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A manual microwave network analyzer was modified to operate under control of a desktop calculator. By automating it and using precise calibration standards, measurements could be performed more quickly and much more accurately. The equipment and software is described in detail.

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CONTENTS

SEMI-AUTOMATIC NETWORK ANALYZER

INTRODUCTION

The purpose of this system is to provide automated reflection-transmission measurements of microwave components without compromising normal swept operations or requiring specially modified instruments. This automation not only permits rapid measurement of unknown devices, it also enables the user to make measurements that are far more accurate than ever possible using manual techniques. Very elaborate automatic network analyzers have been commercially available for some years to provide this function, but the price of above $150,000 has made them available only to a few. Today the decreasing cost of small computer controllers and the availability of instruments having a general purpose digital interface have made possible systems of much reduced cost with performance approaching that of the large systems.

Under these conditions, the versatility and convenience of the new equipment make automation cost effective in small volume production and laboratory applications. The system is laid out on a table top as opposed to being stacked and bolted into position on equipment racks. This "table-top" arrangement of equipment allows easy connections and disconnections when a piece of equipment is needed elsewhere, thus not permanently tying up any equipment. Also, the semi-automatic system will allow the user to make manual measurements should the controller malfunction.

For our system we took an existing manual microwave network analyzer (Hewlett-Packard 8410A system) and mated it to a small desktop computer (HP 9830A) which we had previously used exclusively for scientific calculations. The interfacing was primarily a matter of adding a microwave source and an A/D converter which were programmable plus an interface adapter for the calculator. The existence of the IEEE-488-1975 general purpose interface has greatly simplified the hardware aspects of the interfacing compared to just a few years ago [1]. The system and program structure were patterned after a similar system presented in Hewlett-Packard application note 221 [2], although the programming language and equipment details are different.

Manuscript submitted December 29, 1980.

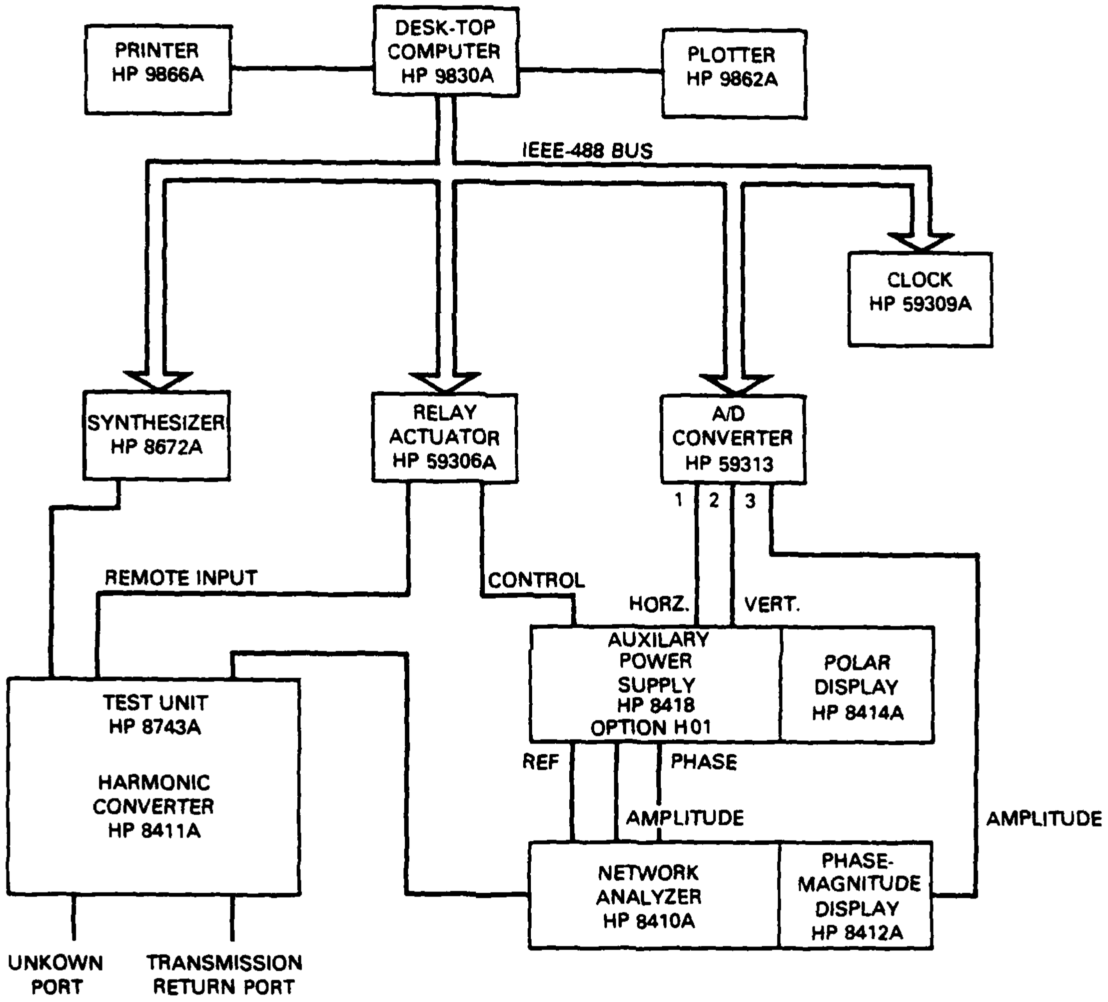


Fig. 1 - Block diagram of the semi-automatic network analyzer

Comparisons were made between this system and Hewlett-Packard fully automatic 8542 network analyzers at NRL, with the overall results that the semi-automatic system came within ±0.2 dB in magnitude and ±1.5° in phase angle of the fully automatic system. Accuracy of either system depends critically on very careful calibration procedures and precise standards. Details of the comparison are presented in the body of this report.

SYSTEM DESCRIPTION

A block diagram of the semi-automatic system is shown in Figure 1. A wideband 2-18 GHz manual network analyzer is linked to a desktop calculator via three instruments which can accept program instructions through the IEEE-488-1975 standard interface bus (also known as the HP-IB or GPIB).

The microwave signal source used is a HP 8672A synthesized signal generator. This unit allows the frequency to be selected very precisely and with excellent repeatability, which is an advantage when trying to maximize the system's accuracy. If this instrument is not available one can use the HP 8620C or a similar sweep generator. An advantage of this latter unit is that because of a special link between it and a 8410B network analyzer, frequency spans of much greater than an octave may be achieved without any manual change. The disadvantage of the sweeper is that the frequency cannot easily be set as accurately (although more than adequately for most measurements), and the power level cannot be set remotely. This latter feature is important for the most accurate amplitude and phase measurements.

The reflection/transmission units are either the model 8743A for coaxial measurements or the various waveguide units. The programmable IF attenuator is incorporated into the HP 8418 auxiliary power supply in order to control the test channel IF signal to the polar display. The analog outputs from the phase/magnitude and polar displays are fed into the multi-channel analog digital converter. The magnitude data is derived from the phase-magnitude display and the phase data from the polar display. This arrangement is used because phase from the phase-magnitude display is ambiguous at ±180 degrees while magnitude derived from the polar display varies as a function of phase (quadrature error). In the new application note 221A, Hewlett-Packard reports that a slight accuracy improvement can be obtained by obtaining magnitude information from the polar display for high-loss components.

The bus-compatible HP 59306A relay actuator controls both the IF attenuator (40, 20, 10 dB steps) and the coaxial reflection/transmission test unit. The details of this wiring are in Appendix F. By adjusting the IF attenuator in the polar display signal line, the display dot can be kept in the best measurement region, neither off-scale nor too close to the center. If the automatic internal attenuator is not available, however, either one must tolerate reduced accuracy with the dot near the center or an attenuator can be manually inserted in the Test Amplitude line. The user must remember in the latter case that changing the attenuation in this line changes the magnitude reading of the 8410B. Thus, each attenuator change requires a new calibration.

All three channels of the analog-to-digital converter are adjusted for a full-scale reading at ±2.5 volts. The 10 bit resolution of this instrument then gives a minimum resolvable step size of about 2.5 mv.

If this degree of resolution is considered inadequate, a very precise digital voltmeter can be included as the measuring instrument. In our case the instrument was controlled through the HP-IB and the three signals to be measured were routed to the meter by switches as shown in Figure 2. Based on a short period of testing, the additional resolution offered by the separate voltmeter does not seem worth the extra complexity because the actual improvement in accuracy is fairly small, due to other instrument factors.

ERROR CORRECTION TECHNIQUES

The error correcting algorithms were taken from Hewlett-Packard's application note and will not be elaborated upon here beyond a short description, using their notation. In addition a detailed description of the algorithm used for computing the center of a sliding load on the Smith chart will be presented since it is not thoroughly discussed in the application note. This information was obtained from HP through private correspondence.

The three major sources of error encountered in network analysis measurements are Directivity, Source Match, and Frequency Tracking. Directivity is the error due to a coupler or bridge's inability to fully separate incident and reflected waves. It can be easily determined by use of a calibrated

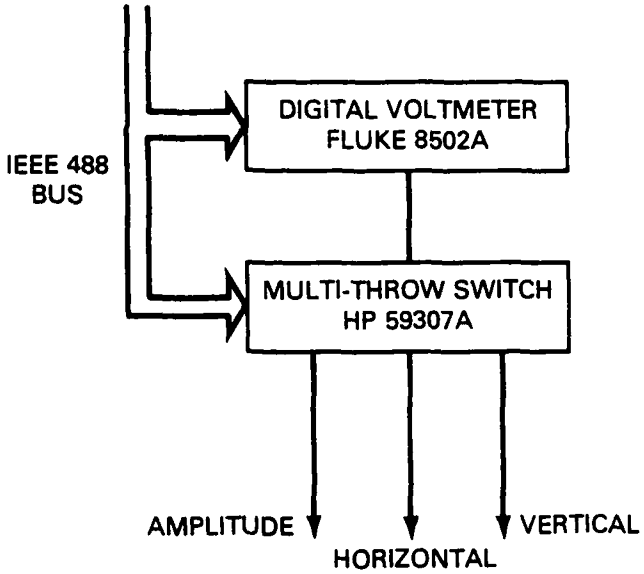


Fig. 2 - Block diagram of the digital voltmeter option

50 ohm load, with best results obtained with a sliding load and the center of a circle routine. The Directivity error vector is then given by

$$E_{DIR} = E_{LOAD}$$

Source Match is the error due to multiple reflections between the test port and the unknown device. These reflections add to the original incident signal, thus causing the reflection coefficient to appear larger or smaller (depending on the phase between the incident and re-reflected signals) than its actual value. Source Match error is an inevitable aspect of the test set, since the test port is never exactly at the characteristic impedance. It is determined by the use of three calibration standards: a load, a short, and either an open circuit or an offset short. The calculation is as follows:

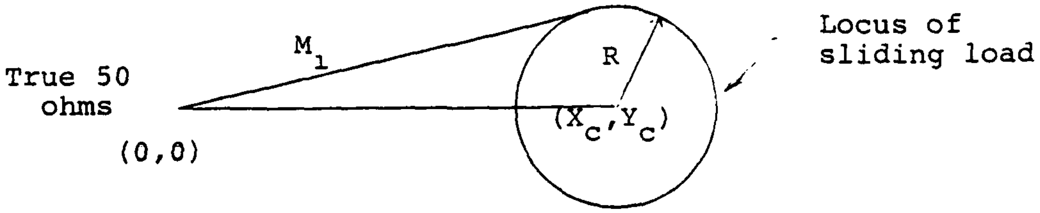
$$E_{SM} = \frac{e^{j\beta}\left(E_{OPEN} - E_{LOAD}\right) - \left(E_{LOAD} - E_{SHORT}\right)}{E_{OPEN} - E_{SHORT}}$$

where β is the phase angle of the open (due to its fringing capacitance) or the phase angle of the offset short (due to the distance the short is offset from the reference plane). β will be calculated for both cases in the MAIN program section.

Frequency Tracking error is caused by physical differences between the test and reference channels. Theoretically the two channels are supposed to be identical, however, realistically this is impossible. The effect of these differences (for example, between the respective couplers and cables and inside the harmonic converter) tend to vary with frequency and can be computed as follows:

$$E_{FT} = \left(1 + E_{SM}\right)\left(E_{LOAD} - E_{SHORT}\right)$$

When using a sliding load to determine the directivity, it becomes necessary to employ the "center of the circle" routine. Vectorally, the directivity of this situation looks as follows:



Thus, the magnitude of the directivity is given by $\sqrt{X_c^2 + Y_c^2}$ and in complex notation, directivity = $X_c \pm jY_c$.

Since the locus of the sliding load is not a perfect circle, any X_c and Y_c will contain some error. The error in X_c and Y_c can be minimized by using a least-squares fitting of a circle to the locus of the sliding load. It then follows that the error in X_c and Y_c is given by the summation:

$$\text{Error} = S = \sum_{n=1}^{N} \left(|P_n - C| - R \right)^2$$

where

$P_n = (X_n, Y_n) = n^{th}$ data point

$C = (X_c, Y_c)$ = center of circle

R = radius of circle

To minimize S, we must find it's partial derivatives with respect to the independent variables, set them equal to zero, and solve for the unknown parameters in terms of known quantities. The resulting equations are as follows:

$$\frac{\partial S}{\partial X_c} = -2NX_c + \sum_{1}^{N} 2X_n - 2R \sum_{1}^{N} \frac{X_n - X_c}{|P_n - C|} = 0$$

$$\frac{\partial S}{\partial Y_c} = -2NY_c + \sum_{1}^{N} 2Y_n - 2R \sum_{1}^{N} \frac{Y_n - Y_c}{|P_n - C|} = 0$$

$$\frac{\partial S}{\partial R} = 2NR - 2 \sum_{1}^{N} |P_n - C| = 0$$

Thus,

$$X_c = \frac{1}{N} \sum_{1}^{N} X_n - \frac{R}{N} \sum_{1}^{N} \frac{X_n - X_c}{|P_n - C|}$$

$$Y_c = \frac{1}{N} \sum_{1}^{N} Y_n - \frac{R}{N} \sum_{1}^{N} \frac{Y_n - Y_c}{|P_n - C|}$$

$$R = \frac{1}{N} \sum_{1}^{N} |P_n - C|$$

These equations can be solved by iteration, using $X_c = \frac{1}{N} \sum_{n=1}^{N} X_n$ and $Y_c = \frac{1}{N} \sum_{n=1}^{N} Y_n$ as the starting point. Then continue by computing an R, substituting it into a new estimate at (X_1, Y_c), and so forth until the solution converges to within a given tolerance of the exact solution. This process usually requires only a few iterations to achieve convergence to 0.5% change in R from one iteration to the next.

