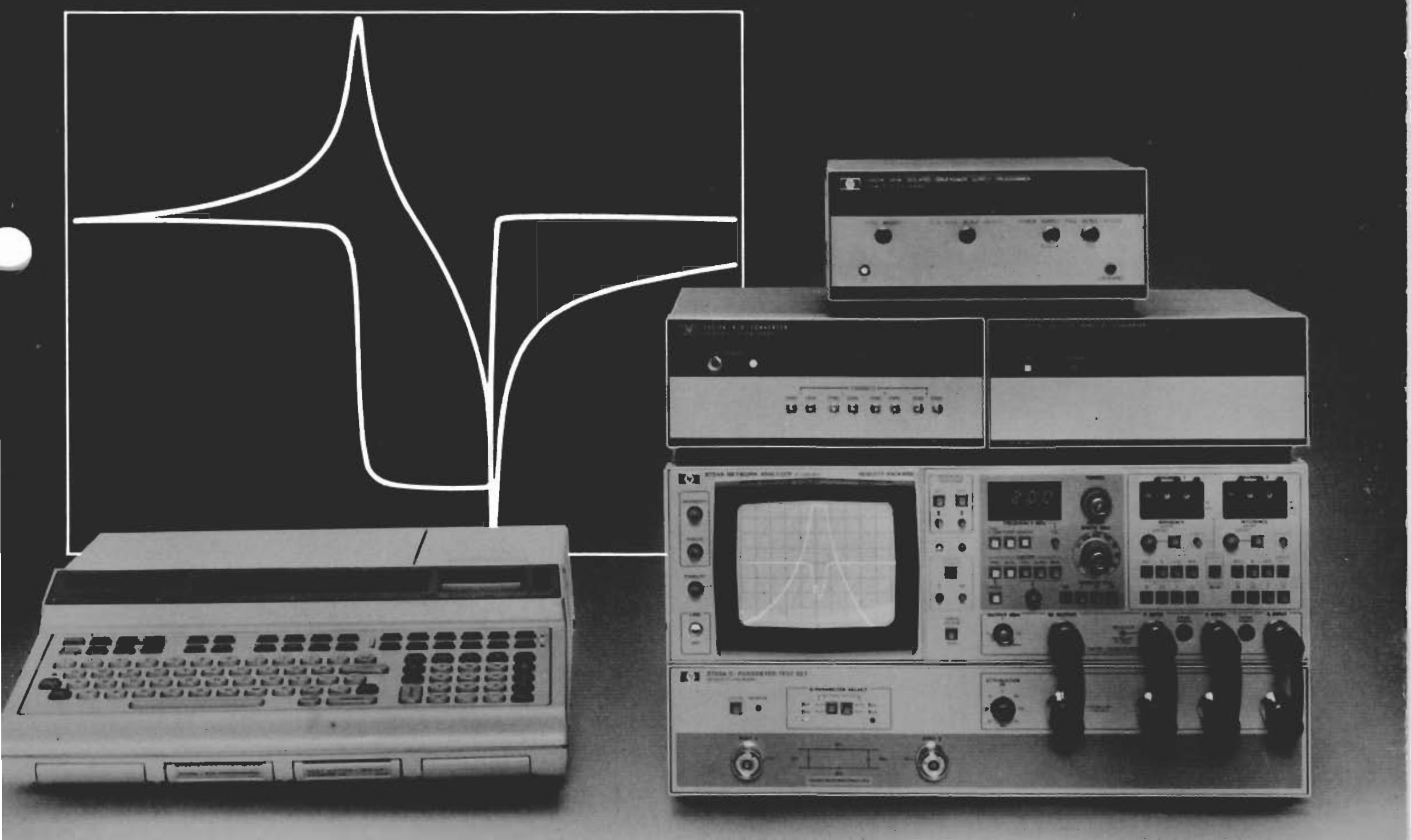
APPLICATION NOTE 294

Semi-Automatic R.F. Network Measurements



Using the HP 8754A Network Analyzer and the HP 9825A Desktop Computer

HEWLETT PACKARD

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INTRODUCTION

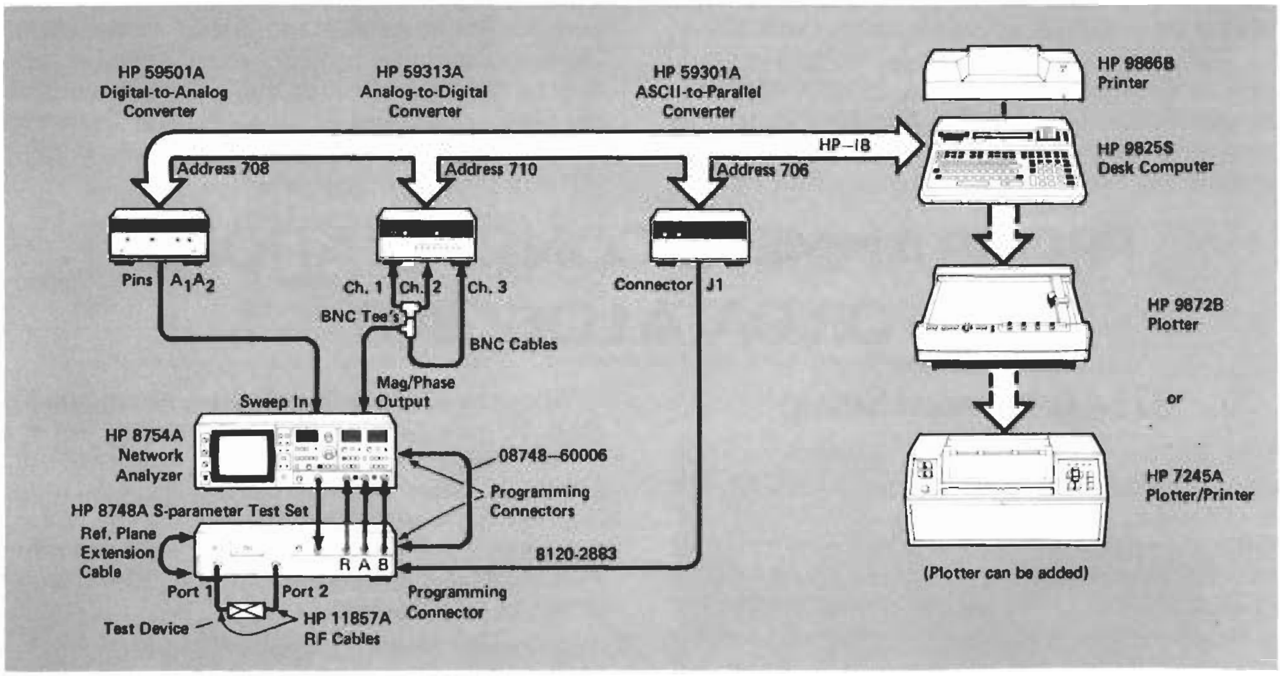

Figure 1. System Block Diagram

The HP Model 8754A, an economical network analyzer with built-in source, measures magnitude and phase of transmission and reflection coefficients from 4 MHz to 1.3 GHz (optional to 2.6 GHz). While not directly controllable by the Hewlett-Packard Interface Bus (HP-IB[1]), the 8754A can be the center of a computer controlled measurement and data logging system through the use of several interface instruments.

This application note describes a configuration that is easily assembled using standard instruments and accessories. The note lists the components and their interconnections. Basic programming commands and subroutines for controlling and logging data from the 8754A Network Analyzer and 8748A S-parameter Test Set are described, allowing the user to compose a program suited to his specific needs. In addition, a sample program which measures all four S-parameters of a two-port device is listed. The programs are written in a modular form to be easily modified by the user to meet specific requirements. For example, the modification necessary to add a synthesizer for making high resolution crystal filter measurements is included.

This semi-automatic system can be especially valuable in production test applications where many measurements must be made efficiently and where collection of actual measured data is important. It should be pointed out that the measurement accuracies achieved are essentially those of the 8754A operated manually. The subject of measurement repeatabilities is discussed on page 11.

