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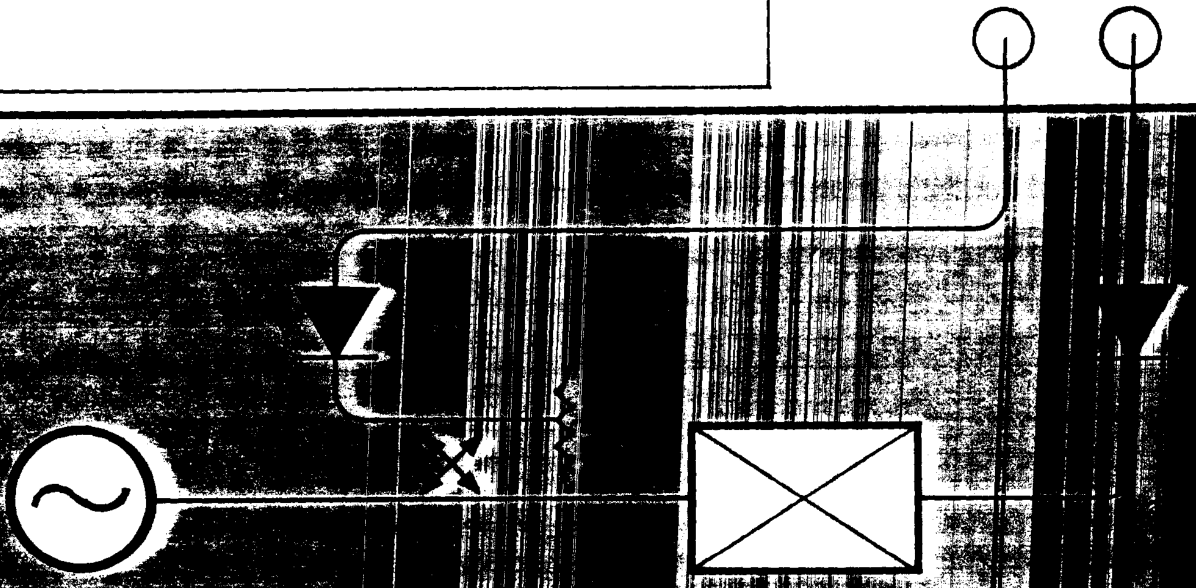

Microwave Scalar Network Measurements Seminar

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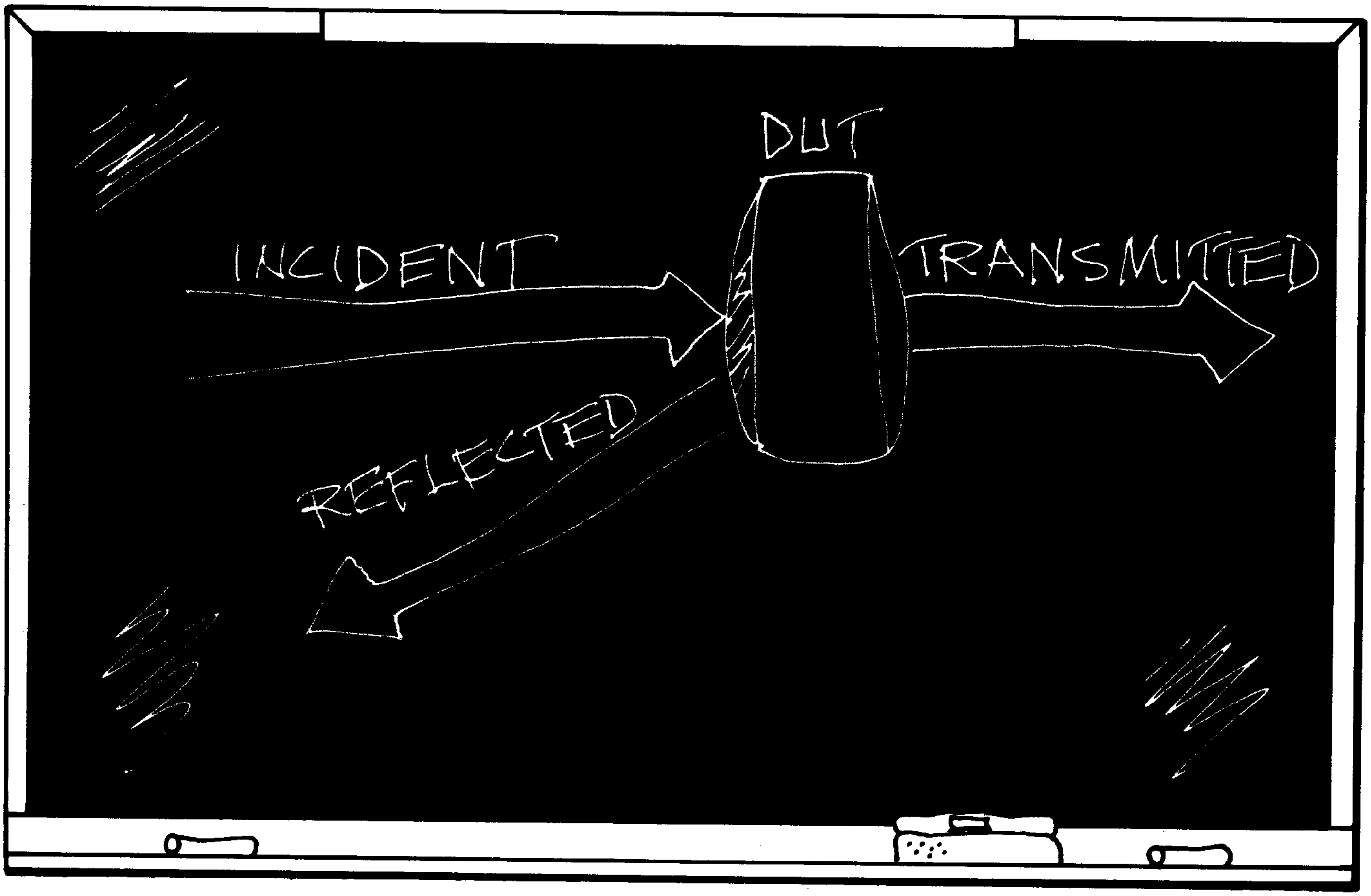
Scalar Measurement Fundamentals



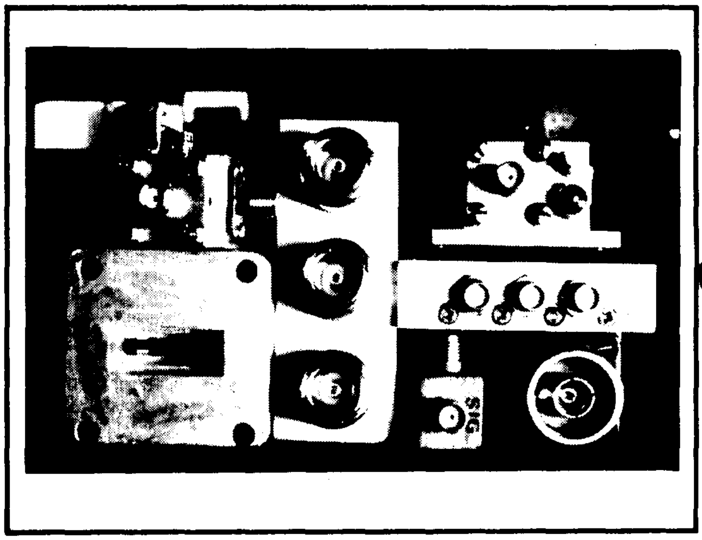
Welcome to the SCALAR MEASUREMENTS SEMINAR. This seminar will show you how to characterize RF and microwave components economically and effectively using scalar network analysis.

Welcome to

Hewlett-Packard's
Scalar Measurements Seminar

3303

Some of the devices that can be characterized with scalar network analysis are shown here, including filters, amplifiers, mixers, and oscillators. This seminar will introduce you to the theory and techniques of characterizing these devices.



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The seminar is divided into three main parts. The first section describes the fundamentals of scalar network measurements, including background theory and how to characterize and reduce some common measurement errors.

The second section shows how to apply network measurements to the characterization of particular devices, such as filters and amplifiers. This section includes many application examples which reinforce the background of the fundamentals section.

The last section describes how to automate scalar network measurements to increase throughput and efficiency in network measurements.

1. **Scalar Measurement Fundamentals**
2. **Scalar Measurement Applications**
3. **Automatic Systems**

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SCALAR MEASUREMENT FUNDAMENTALS

- Basic Microwave Measurements
- Scalar Network Analysis System
- Scalar Reflection Measurements
- Transmission Measurements
- Power Measurements
- Product Summary

In this section, we will discuss measurement fundamentals for network analysis, specifically scalar network analysis. We will look at what comprises a scalar network analysis system and how to make accurate scalar measurements. We will also look at HP's product offerings available to make scalar measurements.

SCALAR MEASUREMENT FUNDAMENTALS

Basic Microwave Measurements

First, let's look at the basic microwave measurements that are commonly made.

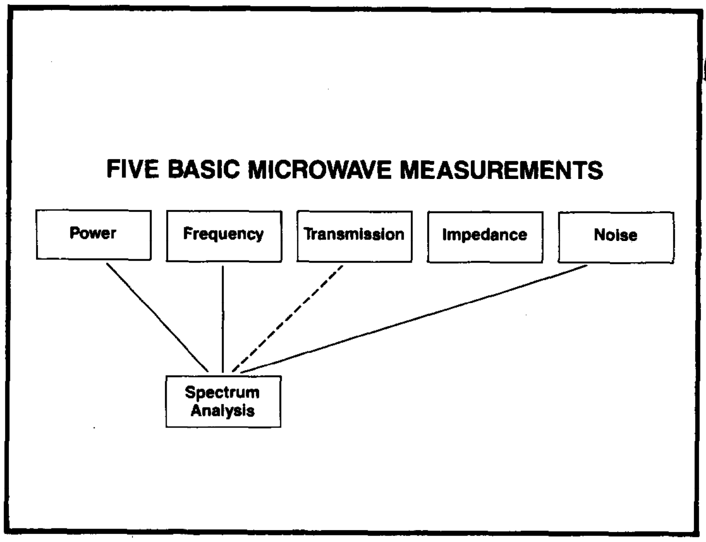
FIVE BASIC MICROWAVE MEASUREMENTS

Power	Frequency	Transmission	Impedance	Noise

3458

There are five basic microwave measurements.

Spectrum analysis primarily measures power, frequency, and noise.

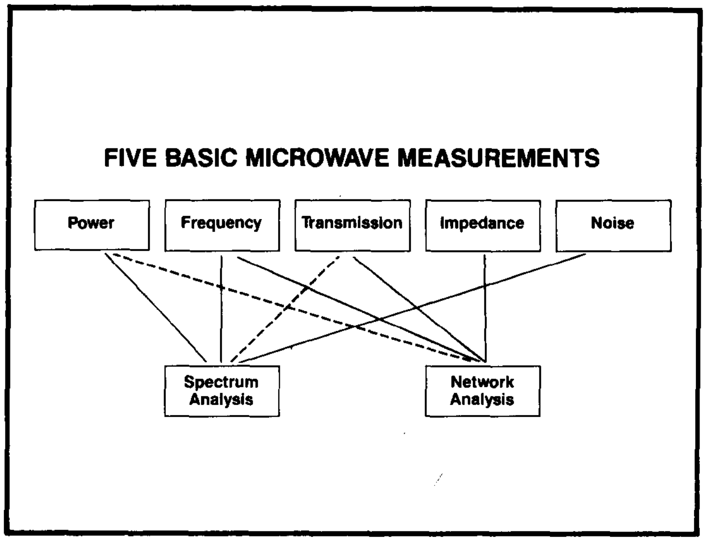

FIVE BASIC MICROWAVE MEASUREMENTS

Power | Frequency | Transmission | Impedance | Noise

Spectrum Analysis

3458

Network analysis is primarily concerned with impedance, transmission, and frequency. Power can also measured in network analysis.


FIVE BASIC MICROWAVE MEASUREMENTS

Power | Frequency | Transmission | Impedance | Noise

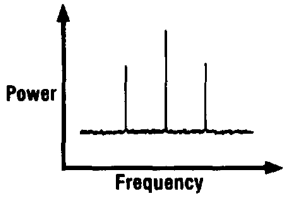
Spectrum Analysis

Network Analysis

The major difference between spectrum and network analysis is illustrated here.

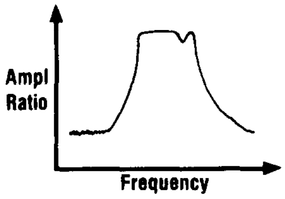
Spectrum analysis is primarily concerned with characterizing a signal; i.e., its spurious and harmonic components, modulation, noise, etc. It indicates discrete frequencies where microwave energy exists.

In network analysis, we want to characterize a microwave component; that is, determine how efficiently energy is transferred into the network (or out of the network), or measure its transmission characteristics to determine how effectively energy is transferred through the network. Frequency is important since parameters are usually measured and displayed as a function of frequency.



Typical Spectrum Analyzer Display

SIGNAL CHARACTERISTICS
- Communications
- Receiver Testing
- Signal Generation Tests



Typical Network Measurements Display

NETWORK CHARACTERISTICS
- Network Test
- Component Test
- System Test

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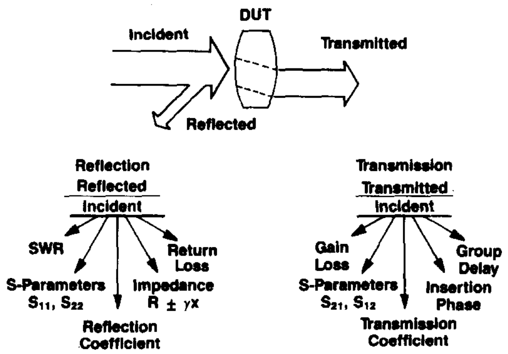


DUT

Incident

Transmitted

Reflected

Reflection

$\frac{\text{Reflected}}{\text{Incident}}$

SWR

Return Loss

S-Parameters S_{11}, S_{22}

Impedance $R \pm jX$

Reflection Coefficient

Transmission

$\frac{\text{Transmitted}}{\text{Incident}}$

Gain Loss

Group Delay

S-Parameters S_{21}, S_{12}

Insertion Phase

Transmission Coefficient

Microwave energy can be likened to light energy. Throughout this seminar we will use this analogy. Three waves will be of interest to us: the incident, the reflected, and the transmitted waves. To characterize a network (or component) completely, both magnitude and phase information is necessary. For many applications, however, scalar (magnitude only) characterization is sufficient.

We will discuss phase only to the extent that it affects scalar measurement accuracies.

WHY MAKE SCALAR MEASUREMENTS INSTEAD OF VECTOR MEASUREMENTS???

3459

Why are we interested in making scalar (magnitude only) measurements instead of making vector (magnitude and phase) measurements?

COST

Scalar N.A. = $12,500

Vector N.A. = $51,000

3460

The major reason is cost. A scalar network analyzer is about on - fourth the cost of a vector network analyzer.

Let's look at what makes up a scalar network analysis measurement system.

SCALAR MEASUREMENT FUNDAMENTALS

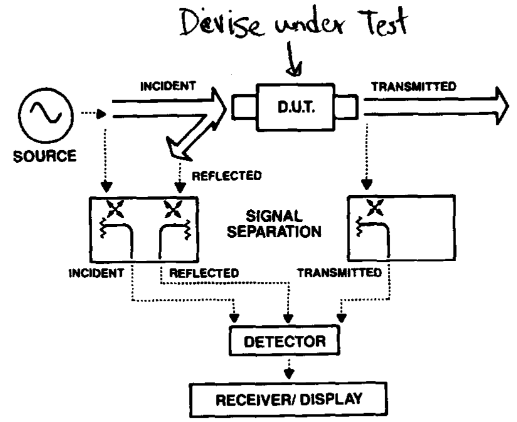
- Basic Microwave Measurements
- Scalar Network Analysis System

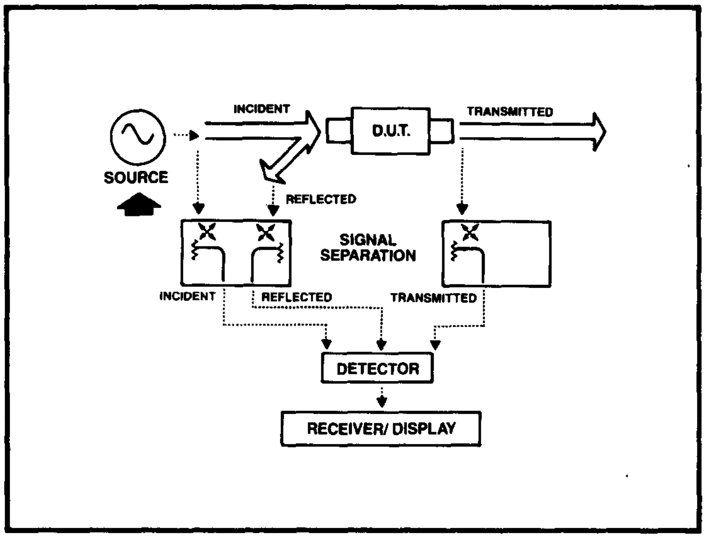
A scalar system consists of four parts; a microwave source, signal separation devices, detectors to convert the microwave energy to a DC or low frequency signal, and an analyzer which receives the detector output and displays the measurement results as a function of frequency.

SCALAR NETWORK ANALYSIS MEASUREMENT SYSTEM

- Stimulus
- Signal Separation Device
- Detectors
- Receiver/Display

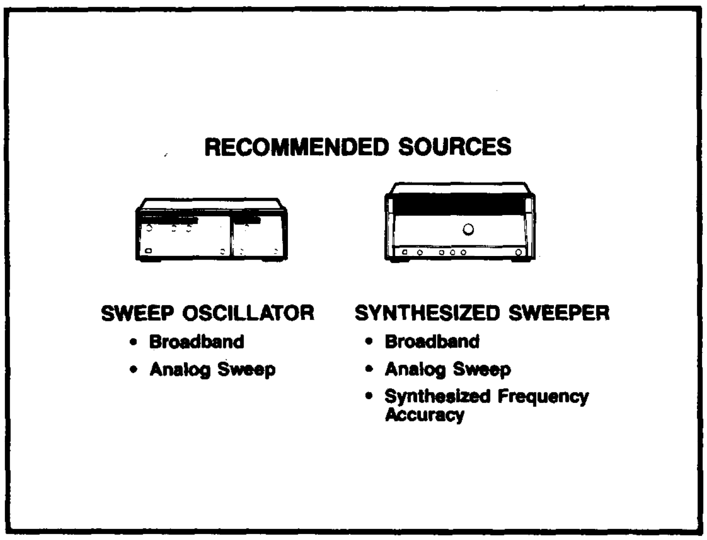
This set-up shows the typical network measurement configuration. Note the device under test is analogous to the "lens" of our previous example with light, the component which we want to characterize.





3461

The microwave source provides the swept frequency stimulus for the measurement system.



RECOMMENDED SOURCES

SWEEP OSCILLATOR
- **Broadband**
- **Analog Sweep**

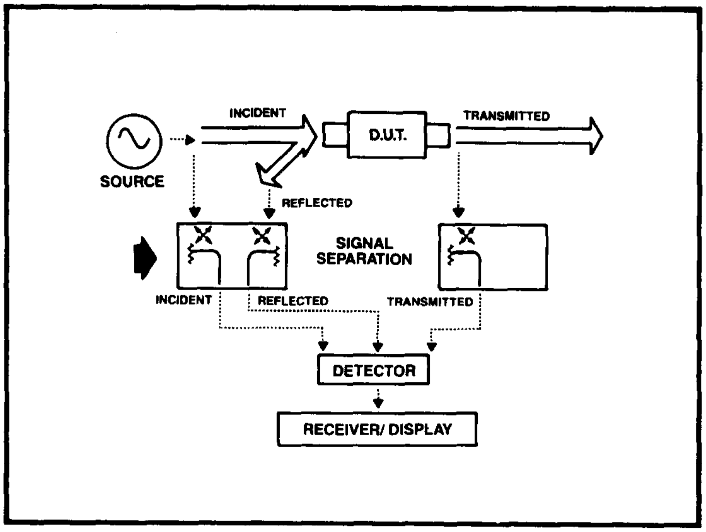
SYNTHESIZED SWEEPER
- **Broadband**
- **Analog Sweep**
- **Synthesized Frequency Accuracy**

3462

The two major sources we will discuss are the sweep oscillator (more commonly called a "sweeper"), and the synthesized sweep oscillator.

