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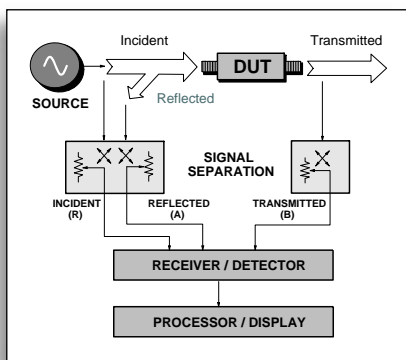
Hints

for making

Better

Network

Analyzer

Measurements
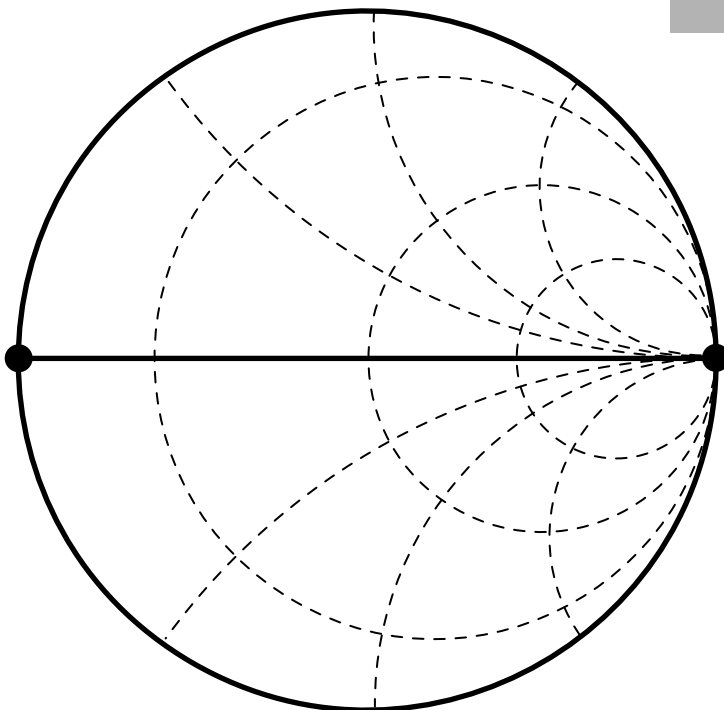
This brochure contains a variety of hints to help you understand and improve your use of network analyzers, and a quick summary of network analyzers and their capabilities.

Contents

Network Analyzer Block Diagram

Overview of network analyzers

Network analyzers characterize the impedance or S-parameters of active and passive networks, such as amplifiers, mixers, duplexers, filters, couplers, attenuators. These components are used in systems as common and low cost as a pager, or in systems as complex and expensive as a communications or radar system. Components can have one port (input or output) or many ports. The ability to measure the input characteristics of each port, as well as the transfer characteristics from one port to another, gives designers the knowledge to configure a component as part of a larger system.

Types of network analyzers

Vector network analyzers

(VNAs) are the most powerful kind of network analyzer and can measure from as low as 5 Hz to up to 110 GHz. Designers, and final test in manufacturing, use VNAs because they measure and display the complete amplitude and phase characteristics of a network. These characteristics include S-parameters, transfer functions, magnitude and phase, standing wave ratios (SWR), insertion loss or gain, attenuation, group delay, return loss, and reflection coefficient.

VNA hardware consists of a sweeping signal source (usually internal), a test set to separate forward and reverse test signals, and a multi-channel, phase-coherent, highly sensitive receiver. In the RF and microwave bands, typical measured parameters are referred to as S-parameters, and are also commonly used in computer-aided design models.

Scalar network analyzers

A scalar network analyzer (SNA) measures only the amplitude portion of the S-parameters, resulting in measurements such as transmission gain and loss, return loss, and SWR. Once a passive or active component has been designed using the total measurement capability of a VNA, an SNA may be a more cost-effective measurement tool for the production line to reveal out-of-specification components. While SNAs require an external or internal sweeping signal source and a signal separation test set, they only need simple amplitude-only detectors, rather than complex (and more expensive) phase-coherent detectors.

Network/spectrum analyzers

A network/spectrum analyzer eliminates the circuit duplication in a benchtest setup of a network and spectrum analyzer. Frequency coverage ranges from 10 Hz to 1.8 GHz. These combination instruments can be an economical alternative in design and test of active components like amplifiers and mixers where analysis of signal performance is also needed.

