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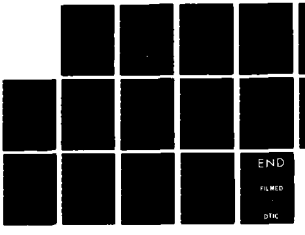

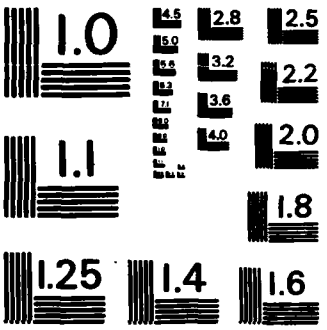

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A Circuit Analysis Program

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Experimental Plasma Physics Branch
Plasma Physics Division

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This memorandum describes two versions of a program for analyzing linear, passive electrical circuits. The first version is analytic and calculates steady state frequency response, while the second is numerical and calculates complete response to initial conditions and/or forcing functions. Both versions prompt the user to describe the circuit by specifying the number of nodes and the components which interconnect them. Any interconnection of resistors, capacitors and inductors is allowed. Both versions are presently written in IBM PC basic.

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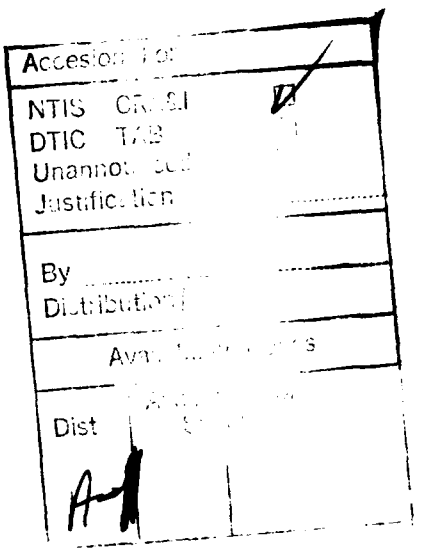

A CIRCUIT ANALYSIS PROGRAM

I. INTRODUCTION

This memorandum describes two versions of a program for analyzing linear, passive electrical circuits. The first version is analytic and calculates steady state frequency response while the second is numerical and calculates complete response to initial conditions and/or forcing functions. Both versions prompt the user to describe the circuit by specifying the number of nodes and the components which interconnect them. Any interconnection of resistors, capacitors and inductors is allowed. The steady state program, and the complete response program with a forcing function, are configured for two port circuits. A common ground is assumed.

The steady state version requires that the frequency range of interest be specified. In addition, the admittance of the driving source must be specified. In the complete response version the user must choose a time step appropriate to the problem being considered. The user is prompted to supply the necessary initial conditions and is offered a selection of forcing functions.

The programs are written in basic. The program list for the steady state version is given in Appendix 1 and that for the complete response version in Appendix 2. The programs are available, for the IBM PC, on $5\frac{1}{4}$" floppy disk.

II. THE STEADY STATE FREQUENCY RESPONSE PROGRAM

To use the program, the circuit nodes are numbered starting with number one at the input and proceeding to the highest number at the output. The ordering for the intermediate nodes is arbitrary and the ground node is not numbered. The program assumes that a sinusoidal current source is attached between node one and ground. The program sets the strength of this current source so as to combine with the specified shunt conductance to yield a unit voltage source (open circuit). The values of the circuit components are entered as admittances (i.e., as capacitance in farads, conductance in mhos, and inverse inductance in inverse Henrys). By this means the absence of any particular component is indicated by inputing the value zero. For example the absence of a resistor connecting two nodes is indicated by specifying zero conductance.

Manuscript approved September 17, 1985.

A lowest frequency (F1 in the program, here called f) is entered (in Hz and as a whole power of ten) together with the number of decades to be covered. The output node voltage and its phase relative to the input are then tabulated for the frequencies f, 2f, 5f, 10f, 20f, 50f, ...

An example of the use of the steady state program is given in Appendix 3. Some useful equivalencies are given in Appendix 5.

III. THEORY FOR THE STEADY STATE PROGRAM

In this program the variables are the node voltages. Conductance is symbolized by G, capacitance by C, and the inverse of inductance by B. Subscripts on these parameters indicate the nodes which the component interconnects. Thus G_{ij} represents a conductance between node i and node j. A repeated index is used to represent a connection between a node and ground. Thus G_{ii} is the conductance between node i and ground. If we sum the currents into each node, assume all variables to have a $e^{i\omega t}$ time dependancy, separate each voltage into its real and imaginary parts, and rearrange terms, there results a set of simultaneous equations as given by Equation 1. A current source of zero phase and strength I is assumed to be attached between node 1 and ground. In the program, lines 300 through 350 incorporate the "self" terms into the diagonal sub-matrices. Lines 490 through 720 accumulate the sums in the diagonal sub-matrices and, in addition, fill in the off diagonal sub-matrices. The restriction of the index J to values greater than I (line 370) is an economy permitted by the identity of elements with interchanged indices, i.e., $G_{12} = G_{21}$ etc.