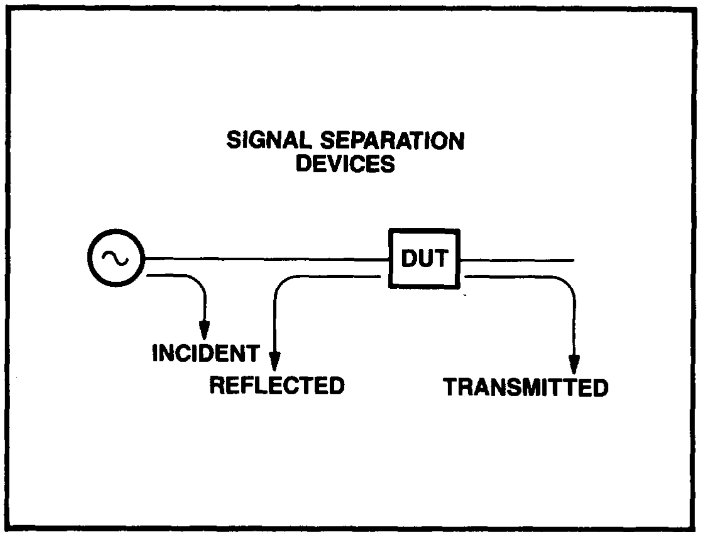
The basic sweeper provides a signal (frequency) that is swept over a broad band of frequencies with settings to select the range over which the source is swept. Additional features such as internal and external power leveling, modulation (AM, FM, Pulse), and programmability are important for more accurate and cost effective systems as we'll see later.

A synthesized sweeper has the additional capabilities of providing very accurate synthesized stepped CW sweeps as well as the standard broadband analog sweep. Narrowband, highly accurate, phase-locked sweeps are also possible with a synthesized sweeper.



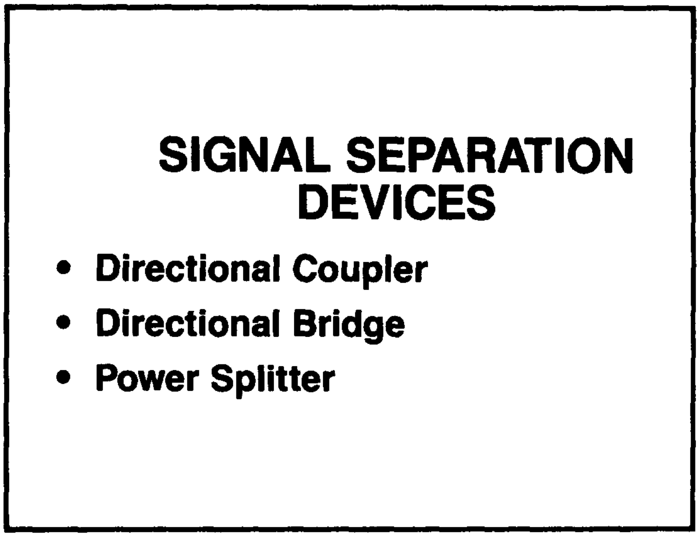
Let's discuss signal separation devices and how they are used in network measurements.

The signal separation device samples the test signal in one direction only. For example, a directional coupler used for reflection measurements only samples the test signal reflected from the input of the DUT but not the incident signal.


SIGNAL SEPARATION DEVICES

3463

The three devices used for sampling the signal of interest are: (1) directional couplers, (2) directional bridges, and (3) the two resistor power splitter.

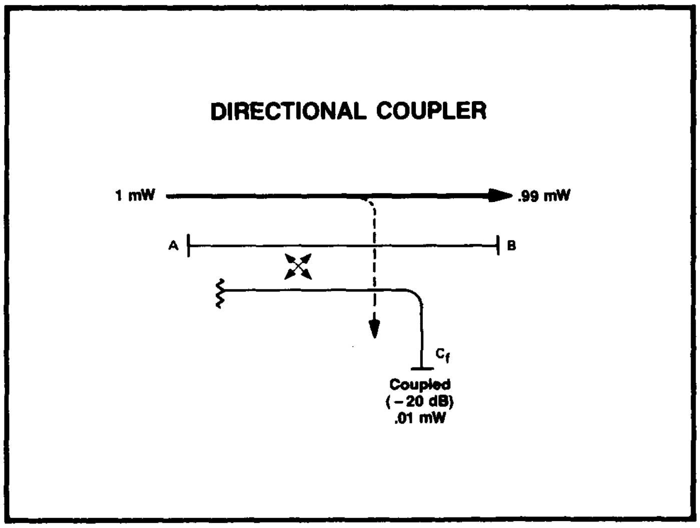

SIGNAL SEPARATION DEVICES

- **Directional Coupler**
- **Directional Bridge**
- **Power Splitter**

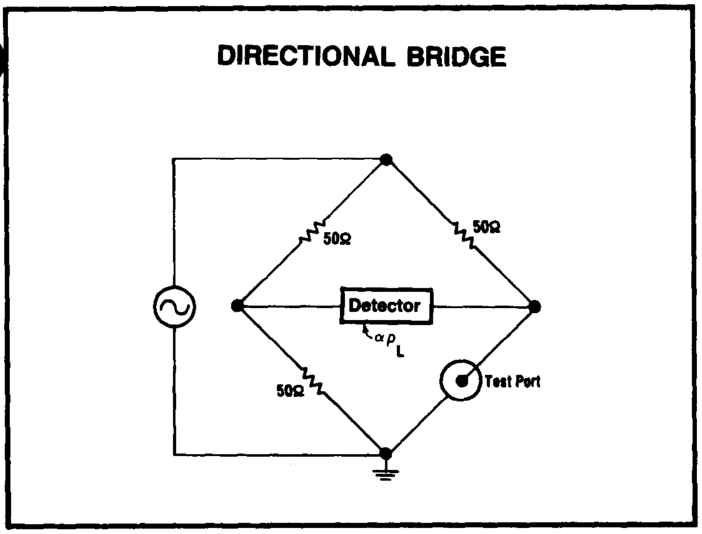
3464

The coupled arm of a directional coupler samples a signal traveling in one direction only. The coupled signal is at a reduced level and the amount of reduced level is called the coupling factor. Notice that in this example of a 20 dB directional coupler that the coupled port is 20 dB below the input. A 20 dB reduction means that the coupled arm is $0.01 \times P_{in}$ or 1% of the input power. The remainder of the signal (99%) travels through the main arm. There is also a frequency response or coupling variation associated with couplers, expressed in ± dB.

The coupler schematic represents the direction that signals will be coupled, depending on which way the arrows are pointing.

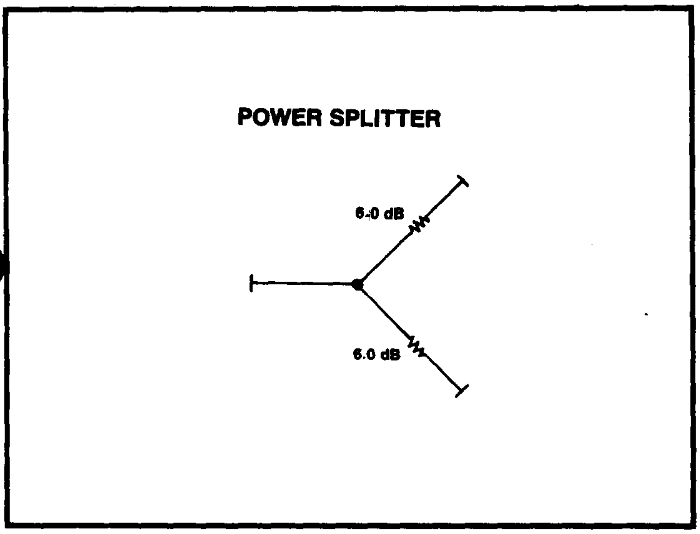

DIRECTIONAL COUPLER

3465



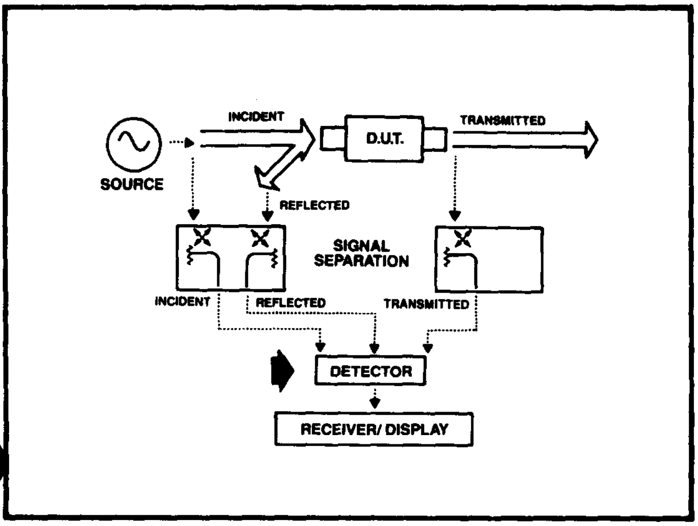
2878

The next signal separation device used in measuring reflected signals is the directional bridge. Its operation is similar to the simple Wheatstone bridge. If all four arms are equal in resistance (i.e., test port = 50 ohms) a voltage null is measured. If the test port load is not 50 ohms, then the voltage across the bridge is proportional to the mismatch (deviation from 50 ohms) of the DUT.



3466

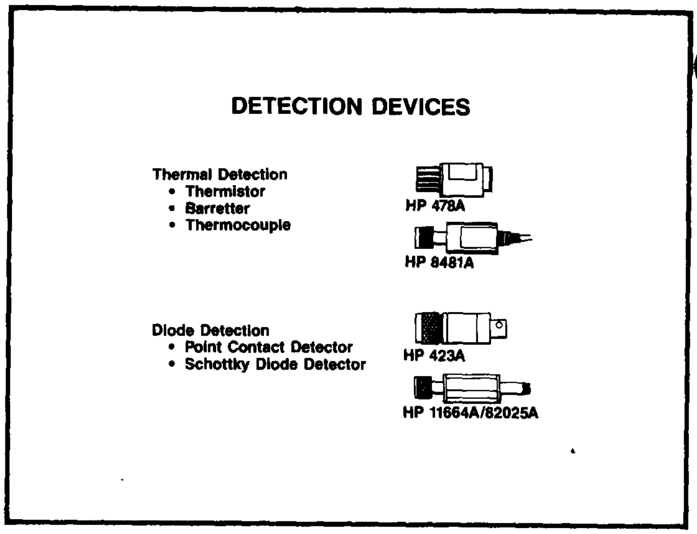
The two resistor power splitter is used to sample either the incident signal or the transmitted signal. The input signal is split equally between the two arms with the output signal (power) from each arm being 6 dB below the input. The typical microwave power splitter is broadband operating over a frequency range from DC to 26.5 GHz.



The next component in our scalar measurement system is the detector.

It is difficult to measure and display voltage and current at microwave frequencies with any degree of accuracy. A means for converting to DC or a lower frequency is necessary. There are several ways of accomplishing this conversion.

Thermal detectors are normally only used with power meters since they are very accurate. They are, however, slow responding devices. Diode detectors are used normally with scalar analyzers because they are fast and less expensive than other devices.



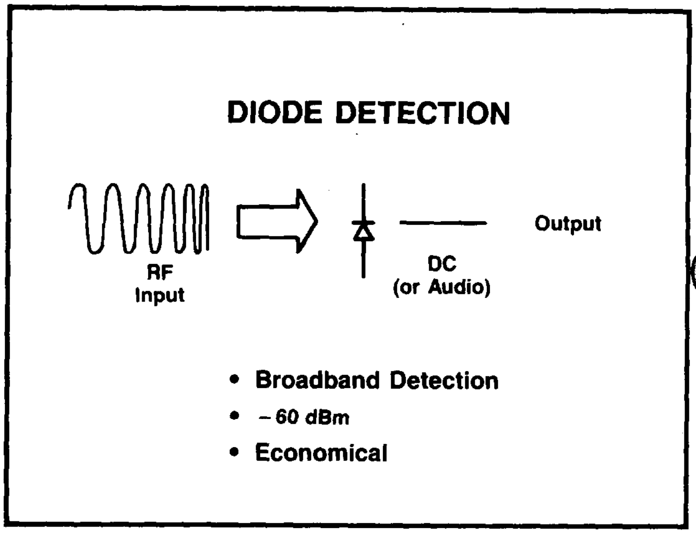
DETECTION DEVICES

Thermal Detection
- Thermistor
- Barretter
- Thermocouple

Diode Detection
- Point Contact Detector
- Schottky Diode Detector

3467

Diode detectors convert the RF signal to a proportional DC voltage. If the signal is amplitude modulated, the diode strips the modulation. Diode detectors can be very broadband (10 MHz to >26.5 GHz), have fast response times, and have a dynamic measurement range of up to 76 dB.

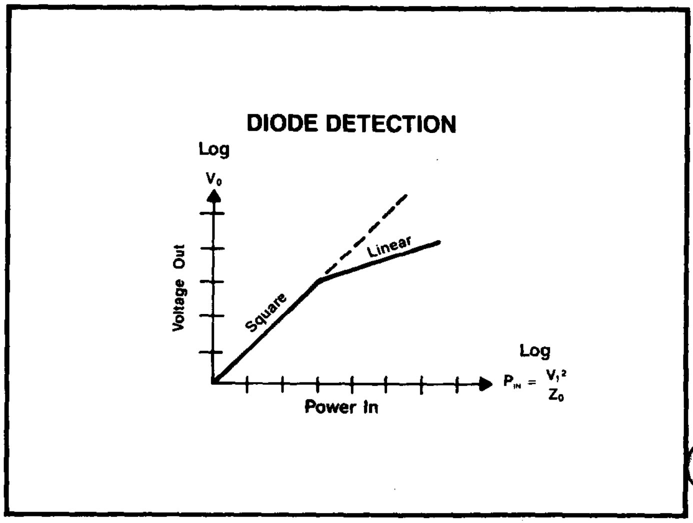


DIODE DETECTION

- Broadband Detection
- −60 dBm
- Economical

3538

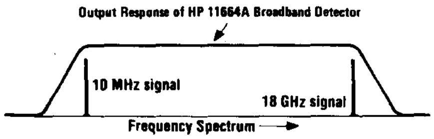
Diode detectors have a square law region over which the voltage out is proportional to ~~the square of~~ the power in. Above a certain power level the response becomes linear. When a diode detector is used with an oscilloscope to display some detected response, its measurement dynamic range is limited to the square law range of the diode. Since the "knee" is predictable and repeatable with certain diodes (the type of diode used with scalar analyzers being one), scalar analyzers can compensate for this characteristic and hence have the ability to measure responses over a larger dynamic range.



DIODE DETECTION

3468

BROADBAND DETECTION AND FILTER REQUIREMENTS



Broadband detectors will respond to any signal or signals present at the input port in the frequency range of the detector. For example, if we are interested in a network's response at 18 GHz, and in addition to 18 GHz there is also a 10 MHz signal present, the system will respond to the composite response. Therefore, in order to observe the response of the 18 GHz signal only, the unwanted signal must be removed in some way.

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DETECTORS

Spec.	Thermal	Diode
Bandwidth	10 MHz-26.5 GHz	10 MHz-40 GHz
Match	20 dB	16 dB
Response Time	Slow	Fast
Cost	Medium	Low
Dynamic Range	50 dB	76 dB

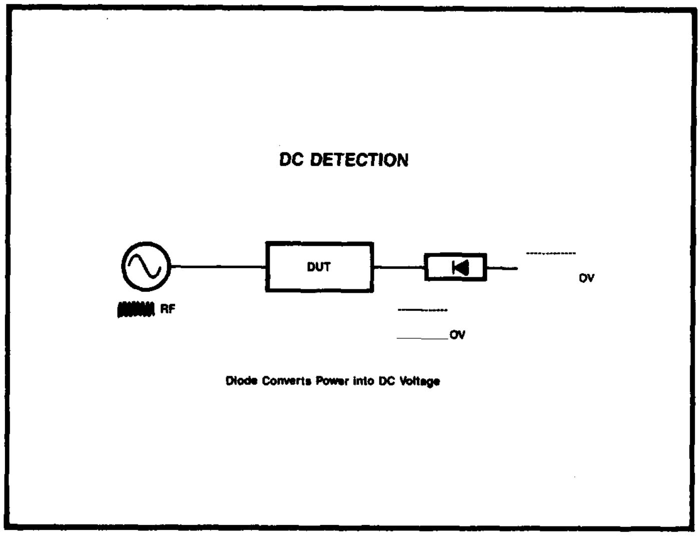
This table summarizes and compares the important specs for thermal and diode detection schemes. The best reasons for using diode detection with scalar network analyzers are its wide bandwidth, its low cost, and its fast response time.

3470

AC DETECTION
DC DETECTION

Diode detection schemes use either "DC detection" or "AC detection".

DC detection produces a DC signal that is proportional to the power incident upon the diode. The diode's output is read directly by the analyzer making the analyzer a fancy voltmeter with a logarithmic response.

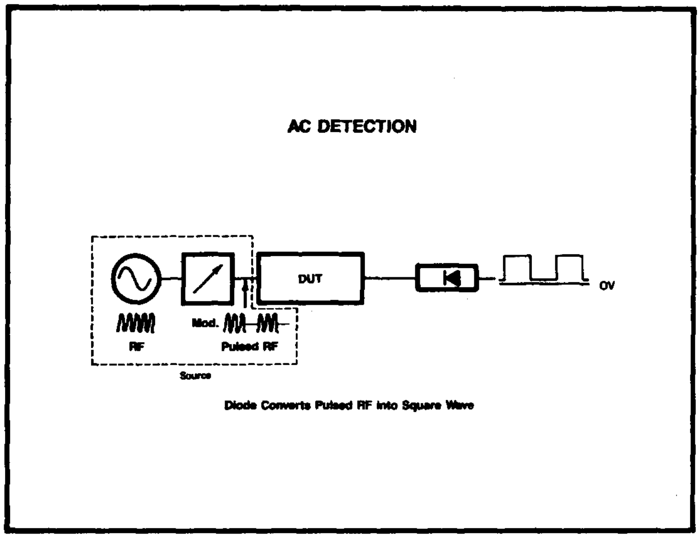


DC DETECTION

Diode Converts Power into DC Voltage

2910

AC detection also produces a signal proportional to the power incident upon the diode. However, the RF power is modulated with a square wave signal. The pulsed RF travels through the DUT and stimulates the diode detector. The pulsed RF signal is turned into a square wave by the detector... the pulse being high when the RF is on and being low when the RF is off.

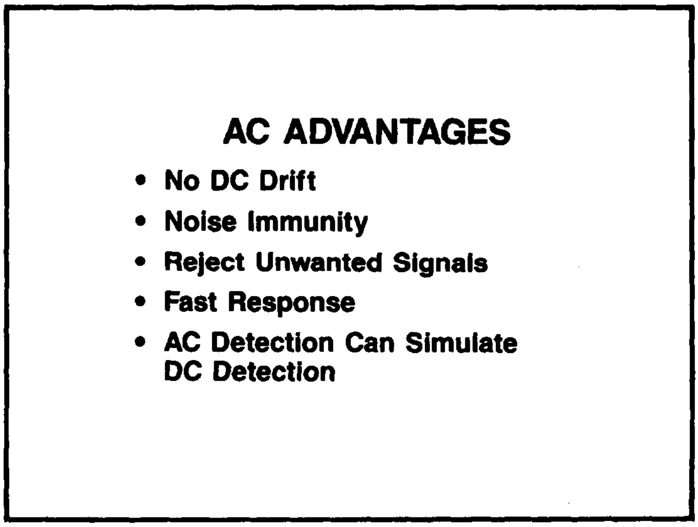


AC DETECTION

Diode Converts Pulsed RF into Square Wave

2911

AC detection can provide many benefits over DC detection because the detector is not affected by signals at the input that are not modulated.