How to Boost and Attenuate Signal Levels when Measuring High-power Amplifiers

Testing high-power amplifiers can sometimes be challenging since the signal levels needed for test may be beyond the stimulus/response range of the network analyzer. High-power amplifiers often require high input levels to characterize them under conditions similar to actual operation. Often these realistic operating conditions also mean the output power of the amplifier exceeds the compression or burn-out level of the analyzer's receiver.

When you need an input level higher than the network analyzer's source can provide, a preamplifier can be used to boost the power level prior to the amplifier under test (AUT). By using a coupler on the output of the preamplifier, a portion of the boosted input signal can be used for the analyzer's reference channel. This configuration removes the preamplifier's frequency response and drift errors (by ratioing), which yields an accurate measurement of the AUT alone.

When the output power of the AUT exceeds the input compression level of the analyzer's receiver, some type of attenuation is needed to reduce the output level. This can be accomplished by using couplers, attenuators, or a combination of both. Care must be taken to choose components that can absorb the high power from the AUT without sustaining damage. Most loads designed for small-signal use can only handle up to about one watt of power. Beyond that, special loads that can dissipate more power must be used.

The frequency-response effects of the attenuators and couplers can be removed or minimized by using the appropriate type of error-correction. One concern when calibrating with extra attenuation is that the input levels to the receiver may be low during the calibration cycle. The power levels must be significantly above the noise floor of the receiver for accurate measurements. For this reason, network analyzers that have a narrowband, tuned-receiver are typically used for high-power applications since their noise floor is typically ≤90 dBm, and they exhibit excellent receiver linearity over a wide range of power levels.

Some network analyzers with full two-port S-parameter capability enable measuring of the reverse characteristics of the AUT to allow full two-port error correction. If attenuation is added to the output port of the analyzer, it is best to use a higher power in the reverse direction to reduce noise effects in the measurement of S_{22} and S_{12}. Many VNAs allow uncoupling of the test-port power to accommodate different levels in the forward and reverse directions.

HP 8753D

Ref In

Coupler

AUT

Preamp

High-power load
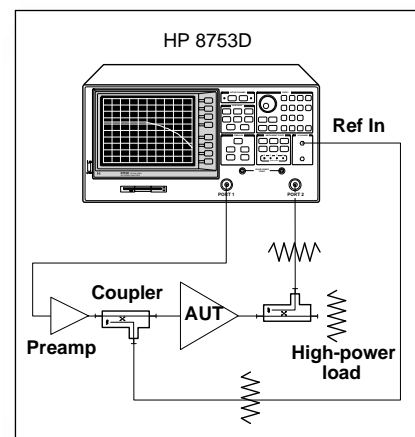
Compensate for Time Delay for Better Cable Measurements

A network analyzer sweeps its source frequency and tuned receiver at the same time to make stimulus-response measurements. Since the frequency of a signal coming from a device under test (DUT) may not be exactly the same as the network analyzer frequency at a given instant of time, this can sometimes lead to confusing measurement results. If the DUT is a long cable with time delay T and the network analyzer sweep rate is df/dt, the signal frequency at the end of the cable (input to the vector net-work analyzer's receiver) will lag behind the network analyzer source frequency by amount $F=T*df/dt$. If this frequency shift is appreciable compared to the network analyzer's IF detec-tion bandwidth (typically a few kHz), then the measured result will be in error by the rolloff of the IF filter.

Figure 1 shows this effect when measuring the transmission response of a twelve-foot long cable on a HP 8714C network analyzer. The upper trace shows the true response of the cable, using a 1-second sweep time. The lower trace uses the default sweep time of 129 msec, and the data is in error by about –0.5 dB due to the frequency shift through the cable. This sweep time is too fast for this particular DUT.

