APPLICATION NOTE 112-1

Low-Frequency Network Analysis With The 675A/676A

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INTRODUCTION

This note is the first of a series, the intent of which is to help the 675A/676A user utilize all the many useful and interesting features of the system. This first note will deal primarily with the basic measurements that can be made with the instruments. Later notes will show how to extend the usefulness of the 675A/676A to more sophisticated measurements.

The basic function of the 675A/676A is to measure the insertion loss or gain of networks that are designed to be terminated in 50 Ω and driven by a 50Ω source. The instruments will provide an indication of the log magnitude and the phase of the insertion loss over a swept band. This indication can be displayed either on an oscilloscope having dc coupling, or on an X-Y recorder.

The system is also capable of similarly measuring the difference in gain and phase between an unknown and a reference network. Suitable accessory equipment will provide a log magnitude vs. log frequency (Bode plot) display of a network instead of the usual gain and/or phase vs. linear frequency. This feature is particularly valuable in feedback amplifier work.

The transfer ratio of networks requiring a high-impedance load can be measured through the use of an accessory probe, HP Model 1123A.

How these measurements are made, along with typical examples, will be presented. Before applications are actualty dealt with, however, it would be profitable to briefly describe the operating principles of the two units. Detailed schematics, circuit descriptions and specifications are available in the appropriate operating and service manuals or data sheets; therefore, the theory of operation will be limited to generalities and simplified block diagrams.

675A/676A NETWORK ANALYZER DESCRIPTION

675A Sweeping Signal Generator

The 675A sweeper is the heart of the 675A/676A Network Analyzer, providing driving signals, markers, blanking, etc., to the 676A. A simplified block diagram of the 675A appears in Figure 1.

The 675A will deliver a swept sinusoidal signal flat to ±0.15 dB over the 0.01MHz to 32 MHz frequency range. The level is adjustable from a maximum of 1 V rms to a level —99 dB below 1 V rms (—89 dBm) by means of two precision step attenuators having 10dB and 1dB steps. There is also a continuous level control useful in precisely setting the RF output to some reference level as indicated on the front-panel meter.

The swept bandwidth and the sweep rate are also adjustable. Any segment of the 0.01MHz to 32MHz band may be swept by appropriately setting the START/STOP controls in Start/Stop mode. In $F_0/\Delta F$ mode, the START control can be used to select a center frequency and a ΔF of 1 kHz to 10 MHz can be selected to sweep about the center frequency. The sweep rate is continuously variable from 100 sec per sweep to 0.01 sec per sweep.

A built-in detector can be used to rectify the output of a network being swept by the 675A, developing a varying dc voltage proportional to the response of the network at any given point in the sweep. A horizontal output jack provides horizontal drive, synchronized with the 675A sweep, for the horizontal channel of an oscilloscope or X-Y recorder. The swept-band response of the network will, of course, be displayed on the oscilloscope or recorder if its horizontal and vertical channels are connected to the 675A horizontal and vertical outputs.

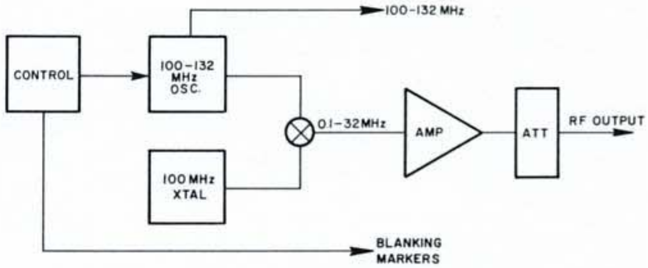


Figure 1: 675A simplified block diagram.

676A Phase/Amplitude Tracking Detector

The 676A detector has been developed to greatly increase the measuring capabilities of the 675A, extending its dynamic range from 30 dB to 80 dB.

The 676A is a tracking detector, and, as such, is completely dependent upon the 675A for all its drive, control and synchronizing signals. In the following description of its operation, refer to Figure 2, which is a simplified block diagram of the 676A.

The RF OUTPUT of the 675A is connected to the RF INPUT terminal of the 676A. The signal is then split in the power divider, and is applied to both the channel A and channel B RF OUT terminals. Particular care has been taken in the circuitry of the two channels to insure that the split signal passes through exactly the same path lengths and types of circuitry. This is to keep any phase shift equal in both channels so that only the phase shift introduced by the network being tested will cause an output at the PHASE A-B SCOPE OUTPUT.

The swept test signal is mixed with another swept signal derived from the 675A. The difference is always 100kHz, so that the IF frequency is constant. Referring to Figure 2, we can readily see how this is accomplished. The 100.01MHz to 132MHz signal (available at the rear panel of the 675A) is beat with a 99.9MHz crystal oscillator to produce a 0.11MHz to 32.1MHz signal which, when mixed with 0.01 to 32 MHz, produces a 100kHz IF signal.

