMM(3,10,10),FHMM(3,10,10),GELGOO(3,10,1
     70)
      COMMON BEE,FKKKK,GPOSS,BPOSS,TPOSS,BQPOSS,WQWPPP,WQWPW,ZETAPP,YOGO
     1PP,GMINSS,BMINSS,TMINSS,BQMINN,WQWPMM,WQWMW,ZETAMM,YOGOMM,GELGPP,E
     2POSS,FPOSS,CKPP,FMPP,FHPP,EMINN,FMINN,CKMM,FMMM,FHMM,GELGOO
  101 READ INPUT TAPE 2,1
      READ INPUT TAPE 2,2,N,NCVS,VO,FIO,FO,A,B,C
      READ INPUT TAPE 2,9,NKK,SFRIQ,FFDEL
      READ INPUT TAPE 2,3,(DGAP(I),I=1,NCVS)
      READ INPUT TAPE 2,4,(RQ(I),I=1,NCVS)
      READ INPUT TAPE 2,4,(QO(I),I=1,NCVS)
      READ INPUT TAPE 2,4,(QEXT(I),I=1,NCVS)
      FRIQ=SFRIQ
      NK=3
      FREQM=-0.0800
      FDEL=0.0800
      NCVSL1=NCVS-1
      NCVSP1=NCVS+1
      READ INPUT TAPE 2,3,(S(I),I=1,NCVSL1)
      READ INPUT TAPE 2,5,THETA
      READ INPUT TAPE 2,20,POTD,WOT,SKIP
      EM=1.759E11
      CL=2.998E8
      EMC2=EM/CL**2
      THETA=THETA*3.14159265/180.0
      EPSO=8.854E-12
      PI=3.14159265
      IF (POTD) 106,107,106
  107 CALL POTDEP(NCVS,VO,FIO,A,B,C,DGAP,VPTR,RSUBD,VBAR,VSUBD)
      DO 110 I=1,NCVS
      VI(I)=VBAR(I)
      GO(I)=FIO/VI(I)
  110 CONTINUE
      VI(NCVSP1)=VSUBD(NCVSP1)
```

N.B.: The Bessel function subroutine called for in this program as BESSELF is GEBSL, Share distribution number 271.

```
      GO(NCVSP1)=FIO/VI(NCVSP1)
      GO TO 111
  106 DO 104 I=1,NCVSP1
      VI(I)=VO
  104 GO(I)=FIO/VI(I)
  111 WRITE OUTPUT TAPE 3,1
      WRITE OUTPUT TAPE 3,6,NCVS,N,VO
      WRITE OUTPUT TAPE 3,14,FIO,FO,A,B,C
      WRITE OUTPUT TAPE 3,13
      WRITE OUTPUT TAPE 3,12,(VI(I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,15,(DGAP(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,16,(RQ(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,17,(QO(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,18,(QEXT(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,19,(S(I),I=1,NCVSL1)
      WRITE OUTPUT TAPE 3,56,NKK,FRIQ,FFDEL
      IF(NKK-1) 320,321,322
  320 PAUSE
  321 NK=1.00
      FREQM=0.00
  322 DO 103 K=1,NK
      FFO(K)=FREQM*FO+FO
      DO 115 I=1,NCVSP1
      VOC(I)=SQRTF(1.0-1.0/(1.0+EMC2*VI(I))**2)
      VS(I)=VOC(I)*CL
      RHO(I)=(39.37**2)*FIO/(PI*(B**2-C**2)*VS(I))
      BP(I)=SQRTF(EM*RHO(I)/EPSO*SQRTF((1.0-VOC(I)**2)**3))/(VS(I)*39.37
     1)
      BE(I)=2.0*PI*FFO(K)/(VS(I)*39.37)
      FK(I)=BE(I)*VOC(I)
      IF (K-1) 120,121,122
  120 PAUSE
  121 GPOS(I)=0.6*BE(I)
      GMINUS(I)=1.8*BE(I)
      GO TO 115
  122 GPOS(I)=0.97*GPST(I)
      GMINUS(I)=2.30*GMST(I)
  115 CONTINUE
  128 DO 105 L=1,N
      DO 102 I=1,NCVSP1
      IF (I-1) 160,161,162
  160 PAUSE
  162 III=I-1
      DO 163 II=1,III
      IF (VI(I)-VI(II)) 163,164,163
  163 CONTINUE
  161 GP(I)=GPOS(I)
      GM(I)=GMINUS(I)
  153 DDG=0.001
  154 CALL SPCRDP(I,A,B,C,DDG,GP,BP,BE,FK,GGPOS,BBPOS,TTPOS)
      GPOS(I)=GGPOS
      BPOS(I)=BBPOS
      TPOS(I)=TTPOS
      BQPOS(L,I)=BE(I)-BPOS(I)
      WQWPP(I)=BQPOS(L,I)/BP(I)
      WQWP(I)=BQPOS(L,I)/BE(I)
      ZETAP(L,I)=BPOS(I)*BQPOS(L,I)*TPOS(I)**2/(GPOS(I)**2*(GPOS(I)**2+T
     1POS(I)**2))
```