Waveguide Measurements

The semi-automatic network analyzer can be easily modified for waveguide measurements. The coax reflection/transmission unit is replaced by a waveguide test set, and minor software changes are made in the Source Match and Frequency Tracking routines of the program. Calculations of Source Match and Frequency Tracking errors will require data from two offset shorts, which are approximately $\lambda_g/4$ difference in distance from the reference flange (one short offset by $\lambda_g/8$ and the other by $3\ \lambda_g/8$). Unlike coaxial measurements, an open waveguide can not be used as a calibration standard, since it more closely resembles a termination than a perfect reflection. The equation for calculating the Source Match becomes

$$E_{SM} = e^{ja}\,\frac{-e^{j\beta}\left(E_{3/8} - E_{LOAD}\right) - \left(E_{LOAD} - E_{1/8}\right)}{E_{3/8} - E_{1/8}}$$

and Frequency Tracking becomes

$$E_{FT} = \left(e^{ja} + E_{SM}\right)\left(E_{LOAD} - E_{1/8}\right)$$

where $\beta = 0.024\ L_2F\sqrt{1 - (F_1/F)^2}$

$a = 0.024\ L_1F\sqrt{1 - (F_1/F)^2}$

All variables in the above expressions are defined or can be derived from the Variable List.

OUTLINE OF MAIN PROGRAM

I. Return Loss

  A. Calibration

    1. Set test unit to reflection.
    2. Connect load (either fixed or sliding)
    3. Read voltages from polar display outputs X and Y and correct for offset voltages. Use these voltages to compute the phase angle:

$$\emptyset = \text{arc tan}\ (Y/X)$$

    4. Read voltage from rectangular display output (50 mv/dB) and convert voltage to dB.

    5. Convert dB reading to scattering coefficients:

$$|\rho| = 10^{dB/20}$$

    6. Now change ρ into rectangular form

$$|\rho|_x = |\rho|\ \text{COS}\ \emptyset$$
$$|\rho|_y = |\rho|\ \text{SIN}\ \emptyset$$

7. Store $|\rho|_x$ and $|\rho|_y$ in directivity array; E(1,F) and E(2,F) respectively.

8. Now connect short and follow steps 3 through 6, store as $E_{SHORT} = P(1,F)$ $jP(2,F)$

9. Connect open and follow steps 3 through 6 and store as $E_{OPEN} = P(3,F) + jP(4,F)$.

10. Now compute the Source Match and Frequency Tracking errors:

$$E_{MATCH} = \frac{\pm\ e^{j\beta}\ [E_{OPEN} - E_{LOAD}] - [E_{LOAD} - E_{SHORT}]}{E_{OPEN} - E_{SHORT}}$$

$e^{j\beta} = \cos(\beta) + j\sin(\beta)$

For open circuit programs,

Use + Sign

$\beta = 2\tan^{-1}(2\pi fcZ_o)$

f = Current frequency

Z_o = Characteristic impedance

C = Capacitance of open circuit

For short circuit programs,

$E_{OPEN} \longrightarrow E_{OFFSET}$

Use - Sign
B = 0.024fL
L = Distance of offset from reference plane

$E_{TRACK} = [1 + E_{MATCH}]\ [E_{LOAD} - E_{SHORT}]$

NOTE: E_{LOAD}, E_{SHORT}, and E_{OPEN} are complex

numbers, thus E_{MATCH} and E_{TRACK} are also complex.

B. Measurements and Calculations

1. Connect the device which is to be measured, and follow steps 3-6 of Section A. The angle computed in step 3 is the uncorrected phase angle just as the reading from the rectangular display is the uncorrected return loss (dB). Store uncorrected ρ for the device in E_{MEAS}

$$E_{CORR} = \frac{E_{MEAS} - E_{LOAD}}{E_{TRACK} + [E_{MEAS} - E_{LOAD}]E_{MATCH}}$$

$$E_{CORR} = X_{CORR} + j\,Y_{CORR}$$

$$\Phi_{CORR} = \text{ATN}\left(Y_{CORR}/X_{CORR}\right)$$

3. Now convert E_{CORR} to dB

$$\text{SWR(dB)} = 20 \log E_{CORR}$$

II. Insertion Loss

A. Calibration

1. Set test unit to transmission
2. Connect straight-through cable
3. Follow steps 3-6 in part I - Section A. Store results as $E_{TRAN} = E(7,F) + jE(8,F)$

B. Measurement and Calculations

1. Insert device and follow step 3 of section A above. Store data as E_{MEAS}.

2. Now compute the corrected insertion loss

$$E_{CORR} = E_{MEAS}/E_{TRAN}$$

$$E_{CORR} = X_{CORR} + jY_{CORR}$$

$$\Phi_{CORR} = \text{ATN } (Y_{CORR}/X_{CORR})$$

3. Now convert E_{CORR} to dB

$$\text{Loss (dB)} = 20 \log E_{CORR}$$

TYPICAL RESULTS AND ACCURACY

A variety of components were measured on the semi-automatic system to check its capabilities and performance. Some were also measured on the more elaborate HP 8542 automatic network analyzer for a comparison.

Figure 3 illustrates the ability of the system to remove large amounts of error. Here a 10 cm. APC-7 airline is added before calibration at the unknown port and reflection data is taken on a 1.2:1 mismatch over the 8-12 GHz band. The uncorrected data curve shows the measured data before any calculations have been performed on it.

The data ripple is largely due to the phasing interaction of the directivity error vector with the device under test. The second curve shows the standard corrected output of the program, and is an obvious and dramatic improvement in accuracy.

Figures 4 through 7 show the printed corrected data for two mismatches measured with and without the 10 cm. airline. The agreement between the two sets of information is extremely good, particularly in magnitude.

Several different calibration standards can be used, depending on the accuracy desired and the time available. An open circuit is the most convenient but offset short circuits can be substituted, with a potential increase in accuracy. This is because the short circuit can be manufactured and characterized more precisely. In addition, waveguide systems can only be operated that way. Also either a fixed or sliding load can be used. As described earlier in the report, with a sliding load the directivity vector center can be measured very accurately, whereas the accuracy with a fixed load depends more heavily on having a high quality load. The time penalty for using a sliding load is fairly substantial because of the extra measurements that are necessary.

A possible source of error (+.25dB, +2°) is the use of different local oscillator harmonics in the harmonic converter during calibration and measurement. The excellent repeatability of the synthesizer minimizes this offset, but other than controlling the LO frequency directly, the only means to reduce it more is to repeat the measurements and average the results. We have made some comparisons between single and multiple measurements and found slight improvement for the latter case with high insertion loss devices. Most of the time the single measurement approach seems sufficient. Another source of error is the AC ripple on the outputs of the polar display. This ripple is most significant when measuring high insertion loss or high return loss devices. In order to reduce this error, each point on the polar display is read ten times and averaged.

These different measurement and calibration approaches make a significant impact on the measurement time. Table 1 shows typical amounts of time to perform calibration and device measurements for various conditions. Performing a more elaborate calibration substantially increases the time required. These times could be reduced by using a faster calculator. Recent desktop computers probably would permit the time to fall by a factor of 6-8, depending on the proportion of running time spent on measurements as opposed to calculations. Newer computers might also have a larger semiconductor memory, which would permit more frequency points to be taken in a single span.

TABLE 1
OPERATION TIMES

Number of Loops	Load Type	Calibration Time (min.)	Device Time (min.)	Number of Freq. Points
One	Fixed	8	3	41
One	Sliding	26	3	41
Five	Sliding	95	10	41

Figures 8 through 10 give a comparison between results obtained by calibrating with an open circuit (upper half of the figures) or with offset short circuits. The data for an open circuit, 2:1 mismatch, and offset short circuit demontrate excellent agreement between the two methods.

Figure 11 is a listing from the semi-automatic system of a 10 dB attenuator while Figure 12 is a similar printout from the 8542 automatic network analyzer for the same device. Figure 13, 8542 data of an open circuit, should be compared against the lower printout in Figure 8. The results from the small system in insertion loss measurements are generally within ±0.2 dB in magnitude and ±1.5° in phase of the more accurate system. Return loss measurements are usually within ±5% of the reflection coefficient measured on the larger system.

Occasionally a bad point will be measured during calibration that will throw the corrected measurements off slightly. To check for this condition, runs should be made with a known reflection component or the same through cable used for calibration. Figures 14 and 15 show examples of successful checks. The magnitude should not change by more than 0.1 dB or the phase by more than 0.5°.

Finally, Figure 16 gives an example of a Smith Chart plot, showing the standard frequency point labels and optional VSWR circle.

CONCLUSION

A manual microwave network analyzer was modified to permit semi-automatic operation and more accurate performance. By storing calibration information in a desktop computer, measurement data can be corrected to be within ±0.2 dB in magnitude and ±1.5° in phase angle of the most accurate computer-controlled analyzer available. The semi-automatic system is fairly easy to use and presents the corrected data in very convenient formats, either tables or plots.

The cost of the additional equipment is comparatively modest, considering the benefits, and can be even more so if the desktop computer is already available.

REFERENCES

1. R.L. Chilluffo and J.M. Eardley, "Microwave Semi-Automatic Network Analyzer", NRL Memo Report 2997, March 1975.

2. Hewlett-Packard, "Semi-Automatic Measurements using the 8410B Microwave Network Analyzer and the 9825A Desk-Top Computer", Application Note 221, May 1978 (2nd edition Feb. 1980).

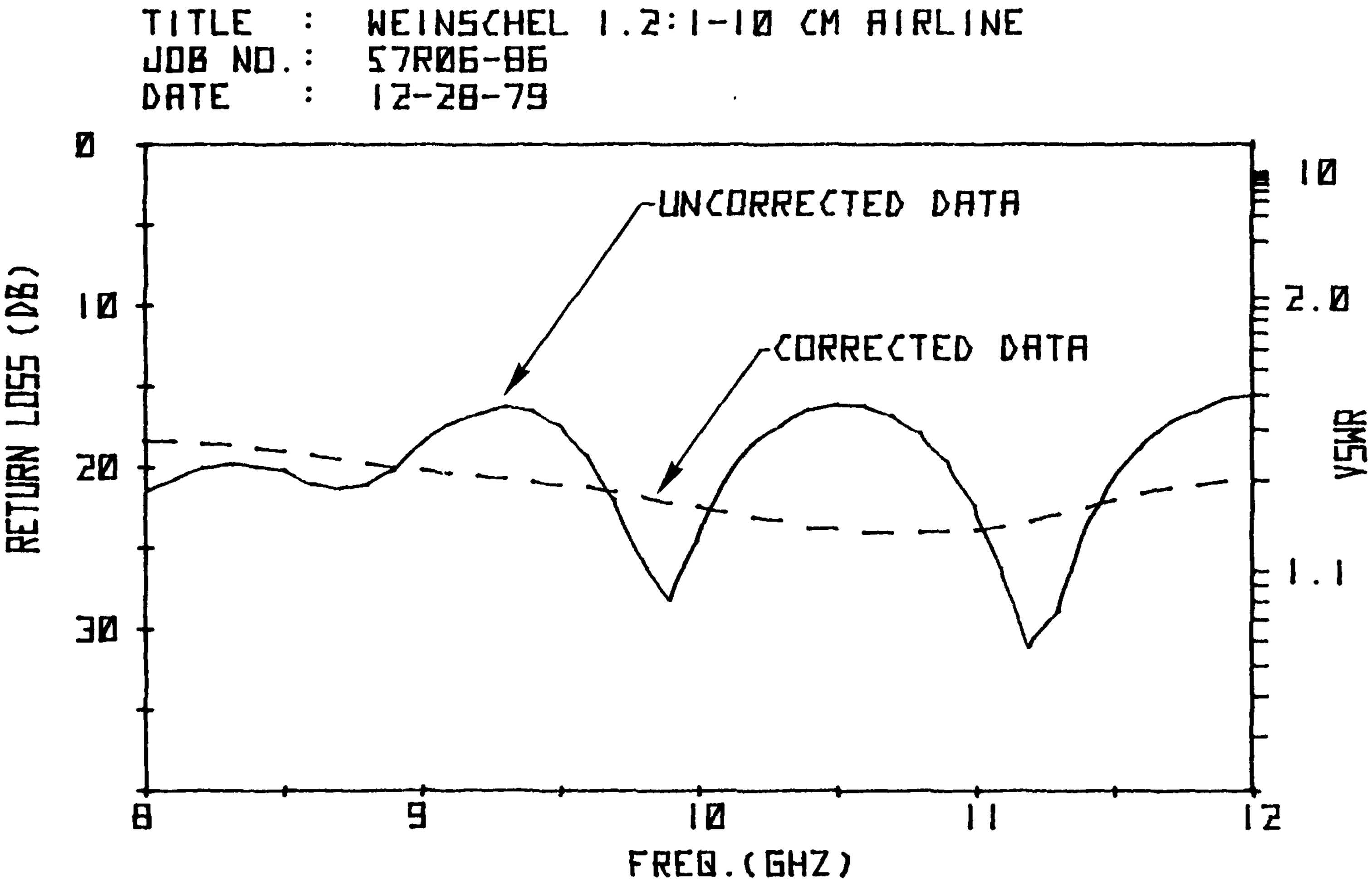


Fig. 3 - Plot of reflection data for 1.2:1 mismatch, showing both corrected and uncorrected curves

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                                        JOB NUMBER :  57R06-66

                                        DATE :  12-27-79
                                        TIME :  12:46

                         WEINSCHEL 1.2:1 MISMATCH

FREQ              VSWR              RETURN-LOSS              REFL-ANG
MHZ                                    -DB-                    -DEG-