Equipment List

Network Analyzer	HP 8754A
S-parameter Test Set	HP 8748A[2]
Digital-to-Analog Converter	HP 59501A
Analog-to-Digital Converter	HP 59313A[3]
ASCII-to-Parallel Converter	HP 59301A
Desktop Computer System	HP 9825S
HP-IB Interface	HP 98034A
RF Cable Set	HP 11857A
½ m HP-IB Cable (4 each)	HP 10631D
2 ft BNC Cables (4 each)	HP 11170B
Programming Cable	8120-2883

System Block Diagram

The 8754A RF Network Analyzer is the central component in the semi-automatic network analyzer configuration shown in Figure 1. The 8754A consists of an integrated source, receiver, and display covering the frequency range of 4 to 1300 MHz. The source is controlled in steps using an external digital-to-analog converter (DAC), the 59501A. The 59501A provides 1000-point resolution over any frequency range selected on the 8754A. The 8748A S-parameter Test Set switches the incident power between test ports 1 and 2 thus facilitating automatic measurement of all four S-parameters of the device under test. The 8502A (50 Ω) or 8502B (75 Ω) Transmission/

[1] HP-IB is Hewlett-Packard's implementation of the IEEE-488 Interface Standard. Internationally, HP-IB is in concert with the IEC main interface document.

[2] The HP 8502A or HP 8502B Transmission/Reflection Test Sets can also be used, but the device must be rotated to measure all four S-parameters.

[3] Digital voltmeters can also be used as analog-to-digital converters. A driver for the HP 3455A is included in this note.

Reflection Test Sets can also be used, but the device must be manually disconnected and rotated to measure all four S-parameters. The 8754A receiver has one analog output which can be internally switched to output either transmission or reflection signals. The 59301A ASCII-to-Parallel Converter does this switching as well as switching the test set from forward to reverse and putting the whole system into either local or remote operation. When the desired output has been selected, an analog to digital converter (ADC), the 59313, is used to digitize the selected output. The versatility and speed of the 9825S Desktop Computer provides a cost effective solution as the controller for the system. It controls the DAC, ADC, and ASCII-to-Parallel Converter via the Hewlett-Packard Interface Bus. Plotting can also be added by the user.

PROGRAMMING CONSIDERATIONS FOR DATA LOGGING

8754A Manual Setup

There are several manual adjustments that need to be made prior to programming the 8754A and taking data. The desired SWEEP WIDTH must be selected manually and the start and stop frequencies entered into the program. The calibration of the sweep should be verified using the crystal markers, then checked periodically for frequency drift. The sweep mode should be set to AUTO and FAST to allow the fastest data rate. The SLOW SWEEP position is not used because a larger capacitor is switched in the sweep circuit and longer settling times are required. The desired output power and test set attenuator settings also need to be manually set.

Network Analyzer and Test Set Control

Both the test set and the network analyzer are controlled from a common programming connector that can be accessed from the rear panel of the 8754A or the 8748A if used (see Figure 5). TTL levels at five pins select local/remote operation, test set forward/reverse, relock, and magnitude or phase of the A/R or B/R analog signal appearing at the "MAG/PHASE" output as summarized in Figure 2.

Pin No.	Function	Input*
21 (L/R)	Local Operation	1
	Remote Operation	0
8 (F/R)	8748A Forward	1
	8748A Reverse	0
19 (M/P	Magnitude Output	1
	Phase Output	0
20 (A/B)	Select A/R	1
	Select B/R	0
24	Forced Relock	1 / 0 (pulse)
	(minimum pulse width = 20 μsec)	

* where 1 = 5 V or open and 0= 0 V or ground.

Figure 2. 8754A/8748A Programming Connector Inputs

When the 8748A test set is used, grounding pin 21 (L/R) will enable remote operation, but the 8754A/8748A will not actually be in remote until a "relock" pulse is sent to pin 24. The local mode can then be reestablished by pressing the LOCAL button on the 8748A. When using a test set other than the 8748A, grounding pin 21 (L/R) will cause 8754A to be in remote.

It is necessary to break the receiver phase lock before proceeding to the next frequency point to ensure that the receiver will properly relock independent of any previous lock point. Remote/local control prevents operator intervention by locking out the front panel.

The five lines are easily controlled using the 59301A ASCII-to-Parallel Converter. Relay switching is not recommended because the receiver must be relocked (pin 24) at every frequency change. An interconnect cable (8120-2883) connects the 8754A or 8748A to the 59301A. The pin connections are described in Figure 3.

8754A or 8748A "PROGRAMMING" connector		59301A connector (J1)
8	⟷	1
19	⟷	2
20	⟷	26
21	⟷	27
24	⟷	48
18	⟷	50*

* ground

Figure 3. 8120-2883 Interconnect Cable.

The following simple subroutine called "Setup," can be used to setup the 8754A/8748A to measure the magnitude or phase of any S-parameter. The subroutine uses a single call parameter with a value from 0 to 8. From the call parameter the proper ASCII character is computed to set the appropriate 8754A lines, summarized in Figure 4.

Subroutine Call Parameter	Measurement	Character Output		8754A/8748A Control Inputs			
		ASCII	DECIMAL	L/R	A/B	M/P	F/R
0	Local	0	48	1	1	1	1
1	Forward A/R Magnitude $\|S_{11}\|$	8	56	0	1	1	1
2	Forward A/A phase $\angle S_{11}$	A	65	0	1	0	1
3	Forward B/R Magnitude $\|S_{21}\|$	C	67	0	0	1	1
4	Forward B/R Phase $\angle S_{21}$	E	69	0	0	0	1
5	Reverse B/R Magnitude $\|S_{12}\|$	D	68	0	0	1	0
6	Reverse B/R Phase $\angle S_{12}$	F	70	0	0	0	0
7	Reverse A/R Magnitude $\|S_{22}\|$	9	57	0	1	1	0
8	Reverse A/R Phase $\angle S_{22}$	B	66	0	1	0	0

Figure 4. 59301A Commands to Setup the 8754A/8748A.

To pulse pin 24 on the 8750A, forcing a relock, the 59301A is sent a decimal ten following the parameter select code.

```
wtb "59301",70,10
            | |
            | └── Relock Pulse
            └──── Selects Reverse B/R Phase Output.
```

When controlling the 8754A, the forced relock should be done after setting each desired frequency. The data can be then read without a further wait. However, a 100 msec wait is recommended after setting the first data point (N=1) after switching from local to remote. Both the relock pulse and 100 msec wait have been incorporated in the "Setup" subroutine.

```
cll 'Setup'(3)
           └── Call Parameter
     (3 Sets Forward B/R Magnitude)
             •
             •
             •
"Setup":
1 (p1>0)(8+4(p1>2)(p1<7)+2(p1mod2=0)+(p1>4))}p2
2 wtb "59301",48+p2+7(p2>9),10
3 wait 100(N=1);ret
```

Note: Printer used to generate listing in this Application Note prints "}" for "→" and "^" for "↑"

In the "Setup" subroutine the variable p1 is equal to the first call parameter (3 in this example). Lines 1 and 2 calculate the proper code to send to the 59301A.

If the HP 8502A/B Reflection/Transmission Test Set is used instead of the 8748A, the "Setup" subroutine will still control the 8754A correctly to output the correct S-parameters. However, the test device must be manually disconnected and reversed to measure the reverse parameters (S_{21} and S_{22}) and a program line added. The subroutine will also work on any test set configuration where A/R is always the reflected signal and B/R is the transmitted. In this configuration the programming cable is connected directly to the 8754A. When using the 8748A S-parameter Test Set, the cable is connected as shown in Figure 5.

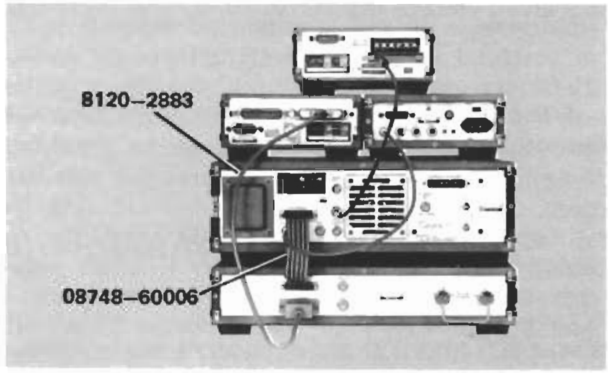

Figure 5. Rear Panel Programming Connections.

