MICROWAVE NETWORK ANALYSIS APPLICATIONS: NEW SOLUTIONS FOR OLDER CHALLENGES

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HEWLETT PACKARD

ABSTRACT: This paper describes the development of new network analysis measurement systems and techniques that can be applied to such diverse areas as millimetric-wave measurements, in-fixture device characterizations, frequency-translation device testing, and antenna-pattern measurements. System configurations are developed and described. Included are discussions of new calibration standards and accuracy enhancement techniques that provide substantial improvements in measurement accuracy.

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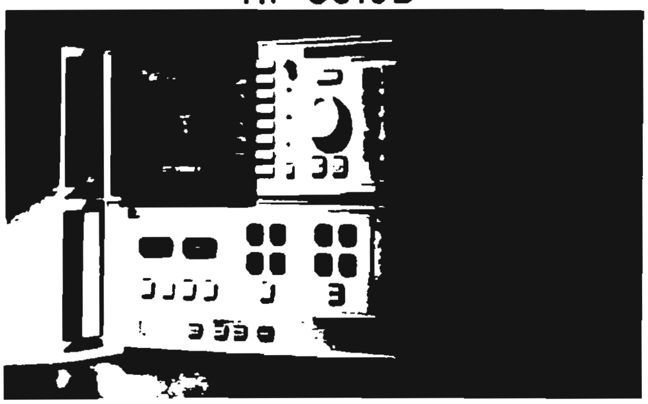
HP 8510B



"New Levels of Performance and New Applications."

5751

Microwave network analysis has evolved significantly over the past twenty years. The latest development is Hewlett-Packard's 8510B network analyzer. This paper will describe the contributions of the HP 8510B both in performance and in measurement accuracy. Also presented will be new techniques made possible by the advances of the HP 8510B for measuring components, antennas, and non-coaxial devices.

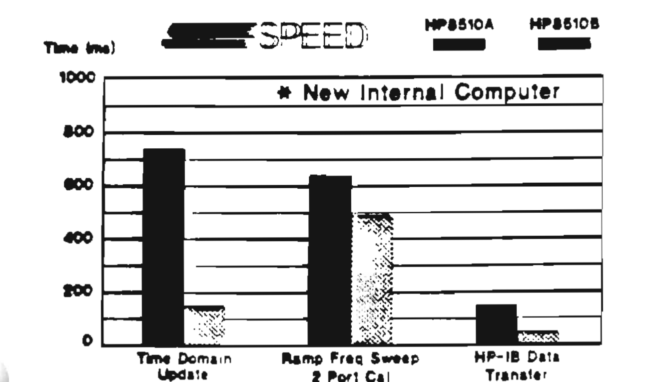
HP 8510B DESIGN GOALS:

- Improve HP8510 for all applications
- Improve accuracy
- Expand into unique applications
- Provide upgrade path/backward compatiblity for HP8510A

5753A

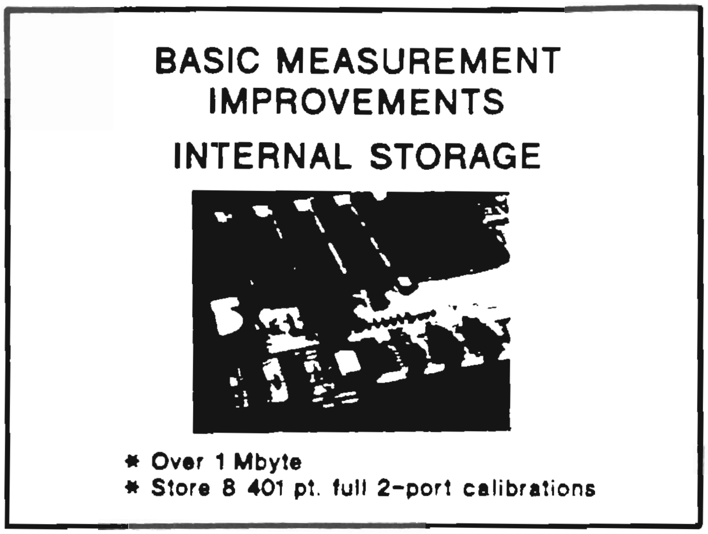
The major design goals for the HP 8510B are shown here and will serve as an outline for this paper. The first objective was to stay one step ahead of the needs in traditional network analysis applications.

BASIC MEASUREMENT IMPROVEMENT:



5754

The HP 8510B has a new, faster processor and enhanced algorithms which greatly increase measurement and data acquisition speed. For example, a 201 point data trace with full two-port error correction applied, is displayed in under 500 milliseconds. In addition, time domain responses are updated from 16 times (51 points) to 2 times (401 points) faster than the HP 8510A. HP-IB data transfer rates have doubled as well. Speed can be particularly important for applications requiring "real-time" information.



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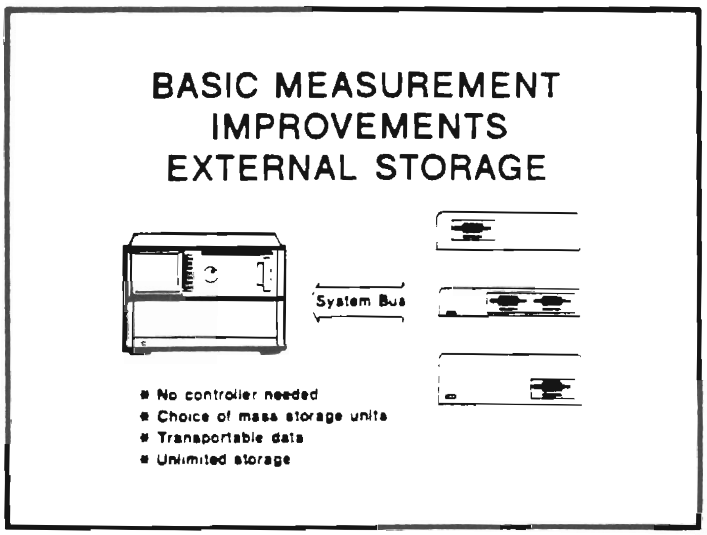
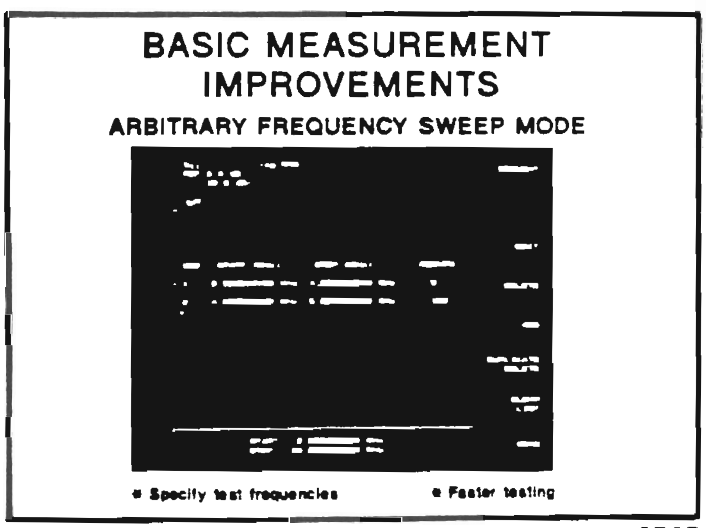
Internal memory in the HP 8510B has increased from 256 Kbytes each of RAM and bubble to 1 Mbyte of RAM and 512 Kbytes of EEPROM. This capability allows storage of eight complete measurement setups (including 401 point, two-port, 12 term error-corrected data for each measurement). Also, 801 point frequency and time domain traces may be displayed simultaneously. Trace memory has been expanded from 4 to 8 full traces, with up to 801 points each, particularly useful for matching applications.