The final result is a 100kHz signal having an instan-

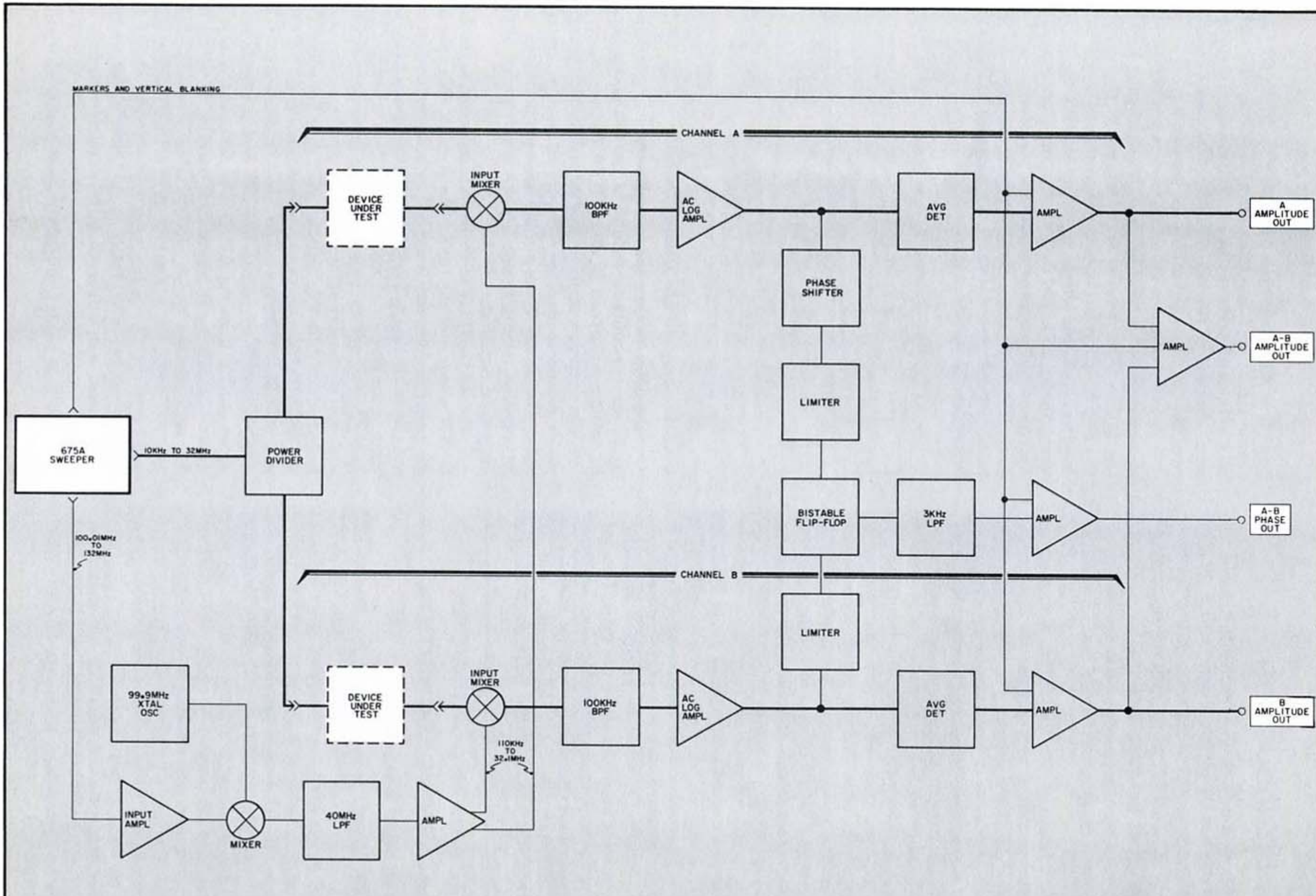


Figure 2: 676A simplified block diagram.

taneous amplitude proportional to the instantaneous amplitude of the output of the network under test. The IF signal is then passed through an 8kHz bandpass filter which prevents undesirable signals (spurious, image, etc.) from contributing to the measurement. The filtered signal is then passed through an amplifier which has an output proportional to the log of the input. This step in the process is the key to overcoming the limited dynamic range of a simple diode detector.

The output of the log amplifier is detected, filtered, and scaled. The resulting dc output voltage is then linearly proportional to the logarithm of the signal which passed through the network under test. This provides linear deflection scaled to 50 mV/dB to a display device.

While the foregoing remarks describe only one channel, they are exactly applicable to both channels, and all the happenings described take place simultaneously in both channels.

Before describing how phase shift is measured, a few words need to be said with regard to the A-B AMPLITUDE output. Since channel A output is log A and channel B is log B, A-B is (log A) - (log B) = log A/B, so the A-B output is really proportional to the logarithm of the ratio of A to B.

For phase shift measurement, we must return to the outputs of the log amplifiers. These outputs, while no longer sinusoidal, still retain the same zero crossings, with respect to time, as they had before log conversion. These signals (from channel A and B) are passed through limiters which preserve the zero crossing vs. time relationship of the two channels and also square up the signals, making them suitable for driving a flip-flop. The leading edge of the signal from one channel turns the flip-flop on, and the leading edge of the signal from the other channel turns it off. This produces a 100kHz rectangular wave with an area proportional to the time difference between the leading edges of the signals from the two channels. When filtered, the result is a dc voltage proportional to the phase shift between channels A and B.

Unless indentical networks are connected in channels A and B of the 676A, an increasing phase difference will occur as frequency is increased. When this difference reaches 360°, the 676A PHASE A-B output will indicate 0° of phase shift. Thus, for every 360° of phase shift a recycling action takes place. A control (PHASE CHANNEL A) is available at the front panel of the 676A which permits the addition of up to 360° of phase shift, flat across the band, to channel A. Thus, the recycling point can be located to suit the operator.

675A/676A Network Analyzer

The 675A/676A Network Analyzer consists of the two units connected together, calibrated, and used to drive an oscilloscope or X-Y recorder. Any oscilloscope that has dc coupling and sufficient gain is suitable, but dual-trace capability is recommended so that gain and phase response can be simultaneously displayed. Refer to Appendix A or to the 676A Operating and Service Manual for instructions for connecting and calibrating the 675A/676A.

Accessories

As previously mentioned, a high-impedance probe (HP Model 1123A) is available for use with the 675A/676A Network Analyzer. If such a probe is used, care must be exercised to avoid introducing extraneous phase shift in one or the other channel. This can easily be avoided by always connecting identical test accessories in both channels, or, provided the device has linear phase shift, by connecting a length of 50Ω coaxial cable in the channel not containing the accessory.

To determine the exact length, simply observe the phase display and add cable until the trace is horizontal. To provide 5° to 10° of fine adjustment to this means of compensation, shunt the compensating cable with a variable capacitor having a value of 7 pF to 45 pF. This method allows nearly all phase shift to be cancelled without the necessity of cutting a precise compensating cable.

APPLICATIONS

If the 675A/676A Network Analyzer has been calibrated properly, the following measurements may be made:

- Insertion loss measurements
- Insertion gain measurements
- Comparison (A-B) measurements
- High-impedance measurements

Each of these measurements yields complex swept results. That is, the magnitude and phase of the insertion loss or gain of an unknown electrical network are measured and presented as a function of frequency.

Each type of measurement will be discussed in turn, and examples of applications will be given.

Insertion Loss/Gain Measurements Preliminary

Before beginning a discussion on 675A/676A applications, a few definitions as to just what the Network Analyzer measures are in order.

Stated simply, the Network Analyzer measures the amplitude variations and phase shift which an unknown network causes when inserted between a 50Ω source and a 50Ω load. These measurements are made on a swept frequency basis and are therefore functions of frequency. Furthermore, the amplitude measurements produce an output which is proportional to the logarithm of the network response, and, as such, represents gain or loss expressed in dB.

The foregoing explanation can be more rigorously presented by making use of s-parameters. A comprehensive explanation of s-parameters can be found in the February, 1967 issue of the HP Journal. A brief explanation of s-parameters is included in Appendix B of this Note.