The lower trace of Figure 2 shows an even more confusing result when measuring the same cable on a HP 8753D with 100 msec sweep time. Not only is there an error in the data, but the size of the error makes some sharp jumps at certain frequencies. These frequencies are the band-edge frequencies in the HP 8753D, and the trace jumps because the network analyzer's sweep rate (df/dt) changes in different bands. This leads to a different frequency shift through the cable, and hence, a different amount of error in the data. In this case instead of increasing the sweep time, the situation can be corrected by removing the R-channel jumper on the front panel of the HP 8753D and connecting a second cable of about the same length as the DUT cable. This balances the delays in the reference and test paths, so that the network analyzer's ratioed transmission measurement does not have the frequency-shift error. The upper trace of Figure 2 shows a measurement of the DUT using the same 100 msec sweep time, but with the matching cable in R channel.
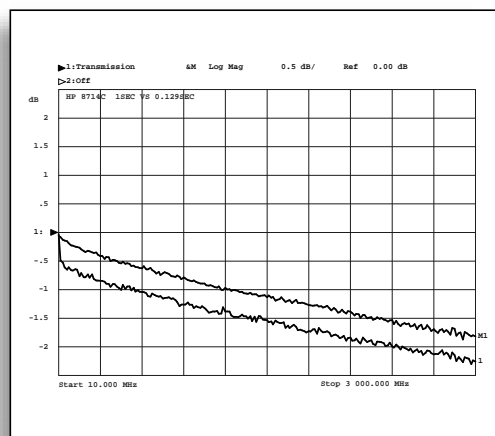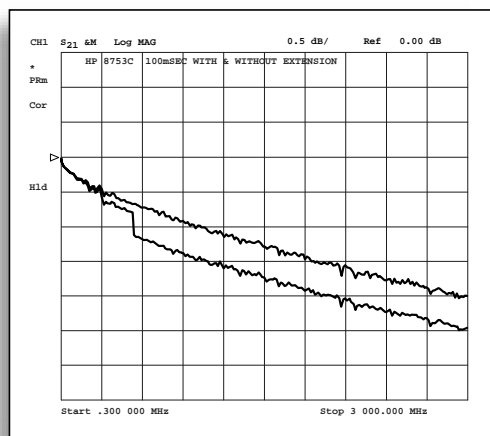

Figure 1

Figure 2

Proper Termination – Key to Improving Reflection Measurements

Making accurate reflection measure-ments on two-port devices with transmission/reflection (T/R) based analyzers (such as the HP 8711C family of RF analyzers) requires a good termination on the unmeasured port. This is especially true for low-loss, bi-directional devices such as filter passbands and cables. T/R-based analyzers only offer one-port calibration for reflection measure-ments, which corrects for errors caused by directivity, source match and frequency response, but not load match.

One-port calibration assumes a good termination at port 2 of the device under test (the port not being measured), since load match is not corrected. One way to achieve this is by connecting a high-quality load (a load from a calibration kit, for example) to port 2 of the device. This technique yields measurement accuracy on a par with more expen-sive S-parameter-based analyzers that use full two-port calibration.

However, if port 2 of the device is connected directly to the network analyzer's test port, the assumption of a good load termination is not valid. In this case, measurement accuracy can be improved consider-ably by placing an attenuator (6 to 10 dB, for example) between port 2 of the device and the test port of the analyzer. This improves the effective load match of the analyzer by twice the value of the attenuator.

Figure 1 shows an example of how this works. Let's say we are meas-uring a filter with 1 dB of insertion loss and 16 dB of return loss (Figure 1A). Using an analyzer with an 18 dB load match and 40 dB directivity would yield a worst-case measurement uncer-tainty for return loss of −4.6 dB, +10.4 dB. This is a rather large variation that might cause a filter that didn't meet its specifications to pass, or a good filter to fail. Figure 1B shows how adding a high-quality (for example, VSWR = 1.05, or 32 dB match) 10-dB attenuator improves the load match of the analyzer to 29 dB [(2 x 10 + 18 dB) combined with 32 dB]. Now our worst-case measurement uncer-tainty is re-duced to +2.5 dB, −1.9 dB, which is much more reasonable.

An example where one-port calibra-tion can be used quite effectively without any series attenuation is when measuring the input match of amplifiers with high-reverse isola-tion. In this case, the amplifier's isolation essentially eliminates the effect of imperfect load match.
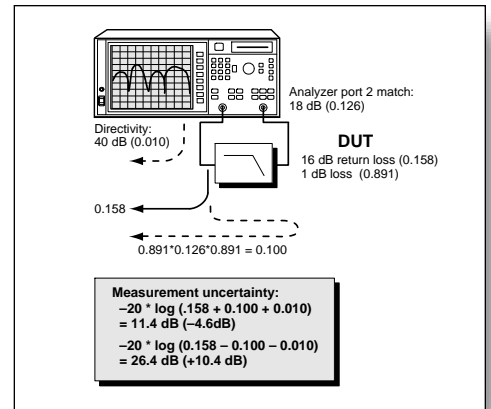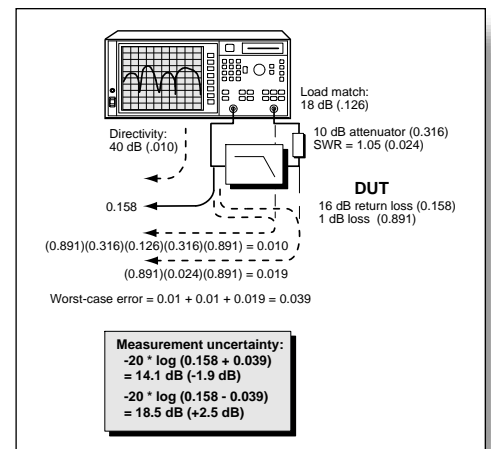