Setting Frequency

When the 8754A is programmed to remote, the frequency sweep is automatically set to external. An external input voltage between 0 and 10 volts is used to step the source over the sweep width selected on the front panel. For example, if the manually set start and stop frequencies are 100 and 300 MHz respectively, 5 volts will set a frequency of 200 MHz. On full sweep, the frequency limits are approximately 0 and 1310 MHz. The 59501A Digital-to-Analog Converter provides an economical and convenient way to step the CW frequency in remote operation. Setting its rear panel mode switch to "UNIPOLAR" (see Figure 6) permits the output of the 59501A to be programmed from 0 to 9.99 volts with a 10 mV resolution (1000 points). The DAC output at terminals A2 and A1 is connected to the Sweep Input on the 8754A.

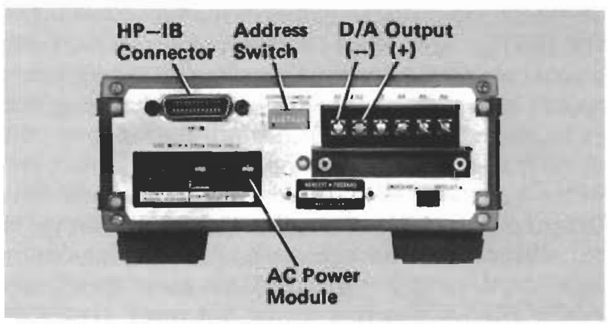

Figure 6. 59501A Rear Panel.

To program a voltage (to set the frequency), the 59501A must be sent four ASCII digits. The first digit selects the range, either a 2 for the high range (0 - 9.99 V) or a 1 for the low range (0 - 0.999 V). The last three digits, between 0 - 999, specify the output within the selected range (i.e., 2000 gives 0 V output and 2999 gives 9.99 V). To properly program the voltage, all leading zeros and the carriage return and line feed characters must be suppressed by using the following format statement:

```
fmt 1,f4.0,z
```

A device statement (dev) can be used to equate the address of 59501A to "dac." The following program line can be used to program the DAC to a given voltage from 0 (W=0) to 9.99 (W=999).

```
fmt 1,f4.0,z;wrt "dac.1",2000+W
```

A useful general purpose subroutine to get a desired frequency would be:

```
"Freq":
fmt 1,f4.0,z
wrt "dac.1",2000+999(F[5]-F[1])/(F[2]-F[1])
ret
```

where F[1] and F[2] are equivalent to the manually set front panel start and stop frequencies and F[5] is the desired frequency to be set. Obviously, F[5] must be between F[1] and F[2]. This subroutine will automatically determine and set the correct DAC voltage. After setting the voltage on the DAC the local oscillator in the 8754A should be forced to relock. Requiring the 8754A to relock at each new frequency insures repeatable measurements independent of the last frequency to which the 8754A was locked. The easiest way to accomplish this is to set the frequency first and then always execute the "Setup" subroutine as described in the previous section.

Reading Data

After the 8754A is switched to give the desired output, the analog voltage must be read with a computer controllable analog-to-digital converter (ADC). The range of the analog output (−100 mV/dB and −10 mV/degree) is +4 to −8 V for magnitude values between +40 dB to −80 dB and ±1.8 V for phase values between ±180°. The HP 59313A Analog-to-Digital Converter provides a cost effective solution. Since the 59313A's range is not programmable, the resolution using one channel (±10 V range) is 1° and 0.1 dB over the entire range. If three channels are used at different ranges a maximum resolution of 0.25° and 0.1 dB from −80 to +40 dB and 0.01 dB from −10 to +10 dB can be achieved. For the maximum resolution of 0.1° and 0.01 dB over the entire range, the high-performance but more costly HP 3455A Digital Voltmeter can be used.

HP 59313A Analog-to-Digital Converter (ADC)

For maximum resolution, three channels of the ADC can be paralleled so they all read the 8754A output. In this configuration the channel full scale range should be manually set at ±1 V, ±2.5 V, and ±10 V (channels 1 - 3 respectively) to calibrate the channel gains refer to 59313A A/D Converter Calibration (page 12). Channel 2 is used to measure phase with a 0.25° resolution and channels 1 and 3 are used to measure magnitude with 0.01 dB and 0.1 dB resolution (channel 4 is not used). The "Read" subroutine (below) selects the appropriate channel (autoranges magnitude), scales the data, and stores it in array D[p1,N] where N is the frequency index and p1 is the call parameter corresponding to the parameter (1 - 8) being measured. (See Figure 4 for Setup call parameter descriptions.)

```
"Read":
1  if p1mod2=0;wrt "dvm","H2AJ";gto +2
2  fmt 1,c,f.0,c2;wrt "dvm.1","H",A,"AJ"
3  rot(rdb("dvm"),8)+rdb("dvm")→p2
4  if p1mod2=0;gto +3
5  if A=1 and abs(p2)>999;4→A;gto -3
6  if A=4 and abs(p2)<100;1→A;gto -4
7  if p1mod2=0;-.25p2→p2
8  if p1mod2;-.1p2(A=4)-.01p2(A=1)→p2
9  if flg0;p2→E[p1,N];ret
10 p2→D[p1,N];ret
```

The first line of this subroutine selects channel 2 if the parameter to be measured is phase (the calling parameter p1 is even). The second line sets the appropriate channel (A=1 for channel 1 or A=4 for channel 3) for magnitude measurements. The variable A must be initially set to 4 before the first time this subroutine is called. The third line reads the analog-to-digital converter ("dvm"), which must be read in two bytes and then rotated and added together to get the reading. If the parameter read is phase, the fourth line jumps around the autoranging. Line 5 will switch to read channel 3 (10 V) if the reading is greater than ±9.99 dB and line 6 switches to read from channel 1 if the reading is less than 10 dB. Lines 7 and 8 scale the ADC reading to degrees (line 7) or dB (line 8). Finally the data is stored in the error coefficient array E[p1,N] if flg 0 (line 9) or in the data array D[p1,N] if flg 0 is not set (line 10).

HP 3455A Voltmeter

When the 3455A Digital Voltmeter is used as the ADC to read data from the 8754A the range should be programmed to 10 Vdc and the trigger should be set to manual. One way to select this is to use the following line (in the beginning of the program) to clear and set the 3455A.

```
clr "dvm";wait 20;wrt "dvm""R3T3"
```

Once this is done, to read data, simply trigger (by sending a "T3") and read the DVM. The value read is in volts and will need to be scaled (times

−10 for magnitude and −100 for phase). By calling the following "Read" subroutine with one parameter (see Figure 4), all of this is done as well as storing the value in the data array.

```
"Read":
wrt "dvm","T3";red "dvm",p2
(-100+90(p1mod2))p2→D[p1,N]
ret
```

Typical Measurement Loop

With subroutines to set frequency, setup the 8754A/8748A, and read data, the next step is to construct the subroutine that will step through a desired frequency range and take measurements at given frequencies. A general purpose measurement loop subroutine can be constructed that will step through the desired frequencies, using the subroutines "Setup," "Freq," and "Read." This routine is called with two parameters (p1 and p2), one is the S-parameter to be measured and the other will select what data operations will be done. Constructing a measurement loop in this manner allows maximum flexibility.

```
cll 'Loop'(3,2)
            │ └──Data Operation (2=normalization)
            └────S-parameter (3=S21 mag and phase)
```

```
   "Loop":
1  1→N;F[1]→F[5]
2  "next":gsb "Freq"
3  cll 'Setup'(p1)
4  cll 'Read'(p1)
5  if p1mod2;p1+1→p1;gto -2
6  if p2=1;cll 'Angle'(E[p1,N],180)
7  if p2=2;cll 'Normal'(p1-1)
8  if N=F[4];gto +3
9  N+1→N;F[5]+F[3]→F[5]
10 p1-1→p1;gto "next"
11 F[1]→F[5];cll 'Freq';gsb "Local"
12 ret
```

The first call parameter in "Loop" selects which S-parameter (magnitude and phase) will be measured. Since both magnitude and phase are always measured with this subroutine, the call parameter codes differ slightly from those in Figure 4. To call a given S-parameter use the value in Figure 4 for the magnitude of the S-parameter (e.g., 3 for S_{21}). The data operations parameter is the second call parameter. In this subroutine there are only two data operations listed (p2=1 for subtracting two phase angles and correcting the value to ±180°, and p2=2 will do a normalization of magnitude and phase). The start (F[1]) and stop (F[2]) frequencies, step size (F[3]), and number of frequency points (F[4]) must be already defined before calling the subroutine.