```
      YOGOP(L,I)=BE(I)/(BQPOS(L,I)*(1.0+EMC2*VI(I))*(2.0+EMC2*VI(I)))
      CALL SPCRDM(I,A,B,C,DDG,GM,BP,BE,FK,GGMIN,BBMIN,TTMIN)
      GMINUS(I)=GGMIN
      BMINUS(I)=BBMIN
      TMINUS(I)=TTMIN
      BQMIN(L,I)=-(BE(I)-BMINUS(I))
      WQWPM(I)=BQMIN(L,I)/BP(I)
      WQWM(I)=BQMIN(L,I)/BE(I)
      ZETAM(L,I)=BMINUS(I)*BQMIN(L,I)*TMINUS(I)**2/(GMINUS(I)**2*(GMINUS
     1(I)**2+TMINUS(I)**2))
      YOGOM(L,I)=BE(I)/(BQMIN(L,I)*(1.0+EMC2*VI(I))*(2.0+EMC2*VI(I)))
      GO TO 181
  164 GPOS(I)=GPOS(II)
      BPOS(I)=BPOS(II)
      TPOS(I)=TPOS(II)
      BQPOS(L,I)=BQPOS(L,II)
      WQWPP(I)=WQWPP(II)
      WQWP(I)=WQWP(II)
      ZETAP(L,I)=ZETAP(L,II)
      YOGOP(L,I)=YOGOP(L,II)
      GMINUS(I)=GMINUS(II)
      BMINUS(I)=BMINUS(II)
      TMINUS(I)=TMINUS(II)
      BQMIN(L,I)=BQMIN(L,II)
      WQWPM(I)=WQWPM(II)
      WQWM(I)=WQWM(II)
      ZETAM(L,I)=ZETAM(L,II)
      YOGOM(L,I)=YOGOM(L,II)
  181 BEE(K,L,I)=BE(I)
      FKKKK(K,L,I)=FK(I)
      GPOSS(K,L,I)=GPOS(I)
      BPOSS(K,L,I)=BPOS(I)
      TPOSS(K,L,I)=TPOS(I)
      BQPOSS(K,L,I)=BQPOS(L,I)
      WQWPPP(K,L,I)=WQWPP(I)
      WQWPW(K,L,I)=WQWP(I)
      ZETAPP(K,L,I)=ZETAP(L,I)
      YOGOPP(K,L,I)=YOGOP(L,I)
      GMINSS(K,L,I)=GMINUS(I)
      BMINSS(K,L,I)=BMINUS(I)
      TMINSS(K,L,I)=TMINUS(I)
      BQMINN(K,L,I)=BQMIN(L,I)
      WQWPMM(K,L,I)=WQWPM(I)
      WQWMW(K,L,I)=WQWM(I)
      ZETAMM(K,L,I)=ZETAM(L,I)
      YOGOMM(K,L,I)=YOGOM(L,I)
      IF (L-1) 125,126,102
  125 PAUSE
  126 GPST(I)=GPOS(I)
      GMST(I)=GMINUS(I)
  102 CONTINUE
      CALL EFCMH(L,A,B,C,NCVS,VI,TPOS,GPOS,BPOS,EPOS,FPOS,CKP,DUM1,DUM2,
     1DUM3)
      CALL EFCMH(L,A,B,C,NCVS,VI,TMINUS,GMINUS,BMINUS,EMIN,FMIN,CKM,DUM1
     1,DUM2,DUM3)
      DO 108 I=1,NCVS
      FMP(L,I)=BESSELF(DGAP(I)*BPOS(I),0,1)
      FMM(L,I)=BESSELF(DGAP(I)*BMINUS(I),0,1)
```

```
      FHP(L,I)=EPOS(I)+(ZETAP(L,I)*FPOS(I))
      FHM(L,I)=EMIN(I)-(ZETAM(L,I)*FMIN(I))
      GELGO(I)=0.25*(FHP(L,I)*YOGOP(L,I)*CKP(L,I)**2*FMP(L,I)**2/((1.0+Z
     1ETAP(L,I))**2)-(FHM(L,I)*YOGOM(L,I)*CKM(L,I)**2*FMM(L,I)**2/((1.0-
     2ZETAM(L,I))**2)))
      GELGOO(K,L,I)=GELGO(I)
      EPOSS(K,L,I)=EPOS(I)
      FPOSS(K,L,I)=FPOS(I)
      CKPP(K,L,I)=CKP(L,I)
      FMPP(K,L,I)=FMP(L,I)
      FHPP(K,L,I)=FHP(L,I)
      EMINN(K,L,I)=EMIN(I)
      FMINN(K,L,I)=FMIN(I)
      CKMM(K,L,I)=CKM(L,I)
      FMMM(K,L,I)=FMM(L,I)
      FHMM(K,L,I)=FHM(L,I)
108   CONTINUE
105   CONTINUE
      FREQM=FREQM+FDEL
103   CONTINUE
      MM=0
      IF(SKIP) 176,175,176
175   READ INPUT TAPE 2,49,(FNU(I),I=1,NCVS)
      IF(FNU(1)-999.999) 400,101,101
400   FRIQ=SFRIQ
176   DO 171 K=1,NKK
      FFO(K)=FRIQ*FO+FO
      DO 189 I=1,NCVS
      GELGOP(I)=0.0
189   CONTINUE
      IF (WOT) 179,180,179
179   IF(MM) 180,401,180
401   WRITE OUTPUT TAPE 3,10,FRIQ
180   DO 172 L=1,N
      IF(NKK-1) 323,324,325
323   PAUSE
325   CALL TERPOL(NCVSP1,L,BEE,FRIQ,BE)
      CALL TERPOL(NCVSP1,L,BEE,FRIQ,BE)
      CALL TERPOL(NCVSP1,L,FKKKK,FRIQ,FK)
      CALL TERPOL(NCVSP1,L,GPOSS,FRIQ,GPOS)
      CALL TERPOL(NCVSP1,L,BPOSS,FRIQ,BPOS)
      CALL TERPOL(NCVSP1,L,TPOSS,FRIQ,TPOS)
      CALL TERPOL(NCVSP1,L,WQWPW,FRIQ,WQWP)
      CALL TERPOL(NCVSP1,L,WQWMW,FRIQ,WQWM)
      CALL TERPOL(NCVSP1,L,WQWPPP,FRIQ,WQWPP)
      CALL TERPOL(NCVSP1,L,GMINSS,FRIQ,GMINUS)
      CALL TERPOL(NCVSP1,L,BMINSS,FRIQ,BMINUS)
      CALL TERPOL(NCVSP1,L,TMINSS,FRIQ,TMINUS)
      CALL TERPOL(NCVSP1,L,WQWPMM,FRIQ,WQWPM)
      CALL AINTER(NCVSP1,L,BQPOSS,FRIQ,BQPOS)
      CALL AINTER(NCVSP1,L,ZETAPP,FRIQ,ZETAP)
      CALL AINTER(NCVSP1,L,YOGOPP,FRIQ,YOGOP)
      CALL AINTER(NCVSP1,L,BQMINN,FRIQ,BQMIN)
      CALL AINTER(NCVSP1,L,ZETAMM,FRIQ,ZETAM)
      CALL AINTER(NCVSP1,L,YOGOMM,FRIQ,YOGOM)
      CALL TERPOL(NCVS,L,GELGOO,FRIQ,GELGO)
```