Figure 1A

Figure 1B

HINT 4

Use Frequency-offset Mode for Accurate Measurements of Mixers, Converters and Tuners

Frequency-translating devices such as mixers, tuners, and converters present unique measurement challenges since their input and output frequencies differ. The traditional way to measure these devices is with broadband diode detection. This technique allows scalar measurements only, with medium dynamic range and moderate measurement accuracy.

For higher accuracy, vector network analyzers such as the HP 8753D and 8720D offer a frequency-offset mode where the frequency of the internal RF source can be arbitrarily offset from the analyzer's receivers. Narrowband detection can be used with this mode, providing high dynamic range and good measurement accuracy, as well as the ability to measure phase and group delay.

There are two basic ways that frequency-offset mode can be used. The simplest way is to take the output of the mixer or tuner directly into the reference input on the analyzer (See Figure 1A). This technique offers scalar measurements only, with up to 35 dB of dynamic range (beyond that, the analyzer's source will not phase lock properly). For mixers, an external LO must be provided. After specifying the measurement setup from the front panel, the proper RF frequency span is calculated by the analyzer to produce the desired IF frequencies, which the receiver will tune to during the sweep. The network analyzer will even sweep the RF source backwards if necessary to provide the specified IF span.
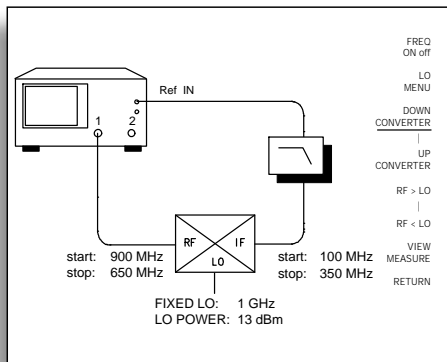
For high-dynamic-range amplitude measurements, a reference mixer must be used. (See Figure 1B.) This mixer provides a signal to the R channel for proper phase lock, but does not affect measurements of the DUT since it is not in the measurement path. For phase or delay measurements, a reference mixer must also be used. The reference mixer and the DUT must share a common LO to guarantee phase coherency.
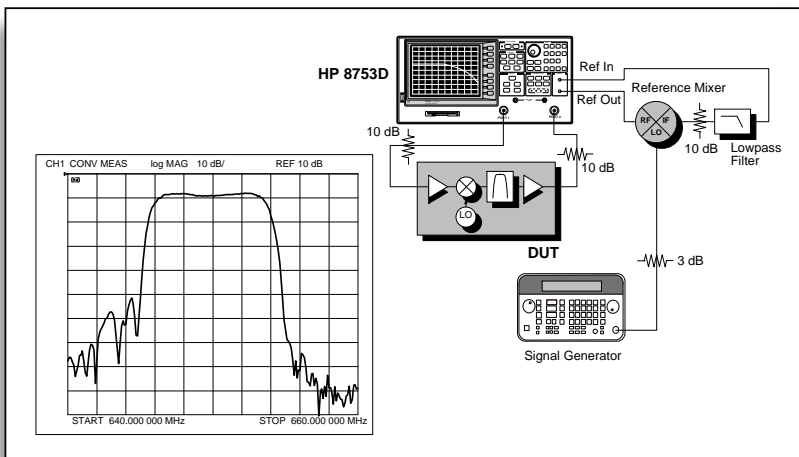
When testing mixers, either technique requires an IF filter to remove the mixer's undesired mixing products as well as the RF and LO leakage signals.

Figure 1A

Figure 1B

Increasing the Accuracy of Noninsertible Device Measurements

Full two-port error correction provides the best accuracy when measuring RF and microwave components. But, if you have a non-insertable device (for example, one with female connectors on both ports), then its test ports cannot be directly connected during calibration. Extra care is needed when making this through connection, especially while measuring a device that has poor output match, such as an amplifier or a low-loss device.