The frequency index (N) and the frequency to be set (F[5]) are initialized (line 1) and then automatically incremented until the last frequency is set. At each frequency point the 8754A and 8748A are setup to measure magnitude. The magnitude is read and then phase (line 5 increments p1 by 1 to set the phase parameter). After both the magnitude and phase are read, the appropriate data operations (normalization, determination of error coefficients, etc.) are selected by the second parameter (p2). In the above example the "Angle" or "Normal" (-ization) subroutines are called when p2=1 or p2=2. (See Annotated Listing for description of these subroutines.) The list of mathematical subroutines can be easily expanded to include any desired error correction or reformating. After the data operations are completed the magnitude parameter is set (line 10) and the next frequency point is set.

It is important to go to local whenever the frequency is not being digitally swept (line 11). If the varactor oscillator is left at a given frequency for any length of time, the accuracy in setting a different frequency will be degraded. The actual frequency will drift because of the "memory" of the past frequency. The longer the oscillator remains at one frequency the longer it will drift. For this reason it is important to keep the oscillator sweeping, either digitally (while taking data) or continuously in the local mode (while outputting data, changing devices, etc.). The SWEEP switch on the rear panel of the 8754A should be left in the INT (internal) position so the 8754A will sweep in "local" mode (the remote line automatically switches to external sweep). The "Loop" subroutine returns the 8754A to local and the DAC output is set to 0 V (F[1]) after the last data point. A flowchart of the "Loop" subroutine is shown in Figure 7. When changing devices the connections can be verified and frequency drift checked.

Timing and Measurement Order

As in all systems, consideration must be made for hardware timing: e.g., source settling, detector settling, switching time for relays, digitizing time, etc. When these times are characterized, the optimum programming order and maximum speed can be determined.

Settling Times

In the 8754A/8748A system there are five areas that must be considered in logging data. The time required for the source and DAC to settle to 0.0006 percent of the step size (12 time constants) is 3 msec. When the output is switched between magnitude and phase or between A/R and B/R there is also a 3 msec settling time. As described earlier, the receiver is forced to relock after setting each frequency. The relock time is again 1.5 msec (which can be included in the other switching times). The 8748A S-parameter Test Set takes 100 msec to switch between forward and reverse.

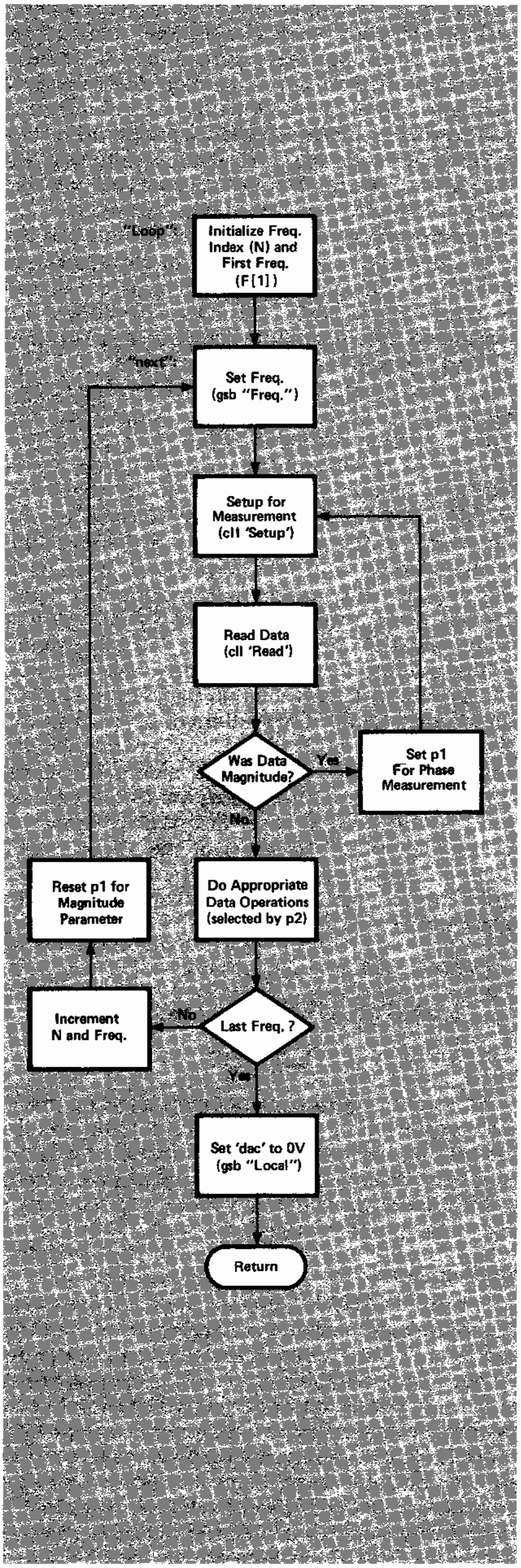

Figure 7. Flowchart of the "Loop" Subroutine.

The analog voltage must be digitized by the ADC and read by the controller. This time varies depending on the ADC used. Settling times for the 8754A/8748A are summarized in Figure 8 below.

DAC and Source Settling	3 msec
Magnitude/Phase Switching*	3 msec
A/R / B/R Switching*	3 msec
Forward/Reverse Switching	100 msec
First Frequency Point	100 msec

* Includes 1.5 msec relock time.

Figure 8. 8754A/8748A Timing.

Measurement Order

Since the three settling times for the 8754A are the same (3 msec), and the 8748A switching is 100 msec, the main consideration for data logging programs is to minimize test set switching. This both saves time and maximizes the life of the 8748A relays. In the following program example, the only programmed "wait" that is needed is for the test set switch. The program execution time for the different subroutines when using the 9825A is longer than the 3 msec required for 8754A settling. The measurement order is to step through the frequency range for each S-parameter, switching to read both magnitude and phase at each frequency. The two forward parameters will always be measured first and then the test set will be switched to measure the reverse parameters.

Typical Measurement Times

Using the following example program, with the 59313A as the ADC, the typical measurement time per S-parameter (magnitude and phase with frequency response removed) is 165 msec as shown in Figure 9. For each S-parameter the "Freq" (-uency) is set, the 8754A/8748A has to be "Setup" for magnitude and then for phase, the data has to be "Read" twice, and the frequency response is then removed in the "Normal" subroutine. The remaining time is the overhead of the "Loop" subroutine. Some of these routines will vary depending on the ADC, the number of S-parameters measured, and the number of frequency points. The total time is also dependent on the program structure.
The times for the HP 3455A voltmeter using the sample program are also summarized in Figure 9.

ADC	'Freq'	'Setup'	'Read'	'Normal'	'Loop'	Total
59313A	10	2x20	2x35	25	20	165
3455A	10	2x20	2x58	25	20	211

Figure 9. Typical Time (msec) per S-parameter per frequency for a 101 Point Measurement.

Sample Program

On the following pages is a sample program, combining the previously discussed subroutines, which measures all four S-parameters of a two-port device and prints the data with the magnitude and phase frequency responses removed. The program requires some manual interaction and equipment setup by the user. The program is intended to be an example on structuring a measurement configuration based on the 8754A Network Analyzer and 9825S Desktop Computer. It can also be used as the base program that can be easily modified for different system configurations and different data output formats.

Program Operation

1. Setup measurement system as shown in Figure 1.
   - It is recommended that the system be allowed a 30-minute warm up.
   - The 59313A Analog-to-Digital Converter and the 59501A Digital-to-Analog Converter should be calibrated when the system is first put together and periodically rechecked. (See A/D Converter Calibration p. 12.)
2. Type in the sample program, obtain a listing, and then compare the checksum to the one at the end of the listing on page 10. If the program is typed identically to the sample, the checksums will be the same. When the program is correctly entered, record the program on a tape cartridge for future use.
3. Begin the program by pressing RUN. When "Set POWER LEVEL and ATTENUATION" appears in the display, manually set the desired output power level on the 8754A and the attenuator setting on the 8748A (if used). Press CONTINUE.
4. When "Set SWEEP and CAL FREQ" appears in the display, manually set the sweep width and check the frequency calibration, using the internal crystal markers and press CONTINUE.
5. The next display, "Set SWEEP" to "AUTO & FAST," is a reminder that the AUTO sweep should be selected and the FAST sweep mode. The SLOW sweep mode will require an additional wait statement to be added to the program, considerably increasing the measurement time. Press CONTINUE.