The frequencies for which these equations are to be solved are established by lines 880 through 960. In the subroutine represented by lines 980 through 1380 the C, G, and B matrices are summed for each frequency (line 1010) the resulting simultaneous equations solved using a Gauss-Jordan elimination method (lines 1080 through 1280) and the phase and amplitude at the output node calculated (lines 1290 through 1350).

$$\omega^2 \begin{bmatrix} \varepsilon C_{1k} & 0 & -C_{12} & 0 & \cdots \\ 0 & \varepsilon C_{1k} & 0 & -C_{12} & \\ -C_{21} & 0 & \varepsilon C_{2k} & 0 & \\ 0 & -C_{21} & 0 & \varepsilon C_{2k} & \\ \vdots & & \vdots & & \ddots \end{bmatrix} \begin{bmatrix} V_{1r} \\ V_{1i} \\ V_{2r} \\ V_{2i} \\ \vdots \end{bmatrix} + \omega \begin{bmatrix} 0 & \varepsilon G_{1k} & 0 & -G_{12} & \cdots \\ -\varepsilon G_{1k} & 0 & G_{12} & 0 & \\ 0 & -G_{21} & 0 & \varepsilon G_{2k} & \\ G_{21} & 0 & -\varepsilon G_{2k} & 0 & \\ \vdots & & \vdots & & \ddots \end{bmatrix} \begin{bmatrix} V_{1r} \\ V_{1i} \\ V_{2r} \\ V_{2i} \\ \vdots \end{bmatrix} + \begin{bmatrix} -\varepsilon B_{1k} & 0 & B_{12} & 0 & \cdots \\ 0 & -\varepsilon B_{1k} & 0 & B_{12} & \\ B_{21} & 0 & -\varepsilon B_{2k} & 0 & \\ 0 & B_{21} & 0 & -\varepsilon B_{2k} & \\ \vdots & & \vdots & & \ddots \end{bmatrix} \begin{bmatrix} V_{1r} \\ V_{1i} \\ V_{2r} \\ V_{2i} \\ \vdots \end{bmatrix} + [1] \begin{bmatrix} 0 \\ \omega I \\ 0 \\ 0 \\ \vdots \end{bmatrix} = 0 \qquad (1)$$

IV. THE COMPLETE RESPONSE PROGRAM

The circuit description is entered in this program in the same manner as in the steady state program. That is, by specifying the number of nodes and the components interconnecting them. When a forcing function is specified, it is assumed to be attached between node one and ground. The output is the highest number node. A time step and number of steps appropriate to the problem under consideration must be entered. The time step must be small compared to the time associated with any oscillation or decay within the circuit.

An example of the use of the complete response program is given in Appendix 4.

V. THEORY FOR THE COMPLETE RESPONSE PROGRAM

By summing the currents into each node and re-arranging terms we obtain an equation for each node of the form,

$$\frac{\partial V(I,\alpha)}{\partial t} \sum_{J=1}^{n} C(I,J) + V(I,\alpha) \sum_{J=1}^{n} G(I,J) + \left(\int_{o}^{t} V(I,\alpha)dt \right) \sum_{J=1}^{n} B(I,J)$$

$$- \sum_{J \neq I} \frac{\partial V(J,\alpha)}{\partial t} C(I,J) - \sum_{J \neq I} V(J,\alpha)\, G(I,J) - \sum_{J \neq I} \left(\int_{o}^{t} V(J,\alpha)dt \right) B(I,J) + IIO(I)$$

$$= I(I) \qquad (2)$$

where:

$V(I,\alpha)$ = voltage at node I for either the present or the next step

$C(I,J)$ = capacitance connecting node I to node J

$G(I,J)$ = conductance connecting node I to node J

$B(I,J)$ = inverse inductance connecting node I to node J

$I(I)$ = current sources attached between node I and ground

$$IIO(I) = \left(\int_{-\infty}^{o} V(I,\alpha)dt \right) \sum_{J=1}^{n} B(I,J) - \sum_{J \neq I} \left(\int_{-\infty}^{o} V(J,\alpha)dt \right) B(I,J)$$

and "self" terms (e.g., C(I,I)) represent connections to ground. In the program the following additional variables are employed:

$$D(I,\alpha) = \frac{\partial V(I,\alpha)}{\partial t}$$

$$S(I,\alpha) = \int_0^t V(I,\alpha)dt$$

$$C(I) = \sum_{J=1}^{N} C(I,J)$$

$$G(I) = \sum_{J=1}^{N} G(I,J)$$

$$B(I) = \sum_{J=1}^{n} B(I,J)$$

$$DS(I) = \sum_{J\neq I} D(J,\alpha)\ C(I,J)$$

$$VS(I) = \sum_{J\neq I} V(J,\alpha)\ \ G(I,J)$$

$$SS(I) = \sum_{J\neq I} S(J,\alpha)\ B(I,J)$$

A second index, $\alpha = 1$ or 2, has been added to the voltage to indicate either the present time step or the next time step forwards. This has been done so that the equations can be integrated using a variation of a second order Runge-Kutta method.

Lines 320 through 860 assemble the description of the circuit (i.e., evaluate C(I,J), G(I,J) and B(I,J) for all I and J) and establish the initial conditions (evaluate V(I,1) and II0(I)).