```
      CALL TERPOL(NCVS,L,EPOSS,FRIQ,EPOS)
      CALL TERPOL(NCVS,L,FPOSS,FRIQ,FPOS)
      CALL TERPOL(NCVS,L,EMINN,FRIQ,EMIN)
      CALL TERPOL(NCVS,L,FMINN,FRIQ,FMIN)
      CALL AINTER(NCVS,L,CKPP,FRIQ,CKP)
      CALL AINTER(NCVS,L,FMPP,FRIQ,FMP)
      CALL AINTER(NCVS,L,FHPP,FRIQ,FHP)
      CALL AINTER(NCVS,L,CKMM,FRIQ,CKM)
      CALL AINTER(NCVS,L,FMMM,FRIQ,FMM)
      CALL AINTER(NCVS,L,FHMM,FRIQ,FHM)
      GO TO 351
  324 DO 349 I=1,NCVSP1
      BE(I)=BEE(1,L,I)
      FK(I)=FKKKK(1,L,I)
      GPOS(I)=GPOSS(1,L,I)
      BPOS(I)=BPOSS(1,L,I)
      TPOS(I)=TPOSS(1,L,I)
      WQWP(I)=WQWPW(1,L,I)
      WQWM(I)=WQWMW(1,L,I)
      WQWPP(I)=WQWPPP(1,L,I)
      GMINUS(I)=GMINSS(1,L,I)
      BMINUS(I)=BMINSS(1,L,I)
      TMINUS(I)=TMINSS(1,L,I)
      WQWPM(I)=WQWPMM(1,L,I)
      BQPOS(L,I)=BQPOSS(1,L,I)
      ZETAP(L,I)=ZETAPP(1,L,I)
      YOGOP(L,I)=YOGOPP(1,L,I)
      BQMIN(L,I)=BQMINN(1,L,I)
      ZETAM(L,I)=ZETAMM(1,L,I)
      YOGOM(L,I)=YOGOMM(1,L,I)
  349 CONTINUE
      DO 350 I=1,NCVS
      GELGO(I)=GELGOO(1,L,I)
      EPOS(I)=EPOSS(1,L,I)
      FPOS(I)=FPOSS(1,L,I)
      EMIN(I)=EMINN(1,L,I)
      FMIN(I)=FMINN(1,L,I)
      CKP(L,I)=CKPP(1,L,I)
      FMP(L,I)=FMPP(1,L,I)
      FHP(L,I)=FHPP(1,L,I)
      CKM(L,I)=CKMM(1,L,I)
      FMM(L,I)=FMMM(1,L,I)
      FHM(L,I)=FHMM(1,L,I)
  350 CONTINUE
  351 DO 183 I=1,NCVS
      GELGOP(I)=GELGOP(I)+GELGO(I)
  183 CONTINUE
      IF (WOT) 178,172,178
  178 IF(MM) 172,402,172
  402 WRITE OUTPUT TAPE 3,11,L
      WRITE OUTPUT TAPE 3,26,(BE(I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,7,(BPOS(I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,8,(BMINUS(I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,21,(GPOS(I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,22,(GMINUS(I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,23,(TPOS(I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,24,(TMINUS(I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,66,(BQPOS(L,I),I=1,NCVSP1)
```

```
      WRITE OUTPUT TAPE 3,67,(BQMIN(L,L),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,25,(WQWPP(I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,27,(WQWPM(I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,28,(WQWP(I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,29,(WQWM(I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,30,(ZETAP(L,I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,31,(ZETAM(L,I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,32,(YOGOP(L,I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,33,(YOGOM(L,I),I=1,NCVSP1)
      WRITE OUTPUT TAPE 3,34,(EPOS(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,35,(EMIN(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,36,(FPOS(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,37,(FMIN(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,38,(CKP(L,I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,39,(CKM(L,I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,40,(FMP(L,I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,41,(FMM(L,I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,42,(FHP(L,I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,43,(FHM(L,I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,44,(GELGO(I),I=1,NCVS)
172   CONTINUE
      IF (WOT) 184,185,184
184   IF(MM) 185,403,185
403   WRITE OUTPUT TAPE 3,45,(GELGOP(I),I=1,NCVS)
      DO 118 I=1,NCVS
      QEL(I)=1.0/(RQ(I)*GELGOP(I)*GO(I))
      Q(I)=1.0/(1.0/QO(I)+1.0/QEL(I)+1.0/QEXT(I))
      QOEL(I)=1.0/(1.0/Q(I)-1,0/QEXT(I))
      GEL(I)=GELGOP(I)*GO(I)
      REL(I)=1.0/GEL(I)
118   CONTINUE
      WRITE OUTPUT TAPE 3,46,(QEL(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,47,(Q(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,48,(QOEL(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,53,(GEL(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,81,(REL(I),I=1,NCVS)
185   IF(SKIP) 177,186,177
186   NN=2*N
      DELO=(FFO(K)-FO)/FO
      CALL FREQ(Q,FNU,DELO,NCVS,FREAL,FIMAG)
      DO 143 I=1,NCVS
      Y(I)=Q(I)/QEL(I)
      ZGR(I)=Y(I)*FREAL(I)/GEL(I)
      ZGI(I)=Y(I)*FIMAG(I)/GEL(I)
      CALL FOMATR(N,I,NCVS,CKP,CKM,FMP,FMM,FHP,FHM,ZETAP,ZETAM,YOGOP,YOG
     1OM,PPLUSR,PPLUSI,COLMR,COLMI,FLMPR,FLMPI)
140   CALL DMATRX(NCVSP1,NN,I,BQPOS,BQMIN,BE,S,DR,DI,FIR,FII)
      IF (I-1) 130,131,132
130   PAUSE
132   IF (I-NCVS) 133,134,130
131   CALL CMMP(DR,DI,NN,NN,COLMR,COLMI,1,FMULTR,FMULTI)
      GO TO 143
133   DO 170 JJ=1,NN
      DO 170 KK=1,NN
      ZGGLR(JJ,KK)=GO(I)*ZGR(I)*FLMPR(JJ,KK)-GO(I)*ZGI(I)*FLMPI(JJ,KK)
      ZGGLI(JJ,KK)=GO(I)*ZGI(I)*FLMPR(JJ,KK)+GO(I)*ZGR(I)*FLMPI(JJ,KK)
170   CONTINUE
      CALL CMSUBT(ZGGLR,FIR,NN,SUMR)
```

