NATIONAL RADIO ASTRONOMY OBSERVATORY

ELECTRONICS DIVISION TECHNICAL NOTE NO. 96

TITLE: LADDER ANALYSIS PROGRAM

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NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

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To: Green Bank Electronics Division

From: Roger Norrod

Subj: LADDER Analysis Program

Introduction:

An APPLE computer system is now available at Green Bank for use by the Electronics Division. The purpose of this memo is to acquaint potential users with a program available on disk. The LADDER program was written by Sandy Weinreb and calculates the input impedance of a network. Results can be displayed in table form or plotted on a Smith chart. The program consists of a group of subroutines which perform various functions. The user writes a series of BASIC language statements describing his network and calling the proper subroutines.

To use the program, first insure that a disk marked NRAO LIBRARY 1.Ø is in the disk drive. Then type RUN LADDER and return. After a few seconds a "menu" will be displayed (Figure 1). Just follow instructions on the menu to execute the program. Table 1 describes the functioning of the menu subprograms.

To describe his network, the user writes a BASIC language program in lines 1ØØ to 998. Table 2 lists subroutines the user can call from within his program, and Table 3 gives a partial list of variables with special meaning to LADDER. To insert his own program into LADDER, the user should type LOAD LADDER, and then DEL 1ØØ,998 to eliminate any old programs. He then types in his own program and SAVE LADDER to store his version on disk.

Example 1:

Figure 2 is a listing of a program used to analyze a three-pole bandpass filter. For those not familiar with Applesoft BASIC, anything following REM (for remark) is ignored by the computer and colons are used to string statements together. Lines 140 through 210 are executed for each frequency defined in line 130. Line 150 initializes RN and XN to the terminating impedance, in this case 75 ohms. Line 160 defines the first filter element, a 2258 pF capacitor in parallel, and calls subroutine 1300. This subroutine converts RN and XN to admittance, combines it with the admittance of the capacitor, converts this total admittance to an impedance, and stores it in RN and XN. Lines 170 through 200 add elements until RN and XN have the input impedance of the total network. Line 210 calculates the resulting reflection coefficient, prints it on the screen and plots it on a Smith chart overlay. Line 220 loops the program back for the next frequency. When all frequency points have been completed, line 999 sends the computer back to wait for the

user to select another menu item. Figure 3 shows the printout caused by selecting menu items (T) and (P) after running the above program. The program takes about three seconds per frequency.

Example 2:

A program written to analyze a coaxial bandpass filter with design cutoff frequency of 10 GHz is listed in Figure 4. Subroutine 1400 is used to rotate impedances through transmission lines. Figure 5 shows the printout for this program. About five seconds were required for each frequency.

Program Listing:

A complete listing of LADDER is included with this memo. Table 4 lists some subroutines used by LADDER internally. These would normally not be called by the user program but are available if needed.

Housekeeping:

Manuals describing the use of the APPLE system are normally kept on the rack housing the computer. A three-ring binder labeled ADIOS #4 has much useful information. I will be glad to assist anyone interested in getting started.

Anyone using LADDER much would probably be wise to have their own disk so that other users don't erase their program. We have several blank disks and copying the NRAO LIBRARY 1.0 disk takes only a few minutes.

Future Expansions:

I hope to add a subroutine in the near future that will calculate the fringing capacitance of a stepped coaxial line. Anyone else who has a suggestion for a useful subroutine, let me know so that it can be made available to all users.

RDN/cjd

Enclosures:

1. Table 1 - LADDER Subprograms Accessed thru Menu
2. Table 2 - LADDER User Subroutines
3. Table 3 - LADDER Variables
4. Table 4 - LADDER Subroutines used by LADDER
5. Figure 1 - Menu Displayed by LADDER
6. Figure 2 - Analysis of Lumped Element Bandpass Filter
7. Figure 3 - Printout for Lumped Element Bandpass Filter
8. Figure 4 - Analysis of Coaxial Lowpass Filter
9. Figure 5 - Printout for Coaxial Lowpass Filter
10. Program Listing

TABLE 1

LADDER SUBPROGRAMS ACCESSED THRU MENU

Menu Item	Line No.	Function	Returns to
H	74	Clears screen.	End
L	42ØØ	Prints list of lines 1ØØ-999.	Menu
R	84	Executes user program.	Menu
S	5Ø14	Loads fresh Smith chart.	Menu
T	93ØØ	Displays table of calculated data with hard copy option.	Menu
U	5ØØØ	Loads utilities (Smith chart and HGR shapes).	Menu
P	65ØØ	Prints copy of graphics table.	Menu

TABLE 2

LADDER USER SUBROUTINES

Line No.	Function	Inputs	Outputs
1ØØØ	Admittance of Series R, L, C	R, L, C, W	G, B
1Ø1Ø	Impedance to Admittance	RE, X	G, B
11ØØ	Impedance of Parallel R, L, C	R, L, C, W	RE, X
111Ø	Admittance to Impedance	G, B	RE, X
12ØØ	Series Branch, Series R, L, C	R, L, C, W, RN, XN	RN, XN (new)
13ØØ	Shunt Branch, Series R, L, C	R, L, C, W, RN, XN	Rn, XN (new)
14ØØ	Series Xmission Line	W, LE, ZØ, RN, XN	RN, XN (new)
15ØØ	ZN to Γ = SR + j SI	RN, XN, RØ	SR, SI
16ØØ	Γ to ZN = RN + j XN	SR, SI, RØ	RN, XN
2ØØØ	Complex Multiply: C = A * B	AR, AI, BR, BI	CR, CI
21ØØ	Complex Reciprocal: C = 1/B	BR, BI	CR, CI
22ØØ	Complex Divide: C = A/B	AR, AI, BR, BI	CR, CI
8ØØØ	Smith Chart Plot	SR, SI	---
9ØØØ	Maxes Table on CRT and Stores F, RN, XN, SR, SI, SWR	F, RN, XN	SR, SI

TABLE 3

LADDER VARIABLES
(Partial List)

Variable	Description
R	Resistance of Circuit Branch, Ohms
L	Inductance of Circuit Branch, nH
C	Capacitance of Circuit Branch, pF
W	Radian Frequency, 2π * GHz
RE	Real Part of Impedance
X	Imaginary Part of Impedance
G	Real Part of Admittance
B	Imaginary Part of Admittance
RN	Real Part of Circuit Input Impedance
XN	Imaginary Part of Circuit Input Impedance
SR	Real Part of Reflection Coefficient
SI	Imaginary Part of Reflection Coefficient
ZØ	Characteristic Impedance of Transmission Line
LN	Length of Transmission Line, mils
AR, BR, CR	Real Part of Complex Number A, B, or C
AI, BI, CI	Imaginary Part of Complex Number A, B, or C
TP	2π, defined by LADDER for user

TABLE 4

LADDER SUBROUTINES USED BY LADDER

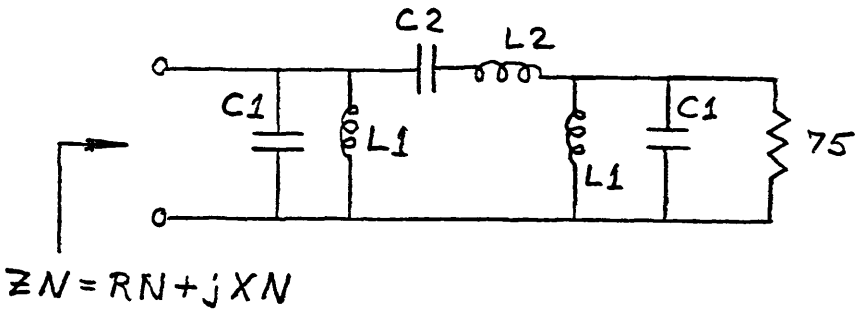
Line No.	Function	Called By
53ØØ	Turns on Printer	92ØØ, 42ØØ
91ØØ	Stores Data in Arrays	9ØØØ
92ØØ	Prints Table of Calculated Data	93ØØ

```
                LADDER
        NETWORK ANALYSIS PROGRAM
          NRAO--APRIL 1, 1981
NORMAL UNITS ARE GHZ,MILS,NH, AND PF
UTILITIES SHOULD BE LOADED AT START OF  EACH SESSION.
TYPE (H) TO HALT
     (L) TO LIST MAIN PROGRAM
     (R) TO RUN ANALYSIS
     (S) TO LOAD FRESH SMITH CHART
     (T) TO MAKE HARD COPY OF DATA
     (U) TO LOAD UTILITIES FROM DISK
     (P) TO PRINT GRAPHIC TABLE

(H),(L),(R),(S),(T),(U),OR (P)?
```

FIGURE 1

MENU DISPLAYED BY LADDER




```
100  REM  LUMPED ELEMENT BPF
105  REM  75 OHM, 0.5DB CHEBYSCHEV, 3POLE,6.0-7.5 MHZ BANDPASS
110 R0 = 75: REM  DEFINE CENTER OF SMITH CHART
120 C1 = 2258:L1 = 249:C2 = 64.5:L2 = 8730: REM  DEFINE ELEMENT VALUES
130  FOR F = 5.5 TO 8.0 STEP 0.1
140 W = TP * F / 1000: REM  CONVERT MHZ TO GHZ
150 RN = 75:XN = 0: REM  TERMINATION=75 OHMS
160 R = 0:L = 0:C = C1: GOSUB 1300: REM  1ST SECTION
170 R = 0:L = L1:C = 0: GOSUB 1300: REM  1ST SECTION COMPLETED
180 R = 0:L = L2:C = C2: GOSUB 1200: REM  2ND SECTION
190 R = 0:L = L1:C = 0: GOSUB 1300: REM  3RD SECTION
200 R = 0:L = 0:C = C1: GOSUB 1300: REM  3RD SECTION COMPLETED
210  GOSUB 9000: GOSUB 8000: REM  STORE & PLOT INPUT IMPEDANCE
220  NEXT F
999  GOTO 72: REM        END ANALYSIS, GO TO PROMPT
```

FIGURE 2

ANALYSIS OF LUMPED ELEMENT BANDPASS FILTER

F	REAL Z	IMAG Z	/GAMMA/	ANGLE	VSWR
5.5	.6	33.2	.987	132.3	153.3
5.6	1.3	39.1	.974	124.9	76.3
5.7	3	48.1	.944	114.6	34.8
5.8	9	63.2	.869	99.3	14.28
5.9	35.1	87.2	.683	76.2	5.31
6	103.4	55.4	.333	45.6	2
6.1	70.8	-1.2	.03	-164	1.06
6.2	45.7	2.8	.244	173.1	1.65
6.3	39.4	12.1	.327	155.2	1.97
6.4	41.9	19.8	.325	139.5	1.96
6.5	51.2	24	.263	124	1.71
6.6	65.3	19.7	.155	108.1	1.37
6.7	74.8	3.1	.021	91.8	1.04
6.8	69.1	-15.6	.115	-104.4	1.26
6.9	55.6	-23.1	.228	-119.9	1.59
7	45.2	-21.3	.3	-134.5	1.86
7.1	40.4	-15.3	.325	-148.6	1.96
7.2	41.8	-7.7	.291	-163.2	1.82
7.3	51.9	0	.182	-179.9	1.44
7.4	79.1	-1.6	.028	-20.4	1.06
7.5	104.3	-53.9	.328	-44.8	1.97
7.6	49.3	-91.5	.616	-69.3	4.2
7.7	16.5	-73.9	.802	-89.4	9.09
7.8	6.5	-58.3	.898	-104	18.55
7.9	3	-48.2	.945	-114.5	35.09
8	1.6	-41.4	.968	-122.2	61.87