When the 675A/676A is used, the first step is to identify a unity gain (0 dB) zero-phase reference level by measuring a short piece of 50Ω cable. The second step is to replace the short cable with the unknown network. Figure 3 shows the equivalent circuits which result when these two steps are made. In both these steps the voltage

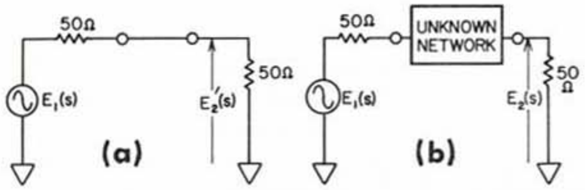


Figure 3: Equivalent 675A/676A circuit when measuring (a) reference short, and (b) unknown network.

drop across the 50Ω terminating resistor is the quantity actually sensed.

Mathematically speaking, then, since a reference level and phase has been defined, the 675A/676A actually measures

$$\frac{E_2(s)}{E_2'(s)} = \frac{E_2(s)}{E_1(s)} \frac{E_1(s)}{E_2'(s)} \qquad (1)$$

From the definitions of s-parameters (see references previously cited),
we find

$$\frac{E_2(s)}{E_1(s)} = S_{21} \qquad (2)$$

$$\frac{E_2'(s)}{E_1(s)} = S_{21}' \qquad (3)$$

Therefore,

$$\frac{E_2(s)}{E_2'(s)} = \frac{S_{21}}{S_{21}'} \qquad (4)$$

but S_{21} (the forward transmission gain of a short cable) is equal to $1\angle 0°$, so it may finally be concluded that the 675A/676A measures the S_{21} of the unknown network.

The parameter S_{21} is, of course, a complex quantity and in the steady state

$$S_{21} = |S_{21}|\angle S_{21} \qquad (5)$$

The 675A/676A converts the magnitude of S_{21} to a logarithmic quantity so that the A and B AMPLITUDE OUTPUTS produce an output which represents

$$20 \log |S_{21}| \text{ decibles.} \qquad (6)$$

The (A-B) AMPLITUDE OUTPUT produces an output which represents

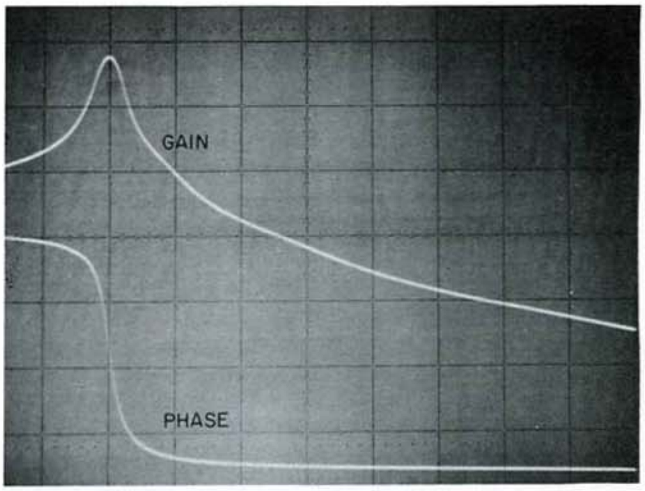


Figure 4: Typical response display.

$$20 \log |S_{21}|\,A - 20 \log |S_{21}|\,B = 20 \log \frac{|S_{21}|\,A}{|S_{21}|\,B} \text{ decibels} \qquad (7)$$

and the A-B PHASE OUTPUT produces an output which represents

$$\angle S_{21} \text{ in degrees.} \qquad (8)$$

These outputs are dc voltages corresponding to the instantaneous values of magnitude and phase of the insertion loss.

In the case of the magnitude, 0 dB is represented by approximately 4 V and —80 dB by approximately 0 V; thus, the amplitude scale is 50 mV per decibel. In the case of phase angle, 0° is represented by 1.8 V, +180° by 3.6 V, and —180° by 0 V; the phase scale is therefore 10 mV per degree.

Insertion Loss Measurements

When a network or circuit is connected into the measuring channels of the 676A, an oscilloscope or X-Y recorder display similar to Figure 4 can be obtained.

What can be learned from such a display . . . what advantage does it offer?

First of all, the 675A (which is supplying the swept signal) can be adjusted to precisely sweep between accurate frequency limits, and the oscilloscope or X-Y recorder can be adjusted to confine the display of this sweep to its calibrated grid or graticule. Hence, a frequency scale is presented along the X-axis which requires no markers to immediately reveal the frequency at a given point. The Y-axis is similarly scaled in dB. Quantitative analysis data which accurately characterizes the network is thus available. The amplitude response tells at a glance if the required passband has been realized, if sufficient attenuation is present at a given frequency in the stop band, and if passband ripple is within design limits.

Phase response has quite often been neglected in the past due to the difficulty encountered in measuring it. Phase response, however, is of vital importance in feedback amplifier work and, with the advent of phase-encoded data transmission, in communications applications.

Envelope Delay

The phase response as measured with the 675A/676A tells how much each frequency is shifted in phase as it traverses the network under test. Phase shift measurements also provide a means of calculating the envelope delay (sometimes called "group delay") of a network.

Phase shift and envelope delay (D_e) are related according to Equation 9:

This relationship is illustrated in Figure 5.

$$D_e = \frac{d\phi}{df} \div 360 \qquad (9)$$

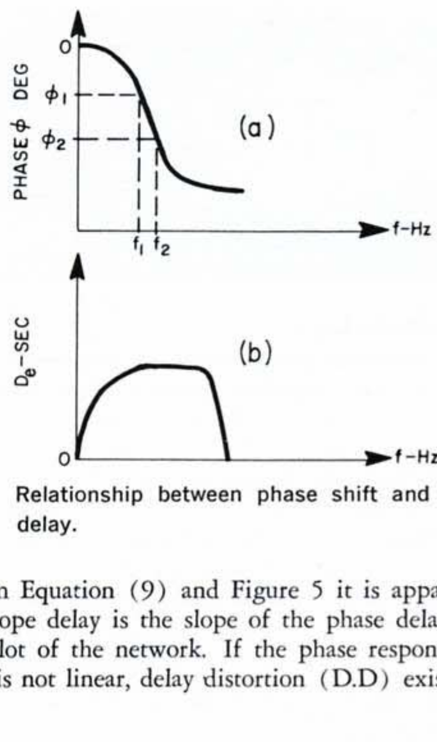


Figure 5: Relationship between phase shift and envelope delay.

From Equation (9) and Figure 5 it is apparent that the envelope delay is the slope of the phase delay vs. frequency plot of the network. If the phase response of the network is not linear, delay distortion (D.D) exists and is equal to

$$D.D = D_e(r) - D_e(x) \qquad (10)$$

where the (r) and (x) of Equation (10) refer to an arbitrary reference frequency and a test frequency respectively.