  8000            1.26                -18.2                    173.8
  8100            1.27                -18.4                    173.1
  8200            1.27                -18.6                    172.7
  8300            1.26                -18.8                    171.9
  8400            1.25                -19.0                    170.9
  8500            1.25                -19.1                    169.3
  8600            1.25                -19.2                    168.6
  8700            1.24                -19.4                    168.3
  8800            1.23                -19.7                    167.5
  8900            1.23                -19.9                    166.6
  9000            1.22                -20.1                    165.8
  9100            1.21                -20.4                    164.8
  9200            1.21                -20.6                    165.3
  9300            1.20                -20.9                    165.3
  9400            1.19                -21.2                    164.7
  9500            1.19                -21.3                    164.8
  9600            1.18                -21.5                    165.2
  9700            1.18                -21.7                    166.1
  9800            1.17                -22.0                    166.1
  9900            1.16                -22.4                    167.0
 10000            1.16                -22.6                    167.6
 10100            1.16                -22.8                    167.0
 10200            1.15                -23.1                    167.2
 10300            1.14                -23.4                    169.2
 10400            1.14                -23.8                    171.9
 10500            1.13                -24.1                    174.7
 10600            1.13                -24.1                    177.6
 10700            1.13                -24.2                   -179.6
 10800            1.13                -24.1                   -175.2
 10900            1.13                -24.2                   -172.1
 11000            1.13                -24.1                   -168.0
 11100            1.14                -23.7                   -166.0
 11200            1.15                -23.3                   -164.8
 11300            1.15                -23.0                   -163.9
 11400            1.16                -22.8                   -162.7
 11500            1.16                -22.5                   -161.2
 11600            1.17                -22.1                   -159.3
 11700            1.18                -21.7                   -159.2
 11800            1.19                -21.2                   -158.8
 11900            1.20                -20.9                   -158.8
 12000            1.20                -20.7                   -159.6
```

Fig. 4 - Table of reflection data for 1.2:1 mismatch, measured directly

JOB NUMBER : 57R06-86

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WEINSCHEL 1.2:1-10 CM AIRLINE

FREQ MHZ	VSWR	RETURN-LOSS -DB-	REFL-ANG -DEG-
8000	1.27	-18.4	176.0
8100	1.27	-18.5	174.7
8200	1.27	-18.6	173.7
8300	1.26	-18.8	172.5
8400	1.25	-18.9	171.0
8500	1.25	-19.1	170.2
8600	1.24	-19.3	169.2
8700	1.24	-19.5	168.6
8800	1.23	-19.8	168.2
8900	1.22	-20.0	166.5
9000	1.22	-20.2	165.8
9100	1.21	-20.4	164.9
9200	1.21	-20.5	164.6
9300	1.20	-20.7	164.9
9400	1.20	-21.0	165.4
9500	1.19	-21.0	165.4
9600	1.19	-21.2	164.9
9700	1.18	-21.5	166.4
9800	1.18	-21.8	167.6
9900	1.17	-22.2	167.7
10000	1.16	-22.5	168.2
10100	1.16	-22.8	168.7
10200	1.15	-23.2	169.9
10300	1.14	-23.4	171.6
10400	1.14	-23.6	172.8
10500	1.14	-23.8	176.4
10600	1.14	-24.0	179.2
10700	1.13	-24.1	-177.5
10800	1.13	-24.0	-173.9
10900	1.14	-23.8	-170.7
11000	1.14	-23.9	-166.5
11100	1.14	-23.7	-163.6
11200	1.15	-23.4	-161.2
11300	1.15	-22.9	-160.5
11400	1.16	-22.5	-160.0
11500	1.17	-22.0	-159.1
11600	1.18	-21.6	-158.0
11700	1.19	-21.3	-157.5
11800	1.20	-21.0	-156.9
11900	1.20	-20.9	-158.0
12000	1.21	-20.6	-159.0

Fig. 5 - Table of reflection data for 1.2:1 mismatch, measured through a 10 cm. airline

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                                                    DATE :   12-27-79
                                                    TIME :   12:59

                              WEINSCHEL 2.0:1 MISMATCH

    FREQ               VSWR               RETURN-LOSS              REFL-ANG
    MHZ                                      -DB-                    -DEG-

     8000              2.00                  -9.5                   -174.5
     8100              2.01                  -9.5                   -174.2
     8200              2.00                  -9.5                   -173.5
     8300              2.02                  -9.4                   -173.4
     8400              2.01                  -9.5                   -173.6
     8500              2.02                  -9.4                   -174.2
     8600              2.04                  -9.3                   -174.3
     8700              2.05                  -9.3                   -174.1
     8800              2.05                  -9.3                   -174.3
     8900              2.06                  -9.2                   -174.6
     9000              2.06                  -9.2                   -174.9
     9100              2.06                  -9.2                   -175.6
     9200              2.07                  -9.2                   -175.6
     9300              2.06                  -9.2                   -175.6
     9400              2.07                  -9.2                   -175.8
     9500              2.07                  -9.1                   -176.1
     9600              2.08                  -9.1                   -176.5
     9700              2.08                  -9.1                   -177.0
     9800              2.08                  -9.1                   -177.4
     9900              2.07                  -9.1                   -177.6
    10000              2.07                  -9.2                   -177.7
    10100              2.07                  -9.2                   -178.4
    10200              2.06                  -9.2                   -179.0
    10300              2.05                  -9.3                   -179.5
    10400              2.03                  -9.4                   -179.4
    10500              2.03                  -9.4                   -179.4
    10600              2.02                  -9.4                   -179.3
    10700              2.02                  -9.4                   -179.4
    10800              2.01                  -9.5                   -179.4
    10900              2.00                  -9.5                   -179.6
    11000              2.00                  -9.6                   -179.4
    11100              1.99                  -9.6                   -178.9
    11200              1.99                  -9.6                   -178.7
    11300              1.98                  -9.7                   -178.9
    11400              1.97                  -9.7                   -179.5
    11500              1.96                  -9.8                   -179.4
    11600              1.95                  -9.9                   -178.7
    11700              1.94                  -9.9                   -178.1
    11800              1.95                  -9.9                   -177.5
    11900              1.94                  -9.9                   -177.2
    12000              1.94                  -9.9                   -176.9
```

Fig. 6 - Table of reflection data for 2:1 mismatch, measured directly

```
                                            JOB NUMBER :  57R06-86

                                            DATE :  12-28-79
                                            TIME :  10:53

                         WEINSCHEL 2.0:1-10 CM AIRLINE

FREQ            VSWR          RETURN-LOSS           REFL-ANG
MHZ                               -DB-                 -DEG-

  8000          2.04              -9.3                -172.2
  8100          2.08              -9.1                -173.4
  8200          2.05              -9.2                -175.8
  8300          2.01              -9.5                -177.0
  8400          1.98              -9.7                -176.3
  8500          1.95              -9.8                -173.0
  8600          1.96              -9.8                -172.5
  8700          1.99              -9.6                -171.2
  8800          2.00              -9.5                -171.2
  8900          2.02              -9.5                -171.4
  9000          2.05              -9.3                -171.5
  9100          2.05              -9.3                -173.3
  9200          2.07              -9.2                -173.9
  9300          2.08              -9.1                -174.3
  9400          2.10              -9.0                -174.2
  9500          2.11              -9.0                -174.8
  9600          2.13              -8.9                -175.7
  9700          2.13              -8.9                -175.7
  9800          2.13              -8.8                -176.7
  9900          2.12              -8.9                -177.4
 10000          2.08              -9.1                -178.7
 10100          2.06              -9.2                -179.5
 10200          2.02              -9.4                -179.2
 10300          2.00              -9.5                -178.9
 10400          1.99              -9.6                -178.3
 10500          2.00              -9.6                -177.7
 10600          2.00              -9.6                -177.6
 10700          1.99              -9.6                -177.0
 10800          1.99              -9.6                -177.4
 10900          2.00              -9.5                -177.3
 11000          2.00              -9.6                -177.8
 11100          1.99              -9.6                -177.5
 11200          1.97              -9.7                -177.4
 11300          1.96              -9.8                -177.7
 11400          1.97              -9.7                -177.7
 11500          1.97              -9.7                -177.7
 11600          1.96              -9.8                -177.2
 11700          1.96              -9.8                -176.6
 11800          1.95              -9.8                -176.9
 11900          1.94              -9.9                -177.3
 12000          1.95              -9.9                -177.1
```

Fig. 7 - Table of reflection data for 2:1 mismatch, measured through a 10 cm. airline

```
                                        JOB NUMBER :  57R06-86

                                        DATE :   12-28-79
                                        TIME :   15:41

                          HP OPEN 2-ED

FREQ          VSWR          RETURN-LOSS          REFL-ANG
MHZ                            -DB-               -DEG-

  8000       -360.07            0.0               -22.9
  8500       -325.68            0.1               -24.2
  9000       -342.88            0.1               -25.9
  9500        999.00           -0.0               -26.9
 10000       -344.05            0.1               -28.2
 10500        999.00            0.0               -30.1
 11000        999.00           -0.0               -31.5
 11500        999.00           -0.0               -32.7
 12000       -387.19            0.0               -33.7
 12500        365.30           -0.0               -35.3
```

```
                                        JOB NUMBER :  57R06-86

                                        DATE :   12-31-79
                                        TIME :   11:58

                          HP OPEN 2-ED

FREQ          VSWR          RETURN-LOSS          REFL-ANG
MHZ                            -DB-               -DEG-

  8000        999.00            0.0               -23.9
  8500       -138.65            0.1               -25.5
  9000       -196.89            0.1               -26.0
  9500        -78.40            0.2               -28.6
 10000       -140.57            0.1               -29.5
 10500       -224.71            0.1               -31.5
 11000       -150.81            0.1               -33.5
 11500       -106.49            0.2               -34.5
 12000       -276.86            0.1               -36.2
 12500       -431.11            0.0               -37.7
```

Fig. 8 - Reflection data for open circuit, calibrated with shielded open (top) and offset short (bottom)

```
                                                        JOB NUMBER :   57R06-86

                                                        DATE :   12-28-79
                                                        TIME :   15:47

                                    HP OFFSET SHORT 5-FP

FREQ            VSWR              RETURN-LOSS              REFL-ANG
MHZ                                  -DB-                    -DEG-

  8000        -447.43                 0.0                    -59.2
  8500        -362.66                 0.0                    -74.6
  9000         279.70                -0.1                    -89.9
  9500        -143.96                 0.1                   -105.9
 10000         999.00                 0.0                   -121.7
 10500        -188.09                 0.1                   -135.9
 11000         999.00                 0.0                   -150.5
 11500         723.11                -0.0                   -165.9
 12000         102.27                -0.2                    178.6
 12500          70.37                -0.2                    163.9

                                                        JOB NUMBER :   57R06-86

                                                        DATE :   12-31-79
                                                        TIME :   11:52

                                    HP OFFSET SHORT 5-FP

FREQ            VSWR              RETURN-LOSS              REFL-ANG
MHZ                                  -DB-                    -DEG-

  8000         669.92                -0.0                    -60.1
  8500        -182.65                 0.1                    -75.6
  9000        -575.71                 0.0                    -90.1
  9500        -116.01                 0.1                   -107.2
 10000         310.48                -0.1                   -122.5
 10500        -179.09                 0.1                   -136.5
 11000         234.65                -0.1                   -151.1
 11500         193.90                -0.1                   -166.0
 12000         104.12                -0.2                    178.4
 12500          87.64                -0.2                    163.6
```

Fig. 9 - Reflection data for short circuit, calibrated with shielded open (top) and offset short (bottom)

```
                                        JOB NUMBER :  57R06-86

                                        DATE :   12-28-79
                                        TIME :   15:44

                         WEINSCHEL 2.0:1 MISMATCH

FREQ            VSWR           RETURN-LOSS            REFL-ANG
MHZ                                -DB-                  -DEG-

  8000          2.01               -9.5                 -174.3
  8500          2.03               -9.4                 -174.3
  9000          2.06               -9.2                 -175.7
  9500          2.07               -9.1                 -176.7
 10000          2.08               -9.1                 -178.4
 10500          2.03               -9.4                 -179.5
 11000          2.00               -9.5                 -179.1
 11500          1.97               -9.7                 -179.2
 12000          1.93              -10.0                 -177.8
 12500          1.95               -9.9                 -175.8
```

```
                                        JOB NUMBER :  57R06-86

                                        DATE :   12-31-79
                                        TIME :   12:00

                         WEINSCHEL 2.0:1 MISMATCH

FREQ            VSWR           RETURN-LOSS            REFL-ANG
MHZ                                -DB-                  -DEG-

  8000          2.00               -9.6                 -174.0
  8500          2.03               -9.3                 -174.1
  9000          2.06               -9.2                 -175.0
  9500          2.09               -9.1                 -176.1
 10000          2.10               -9.0                 -178.4
 10500          2.05               -9.3                 -178.5
 11000          2.00               -9.6                 -179.1
 11500          1.97               -9.7                 -178.8
 12000          1.94               -9.9                 -177.3
 12500          1.96               -9.8                 -176.1
```

Fig. 10 - Reflection data for 2:1 mismatch, calibrated with shielded open (top) and offset short (bottom)

JOB NUMBER : 57R06-67A

DATE : AUGUST 8, 1978

WEINSCHEL 10DB ATTEN

FREQ MHZ	INSERTION-LOSS -DB-	PHASE SHIFT -DEG-
8000	-10.2	36.4
8100	-10.1	31.5
8200	-10.2	27.4
8300	-10.2	23.5
8400	-10.2	18.9
8500	-10.2	15.2
8600	-10.2	10.3
8700	-10.1	6.2
8800	-10.2	2.3
8900	-10.2	-1.4
9000	-10.1	-5.4
9100	-10.2	-9.8
9200	-10.2	-13.6
9300	-10.1	-17.8
9400	-10.2	-20.8
9500	-10.1	-25.1
9600	-10.2	-29.9
9700	-10.1	-34.1
9800	-10.0	-38.5
9900	-10.2	-42.1
10000	-10.0	-44.7
10100	-10.1	-50.2
10200	-10.2	-53.2
10300	-10.2	-57.1
10400	-10.2	-61.2
10500	-10.0	-65.4
10600	-10.1	-69.3
10700	-10.1	-74.7
10800	-10.1	-78.5
10900	-10.2	-84.1
11000	-10.0	-88.3
11100	-10.2	-93.4
11200	-10.1	-97.1
11300	-10.3	-101.2
11400	-10.3	-104.5
11500	-10.4	-108.9
11600	-10.4	-113.3
11700	-10.3	-117.5
11800	-10.5	-123.3
11900	-10.4	-124.9
12000	-10.3	-130.9

Fig. 11 - Insertion loss data for 10 dB attenuator as measured on the semi-automatic system

```
                                                  AUGUST 4, 1978

                             WEINSCHEL 10DB ATTEN

 FREQ-MHZ     VSWR    RTN LOSS  REFL-ANG   LOSS-DB    PHASE
             MEAS 1    MEAS 1    MEAS 1    MEAS 1    MEAS 1
 4000.000      1.12     24.89    161.57      9.97   -161.26
 4200.000      1.07     29.17   -130.81     10.09   -170.12
 4400.000      1.10     26.82     10.92     10.18   -175.66
 4600.000      1.15     23.08     32.97     10.03    175.25
 4800.000      1.17     22.00     94.76     10.12    165.12
 5000.000      1.14     23.46   -171.30     10.22    159.10
 5200.000      1.18     21.56    -74.43     10.08    150.64
 5400.000      1.24     19.41     -8.81     10.10    140.37
 5600.000      1.22     19.96     56.24     10.21    134.51
 5800.000      1.15     23.37    151.07     10.12    126.83
 6000.000      1.19     21.40   -108.84     10.09    116.94
 6200.000      1.23     19.73    -50.45     10.23    110.26
 6400.000      1.17     22.09     -2.76     10.13    102.64
 6600.000      1.05     32.43    101.19     10.08     93.48
 6800.000      1.11     26.03   -132.55     10.25     85.90
 7000.000      1.14     23.81   -114.73     10.26     78.62
 7200.000      1.12     24.99    -98.22     10.20     69.88
 7400.000      1.13     24.43    -85.47     10.28     61.07
 7600.000      1.04     33.59    -11.93     10.23     53.91
 7800.000      1.13     24.54    116.14     10.18     45.49
 8000.000      1.27     18.57   -170.96     10.22     36.42
 8200.000      1.25     19.01   -116.67     10.21     28.72
 8400.000      1.23     19.70    -24.52     10.20     21.15
 8600.000      1.27     18.45     77.73     10.21     13.31
 8800.000      1.34     16.78    157.65     10.20      5.24
 9000.000      1.30     17.66   -129.87     10.09     -2.75
 9200.000      1.24     19.42    -41.15     10.01    -10.71
 9400.000      1.26     18.66     60.66     10.04    -19.23
 9600.000      1.33     17.04    139.13     10.16    -28.03
 9800.000      1.27     18.44   -127.97     10.11    -35.78
 10000.00      1.20     20.87    -29.83      9.95    -43.72
 10200.00      1.28     18.16     59.81     10.01    -51.88
 10400.00      1.24     19.33    135.25     10.10    -60.24
 10600.00      1.21     20.57   -117.32      9.92    -68.42
 10800.00      1.28     18.08    -28.08      9.98    -77.89
 11000.00      1.32     17.20     37.59     10.13    -86.07
 11200.00      1.19     21.20    124.42     10.14    -93.17
 11400.00      1.24     19.48   -128.63     10.13   -102.90
 11600.00      1.40     15.54    -56.72     10.31   -110.47
 11800.00      1.28     18.31     11.08     10.37   -116.93
 12000.00      1.17     22.06     95.28     10.16   -127.99
 12200.00      1.13     24.56   -128.00     10.19   -135.58
 12400.00      1.49     14.13   -110.44     10.29   -141.78
REF PLANE EXT(CM): INPUT=    .00 TRAN=    .00
```