The introduction of forcing functions is accomplished through lines 870 through 1110. When an abrupt change is made in the current I(I) entering a node, several steps of simple (Eulerian) integration will re-establish self-consistant values of the various derivatives. The second order Runge-Kutta does not absorb large inconsistancies and progress stably. Therefore the calculation starts with several steps of Eulerian integration using a very small time step (subroutine 1880).

The use of Equation 2 to construct an algorithm is most clearly seen in subroutine 1880. For any given node not all the terms in Equation 2 may be present. This occurs when some types of components are absent. (e.g., for a node having no capacitve connection, (C(I) = 0). Lines 1980 and 2030 select the appropriate form of Equation 2 to give the highest voltage derivative necessary for each node. It is then possible to perform the Eulerian integration to move forwards in time. Note that for a node joining only inductors, that no integration is necessary because only $S(I,\alpha)$ needs to be known and this is found algebraically from Equation 2 (line 2070). Similarly only a single integration (line 2050) is necessary for a node without capacitors because only $V(I,\alpha)$ and $S(I,\alpha)$ need to be known.

The main algorithm is contained in subroutine 1220. An initial integration is performed in lines 1230 through 1300. A first estimate of the necessary derivatives at the next time step is made in lines 1310 through 1480. This estimate is made using those updated values which the initial integration made available. The integration is then repeated in lines 1480 through 1550 using the average of tne derivatives at the present and next time steps. In lines 1560 through 1720 the estimate of the derivatives at the next time step is refined by using the improved, updated values. A last repetition of the integration is performed in lines 1730 through 1800.

VI. CONCLUSION

The author finds great utility in having a program that establishes and simplifies the simultaneous equations for arbitrary circuit configurations. To write these equations by hand, for each specific case, has always been a tedious and error prone process.

Among the problems to which the program has been applied are, the design of the fast passive integrator (NRL MR 4939), the design of a pulse forming capacitor bank, a lumped parameter modeling of the field problem for an e-beam in an air filled drift tube, the analysis of several electro-accoustic systems and the verification of several 5-pole Butterworth filter designs. All of these problems involve circuits of ≤ 10 nodes for which an analysis by hand would be prohibitively long yet the analysis using a desk top computer requires only a few minutes.

VII. ACKNOWLEDGMENT

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APPENDIX 1

```
10 REM Steady State Program
20 REM This program is configured for a two port circuit. Nodes are numbered
     from the input which is number one, to the output which is number N.
30 REM The ground is not numbered. A Source of one volt (open circuit) and of
     the specified admittance is assumed to be attached to node one.
40 REM Resistance is in Ohms; capacitance in Farads; inductance in Henries;
     frequency in Hertz; and the output amplitude is in Volts.
50 LPRINT TAB(5)"Steady state circuit analysis program, version 1"
60 LPRINT TAB(5) DATE$
70 LPRINT
80 INPUT "no. of nodes ?";N
90 N1=2*N
100 N2=N1+1
110 N3=N1-1
120 N4=N1+2
130 LPRINT TAB(5)"Steady state analysis for a circuit with ";N; "nodes"
140 LPRINT
150 DIM G(N4,N4)
160 DIM C(N4,N4)
170 DIM B(N4,N4)
180 DIM A(N4,N4)
190 FOR I=1 TO N
200 PRINT "1/R,C,1/L ? node ";I; "to gnd"
210 INPUT G
220 INPUT C
230 INPUT B
240 LPRINT TAB(5)"Node ";I;" has 1/R to ground of ";G
250 LPRINT TAB(3)"                C   to ground of ";C
260 LPRINT TAB(3)"                1/L to ground of ";B
270 LPRINT
280 L=2*I-1
290 P=L+1
300 C(L,L)=C(L,L)+C
310 B(L,L)=B(L,L)-B
320 C(P,P)=C(P,P)+C
330 B(P,P)=B(P,P)-B
340 G(L,P)=G(L,P)+G
350 G(P,L)=G(P,L)-G
360 IF I=N THEN GOTO 750
370 FOR J=I+1 TO N
380 M=2*J-1
390 Q=M+1
400 PRINT "1/R,C,1/L ? node ";I;"to node ";J
410 INPUT G
420 INPUT C
430 INPUT B
440 LPRINT TAB(5)"From node ";I;" to node ";J
450 LPRINT TAB(5)"           1/R = ";G
460 LPRINT TAB(5)"           C   = ";C
470 LPRINT TAB(5)"           1/L = ";B
480 LPRINT
490 C(L,M)=-C
500 B(L,M)=B
```

```
510 C(P,Q)=-C
520 B(P,Q)=B
530 C(M,L)=-C
540 B(M,L)=B
550 C(Q,P)=-C
560 B(Q,P)=B
570 G(L,Q)=-G
580 G(P,M)=G
590 G(Q,L)=G
600 G(M,P)=-G
610 C(L,L)=C(L,L)+C
620 B(L,L)=B(L,L)-B
630 C(M,M)=C(M,M)+C
640 B(M,M)=B(M,M)-B
650 C(P,P)=C(P,P)+C
660 B(P,P)=B(P,P)-B
670 C(Q,Q)=C(Q,Q)+C
680 B(Q,Q)=B(Q,Q)-B
690 G(L,P)=G(L,P)+G
700 G(P,L)=G(P,L)-G
710 G(M,Q)=G(M,Q)+G
720 G(Q,M)=G(Q,M)-G
730 NEXT J
740 NEXT I
750 PRINT "Source admittance ?"
760 INPUT IC
770 LPRINT TAB(5)"Source admittance = ";IC
780 G(1,2)=G(1,2)+IC
790 G(2,1)=G(2,1)-IC
800 PRINT "Low frequency, no. of decades ?"
810 INPUT F1
820 INPUT D
830 LPRINT USING "    Lowest frequency considered #.###^^^^";F1
840 LPRINT TAB(5)"No. of decades considered ";D
850 LPRINT
860 PRINT TAB(1)"Freq.";TAB(12)"Phase";TAB(25)"Ampl."
870 LPRINT TAB(5)"Freq.";TAB(16)"Phase";TAB(25)"Ampl."
880 FOR K=0 TO D-1
890 F=F1*10^K
900 FOR L=1 TO 2
910 W=6.283185*L*F
920 GOSUB 980
930 NEXT L
940 W=31.415927#*F
950 GOSUB 980
960 NEXT K
970 GOTO 1390
980 FOR I=1 TO N1
990 FOR J=1 TO N1
1000 A(I,J)=0
1010 A(I,J)=W*W*C(I,J)+W*G(I,J)+B(I,J)
1020 NEXT J
1030 NEXT I
1040 FOR I=1 TO N1
```

```
1050 A(I,N2 =0
1060 NEXT I
1070 A(2,N2)=-IC*W
1080 FOR J=1 TO N1
1090 FOR I=J TO N1
1100 IF A(I,J)<>0 THEN GOTO 1120
1110 NEXT I
1120 FOR M=1 TO N2
1130 X=A(J,M)
1140 A(J,M)=A(I,M)
1150 A(I,M)=X
1160 NEXT M
1170 Y=1/A(J,J)
1180 FOR M=1 TO N2
1190 A(J,M)=Y*A(J,M)
1200 NEXT M
1210 FOR I=1 TO N1
1220 IF I=J THEN GOTO 1270
1230 Y=-A(I,J)
1240 FOR M=1 TO N2
1250 A(I,M)=A(I,M)+Y*A(J,M)
1260 NEXT M
1270 NEXT I
1280 NEXT J
1290 V=SQR(A(N3,N2)*A(N3,N2)+A(N1,N2)*A(N1,N2))
1300 P=57.3*ATN(A(N1,N2)/A(N3,N2))
1310 IF A(N3,N2)>0 THEN GOTO 1360
1320 IF A(N1,N2)>0 THEN GOTO 1350
1330 P=P-180
1340 GOTO 1360
1350 P=P+180
1360 PRINT USING "##.##^^^^    +###     ##.##^^^^ ";W/6.283185,INT(P+.5),V
1370 LPRINT USING "     ##.##^^^^    +###     ##.##^^^^ ";W/6.283185,INT(P+.5),V
1380 RETURN
1390 END
```