6.0-7.5 MHZ BPF

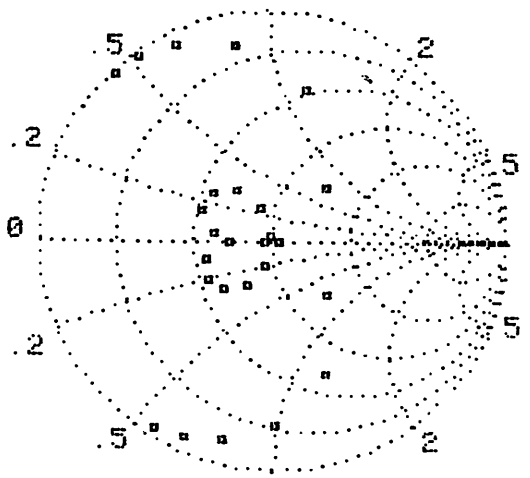


FIGURE 3

PRINTOUT FOR LUMPED ELEMENT BANDPASS FILTER

```
100  REM  SEVEN SECTION, CHEBYSCHEV, COAXIAL LPF.  0.1 DB RIPPLE.
110 R0 = 50: REM  DEFINE CENTER OF SMITH CHART
120  FOR F = 1.0 TO 15.0 STEP 1
130 W = TP * F:RN = 50.0:XN = 0.0: REM  TERMINATION = 50 OHMS
140 R = 0:L = 0:C = .02: GOSUB 1300: REM  FRINGE CAP
150 Z0 = 15:LN = 27: GOSUB 1400: REM   1ST SECTION
160 R = 0:L = 0:C = .04: GOSUB 1300: REM  FRINGE CAP
170 Z0 = 85:LN = 170: GOSUB 1400: REM   2ND SECTION
180 R = 0:L = 0:C = .04: GOSUB 1300: REM  FRINGE CAP
190 Z0 = 15:LN = 49: GOSUB 1400: REM   3RD SECTION
200 R = 0:L = 0:C = .04: GOSUB 1300: REM  FRINGE CAP
210 Z0 = 85:LN = 194: GOSUB 1400: REM   4TH SECTION
220 R = 0:L = 0:C = .04: GOSUB 1300: REM  FRINGE CAP
230 Z0 = 15:LN = 49: GOSUB 1400: REM   5TH SECTION
240 R = 0:L = 0:C = .04: GOSUB 1300: REM  FRINGE CAP
250 Z0 = 85:LN = 170: GOSUB 1400: REM   6TH SECTION
260 R = 0:L = 0:C = .04: GOSUB 1300: REM  FRINGE CAP
270 Z0 = 15:LN = 27: GOSUB 1400: REM   7TH SECTION
280 R = 0:L = 0:C = .02: GOSUB 1300: REM  FRINGE CAP
290  GOSUB 9000: GOSUB 8000: REM  PLOT POINT ON SMITH CHART
300  NEXT F
999  GOTO 72: REM        END ANALYSIS, GO TO PROMPT
```

FIGURE 4

ANALYSIS OF COAXIAL LOWPASS FILTER

F	REAL Z	IMAG Z	/GAMMA/	ANGLE	VSWR
1	49.7	-.5	6E-03	-119.6	1.01
2	50.2	.1	2E-03	30.8	1
3	53.2	.1	.031	.9	1.06
4	56.7	-4.1	.074	-29.2	1.16
5	54.9	-10.6	.111	-59.6	1.25
6	48.6	-11.5	.117	-90.3	1.26
7	46.1	-5.6	.071	-121.8	1.15
8	52.6	1.3	.028	25.2	1.06
9	66.4	-3.1	.143	-9.2	1.33
10	63.1	-17.9	.194	-44.9	1.48
11	50.1	-5.6	.056	-85.3	1.12
12	75	49.2	.411	41.6	2.4
13	269.7	-275.6	.835	-10.7	11.12
14	8	-126.4	.958	-43	46.35
15	1.2	-81.7	.987	-62.9	147.59