5756

An external disc drive interface has been added to the HP 8510B to complement the built-in tape drive. Unlimited amounts of instrument states, calibration data, and measurement data can be stored to and retrieved from any HP-IB controllable disc drive with command subset CS/80, without the need for an external computer. HP Series 200/300 computer formats are used for easy transport of data.



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Arbitrary frequency sweep mode has been added to the HP 8510B to allow testing to be performed only at specified frequencies. Desired frequencies can be entered into the network analyzer via front panel softkeys. Reduction of test time may be very important for high volume component manufacturers.

OTHER MEASUREMENT IMPROVEMENTS

* Smart marker functions
* Enhanced line stretcher
* Analog copy output

⋮

5758

Some other new enhancements of the HP 8510B for network measurements include smart marker functions such as marker search, an analog copy output for direct output to a pattern recorder, and an improved line stretcher which compensates for waveguide dispersion. Electrical delay in waveguide is calculated by the network analyzer using the following equation:

$$\text{Delay (seconds)} = \frac{\ell}{C\sqrt{1-(f_{co}/f)^2}}$$

HP 8510B DESIGN GOALS:

* Improve HP8510 for all applications
* Improve accuracy
* Expand into unique applications
* Provide upgrade path/backward compatiblity for HP8510A

5753B

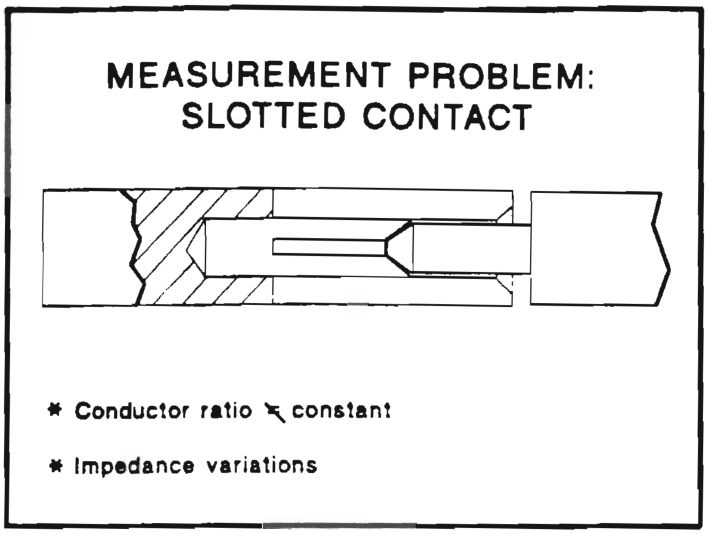
The next major goal of the HP 8510B was to improve the accuracy of all measurements.

BASIC MEASUREMENT IMPROVEMENT

* New calibration standards
* New calibration techniques

5760A

The HP 8510A has allowed us to observe connector performance to levels never before seen. In some cases, the connectors of the calibration standards are the primary limiting factor to achieving higher levels of error-corrected performance. Consequently, a new "slotless" connector is being introduced which significantly improves measurement accuracy. In addition, new accuracy enhancement techniques have been established to provide even more performance.



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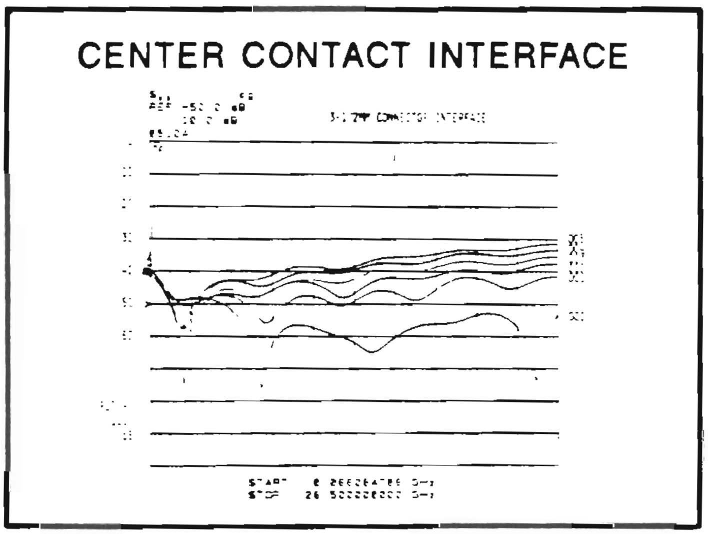
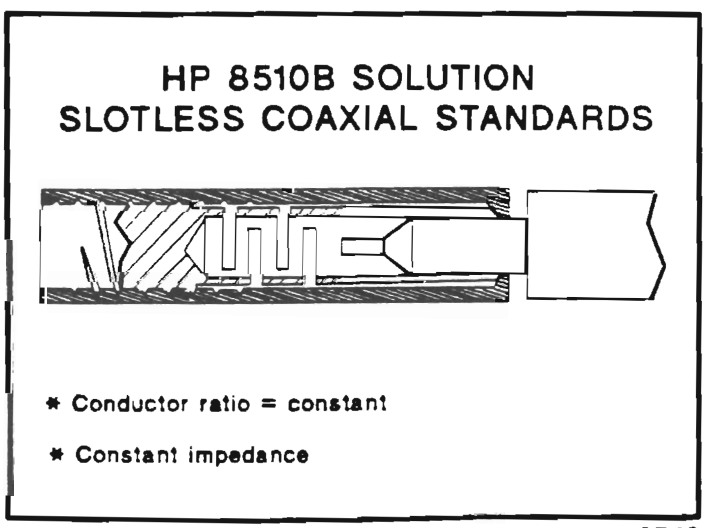
One major limitation in network measurements is the quality of the standards used for calibration. When "sexed" connectors such as Type N and 3.5 mm are mated, the slotted female center conductor will conform to the mated male center pin. Since the size of the male pin varies from connector to connector, impedance at this interface will vary from connection to connection. Significant errors in calibration and measurements result from such variation.