```
      CALL CMSUBT(ZGGLI,FII,NN,SUMI)
      CALL CMMP(SUMR,SUMI,NN,NN,FMULTR,FMULTI,1,CR,CI)
      DO 141 JJ=1,NN
      KK=1
      FMULTR(JJ,KK)=CR(JJ,KK)
      FMULTI(JJ,KK)=CI(JJ,KK)
141   CONTINUE
      CALL CMMP(DR,DI,NN,NN,FMULTR,FMULTI,1,CR,CI)
      DO 142 JJ=1,NN
      KK=1
      FMULTR(JJ,KK)=CR(JJ,KK)
      FMULTI(JJ,KK)=CI(JJ,KK)
142   CONTINUE
      GO TO 143
134   CALL CMMP(PPLUSR,PPLUSI,1,NN,FMULTR,FMULTI,1,CR,CI)
      FIGVGR=CR(1,1)
      FIGVGI=CI(1,1)
143   CONTINUE
      EXPR=COSF(THETA)
      EXPI=SINF(THETA)
      FIVR=FIGVGR*GO(NCVS)
      FIVI=FIGVGI*GO(NCVS)
      FIVER=FREAL(NCVS)*FIVR*EXPR-FIMAG(NCVS)*FIVR*EXPI-FREAL(NCVS)*FIVI
     1*EXPI-FIMAG(NCVS)*FIVI*EXPR
      FIVEI=FREAL(NCVS)*FIVR*EXPI+FIMAG(NCVS)*FIVR*EXPR+FREAL(NCVS)*FIVI
     1*EXPR-FIMAG(NCVS)*FIVI*EXPI
      GVR=-(RQ(NCVS)*QEXT(NCVS)*FIVER)/(1.0+QEXT(NCVS)/QOEL(NCVS))
      GVI=-(RQ(NCVS)*QEXT(NCVS)*FIVEI)/(1.0+QEXT(NCVS)/QOEL(NCVS))
      PHASE(K)=ATANF(GVI/GVR)
      IF (GVR) 155,156,156
155   PHASE(K)=PHASE(K)+PI
      GO TO 157
156   IF (PHASE(K)) 158,157,157
158   PHASE(K)=PHASE(K)+2.0*PI
157   FONE=FREAL(1)**2+FIMAG(1)**2
      FTWO=FREAL(NCVS)**2+FIMAG(NCVS)**2
      FIGV=FIVR**2+FIVI**2
      GAIN(K)=4.0*RQ(1)*RQ(NCVS)*QEXT(1)*QEXT(NCVS)*FONE*FTWO*FIGV/((1.0
     1+QEXT(1)/QOEL(1))**2*(1.0+QEXT(NCVS)/QOEL(NCVS))**2)
      DBGAIN(K)=4.3429*LOGF(GAIN(K))
      IF (WOT) 173,177,173
173   IF(MM) 177,404,177
404   WRITE OUTPUT TAPE 3,52,(Y(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,54,(ZGR(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,55,(ZGI(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,70,FIVR,FIVI,GVR,GVI
177   FRIQ=FRIQ+FFDEL
171   CONTINUE
      IF (SKIP) 101,187,101
187   WRITE OUTPUT TAPE 3,50,(FNU(I),I=1,NCVS)
      WRITE OUTPUT TAPE 3,71,(GAIN(KK),KK=1,NKK)
      WRITE OUTPUT TAPE 3,72,(DBGAIN(KK),KK=1,NKK)
      WRITE OUTPUT TAPE 3,72,(PHASE(KK),KK=1,NKK)
      MM=1
      GO TO 175
C                         FORMAT STATEMENTS
    1 FORMAT (54H
    2 FORMAT (2I5,3E8.0,3F7.4)
```