APPENDIX 2

```
10 REM Complete Response Program
20 REM Nodes are numbered from the input which is number to the output which is
     number N. The ground is not numbered.
30 REM Resistance is in Ohms; capacitance in Farads; inductance in Henries; time
     in seconds; and the output in Volts.
40 LPRINT TAB(5) "Complete responce circuit analysis program, version 1"
50 LPRINT TAB(5) DATE$
60 LPRINT
70 PRINT "No. of nodes"
80 INPUT N
90 LPRINT TAB(5)"Complete responce analysis for a circuit with ";N; " nodes."
100 LPRINT
110 PRINT "Time step"
120 INPUT TS
130 PRINT "No. of steps"
140 INPUT M
150 LPRINT TAB(5)"time step = ";TS; " , number of steps = ";M
160 LPRINT
170 DIM I(N)
180 DIM D(N,2)
190 DIM V(N,2)
200 DIM S(N,2)
210 DIM IO(N,N)
220 DIM C(N,N)
230 DIM G(N,N)
240 DIM B(N,N)
250 DIM CC(N)
260 DIM GG(N)
270 DIM BB(N)
280 DIM DS(N)
290 DIM VS(N)
300 DIM SS(N)
310 DIM IIO(N)
320 FOR I=1 TO N
330 PRINT "1/R,C,1/L from node ";I;" to Gnd."
340 INPUT G
350 INPUT C
360 INPUT B
370 LPRINT TAB(5)"node ";I; "has 1/R to ground of ";G
380 LPRINT TAB(5)"                C to ground of ";C
390 LPRINT TAB(5)"                1/L to ground of ";B
400 LPRINT
410 G(I,I)=G
420 C(I,I)=C
430 B(I,I)=B
440 IF B=0 THEN GOTO 490
450 PRINT"Initial current into node";I;"via the inductor to gnd."
460 INPUT IO(I,I)
470 LPRINT TAB(5)"Initial current into node ";I; "via the inductor to gnd. is ";
IO(I,I); " amps."
480 LPRINT
490 IF I=N THEN GOTO 740
500 FOR J=I+1 TO N
```