50 OHM LPF

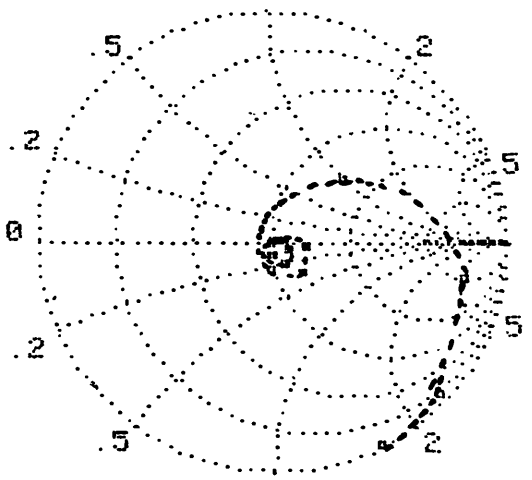


FIGURE 5

PRINTOUT FOR COAXIAL LOWPASS FILTER

PROGRAM LISTING

```
PROGRAM LENGTH= 8040 BYTES          VARIABLES= 35 BYTES
FREE MEMORY= 12404 BYTES
START=16385 LOMEM=24425 FREE=24460 STRING=36864 HIMEM=36864


10  REM              RLADDER VERSION 21MAY81


12  REM  MOVE PROGRAM TO HIGH MEMORY
14  PRINT  CHR$ (4);"BRUN LOMEM:": &  LOMEM: 16384
16  HIMEM: 36864
18  POKE 1013,76: POKE 1014,12: POKE 1015,151
20  POKE 1016,76: POKE 1017,0: POKE 1018,151
25  PRINT  CHR$ (4);"BRUN LOMEM:": &  LOMEM: 16384
30  TEXT : HOME :V = 2
32  VTAB V: HTAB 16: PRINT "LADDER"
33  VTAB V + 3: HTAB 8: PRINT "NETWORK ANALYSIS PROGRAM "
34  VTAB V + 6: HTAB 10: PRINT "NRAO--APRIL 1, 1981"
35  VTAB V + 10: PRINT "NORMAL UNITS ARE GHZ,MILS,NH, AND PF": PRINT
 "UTILITIES SHOULD BE LOADED AT START OF  EACH SESSION.": VTAB V +
 15: REM


38  REM  INITIALIZE CONSTANTS
40 D$ =  CHR$ (4): REM   D$=CTRL D
45 IN = 1E06: DIM FS(50),RS(50),XS(50),MS(50),AS(50),VS(50)
48  HCOLOR= 3: SCALE= 1: ROT= 0
50 TP = 6.28318:K1 = 11811:K2 = 57.2958: REM


58  REM  DEFINE ROUNDING FUNCTIONS
60  DEF  FN R1(X) =  INT (X * 10 + .5) / 10
61  DEF  FN R2(X) =  INT (X * 100 + .5) / 100
62  DEF  FN R3(X) =  INT (X * 1000 + .5) / 1000: REM


68  REM  DISPLAY MENU FOR USER
69  PRINT "TYPE (H) TO HALT": HTAB 6: PRINT "(L) TO LIST MAIN PROGRAM":
 HTAB 6: PRINT "(R) TO RUN ANALYSIS": HTAB 6: PRINT "(S) TO LOAD FRESH
 SMITH CHART"
70  HTAB 6: PRINT "(T) TO MAKE HARD COPY OF DATA "
71  HTAB 6: PRINT "(U) TO LOAD UTILITIES FROM DISK": HTAB 6: PRINT
 "(P) TO PRINT GRAPHIC TABLE"
72  PRINT "(H),(L),(R),(S),(T),(U),OR (P)?";: GET P$: PRINT  CHR$ (0):
 HOME
74  IF P$ = "H" THEN  TEXT : HOME : END
75  IF P$ = "L" THEN  GOTO 4200
76  IF P$ = "R" THEN  GOTO 84
78  IF P$ = "S" THEN  GOTO 5014
79  IF P$ = "T" THEN  GOTO 9300
80  IF P$ = "U" THEN  GOTO 5000
81  IF P$ = "P" THEN  GOTO 6500
82  GOTO 68: REM   DISPLAY MENU
84  REM  BEGIN ANALYSIS
90 IZ = 0
95 I =  PEEK (8125) + 1
96  POKE 8125,I: REM    CHANGE PLOT SHAPE
98  VTAB (21): REM
```

```
99  REM  BEGIN DEFINITION OF PROBLEM
100  REM  SEVEN SECTION, CHEBYSCHEV, COAXIAL LPF.  0.1 DB RIPPLE.
110 R0 = 50: REM  DEFINE CENTER OF SMITH CHART
120  FOR F = 1.0 TO 15.0 STEP 1
130 W = TP * F:RN = 50.0:XN = 0.0: REM  TERMINATION = 50 OHMS
150 Z0 = 15:LN = 27: GOSUB 1400: REM   1ST SECTION
170 Z0 = 85:LN = 170: GOSUB 1400: REM   2ND SECTION
190 Z0 = 15:LN = 49: GOSUB 1400: REM   3RD SECTION
210 Z0 = 85:LN = 194: GOSUB 1400: REM   4TH SECTION
230 Z0 = 15:LN = 49: GOSUB 1400: REM   5TH SECTION
250 Z0 = 85:LN = 170: GOSUB 1400: REM   6TH SECTION
270 Z0 = 15:LN = 27: GOSUB 1400: REM   7TH SECTION
290  GOSUB 9000: GOSUB 8000: REM  PLOT POINT ON SMITH CHART
300  NEXT F
999  GOTO 72: REM        END ANALYSIS, GO TO PROMPT


1000  REM  CONVERT IMPEDANCE TO ADMITTANCE
1001 X = L * W:RE = R
1005  IF C <  > 0 THEN X = X - 1000 / (C * W)
1010 D = RE ^ 2 + X ^ 2:G = RE / D:B =  - X / D: REM   INVERT Z=RE+JX
 TO Y=G+JB
1020  RETURN : REM


1100  REM  CONVERT ADMITTANCE TO IMPEDANCE
1101 G = 1 / R:B = C * W / 1000
1105  IF L <  > 0 THEN B = B - 1 / (L * W)
1110 D = G ^ 2 + B ^ 2:RE = G / D:X =  - B / D: REM   INVERT Y=G+JB
 TO Z=RE+JX
1120  RETURN : REM


1200  REM   SERIES ELEMENT: SERIES R,L,C
1201 X = L * W
1205  IF C <  > 0 THEN X = X - 1000 / (C * W)
1210 RN = R + RN:XN = X + XN
1220  RETURN : REM


1300  REM   SHUNT ELEMENT,SERIES R,L,C
1304 RE = R:X = L * W
1305  IF C <  > 0 THEN X = X - 1000 / (C * W)
1310  REM    SHUNT ELEMENT, RE+JX
1315  GOSUB 1010:G1 = G:B1 = B
1320 RE = RN:X = XN: GOSUB 1010
1330 G = G1 + G:B = B1 + B
1340  GOSUB 1110:RN = RE:XN = X
1350  RETURN : REM


1400  REM  SERIES TRANSMISSION LINE WITH CHARACTERISTIC IMPEDANCE Z0
1410 TN =  TAN (W * LN / K1)
1420 AR = RN:AI = XN + Z0 * TN
1430 BR = 1 - XN * TN / Z0:BI = RN * TN / Z0
1440  GOSUB 2200:RN = CR:XN = CI: REM   CALCULATE RN+J XN=(AR+J AI)/(BR+J
 BI)
1450  RETURN : REM


1500  REM   ZN TO GAMMA (REFLECTION COEFFICIENT SR+J SI); ASSUMES REAL
```

```
R0; DEFAULT R0=50   MS
1505  IF R0 = 0 THEN R0 = 50.0
1510 AR = RN - R0:AI = XN
1520 BR = RN + R0:BI = XN
1530  GOSUB 2200:SR = CR:SI = CI: REM  CALCULATE SR+J SI=(ZN-R0)/(ZN+R0)
1540  RETURN : REM


1600  REM  GAMMA TO ZN; ASSUMES REAL R0; DEFAULT R0=50 OHMS
1605  IF R0 = 0 THEN R0 = 50.0
1610 AR = R0(1 + SR):AI = R0 * SI
1620 BR = 1 - SR:BI =  - SI
1630  GOSUB 2200:RN = CR:XN = CI: REM  CALCULATE RN+J XN=R0(1+SR+J
 SI)/(1-SR-J SI)
1640  RETURN : REM

2000  REM  COMPLEX MULTIPLY C=A*B
2010 CR = AR * BR - AI * BI
2020 CI = AR * BI + AI * BR
2030  RETURN : REM



2100  REM  COMPLEX RECIPROCAL C=1/B
2110 AR = 1:AI = 0: REM


2200  REM    COMPLEX DIVIDE, C=A/B
2210 D = BR ^ 2 + BI ^ 2
2220 CR = (AR * BR + AI * BI) / D
2230 CI = (AI * BR - AR * BI) / D
2240  RETURN : REM


4200  REM  LIST MAIN PROGRAM
4210  TEXT : HOME : POKE 33,30: GOSUB 5300: REM   TURN PRINTER ON
4220  POKE 1913,6: REM  LEFT MARGIN
4240  LIST 100,999
4250  PRINT D$;"PR#0": REM  TURN PRINTER OFF
4260  POKE 33,40: HOME
4270  GOTO 68: REM   DISPLAY MENU


5000  REM  LOADS SHAPES,HGR CHARACTERS,AND SMITH CHART
5001 D$ =  CHR$ (4)
5003  PRINT D$;"BLOAD SHAPES"
5004  POKE 232,191: POKE 233,31
5010  PRINT D$;"BLOAD HGR CHR GEN"
5014  REM  LOAD SMITH CHART INTO GRAPHICS
5015  HGR
5020  PRINT D$;"BLOAD NUMB SMITH,A8192"
5025  POKE 8125,0: REM  PLOT SHAPE PARAMETER IS IN 8125
5030  TEXT : HOME
5040  SCALE= 1: ROT= 0: HCOLOR= 3
5090  GOTO 68: REM     DISPLAY MENU


5300  REM   TURNS ON TRENDCOM PRINTER
5305 D$ =  CHR$ (4): REM  D$=CTRL D
5307  PRINT  CHR$ (0)
5310  PRINT D$;"PR# 1": PRINT  CHR$ (0)
```

```
5320  POKE 1913,0: POKE 1785,70: REM     MARGINS
5330  POKE 1657,80: REM  LINE LENGTH
5340  RETURN : REM


6500  REM  DUMPS GRAPHICS TABLE TO THE PRINTER, NO ROTATION, NORMAL
 SIZE.
6510  POKE  - 16301,0: POKE  - 16300,0: POKE  - 16297,0: POKE  - 16304,0:
 REM  DISPLAY GRAPHICS TABLE
6520  VTAB 23: INPUT "LABEL?";LA$
6540  PRINT D$;"PR#1": PRINT  TAB( 8);LA$: PRINT D$;"PR#0": REM
 PRINT LABEL
6550  POKE 1784,15: POKE 1912,170: POKE 1272,0: POKE 1144,32: POKE
 1528,0: POKE 1400,1: POKE 1656,0: REM  SET PRINTER GRAPHICS TEMPORARIES
6560  CALL  - 16000: REM  CALL PRINTER SERVICE ROUTINE
6580  TEXT : HOME : GOTO 68: REM   DISPLAY MENU


8000  REM  SMITH PLOT
8002  ON I GOSUB 8006,8007,8008,8009
8003  GOTO 8010
8006 SH = 2: ROT= 0: SCALE= 1: RETURN
8007 SH = 2: ROT= 8: SCALE= 2: RETURN
8008 SH = 2: ROT= 0: SCALE= 2: RETURN
8009 SH = 2: ROT= 0: SCALE= 3: RETURN
8010  POKE  - 16304,0: POKE  - 16300,0
8011  POKE  - 16297,0: POKE  - 16301,0
8012  HCOLOR= 3
8020 RM = 79:XC = 140:YC = 80
8030 XP = XC + SR * RM
8040 YP = YC - SI * RM
8050  DRAW SH AT XP,YP
8060  RETURN : REM


8500  REM
8501  RETURN : REM


8510  CALL 25674: REM   INIT HGR CHR GEN
8520  PRINT  CHR$ (1); CHR$ (17)
8530  HCOLOR= 3
8535  DRAW SH AT 1,7 * I
8540  INPUT "COMMENT? ";CM$
8550  VTAB (I): HTAB (2): PRINT CM$
8560  CALL 1013: RETURN : REM


9000  REM  PRINT ON CRT
9005 FZ =  FN R2(F)
9010 RZ =  FN R1(RN)
9020 XZ =  FN R1(XN)
9022  GOSUB 1500
9024 SM =  SQR (SR ^ 2 + SI ^ 2)
9026 SA = K2 *  ATN (SI / SR)
9027  IF SR < 0 THEN SA = SA + 180
9028  IF SA > 180 THEN SA = SA - 360
9035  IF SM >  = 1 THEN SWR = IN
9040  IF SM < 1 THEN SWR = (1 + SM) / (1 - SM)
9045 SM =  FN R3(SM):SA =  FN R1(SA):SWR =  FN R2(SWR): REM   ROUND
 DATA FOR DISPLAY
```

```
9070  PRINT FZ; TAB( 8);RZ; TAB( 16);XZ; TAB( 24);SM; TAB( 32);SA
9080  GOSUB 9100: REM  STORE DATA IN ARRAYS
9090  RETURN : REM
9100  REM  STORES F, ZN, AND GAMMA IN ARRAYS
9110 IZ = IZ + 1
9120 FS(IZ) = FZ:RS(IZ) = RZ:XS(IZ) = XZ
9130 MS(IZ) = SM:AS(IZ) = SA:VS(IZ) = SWR
9140  RETURN : REM


9200  REM  PRINTS TABLE OF CALCULATED DATA
9201  HOME : GOSUB 5300: REM    TURN ON PRINTER
9203 I$ =  CHR$ (9): REM  I$=CTRL I
9205  PRINT I$;"N": REM  DISABLE VIDEO
9207  POKE 33,80: REM  SET APPLESOFT LINE LENGTH
9220  REM  PRINT HEADING
9230  PRINT  TAB( 8);"F"; TAB( 16);"REAL Z"; TAB( 24);"IMAG Z";
9240  PRINT  TAB( 32);"/GAMMA/"; TAB( 40);"ANGLE"; TAB( 48);"VSWR"
9245  FOR J = 1 TO 56: PRINT "-";: NEXT J
9250  PRINT ""
9255  REM  PRINT DATA
9260  FOR J = 1 TO IZ
9275  PRINT  TAB( 8);FS(J); TAB( 16);RS(J); TAB( 24);XS(J);
9280  PRINT  TAB( 32);MS(J); TAB( 40);AS(J); TAB( 48);VS(J)
9285  NEXT J
9290  PRINT D$;"PR#0": REM  TURN PRINTER OFF
9292  POKE 33,40: PRINT I$;"I": REM  RESTORE VIDEO
9295  TEXT : HOME : RETURN : REM


9300  REM  DISPLAYS VIDEO TABLE OF CALCULATED DATA
9302  IF IZ = 0 THEN  PRINT " ** NO TABLE **": PRINT "": GOTO 68
9305 J2% = 0: REM  INITIALIZE ARRAY COUNTER
9310  TEXT : HOME
9320  REM  PRINT HEADING
9330  PRINT "F"; TAB( 8);"REAL Z"; TAB( 16);"IMAG Z": PRINT ""
9340 J1% = 0: REM  INITIALIZE SCREEN COUNTER
9350 J1% = J1% + 1:J2% = J2% + 1: PRINT FS(J2%); TAB( 8);RS(J2%); TAB(
 16);XS(J2%): REM  PRINT LINE
9360  IF J2% = IZ THEN  GOTO 9400: REM  CHECK FOR END OF ARRAY
9370  IF J1% < 20 THEN  GOTO 9350: REM  CHECK FOR FULL SCREEN
9380  VTAB 23: PRINT "PRESS ANY KEY FOR REST OF TABLE";: GET P$: PRINT
  CHR$ (0)
9390  GOTO 9310: REM  PRINT REST OF ARRAY
9400 J2% = 0: REM  INITIALIZE ARRAY COUNTER
9405  VTAB 23: PRINT "PRESS ANY KEY FOR REST OF TABLE";: GET P$: PRINT
  CHR$ (0)
9410  TEXT : HOME
9420  REM  PRINT HEADING
9430  PRINT "F"; TAB( 8);"/GAMMA/"; TAB( 16);"ANGLE"; TAB( 24);"VSWR":
 PRINT ""
9440 J1% = 0: REM  INITIALIZE SCREEN COUNTER
9450 J1% = J1% + 1:J2% = J2% + 1
9455  PRINT FS(J2%); TAB( 8);MS(J2%); TAB( 16);AS(J2%); TAB( 24);VS(J2%):
 REM  PRINT LINE
9460  IF J2% = IZ THEN  GOTO 9500: REM  CHECK FOR END OF ARRAY
9470  IF J1% < 20 THEN  GOTO 9450: REM  CHECK FOR FULL SCREEN
9480  VTAB 23: PRINT "PRESS ANY KEY FOR REST OF TABLE";: GET P$: PRINT
  CHR$ (0)
9490  GOTO 9410: REM  PRINT REST OF TABLE
9500  VTAB 23: PRINT "HARD COPY?(Y/N)";
9510  GET P$: PRINT CHR(0)
9520  IF P$ = "Y" THEN  GOSUB 9200: TEXT : HOME : GOTO 68
9530  IF P$ = "N" THEN  TEXT : HOME : GOTO 68
9540  GOTO 9500: REM
```

NATIONAL RADIO ASTRONOMY OBSERVATORY

ELECTRONICS DIVISION TECHNICAL NOTE NO. 96
ADDENDUM

TITLE: LADDER Analysis Program -- ADDENDUM

AUTHOR(S): Roger D. Norrod

DATE: January 4, 1982

Some revisions and additions have recently been made to the LADDER program at Green Bank. The revised program is stored on the NRAO Library 1.1 diskette under the name LADDER1. The changes are:

1. Three items have been added to the menu. These are:

   (M) TO DISPLAY MENU
   (G) TO DISPLAY GRAPHICS TABLE
   (Z) TO SAVE LINES 100-999 ON DISK

   Item (Z) allows the user to save his analysis program and later EXEC it back into LADDER.