```
 3  FORMAT (7F8.4)
 4  FORMAT (7F10.2)
 5  FORMAT (F10.4)
 6  FORMAT (20H NUMBER OF CAVITIES=I3/17H NUMBER OF MODES=I3/12H DC VO
   1LTAGE=E10.3)
 7  FORMAT (25H    B+                        ,7F12.6)
 8  FORMAT (25H    B-                        ,7F12.6)
 9  FORMAT (I5,2F10.4)
10  FORMAT (/////6H FDEL=F10.4//)
11  FORMAT (///3H M=I5/)
12  FORMAT (25H    DC CAVITY VOLTAGE         ,7E12.3)
13  FORMAT (7H CAVITY26X,1H111X,1H211X,1H311X,1H411X,1H511X,1H611X,1H7
   11)
14  FORMAT (12H DC CURRENT=E10.3/30H CENTER FREQUENCY(CYCLES/SEC)=E12.
   14/3H A=F7.4/3H B=F7.4/3H C=F7.4////)
15  FORMAT (25H    D                         ,7F12.4)
16  FORMAT (25H    R/O                       ,7F12.2)
17  FORMAT (25H    QO                        ,7F12.2)
18  FORMAT (25H    QEXT                      ,7F12.2)
19  FORMAT (29H CENTER GAP TO CENTER GAP     ,7F12.4)
20  FORMAT (3F10.2)
21  FORMAT (25H    G+                        ,7F12.6)
22  FORMAT (25H    G-                        ,7F12.6)
23  FORMAT (25H    T+                        ,7F12.6)
24  FORMAT (25H    T-                        ,7F12.6)
25  FORMAT (25H    WQ+/WP                    ,7F12.6)
26  FORMAT (25H    BE                        ,7F12.6)
27  FORMAT (25H    WQ-/WP                    ,7F12.6)
28  FORMAT (25H    WQ+/W                     ,7F12.6)
29  FORMAT (25H    WQ-/W                     ,7F12.6)
30  FORMAT (25H    ZETA+                     ,7F12.6)
31  FORMAT (25H    ZETA-                     ,7F12.6)
32  FORMAT (25H    YO+/GO                    ,7F12.6)
33  FORMAT (25H    YO-/GO                    ,7F12.6)
34  FORMAT (25H    E+                        ,7F12.6)
35  FORMAT (25H    E-                        ,7F12.6)
36  FORMAT (25H    F+                        ,7F12.6)
37  FORMAT (25H    F-                        ,7F12.6)
38  FORMAT (25H    C+                        ,7F12.6)
39  FORMAT (25H    C-                        ,7F12.6)
40  FORMAT (25H    M+                        ,7F12.6)
41  FORMAT (25H    M-                        ,7F12.6)
42  FORMAT (25H    H+                        ,7F12.6)
43  FORMAT (25H    H-                        ,7F12.6)
44  FORMAT (25H    GELGO                     ,7F12.6)
45  FORMAT (/////25H    GELGOF                    ,7F12.6)
46  FORMAT (25H    QEL                       ,7F12.6)
47  FORMAT (25H    Q                         ,7F12.6)
48  FORMAT (25H    QOEL                      ,7F12.6)
49  FORMAT (7F10.5)
50  FORMAT (//25H    NU                        ,7F12.6)
52  FORMAT (25H    Y                         ,7F12.6)
53  FORMAT (25H    GEL                       ,7F12.6)
54  FORMAT (25H    ZGR                       ,7F12.6)
55  FORMAT (25H    ZGI                       ,7F12.6////)
56  FORMAT (5H NKK=I5/6H FREQ=F10.4/5H DEL=F10.4/)
66  FORMAT (25H    BQPOS                     ,7F12.6)
67  FORMAT (25H    BQMIN                     ,7F12.6)
```

```
70   FORMAT (6H FIVR=F10.6/6H FIVI=F10.6/5H GVR=F10.6/5H GVI=F10.6)
71   FORMAT (//8E14.6/(8E14.6))
72   FORMAT (//8F14.6/(8F14.6))
81   FORMAT(25H     REL                  7F12.6)
     END
```

```
      SUBROUTINE POTDEP(NCVS,VO,FIO,A,B,C,DGAP,VPTR,RSUBD,VBAR,VSUBD)
      DIMENSION VOC(10),DGAP(10),VPTR(10),VSUBD(10),VBAR(10),ROEPS(10),O
     1DDEV(25)
      NCVSP1=NCVS+1
      EM=1.759E11
      CL=2.998E8
      EMC2=EM/CL**2
      VOC(NCVSP1)=SQRTF(1.0-1.0/(1.0+EMC2*VO)**2)
      ODDEV(1)=2.0
      ODDEV(2)=2.0
      DO 42 J=4,24,2
      ODDEV(J-1)=ODDEV(J-2)+2.0
      ODDEV(J)=ODDEV(J-1)
   42 CONTINUE
      PI=3.14159265
      FMGO=376.7
      BPC=B**2+C**2
      BMC=B**2-C**2
      VPTR(NCVSP1)=1.0/(2.0*PI)*FMGO*FIO/VOC(NCVSP1)*(0.5+LOGF(A/B)-BPC/
     1(4.0*BMC)+C**4*LOGF(B/C)/BMC**2)
      VSUBD(NCVSP1)=VO-VPTR(NCVSP1)/(1.0-VPTR(NCVSP1)/(2.0*VO))
      I=0
      RD=B
      RRD=(B-C)/2.0
      GO TO 31
   17 RD=RD-RRD
   31 I=I+1
      TEST=BMC/2.0-BPC/4.0+C**4*LOGF(B/C)/BMC-(B**2-RD**2)/2.0+C**2*LOGF
     1(B/RD)
      IF (I-1) 10,11,12
   10 PAUSE
   12 IF (TEST) 13,14,15
   13 SIGN2=-1.0
      GO TO 16
   15 SIGN2=+1.0
   16 IF (SIGN+SIGN2) 17,18,17
   11 IF (TEST) 19,14,20
   19 SIGN=-1.0
      GO TO 17
   20 SIGN=+1.0
      GO TO 17
   18 RDD=1.0E-6
      IF (RRD-RDD) 14,14,21
   21 RD=RD+RRD
      RRD=RRD/10.0
      GO TO 17
   14 RSUBD=RD
      DO 22 I=1,NCVS
      VOC(I)=SQRTF(1.0-1.0/(1.0+EMC2*VO)**2)
      ROEPS(I)=FMGO/PI*FIO/VOC(I)*1.0/(BMC)*(39.37)**2/(1.0-VPTR(I)/(2.0
     1*VO))
      M=0
   27 M=M+1
      FM=M
      IF (FM/ODDEV(M)-1.0) 40,27,41
   41 PAUSE
   40 FPD=FM*PI/(2.0*DGAP(I))
      IF (C) 28,29,30
```