Fig. 12 - Insertion loss data for 10 dB attenuator as measured on HP8542 network analyzer (compare to Fig. 11)

```
                                   AUGUST 4, 1978

                              HP OPEN 2-ED

FREQ-MHZ    VSWR    RTN LOSS  REFL-ANG
           MEAS 1    MEAS 1    MEAS 1
4000.000   301.69       .06    -13.53
4200.000   869.50       .02    -12.02
4400.000   999.00       .00    -11.81
4600.000   999.00     -.18     -11.72
4800.000   999.00     -.34     -13.25
5000.000   999.00     -.29     -15.45
5200.000   999.00     -.18     -15.73
5400.000   999.00     -.17     -16.19
5600.000   999.00     -.20     -17.09
5800.000   999.00     -.03     -17.95
6000.000   282.34       .06    -17.63
6200.000   999.00     -.03     -19.07
6400.000   999.00     -.01     -18.92
6600.000   999.00       .01    -19.02
6800.000   999.00       .01    -19.67
7000.000   325.94       .05    -20.38
7200.000   202.93       .09    -21.17
7400.000    86.26       .20    -21.01
7600.000   149.77       .12    -21.71
7800.000   124.65       .14    -22.20
8000.000    83.90       .21    -22.91
8200.000    96.16       .18    -26.02
8400.000   999.00     -.09     -26.30
8600.000   999.00     -.13     -26.10
8800.000   999.00     -.09     -26.76
9000.000   999.00     -.15     -26.57
9200.000   999.00     -.35     -27.29
9400.000   999.00     -.38     -29.39
9600.000   999.00     -.23     -30.87
9800.000   999.00     -.16     -30.87
10000.00   999.00     -.07     -31.31
10200.00   999.00     -.20     -31.44
10400.00   643.63       .03    -31.33
10600.00   999.00     -.06     -31.25
10800.00   999.00     -.07     -32.57
11000.00   999.00     -.11     -33.04
11200.00   999.00       .01    -33.73
11400.00   999.00     -.16     -34.68
11600.00   999.00     -.06     -35.54
11800.00   999.00     -.05     -36.13
12000.00   999.00     -.04     -37.10
12200.00   999.00     -.03     -37.59
12400.00   999.00     -.01     -38.15
REF PLANE EXT(CM): INPUT=    .00 TRAN=    .09
```

Fig. 13 - Reflection data for open circuit as measured on HP8542 network analyzer (compare to Fig. 8)

```
                                          JOB NUMBER :  57R06-36

                                          DATE :   12-31-79
                                          TIME :   11:06

                         CAL. CHECK - HP SHORT CIRCUIT

FREQ          VSWR          RETURN-LOSS          REFL-ANG
MHZ                            -DB-                -DEG-

  8000       -117.41            0.1                180.0
  8100        -86.65            0.2                179.7
  8200       -118.30            0.1                179.2
  8300        999.00           -0.0                179.0
  8400        121.80           -0.1                179.2
  8500        193.50           -0.1                179.6
  8600        193.27           -0.1                180.0
  8700        341.76           -0.1               -179.5
  8800        999.00           -0.0               -179.7
  8900        371.16           -0.0               -179.7
  9000       -368.65            0.0                179.9
  9100        206.43           -0.1               -179.0
  9200       -370.69            0.0               -179.9
  9300        999.00            0.0               -179.7
  9400       -376.94            0.0               -179.7
  9500        999.00            0.0               -179.8
  9600       -345.83            0.1               -179.7
  9700       -379.79            0.0               -179.7
  9800       -381.23            0.0               -179.8
  9900       -374.13            0.0               -179.9
 10000       -371.37            0.0                179.5
 10100        999.00           -0.0                179.4
 10200        999.00           -0.0                179.8
 10300        165.13           -0.1                179.5
 10400        340.71           -0.1                180.0
 10500        999.00            0.0               -179.7
 10600        999.00            0.0               -179.8
 10700        999.00           -0.0               -179.3
 10800        999.00            0.0                179.9
 10900        999.00           -0.0               -179.6
 11000        999.00           -0.0               -179.9
 11100       -384.88            0.0               -179.3
 11200        999.00           -0.0               -180.0
 11300        999.00            0.0               -179.7
 11400       -341.14            0.1                179.9
 11500        999.00            0.0               -179.6
 11600       -334.33            0.1               -180.0
 11700        999.00            0.0               -179.2
 11800        999.00           -0.0                179.7
 11900        999.00            0.0               -179.6
 12000        999.00            0.0               -179.9
```

Fig. 14 - Data indicating a successful reflection calibration

```
                                                   JOB NUMBER :  57R06-2

                                                   DATE :   12-28-79
                                                   TIME :   16:07

                              CAL. CHECK - FLEXCO

FREQ               INSERTION-LOSS                    PHASE SHIFT
MHZ                    -DB-                             -DEG-

 8000                  -0.0                             -0.0
 8100                   0.0                             -0.1
 8200                   0.0                              0.0
 8300                  -0.0                              0.0
 8400                   0.0                             -0.0
 8500                   0.0                              0.1
 8600                   0.0                             -0.0
 8700                  -0.0                             -0.2
 8800                   0.0                             -0.0
 8900                  -0.0                             -0.1
 9000                   0.0                             -0.1
 9100                   0.0                             -0.2
 9200                  -0.0                             -0.1
 9300                  -0.0                             -0.3
 9400                   0.0                              0.0
 9500                   0.0                              0.1
 9600                  -0.0                             -0.2
 9700                  -0.0                             -0.0
 9800                   0.0                             -0.1
 9900                   0.0                             -0.1
10000                  -0.0                             -0.1
10100                  -0.0                             -0.3
10200                  -0.0                             -0.1
10300                   0.0                              0.2
10400                  -0.0                             -0.3
10500                   0.0                             -0.1
10600                  -0.0                             -0.1
10700                   0.0                              0.0
10800                   0.0                              0.3
10900                  -0.0                             -0.4
11000                  -0.0                             -0.0
11100                  -0.0                             -0.2
11200                   0.0                              0.2
11300                  -0.0                             -0.1
11400                  -0.0                             -0.2
11500                  -0.0                             -0.4
11600                  -0.0                              0.2
11700                   0.0                             -0.3
11800                  -0.0                              0.4
11900                  -0.0                             -0.5
12000                  -0.0                             -0.3
```

Fig. 15 - Data indicating a successful transmission calibration

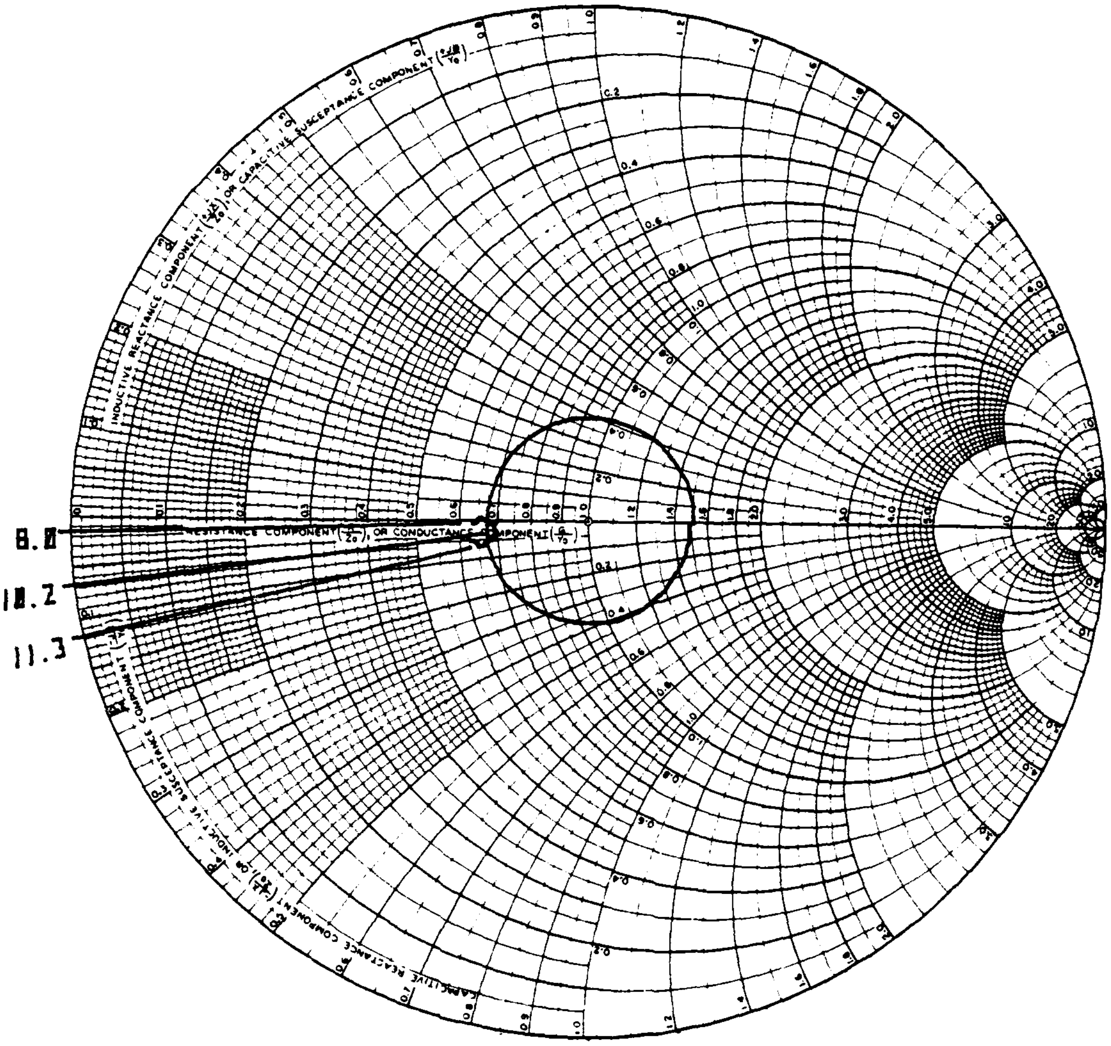


Fig. 16 - Typical Smith chart plot, showing 1.5:1 mismatch data and a reference 1.5:1 circle

APPENDIX A

EQUIPMENT LIST

Network Analyzer	HP 8410B/8411A
Polar Display	HP 8414A
Phase-Magnitude Display	HP 8412A
Auxiliary Power Supply (with Remote Attenuator and special Interface Cables)	HP 8418 opt H01 or K01 8418 Kit
Reflection/Transmission Test Set	HP 8743A or HP 8746A or HP 8745A
Relay Actuator	HP 59306A
Analog-to-Digital Converter	HP 59313A
Digital Clock	HP 59309A
Microwave Synthesizer	HP 8672A
Desk Top Computer with 16K Byte Memory	HP 9830A Opt. 276
Calculator Printer	HP 9866A
Calculator Plotter	HP 9862A
String Variable ROM	HP 11274B
Advanced Programming ROM	HP 11279B
Extended I/O ROM	HP 11272B
HP-IB Interface	HP 98034A
Calibration Components	See "Calibration Standards"
Digital Voltmeter (optional)	Fluke 8502A
VHF Switch	HP 59307A