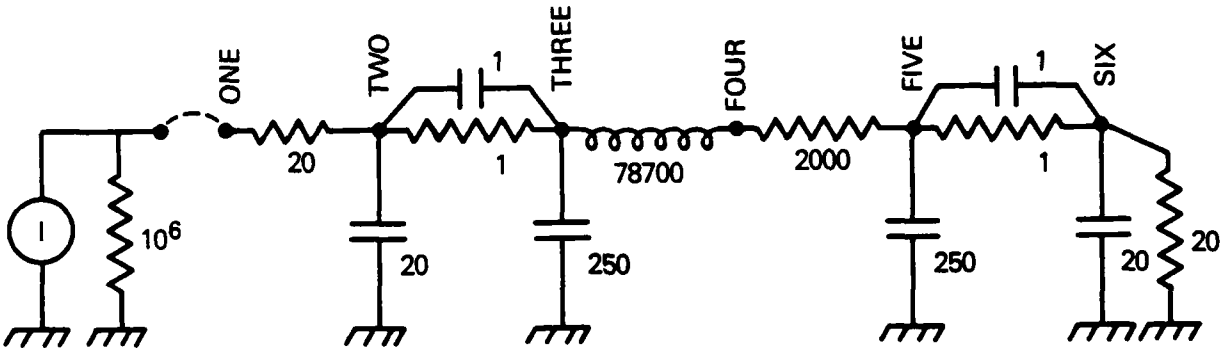
```
510 PRINT "1/R,C,1/L from node ";I;" to node ";J
520 INPUT G
530 INPUT C
540 INPUT B
550 LPRINT TAB(5)"From node ";I; " to node ";J
560 LPRINT TAB(5)"          1/R = ";G
570 LPRINT TAB(5)"          C   = ";C
580 LPRINT TAB(5)"          1/L = ";B
590 LPRINT
600 IF B=0 THEN GOTO 650
610 PRINT"Initial current into node";I;"via the inductor to node";J
620 INPUT IO(I,J)
630 LPRINT TAB(5)"Initial current into node ";I; " via the inductor to node ";J;
 " is ";IO(I,J); " amps."
640 LPRINT
650 G(I,J)=G
660 G(J,I)=G
670 C(I,J)=C
680 C(J,I)=C
690 B(I,J)=B
700 B(J,I)=B
710 IO(J,I)=-IO(I,J)
720 NEXT J
730 NEXT I
740 FOR I=1 TO N
750 FOR J=1 TO N
760 GG(I)=GG(I)+G(I,J)
770 CC(I)=CC(I)+C(I,J)
780 BB(I)=BB(I)+B(I,J)
790 IIO(I)=IIO(I)+IO(I,J)
800 NEXT J
810 IF CC(I)=0 THEN GOTO 860
820 PRINT "Initial voltage on node";I
830 INPUT V(I,1)
840 LPRINT TAB(5)"Initial voltage on node ";I; " is ";V(I,1); " volts."
850 LPRINT
860 NEXT I
870 PRINT"Input a choice of forcing function"
880 PRINT"0 = no forcing function"
890 PRINT"1 = unit impulse"
900 PRINT"2 = unit step"
910 INPUT F
920 LPRINT TAB(5)"The forcing function is type ";F
930 LPRINT
940 T=TS/10000
950 IF F=0 THEN GOTO 1110
960 PRINT"Source admittance"
970 INPUT A
980 LPRINT TAB(5)"Source admittance = ";A
990 LPRINT
1000 G(1,1)=G(1,1)+A
1010 GG(1)=GG(1)+A
1020 IF F=1 THEN GOTO 1060
1030 I(1)=A
```

```
1040 GOSUB 1880
1050 GOTO 1120
1060 I(1)=1000*A/TS
1070 GOSUB 1880
1080 I(1)=0
1090 GOSUB 1880
1100 GOTO 1120
1110 GOSUB 1880
1120 T=TS
1130 V(N,2)=V(N,1)
1140 LPRINT TAB(5)"Time                    Voltage"
1150 FOR L=0 TO INT(M/10)
1160 IF CC(N)=0 AND GG(N)=0 THEN V(N,2)=(S(N,2)-S(N,1))/T
1170 PRINT 10*L*T,V(N,2)
1180 LPRINT USING "    ##.##^^^^              ##.##^^^^ ";10*L*T,V(N,2)
1190 GOSUB 1220
1200 NEXT L
1210 END
1220 FOR K=0 TO 9
1230 FOR I=1 TO N
1240 IF CC(I)=0 THEN GOTO 1280
1250 V(I,2)=V(I,1)+D(I,1)*T
1260 S(I,2)=S(I,1)+V(I,1)*T
1270 GOTO 1300
1280 IF GG(I)=0 THEN GOTO 1300
1290 S(I,2)=S(I,1)+V(I,1)*T
1300 NEXT I
1310 FOR I=1 TO N
1320 DS(I)=-D(I,1)*C(I,I)
1330 VS(I)=-V(I,1)*G(I,I)