```
 28   PAUSE
 30   FI1CD=BESSELF(FPD*C,1,2)
      GO TO 32
 29   FI1CD=0.0
 32   FK1BD=BESSELF(FPD*B,1,3)
      FI0RD=BESSELF(FPD*RSUBD,0,2)
      FK0RD=BESSELF(FPD*RSUBD,0,3)
      UM=(1.0/FPD)**2*(1.0-FPD*B*FK1BD*FI0RD-FPD*C*FK0RD*FI1CD)/(39.37)*
     1*2
      ANR=8.0/(FM**2*PI**2)*ROEPS(I)*SINF(FM*PI/2.0)**2*UM/(1.0-ROEPS(I)
     1*UM/(2.0*VO))
      IF (M-1) 23,24,25
 23   PAUSE
 25   IF (ANR-CHECK) 26,38,38
 24   CHE=1.0E-4
      CHECK=ANR*CHE
      SUM=ANR
      GO TO 27
 38   SUM=SUM+ANR
      GO TO 27
 26   VBAR(I)=VSUBD(NCVSP1)-SUM
 22   CONTINUE
      RETURN
      END
```

```
C                    SPACE CHARGE REDUCTION FACTOR
      SUBROUTINE SPCRDP(I,A,B,C,DDG,GP,BP,BE,FK,GG,BB,T)
      DIMENSION GP(10),BP(10),BE(10),FK(10)
      G=GP(I)
      J=0
      DG=DDG
   20 G=G+DG
      TTT=G**2*(BP(I)**2/((SQRTF(G**2+FK(I)**2)-BE(I))**2)-1.0)
      IF (TTT) 20,20,12
   12 TT=SQRTF(TTT)
      J=J+1
      IF (C) 1,3,2
    1 PAUSE 11111
    2 FJOTC=BESSELF(TT*C,0,1)
      FJ1TC=BESSELF(TT*C,1,1)
      FIOGC=BESSELF(G*C,0,2)
      FI1GC=BESSELF(G*C,1,2)
      FNOTB=BESSELF(TT*B,0,4)
      FN1TB=BESSELF(TT*B,1,4)
      FNOTC=BESSELF(TT*C,0,4)
      FN1TC=BESSELF(TT*C,1,4)
    3 FIOGA=BESSELF(G*A,0,2)
      FIOGB=BESSELF(G*B,0,2)
      FI1GB=BESSELF(G*B,1,2)
      FKOGA=BESSELF(G*A,0,3)
      FKOGB=BESSELF(G*B,0,3)
      FK1GB=BESSELF(G*B,1,3)
      FJOTB=BESSELF(TT*B,0,1)
      FJ1TB=BESSELF(TT*B,1,1)
      BCOTH=(FKOGA*FI1GB+FK1GB*FIOGA)/(FKOGB*FIOGA-FKOGA*FIOGB)
      IF (C) 4,5,6
    4 PAUSE 44444
    5 FOFI=TT*B*FJ1TB-G*B*BCOTH*FJOTB
      GO TO 7
    6 FOFI=(TT*B)**2*(FJ1TB*FN1TC-FJ1TC*FN1TB)-TT*B*G*B*BCOTH*(FJOTB*FN1
     1TC-FJ1TC*FNOTB)+TT*G*B**2*FI1GC/FIOGC*(FJ1TB*FNOTC-FJOTC*FN1TB)-(G
     2*B)**2*BCOTH*FI1GC/FIOGC*(FJOTB*FNOTC-FJOTC*FNOTB)
    7 IF (J-1) 4,70,69
   69 IF (FOFI) 80,10,82
   80 SIGN2=-1.0
      GO TO 83
   82 SIGN2=+1.0
   83 IF (SIGN+SIGN2) 20,8,20
   70 IF (FOFI) 64,10,66
   64 SIGN=-1.0
      GO TO 20
   66 SIGN=+1.0
      GO TO 20
    8 DGG=1.0E-6
      IF (DG-DGG) 10,10,9
    9 G=G-DG
      DG=DG/10.0
      GO TO 20
   10 T=TT
      GG=G
      BB=SQRTF(GG**2+FK(I)**2)
      RETURN
      END
```

```
C                    SPACE CHARGE REDUCTION FACTOR
      SUBROUTINE SPCRDM(I,A,B,C,DDG,GM,BP,BE,FK,GG,BB,T)
      DIMENSION GM(10),BP(10),BE(10),FK(10)
      G=GM(I)
      J=0
      DG=DDG
   20 G=G-DG
      TTT=G**2*(BP(I)**2/((SQRTF(G**2+FK(I)**2)-BE(I))**2)-1.0)
      IF (TTT) 20,20,12
   12 TT=SQRTF(TTT)
      J=J+1
      IF (C) 1,3,2
    1 PAUSE 11111
    2 FJ0TC=BESSELF(TT*C,0,1)
      FJ1TC=BESSELF(TT*C,1,1)
      FI0GC=BESSELF(G*C,0,2)
      FI1GC=BESSELF(G*C,1,2)
      FN0TB=BESSELF(TT*B,0,4)
      FN1TB=BESSELF(TT*B,1,4)
      FN0TC=BESSELF(TT*C,0,4)
      FN1TC=BESSELF(TT*C,1,4)
    3 FI0GA=BESSELF(G*A,0,2)
      FI0GB=BESSELF(G*B,0,2)
      FI1GB=BESSELF(G*B,1,2)
      FK0GA=BESSELF(G*A,0,3)
      FK0GB=BESSELF(G*B,0,3)
      FK1GB=BESSELF(G*B,1,3)
      FJ0TB=BESSELF(TT*B,0,1)
      FJ1TB=BESSELF(TT*B,1,1)
      BCOTH=(FK0GA*FI1GB+FK1GB*FI0GA)/(FK0GB*FI0GA-FK0GA*FI0GB)
      IF (C) 4,5,6
    4 PAUSE 44444
    5 FOFI=TT*B*FJ1TB-G*B*BCOTH*FJ0TB
      GO TO 7
    6 FOFI=(TT*B)**2*(FJ1TB*FN1TC-FJ1TC*FN1TB)-TT*B*G*B*BCOTH*(FJ0TB*FN1
     1TC-FJ1TC*FN0TB)+TT*G*B**2*FI1GC/FI0GC*(FJ1TB*FN0TC-FJ0TC*FN1TB)-(G
     2*B)**2*BCOTH*FI1GC/FI0GC*(FJ0TB*FN0TC-FJ0TC*FN0TB)
    7 IF (J-1) 4,70,69
   69 IF (FOFI) 80,10,82
   80 SIGN2=-1.0
      GO TO 83
   82 SIGN2=+1.0
   83 IF (SIGN+SIGN2) 20,8,20
   70 IF (FOFI) 64,10,66
   64 SIGN=-1.0
      GO TO 20
   66 SIGN=+1.0
      GO TO 20
    8 DGG=1.0E-6
      IF (DG-DGG) 10,10,9
    9 G=G+DG
      DG=DG/10.0
      GO TO 20
   10 T=TT
      GG=G
      BB=SQRTF(GG**2+FK(I)**2)
      RETURN
      END
```