APPENDIX B

PROGRAM LISTING

```
10 REM :  COMPUTES RETURN LOSS AND INSERTION LOSS ON COAXIAL SYSTEMS
20 REM :  FOR REMOTE ATTENUATOR
30 REM :  USES SHIELDED OPEN CIRCUIT IN RETURN LOSS CALIBRATION
40 REM :
50 DIM F[4],F$[30],P$[30],X$[3],D$[15],J$[15],A$[35]
60 DIM P5[12,41],M5[41],E5[8,41],X[41],Y[41]
70 DEG
80 K4=50 ------ Define line impedance
90 C1=409.6---- Define scale factor for 2.5V setting on A/D converter
100 B5=1
110 E5=5          Initialization of auto attenuator reference string
120 CMD "?U1","B123456"------ Zeros auto attenuator
130 A$="B3456A4B56A5B46A45B6A6B45A46B5B-5F6"
140 D$[1,1]="-"     ]
150 D$[2,3]="00"    ]  Clock string
160 D$[4,4]="."     ]
170 DISP "ENTER JOB NUMBER";
180 INPUT J$
190 DISP "ENTER 8672A GEN. OUTPUT CODES";
200 INPUT X$
210 DISP "RETURN LOSS-(Y/N)";]  Define measurement type
220 INPUT H$                 ]
230 DISP "ENTER FREQ RANGE-START,STOP,STEP";]
240 INPUT F[1],F[2],F[3]                    ]
250 F[4]=INT((F[2]-F[1])/F[3])+1            ]
260 IF F[4]<42 THEN 290                     ]
270 BEEP                                    ]
280 GOTO 230                                ]  Set frequency range
290 F[1]=F[1]*1000                          ]  and confirm number
300 F[2]=F[2]*1000                          ]  of data points below 41
310 F[3]=F[3]*1000                          ]
320 BEEP                                    ]
330 DISP "SET FREQ. RANGE ON ANALYZER";
340 STOP
350 CMD "?U3"
360 FORMAT B          Set synthesizer into remote mode
370 OUTPUT (13,360)768
380 FORMAT "K",F2.0     ]
390 FORMAT "L",F2.0     ]
400 FORMAT "O",F2.0     ]  Set output level range and vernier
410 OUTPUT (13,380)X$[1,1]]  on the synthesizer, plus ALC
420 OUTPUT (13,390)X$[2,2]]
430 OUTPUT (13,400)X$[3]  ]
440 DISP "HOW MANY LOOPS DO YOU WANT";]  Set number of loops
450 INPUT J1                          ]
460 IF H$="N" THEN 1010
470 DISP "OPEN UNKNOWN PORT";
480 STOP
490 DISP "SET TEST CHANNEL GAIN";
500 STOP
510 GOSUB 5550 ---------Read polar display offset voltages for each frequency
520 P$="RETURN LOSS"
530 R1=0
540 DISP "ENTER CAPACITANCE OF OPEN"; --- Define capacitance of open circuit
550 INPUT K3
```

```
560 B5=11             Set auto attenuator for sliding
570 E5=15             load connection check
580 CMD "?U1","A5B46
590 DISP "CONNECT CALIBRATION LOAD";
600 STOP
610 DISP "SLIDING TYPE-(Y/N)?";  ┐
620 INPUT L$                     │
630 IF L$="N" THEN 820           │
640 R=1                          │
650 FOR I=1 TO 6                 │
660 GOSUB 1770                   │
670 IF I=6 THEN 790              │
680 IF I>1 THEN 710              │
690 J=2                          │
700 GOTO 750                     │
710 IF I=3 THEN 740              │
720 J=1                          │
730 GOTO 750                     │
740 J=2                          │  Sliding load routine
750 BEEP                         │
760 DISP "SLIDE"J                │
770 STOP                         │
780 R=R+2                        │
790 NEXT I                       ┘
800 GOSUB 2360 -------- Find center of circle and store directivity
810 GOTO 880            as E(1,F), E(2,F)
820 R=1
830 GOSUB 1770 -------- Read data if not sliding load
840 FOR F=1 TO F[4]   ┐
850 E[1,F]=P[1,F]     │ Store directivity as E(1,F), E(2,F)
860 E[2,F]=P[2,F]     │
870 NEXT F            ┘
880 BEEP
890 DISP "CONNECT CALIBRATION SHORT";
900 STOP
910 R=1
920 GOSUB 1770 -------- Read data
930 M1=M[1]
940 BEEP
950 DISP "CONNECT CALIBRATION OPEN";
960 STOP
970 R=3
980 GOSUB 1770 -------- Read data
990 GOSUB 2760 -------- Find source match and frequency tracking; store as
1000 GOTO 1190          E(3,F), E(4,F), and E(5,F), E(6,F) respectively.
1010 CMD "?U1","A2"
1020 DISP "CONNECT THROUGH";
1030 STOP
1040 DISP "SET TEST CHANNEL GAIN";
1050 STOP
1060 GOSUB 5550-------- Read polar display offset voltages for each frequency
1070 BEEP
1080 DISP "RELEASE BUTTON-PRESS CONT,EXEC";
1090 STOP
1100 R=1
1110 R1=1
1120 P$="INSERTION LOSS"
1130 GOSUB 1770-------- Read data
1140 FOR F=1 TO F[4]    Store transmission tracking as E(7,F), E(8,F)
1150 E[7,F]=P[R,F]
1160 E[8,F]=P[R+1,F]
```

```
1170 NEXT F
1180 M2=M[1]
1190 R=1
1200 FOR J=1 TO 6
1210 DISP "CONNECT DEVICE";
1220 STOP
1230 DISP "ENTER LABEL(UP TO 30 CHAR)";
1240 INPUT F$
1250 GOSUB 1770 ----------- Read data
1260 FOR F=1 TO F[4]
1270 X=P[R,F]
1280 Y=P[R+1,F]
1290 GOSUB 3890 ----------- Find uncorrected phase angle and store as
1300 P[4,F]=P3              P(4,F)
1310 IF H$="N" THEN 1400 ---Test for measurement type
1320 V1=P[R,F]-E[1,F]   ]  (EMEAS - ELOAD) = NUM
1330 U1=P[R+1,F]-E[2,F] ]
1340 V2=E[3,F]]
1350 U2=E[4,F]]  ESM
1360 GOSUB 3070 ----- Complex multiply
1370 V3=E[5,F]+X]     (EMEAS- ELOAD) ESM + EFT = DEN
1380 U3=E[6,F]+Y]
1390 GOTO 1440
1400 V1=P[R,F]  ]
1410 U1=P[R+1,F]]     (EMEAS = NUM
1420 V3=E[7,F]]
1430 U3=E[8,F]]       ETT = DEN
1440 GOSUB 3010 ----- Complex divide
1450 P[5,F]=X*10↑3]   ECORR = NUM/DEN
1460 P[6,F]=Y*10↑3]
1470 GOSUB 3890 ----- Correct phase angle
1480 P[3,F]=P3
1490 P[1,F]=SQR(X↑2+Y↑2)
1500 IF P[1,F]=0 THEN 1530
1510 P[1,F]=20*(LGT(P[1,F]))------ |ECORR| dB = 20 log |ECORR|
1520 GOTO 1540
1530 P[1,F]=-9999
1540 NEXT F
1550 GOSUB 3110 ----------- Print Routine
1560 IF O$="Y" THEN 1650
1570 DISP "DO YOU WANT A PLOT";
1580 INPUT C$
1590 IF C$="N" THEN 1610
1600 GOSUB 3940  ---------- Plot Routine
1610 IF J#5 THEN 1650
1620 BEEP                                 ]
1630 DISP "CHECK CALIBRATION!!!"          ]
1640 STOP                                 ]
1650 NEXT J                               ]
1660 BEEP                                 ]
1670 DISP "DO YOU WANT TO RECALIBRATE";   ]
1680 INPUT C$                             ]     Calibration check reminder
1690 IF C$="Y" THEN 1710                  ]     and recalibration option
1700 GOTO 1200                            ]
1710 IF H$="Y" THEN 560                   ]
1720 DISP "CONNECT THROUGH";              ]
1730 STOP                                 ]
1740 GOTO 1100                            ]
1750 END                                  ]
```

```
1760 REM:  READS DATA POINTS
1770 FOR D=1 TO F[4]
1780 P[R,D]=0
1790 P[R+1,D]=0
1800 M[D]=0
1810 NEXT D
1820 FOR Z=1 TO J1 -----------Loop for harmonic phase lock error reduction
1830 D=0
1840 FOR F=F[1] TO F[2] STEP F[3] ---- Cycle through frequencies
1850 CMD "?U3"
1860 D=D+1
1870 FORMAT "P",F10.4,"Z0"
1880 OUTPUT (13,1870)F/1E+04 --------- Set frequency on synthesizer
1890 WAIT (100)
1900 X2=0
1910 Y2=0
1920 FOR K=1 TO 10
1930 CMD "?U&","H1AJ","F5"
1940 X=(ROT(RBYTE13,8)+RBYTE13)/C1       Read X and Y from polar
1950 CMD "?U&","H2AJ","F5"              display, take average, and
1960 Y=(ROT(RBYTE13,8)+RBYTE13)/C1       correct for voltage offset
1970 X2=X2+X
1980 Y2=Y2+Y
1990 NEXT K
2000 X=X2/10-X[D]
2010 Y=Y2/10-Y[D]
2020 M=SQR(X↑2+Y↑2)
2030 IF M>2 THEN 2110 --------- If magnitude too large increase attenuation
2040 IF M>0.5 OR B5=1 THEN 2170 If magnitude too small decrease attenuation
2050 B5=B5-5
2060 E5=E5-5
2070 CMD "?U1"
2080 OUTPUT (13,2320)A$[B5,E5]      Decrease attenuation
2090 WAIT 1000
2100 GOTO 1890
2110 B5=B5+5
2120 E5=E5+5
2130 CMD "?U1"
2140 OUTPUT (13,2320)A$[B5,E5]      Increase attenuation
2150 WAIT 1000
2160 GOTO 1890  ----------------   Magnitude ok, find phase angle
2170 GOSUB 3890
2180 CMD "?U&","H4AJ","F5"
2190 M=(ROT(RBYTE13,8)+RBYTE13)/C1 Read magnitude on 8412
2200 M=M/0.05 -------------------- Convert to dB
2210 S=10↑(M/20) ----------------- Scale
2220 M[D]=M+M[D]
2230 P[R,D]=S*COS(P3)+P[R,D]          Sum data
2240 P[R+1,D]=S*SIN(P3)+P[R+1,D]
2250 NEXT F
2260 NEXT Z
2270 FOR D=1 TO F[4]
2280 P[R,D]=P[R,D]/J1
2290 P[R+1,D]=P[R+1,D]/J1             Find average of data
2300 M[D]=M[D]/J1
2310 NEXT D
2320 FORMAT F2.0
2330 RETURN
```

```
2340 REM:  COMPUTES CENTER OF CIRCLE
2350 REM:  AND STORES DIRECTIVITY IN E(M,F)
2360 FOR F=1 TO F[4]
2370 D=F[1]+(F-1)*F[3]
2380 X=0
2390 Y=0
2400 FOR J=1 TO 11 STEP 2
2410 X=P[J,F]+X
2420 Y=P[J+1,F]+Y
2430 NEXT J
2440 X=X/6 ]
2450 Y=Y/6 ]
```

Average the six points

```
2460 C3=X
2470 C4=Y
2480 K=0
2490 B8=0
2500 R=1
2510 A2=0
2520 B2=0
2530 C=0 ---------- Start wth radius = 0
2540 B8=B8+1
2550 A1=P[R,F]-X
2560 B1=P[R+1,F]-Y
2570 T=SQR(A1↑2+B1↑2)
2580 IF T=0 THEN 2700
2590 A2=A2+A1/T
2600 B2=B2+B1/T
```

$$\sum_{1}^{N} \frac{P_n - C}{|P_n - C|}$$

```
2610 C=C+T --------
```

$$\sum_{I}^{N} |P_n - C|$$

```
2620 R=R+2
2630 IF R<13 THEN 2550
2640 C=C/6 ------------------------------------Radius =
```

$$\frac{1}{N} \sum_{1}^{N} |P_n - C|$$

```
2650 X=C3-C*A2/6 ]
2660 Y=C4-C*B2/6 ]
```

$$C = \frac{1}{N} \sum^{N} P_n - \frac{R}{N} \sum_{1}^{N} \frac{P_n - C}{|P_n - C|}$$

```
2670 IF ABS(C-K)<0.005*K OR B8=10 THEN 2700 ------- If change in R <0.5% or 10
                                                    approximations then finished
2680 K=C
2690 GOTO 2500
2700 E[1,F]=X]
2710 E[2,F]=Y]   Store in E(1,F), E(2,F)
2720 NEXT F
2730 RETURN
```

```
2740 REM:  COMPUTES SOURCE MATCH AND
2750 REM:  REFLECTION TRACKING AND STORES IN E(M,F)
2760 D=0
2770 FOR F=F[1] TO F[2] STEP F[3]
2780 D=D+1
2790 X=P[3,D]-E[1,D]]
2800 Y=P[4,D]-E[2,D]]
```

$E_{OPEN} - E_{LOAD}$

```
2810 V2=E[1,D]-P[1,D]]
2820 U2=E[2,D]-P[2,D]]
```

$E_{LOAD} - E_{SHORT}$

```
2830 V3=P[3,D]-P[1,D]]
2840 U2=P[4,D]-P[2,D]]
```

$E_{OPEN} - E_{SHORT}$

```
2850 G=10↑6/(2*PI*F*K4*K3)
2860 T=2*ATN(1/G)
2870 V1=X*COS(T)-Y*SIN(T)-V2]
2880 U1=X*SIN(T)+Y*COS(T)-U2]
```

$e^{j\beta} (E_{OPEN} - E_{LOAD}) - (E_{LOAD} - E_{SHORT})$

```
2890 GOSUB 3010 ------------ Complex divide
2900 E[3,D]=X ]
2910 E[4,D]=Y ]
```

$$E_{SM} = \frac{e^{j\beta}(E_{OPEN} - E_{LOAD}) - (E_{LOAD} - E_{SHORT})}{E_{OPEN} - E_{SHORT}}$$

```
2920 V1=X+1
2930 U1=Y
2940 GOSUB 3070 -------- Complex Multiply
2950 E[5,D]=X ]
2960 E[6,D]=Y ]
2970 NEXT F
2980 RETURN
```

$E_{ft} = (1 + E_{sm})\ (E_{LOAD} - E_{SHORT})$

```
2990 REM:  COMPLEX DIVIDE
3000 REM:  (V1+JU1)/(V3+JU3)
3010 V=V3↑2+U3↑2
3020 X=(V1*V3+U1*U3)/V
3030 Y=(V3*U1-V1*U3)/V
3040 RETURN


3050 REM:  COMPLEX MULTIPLY
3060 REM:  (V1+JU1)(V2+JU2)
3070 X=V1*V2-U1*U2
3080 Y=V1*U2+V2*U1
3090 RETURN


3100 REM:  PRINT ROUTINE
3110 R3=0
3120 PRINT LIN6
3130 FOR I=1 TO 2
3140 CMD "?U#","C"
3150 CMD "?5C"
3160 ENTER (13,3170)A,D$[5,15]
3170 FORMAT B,F2.0
3180 NEXT I
```

Reads date and time

```
3190 WRITE (15,3200)J$
3200 FORMAT 50X,"JOB NUMBER :  ",B
3210 PRINT
3220 WRITE (15,3230)D$[6,7],D$[1,1],D$[8,9],D$[1,1],D$[2,3]
3230 FORMAT 50X,"DATE :  ",B
3240 WRITE (15,3250)D$[10,11],D$[4,4],D$[12,13]
3250 FORMAT 50X,"TIME :  ",B
```