   These are the only controls that need to be set. No other front panel control settings will affect the value of the measured data.
6. "Enter START FREQ (MHz)" appears next. Type in the start frequency of the sweep you manually set. Press CONTINUE.
7. When "Enter STOP FREQ (MHz)" appears, enter the stop frequency of the sweep you manually set and press CONTINUE.
8. "Enter FREQ STEP (MHz)" is the next display. Enter the desired frequency step size (the maximum number of points is 101, so if the step size is too small, the display will return to step 6).
9. The next instruction is to "Connect Short—Port 1" to calibrate for reflection on port 1. Then press CONTINUE.
10. Similarly, the next display will be "Connect Short—Port 2." Connect a short to the "port 2" which the device will see, using the same adapters and interconnect cables that will be used in the measurement (see 8754A Operation Information 08754-90014, page 12), and press CONTINUE. (If the 8502A/B is used just press CONTINUE.)

FREQUCNCY	RETURN LOSS INPUT (S11)		TRANS. LOSS FORWARD (S21)		TRANS. LOSS REVERSE (S12)		RETURN LOSS OUTPUT (S22)	
MHz	DB	DEG	DB	DEG	DB	DEG	DB	DEG
150.00	0.05	-162.3	76.43	-61.5	75.78	-63.0	0.02	-146.0
155.00	0.05	-166.3	72.97	-59.3	72.47	-64.3	0.02	-149.0
160.00	0.05	-169.8	68.97	-65.3	68.67	-67.0	0.01	-152.5
165.00	0.06	-174.0	64.27	-69.8	64.47	-69.3	0.01	-156.3
170.00	0.07	-179.0	59.37	-74.8	59.27	-75.0	0.02	-160.8
175.00	0.09	175.3	53.16	-81.8	53.27	-82.0	0.03	-167.0
180.00	0.12	167.3	45.46	-91.0	45.56	-91.0	0.06	-174.5
185.00	0.20	154.3	35.26	-105.5	35.46	-105.3	0.15	172.5
190.00	0.53	127.8	20.06	-137.3	20.16	-136.8	0.55	143.0
195.00	13.23	76.3	1.80	77.3	1.85	78.0	17.33	-114.8
200.00	10.12	-147.8	1.29	-74.3	1.28	-73.5	10.72	-171.5
205.00	9.46	11.5	3.18	120.5	3.14	121.8	7.70	-8.8
210.00	0.37	-108.3	25.06	3.5	24.96	3.8	0.28	-93.3
215.00	0.14	-134.8	40.26	-23.3	40.26	-23.0	0.09	-116.0
220.00	0.09	-147.3	51.26	-36.0	51.26	-36.0	0.04	-127.0
225.00	0.07	-155.0	60.06	-43.5	59.96	-43.3	0.02	-133.8
230.00	0.06	-160.8	67.45	-48.5	67.25	-49.3	0.01	-138.8
235.00	0.05	-165.8	73.55	-54.0	73.75	-54.5	0.01	-142.5
240.00	0.06	-169.3	79.15	-56.3	79.35	-59.0	0.01	-146.0
245.00	0.05	-172.5	84.25	-56.3	83.65	-70.5	0.00	-148.3
250.00	0.05	-175.3	87.25	-42.0	86.35	-54.3	0.00	-150.3

Figure 10. Data Printout on 200 MHz Bandpass Filter.

11. The last step in the calibration is to "Connect Thru" for transmission calibration and press CONTINUE.
12. When the calibration is completed the display will show "Connect Device, Enter Label." Connect the device to be tested and type in a heading for the data and press CONTINUE.
13. The program will measure all four S-parameters of the device connected and prints the data with the frequency response removed. If the 8502A Test Set is used the following line has to be added before line 28.

```
if I=5;dsp "Reverse Device";stp
```

14. The program loops back to step 12 for the measurement of another device. At step 12 the measurement system is returned to "Local" operation allowing you to verify the sweep calibration, with the crystal markers or proper connection of the next device. Press STOP and RUN to recalibrate and make measurements over a different frequency range.

See Figure 10 for a sample printout of the data taken on a 200 MHz bandpass filter.

Program Structure

The program structure will be explained to make modifications easier. Flowcharts of the main program and "Loop" subroutine are shown in Figures 11 and 7 respectively. At the end of this section is an annotated listing of the program. The main subroutines are those described earlier, with some minor modifications.

The variables used in this program are assigned as follows:

Matrices:

D[8,101] Array for storing measured and normalized S-parameter data. The first index identifies the parameter measured (corresponding to the call parameters of the "Setup" routine listed in Figure 4). A maximum of 101 data points can be stored.

E[8,101] Array for storing the measured calibration factors for the corresponding S-parameter data stored in the D[8,101] array. This data is subtracted from the data in the D[8,101] array with the result restored in the data array from which the actual data is printed.

F[5] An array containing the start frequency, stop frequency, step frequency, total number of frequency points, and the current frequency being measured (1-5 respectively).

String Variable:

A$[72] A string array containing the label entered for the heading of the printed data.

Simple Variables:

A ADC channel used to measure magnitude (autoranges between channel 1, A=1 and channel 3, A=4).

I,J For/next loop variables used in the output section.

N Data point being measured. Its range is 1 to F[4], which is the number of frequency points.

flag:

0 (0) Data read is NOT calibration data and is assigned to D[8,101].

(1) Data read is calibration data and is stored in E[8,101].