AC ADVANTAGES

- No DC Drift
- Noise Immunity
- Reject Unwanted Signals
- Fast Response
- AC Detection Can Simulate DC Detection

2912

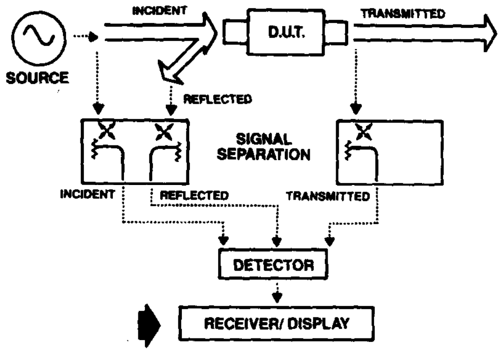
DC ADVANTAGES

When Modulation Affects the Measurement

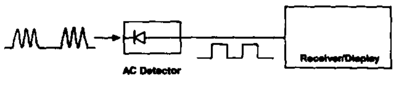
- Amplifiers with AGC
- Amplifiers with Large Low Freq Gain
- Narrow Band Devices (<10 MHz)
- Power Measurements

3471

Although AC detection is usually preferred over DC detection, DC detection does provide some benefits. The major benefit being no modulation of the RF signal to affect the DUT or the measurement results. Modulation can have adverse affects on the measurement of some devices.



The last component of the scalar network analyzer system is th receiver/display.

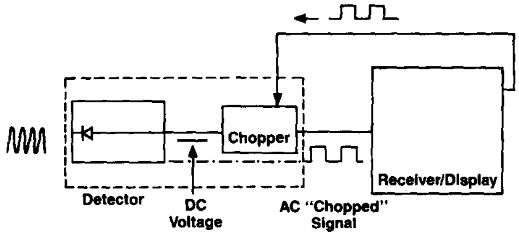


- Display Measurement in dB
- Convert Detected Voltage Signal to dB
- Process an AC Signal

3514

The main purpose of the receiver is to convert the voltage signal from the diode detector to a logarithmic or dB value for display. The time required to convert a DC voltage to a log value is largely dependent upon the power level incident on the detector - the lower th power level, the longer the processing time (thus the slower the sweep speed from the source). An AC voltage on the other hand is converted to a log value much faster and is not dependent upon the power level incident on the detector. HP scalar analyzers process an AC signal (27.8 kHz) to make processing time independent of incident power level.

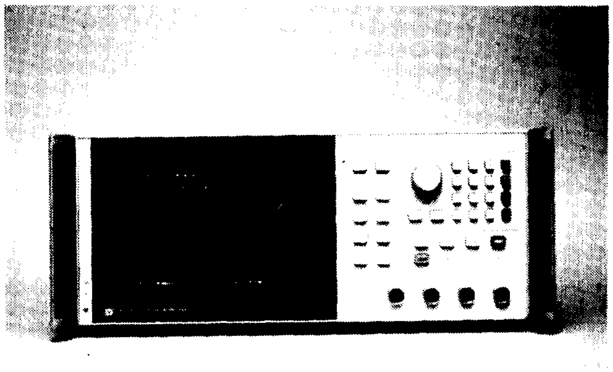
With HP's DC detectors, the DC voltage is "chopped" to create the AC signal which HP's scalar analyzers then process. Thus, with the use of HP's DC detectors, the advantages of DC detection are combined with the advantages of AC signal processing.



- **Advantages of DC Detection**
- **Advantages of AC Signal Processing**

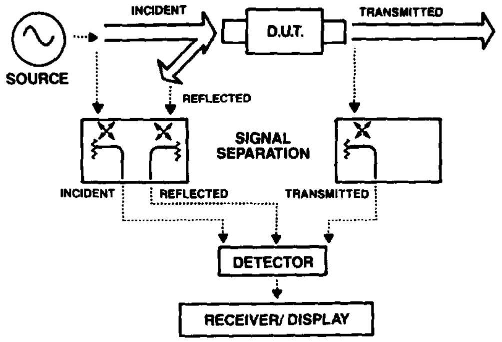
3515

More commonly referred to as the network analyzer, the receiver/display not only processes the detected signals but also controls all of the display functions. The CRT displays measurement annotation, soft key labels, data traces and other information. Hard copies of the displayed information can be obtained by transferring the CRT information to a graphics plotter or printer directly.



3426

We have just described the four parts of a scalar network analyzer. Recall that scalar analyzers use broadband diode detection to measure the magnitude of the signal reflected from and transmitted through the device under test.

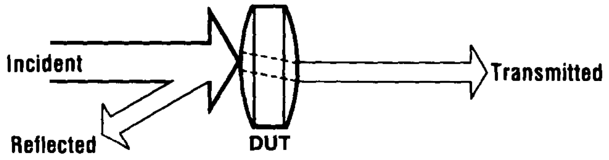


SCALAR MEASUREMENT FUNDAMENTALS

Basic Microwave Measurements
Scalar Network Analysis System
Scalar Reflection Measurements

Let's take a look at making some reflection measurements with our scalar analyzer system.

SCALAR REFLECTION MEASUREMENTS

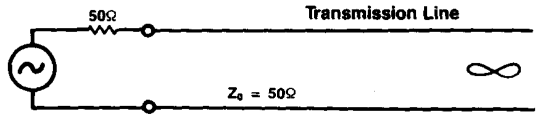


Reflection Coefficient

Return Loss

Standing Wave Ratio

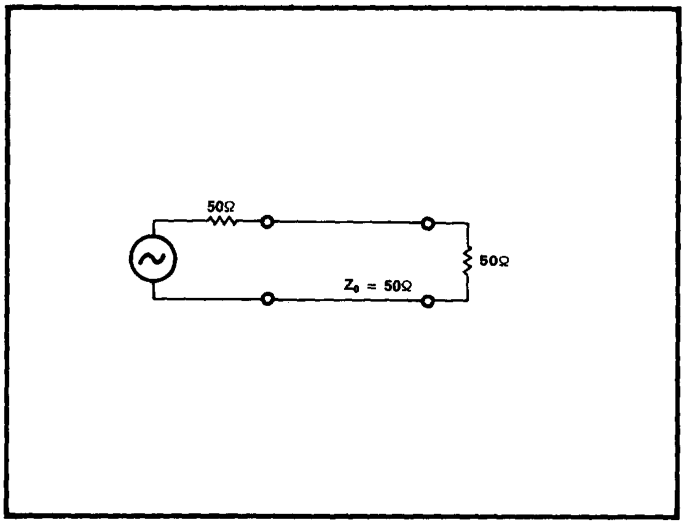
In reflection measurements the wave of interest is the reflected wave. By measuring the reflected wave we can determine the reflection coefficient (or Return Loss) of a DUT.



Before we discuss measuring reflected waves, let's take a look at what causes them. If we have a source of microwave energy with a source impedance of 50 ohms then we can deliver maximum power to the load if the load impedance is equal to the source impedance.

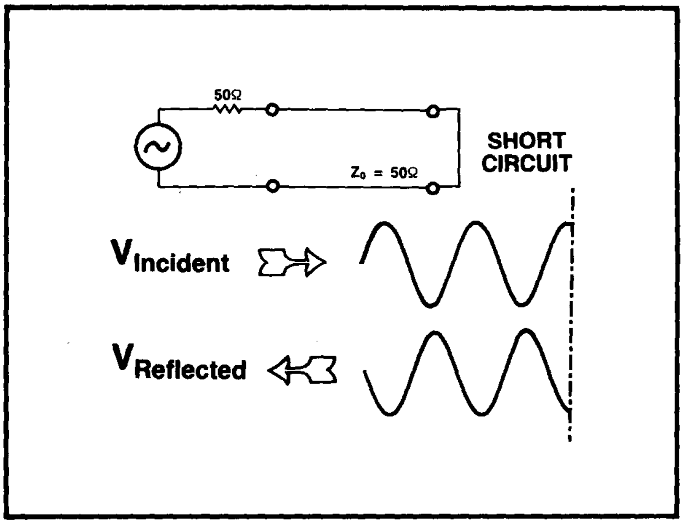
In this case, we have an infinitely long transmission line of 50 ohms (characteristic impedance).

If we terminate the transmission line in 50 ohms, then the termination should absorb all of the power delivered from the source (i.e., the signal cannot tell the difference between a Zo load and a Zo transmission line of infinite length).



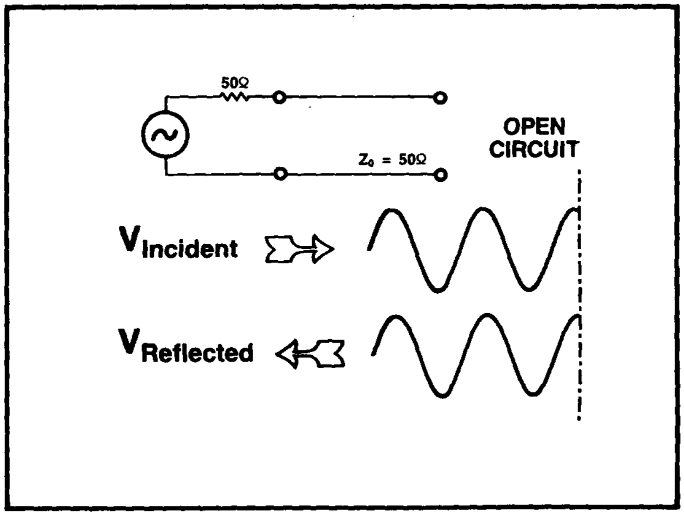
3416

Let's terminate our line with a short circuit. Since a short circuit can dissipate no power, and since there is nowhere else for the energy to go, a "reflected" wave is launched back down the transmission line. Since the short can support no voltage, the reflected wave must be of equal magnitude to the incident wave and be 180 degrees out of phase with it (the sum of the incident voltage wave and the reflected voltage wave must equal zero at the short).



3517

Similarly, when we terminate the transmission line with an open, there is nowhere for the energy to go (the load is an infinite impedance). A "reflected" wave is again launched back down the transmission line. Since an open can support voltage, the reflected voltage wave must be of equal magnitude and be in phase with the incident signal.



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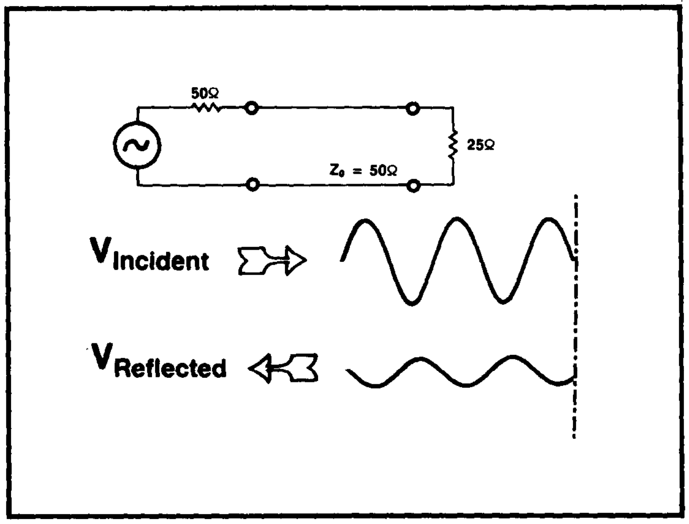


3519

If we terminate our transmission line with a 25 ohm resistor (an impedance somewhere between an open and a short), we will find that our reflected voltage wave will have an amplitude of 1/3 of that of the incident wave and that the two waves will be 180 degrees out of phase with each other.

$$\Gamma = \frac{V_{REFL}}{V_{INC}} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

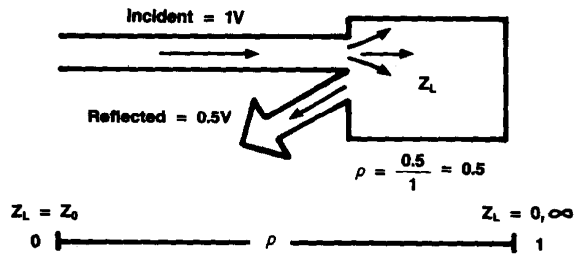
$$\rho = |\Gamma|$$

We can conclude from all of this that the reflected wave tells us something about the impedance of whatever we use to terminate the transmission line.

The exact mathematical relationship between the impedance of the termination and the reflected wave is shown on the slide. It's important because it shows clearly that since Zo is known, we can determine the load impedance by measuring Vi and Vr (the incident and reflected voltage waves).

SCALAR REFLECTION TERMS

ρ = ***REFLECTION COEFFICIENT*** = $\frac{\textit{E reflected}}{\textit{E incident}}$

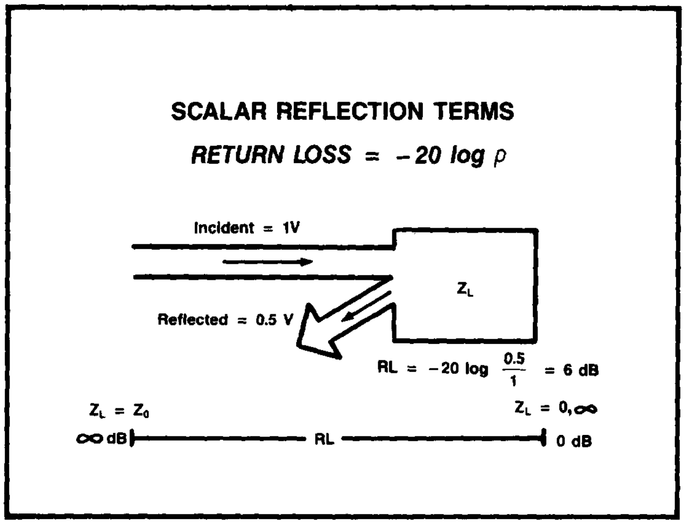


3060

Reflection coefficient is equal to the ratio of the reflected voltage wave to the incident voltage wave. For a transmission line of characteristic impedance Zo terminated with a Zo load, all energy is transferred to the load and none is reflected: Er = 0 and ρ = 0. When the line is terminated with an open or short circuit, all of the energy is reflected and Er = Ei and ρ = 1. The range of possible values for ρ then is 0 to 1.

Since many displays are logarithmic, we need a term to express reflection coefficient in dB. Return loss can be thought of as the number of dB that the reflected signal is below the incident signal. The range of values for return loss are infinity for a Zo impedance to 0 for an open or short circuit.

For an explanation of dB's, refer to Appendix A.

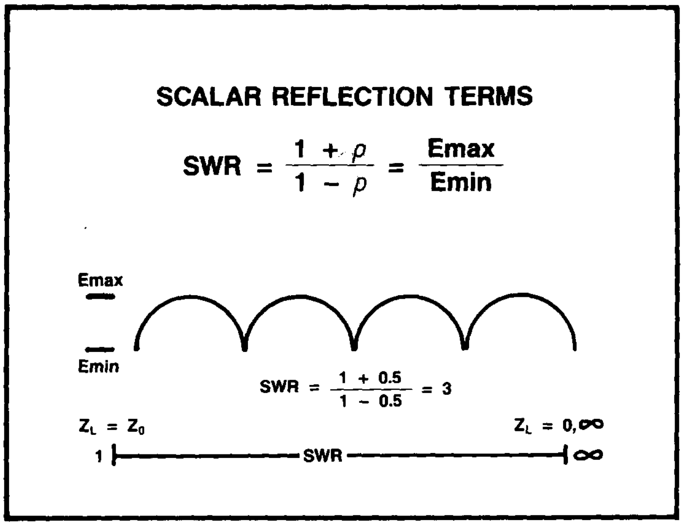


SCALAR REFLECTION TERMS

RETURN LOSS $= -20 \log \rho$

3520

Any two waves traveling in opposite directions cause a "standing wave" to be formed on the transmission line. Standing wave ratio (SWR) is defined as the maximum voltage over the minimum voltage of the standing wave on our line. It can also be defined as $(1 + \rho)/(1 - \rho)$. The values of SWR are 1 to infinity.

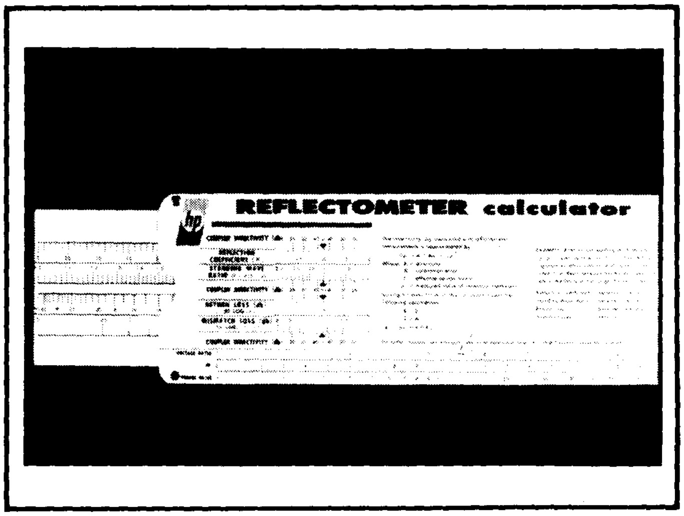


SCALAR REFLECTION TERMS

$$SWR = \frac{1 + \rho}{1 - \rho} = \frac{Emax}{Emin}$$

3062

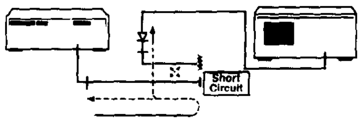
We can use a reflectometer calculator to convert between reflection coefficient, return loss, and SWR. For example: let $\rho = 0.5$ and use the calculator to determine the equivalent return loss and SWR. Move the slide portion of the calculator until 0.5 on the reflection coefficient scale (the upper scale on the slide) is directly below the blue arrow. Read the return loss value on the return loss scale directly below the blue arrow and read the SWR value on the SWR scale directly above the blue arrow.



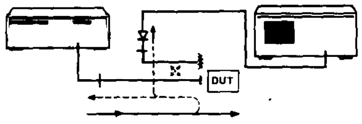
3473

BASIC REFLECTOMETER

Calibration



Measurement



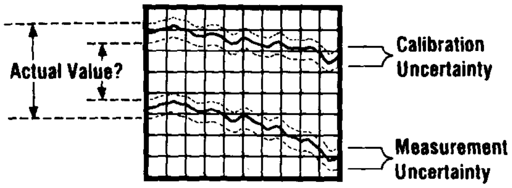
3474

There are two parts to a reflection measurement. First, a reference line is established on the CRT with a known standard (in this case a short circuit). This trace is stored for future subtraction (normalization). Measuring the short establishes a zero dB return loss reference line.

The dB change when the DUT is inserted is the return loss of the DUT.

We assume that the source has a perfect Zo output impedance and that the signal separation device can separate the reflected signal without any leakage of the incident signal.

REFLECTION UNCERTAINTY



3475

The actual value of our DUT is the difference between the measured RL value and the calibration (Meas - Cal). But since we do not have "perfect" measurement system components we have some uncertainty associated with our two measurements (Meas and Cal). This uncertainty will make it difficult for us to determine what the actual RL value of our DUT is. We need to qualify our system to determine if it is accurate enough for our requirements.

REFLECTION UNCERTAINTY EQUATION

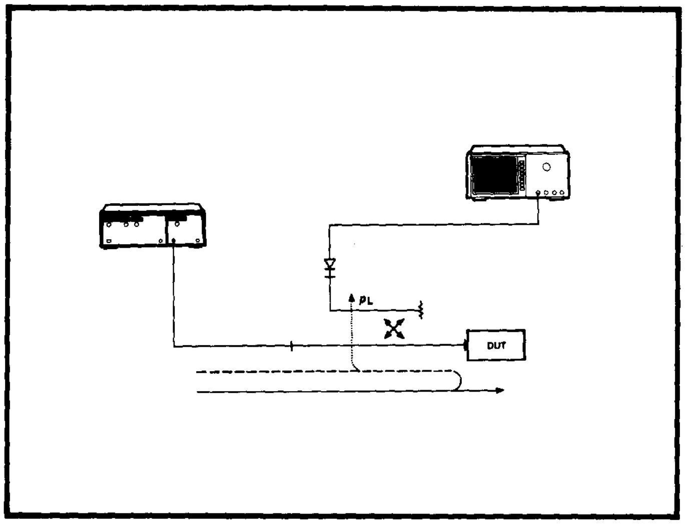
$$\Delta\rho = A + B\rho_L + C\rho_L^2$$

A = Directivity
B = Calibration Error, Frequency Response, Display and Instrument Errors
C = Effective Source Match
ρ_L = Reflection Coefficient of DUT

3521

This equation is a simplification of a complex flowgraph analysis of reflectometer uncertainties. $\Delta\rho$ is the worst case uncertainty in the measurement where ρ_L is the measured reflection coefficient of the DUT. A, B, and C are all in linear terms. Each term in this equation will be analyzed separately.