There are four general ways to handle the potential errors with a through connection for a noninsertable device:

1. Use a very short through. This allows you to disregard the potential errors. When you connect port 1 to port 2 during a calibration, the analyzer calculates the return loss of the second port (the load match) as well as the transmission term. When the calibration kit definition does not contain the correct length of the through, an error occurs in the measurement of the load match. If a barrel is used to connect port 1 to port 2, the measurement of the port 2 match will not have the correct phase, and the error-correction algorithm will not remove the effects of an imperfect port 2 impedance.

This approach will work well enough if the through connection is quite short. However, for a typical network analyzer, "short" means less than one hundredth of a wavelength. If the through connection is one tenth of a wavelength (at the frequency of interest), the corrected load match is no better than the raw load match. As the through

length approaches a quarter wavelength, the residual load match can actually get as high as 6 dB worse than the raw load match. For a 1-GHz measurement, one hundredth of a wavelength means less than 3 mm (about 0.12 inches).

2. Use swap equal adapters. In this method you use two matched adapters of the same electrical length, one with male/female connectors and one that matches the device under test.

Suppose your instrument test ports are both male, such as the ends of a pair of test-port cables, and your device has two female ports. Put a female-to-female through adapter, usually on port 2, and do the transmission portion of the calibration. After the four transmission measurements, swap in the male-to-female adapter (now you have two male test ports), and do the reflection portion of the calibration. Now you are ready to measure your device. All the adapters in the calibration kits are of equal electrical length (even if their physical lengths are different).

3. Modify the through-line-standard. If your application is manufacturing test, the "swap-equal-adapters" method's requirement for additional adapters may be a drawback. Instead, it is possible to modify the calibration kit definition to include the length of the through line. If the calibration kit has been modified to take into account the loss and delay of the through, then the correct value for load match will be measured. It's easy to find these values for the male-to-male through and the
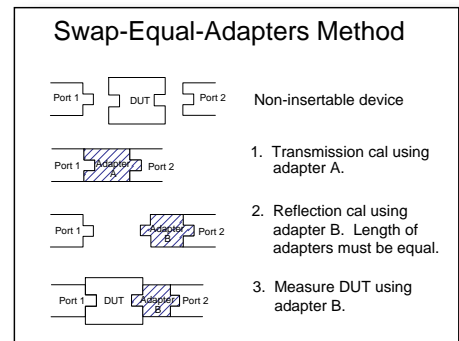
female-to-female through. First, do a swap-equal-adapter calibration, ending up with both female or both male test ports. Then simply measure the "noninsertable" through and look at S_{21} delay (use the midband value) and loss at 1 GHz. Use this value to modify the calibration kit.

4. Use the adapter-removal technique. Several HP vector network analyzer models offer an adapter-removal technique to eliminate all effects of through adapters. This technique requires two full two-port calibrations, but yields the most accurate measurement results.

Swap-Equal-Adapters Method

Port 1 — DUT — Port 2   Non-insertable device

Port 1 — Adapter A — Port 2   1. Transmission cal using adapter A.

Port 1 — Adapter B — Port 2   2. Reflection cal using adapter B. Length of adapters must be equal.

Port 1 — DUT — Adapter B — Port 2   3. Measure DUT using adapter B.