If the phase response of the network under test is linear or nearly so, the envelope delay is equal to the slope of the phase response. The envelope delay, D_e, can be found from a phase display similar to that of Figure 5 (a) by the following relationship:

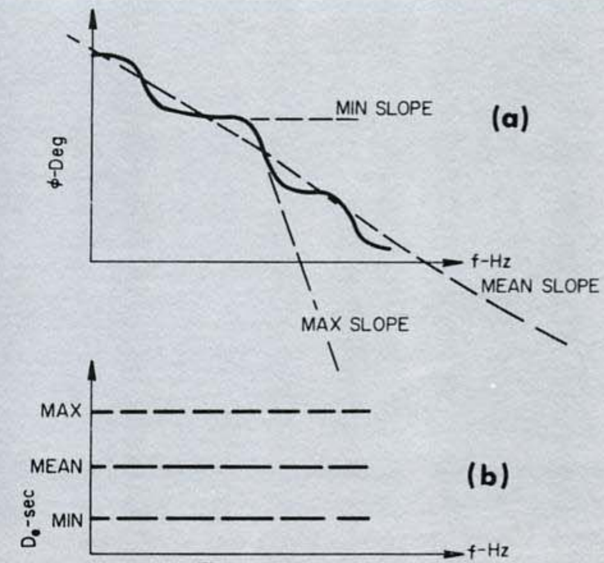


Figure 6: Measuring envelope with the 675A/676A; (a) scope presentation, (b) plot derived from scope presentation.

$$D_e = \frac{(\phi_2 - \phi_1)}{(f_2 - f_1)\,360} \qquad (11)$$

The frequency sweep, $(f_2 - f_1)$, can be adjusted to eliminate the constant in the denominator of Equation (11), so that D_e is proportional to $(\phi_2 - \phi_1)$. Table 1 lists the frequency sweeps to use to obtain displays that can be read directly in units of time.

If the phase response of a network is not linear, its envelope delay distortion can be approximated. The accuracy of the approximation will depend upon the pains the measurer is willing to take. The procedure is as follows:

1. Determine the average slope of the phase response using Table 1. This will be the mean delay.
2. Determine the smallest slope over the frequency range of interest, again using Table 1. This will represent the minimum delay.
3. Determine the largest slope over the frequency range of interest to find the maximum delay.

Plotting this information will yield something similar to Figure 6.

Many networks have very complex phase responses over a large frequency range. These too can be analyzed for their envelope delay by following the steps outlined above for each significant phase slope area.

While the preceding paragraphs describe how a network's insertion loss can be measured and the network analyzed quantitatively, a more practical use of the system stems from the fact that changes can be made to the network under dynamic conditions. Thus, if a network design-

TABLE 1

Envelope Delay Measurement Factors

$f_2 - f_1$	D_e
2.78 kHz	$(\phi_2 - \phi_1) \times \mu s$
27.8 kHz	$(\phi_2 - \phi_1) \times 100$ ns
278 kHz	$(\phi_2 - \phi_1) \times 10$ ns
2.78 MHz	$(\phi_2 - \phi_1) \times$ ns
27.8 MHz	$(\phi_2 - \phi_1) \times \text{ns} \times 10^{-1}$

er tests his theoretically constructed network and it fails to meet design specifications, he can quickly make the adjustments necessary to meet such specifications.

Insertion Gain Measurements

So far, this note has dealt with only passive networks—those displaying only loss. Active networks having gain can, of course, be tested in exactly the same way as passive networks, except that the attenuator controls of the 675A should be set so that the signal introduced into the active network input port is attenuated by an amount equal to the highest gain expected in the device under test (often the dc gain of the device). This will ensure that the maximum signal out of the device does not exceed 0 dBm. Attenuate as required if the device under test is designed for an even lower output signal, but in no case should +2 dBm (0.28 V across 50 Ω) be exceeded.

An example of this application might be measuring the closedloop gain of a feedback amplifier or system for several values of feedback attenuation (Beta).

Figure 7 shows the amplitude and phase response of a video amplifier for several feedback values. The amplifier has deliberately been made "peaky" to demonstrate the measurement capabilities of the 675A/676A system.

Since feedback amplifiers typically have very high input impedance and very low output impedance, no difficulty should be encountered either in driving them from a 50Ω source or terminating them in 50 Ω. If 50 Ω loads the amplifier, use the 1123A probe.

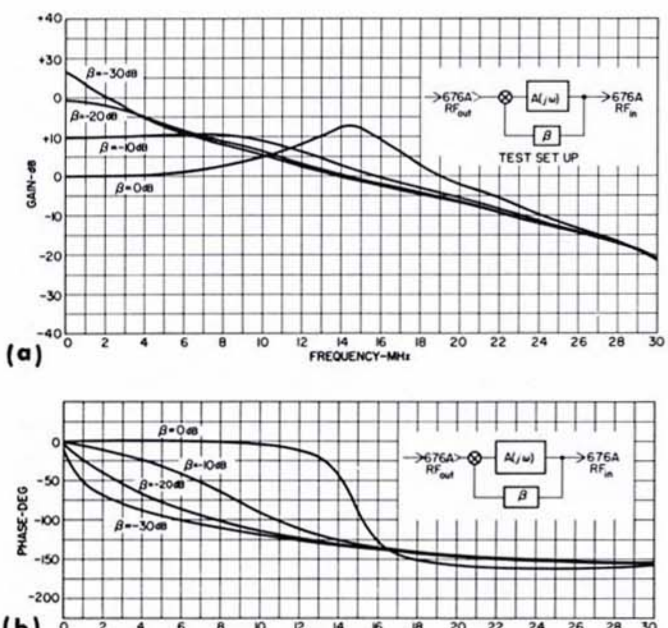


Figure 7: Response of video amplifier.

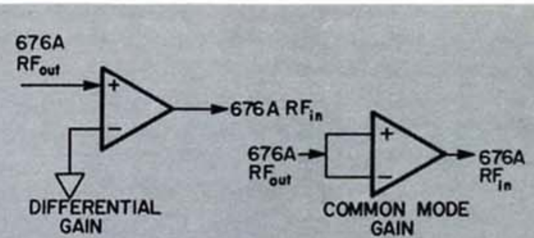


Figure 8: CMR test using 675A/676A.

Common-Mode Rejection

An important characteristic of differential amplifiers is common-mode rejection (CMR). This is defined as follows:

$$\text{CMR} = 20 \log \frac{E_d}{E_c} = 20 (\log E_d - \log E_c) \tag{12}$$

Where: E_d = the differential or normal-mode gain of the amplifier,
E_c = the common-mode gain of the amplifier.