5795

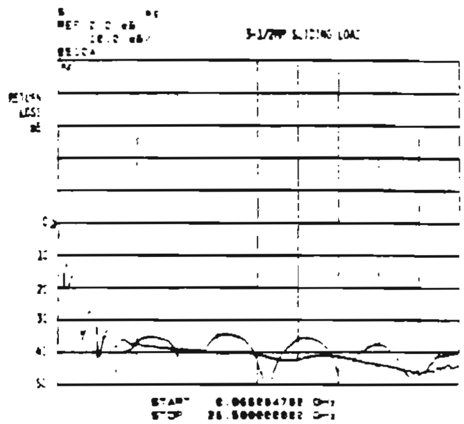
What is needed is a consistent contact independent of male pin size, and where the inner contact shoulder is flush with the outer conductor. Shown is a measurement of return loss of a 3.5 mm interface with varying gaps between the shoulder of the male center contact and the end of the female center contact.



5762

"Slotless" connectors such as this one provide a flush contact between the inner contact shoulder and the outer conductor to the best extent possible (.0001"). Also, the impedance is independent of male pin size. When the male pin is inserted, the outside front corners of the inner contact fingers are forced to slide up on the inner 45 degree slope of the pin. The integral spring in the back of the inner contact provides the proper contact pressure between the inner contact and the inner slope of the female pin. Thus, the ratio of the outer conductor to the inner conductor is constant resulting in a consistent impedance.

SLOTTED VS SLOTLESS



5796

Shown is a measurement of S11 of a sliding load with a "slotted" contact and with a "slotless" contact. Notice the improvement in directivity.

HP 8510B SOLUTION
New Slotless Coaxial Standards

5763

Shown is a photo of a "slotless" open and a "slotless" short.

PERFORMANCE IMPROVEMENT
3.5mm

	STANDARD	SLOTLESS
Effective Directivity	38 dB	44 dB
Source Match	30 dB	31 dB
Tracking	±.15 dB	± .06 dB

* Traceablity to NBS through mechanical tolerances

5764

"Slotless" standards increase measurement accuracy considerably. For example, in 3.5 mm. effective directivity is 44 dB, source match is 31 dB, tracking is .06 dB, and the characterisitc impedance does not vary. In addition, 3.5 mm and Type N measurements are traceable to NBS based on the tightly controlled dimensions of the precision "slotless" standards.

MORE PERFORMANCE FOR WAVEGUIDE

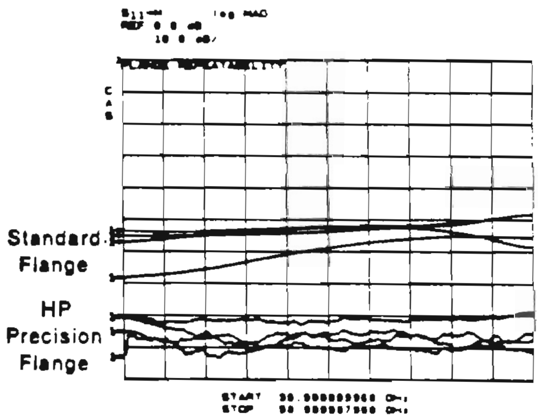
* Eliminates cocking
* Eliminates misalignment

5765

In waveguide measurements, flange connection repeatability is a major source of error after calibration. Each time the flange is connected, the waveguide apertures can be slightly misaligned from the previous connection. As a result, the contact impedance varies from connection to connection.

To help alleviate this problem, precision millimeter-wave flanges were recently introduced. By tightening the tolerances of the alignment pin locations and pin diameters, the possible misalignment of the waveguide apertures can be minimized. Also, addition of precision locating pins and a lip around the perimeter of the flange helps eliminate the possibility of disarranging the flanges.

MEASUREMENT REPEATABLITY



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Shown is a measurement of flange repeatability made by measuring a fixed load and storing the measurement data into the display memory of the HP 8510B. The flange was disconnected, reconnected, and measured again, subtracting the previous measurement using trace math. This process was then repeated several times. This measurement shows a comparison of the standard flange to the precision flange. Note that the repeatability error for the precision flange is on the order of 80 to 90 dB down, considerably less than the residual system errors after correction.

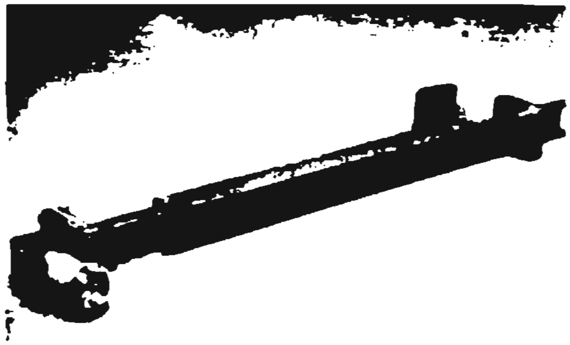
BASIC MEASUREMENT IMPROVEMENT

* New calibration standards
* New calibration techniques

5760B

Now, let's look at a new calibration technique for measuring noninsertable devices. Other new calibration techniques will be presented later.

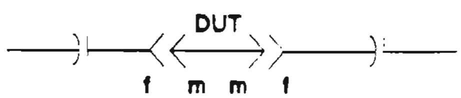
MEASUREMENT PROBLEM
NONINSERTABLE DEVICE



5767

Most microwave devices are noninsertable (i.e., input and output connectors are same sex or of different families). Calibrating a network analyzer for these types of devices has always been a challenge. Shown is an example of a noninsertable device, a coax to waveguide coupler.

NONINSERTABLE DEVICE



TRANSMISSION CALIBRATION

Can not directly mate test ports

* Insert adapter
* Switch equal adapters

5768

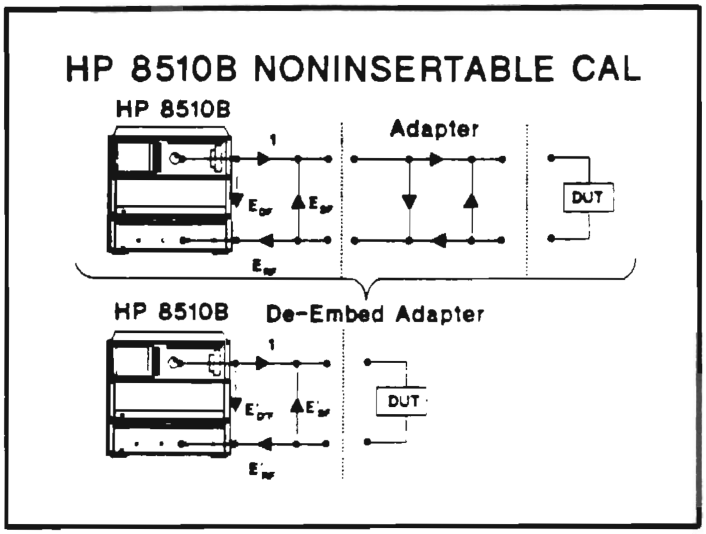
The problem with measuring noninsertable devices is that the ports of the test system can not be mated directly during calibration. Thus, an inserted or switched adapter is required for the transmission calibration step. When the switched adapters are not perfectly matched, or the inserted adapter is not fully known, uncertainty is added to the measurement.