Prints date and time

```
3260 PRINT
3270 PRINT "                                  "F$
3280 PRINT
3290 IF R1=1 THEN 3600
3300 WRITE (15,3310)
3310 FORMAT 10X,"FREQ",10X,"VSWR",10X,"RETURN-LOSS",10X,"REFL-ANG"
3320 WRITE (15,3330)
3330 FORMAT 10X,"MHZ",29X,"-DB-",15X,"-DEG-"
3340 PRINT
3350 D=0
3360 FOR F=F[1] TO F[2] STEP F[3]
3370 D=D+1
3380 IF P[1,D]=0 THEN 3410
3390 V1=(1+10↑(P[1,D]/20))/(1-10↑(P[1,D]/20))
3400 IF 999>ABS(V1) THEN 3420
3410 V1=999
3420 WRITE (15,3430)F,V1,P[1,D],P[3,D]
3430 FORMAT 10X,F6.0,6X,F8.2,10X,F6.1,15X,F6.1
```

```
3440 NEXT F
3450 IF R3=1 THEN 3860
3460 DISP "UNCORRECTED DATA ALSO-(Y/N)";
3470 INPUT O$
3480 IF O$="N" THEN 3860
3490 PRINT LIN14
3500 PRINT "                               UNCORRECTED DATA"
3510 PRINT
3520 PRINT "                               "F$
3530 PRINT
3540 FOR D=1 TO F[4]
3550 P[1,D]=M[D]-M1
3560 P[3,D]=P[4,D]
3570 NEXT D
3580 R3=1
3590 GOTO 3300
3600 WRITE (15,3610)
3610 FORMAT 10X,"FREQ",15X,"INSERTION-LOSS",15X,"PHASE SHIFT
3620 WRITE (15,3630)
3630 FORMAT 10X,"MHZ",21X,"-DB-",23X,"-DEG-"
3640 PRINT
3650 D=0
3660 FOR F=F[1] TO F[2] STEP F[3]
3670 D=D+1
3680 WRITE (15,3690)F,P[1,D],P[3,D]
3690 FORMAT 9X,F6.0,18X,F6.1,21X,F6.1
3700 NEXT F
3710 IF R3=1 THEN 3860
3720 DISP "UNCORRECTED DATA ALSO-(Y/N)";
3730 INPUT O$
3740 IF O$="N" THEN 3860
3750 PRINT LIN14
3760 PRINT "                               UNCORRECTED DATA"
3770 PRINT
3780 PRINT "                               "F$
3790 PRINT
3800 FOR D=1 TO F[4]
3810 P[1,D]=M[D]-M2
3820 P[3,D]=P[4,D]
3830 NEXT D
3840 R3=1
3850 GOTO 3600
3860 PRINT LIN10
3870 RETURN



3880 REM:  DETERMINES PHASE ANGLE
3890 P3=90*SGN(Y)
3900 IF X=0 THEN 3920
3910 P3=ATN(Y/X)+P3*(1-SGN(X))
3920 RETURN



3930 REM: PLOT ROUTINE
3940 DISP "DO YOU WANT SMITH CHART PLOT";
3950 INPUT C$
3960 IF C$="N" THEN 4660
3970 DISP "PLACE SMITH CHART ON PLOTTER";
3980 STOP
```

```
3990 DISP "ADJUST CORNERS PROPERLY";
4000 STOP
4010 SCALE -1180,1185,-1280,1400
4020 DEG
4030 PLOT -950,1310,0
4040 LABEL (*,1.5,2,0,9.6/8.5)
4050 LETTER
4060 PLOT -450,1310,0
4070 LABEL (*)F$;
4080 PLOT 673,1290,0
4090 LABEL (*)D$[6,7];D$[1,1];D$[8,9];D$[1,1];D$[2,3];----- Prints date
4100 PLOT 673,1215,0
4110 LABEL (*)P$
4120 T=1030
4130 FORMAT F5.1
4140 D=0
4150 K=0
4160 FOR F=F[1] TO F[2] STEP F[3]
4170 O5=0
4180 D=D+1
4190 A1=ABS(P[3,D])
4200 PLOT P[5,D],P[6,D],0
4210 IPLOT 0,0,2
4220 IF D=1 THEN 4340
4230 FOR I=1 TO K
4240 A2=ABS(P[12,I])
4250 IF A1>175 AND A2>175 OR A1<5 AND A2<5 THEN 4280
4260 IF ABS(P[3,D]-P[12,I]) >= 5 THEN 4320
4270 GOTO 4290
4280 IF ABS(A1-A2) >= 5 THEN 4320
4290 I=K
4300 O5=1
4310 IPLOT 0,0,1
4320 NEXT I
4330 IF O5=1 THEN 4490
4340 LABEL (*,1.25,2,P[3,D],9.6/8.5)
4350 CPLOT 1,0
4360 PLOT T*COS(P[3,D]),T*SIN(P[3,D]),2
4370 IF A1<90 THEN 4450
4380 A=P[3,D]+180
4390 LABEL (*,1.25,2,A,9.6/8.5)
4400 IF A1 >= 175 THEN 4430
4410 CPLOT -5.5,-0.5
4420 GOTO 4460
4430 CPLOT -5,-0.5
4440 GOTO 4460
4450 CPLOT 0,-0.5
4460 LABEL (4130)F/1000
4470 K=K+1
4480 P[12,K]=P[3,D]
4490 NEXT F
4500 BEEP
4510 DISP "DO YOU WANT A VSWR CIRCLE";
4520 INPUT C$
4530 IF C$="N" THEN 4620
4540 DISP "WHAT VSWR";
4550 INPUT G
4560 G=(G-1)*1000/(G+1)
4570 PLOT G,0,-2
4580 FOR D=0 TO 360 STEP 2
4590 PLOT G*COS(D),G*SIN(D),0
```

```
4600 NEXT D
4610 PEN
4620 BEEP
4630 DISP "DO YOU WANT RECT. PLOT";
4640 INPUT C$
4650 IF C$="N" THEN 5520
4660 DISP "PLACE PAPER ON PLOTTER & ADJUST";
4670 STOP
4680 SCALE -33,33,-24,25
4690 OFFSET -24.5,16
4700 C3=50/((F[2]-F[1])/1000)
4710 C4=35/40
4720 M=1 -------------------------------- Set dashed curve
4730 DISP "IS THIS AN OVERLAY";
4740 INPUT C$
4750 IF C$="Y" THEN 5370
4760 M=2 -------------------------------- Set solid curve
4770 YAXIS 0,-5*C4,0,-35
4780 LABEL (*,2.4,2,0,8.5/11)
4790 FOR T=0 TO 30 STEP 10
4800 PLOT 0,-T*C4,1
4810 CPLOT -4,-0.25
4820 LABEL (*)T
4830 NEXT T
4840 XAXIS -35,C3/2,0,50
4850 A1=INT(F[1]/1000)
4860 A2=INT(F[2]/1000)
4870 IF A1 >= F[1]/1000 THEN 4890
4880 A1=A1+1
4890 IF A2 <= F[2]/1000 THEN 4910
4900 A2=A2-1
4910 FOR F=A1 TO A2
4920 PLOT (F-F[1]/1000)*C3,-35,1
4930 CPLOT -1.5,-1
4940 LABEL (*)F
4950 NEXT F
4960 YAXIS 50,-1,-35,0
4970 IF R1=1 THEN 5230
4980 B8=1
4990 FORMAT F4.1
5000 U1=1.01
5010 U2=1.09
5020 U3=0.01
5030 FOR I=U1 TO U2 STEP U3
5040 IF B8>1 THEN 5060
5050 IF I<U1+2*U3 THEN 5130
5060 V1=20*LGT((I-1)/(I+1))
5070 PLOT 50,C4*V1,1
5080 CPLOT 0,-0.3
5090 LABEL (*)"-"
5100 IF I>U1 THEN 5130
5110 CPLOT 0.5,1
5120 LABEL (4990)U1
5130 NEXT I
5140 B8=B8+1
5150 U1=U1+9*U3
5160 U3=10*U3
5170 U2=U1+8*U3
5180 IF B8<4 THEN 5030
5190 V1=20*LGT(9/11)
5200 PLOT 50,C4*V1,1
```

Changes needed to make the plot scale a variable:

```
4702  Disp "Enter Plot Range";
4704  Input X
4710  C4 = 35/X
4790  For T = 0  To X-10 Step 10
```

```
5210 CPLOT 2,-0.3
5220 LABEL (*)"10"
5230 XAXIS 0,1,50,0
5240 PLOT -5,-22,1
5250 LABEL (*,2.4,2,90,8.5/11)P$" (DB)"
5260 PLOT 22,-39.5,1
5270 LABEL (*,2.4,2,0,8.5/11)"FREQ.(GHZ)"
5280 IF R1=1 THEN 5310
5290 PLOT 55,-18,1
5300 LABEL (*,2.4,2,90,8.5/11)"VSWR"
5310 PLOT 0,6,1
5320 LABEL (*,2.4,2,0,8.5/11)"TITLE  :  "F$;
5330 PLOT 0,4,1
5340 LABEL (*)"JOB NO.:  "J$;
5350 PLOT 0,2,1
5360 LABEL (*)"DATE   :  "D$[6,7];D$[1,1];D$[8,9];D$[1,1];D$[2,3];
```

— Prints date

```
5370 D=0
5380 FOR F=F[1]/1000 TO F[2]/1000 STEP F[3]/1000
5390 D=D+1
5400 IF D>1 THEN 5460
5410 IF P[1,D] >= -40 THEN 5440
5420 PLOT (F-F[1]/1000)*C3,-40*C4,-M*D
5430 GOTO 5500
5440 PLOT (F-F[1]/1000)*C3,C4*P[1,D],-M*D
5450 GOTO 5500
5460 IF P[1,D] >= -40 THEN 5490
5470 PLOT (F-F[1]/1000)*C3,-40*C4,M*D
5480 GOTO 5500
5490 PLOT (F-F[1]/1000)*C3,C4*P[1,D],M*D
```

If using variable scale, replace all "-40's" by X's

```
5500 NEXT F
5510 PEN
5520 RETURN
```

```
5530 REM:  READ POLAR DISPLAY OFFSET VOLTAGE
5540 REM:
5550 DISP "PRESS BEAM CTR ON POLAR DISPLAY"
5560 STOP
5570 D=0
5580 FOR F=F[1] TO F[2] STEP F[3]
5590 CMD "?U3"
5600 D=D+1
5610 FORMAT "P",F10.4,"Z0"
5620 OUTPUT (13,5610)F/1E+04
```

------------ Set frequency on synthesizer

```
5630 WAIT (100)
5640 CMD "?U&","H1AJ","F5"
5650 X[D]=(ROT(RBYTE13,8)+RBYTE13)/C1
5660 CMD "?U&","H2AJ","F5"
5670 Y[D]=(ROT(RBYTE13,8)+RBYTE13)/C1
5680 NEXT F
```

Read X and Y offsets from polar display

```
5690 RETURN
```

```
10 REM :  COMPUTES RETURN LOSS AND INSERTION LOSS ON COAXIAL SYSTEMS
20 REM :  FOR REMOTE ATTENUATOR
30 REM :  USES OFFSET SHORT CIRCUIT IN RETURN LOSS CALIBRATION
40 REM :
50 DIM F[4],F$[30],P$[30],X$[3],D$[15],J$[15],A$[35]
60 DIM PS[12,41],MS[41],ES[8,41],X[41],Y[41]
70 DEG
80 K4=50
90 C1=409.6
100 B5=1
110 E5=5
120 CMD "?U1","B123456"
130 A$="B3456A4B56A5B46A45B6A6B45A46B5B4A56"
140 D$[1,1]="-"
150 D$[2,3]="80"
160 D$[4,4]=":"
170 DISP "ENTER JOB NUMBER";
180 INPUT J$
190 DISP "ENTER 8672A GEN. OUTPUT CODES";
200 INPUT X$
210 DISP "RETURN LOSS-(Y/N)";
220 INPUT H$
230 DISP "ENTER FREQ RANGE-START,STOP,STEP";
240 INPUT F[1],F[2],F[3]
250 F[4]=INT((F[2]-F[1])/F[3])+1
260 IF F[4]<42 THEN 290
270 BEEP
280 GOTO 230
290 IF F[1]<12 THEN 330
300 L=0.5258
310 N=7
320 GOTO 430
330 IF F[1]<8 THEN 370      Define offset short number
340 L=0.7346                and length in centimeters
350 N=6
360 GOTO 430
370 IF F[1]<4 THEN 410
380 L=1.248
390 N=5
400 GOTO 430
410 L=2.498
420 N=4
430 F[1]=F[1]*1000
440 F[2]=F[2]*1000
450 F[3]=F[3]*1000


1000 BEEP
1010 DISP "CONNECT CALIBRATION SHORT";
1020 STOP
1030 R=1
1040 GOSUB 1890 --------- Read data
1050 M1=M[1]
1060 BEEP
1070 DISP "CONNECT OFFSET SHORT#"N;
1080 STOP
1090 R=3
1100 GOSUB 1890 --------- Read data
1110 GOSUB 2880 --------- Find source match and frequency tracking; store
                          in E(3,F), E(4,F), and E(5,F), E(6,F) respectively
```

```
2860 REM:  COMPUTES SOURCE MATCH AND
2870 REM:  REFLECTION TRACKING AND STORES IN E(M,F)
2880 D=0
2890 FOR F=F[1] TO F[2] STEP F[3]
2900 D=D+1
2910 X=P[3,D]-E[1,D]
2920 Y=P[4,D]-E[2,D]
```

$E_{OFFSET} - E_{LOAD}$

```
2930 V2=E[1,D]-P[1,D]
2940 U2=E[2,D]-P[2,D]
```

$E_{LOAD} - E_{SHORT}$

```
2950 V3=P[3,D]-P[1,D]
2960 U3=P[4,D]-P[2,D]
```

$E_{OFFSET} - E_{SHORT}$

```
2970 T=0.024*L*F
2980 V1=-X*COS(T)+Y*SIN(T)-V2
2990 U1=-X*SIN(T)-Y*COS(T)-U2
```

$-e^{j\beta} (E_{OFFSET} - E_{LOAD}) - (E_{LOAD} - E_{SHORT})$

```
3000 GOSUB 3120
```

------ Complex divide

```
3010 E[3,D]=X
3020 E[4,D]=Y
```

$$E_{sm} = \frac{e^{j\beta} (E_{OFFSET}-E_{LOAD}) - (E_{LOAD}-E_{SHORT}{}^{0}}{E_{OFFSET} - E_{SHORT}}$$

```
3030 V1=X+1
3040 U1=Y
3050 GOSUB 3180
```

--- Complex multiply

```
3060 E[5,D]=X
3070 E[6,D]=Y
```

$E_{ft} = (1 + E_{sm}) (E_{LOAD} - E_{SHORT})$

```
3080 NEXT F
3090 RETURN
```

```
10 REM :  COMPUTES RETURN LOSS AND INSERTION LOSS ON WAVEGUIDE SYSTEMS
20 REM :  FOR REMOTE ATTENUATOR
30 REM :
```

```
220 DISP "ENTER FREQ RANGE-START,STOP,STEP";
230 INPUT F[1],F[2],F[3]
240 F[4]=INT((F[2]-F[1])/F[3])+1
250 IF F[4]<42 THEN 280
260 BEEP
270 GOTO 220
280 IF F[1]>12 THEN 330
290 F1=6560
300 L1=0.559
310 L2=1.118
320 GOTO 360
330 F1=9490
340 L1=0.352
350 L2=0.703
360 F[1]=F[1]*1000
```

Define offset short lengths (λ/8 and 3λ/8)

L1 = λ/8

L2 = 3λ/8 - λ/8

Also define cutoff frequency in MHZ

```
930 BEEP
940 DISP "CONN 1/8 WAVELENGTH OFFSET SHORT";
950 STOP
960 R=1
970 GOSUB 1810 ------- Read data
980 M1=M[1]
990 BEEP
1000 DISP "CONN 3/8 WAVELENGTH OFFSET SHORT";
1010 STOP
1020 R=3
1030 GOSUB 1810 ------ Read data
1040 GOSUB 2800 ------ Find source match and frequency tracking; store
                       in E(3,F), E(4,F) and E(5,F), E(6,F) respectively
```

```
2780 REM:  COMPUTES SOURCE MATCH AND
2790 REM:  REFLECTION TRACKING AND STORES IN E(M,F)
2800 D=0
2810 FOR F=F[1] TO F[2] STEP F[3]
2820 D=D+1
2830 X=P[3,D]-E[1,D]
2840 Y=P[4,D]-E[2,D]
```

$E_{OFFSET(2)} - E_{LOAD} = \text{Num 1}$

```
2850 V2=E[1,D]-P[1,D]
2860 U2=E[2,D]-P[2,D]
```

$E_{LOAD} - E_{OFFSET(1)} = \text{Num 2}$

```
2870 V3=P[3,D]-P[1,D]
2880 U3=P[4,D]-P[2,D]
```

$E_{OFFSET(2)} - E_{OFFSET(1)} = \text{DEN}$

```
2890 T=0.024*L2*F*SQR(1-(F1/F)↑2)
2900 V1=-X*COS(T)+Y*SIN(T)-V2
2910 U1=-X*SIN(T)-Y*COS(T)-U2
```

$e^{-j\beta \ell_2} (\text{NUM 1}) - \text{NUM 2}$

```
2920 GOSUB 3050 --- Complex divide
2930 T=0.024*L1*F*SQR(1-(F1/F)↑2)
2940 E[3,D]=X*COS(T)-Y*SIN(T)
2950 E[4,D]=X*SIN(T)+Y*COS(T)
```

$E_{sm} = e^{j\beta \ell_1} \quad \frac{e^{-j\beta \ell_2} (\text{Num 1}) - \text{Num 2}}{\text{DEN}}$

```
2960 V1=X+COS(T)
2970 U1=Y+SIN(T)
2980 GOSUB 3110 --------- Complex multiply
2990 E[5,D]=X
3000 E[6,D]=Y
```

$E_{ft} = (E_{sm} + e^{j\beta \ell_1}) (E_{LOAD} - E_{OFFSET\ (1)})$

```
3010 NEXT F
3020 RETURN
```

APPENDIX C

VARIABLE LIST

- NUMERIC VARIABLES -

A9 - Used only in manual attenuator programs to let the machine know when to check the X and Y voltages

B5 - Beginning of auto attenuator string

C1 - Digital-to-voltage conversion factor when using the A/D converter

E5 - End of auto attenuator string

ES(8,41) - Error correction vectors

$E_{DIR} = E(1,F) + jE(2,F)$

$E_{SM} = E(3,F) + jE(4,F)$

$E_{FT} = E(5,F) + jE(6,F)$

$E_{TT} = E(7,F) + jE(8,F)$, where F is the frequency increment

F(1) - Start Freq. (MHz)

F(2) - Stop Freq. (MHz)

F(3) - Step Size (Mhz)

F(4) - Number of steps

G - Stores VSWR circle size in Smith Chart plot routine.