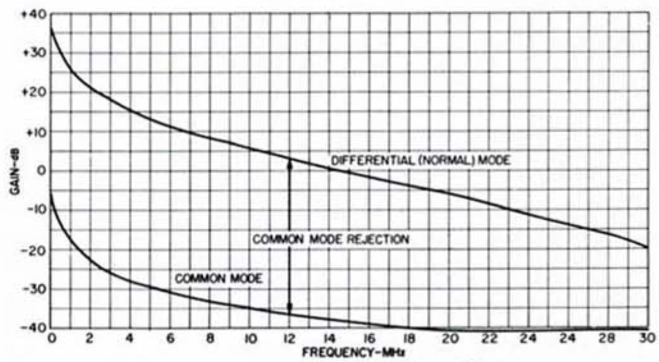


Figure 9: CMR X-Y recorder display.

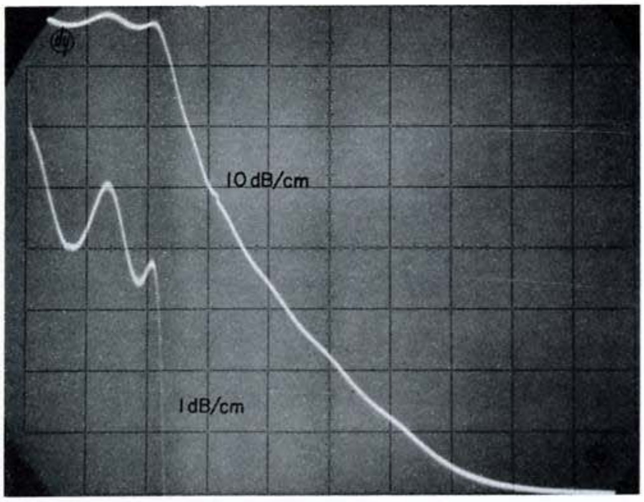


Figure 10: Display of network response using normal and expanded scale.

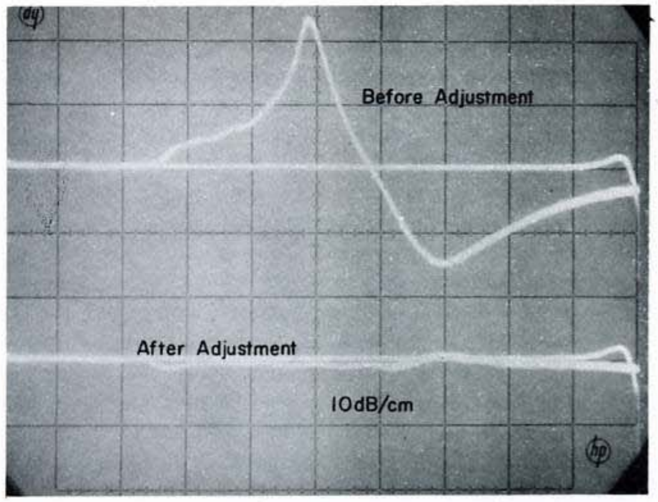


Figure 11: Comparison of unknown to reference network.

Since the 675A/676A can measure the gain of an amplifier in dB, all that is required is to measure E_d and E_c, and plot each on an X-Y recorder. The difference across the frequency band will then represent the CMR in dB. Figure 8 and 9 illustrate this.

Expanded Dynamic Range

Frequently, a passive network has insertion loss in its passband. When this is the case, some of the dynamic range of the 675A/676A is lost. For example, if a given bandpass filter has 20 dB of insertion loss, then only 60 dB of its skirts can be measured using the 675A/676A. This loss of range can be recovered, however, by placing a suitable "flat" amplifier in series with the network being tested. A satisfactory amplifier for this purpose is the HP 461A. Using this amplifier set to its 20dB gain position, an effective dynamic range of 100 dB is obtainable. The 40dB range can also be used, but noise at —110 dB and —120 dB may be objectionable in some applications.

The phase response of the amplifier used will be added to that of the device under test; therefore, an equal amount of phase shift must be introduced into the other channel if accurate phase measurements are to be made.

Comparison and Extended Precision Transfer Measurements

So far, the accuracy of the measurements made were within the specifications of the 675A/676A. That is, ± 1.5 dB for amplitude and $\pm 1°$ for phase.

The A-B scope output of the 676A provides a means for improving these specifications and making comparative measurements. While these two features are closely related, their application may be quite diverse. Extended precision might have more usefulness in design work, while comparison measurements would be more useful on the production line.

In order to obtain greater precision, both a highly accurate attenuator and a display device with good vertical deflection accuracy are needed. If these are used, the accuracy obtained will be limited only by the accuracy of the poorer of the two (attenuator or display device).

To calibrate for greater precision, connect the precision attenuator into channel B of the 676A. Connect the vertical channel of the display device to the A-B amplitude output of the 676A, and adjust the vertical sensitivity of the display device for the desired resolution (50 mV/div for 1 dB/div, 5 mV/div for 0.1dB/div, etc.). Adjust the precision attenuator to the loss area of interest (—10 dB, —20 dB, —30 dB, etc.). Adjust the position controls on the display device to position the trace conveniently. Now (using the precision attenuator 1dB or 0.1dB switch position), adjust the vernier sensitivity control to obtain the number of divisions per dB (or 0.1 dB) which best suit the application. The vertical scale is now precisely adjusted for high resolution and high accuracy. If deflection over the entire display surface is not linear, adjust the vertical sensitivity to best balance the error.

Now the detailed examination of such things as passband ripple can be accomplished. Furthermore, if a dual-trace oscilloscope is the display device, one channel can be used for expanded-scale examination while the other displays the normal 10dB/div frequency response. An example of this is shown in Figure 10.

Resolution on the order of 0.1°/div can be obtained by adjusting the vertical sensitivity of the display device. Use the PHASE CHANNEL A control to keep the trace on the screen. Accuracy can be verified by depressing the 5° CAL button which is accurate to within $\pm 0.2°$. Fine adjustment of the display device vertical sensitivity can be used to scale the 5° CAL deflection to an even number of graticule lines or recording paper divisions.

One precaution is in order with respect to the extended precision described above: its validity holds only in the dynamic region where the calibration was performed. In other words, if the region around —20 dB has been expanded and calibrated, one cannot move to 0 dB and expect the calibration to hold. Since the cyclical error of the log amplifiers repeats at intervals of 12 dB, the region of validity for extended precision is about ±1 dB.

On production lines or at quality control stations it is often desirable to check hundreds of units quickly. The A-B feature of the 675A/676A lends itself conveniently to such an application. Simply place a standard network in channel A and make the channel B terminal available at the production test station. Any difference between the production unit connected thereto and the standard unit will appear as a deviation from a straight line on an oscilloscope trace. Limits to which the units must be adjusted can be grease penciled or taped onto the scope face. The sensitivity used can be determined by the degree of identity required between the standard and production units. An example of this application is shown in Figure 11.