2. A soft reentry point has been provided. The user may restart LADDER after halting (with menu item H) by typing ESC 9.

3. Subroutine 1700 has been added. This routine combines the impedance RN + j XN with the admittance of a shunt stub having impedance ZØ and length LN.

4. Subroutine 7000 has been added. This routine calculates and stores the reflection coefficient, VSWR, and reflection loss of the impedance RN + j XN at frequency F. This could be used when studying filter networks and would be called instead of subroutine 9000.

A listing of the revised program follows.

Distribution:

M. Balister	J. Payne	R. Lacasse	TU Mountain File
S. Weinreb	P. Napier	H. Hvatum	TU Downtown File
GB Library	CV Library	VLA Library	C. Burgess

```
PROGRAM LENGTH= 9509 BYTES          VARIABLES= 35 BYTES
FREE MEMORY= 10835 BYTES
START=16385 LOMEM=25994 FREE=26029 STRING=36864 HIMEM=36864


10  REM       RLADDER VERSION 4JAN82


12  REM  MOVE PROGRAM TO HIGH MEMORY
14  PRINT  CHR$ (4);"BRUN LOMEM:": &  LOMEM: 16384
16  HIMEM: 36864
18  POKE 1013,76: POKE 1014,12: POKE 1015,15)
20  POKE 1016,76: POKE 1017,0: POKE 1018,151
25  DIM U1(50),U2(50),U3(50),U4(50),U5(50),U6(50): REM


30  TEXT : HOME :V = 2
32  VTAB V: HTAB 16: PRINT "LADDER1"
33  VTAB V + 2: HTAB 8: PRINT "NETWORK ANALYSIS PROGRAM "
34  VTAB V + 4: HTAB 10: PRINT "NRAO--4JAN1982"
35  VTAB V + 6: PRINT "NORMAL UNITS ARE GHZ,MILS,NH, AND PF": PRINT
 "UTILITIES SHOULD BE LOADED AT START OF  EACH SESSION.": VTAB V +
 10: REM
38  REM  INITIALIZE CONSTANTS
40 D$ =  CHR$ (4): REM   D$=CTRL D
45 IN = 1E06
48  HCOLOR= 3: SCALE= 1: ROT= 0
50 TP = 6.28318:K1 = 11811:K2 = 57.2958: REM


52  REM   DEFINE ROUNDING FUNCTIONS
54  DEF  FN R1(X) =  INT (X * 10 + .5) / 10
56  DEF  FN R2(X) =  INT (X * 100 + .5) / 100
58  DEF  FN R3(X) =  INT (X * 1000 + .5) / 1000: REM


60  REM   DISPLAY MENU FOR USER
62  PRINT "TYPE (G) TO DISPLAY GRAPHICS": HTAB 6: PRINT "(H) TO HALT
 (USE ESC9 TO RESTART)": HTAB 6: PRINT "(L) FOR HARDCOPY LINES 100,999"
63  HTAB 6: PRINT "(M) TO DISPLAY MENU": HTAB 6: PRINT "(R) TO RUN
 PROGRAM 100": HTAB 6: PRINT "(S) TO LOAD FRESH SMITH CHART"
64  HTAB 6: PRINT "(T) TO DISPLAY TABLE OF DATA"
66  HTAB 6: PRINT "(U) TO LOAD UTILITIES FROM DISK": HTAB 6: PRINT
 "(P) TO PRINT GRAPHIC TABLE": HTAB 6: PRINT "(Z) TO SAVE MAIN PROGRAM"
68  PRINT : PRINT "ENTER SELECTION ";: GET P$: PRINT  CHR$ (0): HOME

70  IF P$ = "H" THEN  TEXT : HOME : END
71  IF P$ = "M" THEN  TEXT : HOME : GOTO 60
72  IF P$ = "L" THEN  GOTO 4200
73  IF P$ = "G" THEN  GOTO 8500
74  IF P$ = "R" THEN  GOTO 90
76  IF P$ = "S" THEN  GOTO 5014
78  IF P$ = "T" THEN  GOTO 9300
80  IF P$ = "U" THEN  GOTO 5000
81  IF P$ = "P" THEN  GOTO 6500
82  IF P$ = "Z" THEN  GOTO 2500
89  GOTO 60: REM  DISPLAY MENU


90  REM  BEGIN ANALYSIS
```

```
92 IZ = 0
95 I =  PEEK (8125) + 1
96  POKE 8125,I: REM    CHANGE PLOT SHAPE
98  VTAB (21): REM

99  REM  BEGIN DEFINITION OF PROBLEM
```