Let's take a closer look at our basic measurement system to see what causes error signals to exist and how those signals add to the uncertainty of our measurement. The component we will start with is our signal seperation device - the directional coupler.

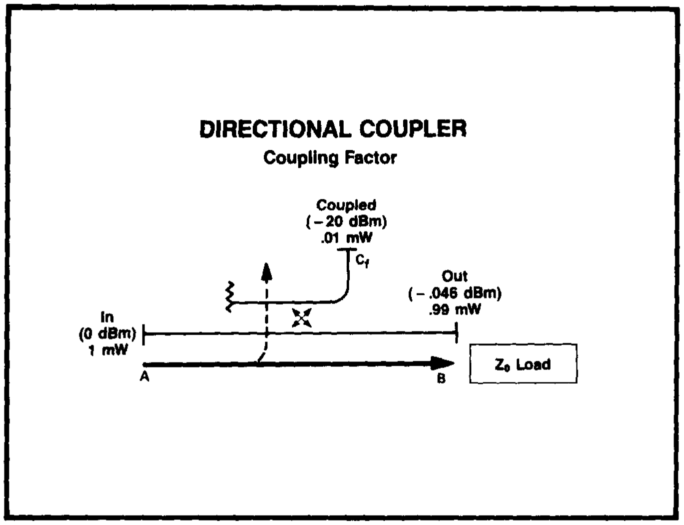


3522

Recall that a directional coupler couples a portion of the signal flowing through the main arm to the auxiliary arm. We've defined the coupling factor (dB) to be:

Coup Fact (dB) = -10 log $[P_{cf}/P_{in}]$.

In defining coupling factor, we have assumed the coupler is terminated with a perfect load and thus no other signal is present in the auxiliary arm.

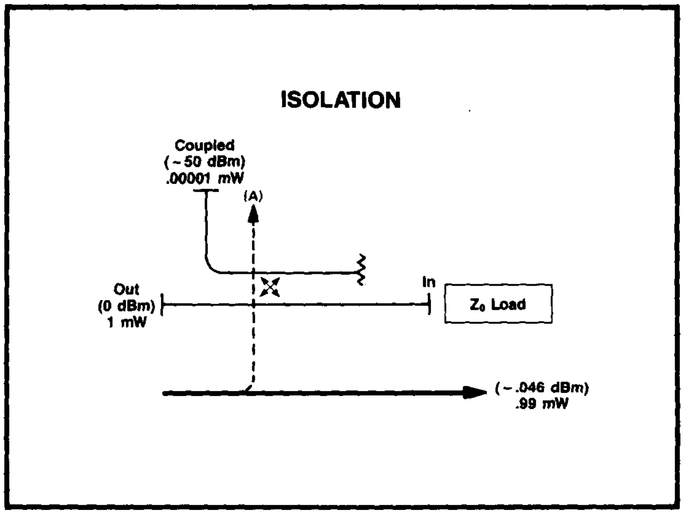

DIRECTIONAL COUPLER

Coupling Factor

3476

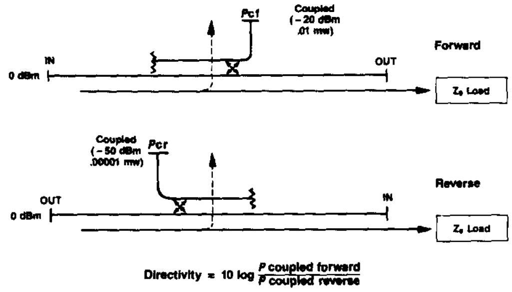
If we turn the coupler around and flow power in the reverse direction through the coupler, we ideally would measure no power in the auxiliary arm. However, some energy does leak across the coupler (sneaks in the back door). A measure of this leakage signal is defined as the isolation of the coupler:

Isolation (dB) = -10 log $[P_{cr}/P_{in}]$.


ISOLATION

3477

DIRECTIVITY



$$\text{Directivity} = 10 \log \frac{P\text{ coupled forward}}{P\text{ coupled reverse}}$$

3523

The ablility to separate signals flowing in opposite directions within the coupler is directivity. We measure that ability by relating the power measured in the auxiliary arm from the coupler in the forward direction (P_{cf}) to the power measured in the auxiliary arm with the coupler in the reverse direction (P_{cr}). When measuring P_{cf} and P_{cr}, notice that we have the coupler terminated in a Zo load and that we have the same input power level.

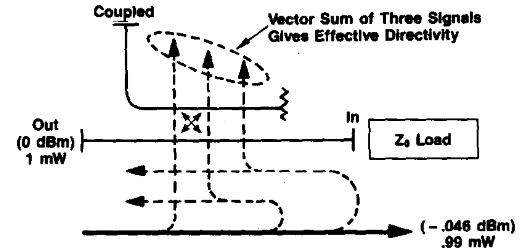
Directivity (dB)= 10 log [P_{cf}/P_{cr}].

Equivalent expressions for directivity are:

Dir (dB)= 10 log [Coup Fact/Iso]

Dir (dB)= Iso (dB) -Coup Fact (dB)

DIRECTIVITY

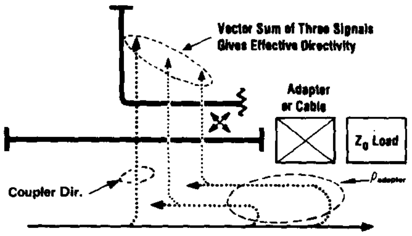


3524

The sources of imperfect directivity are 1) leakage, 2) internal coupler load reflections, and 3) connector reflections. Coupler directivity is the sum of all three signals.

USING ADAPTERS OR CABLES
ON DIRECTIONAL DEVICES

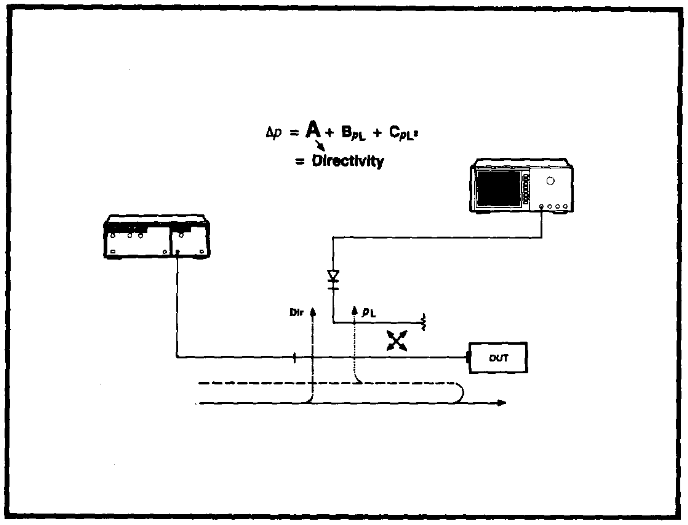
Measurement Directivity Degraded



2876

The effects of adapters on effective directivity are often misunderstood. As the flow-graph shows, the adapter has the same relationship to directivity as the output connector on the coupler. If the adapter has a SWR of say 1.5:1 (the $2.00 variety), the effective directivity of the coupler drops to no better than 14 dB, even if the coupler has infinite directivity. In other words, with a perfect Zo load on the output of the adapter, the reflected signal appearing at the coupled arm would be 14 dB less than the reflection from a short circuit.

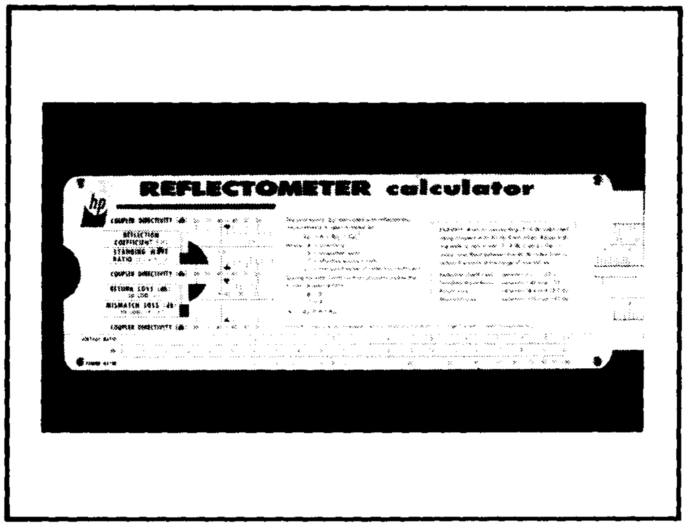
The effects of directivity on our measurement is shown here. The **A** term in our uncertainty equation is directivity. It is independent of the reflection coefficient of the DUT and adds (worst case) directly to the total uncertainty. If the signal reflected from the DUT is large, for example for a short circuit, then the directivity will be small compared to the reflected signal and the effect of directivity will be insignificant. If the signal reflected from the DUT is small (high return loss), then the directivity signal will be significant compared to the reflected signal and the uncertainty due to directivity is significant.


$$\Delta\rho = \mathbf{A} + B\rho_L + C\rho_L^2$$
= Directivity

3525

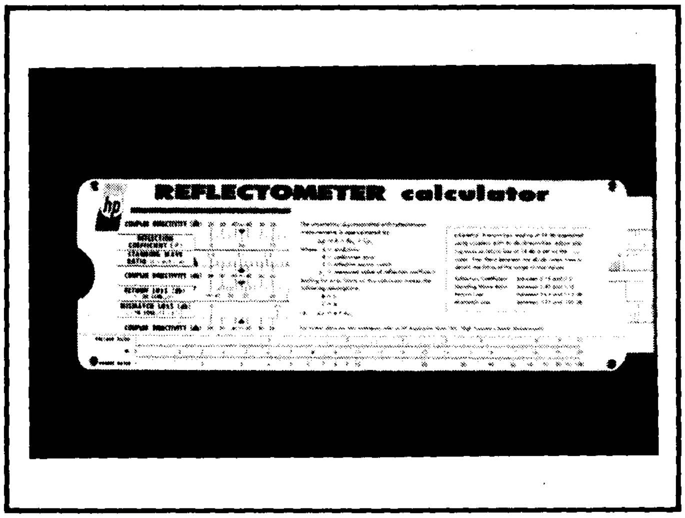
We can use the reflectometer calculator to convert directivity in dB to a linear term which is need in our uncertainty equation. For example, 40 dB directivity converts to A = .01.

On the reflectometer calculator, place the dB value for directivity under the blue arrow on the RL scale. Read the linear value below the blue arrow on the reflection coefficient scale.



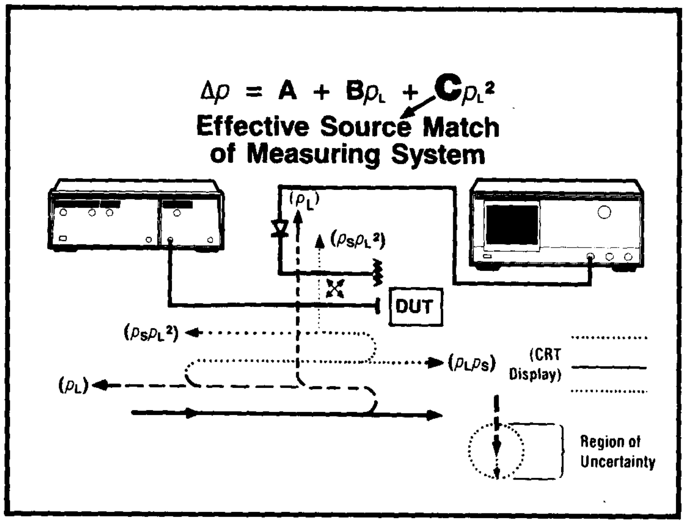
3553

We can use the reflectometer calculator to see the effect of directivity on the uncertainty of a measurement. For example, set ρ to 0.05. Now read the error limits using the coupler directivity scale and the directivity of the coupler used in the measurement. A coupler with 40 dB directivity causes a ± 0.01 error in the measurement of $\rho \approx +0.05$. On the return loss scale this error is ± 2.5 dB. This is significant measurement error.



3526

The coupler directivity error window in the refectometer calculator uses the sum of two error terms, A & C (directivity and source match terms) and assumes that A = C. A discussion of the C term will follow directly. When ρ_L is small, ρ_L^2 is even smaller, and therefore the effect of the C term is negligible, and directivity is the dominant error. If ρ_L is large, i.e. near 1.0, then the C term has a significant error contribution.

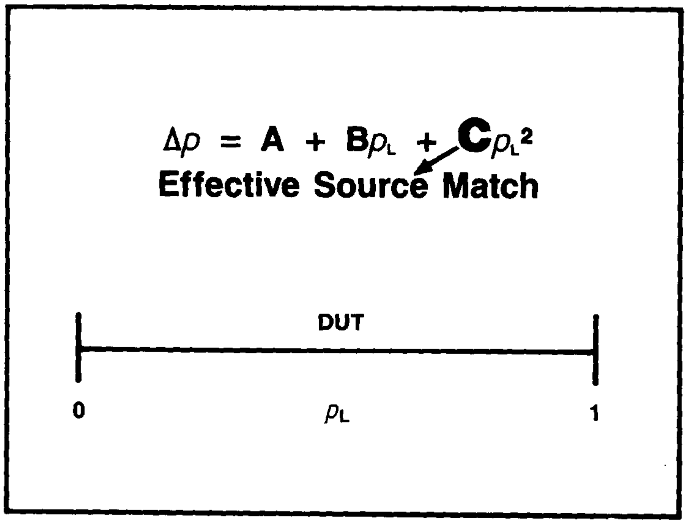


$\Delta\rho = A + B\rho_L + C\rho_L^2$

Effective Source Match of Measuring System

2958

What happens to our measurement uncertainty when our source is not perfect (i.e. do not have perfect source impedance).
From following the flowgraph, we can see that effective source match belongs in the C term. The first reflection from the DUT is ρ_L ; this is what we want to measure. This signal continues back toward the source where it is re-reflected if the reflection coefficient of the source is not perfect, resulting in a signal normalized to $\rho_L * \rho_S$ flowing back toward the DUT where it is again reflected and sampled as $\rho_S * \rho_L^2$.



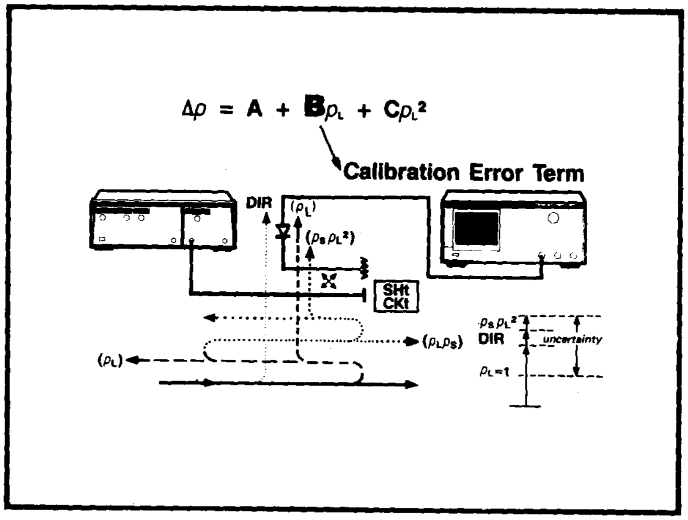
$\Delta\rho = A + B\rho_L + C\rho_L^2$

Effective Source Match

3548

When the reflected signal is large (low return loss) source match is the major error term. For example, when measuring a 3 dB return loss device (ρ_L = 0.71) with a source match of 2:1 SWR (ρ_S =0.33) the uncertainty due to source match alone is 0.17 worst case. But if we measured a DUT with a return loss of 30 dB (ρ_L = 0.03) then the uncertainty of our measurement is 0.0003.

The last contributor to our measurement uncertainty that we will discuss is calibration error. We calibrate with a short circuit because we know that the reflection coefficient of the short has a value of 1 (Return Loss = 0 dB).



$\Delta\rho = A + B\rho_L + C\rho_L^2$

Calibration Error Term

3479

But instead of measuring just the reflection coefficient of the short, we also measure some error terms. Directivity is always present and will be measured. Source match is also present and will be measured along with our standard. The sum of directivity and source match (A + C) will cause uncertainty in the measurement of our standard. If we assume no other errors are present then our best case calibration error (B term) is equal to the sum of directivity and source match.

$$B = A + C$$

Lets take a look at a simple example:

RL of DUT = 6 dB (.5)
Directivity = 30 dB (.0316)
Source Match = 1.9:1 (0.31)
B= A+C = (.3416)

$$=A + B\rho_L + C\rho_L^2$$

$$= .0316 + .3416(.5) + .31(.5)^2$$
$$= \pm 0.28$$

SIMPLE REFLECTOMETER ACCURACY

$$\Delta_{\rho} = A + B_{\rho L} + C_{\rho L}^2$$

Example:

Directivity 30 dB (.0316)
Source SWR 1.9:1 (0.31)
A = .0316 Load R.L. = 6 dB (.5)
B = .3416
C = 0.31
$\rho_L = 0.5$

$$\Delta\rho = .0316 + .3416\,(.5) + .31\,(.5)^2 = \pm 0.28$$

3480

From our previous example, it should be obvious that we would want much less uncertainty in our measurement if we could get it. We can improve our reflection measurements (i.e., reduce uncertainty) by either removing our calibration error or by improving source match or both.

IMPROVING REFLECTION MEASUREMENTS

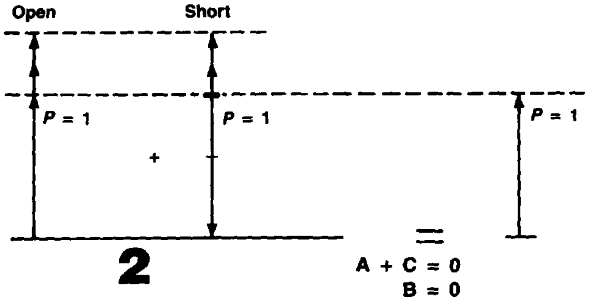
- **Remove Calibration Error**
- **Improve Source Match**

3481

The calibration error due to the sum of the directivity and source match errors can be removed by averaging the short and open circuit responses. Though the reflection from an open circuit is 180 degrees out of phase with that from a short circuit, the errors due to the sum of directivity and source match do not change phase when the load is changed from an open to a short.

The open/short average then averages out calibration error thus making B=0.

OPEN/SHORT AVERAGING REMOVES CALIBRATION ERROR



3528

$$\Delta\rho = A + \underset{\swarrow}{C_{\rho L}^{2}}$$

IMPROVE SOURCE MATCH WITH:

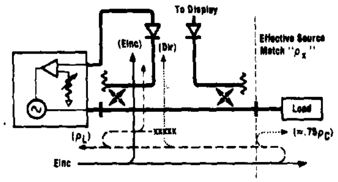
- **External Leveling**
- **Ratioing**
- **Isolation**

3529

The other method of reducing uncertainty is by improving source match.

The perfect source would deliver a constant power to a load regardless of the reflections from the load. Leveling the sweeper output improves source match by varying the power out of the source to compensate for the power reflected by the source, thus the power delivered to the load is constant (it appears the source has absorbed the power flowing into it). Any signal re-reflected from the sweeper is sensed by the leveling loop which corrects the output from the sweeper accordingly.