HP 8510B SOLUTION
NONINSERTABLE CALIBRATION

* Completely characterize inserted adapter
* Completely characterize difference between switched adapters
* Automatically remove adapter effects from measurement

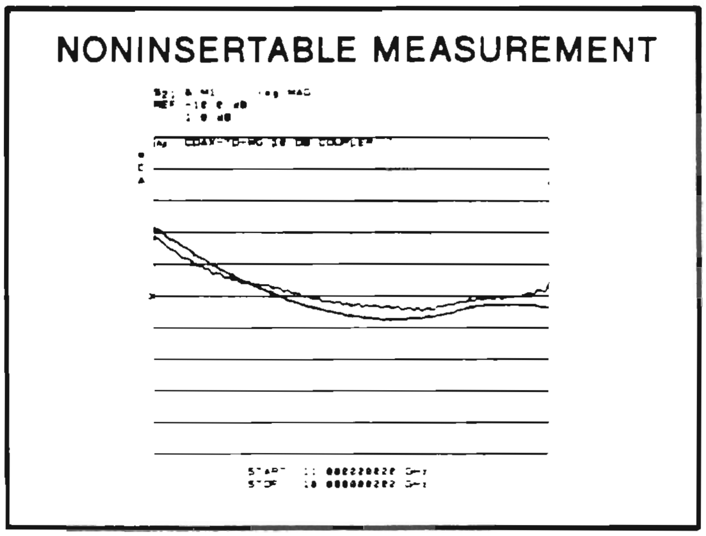
5769

A new noninsertable calibration built into the HP 8510B completely characterizes and removes the effects of an inserted or switched adapter.



5770A.B

The calibration begins by performing two full two-port calibrations (one with the adapter on port 1, and then with the adapter on port 2). Now, enough measurements are made to completely characterize (all 4 s-parameters) the adapter. A simplified 1-port flowgraph analysis is shown here. The network analyzer measures the errors introduced by the adapter and creates a cascaded error model.



5771

Here is a measurement of coupling factor for a coax to waveguide 10 dB coupler. One measurement was made using the insert adapter method while the other used the noninsertable calibration method. Transitional adapters, like coax to waveguide, present significant discontinuities and are difficult to characterize. The noninsertable calibration, however, allows us to see the true response of the test device by completely removing the adapter response.

HP 8510B DESIGN GOALS:

- * Improve HP8510 for all applications
- * Improve accuracy
- * Expand into unique applications

5753C

Network analyzers have traditionally been used for measuring components. Another major goal of the HP 8510B was to expand the use of network analyzers into unique and demanding component applications including frequency translation devices, millimeter-wave devices, antennas, and fixtured devices.

ENHANCED APPLICATION CAPABILITIES

1) Components

2) Antennas

3) Semiconductor Devices

5772A

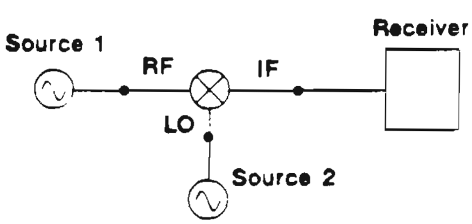
Let's look at making some measurements on some of these unique devices.

MEASURING FREQUENCY TRANSLATION DEVICES MIXERS

5773

We'll start by seeing how a network analyzer measures a frequency translation device such as a mixer. Today, there are requirements for mixers that are matched according to their amplitude and phase response.

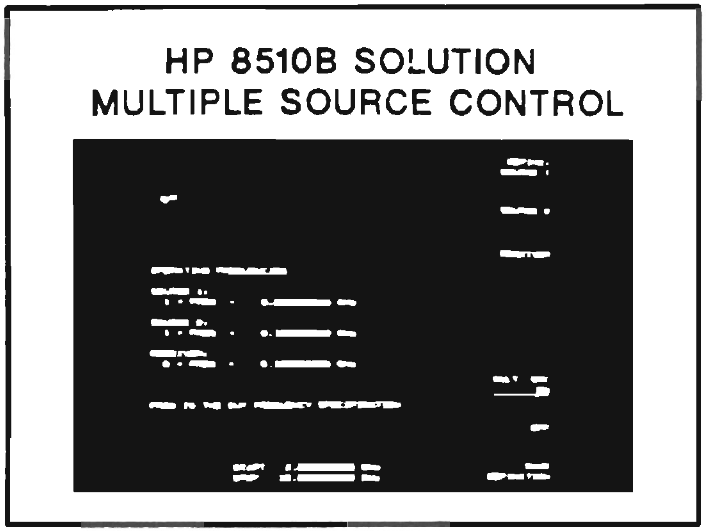
MIXER MEASUREMENT CONSIDERATIONS



* Need to control 2 sources
* Source frequencies ≠ receiver frequency
* Compare conversion loss and phase

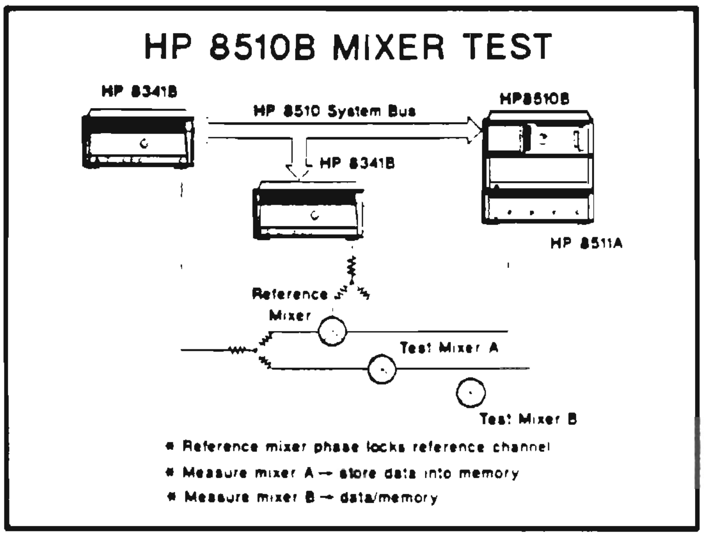
5774

A mixer has been a difficult device to measure on a network analyzer. First, two sources are needed and must be controlled. Plus, the source frequencies differ from the receiver frequency. In the past, an external computer was needed to simultaneously control the two sources and the receiver in order to make mixer measurements.