INSERT USER PROGRAM HERE

```
999  GOTO 68: REM          END ANALYSIS DISPLAY PROMPT
1000  REM  CONVERT IMPEDANCE TO ADMITTANCE
1001 X = L * W:RE = R
1005  IF C <  > 0 THEN X = X - 1000 / (C * W)
1010 D = RE ^ 2 + X ^ 2:G = RE / D:B =  - X / D: REM   INVERT Z=RE+JX
 TO Y=G+JB
1020  RETURN : REM


1100  REM  CONVERT ADMITTANCE TO IMPEDANCE
1101 G = 1 / R:B = C * W / 1000
1105  IF L <  > 0 THEN B = B - 1 / (L * W)
1110 D = G ^ 2 + B ^ 2:RE = G / D:X =  - B / D: REM   INVERT Y=G+JB
 TO Z=RE+JX
1120  RETURN : REM


1200  REM   SERIES ELEMENT: SERIES R,L,C
1201 X = L * W
1205  IF C <  > 0 THEN X = X - 1000 / (C * W)
1210 RN = R + RN:XN = X + XN
1220  RETURN : REM


1300  REM   SHUNT ELEMENT,SERIES R,L,C
1304 RE = R:X = L * W
1305  IF C <  > 0 THEN X = X - 1000 / (C * W)
1310  REM    SHUNT ELEMENT, RE+JX
1315  GOSUB 1010:G1 = G:B1 = B
1320 RE = RN:X = XN: GOSUB 1010
1330 G = G1 + G:B = B1 + B
1340  GOSUB 1110:RN = RE:XN = X
1350  RETURN : REM


1400  REM  SERIES TRANSMISSION LINE WITH CHARACTERISTIC IMPEDANCE Z0
1410 TN =  TAN (W * LN / K1)
1420 AR = RN:AI = XN + Z0 * TN
1430 BR = 1 - XN * TN / Z0:BI = RN * TN / Z0_
```

```
BI)
1450  RETURN : REM


1500  REM   ZN TO GAMMA (REFLECTION COEFFICIENT SR+J SI); ASSUMES REAL
 R0; DEFAULT R0=50 OHMS
1505  IF R0 = 0 THEN R0 = 50.0
1510 AR = RN - R0:AI = XN
1520 BR = RN + R0:BI = XN
1530  GOSUB 2200:SR = CR:SI = CI: REM  CALCULATE SR+J SI=(ZN-R0)/(ZN+R0)
1540 SM =  SQR (SR ^ 2 + SI ^ 2)
1545 SA = K2 *  ATN (SI / SR)
1550  IF SR < 0 THEN SA = SA + 180
1555  IF SA > 180 THEN SA = SA - 360
1560  IF SM >  = .999 THEN SWR = IN
1565  IF SM < .999 THEN SWR = (1 + SM) / (1 - SM)
1570  RETURN : REM


1600  REM  GAMMA TO ZN; ASSUMES REAL R0; DEFAULT R0=50 OHMS
1605  IF R0 = 0 THEN R0 = 50.0
1610 AR = R0(1 + SR):AI = R0 * SI
1620 BR = 1 - SR:BI =  - SI
1630  GOSUB 2200:RN = CR:XN = CI: REM  CALCULATE RN+J XN=R0(1+SR+J
 SI)/(1-SR-J SI)
1640  RETURN : REM

1700  REM  SHUNT SHORTED STUB, LENGTH LN, IMPEDANCE Z0
1710 RE = RN:X = XN: GOSUB 1010: REM  CALC INPUT ADMITTANCE AND SAVE
1720 G1 = G:B1 = B
1730 RN = 0:XN = 0: GOSUB 1400: REM  CALC INPUT IMPEDANCE OF STUB
1740 RE = RN:X = XN: GOSUB 1010: REM  CALC STUB ADMITTANCE
1750 G = G + G1:B = B + B1: GOSUB 1110: REM  COMBINE ADMITTANCES AND
 CONVERT TO IMPEDANCE
1760 RN = RE:XN = X
1770  RETURN : REM
1900  RUN 25: REM     REENTRY VIA ESC 9


2000  REM  COMPLEX MULTIPLY C=A*B
2010 CR = AR * BR - AI * BI
2020 CI = AR * BI + AI * BR
2030  RETURN : REM



2100  REM  COMPLEX RECIPROCAL C=1/B
2110 AR = 1:AI = 0: REM


2200  REM    COMPLEX DIVIDE, C=A/B
2210 D = BR ^ 2 + BI ^ 2
2220 CR = (AR * BR + AI * BI) / D
2230 CI = (AI * BR - AR * BI) / D
2240  RETURN : REM


2500  REM   CAPTURE LISTING
2505  TEXT : HOME
```

```
2514  PRINT ":"
2516  PRINT "THE TEXT FILE CAN BE RECALLED INTO"
2518  PRINT "THE LADDER1 PROGRAM BY:"
2520  PRINT  TAB( 5);"FIRST - LOAD LADDER1"
2522  PRINT  TAB( 4);"SECOND - EXEC FILENAME"
2524  PRINT  TAB( 5);"THIRD - RUN"
2526  PRINT ":"
2530  INPUT "NOW, WHAT NAME WOULD YOU LIKE LINE NUMBERS 100-999 SAVED
 UNDER? ";TF$
2535  PRINT " ": PRINT "THANK YOU, PLEASE WAIT"
2540  PRINT D$;"OPEN";TF$
2545  PRINT D$;"DELETE";TF$
2550  PRINT D$;"OPEN";TF$
2555  PRINT D$;"WRITE";TF$
2560  POKE 33,30
2565  LIST 100,999
2570  PRINT D$;"CLOSE";TF$
2575  TEXT : HOME : PRINT "LINES 100-999 SAVED UNDER FILENAME ";TF$
2580  VTAB 5: GOTO 60: REM   DISPLAY MENU
4200  REM  LIST MAIN PROGRAM
4210  TEXT : HOME : POKE 33,30: GOSUB 5300: REM   TURN PRINTER ON
4220  POKE 1913,6: REM  LEFT MARGIN
4240  LIST 100,999
4250  PRINT D$;"PR#0": REM  TURN PRINTER OFF
4260  POKE 33,40: HOME
4270  GOTO 60: REM    DISPLAY MENU


5000  REM  LOADS SHAPES,HGR CHARACTERS,AND SMITH CHART
5001 D$ =  CHR$ (4)
5003  PRINT D$;"BLOAD SHAPES,A8127": REM  LENGTH 24 BYTES
5004  POKE 232,191: POKE 233,31
5010  PRINT D$;"BLOAD HGR CHR GEN,A2048": REM  LENGTH 3328 BYTES
5014  REM  LOAD SMITH CHART INTO GRAPHICS
5015  HGR
5020  PRINT D$;"BLOAD NUMB SMITH,A8192": REM  LENGTH 8192 BYTES
5025  POKE 8125,0: REM  PLOT SHAPE PARAMETER IS IN 8125
5030  TEXT : HOME
5040  SCALE= 1: ROT= 0: HCOLOR= 3
5090  GOTO 60: REM      DISPLAY MENU
5300  REM   TURNS ON TRENDCOM PRINTER
5305 D$ =  CHR$ (4): REM  D$=CTRL D
5307  PRINT  CHR$ (0)
5310  PRINT D$;"PR# 1": PRINT  CHR$ (0)
5320  POKE 1913,0: POKE 1785,70: REM     MARGINS
5330  POKE 1657,80: REM  LINE LENGTH
5340  RETURN : REM


6500  REM  DUMPS GRAPHICS TABLE TO THE PRINTER, NO ROTATION, NORMAL
 SIZE.
6510  POKE  - 16301,0: POKE  - 16300,0: POKE  - 16297,0: POKE  - 16304,0:
 REM  DISPLAY GRAPHICS TABLE
6520  VTAB 23: INPUT "LABEL?";LA$
6540  PRINT D$;"PR#1": PRINT  TAB( 8);LA$: PRINT D$;"PR#0": REM
 PRINT LABEL
6550  POKE 1784,15: POKE 1912,170: POKE 1272,0: POKE 1144,32: POKE
 1528,0: POKE 1400,1: POKE 1656,0: REM  SET PRINTER GRAPHICS TEMPORARIES
6560  CALL  - 16000: REM  CALL PRINTER SERVICE ROUTINE
6580  TEXT : HOME : GOTO 60: REM    DISPLAY MENU
```

```
7000  REM  PRINTS REFL COEFF, SWR, AND LOSS ON CRT
7010  GOSUB 1500: REM  CALCULATE GAMMA AND VSWR
7020 LOSS =  - 4.342945 *  LOG (1 - SM * SM): REM   CALCULATE INSERTION
 LOSS IN DB
7030 FZ =  FN R2(F):LOSS =  FN R2(LOSS):SWR =  FN R2(SWR): REM   ROUND
 DATA
7040 SM =  FN R3(SM):SA =  FN R1(SA)
7050  PRINT FZ; TAB( 8);LOSS; TAB( 16);SWR; TAB( 24);SM; TAB( 32);SA
7055 U1$ = "FREQ":U2$ = "LOSS":U3$ = "VSWR":U4$ = "/GAMMA/":U5$ = "ANGLE":
U6$ = ""
7060  GOSUB 7100: REM  STORE DATA IN ARRAY
7070  RETURN : REM


7100  REM  STORES F, LOSS, GAMMA, AND SWR IN ARRAYS
7110 IZ = IZ + 1
7120 U1(IZ) = FZ:U2(IZ) = LOSS:U3(IZ) = SWR:U4(IZ) = SM:U5(IZ) = SA
7140  RETURN : REM


8000  REM  SMITH PLOT
8002  ON I GOSUB 8006,8007,8008,8009
8003  GOTO 8010
8006 SH = 2: ROT= 0: SCALE= 1: RETURN
8007 SH = 2: ROT= 8: SCALE= 2: RETURN
8008 SH = 2: ROT= 0: SCALE= 2: RETURN
8009 SH = 2: ROT= 0: SCALE= 3: RETURN
8010  POKE  - 16304,0: POKE  - 16300,0
8011  POKE  - 16297,0: POKE  - 16301,0
8012  HCOLOR= 3
8020 RM = 79:XC = 140:YC = 80
8030 XP = XC + SR * RM
8040 YP = YC - SI * RM
8050  DRAW SH AT XP,YP
8060  RETURN : REM


8500  REM  DISPLAYS GRAPHICS TABLE AND
8510  REM  THEN RETURNS TO PROMPT.
8520  POKE  - 16304,0: POKE  - 16300,0
8530  POKE  - 16297,0: POKE  - 16301,0
8540  VTAB 22: GOTO 68: REM


9000  REM  PRINT ON CRT
9005 FZ =  FN R2(F)
9010 RZ =  FN R3(RN)
9020 XZ =  FN R3(XN)
9022  GOSUB 1500
9045 SM =  FN R3(SM):SA =  FN R1(SA):SWR =  FN R2(SWR): REM   ROUND
 DATA FOR DISPLAY
9070  PRINT FZ; TAB( 8);RZ; TAB( 16);XZ; TAB( 24);SM; TAB( 32);SA
9075 U1$ = "FREQ":U2$ = "REAL Z":U3$ = "IMAG Z":U4$ = "/GAMMA/":U5$
 = "ANGLE":U6$ = "VSWR"
9080  GOSUB 9100: REM  STORE DATA IN ARRAYS
9090  RETURN : REM
9100  REM  STORES F, ZN, AND GAMMA IN ARRAYS
9110 IZ = IZ + 1
```

```
9140  RETURN : REM


9200  REM  PRINTS TABLE OF CALCULATED DATA
9201  HOME : GOSUB 5300: REM     TURN ON PRINTER
9203 I$ =  CHR$ (9): REM  I$=CTRL I
9205  PRINT I$;"N": REM  DISABLE VIDEO
9207  POKE 33,80: REM  SET APPLESOFT LINE LENGTH
9220  REM  PRINT HEADING
9230  PRINT  TAB( 8);U1$; TAB( 16);U2$; TAB( 24);U3$;
9240  PRINT  TAB( 32);U4$; TAB( 40);U5$; TAB( 48);U6$
9245  FOR J = 1 TO 56: PRINT "-";: NEXT J
9250  PRINT ""
9255  REM  PRINT DATA
9260  FOR J = 1 TO IZ
9275  PRINT  TAB( 8);U1(J); TAB( 16);U2(J); TAB( 24);U3(J);
9280  PRINT  TAB( 32);U4(J); TAB( 40);U5(J); TAB( 48);U6(J)
9285  NEXT J
9290  PRINT D$;"PR#0": REM  TURN PRINTER OFF
9292  POKE 33,40: PRINT I$;"I": REM  RESTORE VIDEO
9295  TEXT : HOME : RETURN : REM


9300  REM  DISPLAYS VIDEO TABLE OF CALCULATED DATA
9302  IF IZ = 0 THEN  PRINT " ** NO TABLE **": PRINT "": GOTO 68
9305 J2% = 0: REM  INITIALIZE ARRAY COUNTER
9310  TEXT : HOME
9320  REM  PRINT HEADING
9330  PRINT U1$; TAB( 8);U2$; TAB( 16);U3$: PRINT ""
9340 J1% = 0: REM  INITIALIZE SCREEN COUNTER
9350 J1% = J1% + 1:J2% = J2% + 1: PRINT U1(J2%); TAB( 8);U2(J2%); TAB(
 16);U3(J2%): REM    PRINT LINE
9360  IF J2% = IZ THEN  GOTO 9400: REM  CHECK FOR END OF ARRAY
9370  IF J1% < 20 THEN  GOTO 9350: REM  CHECK FOR FULL SCREEN
9380  VTAB 23: PRINT "PRESS ANY KEY FOR REST OF TABLE";: GET P$: PRINT
  CHR$ (0)
9390  GOTO 9310: REM  PRINT REST OF ARRAY
9400 J2% = 0: REM  INITIALIZE ARRAY COUNTER
9405  VTAB 23: PRINT "PRESS ANY KEY FOR REST OF TABLE";: GET P$: PRINT
  CHR$ (0)
9410  TEXT : HOME
9420  REM  PRINT HEADING
9430  PRINT U1$; TAB( 8);U4$; TAB( 16);U5$; TAB( 24);U6$: PRINT ""
9440 J1% = 0: REM  INITIALIZE SCREEN COUNTER
9450 J1% = J1% + 1:J2% = J2% + 1
9455  PRINT U1(J2%); TAB( 8);U4(J2%); TAB( 16);U5(J2%); TAB( 24);U6(J2%):
 REM    PRINT LINE
9460  IF J2% = IZ THEN  GOTO 9500: REM  CHECK FOR END OF ARRAY
9470  IF J1% < 20 THEN  GOTO 9450: REM  CHECK FOR FULL SCREEN
9480  VTAB 23: PRINT "PRESS ANY KEY FOR REST OF TABLE";: GET P$: PRINT
  CHR$ (0)
9490  GOTO 9410: REM  PRINT REST OF TABLE
9500  VTAB 23: PRINT "HARD COPY?(Y/N)";
9510  GET P$: PRINT CHR(0)
9520  IF P$ = "Y" THEN  GOSUB 9200: TEXT : HOME : GOTO 60
9530  IF P$ = "N" THEN  TEXT : HOME : GOTO 60
9540  GOTO 9500: REM
```

NATIONAL RADIO ASTRONOMY OBSERVATORY

ELECTRONICS DIVISION TECHNICAL NOTE NO. 96

TITLE: LADDER ANALYSIS PROGRAM

AUTHOR(S): Roger D. Norrod

DATE: May 28, 1981

Distribution: M. Balister
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J. Payne
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R. Lacasse
H. Hvatum
C. Burgess

NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

MEMORANDUM May 28, 1981

To: Green Bank Electronics Division

From: Roger Norrod

Subj: LADDER Analysis Program

Introduction:

An APPLE computer system is now available at Green Bank for use by the Electronics Division. The purpose of this memo is to acquaint potential users with a program available on disk. The LADDER program was written by Sandy Weinreb and calculates the input impedance of a network. Results can be displayed in table form or plotted on a Smith chart. The program consists of a group of subroutines which perform various functions. The user writes a series of BASIC language statements describing his network and calling the proper subroutines.