LEVELED SOURCE



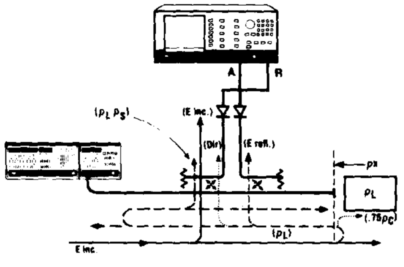
ρ_x = Effective Source Match

$\rho_x = \sqrt{Dir^2 + (.75\rho_C)^2}$

2884

Although leveling improves source match, there are still inherent uncertainties. First, the output connector of the coupler has some reflection. In addition, directivity error also enters in. ρ_x is defined as effective source match . If a non HP coupler is used, then effective source match must be calculated from the equation shown. The equation for effective source match very closely approximates the flowgraph analysis of a leveled source using a directional coupler.

RATIO MEASUREMENT TECHNIQUE

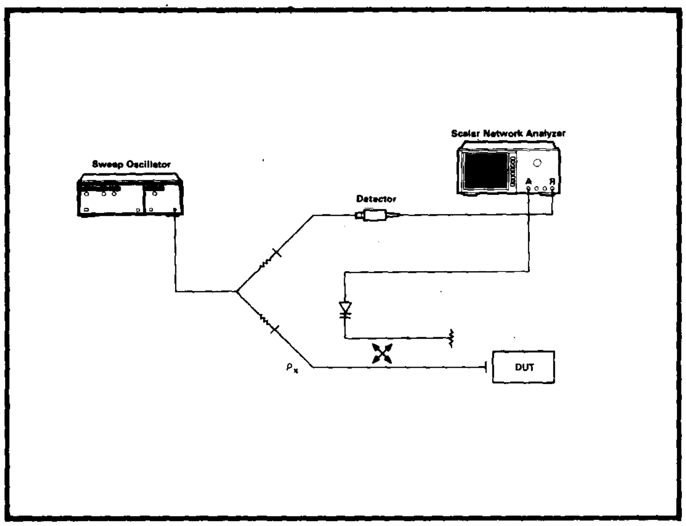


$\rho_x = \sqrt{Dir^2 + (.75\rho_C)^2}$

2885

Effective source match can also be improved by ratioing the incident and reflected signals. With this technique, the absolute incident power is not controlled as in leveling but the variations are ratioed out. Any re-reflections are seen by both detectors and when you take the ratio A/R on the analyzer, the effect of ρ_s is cancelled. Again since the coupler is not perfect, the "effective source match" must be calculated. Effective source match is determined by the same equation as for leveling.

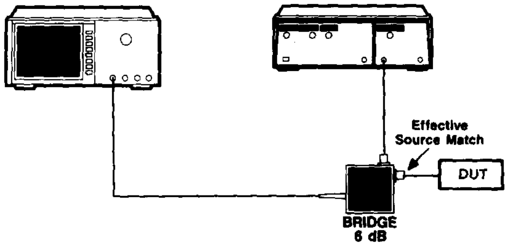
Of course, a power splitter may be used for both of these examples rather than a directional coupler. A splitter may be a better choice due to its smaller size and broadband response but the equation for effective source match does not apply. Since we essentially "buy" source match, the effective source match is the specification on the data sheet of the splitter.



3560

The insertion loss of a directional bridge isolates the DUT from the source and improves the effective source match by attenuating the reflected and re-reflected signals each time they pass through the bridge. Assuming 12 dB isolation (6 dB each way) and bridge test port match of 1.25 SWR, the effective source match is improved from 1.9 to 1.46 SWR. A 6 dB attenuator would serve the same purpose.

ISOLATION IMPROVES EFFECTIVE SOURCE MATCH



3531

Let's see how much we reduce the uncertainty in the example measurement using open/short averaging and ratioing with a coupler.

Effective source match = ρ_x =0.153

$$= A + B\rho_L + C\rho_L^2$$

$$= .0316 + .153(.5)^2 \quad B=0$$

$$= \pm .07$$

whereas before we had ± 0.28.

MEASUREMENT IMPROVEMENT

Example

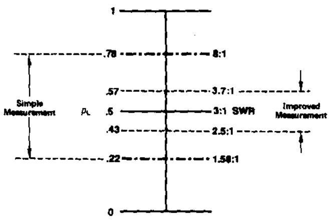
Directivity = 30 dB **Return Loss DUT = 6 dB**
Coupler SWR = 1.5:1
Effective Source Match (Coupler) = ρ_x = .153

$$\Delta\rho = A + \overset{0}{\cancel{B}}\rho_L + C\rho_L^2$$

$$\Delta\rho = .0316 + .153\,(.5)^2$$
$$= \pm 0.07$$

3482

MEASUREMENT IMPROVEMENT



3483

The improvement in reflection coefficient uncertainty translates to an improvement in SWR of between 2.5 and 3.7, much more reasonable than the 1.58 to 8.1 window with the simple reflectomter.

IMPROVING REFLECTION MEASUREMENTS

1. Leveling, Ratioing, Isolation

$$\Delta\rho = A + B\rho_L + \mathbf{C}\rho_L^2$$

2. Open/Short Averaging

$$\Delta\rho = A + \mathbf{B}\rho_L + C\rho_L^2$$

3532

We have discussed two ways of improving the accuracy of reflection measurements - both are simple and inexpensive. The source match improvement techniques reduce the C term of the uncertainty equation and open/short averaging (which is included in the HP 8756/8757 firmware) removes the B term from the same equation.

The high directivity (40 dB) bridges in HP's product line reduce the A term for accurate measurements of low reflection DUT's.

SCALAR MEASUREMENT FUNDAMENTALS

Basic Microwave Measurements

Scalar Network Analysis System

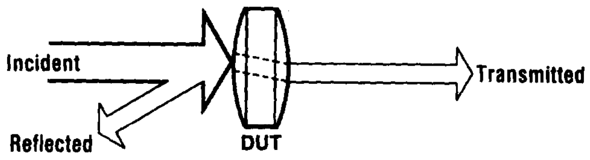
- Scalar Reflection Measurements
- Transmission Measurements

3457

The two basic measurements used to characterize linear networks are reflection and transmission. This next section will describe transmission measurements and investigate the associated errors.

Scalar transmission is defined as the change in power (at a detector) resulting from the insertion of the device under test.

SCALAR TRANSMISSION MEASUREMENTS



Insertion Loss

Gain

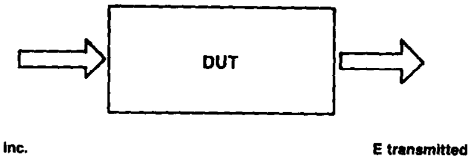
Attenuation

3485

The scalar transmission coefficient is defined as the transmitted voltage divided by the incident voltage. The transmission coefficient (dB) is:

20 log [E transmitted/ E incident].

SCALAR TRANSMISSION TERMS
TRANSMISSION COEFFICIENT



$$T = \frac{E\ \text{transmitted}}{E\ \text{incident}}$$

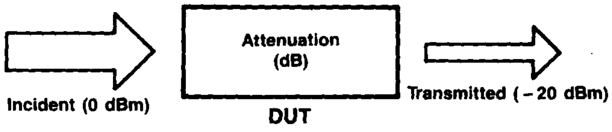
$$\text{Transmission Coeff. (dB)} = 20 \log \frac{E\ \text{transmitted}}{E\ \text{incident}}$$

3533

Attenuation (dB) or Insertion Loss (dB) is defined as the incident power (dBm) - transmitted power (dBm) when the transmitted power is less than the incident power.

SCALAR TRANSMISSION TERMS

ATTENUATION (dB) = INCIDENT PWR (dBm) - TRANSMITTED PWR (dBm)



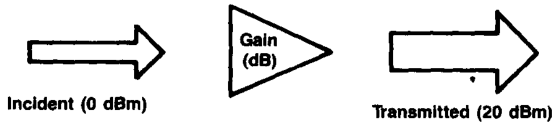
Attenuation (dB) = 0 dBm -(-20 dBm)
= 20 dB

Attenuation (dB) = Insertion Loss (dB)

3486

SCALAR TRANSMISSION TERMS

GAIN (dB) = TRANSMITTED PWR (dBm) - INCIDENT PWR (dBm)



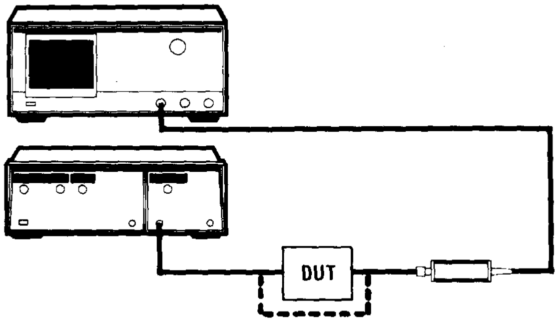
Gain (dB) = 20 dBm - 0 dBm
= 20 dB

3064

Gain (dB) is defined as the transmitted power (dBm) - incident power (dBm) when the transmitted power is greater than the incident power. In linear terms Gain = P(out)/P(in).

"THROUGH" SUBSTITUTION

Normalizes Transmission Measurement



"Through" Substitution

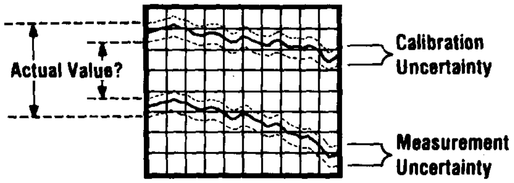
2941

Before we can determine transmission loss or gain we must establish a reference (i.e. we need to know what the incident power is). By measuring a "through", we establish a 0 dB reference trace on the analyzer display.

By subtracting our "thru" reference from the measurement obtained with a DUT (**normalization**) we can determine what the insertion loss or gain of the DUT is. Normalization also removes the frequency response of the test setup.

TRANSMISSION MEASUREMENT UNCERTAINTIES

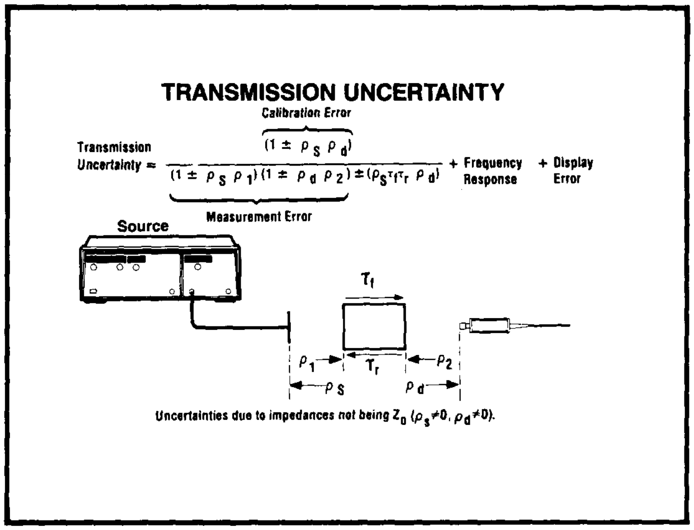
WITH SOURCE $\neq Z_0$
&/or DETECTOR $\neq Z_0$



3487

As with reflection measurements, uncertainties exist with transmission measurements. Total measurement uncertainty is affected by calibration uncertainty as well as the measurement uncertainty.

The transmission uncertainty equation quantifies the worst case error window caused by the system. Source and detector mismatch cause an uncertainty around both the calibration and the measurement traces. Frequency response errors are elimated through normalization. Since it is a tedious task to evaluate this linear equation, let's explore an easier and more understandable quantification.



TRANSMISSION UNCERTAINTY

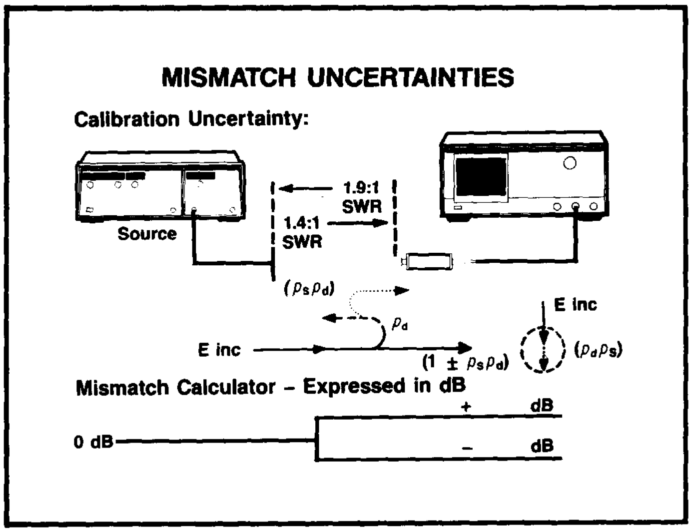
$$\text{Transmission Uncertainty} = \frac{\overbrace{(1 \pm \rho_S \rho_d)}^{\text{Calibration Error}}}{\underbrace{(1 \pm \rho_S \rho_1)(1 \pm \rho_d \rho_2)}_{\text{Measurement Error}} \pm (\rho_S \tau_f \tau_r \rho_d)} + \text{Frequency Response} + \text{Display Error}$$

Uncertainties due to impedances not being Z_0 ($\rho_s \neq 0$, $\rho_d \neq 0$).

3488

Let's quantify the transmission uncertainties. Please get out your reflectometer calculator.

Let's first investigate the uncertainties associated with the calibration stage of the measurement. As shown, when the detector is connected to the source, the incident signal first encounters the detector impedance where part of the incident is reflected (normalized to ρ_d). This reflected signal is then re-reflected by the source mismatch resulting in an uncertainty vector of $\rho_s * \rho_d$ at some unknown phase relationship to the incident signal. Worst case, the extremes of the signal seen by the detector would be $1 \pm \rho_s * \rho_d$.



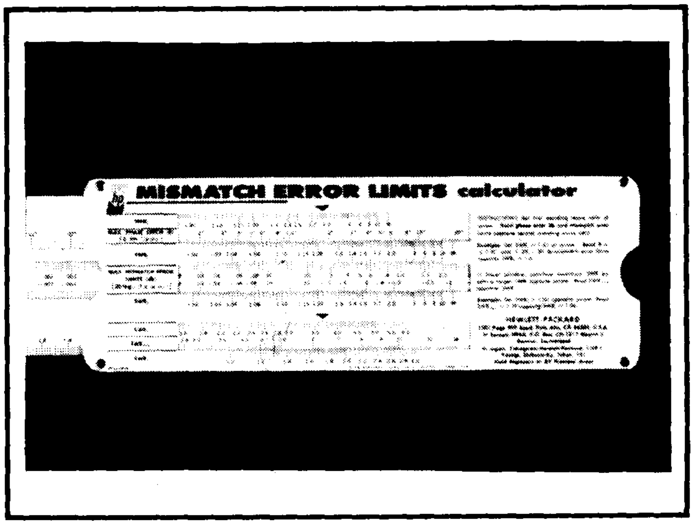
MISMATCH UNCERTAINTIES

Calibration Uncertainty:

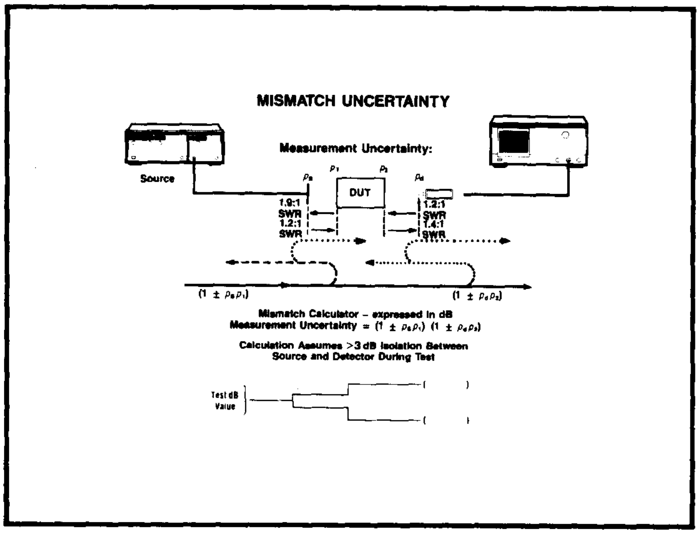
Mismatch Calculator - Expressed in dB

2944

The Mismatch Error Limits side of the refectometer calculator converts the two SWR's into the uncertainty limits in dB. Place the black arrow over the SWR of either the source (1.9 in this example) or the detector (1.4). Under the SWR of the other device read the (+) value of Max Mismatch Error (+.44 dB). Directly below this read the (-) value (-.46 dB).



3552



MISMATCH UNCERTAINTY

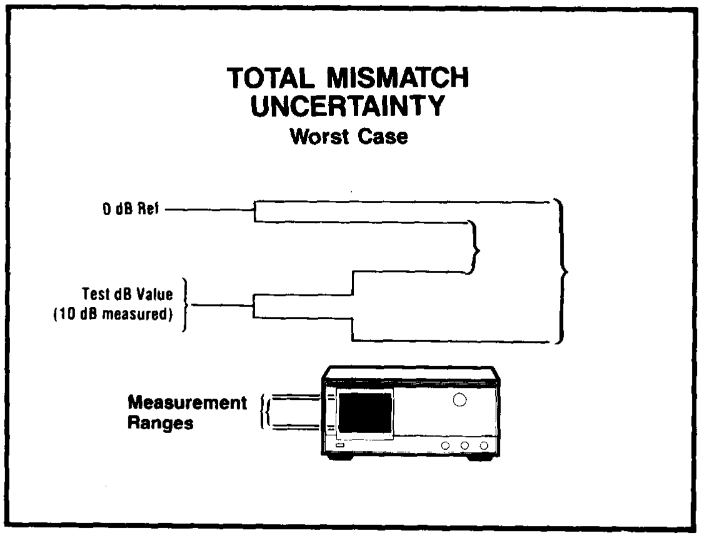
Measurement Uncertainty:

Mismatch Calculator – expressed in dB
Measurement Uncertainty = $(1 \pm \rho_s \rho_1)\,(1 \pm \rho_d \rho_2)$

Calculation Assumes >3 dB Isolation Between Source and Detector During Test

Similarly, there are uncertainties in the measurement stage due to the source/DUT input mismatch $(1 \pm \rho_s * \rho_1)$ and the DUT output/detector mismatch $(1 \pm \rho_2 * \rho_d)$. Each of these uncertainties can be found with the Mismatch Error Limits Calculator just as before. They are then added to get the uncertainty window in the measurement stage. Assume that the DUT SWR is 1.2:1.

In this example we assume that the DUT has an input to output isolation of >3 dB so that multiple reflections have a negligible effect on the measurement uncertainty.



TOTAL MISMATCH UNCERTAINTY

Worst Case

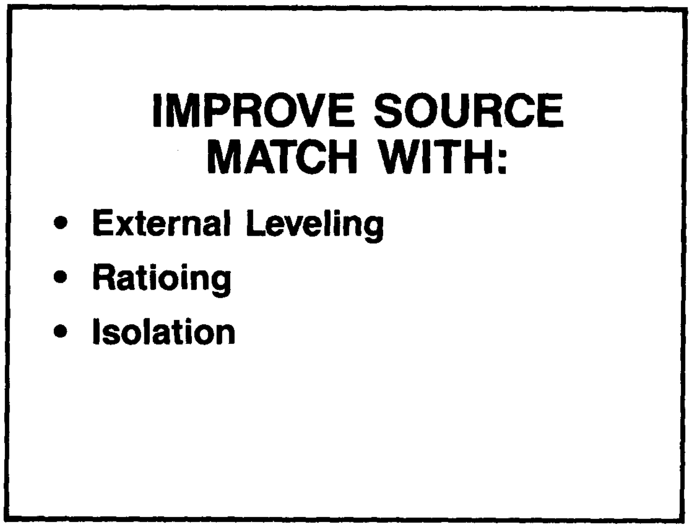
As the diagram shows, when the calibration window and the measurement window are combined, the total worst case uncertainty for a particular measuring system and DUT can be determined. In this example we see that the worst case uncertainty in measuring a 10 dB attenuator is almost ± 1 dB.

IMPROVE TRANSMISSION MEASUREMENTS

- **Improve Source Match**
- **Improve Detector Match**

Obviously, as seen from the previous example, we need to improve our transmission measurement accuracy.

As with reflection measurements, we can reduce transmission uncertainty by improving source match.