HINT 6

Check for Aliasing in Phase or Delay Format

Figure 1

Figure 2

When measuring a device under test (DUT) that has a long electrical length, use care to select appropriate measurement parameters. The VNA samples its data at discrete frequency points, then "connects the dots" on the display to make it more visually appealing. If the phase shift of the DUT changes by more than 180 degrees between adjacent frequency points, the display can look like the phase slope is reversed! The data is under-sampled and aliasing occurs. This is analogous to filming a wagon wheel in motion, where typically too few frames are shot to accurately portray the motion and the wheel appears to spin backwards.
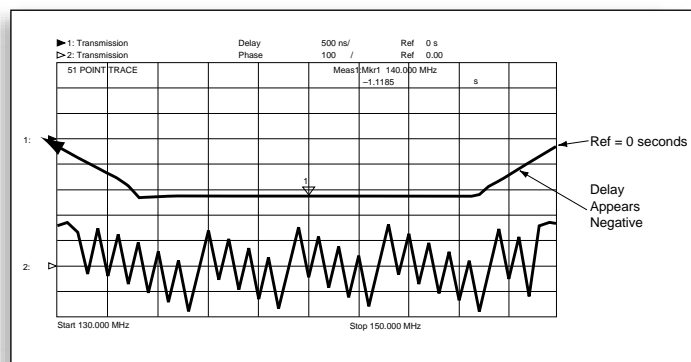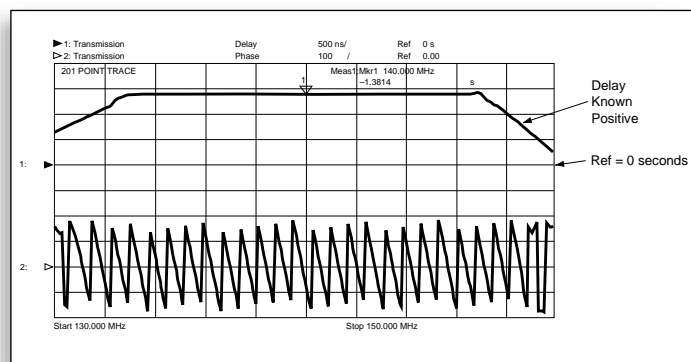
In addition, the VNA calculates group delay data from phase data. If the slope of the phase is reversed, then the group delay will change sign. A SAW filter may appear to have negative group delay – clearly not a correct answer. If you suspect aliasing might be occurring in your measurements, try this simple test. Just decrease the spacing between frequency points and see if the data on the VNA's display changes. Either increase the number of points, or reduce the frequency span.

Figure 1 shows a measurement of a SAW bandpass filter on an HP 8714C VNA, with 51 points in the display. The indicated group delay is negative – a physical impossibility. But if the number of points increases to 201 (figure 2), it becomes is clear that the VNA settings created an aliasing problem.

Quick Calibration Verification

If you've ever measured a device and the measurements didn't look quite right, or you were unsure about a particular analyzer's accuracy or performance, here are a few "quick check" methods you can use to verify an instrument's calibration or performance. All you need are a few calibration standards.

Verifying reflections measurements

To verify reflection (S_{11}) measurements on the source port (port 1) perform one or more of the following steps:

1. For a quick first check, leave port 1 open and verify that the magnitude of S_{11} is near 0 dB (within about ±1 dB).

2. Connect a load calibration standard to port 1. The magnitude of S_{11} should be less than the specified calibrated directivity of the analyzer (typically less than –30 dB).

3. Connect either an open or short circuit calibration standard to port 1. The magnitude of S_{11} should be close to 0 dB (within a few tenths of a dB).

To verify transmission (S_{21}) measurements:

1. Connect a through cable from port 1 to port 2. The magnitude of S_{21} should be close to 0 dB (within a few tenths of a dB).

2. To verify S_{21} isolation, connect two loads: one on port 1 and one on port 2. Measure the magnitude of S_{21} and verify that it is less than the specified isolation (typically less than –80 dB).

To get a more accurate range of expected values for these measurements, consult the analyzer's specifications. You might also consider doing these verifications immediately after a calibration to verify the quality of the calibration.
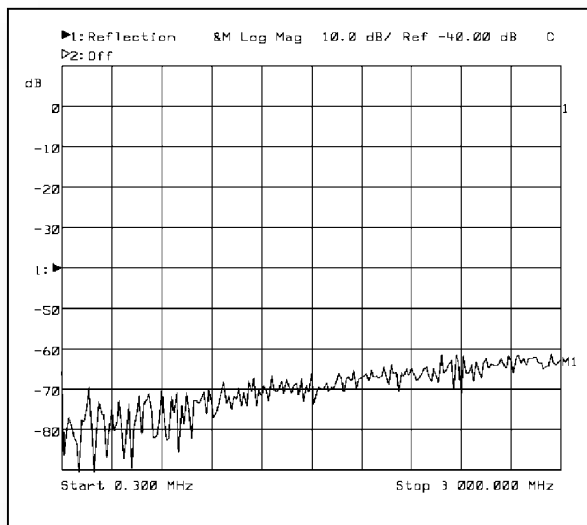
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Make your Measurements Real-time, Accurate *and* Automated

Tuning and testing RF devices in a production environment often requires speed and accuracy from a network analyzer. However, at fast sweep speeds an analyzer's optimum accuracy may be unavailable. By using save/recall registers you can get both fast and accurate measurements.

Using save/recall registers
For example, when adjusting the passband and stopband rejection of a bandpass filter, first set up the basic measurement on the analyzer (the start and stop frequencies, power level, etc.).