At this point it should be recalled that the A-B AMPLITUDE OUTPUT represents the log of the ratio of the network in the A channel to the network in the B channel.

High-Impedance Transfer Measurements Using 1123A Probe

It may be desirable to make measurements on a circuit requiring a termination greater than 50 Ω, such as frequency response at internal test points. This type measurement can be made using the HP 1123A probe. The probe has 100 kΩ of input resistance shunted by 3 pF of capacitance. To use the probe, connect its power cord to one of the sockets provided on the 676A front panel, and connect the probe's spring-mounted BNC connector the 676A channel A or B RF INPUT. Terminate the channel A or B (whichever is used) RF OUTPUT in 50 Ω. Connect the probe tip to the terminated RF output and adjust the A or B CAL control for 10dB/div deflection sensitivity if required. Refer to the procedure outlined in Appendix A if difficulty is encountered.

The probe is now ready to make bridged amplitude measurements. If phase measurements are required, either connect another probe or six feet of coaxial cable into the unused channel to obtain a flat phase measurement across the 0.01MHz to 32MHz band. For fine phase adjustment, shunt the phase compensating cable with a 7 to 45pF variable capacitor. This provides about 10° of fine adjustment.

Figure 12 is an example of a high-impedance measurement made with an 1123A probe. This is the amplitude and phase response of an LC low-pass filter for various values of damping factors.

Another application of this type would be to measure the response of each of the stages of an IF strip. In this way, correct stagger tuning could be checked and adjusted.

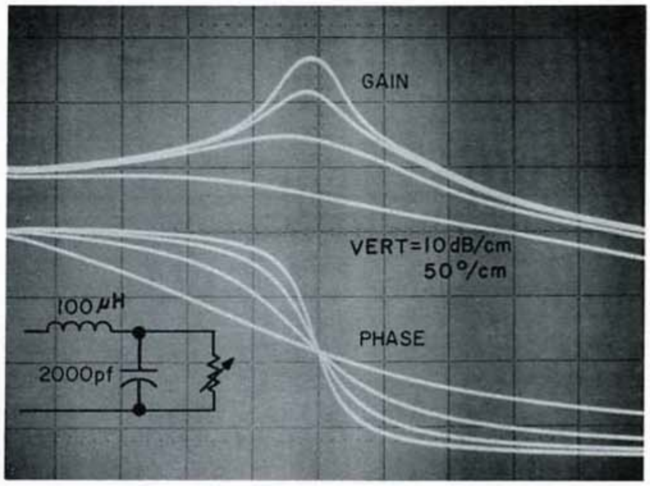


Figure 12: LC filter amplitude/phase response.

Bode Plot Presentation

The normal display of the 675A/676A consists of a scale of log magnitude vs. linear frequency. True Bode plots consist of log magnitude vs. log frequency. This can be achieved with the 675A/676A system if the horizontal output from the 675A is passed through a log converter such as the HP Model 7562A. Figure 13 shows the necessary equipment arrangements.

Since the horizontal axis is now a logarithmic function of frequency, the linear scale of the oscilloscope graticule can no longer be used as a frequency scale. Instead, markers must be relied upon. For this reason it may be more desirable to use an X-Y recorder as the display device, since semi-log graph paper can be used which will result in a permanent, precisely scaled record of the tests made. Markers, of course, will not be seen if an X-Y recorder is used.

An example of this application is shown in Figure 14. The figure is a Bode plot of a second-order or two-pole system having a small damping factor. Markers spaced 1 MHz apart were used, with the first one at 1 MHz.

Another example of this technique is shown in Figure

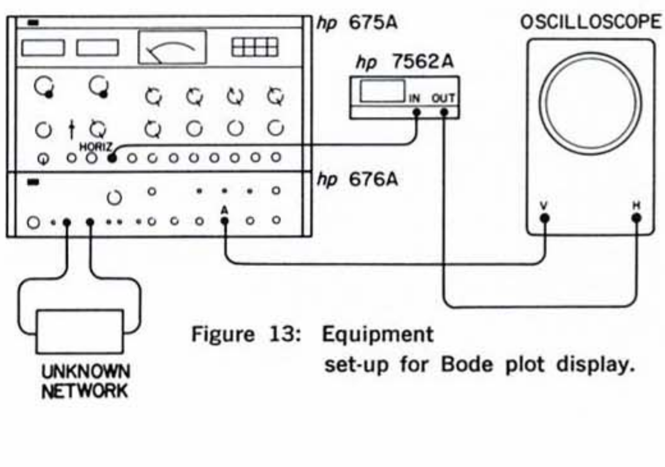


Figure 13: Equipment set-up for Bode plot display.

15. In this case, an operational amplifier connected for unity gain was tested. Again, the markers were at 1MHz intervals, with the first one being at 1 MHz. The linear

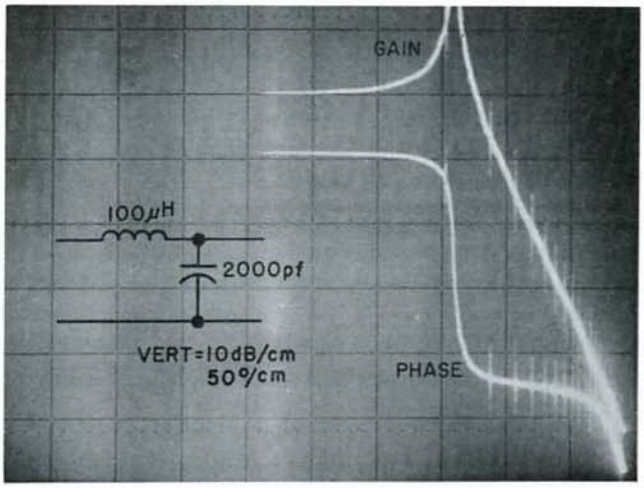


Figure 14: 675A/676A Bode plot of second-order system with small damping ratio.

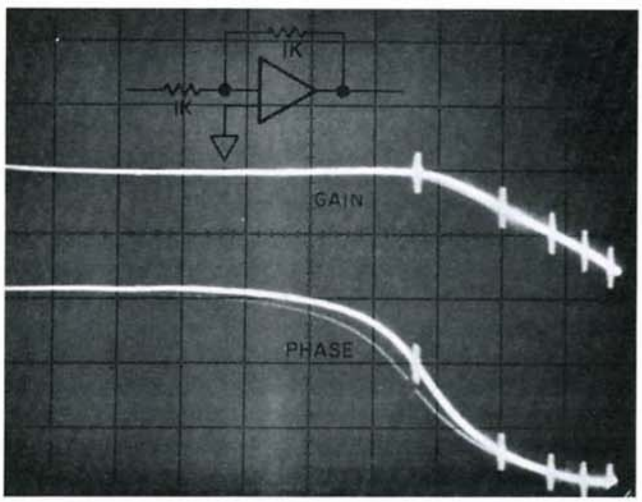


Figure 15: 675A/676A Bode plot for unity gain amplifier.

roll-off is clearly shown as is the phase response.