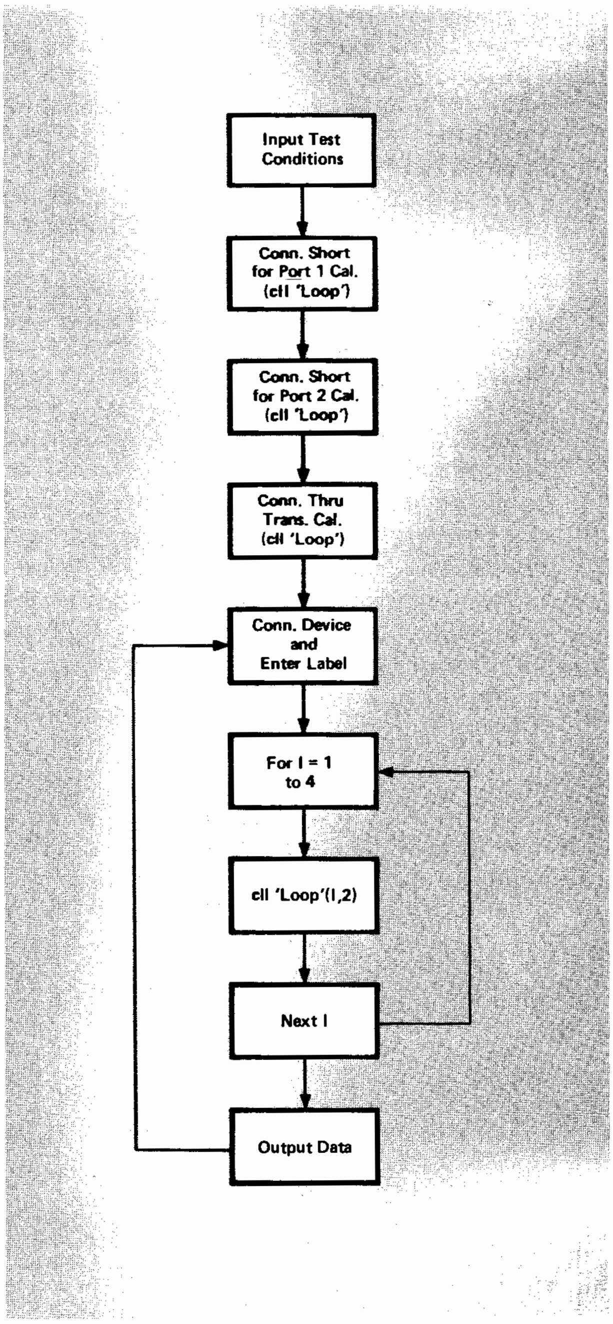

Figure 11. Flowchart of Main Program.

```
0: dim D[8,101],E[8,101],A$[72],F[5]
1: dev "dac",708,"dvm",710,"59301",706,"W",6
2: deg;4}A;cli 7;clr 7
3:
4: "TEST CONDITIONS SECTION ***********************************************":
5:
6: gsb "Local"
7: dsp "Set POWER LEVEL and ATTENUATION";stp
8: dsp "Set SWEEP and CAL FREQ";stp
9: dsp "Set SWEEP to AUTO & FAST";stp
10: ent "Enter START FREQ (MHz)",F[1]
11: ent "Enter STOP FREQ (MHz)",F[2]
12: ent "Enter FREQ STEP (MHz)",F[3]
13: 1+int((F[2]-F[1])/F[3])}F[4];if F[4]>101 or F[4]<1;gto -3
14:
15: "CALIBRATION SECTION **************************************************":
16:
17: sfg 0
18: ent "Connect Short - Port 1",A$;cll 'Loop'(1,1)
19: ent "Connect Short - Port 2",A$;cll 'Loop'(7,1)
20: ent "Connect Thru",A$;cll 'Loop'(3,0)
21: cll 'Loop'(5,0)
22:
23: "MEASUREMENT SECTION **************************************************":
24:
25: "Meas":cfg 0
26: ent "Connect Device, Enter Label",A$
27: for I=1 to 7 by 2
28: cll 'Loop'(1I,2)
29: next I
30:
31: "OUTPUT SECTION *******************************************************":
32:
33: fmt 1,3/,c40,2/;wrt "W.1",A$
34: fmt 1,"FREQUENCY",3x,z;fmt 2,"RETURN LOSS",7x,z
35: fmt 3,"TRANS. LOSS",7x,z;fmt 4," INPUT (S11)",6x,z
36: fmt 5,"FORWARD (S21)",5x,z;fmt 6,"REVERSE (S12)",5x,z
37: fmt 7," OUTPUT (S22)",5x,z;wrt "W.1";fmt 1,z
38: wrt "W.2";wrt "W.3";wrt "W.3";wrt "W.2";wrt "W"
39: fmt 1,11x,z;wrt "W.1";fmt 3,z;wrt "W.4";wrt "W.5";wrt "W.6";wrt "W.7"
40: wrt "W";fmt 2,"DB",6x,"DEG",7x,z;fmt 1,2x,"MHz",7x,z
41: wrt "W.1";for J=1 to 4;wrt "W.2";next J
42: fmt 1,/;wrt "W.1";for J=1 to F[4]
43: F[1]+(J-1)F[3]}D;fmt 1,f7.2,3x,z;wrt "W.1",D
44: for I=1 to 4
45: fmt 2,f6.2,2x,f6.1,4x,z;wrt "W.2",-D[2I-1,J],D[2I,J]
46: next I;wrt "W";next J;fmt 1,4/;wrt "W.1"
47: gto 23
48:
```

- Line 2 → Select channel 3 of voltmeter and clear HP-IB
- Line 13 → Calculate the number of frequency points (101 max)
- Lines 17–21 → Measure frequency response for reflection and transmission for both ports
- Lines 25–29 → Measure device S-parameters
- Line 33 → Print device label
- Lines 34–41 → Print column headings
- Line 43 → Print frequency
- Line 45 → Print 4 S-parameters

Note: Printer used to generate listing in this Application Note prints "}" for "→" and "^" for "↑".

```
49: "SUBROUTINES ************************************************************":
50:
51: "Local":cll 'Setup'(0);ret
52:
53: "Setup":
54: (p1>0)(8+4(p1>2)(p1<7)+2(p1mod2=0)+(p1>4))}p2
55: wtb "59301",48+p2+7(p2>9),10
56: wait 100(N=1);ret
57:
58: "Freq":
59: fmt 1,f4.0,z
60: wrt "dac.1",2000+999(F[5]-F[1])/(F[2]-F[1])
61: ret
62:
63: "Read":
64: if p1mod2=0;wrt "dvm","H2AJ";gto +2
65: fmt 1,c,f.0,c2;wrt "dvm.1","H",A,"AJ"
66: rot(rdb("dvm"),8)+rdb("dvm")}p2
67: if p1mod2=0;gto +3
68: if A=1 and abs(p2)>999;4}A;gto -3
69: if A=4 and abs(p2)<100;1}A;gto -4
70: if p1mod2=0;-.25p2}p2
71: if p1mod2;-.1p2(A=4)-.01p2(A=1)}p2
72: if flg0;p2}E[p1,N];ret
73: p2}D[p1,N];ret
74:
75: "Loop":
76: 1}N;F[1]}F[5]
77: "next":gsb "Freq"
78: cll 'Setup'(p1)
79: cll 'Read'(p1)
80: if p1mod2;p1+1}p1;gto -2
81: if p2=1;cll 'Angle'(E[p1,N],180)
82: if p2=2;cll 'Normal'(p1-1)
83: if N=F[4];gto +3
84: N+1}N;F[5]+F[3]}F[5]
85: p1-1}p1;gto "next"
86: F[1]}F[5];cll 'Freq';gsb "Local"
87: ret
88:
89: "Angle":
90: p1-p2}p3
91: (p3mod360}p3)-360(p3>180)}p1
92: ret
93:
94: "Normal":
95: D[p1,N]-E[p1,N]}D[p1,N]
96: cll 'Angle'(D[p1+1,N],E[p1+1,N])
97: ret
*23284
```

- Line 51 → Put 8754/8748 to Local
- Lines 53–56 → Setup 8754/8748 for measurement specified by call parameter 0-8 (see Figure 4)
- Lines 58–61 → Set frequency via programming "dac". Frequency set is F[5]
- Lines 64–66 → Setup "dvm" to read two bytes and combine them
- Lines 68–69 → Autorange if necessary
- Lines 70–71 → Scale data
- Lines 72–73 → Store data
- Line 76 → Initialize first frequency and index
- Lines 80–82 → Data operations
- Lines 90–92 → Subtract two angles and rescale to be between ±180″
- Lines 95–97 → Frequency response is removed from data

Note: Printer used to generate listing in this Application Note prints "}" for "→" and "^" for "↑".

Measurement Performance

The typical measurement repeatability and accuracy for a given device will depend on the power level into the test and reference channels, the slope of the data (dB/MHz or deg/MHz), and the quality of connectors, cables, etc., used to connect the device to the test set. The repeatability of the source and receiver have been characterized below.

Accuracy

The dynamic accuracy of the magnitude and phase measurements are the same as those specified for the manual 8754A. These are described in the 8754A Operation and Service manual.

Frequency Repeatability

The frequency repeatability of the source in the 8754A is dependent on the DAC resolution, sweep width, residual FM, and the frequency drift. The frequency repeatability can be divided into short-term and long-term repeatabilities.

SHORT-TERM

The residual FM specification of the 8754A source is 7 kHz RMS (in a 10 kHz bandwidth). The 59501A Digital-to-Analog Converter (DAC) has a resolution of 1000 points. Therefore there is 1000 point resolution in any sweep width which will limit the repeatability in sweep widths greater than 20 MHz (in full sweep the repeatability is 1.3 MHz). For sweep widths less than 20 MHz the resolution is limited (in non-synthesizer systems) by the residual FM. Typical frequency repeatabilities are 25 kHz.

LONG-TERM

The frequency drift of the source is typically less than ±400 kHz/°C and ±100 kHz/hour. This can be easily monitored by using the built-in crystal markers between measurements when the 8754A is in "local" operation.

Magnitude and Phase Repeatability

The repeatability of magnitude and phase measurements is determined by the resolution of the dvm used, the detector (mag or phase) repeatability, which varies with power level, and any magnitude or phase change caused by frequency repeatability. The short-term repeatability for devices with fairly flat frequency response (i.e., pads, amplifiers, etc.) is typically 0.02 dB and 0.1 degree for power levels above −30 dBm (at the test channel detector). For lower levels, the typical repeatabilities are summarized in Figure 12.

For devices that have a magnitude and frequency response which varies rapidly with frequency, additional repeatability errors must be accounted for. For example, the short-term repeatability is calculated below when measuring the skirt of a filter with a magnitude slope of 2 dB/MHz at a power level of −40 dBm.

Magnitude Detector Repeatability (from Figure 12.)	0.03 dB
Frequency Repeatability x Magnitude Slope 25 kHz x 2 dB/MHz	0.05 dB
Total	0.08 dB*

* When the 59313A ADC is used the repeatability is limited by the resolution (0.1 dB).