1340 SS(I)=-S(I,1)*B(I,I)
1350 FOR J=1 TO N
1360 DS(I)=DS(I)+D(J,1)*C(I,J)
1370 VS(I)=VS(I)+V(J,1)*G(I,J)
1380 SS(I)=SS(I)+S(J,1)*B(I,J)
1390 NEXT J
1400 IF CC(I)=0 THEN GOTO 1430
1410 D(I,2)=(DS(I)+VS(I)+SS(I)+I(I)+II0(I)-V(I,2)*GG(I)-S(I,2)*BB(I))/CC(I)
1420 GOTO 1470
1430 IF GG(I)=0 THEN GOTO 1460
1440 V(I,2)=(VS(I)+SS(I)+I(I)+II0(I)-S(I,2)*BB(I))/GG(I)
1450 GOTO 1470
1460 S(I,2)=(SS(I)+I(I)+II0(I))/BB(I)
1470 NEXT I
1480 FOR I=1 TO N
1490 IF CC(I)=0 THEN GOTO 1530
1500 S(I,2)=S(I,1)+T*(V(I,2)+V(I,1))/2
1510 V(I,2)=V(I,1)+T*(D(I,2)+D(I,1))/2
1520 GOTO 1550
1530 IF GG(I)=0 THEN GOTO 1550
1540 S(I,2)=S(I,1)+T*(V(I,2)+V(I,1))/2
1550 NEXT I
1560 FOR I=1 TO N
1570 DS(I)=-D(I,2)*C(I,I)
```

```
1580 VS(I)=-V(I,2)*G(I,I)
1590 SS(I)=-S(I,2)*B(I,I)
1600 FOR J=1 TO N
1610 DS(I)=DS(I)+D(J,2)*C(I,J)
1620 VS(I)=VS(I)+V(J,2)*G(I,J)
1630 SS(I)=SS(I)+S(J,2)*B(I,J)
1640 NEXT J
1650 IF CC(I)=0 THEN GOTO 1680
1660 D(I,2)=(DS(I)+VS(I)+SS(I)+I(I)+II0(I)-V(I,2)*GG(I)-S(I,2)*BB(I))/CC(I)
1670 GOTO 1720
1680 IF GG(I)=0 THEN GOTO 1710
1690 V(I,2)=(VS(I)+SS(I)+I(I)+II0(I)-S(I,2)*BB(I))/GG(I)
1700 GOTO 1720
1710 S(I,2)=(SS(I)+I(I)+II0(I))/BB(I)
1720 NEXT I
1730 FOR I=1 TO N
1740 IF CC(I)=0 THEN GOTO 1780
1750 S(I,2)=S(I,1)+T*(V(I,2)+V(I,1))/2
1760 V(I,2)=V(I,1)+T*(D(I,2)+D(I,1))/2
1770 GOTO 1800
1780 IF GG(I)=0 THEN GOTO 1800
1790 S(I,2)=S(I,1)+T*(V(I,2)+V(I,1))/2
1800 NEXT I
1810 FOR I=1 TO N
1820 D(I,1)=D(I,2)
1830 V(I,1)=V(I,2)
1840 S(I,1)=S(I,2)
1850 NEXT I
1860 NEXT K
1870 RETURN
1880 FOR K=0 TO 9
1890 FOR I=1 TO N
1900 DS(I)=-D(I,1)*C(I,I)
1910 VS(I)=-V(I,1)*G(I,I)
1920 SS(I)=-S(I,1)*B(I,I)
1930 FOR J=1 TO N
1940 DS(I)=DS(I)+D(J,1)*C(I,J)
1950 VS(I)=VS(I)+V(J,1)*G(I,J)
1960 SS(I)=SS(I)+S(J,1)*B(I,J)
1970 NEXT J
1980 IF CC(I)=0 THEN GOTO 2030
1990 D(I,1)=(DS(I)+VS(I)+SS(I)+I(I)+II0(I)-V(I,1)*GG(I)-S(I,1)*BB(I))/CC(I)
2000 V(I,1)=V(I,1)+D(I,1)*T
2010 S(I,1)=S(I,1)+V(I,1)*T
2020 GOTO 2080
2030 IF GG(I)=0 THEN GOTO 2070
2040 V(I,1)=(VS(I)+SS(I)+I(I)+II0(I)-S(I,1)*BB(I))/GG(I)
2050 S(I,1)=S(I,1)+V(I,1)*T
2060 GOTO 2080
2070 S(I,1)=(SS(I)+I(I)+II0(I))/BB(I)
2080 NEXT I
2090 NEXT K
2100 RETURN
```