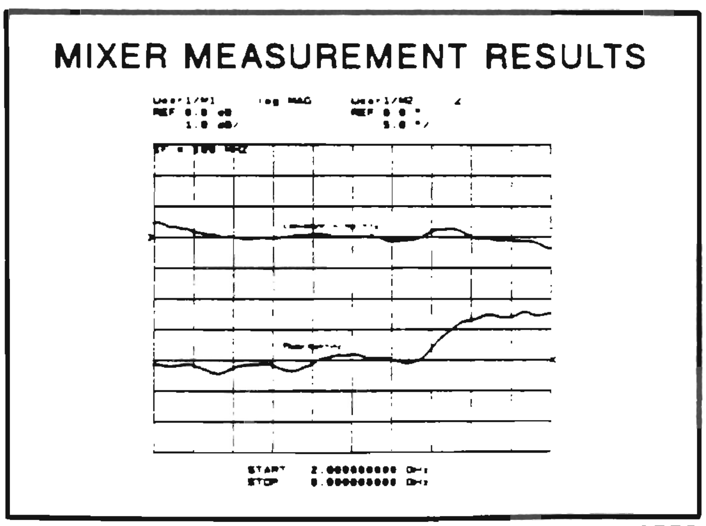
5775

The system control capability of the HP 8510B has been expanded to measurement systems that require multiple RF sources and for measurements of devices that perform frequency conversion. Built-in stimulus control has been extended to coordinate independent control of the frequency and power level of up to two signal sources and the receiver frequency. The front panel menu structure shown here accepts entry of these frequencies for the primary (test or RF) and secondary (LO) sources as well as the receiver (IF). This multiple source control mode may be used in any application where two sources and or the receiver must be operated at different frequencies.



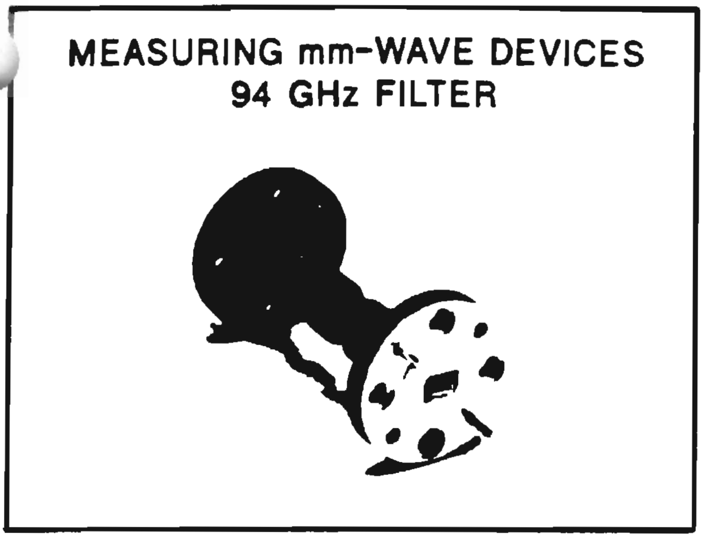
5776

Multiple source control allows swept measurements of mixer amplitude and phase without an external computer. In this set-up, measurements are made relative to a reference mixer, which is used to provide a reference signal at the same frequency as the test signal. The RF ranges from 2 to 8 GHz as the LO sweeps from 2.1 to 8.1 GHz. The IF is held constant at 100 MHz.



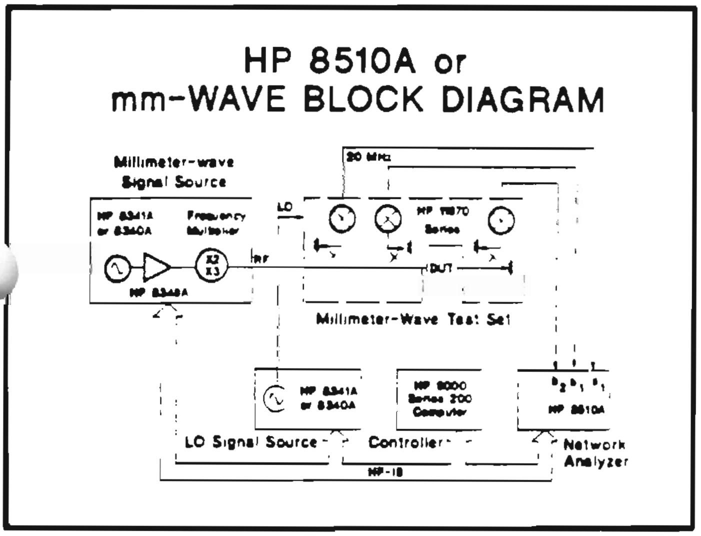
5777

Shown are the results of a mixer amplitude and phase matching measurement. First, mixer A is measured and the results stored into memory. Next, mixer B is measured and its data subtracted from memory using trace math. This may be repeated to compare several mixers. In this example, the mixers are matched within 1 dB and 5 degrees.



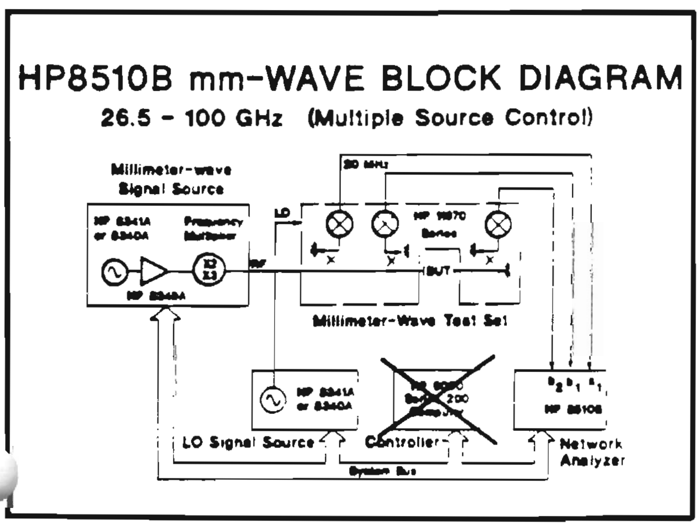
5778

Multiple source control also proves useful in measuring millimeter-wave devices such as this 94 GHz bandpass filter.



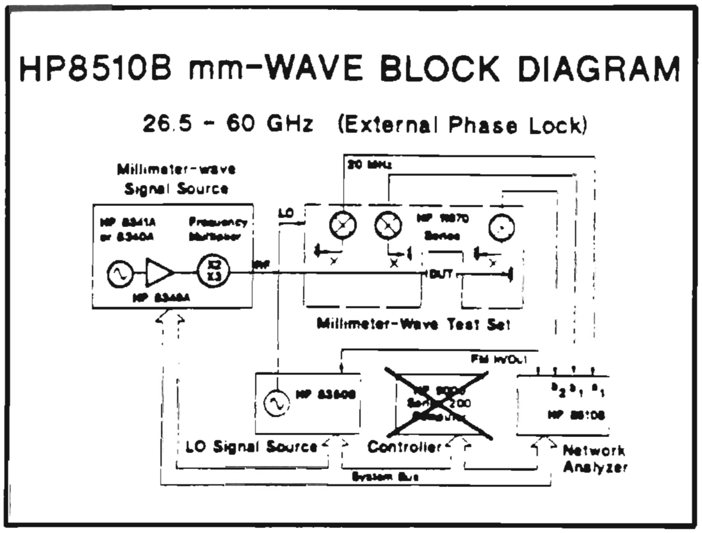
5779A

With the HP 8510A, a millimeter-wave system block diagram looked like this. A computer was needed to control both sources and receiver frequencies.