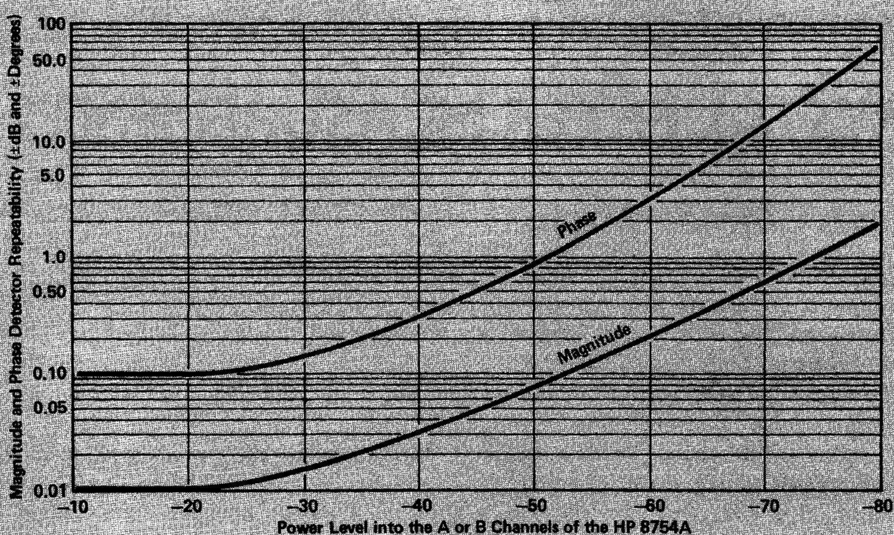

Figure 12. Typical Magnitude Repeatabilities.

59313A A/D Converter Calibration

Calibration should be performed when the system is first installed, then checked every three months thereafter. The following procedure will calibrate the 59313A for data taking with the 8754A. Channels 1 through 3 must be internally set with appropriate jumper positions at ±1.0 V, ±2.5 V and ±10 V respectively.

1. Enter calibration program.

```
0: for I=1 to 3
1: fmt 1,c,f.0,c2;wrt 710.1,"H",2^(I-1),"AJ"
2: rot(rdb(710),8)+rdb(710)→rI
3: next I;fxd 0;dsp r1,r2,r3;gto -3
*3570
```

2. Remove 59313A Channel 1, 2, and 3 phone plugs from their rear panel receptacles.
3. Press RUN to execute the program. 9825A LED display shows A/D converter output values.
4. Set rear panel CAL switch to 0 (zero). Adjust Channel 1, 2, and 3 front panel ZERO controls for 0.
5. Set rear panel CAL switch to −1. Adjust Channel 1, 2, and 3 front panel GAIN controls for −1000, −400, and −100 respectively.
6. Set rear panel CAL switch to −5. Adjust Channel 3 front panel GAIN control for a Channel 3 reading of −500.
7. Reconnect the phone plugs. The 59313A is now calibrated and ready to use.

   Note: The calibration of the 8754A "MAG/PHASE" output should be checked. Refer to 8754A Operating and Service Manual.

59501A D/A Converter Calibration

Calibration should be performed when the system is first installed, then checked every three months thereafter.

1. Enter calibration program.

```
0: fmt 1,c4,z
1: wrt 708.1,"2000"
2: cll 'Read'(r1)
3: wrt 708.1,"2999"
4: cll 'Read'(r2)
5: dsp r1,r2;gto -4
6:
7: "Read":
8: wrt 710,"H4AJ"
9: rot(rdb(710),8)+rdb(710)→p1
10: .01p1→p1;ret
*19863
```

2. Connect the 59501A DAC output to Channel 3 of the 59313A. (59313A should already be calibrated.)
3. Press "RUN" to execute program. 9825A LED display shows the ZERO voltage level and the FULL SCALE voltage value.
4. Adjust the 59501A front panel ZERO ADJUST for a 0.00 on the first displayed value.
5. Adjust the 59501A front panel D/A FULL SCALE ADJUST for a 10.00 on the second value.
6. Reconnect the DAC output and Channel 3 input to the 8754A. The 59501A is now calibrated and ready to use.

   Note: A different ADC can be used to calibrate the 59501A by changing the "Read" subroutine to correspond to the voltmeter.

CRYSTAL FILTER MEASUREMENTS

General Source Considerations

The residual FM of the source of the 8754A, 7 kHz RMS, precludes the measurement of narrow-band devices such as crystal filters. For these applications a stable external source can be used in place of the built-in source. In automatic operation the external source needs to be computer controllable and capable of supplying +10 dBm for full measurement range. One cost effective source for crystal filter measurements is the HP 3335A, 200 Hz to 80 MHz Frequency Synthesizer (however any programmable source can be used). For measurements beyond 80 MHz a doubler and amplifier can be used to provide a 1 to 160 MHz source (see Figure 13).

The source frequency is stepped across the desired frequency range and at each point the sampling receiver in the 8754A relocks to each new frequency just as if the internal source was used. After the receiver has relocked, the data is read.

Modifying the Sample Program

The sample program described in Section II can be easily modified for narrow-band operation with an external source. The main program modification is to replace the "Freq" subroutine so it will program the external source instead of the internal one.

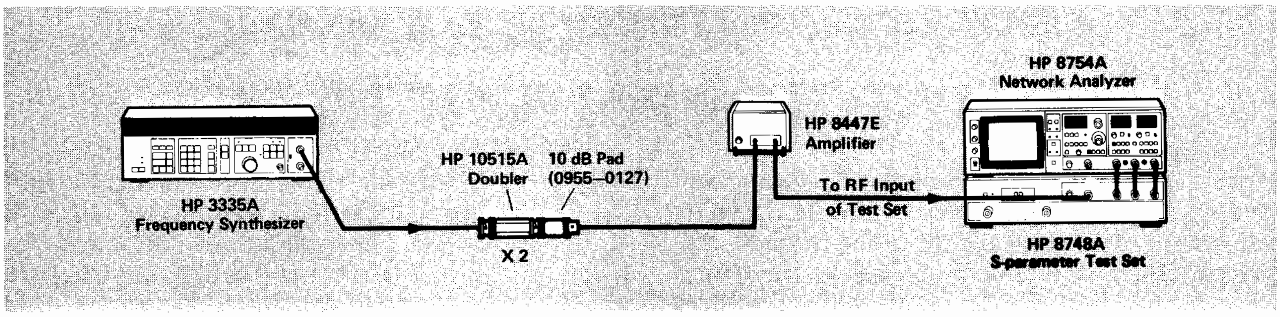

Figure 13. Frequency Synthesizer with Doubler.

Setting Frequency

If the 3335A Frequency Synthesizer is used as the source, the original "Freq" subroutine should be replaced with:

```
"Freq":
1 fmt 1,f4.0,z
2 wrt "dac.1",2000+999F[5]/1310
3 fmt 1,"F",f13.9,"M"
4 wrt "syn.1",F[5]
5 wait 20;ret
```

where F[5] is the desired frequency (in MHz) to be set. The internal source is first set to the desired frequency to ensure that the receiver phase-lock loop gain will be correct for locking on the signal from the synthesizer (line 2). The synthesizer is then programmed (line 4). A wait of 20 msec (line 5) is included after setting frequency to allow the source to settle. If the doubler circuit (Figure 13) is used, line 4 should be modified as:

```
wrt "syn.1",.5F[5]
```

Program Modifications

Since this subroutine uses a device label for the synthesizer, the label and select code needs to be added to the device statement (line 1 of the sample program).

```
dev "dac",708,"dvm",710,"59301",706,"W",6,"syn",704
```

The power level of the synthesizer needs to be set at the beginning of the program. To set the amplitude to +10 dBm, add the following code to the end of line 2 of the sample program.

```
deg;4)A;cli 7;clr 7;wrt "syn","A10K"
```

In the data output section the resolution of the printed frequency needs to be increased. For 100 Hz resolution the format statement (line 43) needs to be changed to:

```
F[1]+(J-1)F[3])D;fmt 1,f8.4,2x,z;wrt "W.1",D
```

With this set of changes the check sum after listing the program should be 18323 (for the synthesizer without multiplier).