APPENDIX 3

This appendix presents the results of a steady state analysis of the following circuit. All quantities are given as admittances. The node numbers are indicated and the source is also shown.



```
Steady state circuit analysis program, version 1
02-01-1985

Steady state analysis for a circuit with  6 nodes

Node  1  has 1/R to ground of  0
             C   to ground of  0
             1/L to ground of  0

From node  1  to node  2
          1/R =  20
          C   =  0
          1/L =  0

From node  1  to node  3
          1/R =  0
          C   =  0
          1/L =  0

From node  1  to node  4
          1/R =  0
          C   =  0
          1/L =  0

From node  1  to node  5
          1/R =  0
          C   =  0
          1/L =  0

From node  1  to node  6
          1/R =  0
          C   =  0
          1/L =  0

Node  2  has 1/R to ground of  0
             C   to ground of  20
             1/L to ground of  0

From node  2  to node  3
          1/R =  1
          C   =  1
          1/L =  0

From node  2  to node  4
          1/R =  0
          C   =  0
          1/L =  0

From node  2  to node  5
          1/R =  0
          C   =  0
          1/L =  0
```

```
From node  2  to node  6
          1/R =  0
          C   =  0
          1/L =  0

Node  3  has 1/R to ground of  0
             C   to ground of  250
             1/L to ground of  0

From node  3  to node  4
          1/R =  0
          C   =  0
          1/L =  78700

From node  3  to node  5
          1/R =  0
          C   =  0
          1/L =  0

From node  3  to node  6
          1/R =  0
          C   =  0
          1/L =  0

Node  4  has 1/R to ground of  0
             C   to ground of  0
             1/L to ground of  0

From node  4  to node  5
          1/R =  2000
          C   =  0
          1/L =  0

From node  4  to node  6
          1/R =  0
          C   =  0
          1/L =  0

Node  5  has 1/R to ground of  0
             C   to ground of  250
             1/L to ground of  0

From node  5  to node  6
          1/R =  1
          C   =  1
          1/L =  0

Node  6  has 1/R to ground of  20
             C   to ground of  20
             1/L to ground of  0

Source admittance =  1000000
Lowest frequency considered 0.100E-02
No. of decades considered  6
```

Freq.	Phase	Ampl.
1.00E-03	-65	9.83E-03
2.00E-03	-73	6.89E-03
5.00E-03	-83	2.89E-03
1.00E-02	-87	1.43E-03
2.00E-02	-89	7.18E-04
5.00E-02	-90	2.88E-04
1.00E-01	-92	1.44E-04
2.00E-01	-94	7.18E-05
5.00E-01	-101	2.86E-05
1.00E+00	-113	1.41E-05
2.00E+00	-136	6.61E-06
5.00E+00	+164	1.40E-06
1.00E+01	+127	2.18E-07
2.00E+01	+108	2.83E-08
5.00E+01	+97	1.83E-09
1.00E+02	+94	2.28E-10
2.00E+02	+92	2.86E-11
5.00E+02	+91	1.83E-12

APPENDIX 4

This appendix presents the results of a complete response analysis applied to the same circuit as in Appendix 3.

```
Complete response circuit analysis program, version 1
03-22-1985

Complete response analysis for a circuit with  6  nodes.

time step =  .001  , number of steps =  500

node  1 has 1/R to ground of  0
              C to ground of  0
              1/L to ground of  0

From node  1  to node  2
          1/R =  20
          C   =  0
          1/L =  0

From node  1  to node  3
          1/R =  0
          C   =  0
          1/L =  0

From node  1  to node  4
          1/R =  0
          C   =  0
          1/L =  0

From node  1  to node  5
          1/R =  0
          C   =  0
          1/L =  0

From node  1  to node  6
          1/R =  0
          C   =  0
          1/L =  0

node  2 has 1/R to ground of  0
              C to ground of  20
              1/L to ground of  0

From node  2  to node  3
          1/R =  1
          C   =  1
          1/L =  0

From node  2  to node  4
          1/R =  0
          C   =  0
          1/L =  0

From node  2  to node  5
          1/R =  0
          C   =  0
```

```
          1/L =  0

From node  2  to node  6
          1/R =  0
          C   =  0
          1/L =  0

node  3 has 1/R to ground of  0
               C to ground of  250
               1/L to ground of  0

From node  3  to node  4
          1/R =  0
          C   =  0
          1/L =  78700

Initial current into node  3  via the inductor to node  4  is  0  amps.

From node  3  to node  5
          1/R =  0
          C   =  0
          1/L =  0

From node  3  to node  6
          1/R =  0
          C   =  0
          1/L =  0

node  4 has 1/R to ground of  0
               C to ground of  0
               1/L to ground of  0

From node  4  to node  5
          1/R =  2000
          C   =  0
          1/L =  0

From node  4  to node  6
          1/R =  0
          C   =  0
          1/L =  0

node  5 has 1/R to ground of  0
               C to ground of  250
               1/L to ground of  0

From node  5  to node  6
          1/R =  1
          C   =  1
          1/L =  0

node  6 has 1/R to ground of  20
               C to ground of  20
               1/L to ground of  0
```

Initial voltage on node 2 is 0 volts.

Initial voltage on node 3 is 0 volts.

Initial voltage on node 5 is 0 volts.

Initial voltage on node 6 is 0 volts.