To use the program, first insure that a disk marked NRAO LIBRARY 1.Ø is in the disk drive. Then type RUN LADDER and return. After a few seconds a "menu" will be displayed (Figure 1). Just follow instructions on the menu to execute the program. Table 1 describes the functioning of the menu subprograms.

To describe his network, the user writes a BASIC language program in lines 1ØØ to 998. Table 2 lists subroutines the user can call from within his program, and Table 3 gives a partial list of variables with special meaning to LADDER. To insert his own program into LADDER, the user should type LOAD LADDER, and then DEL 1ØØ,998 to eliminate any old programs. He then types in his own program and SAVE LADDER to store his version on disk.

Example 1:

Figure 2 is a listing of a program used to analyze a three-pole bandpass filter. For those not familiar with Applesoft BASIC, anything following REM (for remark) is ignored by the computer and colons are used to string statements together. Lines 140 through 210 are executed for each frequency defined in line 130. Line 150 initializes RN and XN to the terminating impedance, in this case 75 ohms. Line 160 defines the first filter element, a 2258 pF capacitor in parallel, and calls subroutine 1300. This subroutine converts RN and XN to admittance, combines it with the admittance of the capacitor, converts this total admittance to an impedance, and stores it in RN and XN. Lines 170 through 200 add elements until RN and XN have the input impedance of the total network. Line 210 calculates the resulting reflection coefficient, prints it on the screen and plots it on a Smith chart overlay. Line 220 loops the program back for the next frequency. When all frequency points have been completed, line 999 sends the computer back to wait for the

user to select another menu item. Figure 3 shows the printout caused by selecting menu items (T) and (P) after running the above program. The program takes about three seconds per frequency.

Example 2:

A program written to analyze a coaxial bandpass filter with design cutoff frequency of 10 GHz is listed in Figure 4. Subroutine 1400 is used to rotate impedances through transmission lines. Figure 5 shows the printout for this program. About five seconds were required for each frequency.

Program Listing:

A complete listing of LADDER is included with this memo. Table 4 lists some subroutines used by LADDER internally. These would normally not be called by the user program but are available if needed.

Housekeeping:

Manuals describing the use of the APPLE system are normally kept on the rack housing the computer. A three-ring binder labeled ADIOS #4 has much useful information. I will be glad to assist anyone interested in getting started.

Anyone using LADDER much would probably be wise to have their own disk so that other users don't erase their program. We have several blank disks and copying the NRAO LIBRARY 1.0 disk takes only a few minutes.

Future Expansions:

I hope to add a subroutine in the near future that will calculate the fringing capacitance of a stepped coaxial line. Anyone else who has a suggestion for a useful subroutine, let me know so that it can be made available to all users.

RDN/cjd

Enclosures:

1. Table 1 - LADDER Subprograms Accessed thru Menu
2. Table 2 - LADDER User Subroutines
3. Table 3 - LADDER Variables
4. Table 4 - LADDER Subroutines used by LADDER
5. Figure 1 - Menu Displayed by LADDER
6. Figure 2 - Analysis of Lumped Element Bandpass Filter
7. Figure 3 - Printout for Lumped Element Bandpass Filter
8. Figure 4 - Analysis of Coaxial Lowpass Filter
9. Figure 5 - Printout for Coaxial Lowpass Filter
10. Program Listing

TABLE 1

LADDER SUBPROGRAMS ACCESSED THRU MENU

Menu Item	Line No.	Function	Returns to
H	74	Clears screen.	End
L	42ØØ	Prints list of lines 1ØØ-999.	Menu
R	84	Executes user program.	Menu
S	5Ø14	Loads fresh Smith chart.	Menu
T	93ØØ	Displays table of calculated data with hard copy option.	Menu
U	5ØØØ	Loads utilities (Smith chart and HGR shapes).	Menu
P	65ØØ	Prints copy of graphics table.	Menu

TABLE 2

LADDER USER SUBROUTINES

Line No.	Function	Inputs	Outputs
1ØØØ	Admittance of Series R, L, C	R, L, C, W	G, B
1Ø1Ø	Impedance to Admittance	RE, X	G, B
11ØØ	Impedance of Parallel R, L, C	R, L, C, W	RE, X
111Ø	Admittance to Impedance	G, B	RE, X
12ØØ	Series Branch, Series R, L, C	R, L, C, W, RN, XN	RN, XN (new)
13ØØ	Shunt Branch, Series R, L, C	R, L, C, W, RN, XN	Rn, XN (new)
14ØØ	Series Xmission Line	W, LN, ZØ, RN, XN	RN, XN (new)
15ØØ	ZN to Γ = SR + j SI	RN, XN, RØ	SR, SI
16ØØ	Γ to ZN = RN + j XN	SR, SI, RØ	RN, XN
2ØØØ	Complex Multiply: C = A * B	AR, AI, BR, BI	CR, CI
21ØØ	Complex Reciprocal: C = 1/B	BR, BI	CR, CI
22ØØ	Complex Divide: C = A/B	AR, AI, BR, BI	CR, CI
8ØØØ	Smith Chart Plot	SR, SI	---
9ØØØ	Maxes Table on CRT and Stores F, RN, XN, SR, SI, SWR	F, RN, XN	SR, SI

TABLE 3

LADDER VARIABLES
(Partial List)

Variable	Description
R	Resistance of Circuit Branch, Ohms
L	Inductance of Circuit Branch, nH
C	Capacitance of Circuit Branch, pF
W	Radian Frequency, 2π * GHz
RE	Real Part of Impedance
X	Imaginary Part of Impedance
G	Real Part of Admittance
B	Imaginary Part of Admittance
RN	Real Part of Circuit Input Impedance
XN	Imaginary Part of Circuit Input Impedance
SR	Real Part of Reflection Coefficient
SI	Imaginary Part of Reflection Coefficient
ZØ	Characteristic Impedance of Transmission Line
LN	Length of Transmission Line, mils
AR, BR, CR	Real Part of Complex Number A, B, or C
AI, BI, CI	Imaginary Part of Complex Number A, B, or C
TP	2π, defined by LADDER for user

TABLE 4

LADDER SUBROUTINES USED BY LADDER

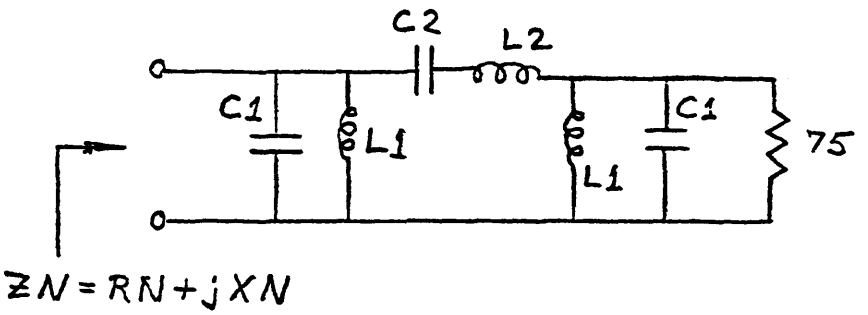
Line No.	Function	Called By
53ØØ	Turns on Printer	92ØØ, 42ØØ
91ØØ	Stores Data in Arrays	9ØØØ
92ØØ	Prints Table of Calculated Data	93ØØ

```
                LADDER
        NETWORK ANALYSIS PROGRAM
          NRAO--APRIL 1, 1981
NORMAL UNITS ARE GHZ,MILS,NH, AND PF
UTILITIES SHOULD BE LOADED AT START OF  EACH SESSION.
TYPE (H) TO HALT
     (L) TO LIST MAIN PROGRAM
     (R) TO RUN ANALYSIS
     (S) TO LOAD FRESH SMITH CHART
     (T) TO MAKE HARD COPY OF DATA
     (U) TO LOAD UTILITIES FROM DISK
     (P) TO PRINT GRAPHIC TABLE

(H),(L),(R),(S),(T),(U),OR (P)?
```

FIGURE 1

MENU DISPLAYED BY LADDER




```
100  REM  LUMPED ELEMENT BPF
105  REM  75 OHM, 0.5DB CHEBYSCHEV, 3POLE,6.0-7.5 MHZ BANDPASS
110 R0 = 75: REM  DEFINE CENTER OF SMITH CHART
120 C1 = 2258:L1 = 249:C2 = 64.5:L2 = 8730: REM  DEFINE ELEMENT VALUES
130  FOR F = 5.5 TO 8.0 STEP 0.1
140 W = TP * F / 1000: REM  CONVERT MHZ TO GHZ
150 RN = 75:XN = 0: REM  TERMINATION=75 OHMS
160 R = 0:L = 0:C = C1: GOSUB 1300: REM  1ST SECTION
170 R = 0:L = L1:C = 0: GOSUB 1300: REM  1ST SECTION COMPLETED
180 R = 0:L = L2:C = C2: GOSUB 1200: REM  2ND SECTION
190 R = 0:L = L1:C = 0: GOSUB 1300: REM  3RD SECTION
200 R = 0:L = 0:C = C1: GOSUB 1300: REM  3RD SECTION COMPLETED
210  GOSUB 9000: GOSUB 8000: REM  STORE & PLOT INPUT IMPEDANCE
220  NEXT F
999  GOTO 72: REM          END ANALYSIS, GO TO PROMPT
```

FIGURE 2

ANALYSIS OF LUMPED ELEMENT BANDPASS FILTER

F	REAL Z	IMAG Z	/GAMMA/	ANGLE	VSWR
5.5	.6	33.2	.987	132.3	153.3
5.6	1.3	39.1	.974	124.9	76.3
5.7	3	48.1	.944	114.6	34.8
5.8	9	63.2	.869	99.3	14.28
5.9	35.1	87.2	.683	76.2	5.31
6	103.4	55.4	.333	45.6	2
6.1	70.8	-1.2	.03	-164	1.06
6.2	45.7	2.8	.244	173.1	1.65
6.3	39.4	12.1	.327	155.2	1.97
6.4	41.9	19.8	.325	138.5	1.96
6.5	51.2	24	.263	124	1.71
6.6	65.3	19.7	.155	108.1	1.37
6.7	74.8	3.1	.021	91.8	1.04
6.8	69.1	-15.6	.115	-104.4	1.26
6.9	55.6	-23.1	.228	-119.9	1.59
7	45.2	-21.3	.3	-134.5	1.86
7.1	40.4	-15.3	.325	-148.6	1.96
7.2	41.8	-7.7	.291	-163.2	1.82
7.3	51.9	0	.182	-179.9	1.44
7.4	79.1	-1.6	.028	-20.4	1.06
7.5	104.3	-53.9	.328	-44.8	1.97
7.6	49.3	-91.5	.616	-69.3	4.2
7.7	16.5	-73.9	.802	-89.4	9.09
7.8	6.5	-58.3	.898	-104	18.55
7.9	3	-48.2	.945	-114.5	35.09
8	1.6	-41.4	.968	-122.2	61.87