Then increase the IF bandwidth and reduce the number of data points (to speed up the trace) and save this as State 1.

Next, reduce the IF bandwidth and increase the number of data points (to get a more accurate measurement).

Add the final limit lines and save this as State 2. Now, by alternately recalling these two states you can adjust the filter in real time and then accurately verify its specifications.
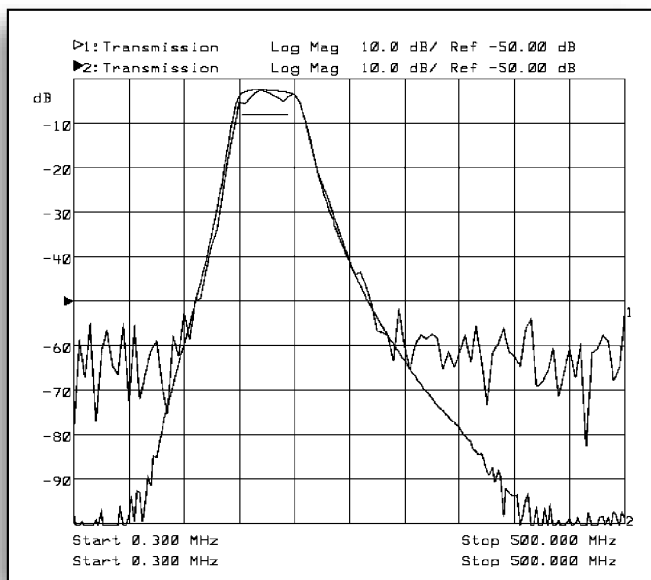
Hands-free toggling between instrument states
Some network analyzers like the HP 8711C family include a BNC input that can be connected to a footswitch for toggling between two (or more) states.

Instrument automation
For more complex testing such as final test, an analyzer with IBASIC programming capability (HP 8711C family, HP E5100, and HP 8751) provides complex computation and control so you can easily automate measurements.
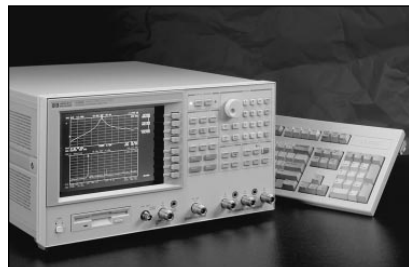
Using the IBASIC program doesn't require programming experience. You can easily customize each test or combination of tests and activate them by a softkey or footswitch to automatically set up system parameters for each device you test.

Guide to HP Network Analyzers

**HP 4396B Network/Spectrum/
Impedence Analyzer**
The HP 4396B provides excellent
RF vector network, spectrum, and
optional impedance measurements
for lab and production applications.
Measure and evaluate, with one
instrument, the gain, phase, group
delay, distortion, spurious, carrier-
to-noise ratio, and noise of your
components and circuits. As a
vector network analyzer, the
HP 4396B operates from 100 kHz
to 1.8 GHz with 1 MHz resolution
for network analyzer measurements.
When combined with a test set,
the HP 4396B provides reflection
measurements, such as return loss,
and SWR, and S-parameters.

**HP E5100A/B High-Speed
Network Analyzers**
The HP E5100A/B network analy-
zers have been designed resonator
and filter manufacturers who need
extra-high throughput. Numerous
options tailor these analyzer with a
minimum investment. The frequency
range is from 10 kHz to 300 MHz.
With 0.04 ms/point measurement
speed, waveform analysis capabil-
ity, very low noise circuitry, and
IBASIC automation capability, the
HP E5100 will improve your manu-
facturing productivity.
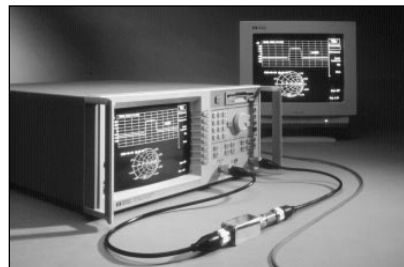
**HP 8711C RF
Network Analyzers**
The HP 8711C, 8712C, 8713C,
and 8714C network analyzers are
optimized for economical, high-
volume component manufacturing.
They offer great flexibility with
their many options, including AM
group delay, 50 or 75 ohm system
impedance, and internal 60-dB step
attenuator. Some models also offer
measurements of amplitude, phase,
and group delay. The high-speed
CPU, large VGA-compatible display,
IBASIC automation, and LAN
interconnectivity round out this
family's capabilities. Frequency
range is 300 kHz to 1.3 or 3.0 GHz.