The forcing function is type 1

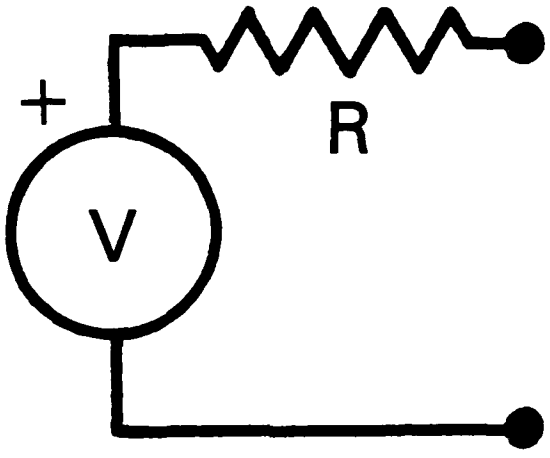
Source admittance = 1000000

Time	Voltage
0.00E+00	7.48E-14
1.00E-02	2.49E-06
2.00E-02	8.71E-06
3.00E-02	1.71E-05
4.00E-02	2.66E-05
5.00E-02	3.62E-05
6.00E-02	4.55E-05
7.00E-02	5.41E-05
8.00E-02	6.18E-05
9.00E-02	6.84E-05
1.00E-01	7.40E-05
1.10E-01	7.87E-05
1.20E-01	8.24E-05
1.30E-01	8.53E-05
1.40E-01	8.75E-05
1.50E-01	8.92E-05
1.60E-01	9.03E-05
1.70E-01	9.11E-05
1.80E-01	9.16E-05
1.90E-01	9.19E-05
2.00E-01	9.19E-05
2.10E-01	9.19E-05
2.20E-01	9.18E-05
2.30E-01	9.17E-05
2.40E-01	9.15E-05
2.50E-01	9.13E-05
2.60E-01	9.11E-05
2.70E-01	9.10E-05
2.80E-01	9.08E-05
2.90E-01	9.07E-05
3.00E-01	9.06E-05
3.10E-01	9.05E-05
3.20E-01	9.04E-05
3.30E-01	9.03E-05
3.40E-01	9.03E-05
3.50E-01	9.03E-05
3.60E-01	9.02E-05
3.70E-01	9.02E-05
3.80E-01	9.02E-05
3.90E-01	9.02E-05

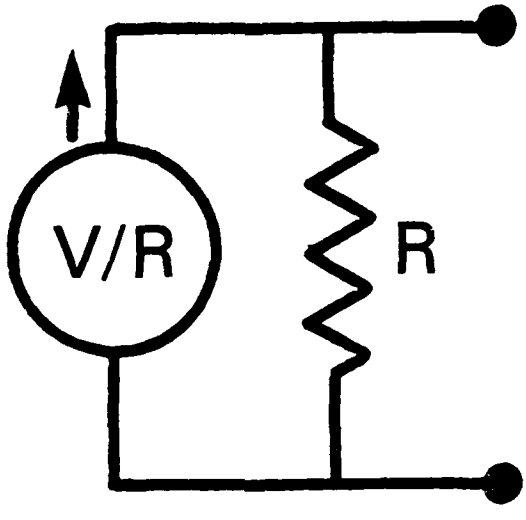
4.00E-01	9.02E-05
4.10E-01	9.02E-05
4.20E-01	9.02E-05
4.30E-01	9.02E-05
4.40E-01	9.02E-05
4.50E-01	9.02E-05
4.60E-01	9.02E-05
4.70E-01	9.02E-05
4.80E-01	9.02E-05
4.90E-01	9.02E-05
5.00E-01	9.02E-05

APPENDIX 5

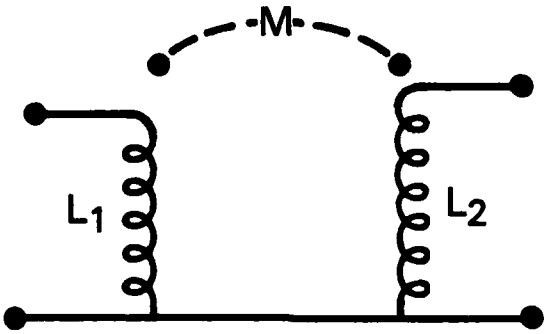
The following equivalencies may be useful in applying the program. In this Appendix we use impedances (in Ohms and Henries). The conversion from a Thevenin to a Norton Source is,



to,



Three equivalents for a transformer are,



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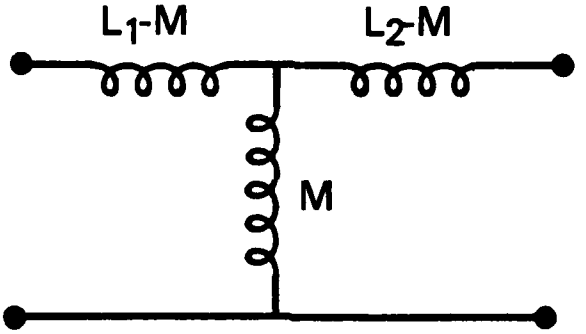
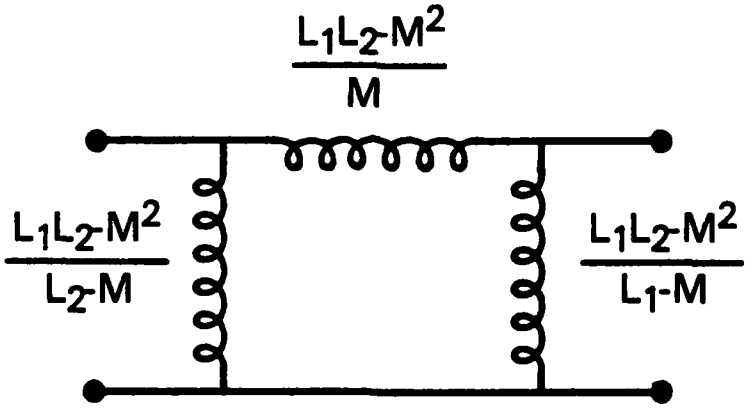


and



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