Frequently in the design of operational amplifiers, the designer wishes to know how his circuit performs at relatively high frequencies. Open-loop gain and phase response can also be measured using the 675A/676A. Open-loop response of amplifiers having 100 dB of gain may be difficult to obtain. One method of connecting an operational amplifier so that its high-frequency, open-loop gain is measurable with the 675A/676A is shown in Figure 16. This arrangement provides unity feedback at dc and open-loop gain above approximately 100 kHz.

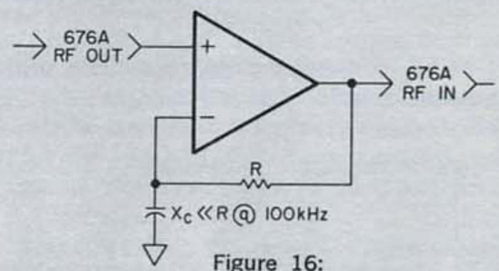


Figure 16:
Method of arranging operational amplifier for unity gain at dc and open-loop gain at higher frequencies.

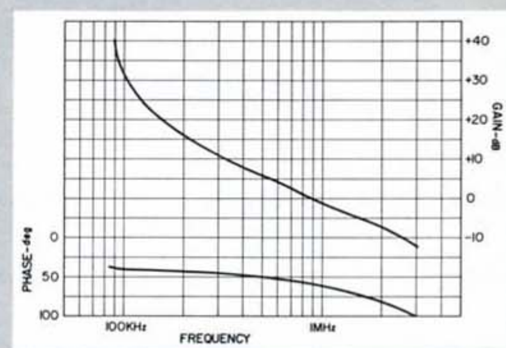


Figure 17:
Operational amplifier high-frequency, open-loop gain/phase response.

After the operational amplifier is connected according to Figure 16, it may be inserted into the A or B measurement channel of the 676A. Before doing this, however, the 675A should be adjusted to a level which will not overdrive the amplifier, say 30 or 40 dB below maximum output. A short circuit in the measurement channel should then be relied upon to establish unity gain and zero phase.

Figure 17 is an example of the results of this type of measurement. The figure contains the critical information peculiar to operational amplifiers—the gain crossover frequency and the phase shift at that frequency.

Conclusion

The 675A/676A Network Analyzer is a versatile measurement system providing a wide range of useful information. Many measurements which were neglected in the past because of their difficulty can now be made quickly and easily with the Network Analyzer. This note has described the basic applications of the system, and a continuation of this series of application notes will deal with more complex and varied types of measurements.

APPENDIX A

CALIBRATION OF THE 675A/676A NETWORK ANALYZER

Figure A-1 illustrates the interconnections required between sweeper, detector, and oscilloscope.

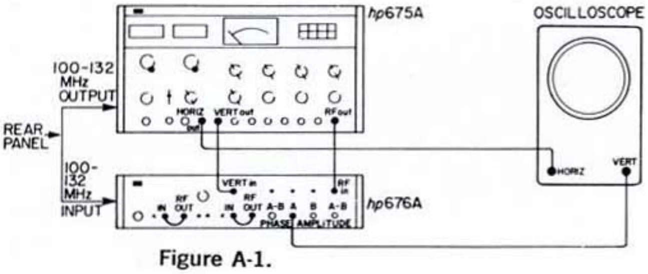


Figure A-1.

To calibrate the 675A/676A, proceed as follows.

1. Set the controls according to Table A-1.

TABLE A-1

675A/676A System Calibration Control Settings

Control	Setting
675A	
Sweep mode	Auto
Function	Start/Stop
10dB switch	+10
Blanking	Vert
1dB switch	0
Marker switch	Off
RF output amplitude	+3 dB
Sweep time	0.1 sec
Start	00.0 MHz
Stop	32.0 MHz
676A	
A channel phase	0°
Oscilloscope	
Sweep	Ext.
Vertical sensitivity	0.5 V/div

2. Connect the oscilloscope to the CHANNEL A SCOPE OUTPUT of the 676A.
3. Adjust horizontal controls so that a trace and retrace are centered about the middle eight divisions of the oscilloscope result.
4. Reduce the 675A RF output 80 dB by rotating the 10dB step attenuator to —70 dB.
5. Adjust the oscilloscope vertical position control so that the trace (not the retrace) registers on the graticule line which is 4 cm below the graticule center line.
6. Restore the 675A to full RF output (+10 dBm).
7. Adjust the 676A CHANNEL A CAL control until the trace registers on the graticule line which is 4 cm above the center graticule line.
8. Rotate the 675A 10dB step attenuator to insure that the trace shifts one cm for each 10 dB ±1.5 dB.

The 676A B channel can be calibrated in exactly the same manner or, better yet, the following A-B amplitude calibration procedure can be followed.

1. Set the 675A to +10 dBm.
2. Use the 676A A and B CAL controls to adjust the 676A A and B scope outputs to 4.225 V, as read on a digital voltmeter.
3. Set the 675A to —70 dBm and note the difference between the digital voltmeter readings taken at the A and B scope outputs.
4. Set the 675A to 0 dBm and adjust the CHANNEL B CAL control until the same difference, noted in step 3, is achieved.
5. Connect the digital voltmeter to the A-B scope output and check the voltage over 80 dB of range. It should be within +10 mV, i.e., ±0.2 dB.

When the preceding calibration procedure is completed, the 675A/676A Network Analyzer is ready to make amplitude insertion loss or gain measurements. To prepare the system for making accurate phase shift measurements as well, perform the following steps.

1. Connect the oscilloscope vertical channel to the PHASE A-B SCOPE OUTPUT of the 676A.
2. Adjust the oscilloscope vertical sensitivity for 0.1 V/div.
3. Adjust the scope vertical position control and/or the 676A PHASE CHANNEL A control until the trace registers on the bottom graticule line.
4. Press the 676A 100° button and adjust the PHASE A-B CAL pot until the deflection obtained is a full 10 divisions. The scope vertical position control will have to be manipulated between adjustments to maintain the trace on the bottom graticule.

The foregoing calibration procedures assumed that the display device was an oscilloscope, but an X-Y recorder could be used just as easily.