Results

When using the sample program with the modifications, the operation is the same. The frequency of the source in the 8754A still needs to nominally be set to the frequency being set on the synthesizer. This is accomplished by leaving the D/A connected to the SWEEP INPUT and using the "Freq" subroutine described above and by selecting the full sweep mode on the front panel of the 8754A. This insures the proper loop gain for locking the receiver to the external signal. Figure 14 shows the printout of a 20 MHz crystal filter using the modified program and the HP 3335A Frequency Synthesizer.

The measurement repeatability as described earlier applies here also. The frequency repeatability becomes that of the synthesizer and the magnitude and phase detector repeatability remains the same. In calculating the measurement repeatability, the component due to frequency repeatability and frequency response is essentially eliminated due to the good frequency repeatability of the synthesizer. This leaves only the magnitude and phase detector repeatabilities (Figure 12).

FREQUENCY	RETURN LOSS INPUT (S11)		TRANS. LOSS FORWARD (S21)		TRANS. LOSS REVERSE (S12)		RETURN LOSS OUTPUT (S22)	
MHz	DB	DEG	DB	DEG	DB	DEG	DB	DEG
19.9950	1.15	148.8	62.34	-140.8	62.44	-139.8	1.13	122.0
19.9960	1.17	144.0	53.04	-146.5	53.14	-146.8	1.16	117.0
19.9970	1.22	134.5	40.93	-158.5	40.94	-158.3	1.26	108.3
19.9980	1.66	106.0	22.14	169.8	22.14	170.3	1.71	87.0
19.9990	8.71	148.0	4.53	-7.8	4.64	-7.3	7.97	42.5
20.0000	16.83	-4.5	3.14	-171.5	3.09	-172.3	16.33	-172.8
20.0010	2.30	-130.5	11.18	-4.0	11.21	-3.5	6.36	-97.3
20.0020	1.16	-164.3	34.04	-72.8	34.04	-73.0	1.58	-178.3
20.0030	1.12	-174.5	47.54	-88.5	47.64	-88.8	1.31	166.8
20.0040	1.10	-179.8	57.23	-96.3	57.23	-96.0	1.23	159.3
20.0050	1.09	176.8	64.84	-100.5	64.74	-102.0	1.19	155.0

Figure 14. Data Printout on a 20 MHz Crystal Filter.

APPENDIX "A": PROGRAMMING CONNECTOR PIN FUNCTIONS

For automatic measurements, all 8754A and 8748A S-parameter functions in addition to several analog outputs are accessible through the rear panel J7 programming connector. Control is accomplished with TTL levels (1 = 5 V, 0 = 0 V) or contact closure (1 = open, 0 = ground).

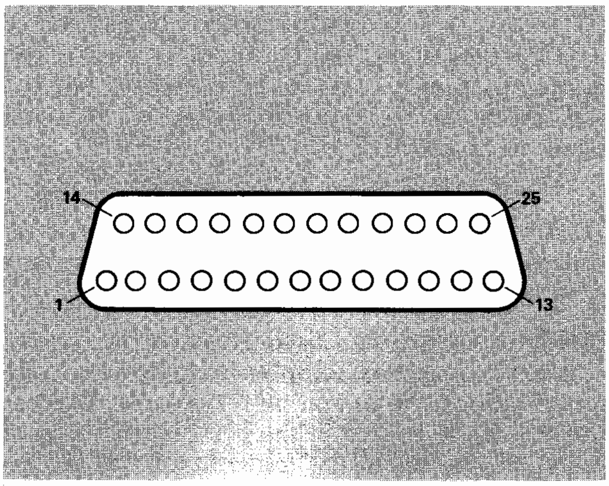

Figure 15. J7 Programming Connector.

Pin No. **Function**

J7 INPUTS

21 **Remote Select.**

1 = Local Operation

0 = Remote Operation

8754A: Ground selects remote operation, which switches the sweep generator to EXT SWEEP mode, disables the front panel receiver controls, and enables A/R or B/R select (pin 20).

8748A: Ground allows remote operation of 8754A and 8748A to be selected when a relock pulse is applied to J7 pin 24. Remote operation enables 8748A S-parameter select (pin 8).

10 **Reverse 8754A and B INPUT Functions**

1 = Normal Operation.

0 = Reverse A and B nomenclature on the front panel.

Selecting Reverse exchanges the A and B inputs so the "A" receiver will be controlled by the "B" front panel switches (for A, A/R, and A/R polar) and appear as a B analog output. This is useful when used with the 8748A Test Set because reflection measurements are always controlled by the "A" switch setup. For serial prefix 1908A and higher, the electrical length controls are NOT reversed when pin 10 is low. For serial prefix 1908A and below, the electrical length controls are reversed when pin 10 is low.

19 **Magnitude or Phase Output Select**

1 = Magnitude Ratio Output.

0 = Phase Angle Output.

Selects output at rear panel MAG/PHASE output and J7 pins 11 and 22.

20 **Remote A/R or B/R Select**

1 = Selects A/R.

0 = Selects B/R.

Controls selection of detector outputs applied to J7 pins 11 and 22, and MAG/PHASE output. Enabled by grounding J7 pin 21, 8754A Remote Select (see also J7 pin 19). If not enabled, outputs are selected by front panel controls.

24 **Relock and Trace Blanking**

Is used with external source or when changing the frequency externally. When grounded, CRT trace is blanked. Transition from 0 V to +5 V forces 1.5 millisecond relock sequence during which the trace remains blanked. Minimum pulse width is 20 μsec.

3 **Relock and Trace Blanking**

Same as pin 24, except inverted polarity (for instruments with serial prefix 1908A and higher). For prefixes below 1908A pin is open.

13 **Electrical Length or Degrees/Sweep Select**

1 = Electrical Length, 0 — 16 cm.

0 = Degrees/Sweep, 0 — 190 degrees/sweep.

Selects function of the front panel A/R LENGTH and B/R LENGTH controls. "Electrical length" introduces a phase shift proportional to RF frequency which compensates electrical length differences between A, B, and R inputs. "Degrees/Sweep" introduces a phase shift proportional to CRT X-axis (sweep). The phase introduced is zero at the beginning of the sweep and increases linearly to the selected value at the end of the sweep. The equivalent length added to the R input depends on the sweep width and is calculated as follows:

Electrical length (m) =

$$\frac{\text{linear insertion phase (degrees)}}{\text{sweep width (MHz)} \times 1.2}$$

Degrees/Sweep may be useful to equalize large differences in electrical length over narrow sweep widths.

15 **Stop Sweep**

1 = Continue Sweep.

0 = Stop Sweep.

Allows external control of sweep.

16 **Sweep Trigger (negative going edge trigger)**

When grounded, a sweep will be triggered (if the front panel TRIG button is pushed and the retrace cycle has completed).

23 **Tuning Marker (Output and Input)**

As an input, when ground is applied, trace moves up ¼ major division on the rectangular trace or increased intensity on polar trace. In full sweep mode, pin 23 is an output and a pulse ⊔ is output at Tuning Marker position.

8 **Test Set Remote S-parameter Select**

1 = Test Set in Forward (measuring S_{11} and S_{21}).

0 = Test Set in Reverse (measuring S_{22} and S_{12}).

Not used in 8754A. Enabled by grounding pin 21, 8754A remote select, and pulsing pin 24 (relock).

J7 OUTPUTS

11 & 22 **Two identical Magnitude or Phase Outputs**

Magnitude = −0.1 V/dB.

Phase = −0.01 V/degree.

Output is determined by J7 pins 20 20 and 19 as follows:

J7 Pin 20 A/R or B/R Select	J7 Pin 19 Mag or Phase Select	J7 Pins 11, 20 MAG/PHASE Outputs
0	0	B/R Phase Angle
0	1	B/R Magnitude Ratio
1	0	A/R Phase Angle
1	1	A/R Magnitude Ratio

These outputs are identical to the rear panel MAG/PHASE output. The signal at J7 pin 10, Reverse A and B, is active in Remote. (If not enabled, then the front panel controls select output.)

17 **−5 to +5 V Sweep Output**

Internal Sweep output. Same as the rear panel SWEEP OUTPUT.

4 **0 to 10 V Sweep Output**

Same as J7 pin 17 except with different levels.

J7 ACCESSORY

14 +20 Vdc. This is used for the 8748A test set. It is not recommended for other external uses (maximum available current is 50 ma). "DO NOT SHORT."

12 & 18 **Ground.**