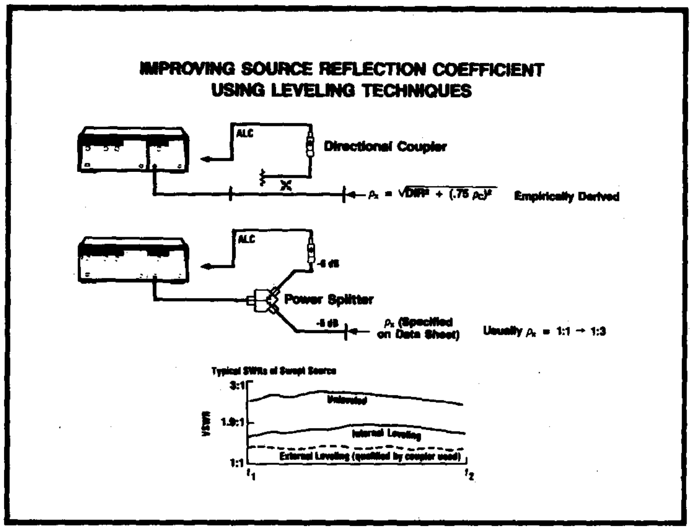


IMPROVE SOURCE MATCH WITH:

- External Leveling
- Ratioing
- Isolation

2946

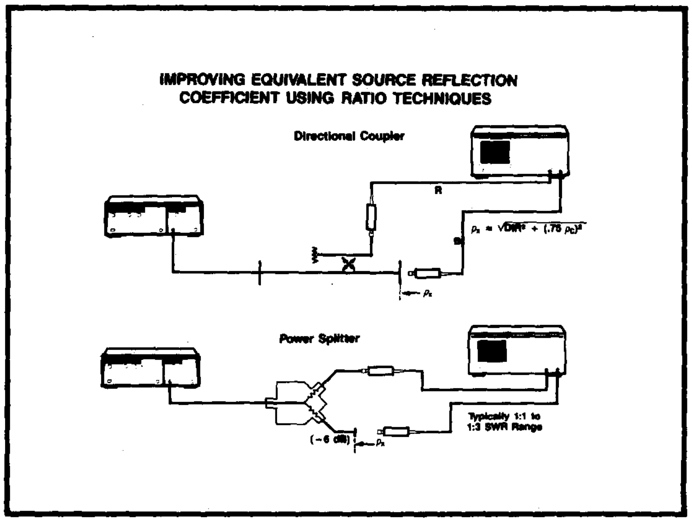
Leveling the source improves source match for transmission measurements. Source match improvement (when using a directional coupler) is similar to that gained in reflection measurements.



IMPROVING SOURCE REFLECTION COEFFICIENT USING LEVELING TECHNIQUES

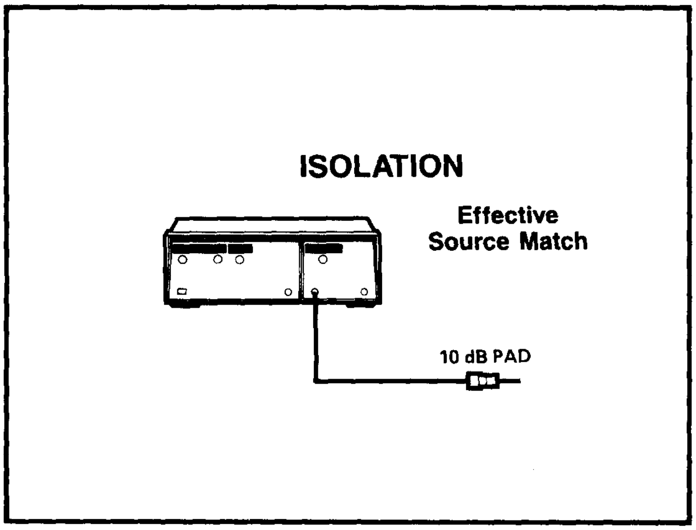
2947

The effects of power variations are removed with ratioing. Source match improvement similar to that gained previously in reflection measurements is obtained.



IMPROVING EQUIVALENT SOURCE REFLECTION COEFFICIENT USING RATIO TECHNIQUES

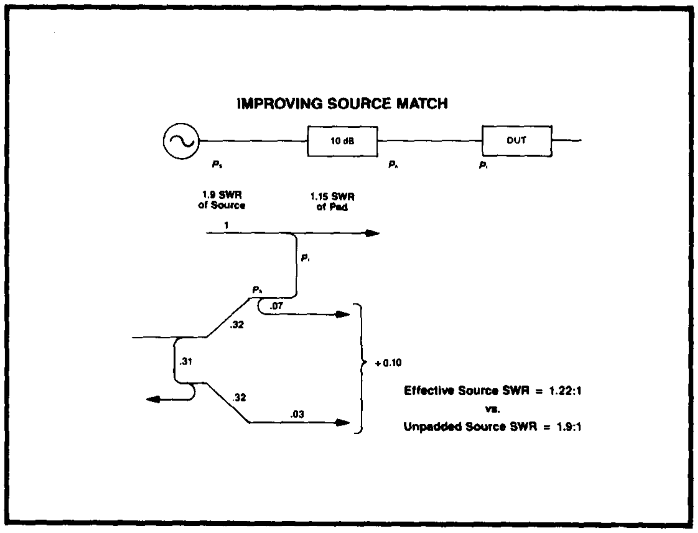
2948



ISOLATION

3490

Isolation improves source match by attenuating the reflected signal each time the reflected signal flows through the attenuator.

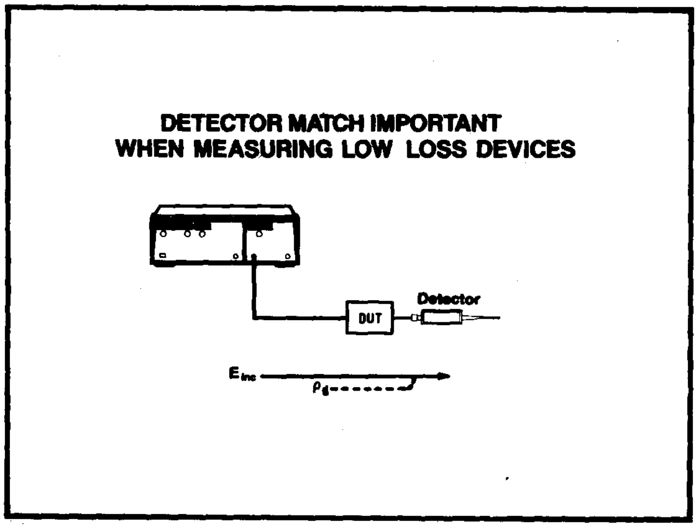


IMPROVING SOURCE MATCH

Effective Source SWR = 1.22:1
vs.
Unpadded Source SWR = 1.9:1

3534

We can see by this flow diagram that the 10 dB attenuator improves effective source match considerably. The major drawback to this method is the loss of measurement dynamic range.

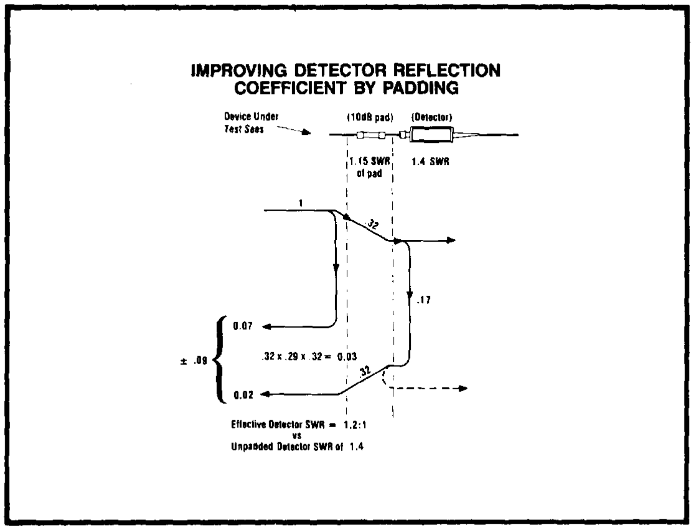


DETECTOR MATCH IMPORTANT WHEN MEASURING LOW LOSS DEVICES

2953

Detector mismatch also contributes to transmission measurement error. If the DUT has low insertion loss (for example a transmission line), then the signal reflected from the detector and re-reflected from the source will cause a significant error.

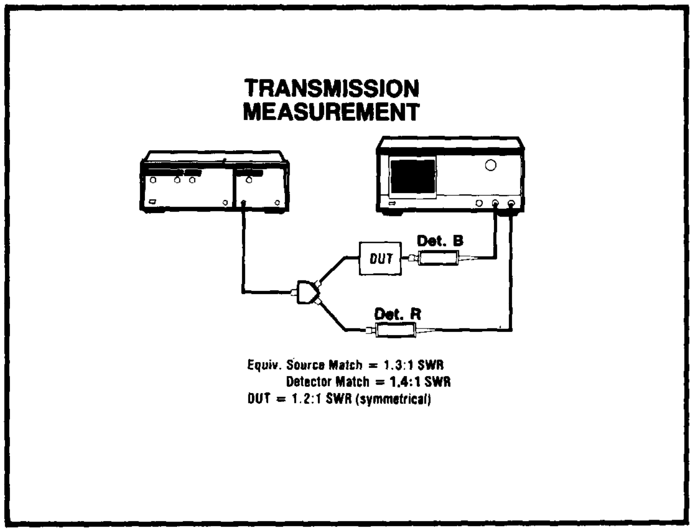
A way of reducing detector mismatch is to use an attenuator for isolation. In this example, a 10 dB pad is used at the input of the detector to improve the match to that of the pad. The major drawback of this technique is that dynamic range is decreased.



IMPROVING DETECTOR REFLECTION COEFFICIENT BY PADDING

Effective Detector SWR = 1.2:1
vs
Unpadded Detector SWR of 1.4

Here is an example on an improved transmission measurment system. Ratioing is used to improve the source match to 1.3:1 SWR.



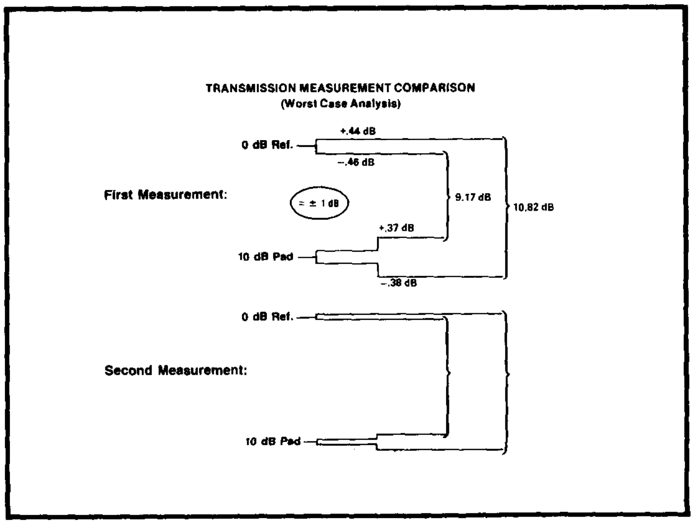
TRANSMISSION MEASUREMENT

Equiv. Source Match = 1.3:1 SWR
Detector Match = 1.4:1 SWR
DUT = 1.2:1 SWR (symmetrical)

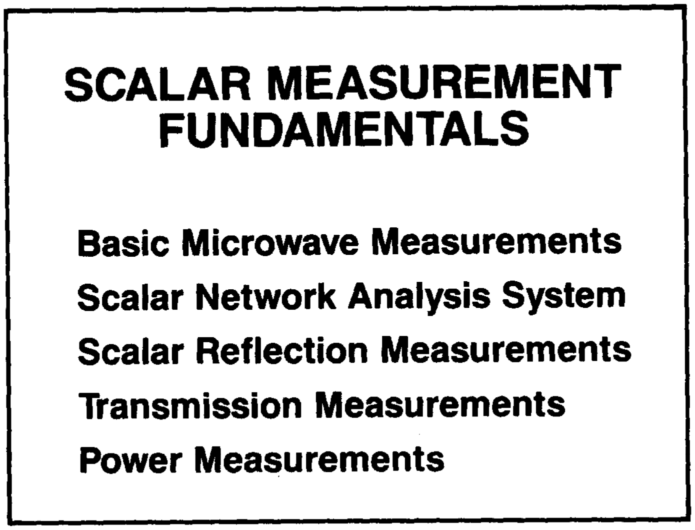
How much improvement do we get with ratioing? The top brackets show the uncertainty we obtained with the original simple measurement: approximately ± 1 dB.

Using the Mismatch Error Limits calculator to calulate the improved uncertainty, we see it is approximately ± .4 dB. Again this is worst case uncertainty.

Note that the uncertainty is independent of the measured value of transmission as long as it is >3 dB (for example, if we measued a 20 dB pad the uncertainty would be the same).



TRANSMISSION MEASUREMENT COMPARISON
(Worst Case Analysis)



SCALAR MEASUREMENT FUNDAMENTALS

Basic Microwave Measurements

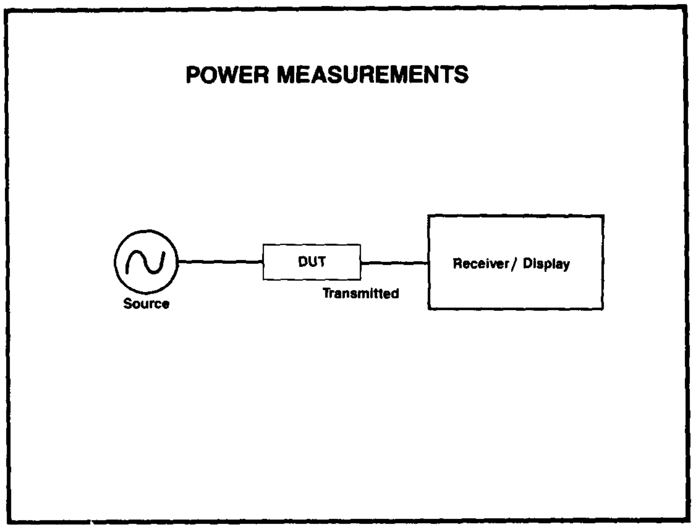
Scalar Network Analysis System

Scalar Reflection Measurements

Transmission Measurements

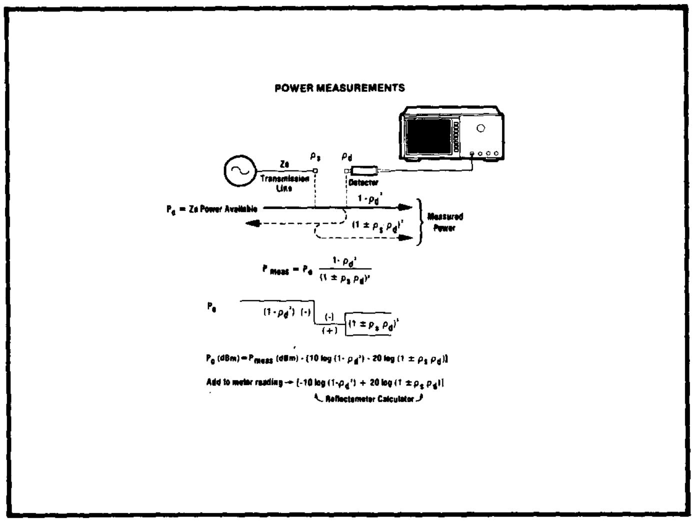
Power Measurements

In order to make accurate impedance and transmission measurements, some knowledge of absolute power is required so that (1) we are aware of the dynamic range available to us with the measuring system used, (2) we are assured that the analyzer's maximum power is not exceeded, and (3) we know the power level into such level-sensitive DUT's as amplifiers and mixers.



POWER MEASUREMENTS

A power measurement is similar to a transmission measurement.



POWER MEASUREMENTS

$$P_{meas} = P_o \frac{1 - \rho_d^2}{(1 \pm \rho_s \rho_d)^2}$$

$$P_o\,(\text{dBm}) = P_{meas}\,(\text{dBm}) - [10 \log (1 - \rho_d^2) - 20 \log (1 \pm \rho_s \rho_d)]$$

Add to meter reading → $[-10 \log (1 - \rho_d^2) + 20 \log (1 \pm \rho_s \rho_d)]$

Reflectometer Calculator

However, since we are interested in the power that will be delivered to a load, we must account for simple mismatch loss. This is the power not seen by the detector because it is reflected by ρ_d, causing an error. The signals re- reflected result in further uncertainty. The actual Po available would then be between the limits defined by the equation.

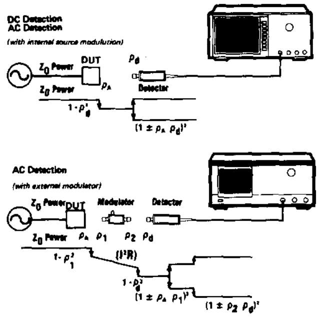
The accuracy of the measurement also depends upon the frequency response of the detector.

Two parts of the uncertainty/error can be found using the Mismatch Loss scale and the Max Mismatch Error Limits scale on the reflectometer calculator.

Since the scalar analyzers have the capability to measure power, the same mismatch considerations apply. Using DC detection, the accuracy of the power level at the detector depends, as in the previous example, on the reflection coefficients ρ_d and ρ_A where ρ_A is the reflection coefficient looking back towards the source.

However, if AC detection is used to measure power of a DUT that cannot be modulated (i.e. an oscillator, an amplifier with an ALC loop, etc), then the mismatch of the additional external modulator must be accounted for. This increases the inherent inaccuries.

POWER MEASUREMENTS



3444

We have concluded our discussions on scalar fundamentals. To wrap up this portion of the seminar, let's look at HP's product line available to make scalar measurements.

SCALAR MEASUREMENT FUNDAMENTALS

- **Basic Microwave Measurements**
- **Scalar Network Analysis System**
- **Scalar Reflection Measurements**
- **Transmission Measurements**
- **Power Measurements**
- **Product Summary**

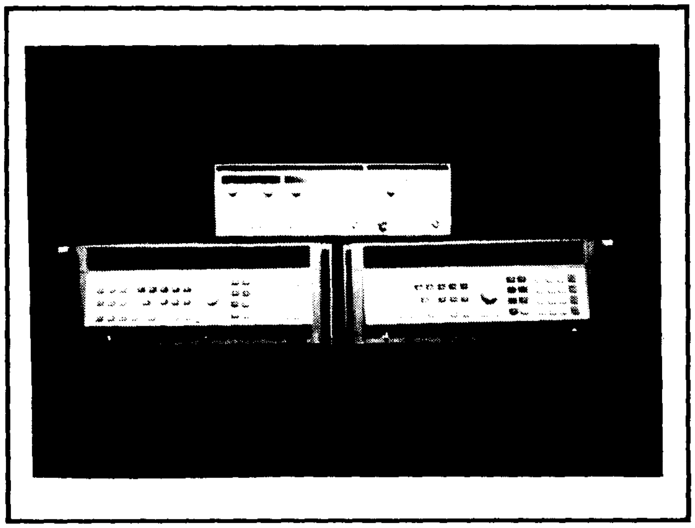
3457

HP offers a complete product line for scalar network analysis from sources to network analyzers.