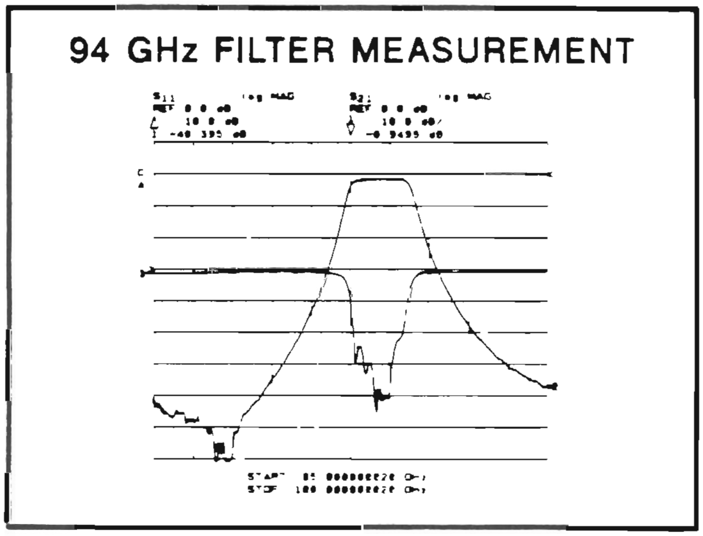
5779B

With the HP 8510B, a computer is no longer required since the analyzer can control both sources over its system bus.



5779C

For HP 8510B based millimeter-wave systems up to 60 GHz, an HP8350B sweep oscillator may be used as the LO in place of a synthesizer. This significantly lowers the system cost. The HP 8510B's external phase lock mode extends the phase lock loop of the receiver through the DC FM input of the sweeper.



5780

This trace shows the insertion loss of the 94 GHz filter to be about 1 dB and return loss to be about 40 dB at 94 GHz. Even in this frequency range, over 80 dB of dynamic range can be realized.

ENHANCED APPLICATION CAPABILITIES

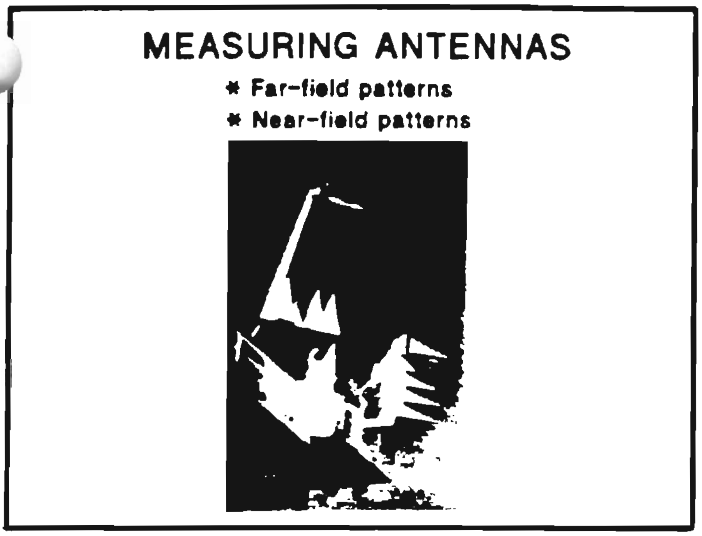
1) Components

2) Antennas

3) Semiconductor Devices

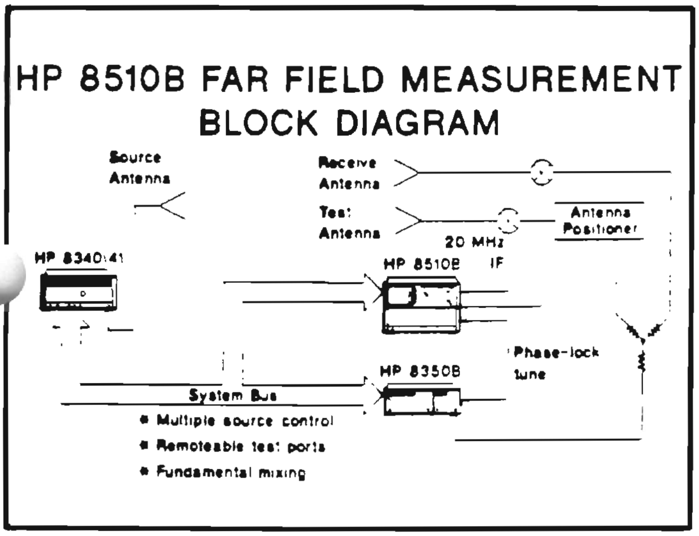
5772B

Multiple source control can also be utilized for antenna measurements. In addition, several other new capabilities of the HP 8510B will help in measuring antennas.



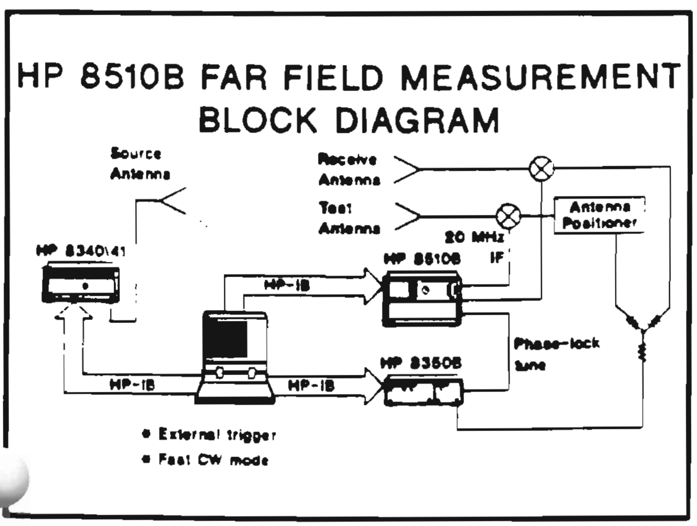
5788

We'll concentrate on a far-field measurement here although the discussion applies to near-field measurements as well. By far-field we mean that the source and test antennas are far enough apart [(2D)*2 lambda], that a planar waveform is incident on the test antenna. Thus, the radiation pattern of the antenna undergoes very little change. Near-field measurements take place from 2-10 wavelengths away from the source antenna.