G9 - Used only in manual attenuator programs. Stores test channel gain setting during insertion loss measurements. Only for user's convenience, does not enter calculations.

J1 - Frequency loop increment variable (to lower harmonic phase lock error of the network analyzer)

K3 - Capacitance of open in picofarads

K4 - Characteristic line impedance (usually 50 ohms)

MS(41) - Magnitude from rectangular display

M1 - Reference line for short circuit

M2 - Reference line for straight through connection in insertion loss measurements

PS(12,41) - General array (using in I/O routines, also used to store the six data points in the sliding load routine)

R1 - 0 when inputting or outputting return loss data

- 1 when inputting or outputting insertion loss data

X(41) - X offset voltage

Y(41) - Y offset voltage

- STRING VARIABLES -

A$(35) - Auto attenuator reference string

D$(15) - Date

F$(30) - Label for unknown device

H$ - "Y" for return loss

J$(15) - Job Number

L$ - "Y" when using sliding load

P$(30) - General purpose string variable

X$(3) - Arguments for 8672A synthesizer

X$(1,1) - range

X$(2,2) - vernier level

X$(3) - ALC argument

- MULTI-USE VARIABLES -

A, A1, A2, B1, B2, C, C3, C4, K, M, S, T, U1, U2, U3, V1, V2, V3, X, Y

- GENERAL INCREMENT VARIABLES -

B8, D, F, I, J, Z

- OFFSET SHORT PROGRAM ONLY -

L - Offset short length in cm.

N - Offset short number

- WAVEGUIDE PROGRAM ONLY -

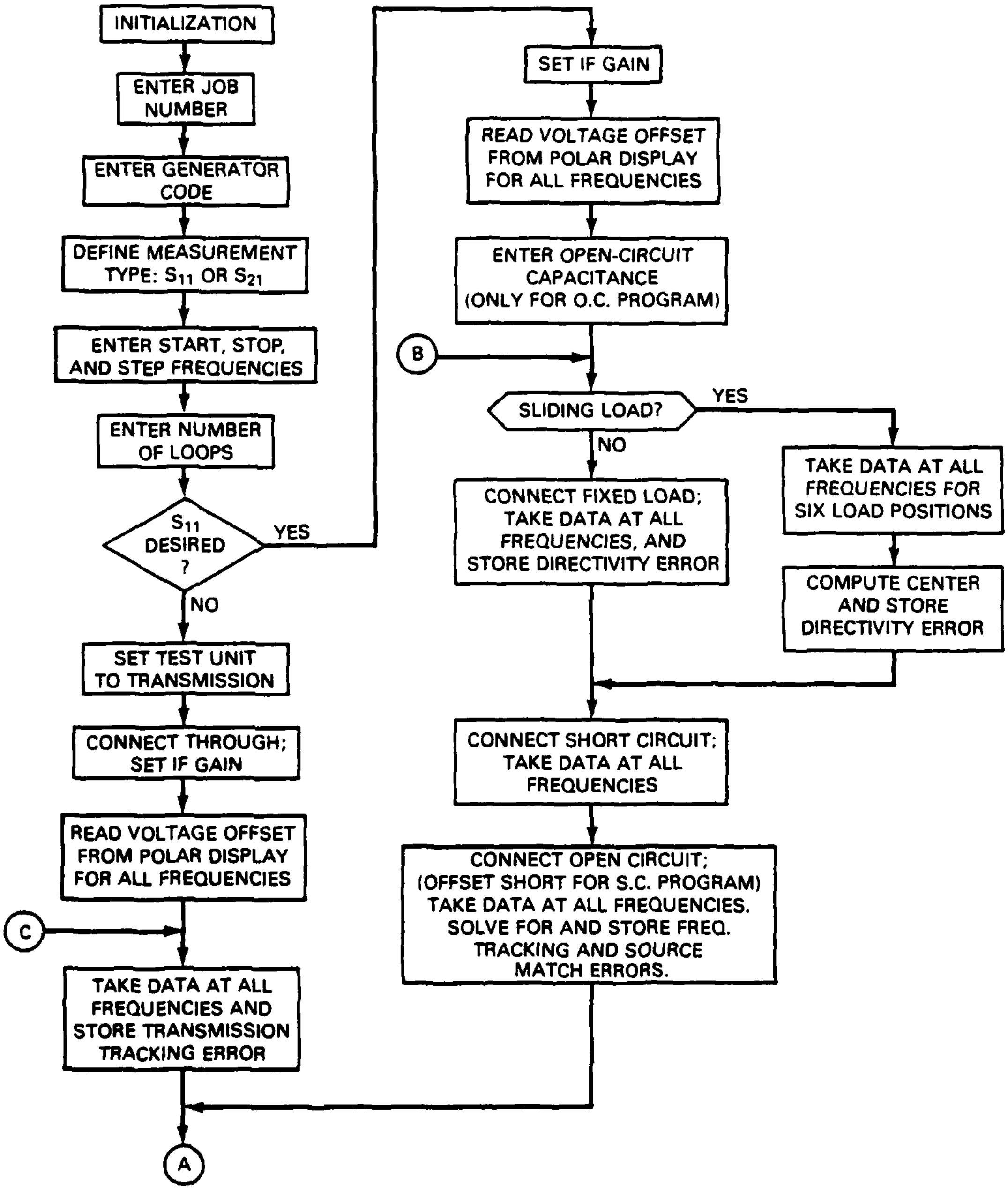
F1 - Cutoff frequency in MHz.

L1 - Offset length of 1/8 cutoff wavelength in cm.

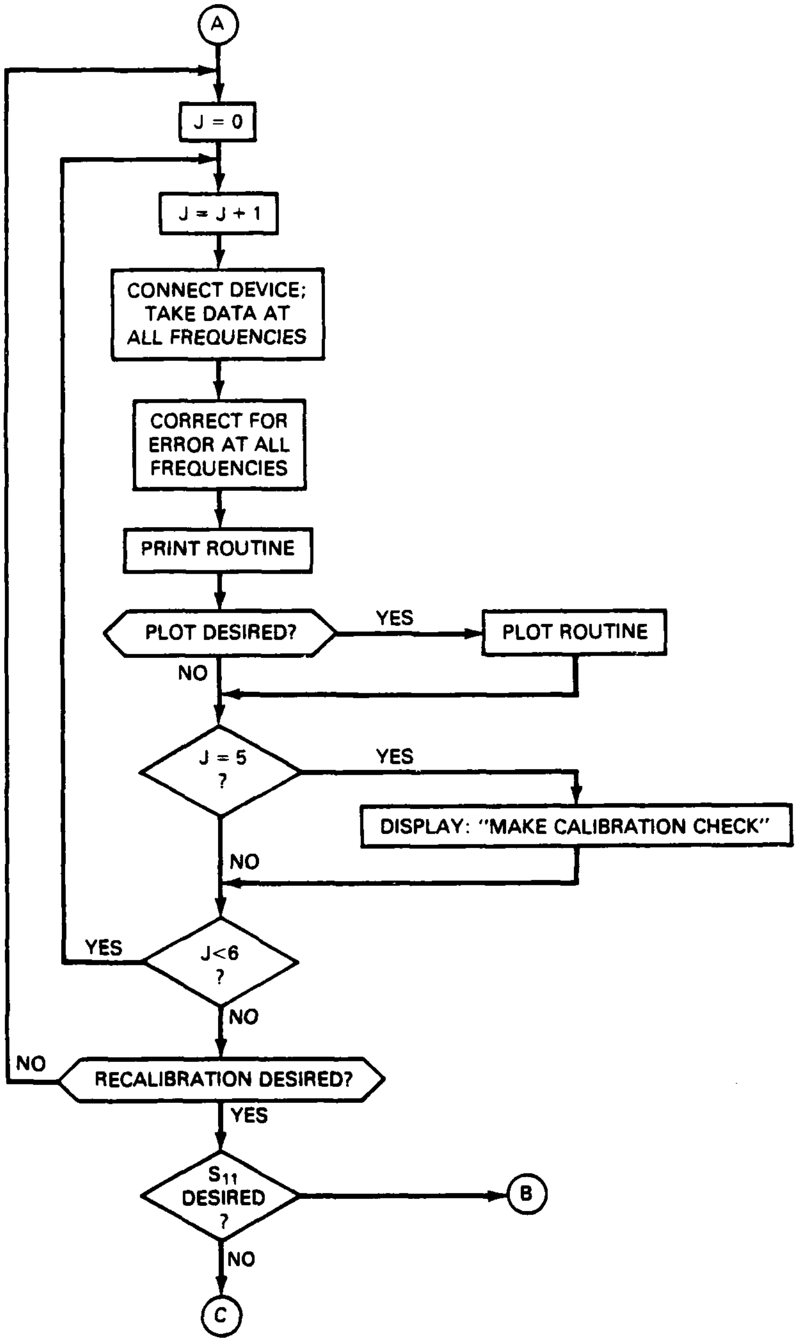
L2 - [3/8 cutoff wavelength - 1/8 cutoff wavelength] in cm.

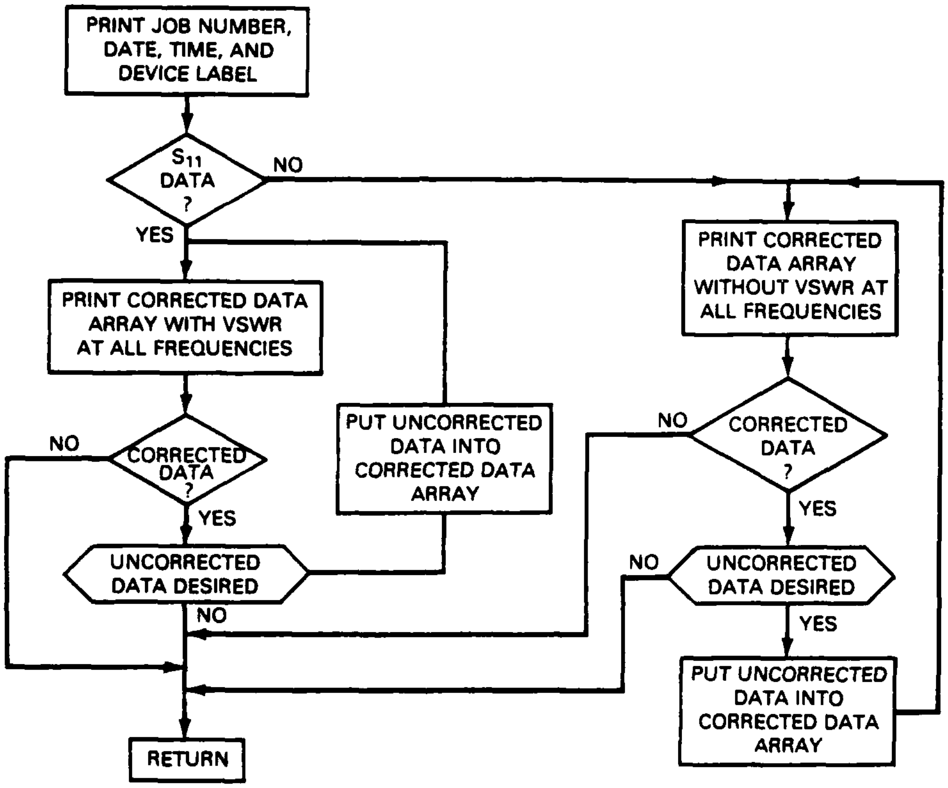
APPENDIX D

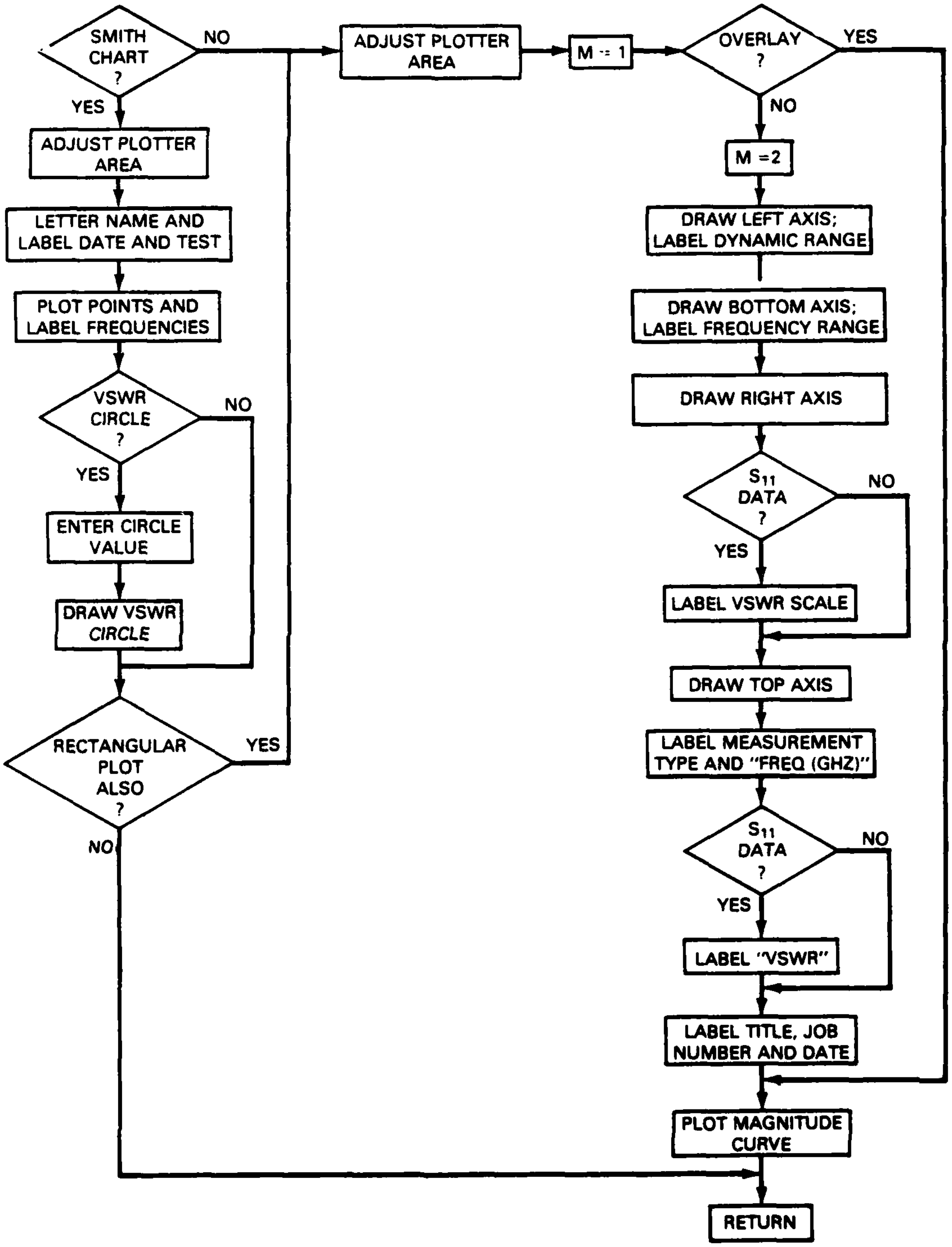
FLOW CHARTS



NOTE: FOR MANUAL ATTENUATOR PROGRAM, PRELIMINARY CALCULATIONS PERMIT THE TEST GAIN TO BE SET FOR MAXIMUM DEFLECTION (UP TO ± 2 VOLTS) ON THE POLAR DISPLAY WITH SHORT CIRCUIT CONNECTED.