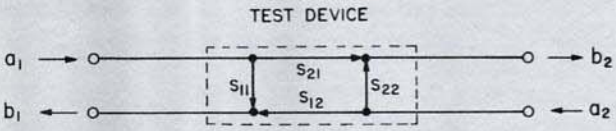
When an X-Y recorder is used, operate the 675A in manual sweep mode and switch the vertical blanking off. If the recorder is equipped with a pen lift input, connect this to the 675A. Otherwise, manually lift the pen and set the 675A to retrace after one sweep. The sweep rate should be set between 100 sec/sweep and 10 sec/ sweep. Unless a dual-trace X-Y recorder is used, two sweeps will be required to record gain and phase for a given network. Do not change any settings except the recorder vertical position control between sweeps; otherwise, frequency registration between the two traces may be lost.

APPENDIX B

WHAT ARE "S" PARAMETERS?

"S" parameters are reflection and transmission coefficients, familiar concepts to RF and microwave designers. Transmission coefficients are commonly called gains or attenuations; reflection coefficients are directly related to VSWR's and impedances.

Conceptually they are like "h," "y," or "z" parameters because they describe the inputs and outputs of a black box. The inputs and outputs are in terms of power for "s" parameters, while they are voltages and currents for "h," "y," and "z" parameters. Using the convention that "a" is a signal into a port and "b" is a signal out of a port, the figure below will help to explain "s" parameters.



In this figure, "a" and "b" are the square roots of power; $(a_1)^2$ is the power incident at port 1, and $(b_2)^2$ is the power leaving port 2. The diagram shows the relationship between the "s" parameters and the "a's" and "b's." For example, a signal a_1 is partially reflected at port 1 and the rest of the signal is transmitted through the device and out of port 2. The fraction of a_1 that is reflected at port 1 is s_{11}, and the fraction of a_1 that is transmitted is s_{21}. Similarly, the fraction of a_2 that is reflected at port 2 is s_{22}, and the fraction s_{12} is transmitted.

The signal b_1 leaving port 1 is the sum of the fraction of a_1 that was reflected at port 1 and the fraction of a_2 that was transmitted from port 2.

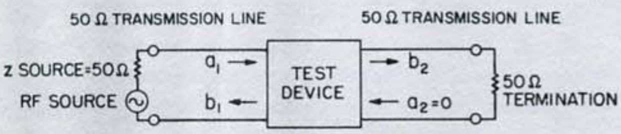
Thus, the outputs can be related to the inputs by the equations:

$$b_1 = s_{11} a_1 + s_{12} a_2$$
$$b_2 = s_{21} a_1 + s_{22} a_2$$

When $a_2 = 0$, and when $a_1 = 0$,

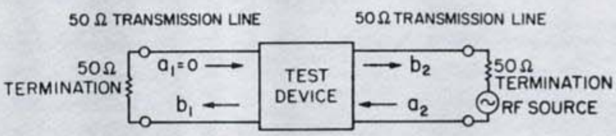
$$s_{11} = \frac{b_1}{a_1},\ s_{21} = \frac{b_2}{a_1} \qquad s_{12} = \frac{b_1}{a_2},\ s_{22} = \frac{b_2}{a_2}$$

The setup below shows how s_{11} and s_{21} are measured.



Port 1 is driven and a_2 is made zero by terminating the 50 Ω transmission line coming out of port 2 in its characteristic 50 Ω impedance. This termination ensures that none of the transmitted signal, b_2, will be reflected toward the test device.

Similarly, the setup for measuring s_{12} and s_{22} is:



If the usual "h," "y," or "z" parameters are desired, they can be calculated readily from the "s" parameters. Electronic computers and calculators make these conversions especially easy.

WHY "S" PARAMETERS

Total Information

"S" parameters are vector quantities; they give magnitude and phase information. Most measurements of microwave components, like attenuation, gain, and VSWR, have historically been measured only in terms of magnitude. Why? Mainly because it was too difficult to obtain both phase and magnitude information.

"S" parameters are measured so easily that obtaining accurate phase information is no longer a problem. Measurements like electrical length or dielectric coefficient can be determined readily from the phase of a transmission coefficient. Phase is the difference between only knowing a VSWR and knowing the exact impedance. VSWR's have been useful in calculating mismatch uncertainty, but when components are characterized with "s" parameters there is no mismatch uncertainty. The mismatch error can be precisely calculated.

Easy To Measure

Two-port "s" parameters are easy to measure at high frequencies because the device under test is terminated in the characteristic impedance of the measuring system. The characteristic impedance termination has the following advantages:

1. The termination is accurate at high frequencies . . . it is possible to build an accurate characteristic impedance load. "Open" or "short" terminations are required to determine "h," "y," or "z" parameters, but lead inductance and capacitance make these terminations unrealistic at high frequencies.

2. No tuning is required to terminate a device in the characteristic impedance . . . positioning an "open" or "short" at the terminals of a test device requires precision tuning. A "short" is placed at the end of a transmission line, and the line length is precisely varied until an "open" or "short" is reflected to the device terminals. On the other hand, if a characteristic impedance load is placed at the end of the line, the device will see the characteristic impedance regardless of line length.

3. Broadband swept frequency measurements are possible . . . because the device will remain terminated in the characteristic impedance as frequency changes. However, a carefully reflected "open" or "short" will move away from the device terminals as frequency is changed, and will need to be "tuned-in" at each frequency.

4. The termination enhances stability . . . it provides a resistive termination that stabilizes many negative resistance devices, which might otherwise tend to oscillate.

An advantage due to the inherent nature of "s" parameters is:

5. Different devices can be measured with one setup . . . probes do not have to be located right at the test device. Requiring probes to be located at the test device imposes severe limitations on the setup's ability to adapt to different types of devices.

Easy To Use

Quicker, more accurate microwave design is possible with "s" parameters. When a Smith Chart is laid over a polar display of s_{11} or s_{22}, the input or output impedance is read directly. If a swept-frequency source is used, the display becomes a graph of input or output impedance versus frequency. Likewise, CW or swept-frequency displays of gain or attenuation can be made.

"S" parameter design techniques have been used for some time. The Smith Chart and "s" parameters are used to optimize matching networks and to design transistor amplifiers. Amplifiers can be designed for maximum gain, or for a specific gain over a given frequency range. Amplifier stability can be investigated, and oscillators can be designed.

These techniques are explained in the literature listed at the bottom of this page. Free copies can be obtained from your local Hewlett-Packard Sales Representative.

References:

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2. "Scattering Parameters Speed Design of High Frequency Transistor Circuits," by Fritz Weinert, Electronics, September 5, 1966.
3. "S" Parameter Techniques for Faster, More Accurate Network Design," by Dick Anderson, Hewlett-Packard Journal, February 1967.
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