```
C                   FINDING E,F,C,M,H
      SUBROUTINE EFCMH(L,A,B,C,NCVS,VI,X,Y,ZZ,EE,FF,CCK,DUM1,DUM2,DUM3)
      DIMENSION X(10),Y(10),ZZ(10),EE(10),FF(10),CCK(10,10),VI(10)
      DUM1=DUM2+DUM3
      DO 10 I=1,NCVS
      IF (I-1) 15,11,12
   15 PAUSE
   12 III=I-1
      DO 13 II=1,III
      IF (VI(I)-VI(II)) 13,14,13
   13 CONTINUE
   11 T=X(I)
      G=Y(I)
      BT=ZZ(I)
      IF (C) 1,2,3
    1 PAUSE 11111
    3 FNOTB=BESSELF(T*B,0,4)
      FN1TB=BESSELF(T*B,1,4)
      FJOTC=BESSELF(T*C,0,1)
      FJ1TC=BESSELF(T*C,1,1)
      FNOTC=BESSELF(T*C,0,4)
      FN1TC=BESSELF(T*C,1,4)
      FI0GC=BESSELF(G*C,0,2)
      FI1GC=BESSELF(G*C,1,2)
    2 FJOTB=BESSELF(T*B,0,1)
      FJ1TB=BESSELF(T*B,1,1)
      FI0GA=BESSELF(G*A,0,2)
      FI0GB=BESSELF(G*B,0,2)
      FK0GA=BESSELF(G*A,0,3)
      FK0GB=BESSELF(G*B,0,3)
      FI1GB=BESSELF(G*B,1,2)
      IF (C) 4,5,6
    4 PAUSE 44444
    5 E=FJOTB**2+FJ1TB**2
      F=FJOTB**2*(1.0+G**2/T**2+1.0/((T*B*(FI0GB*FK0GA-FI0GA*FK0GB))**2)
     1)
      CK=2.0*(T*B*FI0GB*FJ1TB+G*B*FI1GB*FJOTB)/((G**2*B**2+T**2*B**2)*FI
     10GA*(FJOTB**2+FJ1TB**2))
      GO TO 7
    6 BB=-(T*FJ1TC+G*FI1GC*FJOTC/FI0GC)/(T*FN1TC+G*FI1GC*FNOTC/FI0GC)
      E=(B**2*((FJOTB**2+FJ1TB**2)+2.0*BB*(FJOTB*FNOTB+FJ1TB*FN1TB)+BB**
     12*(FNOTB**2+FN1TB**2))-C**2*((FJOTC**2+FJ1TC**2)+2.0*BB*(FJOTC*FNO
     2TC+FJ1TC*FN1TC)+BB**2*(FNOTC**2+FN1TC**2)))/(B**2-C**2)
      F=(1.0+G**2/T**2)*(B**2*(FJOTB+BB*FNOTB)**2-C**2*(FJOTC+BB*FNOTC)*
     1*2)/(B**2-C**2)+(FJOTB+BB*FNOTB)**2/(T**2*(B**2-C**2)*(FI0GB*FK0GA
     1-FI0GA*FK0GB)**2)
      CK=2.0*((T*B*FI0GB*(FJ1TB+BB*FN1TB)+G*B*FI1GB*(FJOTB+BB*FNOTB))-(T
     1*C*FI0GC*(FJ1TC+BB*FN1TC)+G*C*FI1GC*(FJOTC+BB*FNOTC)))/(E*FI0GA*(B
     2**2-C**2)*(G**2+T**2))
    7 EE(I)=E
      FF(I)=F
      CCK(L,I)=CK
      GO TO 10
   14 EE(I)=EE(II)
      FF(I)=FF(II)
      CCK(L,I)=CCK(L,II)
   10 CONTINUE
      RETURN
      END
```

```
C                         FREQUENCY FUNCTION SUBROUTINE
      SUBROUTINE  FREQ(Q,TU,DELO,NCVS   ,FREAL,FIMAG)
      DIMENSION Q(10),TU(10),FREAL(10),FIMAG(10)
      DO 10 I=1,NCVS
      CFCTR = Q(I)*(2.+DELO+TU(I))*(DELO-TU(I))/((1.+DELO)*(1.+TU(I)))
      FREAL(I) = 1./(1.+CFCTR**2)
   10 FIMAG(I) = -CFCTR*FREAL(I)
      RETURN
      END


C                        INTERPOLATION
      SUBROUTINE TERPOL(N,L,Y,X,ANSR)
      DIMENSION Y(3,10,10),ANSR(10)
      DO 10 I=1,N
      A=Y(2,L,I)
      B=(Y(3,L,I)-Y(1,L,I))/0.16
      C=(Y(1,L,I)+Y(3,L,I)-2.0*Y(2,L,I))/0.0128
      ANSR(I)=A+B*X+C*X**2
   10 CONTINUE
      RETURN
      END


C                         AGAIN INTERPOLATION
      SUBROUTINE AINTER(N,L,Y,X,YY)
      DIMENSION Y(3,10,10),YY(10,10)
      DO 10 I=1,N
      A=Y(2,L,I)
      B=(Y(3,L,I)-Y(1,L,I))/0.16
      C=(Y(1,L,I)+Y(3,L,I)-2.0*Y(2,L,I))/0.0128
      YY(L,I)=A+B*X+C*X**2
   10 CONTINUE
      RETURN
      END
```