6.0-7.5 MHZ BPF

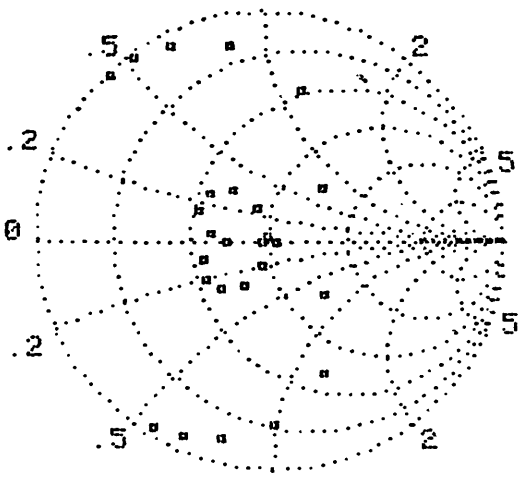


FIGURE 3

PRINTOUT FOR LUMPED ELEMENT BANDPASS FILTER

```
100  REM  SEVEN SECTION, CHEBYSCHEV, COAXIAL LPF.  0.1 DB RIPPLE.
110 R0 = 50: REM  DEFINE CENTER OF SMITH CHART
120  FOR F = 1.0 TO 15.0 STEP 1
130 W = TP * F:RN = 50.0:XN = 0.0: REM  TERMINATION = 50 OHMS
140 R = 0:L = 0:C = .02: GOSUB 1300: REM  FRINGE CAP
150 Z0 = 15:LN = 27: GOSUB 1400: REM   1ST SECTION
160 R = 0:L = 0:C = .04: GOSUB 1300: REM  FRINGE CAP
170 Z0 = 85:LN = 170: GOSUB 1400: REM   2ND SECTION
180 R = 0:L = 0:C = .04: GOSUB 1300: REM  FRINGE CAP
190 Z0 = 15:LN = 49: GOSUB 1400: REM   3RD SECTION
200 R = 0:L = 0:C = .04: GOSUB 1300: REM  FRINGE CAP
210 Z0 = 85:LN = 194: GOSUB 1400: REM   4TH SECTION
220 R = 0:L = 0:C = .04: GOSUB 1300: REM  FRINGE CAP
230 Z0 = 15:LN = 49: GOSUB 1400: REM   5TH SECTION
240 R = 0:L = 0:C = .04: GOSUB 1300: REM  FRINGE CAP
250 Z0 = 85:LN = 170: GOSUB 1400: REM   6TH SECTION
260 R = 0:L = 0:C = .04: GOSUB 1300: REM  FRINGE CAP
270 Z0 = 15:LN = 27: GOSUB 1400: REM   7TH SECTION
280 R = 0:L = 0:C = .02: GOSUB 1300: REM  FRINGE CAP
290  GOSUB 9000: GOSUB 8000: REM  PLOT POINT ON SMITH CHART
300  NEXT F
999  GOTO 72: REM        END ANALYSIS, GO TO PROMPT
```

FIGURE 4

ANALYSIS OF COAXIAL LOWPASS FILTER

F	REAL Z	IMAG Z	/GAMMA/	ANGLE	VSWR
1	49.7	-.5	6E-03	-119.6	1.01
2	50.2	.1	2E-03	30.8	1
3	53.2	.1	.031	.9	1.06
4	56.7	-4.1	.074	-29.2	1.16
5	54.9	-10.6	.111	-59.6	1.25
6	48.6	-11.5	.117	-90.3	1.26
7	46.1	-5.6	.071	-121.8	1.15
8	52.6	1.3	.028	25.2	1.06
9	66.4	-3.1	.143	-9.2	1.33
10	63.1	-17.9	.194	-44.9	1.48
11	50.1	-5.6	.056	-85.3	1.12
12	75	49.2	.411	41.6	2.4
13	269.7	-275.6	.835	-10.7	11.12
14	8	-126.4	.958	-43	46.35
15	1.2	-81.7	.987	-62.9	147.59