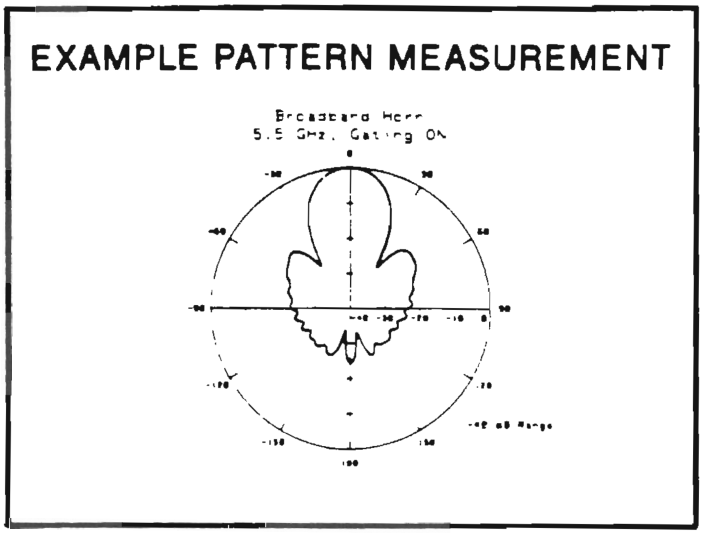
5789A

Here is a typical far-field measurement block diagram. To perform a pattern measurement, the RF source is set to a CW frequency and the antenna is rotated while a receiver measures the signal at the output of the antenna under test. Multiple source control allows independent control of the RF and LO. For high sensitivity, the test ports may be remoted up to 150 feet and fundamental or harmonic mixers used to downconvert the microwave frequency to a 20 MHz IF. Built-in external phase lock allows a sweep oscillator LO source to be phase locked for remote downconversion of the test and reference signals. This mixing process occurs at the receive antenna output.



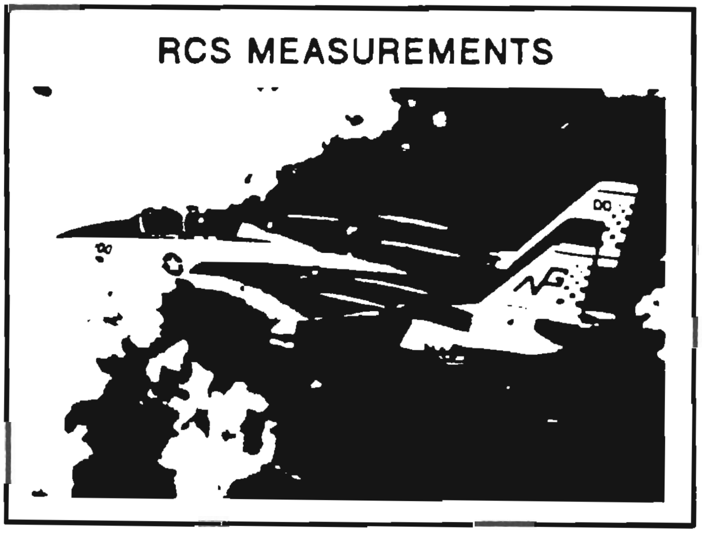
5789B

We can automate our antenna range with the addition of an external computer to coordinate antenna pattern measurements with antenna position. With external trigger mode, the analyzer can be triggered to take data as the test antenna is rotated. The high speed data collection capability of Fast CW mode, greater than 1000 measurements per second, is ideal for high volume data requirements. The data, both amplitude and phase, correspond precisely with antenna azimuth and elevation.



5790

Shown is an example pattern measured on the HP 8510B. Analog copy output allows for direct pattern recording.



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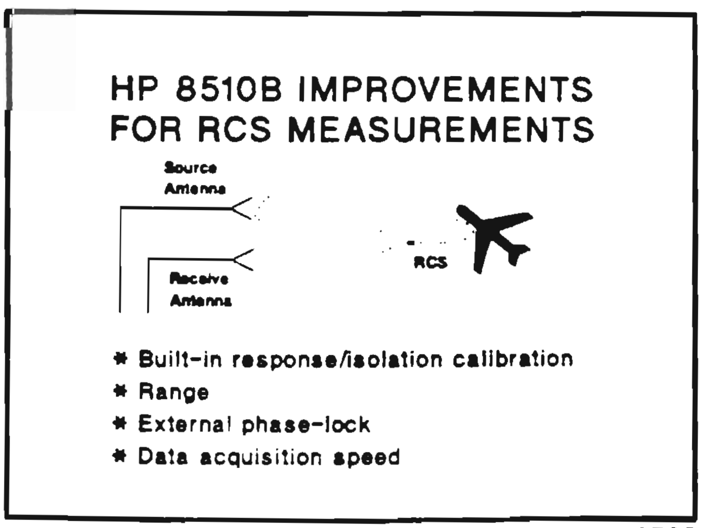
Network analyzers are also well suited as receivers for Radar Cross Section (RCS) measurements. In RCS measurements, we are interested in how big something looks to a radar signal.



5792

With external mixers and a sweep oscillator LO acting as our "test set", we can achieve outstanding measurement sensitivity. 801 points provide long range, high resolution measurements. In addition, a new Response/Isolation calibration is built into the HP 8510B to characterize and remove low level test chamber reflections. Using Fast CW mode, single point measurements can be made and transferred to an external computer in less that 1 millisecond per point. Ramp sweep measurements can be made using the HP 8511A as our test set.

ENHANCED APPLICATION CAPABILITIES

1) Components

2) Antennas

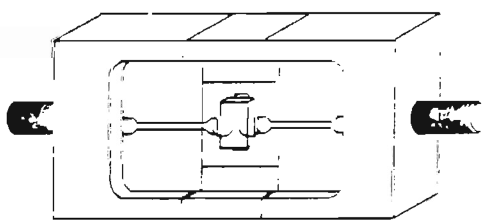
3) Semiconductor Devices

5772C

Next, let's look at using a network analyzer to make measurements of non-coaxial devices like semiconductors.

CHARACTERIZING SEMICONDUCTOR DEVICES:

FIXTURED TRANSISTOR



5782

Accurately characterizing such devices has always been difficult. Let's take a typical situation: a fixture is needed to connect the coaxial ports of a network analyzer to a microstrip substrate, on which the device is mounted.