**HP 8751A Precision
Network Analyzer**
For highly accurate measurements
at lower frequencies (5 Hz to 500
MHz), the HP 8751A network
analyzer provides 0.001 Hz, and
10 ps resolution using full two-port
calibrations. The 8751A also offers
unique features such as conjugate
matching analysis. With IBASIC
automation and built-in disk drive,
the HP 8751A is also ready for
manufacturing applications.
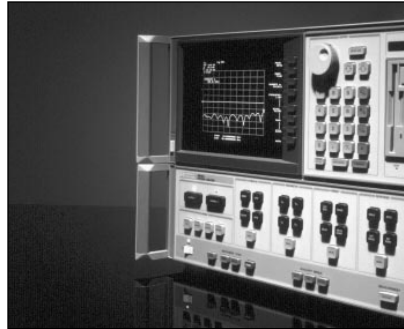
HP Network Analyzers

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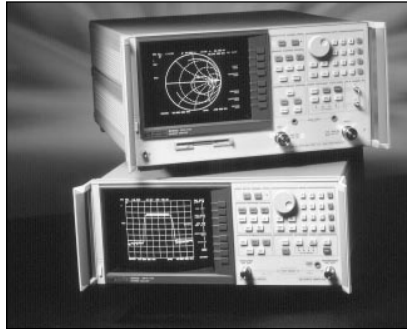
HP 8752C and 8753D RF Network Analyzers

A rich set of measurement capabilities with excellent performance and accuracy make the HP 8752/8753 family the standard by which other analyzers are measured. A fully integrated S-parameter test set, exceptional dynamic range, harmonic and offset frequency measurement capabilties, plus three independent, tuned receivers provide affordable excellence. Options for time domain (including TDR functionality), 6 GHz frequency range, high-stability source for SAW measurements, 75 ohms and many others make the HP 8753D a very versatile network analyzer.

HP 8720D Microwave Network Analyzers

For microwave frequencies, the HP 8720D family of network analyzers offers excellent performance at an affordable price. Compact and easy to use, this family has the same control and interface as the HP 8753D RF network analyzer, but provides frequency-response coverage from 50 MHz to 13.5, 20, or 40 GHz. Options include four-sampler architecture for full TRL/LRL calibrations for on-wafer and other noncoaxial measurements, a high-power test set, direct sampler access, and time-domain. DX models come preconfigured with options for non-coaxial applications at a value price.

HP 8510C Microwave Network Analyzer

Since its introduction in 1985, the HP 8510 series of microwave network analyzers have set the standard for performance. These analyzers provide a complete solution for characterizing the linear behavior of active or passive networks from 45 MHz to 50 GHz. On-wafer, millimeter-wave measurements, pulsed-RF measurements, broadband bias, calibration and control – the HP 8510 does it all. With options for electronic calibration, frequency to 110 GHz, frequency converters for mixer measurements and multiple-test-set support, the HP 8510 family meets every need.
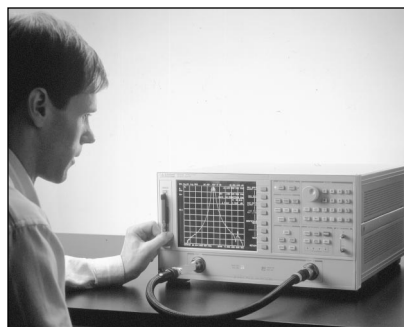
For more information, visit our web site at Access HP: http://www.tmo.hp.com/ For more information about Hewlett-Packard test and measurement products, applications, services, and for a current sales office listing, visit our web site, http://www.hp.com/go/tmdir. You can also contact one of the following centers and ask for a test and measurement sales representative.

United States:
Hewlett-Packard Company
Test and Measurement Call Center
P.O. Box 4026
Englewood, CO 80155-4026
1 800 452 4844

Canada:
Hewlett-Packard Canada Ltd.
5150 Spectrum Way
Mississauga, Ontario
L4W 5G1
(905) 206 4725

Europe:
Hewlett-Packard
European Marketing Centre
P.O. Box 999
1180 AZ Amstelveen
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(31 20) 547 9900

Japan:
Hewlett-Packard Japan Ltd.
Measurement Assistance Center
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Fax: (852) 2506 9285