50 OHM LPF

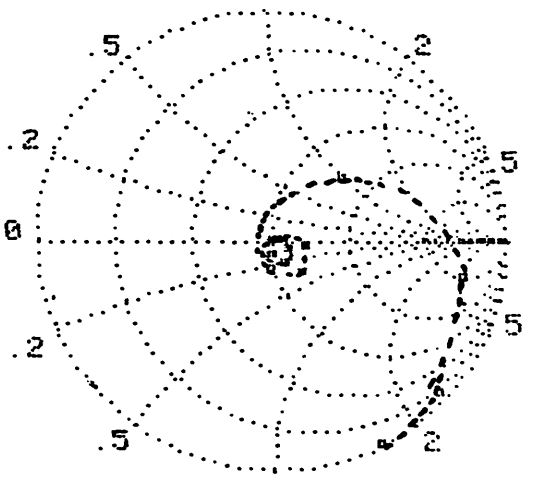


FIGURE 5

PRINTOUT FOR COAXIAL LOWPASS FILTER

PROGRAM LISTING

```
PROGRAM LENGTH= 8040 BYTES          VARIABLES= 35 BYTES
FREE MEMORY= 12404 BYTES
START=16385 LOMEM=24425 FREE=24460 STRING=36864 HIMEM=36864


10  REM              RLADDER VERSION 21MAY81


12  REM  MOVE PROGRAM TO HIGH MEMORY
14  PRINT  CHR$ (4);"BRUN LOMEM:": &  LOMEM: 16384
16  HIMEM: 36864
18  POKE 1013,76: POKE 1014,12: POKE 1015,151
20  POKE 1016,76: POKE 1017,0: POKE 1018,151
25  PRINT  CHR$ (4);"BRUN LOMEM:": &  LOMEM: 16384
30  TEXT : HOME :V = 2
32  VTAB V: HTAB 16: PRINT "LADDER"
33  VTAB V + 3: HTAB 8: PRINT "NETWORK ANALYSIS PROGRAM "
34  VTAB V + 6: HTAB 10: PRINT "NRAO--APRIL 1, 1981"
35  VTAB V + 10: PRINT "NORMAL UNITS ARE GHZ,MILS,NH, AND PF": PRINT
 "UTILITIES SHOULD BE LOADED AT START OF  EACH SESSION.": VTAB V +
 15: REM


38  REM  INITIALIZE CONSTANTS
40 D$ =  CHR$ (4): REM   D$=CTRL D
45 IN = 1E06: DIM FS(50),RS(50),XS(50),MS(50),AS(50),VS(50)
48  HCOLOR= 3: SCALE= 1: ROT= 0
50 TP = 6.28318:K1 = 11811:K2 = 57.2958: REM


58  REM  DEFINE ROUNDING FUNCTIONS
60  DEF  FN R1(X) =  INT (X * 10 + .5) / 10
61  DEF  FN R2(X) =  INT (X * 100 + .5) / 100
62  DEF  FN R3(X) =  INT (X * 1000 + .5) / 1000: REM


68  REM  DISPLAY MENU FOR USER
69  PRINT "TYPE (H) TO HALT": HTAB 6: PRINT "(L) TO LIST MAIN PROGRAM":
 HTAB 6: PRINT "(R) TO RUN ANALYSIS": HTAB 6: PRINT "(S) TO LOAD FRESH
 SMITH CHART"
70  HTAB 6: PRINT "(T) TO MAKE HARD COPY OF DATA "
71  HTAB 6: PRINT "(U) TO LOAD UTILITIES FROM DISK": HTAB 6: PRINT
 "(P) TO PRINT GRAPHIC TABLE"
72  PRINT "(H),(L),(R),(S),(T),(U),OR (P)?";: GET P$: PRINT  CHR$ (0):
 HOME
74  IF P$ = "H" THEN  TEXT : HOME : END
75  IF P$ = "L" THEN  GOTO 4200
76  IF P$ = "R" THEN  GOTO 84
78  IF P$ = "S" THEN  GOTO 5014
79  IF P$ = "T" THEN  GOTO 9300
80  IF P$ = "U" THEN  GOTO 5000
81  IF P$ = "P" THEN  GOTO 6500
82  GOTO 68: REM   DISPLAY MENU
84  REM  BEGIN ANALYSIS
90 IZ = 0
95 I =  PEEK (8125) + 1
96  POKE 8125,I: REM    CHANGE PLOT SHAPE
98  VTAB (21): REM
```

```
99  REM  BEGIN DEFINITION OF PROBLEM
100  REM  SEVEN SECTION, CHEBYSCHEV, COAXIAL LPF.  0.1 DB RIPPLE.
110 R0 = 50: REM  DEFINE CENTER OF SMITH CHART
120  FOR F = 1.0 TO 15.0 STEP 1
130 W = TP * F:RN = 50.0:XN = 0.0: REM  TERMINATION = 50 OHMS
150 Z0 = 15:LN = 27: GOSUB 1400: REM   1ST SECTION
170 Z0 = 85:LN = 170: GOSUB 1400: REM   2ND SECTION
190 Z0 = 15:LN = 49: GOSUB 1400: REM   3RD SECTION
210 Z0 = 85:LN = 194: GOSUB 1400: REM   4TH SECTION
230 Z0 = 15:LN = 49: GOSUB 1400: REM   5TH SECTION
250 Z0 = 85:LN = 170: GOSUB 1400: REM   6TH SECTION
270 Z0 = 15:LN = 27: GOSUB 1400: REM   7TH SECTION
290  GOSUB 9000: GOSUB 8000: REM  PLOT POINT ON SMITH CHART
300  NEXT F
999  GOTO 72: REM        END ANALYSIS, GO TO PROMPT


1000  REM  CONVERT IMPEDANCE TO ADMITTANCE
1001 X = L * W:RE = R
1005  IF C <  > 0 THEN X = X - 1000 / (C * W)
1010 D = RE ^ 2 + X ^ 2:G = RE / D:B =  - X / D: REM   INVERT Z=RE+JX
 TO Y=G+JB
1020  RETURN : REM


1100  REM  CONVERT ADMITTANCE TO IMPEDANCE
1101 G = 1 / R:B = C * W / 1000
1105  IF L <  > 0 THEN B = B - 1 / (L * W)
1110 D = G ^ 2 + B ^ 2:RE = G / D:X =  - B / D: REM   INVERT Y=G+JB
 TO Z=RE+JX
1120  RETURN : REM


1200  REM   SERIES ELEMENT: SERIES R,L,C
1201 X = L * W
1205  IF C <  > 0 THEN X = X - 1000 / (C * W)
1210 RN = R + RN:XN = X + XN
1220  RETURN : REM


1300  REM   SHUNT ELEMENT,SERIES R,L,C
1304 RE = R:X = L * W
1305  IF C <  > 0 THEN X = X - 1000 / (C * W)
1310  REM    SHUNT ELEMENT, RE+JX
1315  GOSUB 1010:G1 = G:B1 = B
1320 RE = RN:X = XN: GOSUB 1010
1330 G = G1 + G:B = B1 + B
1340  GOSUB 1110:RN = RE:XN = X
1350  RETURN : REM


1400  REM  SERIES TRANSMISSION LINE WITH CHARACTERISTIC IMPEDANCE Z0
1410 TN =  TAN (W * LN / K1)
1420 AR = RN:AI = XN + Z0 * TN
1430 BR = 1 - XN * TN / Z0:BI = RN * TN / Z0
1440  GOSUB 2200:RN = CR:XN = CI: REM   CALCULATE RN+J XN=(AR+J AI)/(BR+J
 BI)
1450  RETURN : REM


1500  REM   ZN TO GAMMA (REFLECTION COEFFICIENT SR+J SI); ASSUMES REAL
```

```
R0; DEFAULT R0=50   MS
1505  IF R0 = 0 THEN R0 = 50.0
1510 AR = RN - R0:AI = XN
1520 BR = RN + R0:BI = XN
1530  GOSUB 2200:SR = CR:SI = CI: REM  CALCULATE SR+J SI=(ZN-R0)/(ZN+R0)
1540  RETURN : REM


1600  REM  GAMMA TO ZN; ASSUMES REAL R0; DEFAULT R0=50 OHMS
1605  IF R0 = 0 THEN R0 = 50.0
1610 AR = R0(1 + SR):AI = R0 * SI
1620 BR = 1 - SR:BI =  - SI
1630  GOSUB 2200:RN = CR:XN = CI: REM  CALCULATE RN+J XN=R0(1+SR+J
 SI)/(1-SR-J SI)
1640  RETURN : REM

2000  REM  COMPLEX MULTIPLY C=A*B
2010 CR = AR * BR - AI * BI
2020 CI = AR * BI + AI * BR
2030  RETURN : REM



2100  REM  COMPLEX RECIPROCAL C=1/B
2110 AR = 1:AI = 0: REM


2200  REM    COMPLEX DIVIDE, C=A/B
2210 D = BR ^ 2 + BI ^ 2
2220 CR = (AR * BR + AI * BI) / D
2230 CI = (AI * BR - AR * BI) / D
2240  RETURN : REM


4200  REM  LIST MAIN PROGRAM
4210  TEXT : HOME : POKE 33,30: GOSUB 5300: REM   TURN PRINTER ON
4220  POKE 1913,6: REM  LEFT MARGIN
4240  LIST 100,999
4250  PRINT D$;"PR#0": REM  TURN PRINTER OFF
4260  POKE 33,40: HOME
4270  GOTO 68: REM   DISPLAY MENU


5000  REM  LOADS SHAPES,HGR CHARACTERS,AND SMITH CHART
5001 D$ =  CHR$ (4)
5003  PRINT D$;"BLOAD SHAPES"
5004  POKE 232,191: POKE 233,31
5010  PRINT D$;"BLOAD HGR CHR GEN"
5014  REM  LOAD SMITH CHART INTO GRAPHICS
5015  HGR
5020  PRINT D$;"BLOAD NUMB SMITH,A8192"
5025  POKE 8125,0: REM  PLOT SHAPE PARAMETER IS IN 8125
5030  TEXT : HOME
5040  SCALE= 1: ROT= 0: HCOLOR= 3
5090  GOTO 68: REM     DISPLAY MENU


5300  REM   TURNS ON TRENDCOM PRINTER
5305 D$ =  CHR$ (4): REM  D$=CTRL D
5307  PRINT  CHR$ (0)
5310  PRINT D$;"PR# 1": PRINT  CHR$ (0)
```

```
5320  POKE 1913,0: POKE 1785,70: REM     MARGINS
5330  POKE 1657,80: REM  LINE LENGTH
5340  RETURN : REM


6500  REM  DUMPS GRAPHICS TABLE TO THE PRINTER, NO ROTATION, NORMAL
 SIZE.
6510  POKE  - 16301,0: POKE  - 16300,0: POKE  - 16297,0: POKE  - 16304,0:
 REM  DISPLAY GRAPHICS TABLE
6520  VTAB 23: INPUT "LABEL?";LA$
6540  PRINT D$;"PR#1": PRINT  TAB( 8);LA$: PRINT D$;"PR#0": REM
 PRINT LABEL
6550  POKE 1784,15: POKE 1912,170: POKE 1272,0: POKE 1144,32: POKE
 1528,0: POKE 1400,1: POKE 1656,0: REM  SET PRINTER GRAPHICS TEMPORARIES
6560  CALL  - 16000: REM  CALL PRINTER SERVICE ROUTINE
6580  TEXT : HOME : GOTO 68: REM   DISPLAY MENU


8000  REM  SMITH PLOT
8002  ON I GOSUB 8006,8007,8008,8009
8003  GOTO 8010
8006 SH = 2: ROT= 0: SCALE= 1: RETURN
8007 SH = 2: ROT= 8: SCALE= 2: RETURN
8008 SH = 2: ROT= 0: SCALE= 2: RETURN
8009 SH = 2: ROT= 0: SCALE= 3: RETURN
8010  POKE  - 16304,0: POKE  - 16300,0
8011  POKE  - 16297,0: POKE  - 16301,0
8012  HCOLOR= 3
8020 RM = 79:XC = 140:YC = 80
8030 XP = XC + SR * RM
8040 YP = YC - SI * RM
8050  DRAW SH AT XP,YP
8060  RETURN : REM


8500  REM
8501  RETURN : REM


8510  CALL 25674: REM   INIT HGR CHR GEN
8520  PRINT  CHR$ (1); CHR$ (17)
8530  HCOLOR= 3
8535  DRAW SH AT 1,7 * I
8540  INPUT "COMMENT? ";CM$
8550  VTAB (I): HTAB (2): PRINT CM$
8560  CALL 1013: RETURN : REM


9000  REM  PRINT ON CRT
9005 FZ =  FN R2(F)
9010 RZ =  FN R1(RN)
9020 XZ =  FN R1(XN)
9022  GOSUB 1500
9024 SM =  SQR (SR ^ 2 + SI ^ 2)
9026 SA = K2 *  ATN (SI / SR)
9027  IF SR < 0 THEN SA = SA + 180
9028  IF SA > 180 THEN SA = SA - 360
9035  IF SM >  = 1 THEN SWR = IN
9040  IF SM < 1 THEN SWR = (1 + SM) / (1 - SM)
9045 SM =  FN R3(SM):SA =  FN R1(SA):SWR =  FN R2(SWR): REM   ROUND
 DATA FOR DISPLAY
```

```
9070  PRINT FZ; TAB( 8);RZ; TAB( 16);XZ; TAB( 24);SM; TAB( 32);SA
9080  GOSUB 9100: REM  STORE DATA IN ARRAYS
9090  RETURN : REM
9100  REM  STORES F, ZN, AND GAMMA IN ARRAYS
9110 IZ = IZ + 1
9120 FS(IZ) = FZ:RS(IZ) = RZ:XS(IZ) = XZ
9130 MS(IZ) = SM:AS(IZ) = SA:VS(IZ) = SWR
9140  RETURN : REM


9200  REM  PRINTS TABLE OF CALCULATED DATA
9201  HOME : GOSUB 5300: REM    TURN ON PRINTER
9203 I$ =  CHR$ (9): REM  I$=CTRL I
9205  PRINT I$;"N": REM  DISABLE VIDEO
9207  POKE 33,80: REM  SET APPLESOFT LINE LENGTH
9220  REM  PRINT HEADING
9230  PRINT  TAB( 8);"F"; TAB( 16);"REAL Z"; TAB( 24);"IMAG Z";
9240  PRINT  TAB( 32);"/GAMMA/"; TAB( 40);"ANGLE"; TAB( 48);"VSWR"
9245  FOR J = 1 TO 56: PRINT "-";: NEXT J
9250  PRINT ""
9255  REM  PRINT DATA
9260  FOR J = 1 TO IZ
9275  PRINT  TAB( 8);FS(J); TAB( 16);RS(J); TAB( 24);XS(J);
9280  PRINT  TAB( 32);MS(J); TAB( 40);AS(J); TAB( 48);VS(J)
9285  NEXT J
9290  PRINT D$;"PR#0": REM  TURN PRINTER OFF
9292  POKE 33,40: PRINT I$;"I": REM  RESTORE VIDEO
9295  TEXT : HOME : RETURN : REM


9300  REM  DISPLAYS VIDEO TABLE OF CALCULATED DATA
9302  IF IZ = 0 THEN  PRINT " ** NO TABLE **": PRINT "": GOTO 68
9305 J2% = 0: REM  INITIALIZE ARRAY COUNTER
9310  TEXT : HOME
9320  REM  PRINT HEADING
9330  PRINT "F"; TAB( 8);"REAL Z"; TAB( 16);"IMAG Z": PRINT ""
9340 J1% = 0: REM  INITIALIZE SCREEN COUNTER
9350 J1% = J1% + 1:J2% = J2% + 1: PRINT FS(J2%); TAB( 8);RS(J2%); TAB(
 16);XS(J2%): REM  PRINT LINE
9360  IF J2% = IZ THEN  GOTO 9400: REM  CHECK FOR END OF ARRAY
9370  IF J1% < 20 THEN  GOTO 9350: REM  CHECK FOR FULL SCREEN
9380  VTAB 23: PRINT "PRESS ANY KEY FOR REST OF TABLE";: GET P$: PRINT
  CHR$ (0)
9390  GOTO 9310: REM  PRINT REST OF ARRAY
9400 J2% = 0: REM  INITIALIZE ARRAY COUNTER
9405  VTAB 23: PRINT "PRESS ANY KEY FOR REST OF TABLE";: GET P$: PRINT
  CHR$ (0)
9410  TEXT : HOME
9420  REM  PRINT HEADING
9430  PRINT "F"; TAB( 8);"/GAMMA/"; TAB( 16);"ANGLE"; TAB( 24);"VSWR":
 PRINT ""
9440 J1% = 0: REM  INITIALIZE SCREEN COUNTER
9450 J1% = J1% + 1:J2% = J2% + 1
9455  PRINT FS(J2%); TAB( 8);MS(J2%); TAB( 16);AS(J2%); TAB( 24);VS(J2%):
 REM  PRINT LINE
9460  IF J2% = IZ THEN  GOTO 9500: REM  CHECK FOR END OF ARRAY
9470  IF J1% < 20 THEN  GOTO 9450: REM  CHECK FOR FULL SCREEN
9480  VTAB 23: PRINT "PRESS ANY KEY FOR REST OF TABLE";: GET P$: PRINT
  CHR$ (0)
9490  GOTO 9410: REM  PRINT REST OF TABLE
9500  VTAB 23: PRINT "HARD COPY?(Y/N)";
9510  GET P$: PRINT CHR(0)
9520  IF P$ = "Y" THEN  GOSUB 9200: TEXT : HOME : GOTO 68
9530  IF P$ = "N" THEN  TEXT : HOME : GOTO 68
```