HEWLETT-PACKARD PRODUCT LINE OFFERING

- **Sources**
- **Signal Separation Devices**
- **Detectors**
- **Network Analyzers**

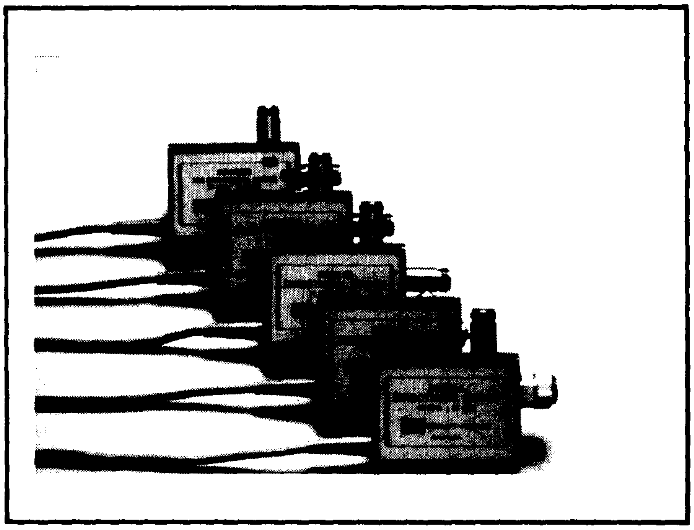
3495



2917

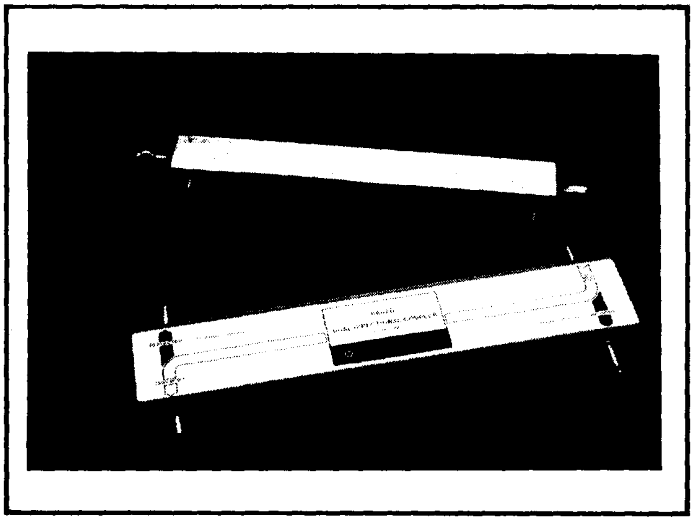
The HP 8350B and family of plug-ins offer a low cost, wide selection of swept sources.

The HP 8340/8341 Synthesized Sweepers offer both analog sweep and stepped CW sweep, with synthesizer accuracy CW frequencies.



3497

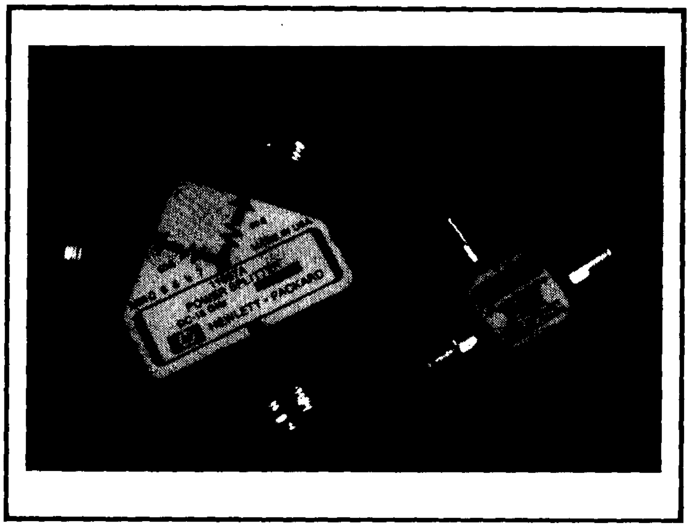
A full line of 40 dB directivity reflectometer bridges from 10 MHz to 40 GHz are available to separate reflection signals.



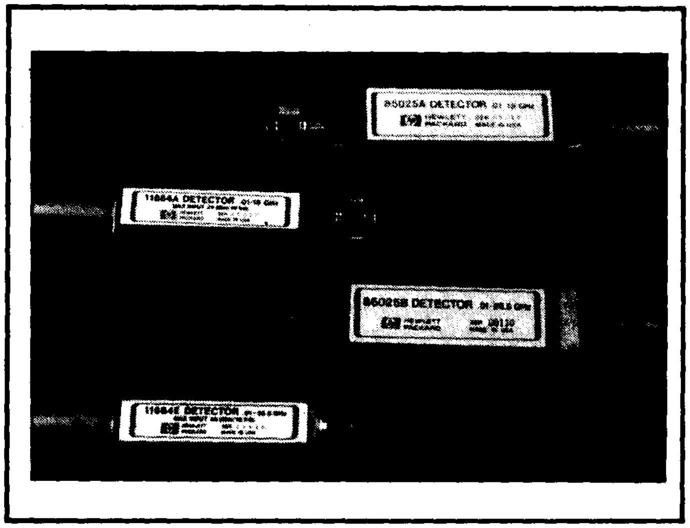
3535

Broadband as well as octave band couplers are available.

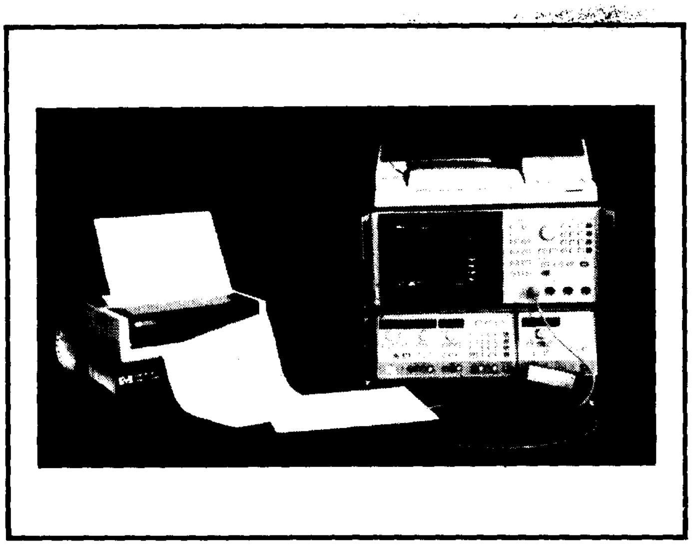
Power splitters with various connector types are also available.



We have AC detectors from 10 MHz to 40 GHz and AC/DC detectors from 10 MHz to 26.5 GHz.

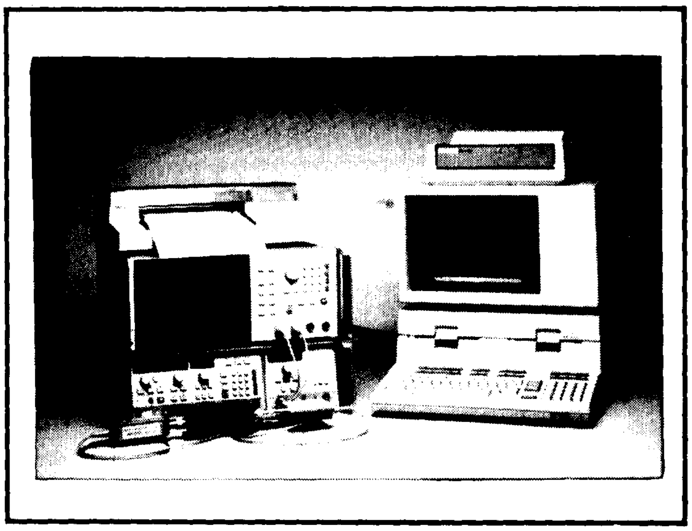


Three HP network analyzers are available with very friendly operation and superb performance. In the next session of the seminar, we'll show how all these instruments are used in specific applications.



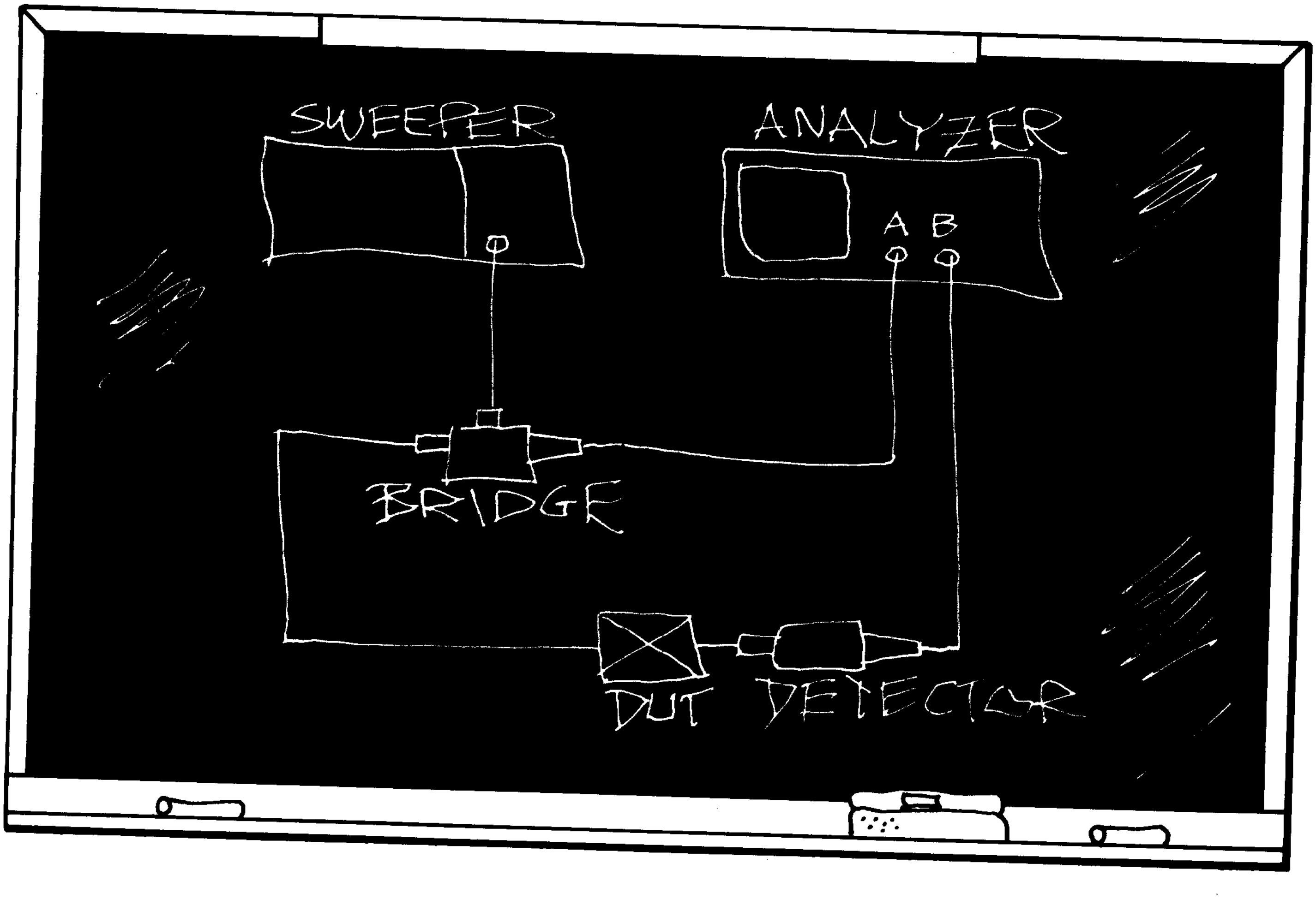
3397

A complete measurement system might look like this, with a plotter and a printer.



By adding a computer, you can automate your system to improve productivity. The last section of this seminar will discuss automatic measurements.

Scalar Measurement Applications

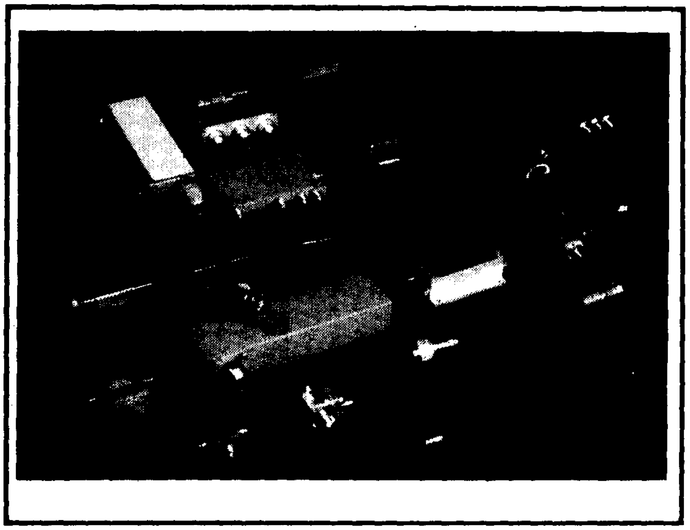


Now that we are familiar with network analysis and some of the measurement techniques, we are now equipped to apply these techniques to real applications.

SCALAR MEASUREMENT APPLICATIONS

3205

Scalar network measurements provide an economical way to characterize the frequency response of RF and microwave components such as filters, attenuators, amplifiers, mixers, oscillators, antennas, and other devices. This section of the seminar is devoted to understanding how scalar measurements can be used to characterize these particular devices.



3087

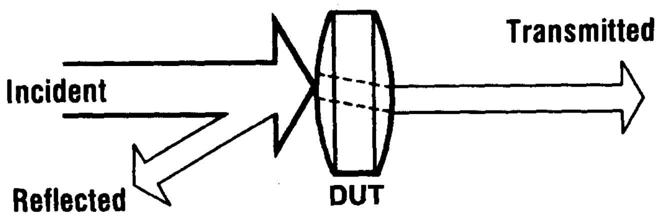
First, we will define and understand the function of some particular components to be measured and what parameters we are interested in measuring. Then we will determine the characteristics of the measurement system required, and apply the measurement solution that best characterizes the device.

OBJECTIVES

1. Define Component Characteristics to be Measured
2. Determine the Requirements of the Measurement System
3. Apply Appropriate Scalar Measurement Techniques

3206

SCALAR PARAMETERS



Reflection Coefficient
Return Loss
Standing Wave Ratio

Insertion Loss
Gain
Attenuation

2934

These scalar measurement parameters were defined in the previous section. Reflection coefficient, return loss, and standing wave ratio are used to describe reflection from the device, and insertion loss, gain, and attenuation are used to describe transmission through the device. Swept power measurements can also be made as we will see in some examples.

REQUIREMENTS OF THE MEASUREMENT SYSTEM:

1. Source
   - Power
   - Frequency Accuracy/Stability
   - Harmonics

2. Directional Bridges/Couplers
   - Directivity
   - Match

The specific component characteristics being measured will dictate what requirements we place on the four parts of the scalar measurement system. Some measurements have very stringent requirements that must be met by expensive or complex measurement equipment. Other measurements with less stringent requirements can be accomplished without added expense or complexity.

The source must not only provide enough power, but must also have sufficient frequency accuracy and harmonic performance. The signal separation devices must have high directivity and good impedance match to avoid significant measurement errors.

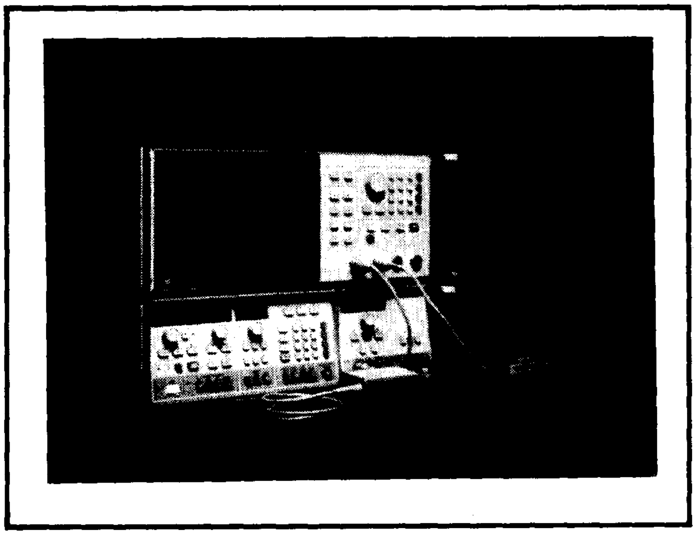
3. Detectors
   - Dynamic Accuracy
   - Power Accuracy
   - Match
   - Dynamic Range
   - Sensitivity

4. Receiver
   - Signal Processing
   - Display
   - Operation

The detectors should be accurate and their response should be independent of power level (dynamic accuracy). The detectors must not introduce significant reflections, and the dynamic range and sensitivity must be sufficient to characterize the component.

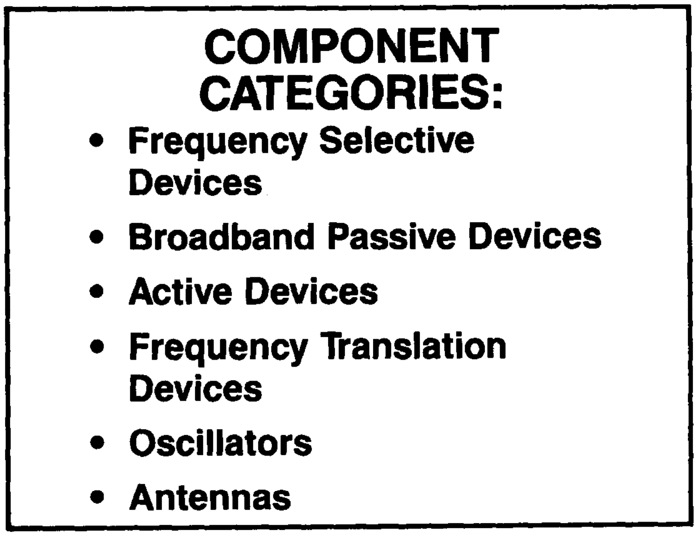
The receiver must process the received data and display the necessary measurement information clearly. The receiver should also be easy to operate so that accurate measurements can be made quickly.

When measuring any component, the requirements of the measurement system must be evaluated. In this discussion, we will see how these system requirements affect the measurement of specific device characteristics.



3447

There are many types of components that can be measured using scalar network analysis. For the purposes of this discussion, we have placed these devices into six categories. Devices in each one of these categories exhibit similar characteristics and place similar requirements on the measurement system.

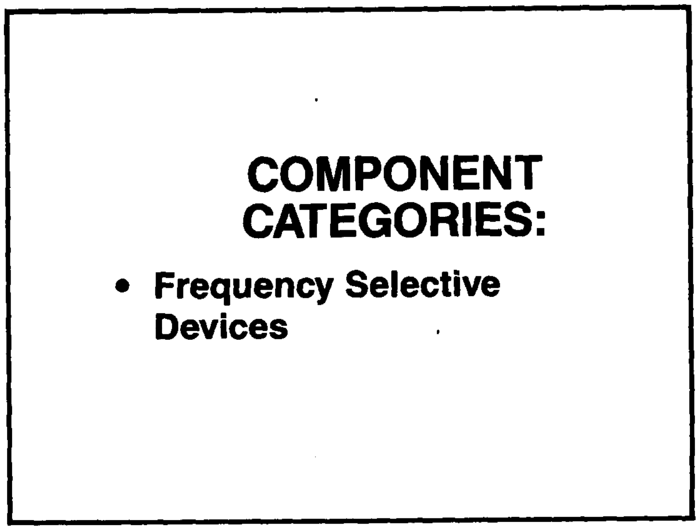


COMPONENT CATEGORIES:

- Frequency Selective Devices
- Broadband Passive Devices
- Active Devices
- Frequency Translation Devices
- Oscillators
- Antennas

3211

Let's begin with frequency selective devices.



COMPONENT CATEGORIES:

- Frequency Selective Devices

3212

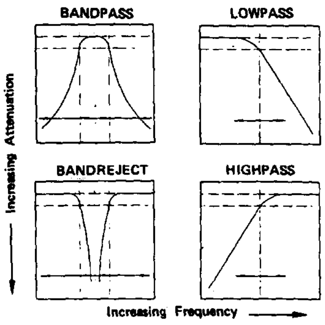
FREQUENCY SELECTIVE DEVICES:

1. Filters
    - Low Pass
    - High Pass
    - Band Pass
    - Band Reject (Notch)
2. Multiplexers

3213

This category includes any device that passes some frequency range and rejects another frequency range. This includes all types of filters and multiplexers. First we will concentrate on filter measurements.

FILTER TYPES



3214

There are four basic filter types as shown here, and each type has certain parameters that characterize it. For example, bandpass filters are often specified by 3-dB bandwidth, and lowpass and highpass filters are specified by upper and lower 3-dB cutoff frequencies.