```
C                         FORMATION OF MATRICES
      SUBROUTINE FOMATR(N,I,NCVS,CKP,CKM,FMP,FMM,FHP,FHM,ZETAP,ZETAM,YOG
     1OP,YOGOM,PPLUSR,PPLUSI,COLMR,COLMI,FLMPR,FLMPI)
      DIMENSION CKP(10,10),CKM(10,10),FMP(10,10),FMM(10,10),FHP(10,10),F
     1HM(10,10),ZETAP(10,10),ZETAM(10,10),YOGOP(10,10),YOGOM(10,10),PPLU
     2SR(20,20),PPLUSI(20,20),COLMR(20,20),COLMI(20,20),FLMPR(20,20),FLM
     3PI(20,20)
      L=0
      NN=2*N
      DO 1 K=1,NN,2
      J=1
      L=L+1
      PPLUSR(J,K)=CKP(L,I)*FMP(L,I)*FHP(L,I)*YOGOP(L,I)/(1.0+ZETAP(L,I))
      PPLUSR(J,K+1)=-CKM(L,I)*FMM(L,I)*FHM(L,I)*YOGOM(L,I)/(1.0-ZETAM(L,
     1I))
      PPLUSI(J,K)=0.0
      PPLUSI(J,K+1)=0.0
    1 CONTINUE
      L=0
      DO 2 J=1,NN,2
      K=1
      L=L+1
      COLMR(J,K)=CKP(L,I)*FMP(L,I)/(2.0*(1.0+ZETAP(L,I)))
      COLMR(J+1,K)=CKM(L,I)*FMM(L,I)/(2.0*(1.0-ZETAM(L,I)))
      COLMI(J,K)=0.0
      COLMI(J+1,K)=0.0
    2 CONTINUE
      DO 3 J=1,NN
      DO 3 K=1,NN
      L=1
      FLMPR(J,K)=COLMR(J,L)*PPLUSR(L,K)
      FLMPI(J,K)=COLMI(J,L)*PPLUSI(L,K)
    3 CONTINUE
      RETURN
      END
```

```
C                          FORMATION OF D MATRIX
      SUBROUTINE DMATRX(NCVSP1,N,I,BQPOS,BQMIN,BE,S,DR,DI,FIR,FII)
      DIMENSION BQPOS(10,10),BQMIN(10,10),BE(10),S(10),DR(20,20),DI(20,2
     10),FIR(20,20),FII(20,20)
      DO 1 J=1,N,2
      M=0
      DO 2 K=1,N,2
      M=M+1
      IF (J-K) 3,4,3
    3 DR(J,K)=0.0
      DI(J,K)=0.0
      DR(J+1,K)=0.0
      DI(J+1,K)=0.0
      DR(J,K+1)=0.0
      DI(J,K+1)=0.0
      DR(J+1,K+1)=0.0
      DI(J+1,K+1)=0.0
      FIR(J,K)=0.0
      FII(J,K)=0.0
      FIR(J+1,K)=0.0
      FII(J+1,K)=0.0
      FIR(J,K+1)=0.0
      FII(J,K+1)=0.0
      FIR(J+1,K+1)=0.0
      FII(J+1,K+1)=0.0
      GO TO 2
    4 SXP=SINF(BE(NCVSP1)*S(I))
      CXP=COSF(BE(NCVSP1)*S(I))
      SYP=SINF(BQPOS(M,NCVSP1)*S(I))
      CYP=COSF(BQPOS(M,NCVSP1)*S(I))
      SYM=SINF(BQMIN(M,NCVSP1)*S(I))
      CYM=COSF(BQMIN(M,NCVSP1)*S(I))
      DR(J,K)=SXP*SYP+CXP*CYP
      DI(J,K)=SYP*CXP-SXP*CYP
      DR(J+1,K+1)=CXP*CYM-SXP*SYM
   13 DI(J+1,K+1)=-(SXP*CYM+SYM*CXP)
      FIR(J,K)=1.0
      FII(J,K)=0.0
      FIR(J+1,K+1)=1.0
      FII(J+1,K+1)=0.0
    2 CONTINUE
    1 CONTINUE
      RETURN
      END
```

```
C               COMPLEX MATRIX MULTIPLICATION (UP TO 10X10)
C                                 AXB=C
C                           N = ROWS OF A AND C
C                           M = ROWS OF B AND COLUMNS OF A
C                           L = COLUMNS OF B AND C
      SUBROUTINE CMMP(AR,AI,N,M,BR,BI,L,CR,CI)
      DIMENSION AR(20,20),AI(20,20),BR(20,20),BI(20,20),CR(20,20),CI(20,
     120),D(20,20),E(20,20)
      CALL RMMP(AR,N,M,BR,L,D)
      CALL RMMP(AI,N,M,BI,L,E)
      DO 10 I=1,N
      DO 10 J=1,L
   10 CR(I,J)=D(I,J)-E(I,J)
      CALL RMMP(AI,N,M,BR,L,D)
      CALL RMMP(AR,N,M,BI,L,E)
      DO 20 I=1,N
      DO 20 J=1,L
   20 CI(I,J)=D(I,J)+E(I,J)
      RETURN
      END
```

```
C                      COMPLEX MATRIX SUBTRACTION
      SUBROUTINE CMSUBT(ZGGL,FI,NN,SUM)
      DIMENSION ZGGL(20,20),FI(20,20),SUM(20,20)
      DO 1 J=1,NN
      DO 1 K=1,NN
      SUM(J,K)=FI(J,K)-ZGGL(J,K)
    1 CONTINUE
      RETURN
      END
```

```
C                            REAL MATRIX MULTIPLICATION
      SUBROUTINE RMMP (A,N,M,B,L,C)
      DIMENSION A(20,20),B(20,20),C(20,20)
      DO 5 I=1,N
      DO 5 J=1,L
      C(I,J)=0.0
      DO 5 K=1,M
    5 C(I,J)=C(I,J)+A(I,K)*B(K,J)
      RETURN
      END
```

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