A
J = 0
J = J + 1
CONNECT DEVICE; TAKE DATA AT ALL FREQUENCIES
CORRECT FOR ERROR AT ALL FREQUENCIES
PRINT ROUTINE
PLOT DESIRED?
YES
PLOT ROUTINE
NO
J = 5 ?
YES
DISPLAY: "MAKE CALIBRATION CHECK"
NO
YES
J<6 ?
NO
NO
RECALIBRATION DESIRED?
YES
S11 DESIRED ?
B
NO
C


PRINT JOB NUMBER, DATE, TIME, AND DEVICE LABEL
S_{11} DATA ?
NO
YES
PRINT CORRECTED DATA ARRAY WITH VSWR AT ALL FREQUENCIES
CORRECTED DATA ?
NO
YES
UNCORRECTED DATA DESIRED
NO
PUT UNCORRECTED DATA INTO CORRECTED DATA ARRAY
RETURN
PRINT CORRECTED DATA ARRAY WITHOUT VSWR AT ALL FREQUENCIES
CORRECTED DATA ?
NO
YES
UNCORRECTED DATA DESIRED
NO
YES
PUT UNCORRECTED DATA INTO CORRECTED DATA ARRAY



NOTE: M = 1 FOR DASHED LINE
M = 2 FOR SOLID LINE

APPENDIX E

CALIBRATION STANDARDS

Connector Type	Sliding Load	Calibration Kit	Open Capacitance (pf)
APC-7	905A	11637A	.081
N-Male	905A	85032A	.032
N-Female	905A	85032A	.180
SMA-Male	911A	85033A	-.064
SMA-Female	911A	85033A	.032

OFFSET SHORTS

Short	Frequency Band	Length (cm)
4-FY	2-4 GHz	2.498
5-FP	4-8	1.248
6-FM	8-12.4	0.7346
7-F	12.4-18	0.5258

THEORETICAL REFLECTION COEFFICIENT ANGLE FOR OPEN AND OFFSET SHORT CIRCUITS

	OFFSET SHORTS				OPENS			
Freq	Short	4-FY	5-FP	6-FM	.081	-.064	0.032	-.180
4 GHz	-180.0	-59.8	60.2	109.5	-11.6	9.2	-4.6	25.5
5	-180.0	-119.8	30.2	91.8	-14.5	11.5	-5.8	31.6
6	-179.9	-179.7	0.3	74.2	-17.4	13.8	-6.9	37.5
7	179.8	120.3	-29.7	56.6	-20.2	16.0	-8.1	43.2
8	-179.9	60.4	-59.6	39.0	-23.0	18.3	-9.2	48.7
9	179.7	0.4	-89.6	21.3	-25.8	20.5	-10.3	53.9
10	-179.9	-59.5	-119.5	3.7	-28.6	22.7	-11.5	59.0
11	179.9	-119.5	-149.5	-13.9	-31.3	24.9	-12.6	63.8
12	-179.9	-179.4	-179.4	-31.6	-34.0	27.1	-13.8	68.3

APPENDIX F

SPECIAL CODES AND WIRING

8672A SYNTHESIZER OUTPUT CODES

ALC ARGUMENTS

Function	Code
RF OFF	0,2,4,6,8
INT NORMAL	1
INT, + 10 RANGE	3
XTAL, NORMAL	5
XTAL, + 10 RANGE	7
MTR, NORMAL	=
MTR, + 10 RANGE	?

OUTPUT LEVEL RANGE

Scale	Code
0 dBm	0
-10	1
-20	2
-30	3
-40	4
-50	5
-60	6
-70	7
-80	8
-90	9
-100	:
-110	;

OUTPUT LEVEL VERNIER

Setting	Code
+3 dB	0
+2	1
+1	2
0	3
-1	4
-2	5
-3	6
-4	7
-5	8
-6	9
-7	:
-8	;
-9	<
-10	=

NOTE: For proper synthesizer operation, whenever the +10dBm overrange is selected with the ALC program code, the argument for the output level range program code should be zero.

HP-IB ADDRESS CODES

Device	Talk	Listen
Calculator	U	5
Synthesizer	S	3
A/D Converter	F	&
Relay		1
Fluke Meter	5	!
Digital Clock	C	#

REMOTE/MANUAL WIRING

A 36 pin connector on the rear panel of the 8743A provides contacts for remote selection of transmission or reflection measurements. Only four of the 36 pins are used. These pins and their uses are given in the following table.

	Pin 18 or 36 to	
Measurement	Pin 17	Pin 24
Transmission	Shorted	Shorted
Reflection	Shorted	Open

When remote-manual select pin 17 is open and not connected to a remote control common (pin 18 or 36), the 8743A is in the manual mode. When the remote-manual select pin is connected to a remote control common, the 8743A is in the remote mode. In this mode the front-panel push buttons are disabled allowing selection of transmission or reflection measurements only through the remote input pin 24.

A special wiring harness for these connections and the ones for control of the IF automatic attenuator is included by Hewlett-Packard when the remote IF attenuator option is ordered for the 8418A unit.

APPENDIX G

PROGRAM INSTRUCTIONS

There are two coaxial and one waveguide semiautomatic network analyzer programs which have slightly different input parameters. Tapes #1 and #2 are identical and contain the programs for coaxial measurements. Tapes #3 and #4 are also identical and contain the program for waveguide measurements. The programs are stored as follows:

Tapes #1 and #2

File 1 - Offset short - remote attenuator
File 2 - Open - remote attenuator

Tapes #3 and #4

File 0 - Remote attenuator
File 1 - Blank (50 words)

The following is a description of the sequence of events that occur when measuring a coaxial device using the remote attenuator and the shielded open as a calibration standard.

1. Setup equipment as in Figure 1.

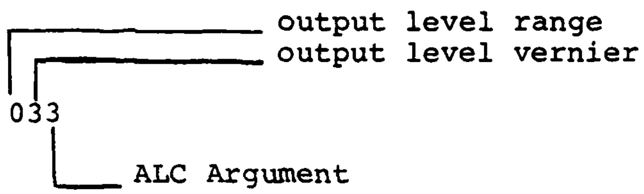
2. Insert tape #1 or #2 and rewind.

3. Press LOAD2; EXECUTE

4. When ⊢ appears on the display, the program is in the 9830A's memory. Now press RUN; EXECUTE.

5. "ENTER JOB NUMBER?" will appear. Input job number up to 15 characters and EXECUTE. If no job number is desired in the printout then press space bar; EXECUTE.

6. "ENTER 8672A GEN. OUTPUT CODES?" will appear. The order in which these codes are entered is extremely important. The format is as follows:



(NOTE: No space or punctuation between numbers).

The above example will set the output level range to 0dBm, the output level vernier to 0, and the ALC argument will cause the synthesizer to go into the +10 dBm overange output and turn the RF signal on with internal leveling. All the necessary generator codes are listed in Appendix F.

7. "RETURN LOSS -(Y/N)?" will appear after generator codes have been entered. Input Y or N; EXECUTE.

8. "ENTER FREQ RANGE - START, STOP STEP?" appears. These frequencies should be entered in GHz, and can be entered in two fashions:

Start; EXECUTE
Stop ; EXECUTE
Step ; EXECUTE
or
Start, Stop, Step; EXECUTE

NOTE: This program is limited to 41 frequency points with a 16K byte computer. If more than 41 points are chosen, the program automatically jumps back to "ENTER FREQ RANGE - START, STOP, STEP?". Also the frequency range should be over only one octave on the network analyzer. This frequency range should be set accordingly on the network analyzer.

9. "SET FREQ. RANGE ON ANALYZER" is displayed as a reminder for the user.

10. "HOW MANY LOOPS DO YOU WANT?" appears. Enter accordingly and EXECUTE. This is the looping that minimizes the harmonic phase-lock error of the network analyzer.

11. "OPEN UNKNOWN PORT" is now displayed. Disconnect any device that is connected to the unknown port of the test unit, and press CONT; EXECUTE. When making insertion loss measureents, "CONNECT THROUGH" will appear.

12. "SET TEST CHANNEL GAIN" reminds the user to make a fixed setting so the computer will have a known point when setting the IF attenuator.

13. "PRESS BEAM CTR ON POLAR DISPLAY" will appear. Hold beam center button on polar display while pressing all caps CONT; EXECUTE. Do not release the button until the next command appears.

14. If return loss was chosen then "ENTER CAPACITANCE OF OPEN?" appears. This capacitance should be entered in picofarads. See "CALIBRATION STANDARDS" for capacitance of open circuit being used. If return loss was not chosen go "RELEASE BUTTON-PRESS CONT; EXEC" will appear. Press CONT; EXECUTE and skip to step 17.

15. "CONNECT CALIBRATION LOAD" appears. Connect the load (make sure a good electrical connection is made when using the sliding load by moving the load through its entire range and observing the polar display) and press CONT; EXECUTE.

"SLIDING TYPE-(Y/N) - Respond accordingly. The sliding load is suggested for more accurate results. Thus, if a sliding load is available and appropriate for the frequency range, answer Y; EXECUTE. The system then measures the load at all test frequencies. Then a total of five additional load positions are requested: SLIDE 2, SLIDE 1, SLIDE 2, SLIDE 1, and SLIDE 2. Each division on the load is 1/4 inch. Start at the end closest to the test set.

Extreme care must be taken in connecting the sliding load in order to assure a good electrical connection. The load should be varied through its entire range once or twice, noticing the locus of points. A discontinuity in the locus of points indicates a bad electrical connection.

16. "CONNECT CALIBRATION SHORT" - Connect the short and press CONT; EXECUTE. All frequencies will be measured.

17. "CONNECT CALIBRATION OPEN" will be displayed - Connect the appropriate open circuit and press CONT: EXECUTE. All frequencies will be measured.

18. Then "CONNECT DEVICE" appears. Connect the device and press CONT, EXECUTE.

19. "ENTER LABEL (UP to 30 CHAR)?" is displayed. Enter label and press EXECUTE. For unlabeled data, space bar; EXECUTE. The system next reads data at all frequencies, makes the appropriate error corrections, and prints the corrected data.

20. After the corrected data is printed, "UNCORRECTED DATA ALSO-(Y/N)?" appears. Input Y or N; EXECUTE.

NOTE: If uncorrected data is desired, the plot routine is automatically skipped and the program cycles back to step 17.

21. If uncorrected data is not desired, then enter N; EXECUTE. Then "DO YOU WANT A PLOT?" will appear. If the user inputs N, then the program will cycle back to step 18.

23. If the user inputs Y, then the program will jump to the plot routine, which is discussed separately. After the plotting is complete, the program cycles back to step 18. After five measurements, the software reminds the user to make a calibration check by displaying "MAKE CALIBRATION CHECK !!!; press CONT; EXECUTE. If a calibration check is desired, connect the appropriate calibration standard (a short or straight through) when "CONNECT DEVICE" is displayed. After the calibration check is finished, the user is given the option of recalibrating the system.

NOTE: It is recommended that the user make a calibration check before starting actual measurements on the unknown devices and after a considerable length of time has elapsed since the calibration. Examples of a return loss and an insertion loss calibration check are presented in Figures 14 and 15.

PLOT ROUTINE

When making a Smith chart plot of the data, the user must take extreme care in placing the Smith Chart on the plotter surface and adjusting the plotting area. The lower edge of the Smith chart should fit flush against the lower ridge on the plotter surface. Set the lower left and upper right corners of the plotting area as close as possible to the points indicated in Figure 16. Large deviations from these points will offset the origin of the Smith chart and distort the user's units. After the corners have been properly adjusted press CONT; EXECUTE and the plotter will then enter the LETTER mode (a ? should appear on the display), and the pen should move to the NAME box on the Smith chart heading. When in the LETTER mode, the pen is controlled directly from the 9830A keyboard. Type in the appropriate NAME and make any additional comments. To exit from the LETTER mode, press the STOP key. After all the labeling and plotting is complete, the user has the option of drawing a VSWR circle (see Figure 16).

When the user does not desire a Smith Chart plot, the program assumes a rectangular plot is desired and "PLACE PAPER ON PLOTTER" is displayed. The plotting area should be adjusted for the maximum plotting space (there are no specific points to set the corners of the plotting area, as in the Smith chart section of this routine). After the plotting area has been set "IS THIS AN OVERLAY?" will be displayed. For overlays, only the curve is plotted (no graph or labeling is done). An example of how the overlay can be used is illustrated in Figure 3; the curve drawn with dashes is the overlay.

NOTE: When making Smith chart plots, it is recommended that no more than 20 data points be used so that the plot will not appear crowded. As many data points as possible should be used when making a rectangular plot so that the plot will resemble a continuous curve.

NOTE: When additional comments are desired as in Figure 3, the LETTER mode may be entered by typing LETTER; EXECUTE at any point where the program has been halted.

NOTE: The scale for the rectangular plot can be made a variable by the addition or revision of four commands. The changes necessary are listed in the program listing.