PROBLEM:

* Remove effects of fixture

SOLUTION:

* Calibrate in fixture

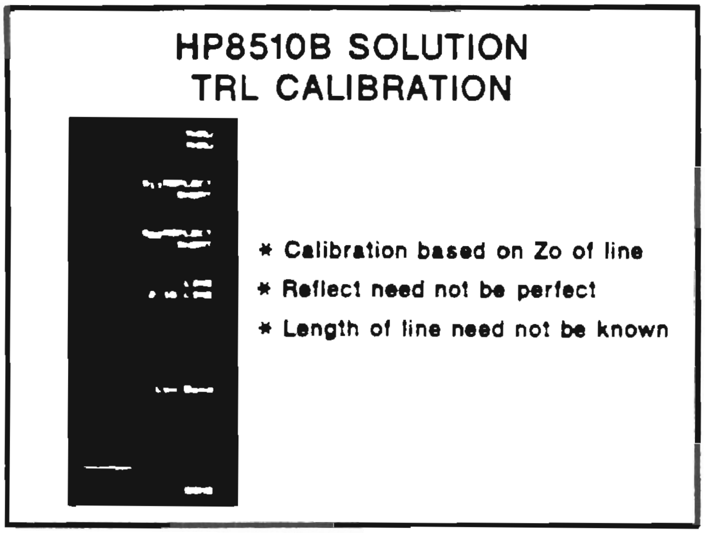
PROBLEM:

* Quality loads and shorts difficult to make

NEED ALTERNATE CALIBRATION METHOD

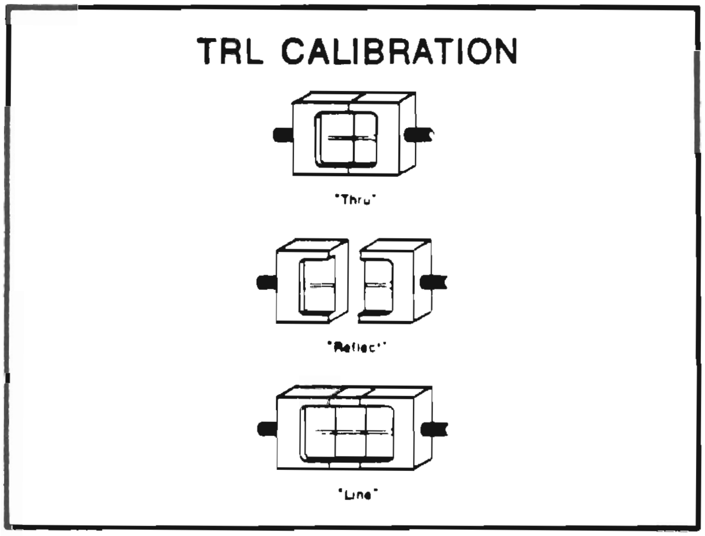
5783A,B,C

The problem is to remove the effects of the fixture from the measurement. The most direct calibration method is to calibrate at the DUT interface. Known in-fixture standards, however, are not always available or are difficult to make. A technique using derived models, which represent the fixture's response "de-embedded" from the device data, has been used in the past. This technique, however, requires a computer and thorough knowledge of the fixture.



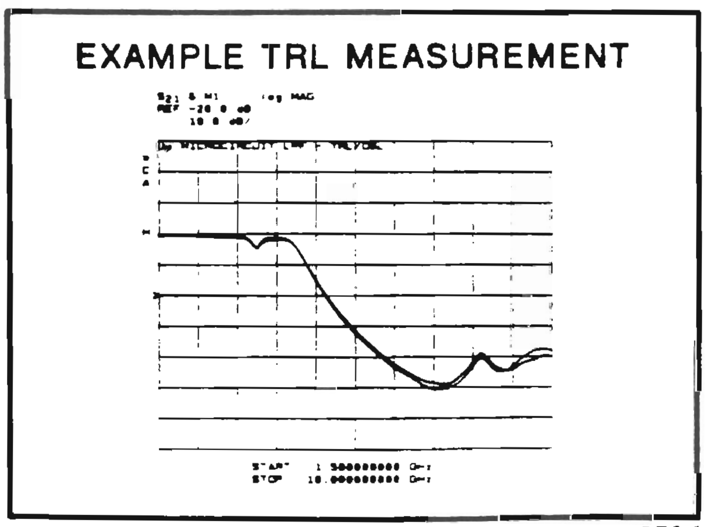
5784

A new calibration technique has been developed in the HP 8510B for measuring in-fixture devices, called TRL (Thru, Reflect, Line). TRL is ideal for calibrating in dispersive media such as microstrip where quality opens, shorts, and loads are difficult to make. TRL, however, is a general calibration technique which equally extends to coaxial measurements as well. It is based on the Zo of the Line. The "Reflect" and length of line need not be known precisely. Thus, the standards are more physically realizable and fewer standards are needed.



5785A,B,C

By measuring 2 different length Zo transmission lines, and any reflective device, a full two-port, error-corrected calibration is completed. Generally speaking, all of the two-port error terms can be grouped into eight individual terms. Four measurements are made by both the thru and the line while the reflect performs two measurements. This leaves us with 10 equations and 8 unknowns, more than enough information to solve for our error terms. The two additional unknowns may be the length of the line and the impedance of the reflect. Further information can be found in reference #9.



5786

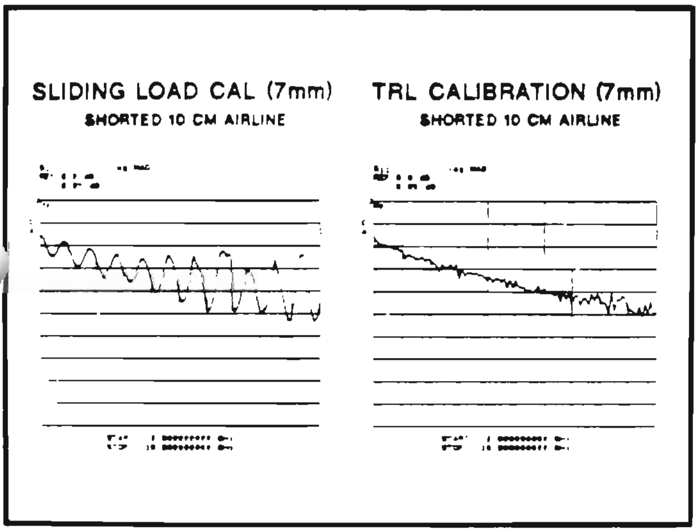
Here is the measured transmission response of a microcircuit low pass filter. One measurement was made using a conventional open/short/load calibration at the fixture interface. Note that the effects of the fixture are in our measurement. The other measurement was made using a TRL calibration.

USING TRL in 7mm COAX

	STANDARD	TRL
Effective Directivity	52 dB	60 dB
Source Match	41 dB	60 dB
Tracking	±.05 dB	.01 dB

5787

As mentioned above, TRL can be used in coaxial and waveguide measurements as well. The HP 8510B currently provides standards for TRL calibrations in 7 mm, providing 60 dB directivity and port match and less than .01 dB tracking error.



5797

Shown is a measurement of a 7 mm 10 cm airline terminated in a short circuit first measured with a sliding load calibration and then with a TRL calibration. Note the reduction of ripple for the TRL case.

HP 8510B DESIGN GOALS:

* Improve HP8510 for all applications
* Improve accuracy
* Expand into unique applications
* Provide upgrade path/backward compatiblity for HP8510A

5753D

The final major goal of the HP 8510B was to protect the investment customers have made into the HP 8510A. Backward compatibility and a migration path were designed into the HP 8510B from the start. For further information on how to upgrade an HP 8510A to an HP 8510B, see your local HP sales representative.

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