FILTER PARAMETERS:

Passband:

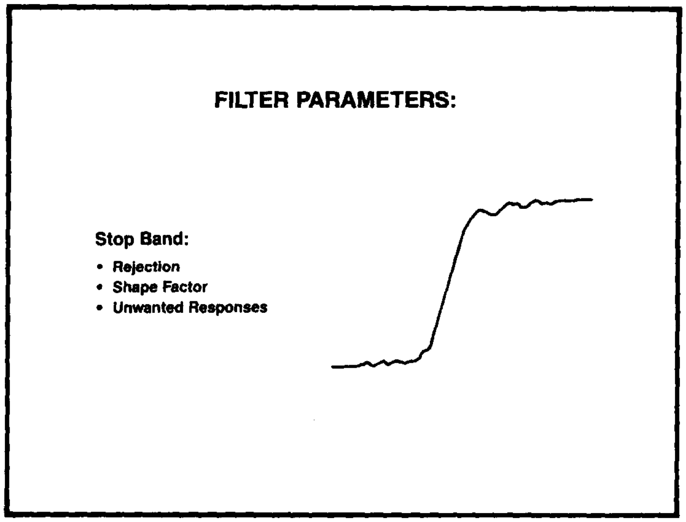
- Bandwidth
- Insertion Loss
- Ripple (Flatness)
- Input/Output Return Loss
- Phase Linearity/Group Delay

3215

There are a number of parameters commonly specified for filters -- both in the pass band (frequency range that is passed through the filter) and in the stop band (frequency range that is rejected by the filter). The common pass band parameters of importance include bandwidth (or upper/lower cutoff frequency), insertion loss, ripple, return loss, and phase linearity or group delay. The phase component of these parameters will not be considered here.

In the stop band, the specifications all relate to how effectively the filter rejects unwanted frequencies, that is, how far down is the response in the stop band from the response in the pass band.

Shape factor, which is defined in several ways, is a quantitative way of describing how quickly the filter makes the transition from the pass band to the stop band. For example, one definition of shape factor on a band-pass filter is as the ratio of the 60 dB bandwidth to the 6 dB bandwidth. If the filter has a shape factor close to 1.0, then it is a very "sharp" filter with steep transition to the stop band.



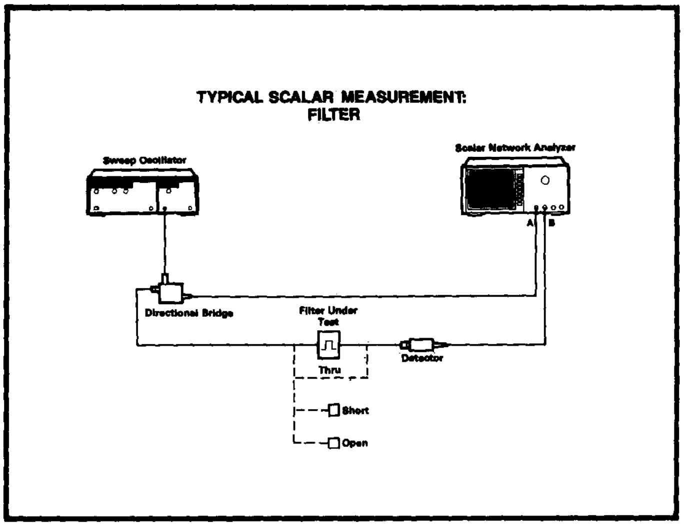
FILTER PARAMETERS:

Stop Band:

- Rejection
- Shape Factor
- Unwanted Responses

3216

This slide shows a typical filter measurement with source, directional bridge, detector and analyzer. Note that this setup permits simultaneous measurement of insertion loss, normalized to a "thru" connection, and return loss, normalized to the short/open average. (The HP 8757A and 8756A both guide the user through the short/open calibration procedure, compute the short/open average, and store the average into calibration memory.)

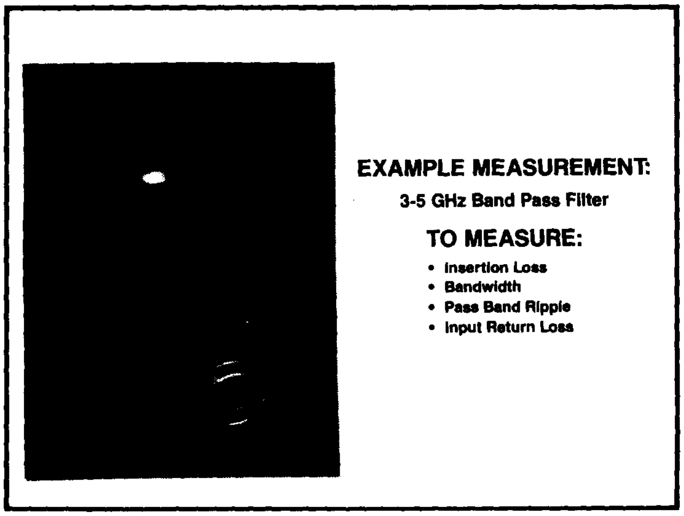


TYPICAL SCALAR MEASUREMENT: FILTER

3217

Accurate filter measurements depend on certain characteristics of the measurement system. As discussed earlier, the source and detectors must provide good match to avoid re-reflections that cause mismatch errors, particularly for measurements in the pass band (low insertion loss). The measurement of the stop band response requires a wide dynamic range and low source harmonics.

Let's take a look at a 3-5 GHz band-pass filter. We will characterize the insertion loss, bandwidth, passband ripple, and return loss.



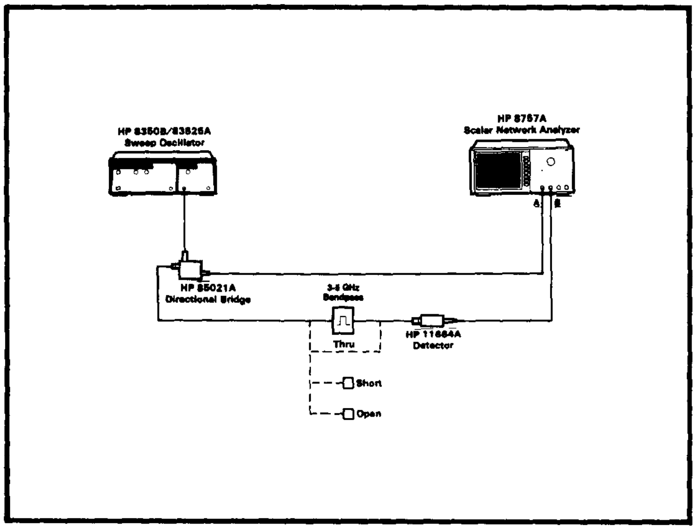
EXAMPLE MEASUREMENT:

3-5 GHz Band Pass Filter

TO MEASURE:

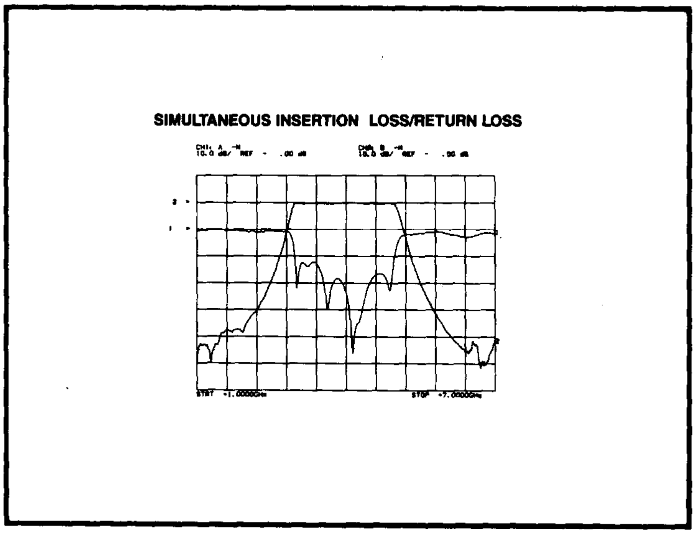
- Insertion Loss
- Bandwidth
- Pass Band Ripple
- Input Return Loss

3218



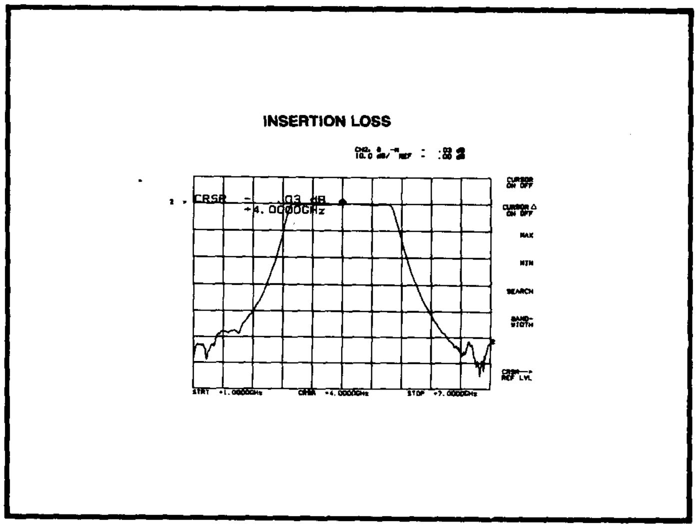
3220

Here is the measurement hardware used. Remember that the directional bridge introduces a 6-dB power loss, which will decrease the dynamic range of the measurement by 6 dB. If the dynamic range were needed, a directional coupler could be used instead of a bridge.


SIMULTANEOUS INSERTION LOSS/RETURN LOSS

3221

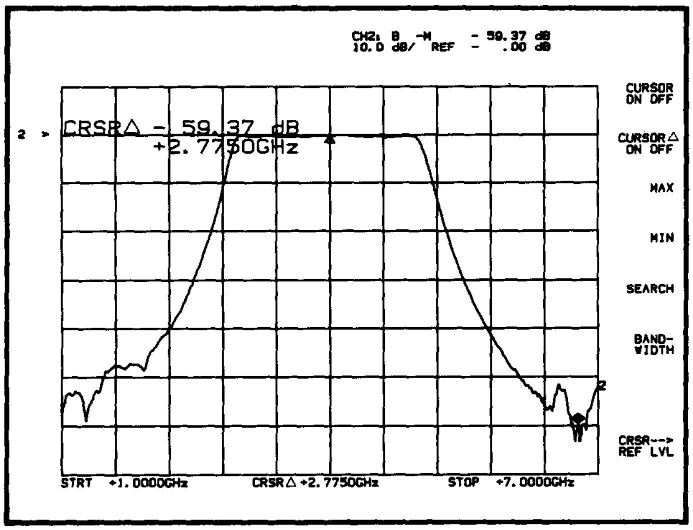
Shown here are insertion loss and return loss responses. Both are normalized to the appropriate calibration standards, as indicated by the "measurement minus memory" labels "A - M" and "B - M". The short/open average is stored in channel 1 memory, and the "thru" is stored in channel 2 memory.


INSERTION LOSS

3222

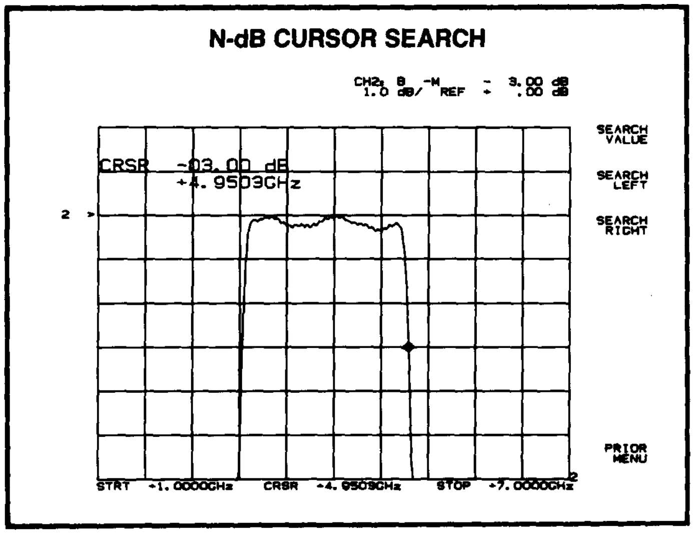
Now let's take a closer look at the insertion loss data. Using a "cursor", the operator can dial a pointer to any point on the trace for a quick, clear reading of the measured insertion loss and the frequency. With "cursor max" and "cursor min", the cursor moves to the highest or lowest point on the trace.

For a quick reading of the relative relationship between two data points (magnitude and frequency difference), the cursor delta function is available. For example, if we want to measure the out-of-band response relative to the pass band, we would dial the cursor to the reference point in the pass band and activate the cursor delta. A marker is placed at that data point, and the cursor can be moved into the stop band. The analyzer display now shows the difference -- both magnitude and frequency -- between that point and the fixed reference marker. In this case we measure 59 dB of rejection 2.775 GHz from the center frequency.



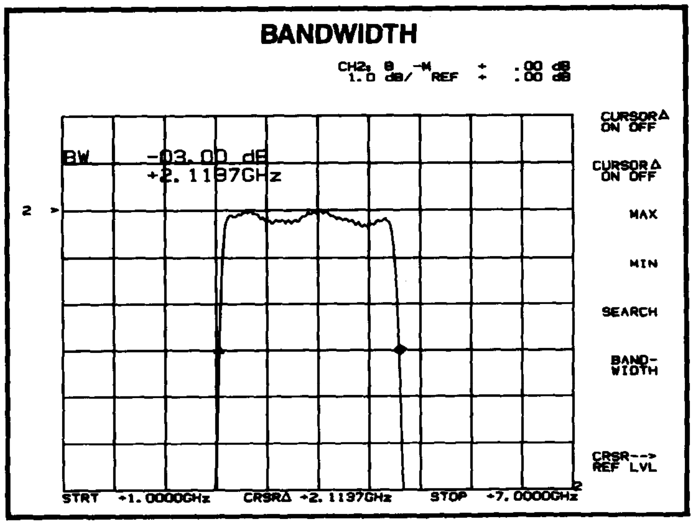
3223

We can also locate the frequencies where the response is down by some exact amount, for example 3 dB. This point can be found using the cursor delta or by using the "N dB search" function of the HP 8757A. The operator can quickly search for the left hand 3-dB point (search left) or the right hand 3-dB point (search right). The 3-dB points of this filter are 2.84 GHz and 4.95 GHz.



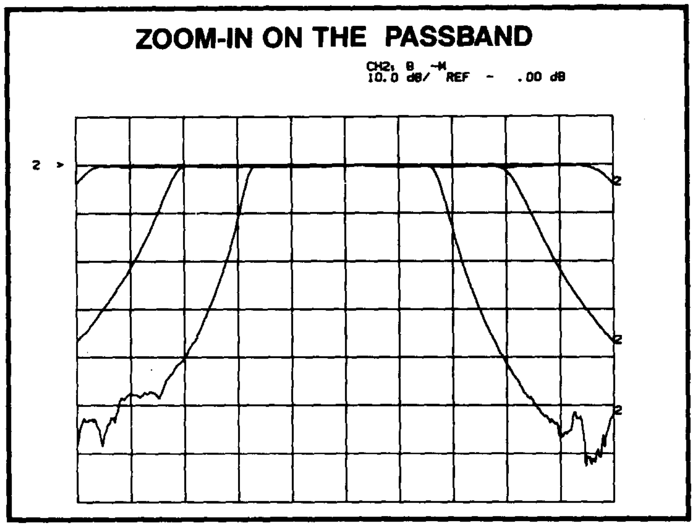
3224

To measure the bandwidth, or the difference between the two 3-dB points, cursor delta can again be used. Or to avoid dialing in to the 3 dB points, the "bandwidth" function of the HP 8757A will perform the searches automatically and display the difference between the two 3-dB points, that is, the bandwidth. In this case, the bandwidth is 2.1137 GHz.



3225

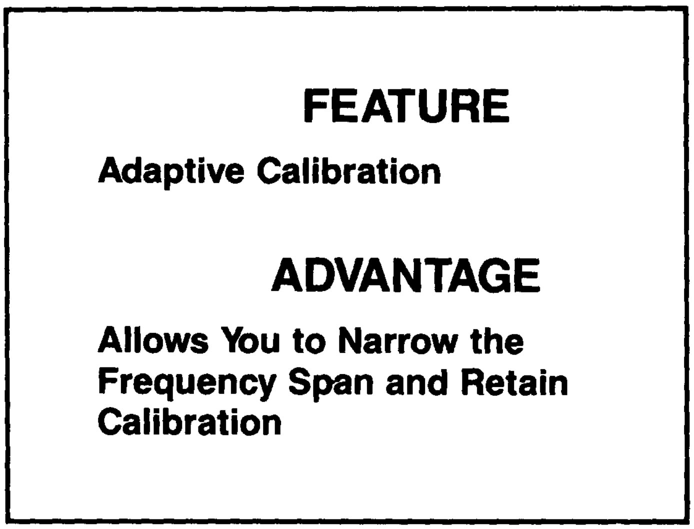
The data in these measurements is digitized at discrete frequencies. In general, no digitized data point will be exactly 3.00 dB. Therefore, both the search and bandwidth features use linear interpolation between data points to find the exact 3.00 dB points.



ZOOM-IN ON THE PASSBAND

3226

Now let's zoom in on the passband and look at the passband ripple more closely. This is easily accomplished by narrowing the swept frequency range on the source, delta F. When this is done, the HP 8757A adjusts the calibration data to retain calibration.



FEATURE

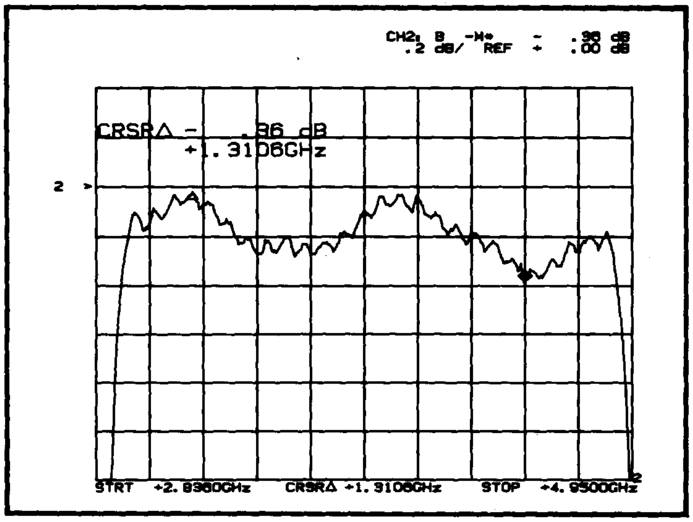
Adaptive Calibration

ADVANTAGE

Allows You to Narrow the Frequency Span and Retain Calibration

3227

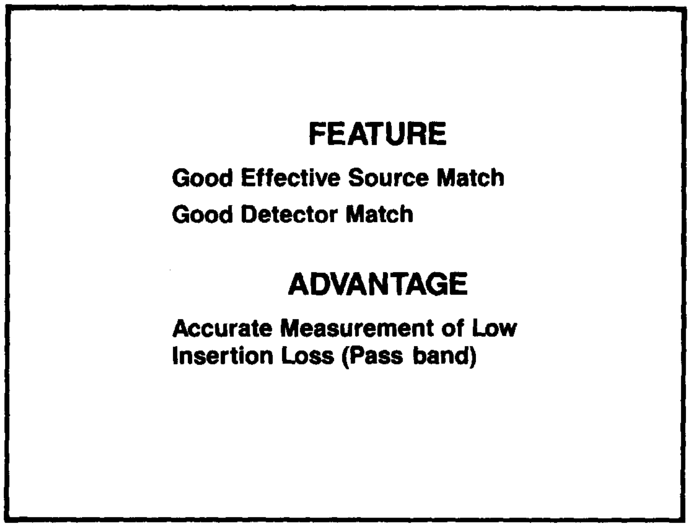
This "adaptive calibration" feature makes measurements more convenient, because it is not necessary to recalibrate when the frequency span is narrowed.



3228

The passband ripple can now be observed with high resolution, in this case 0.2 dB per division. The cursor delta function again shows the variation in response, in this case a 0.36 dB peak to peak ripple. It is important to remember that some of this ripple could be caused not by the filter but by the measurement system itself. The extent of this measurement system ripple, as you may recall from the fundamentals section, depends on the impedance match of the detector and of the source. With good source and detector match, these measurement system responses can be kept to a minimum.

Remember good effective source match and good detector match are particularly important when measuring devices with low insertion loss, since reflected signals pass through the device under test with little or no attenuation. Therefore, detector and source match are important in measurements of insertion loss in the pass band.



FEATURE

Good Effective Source Match

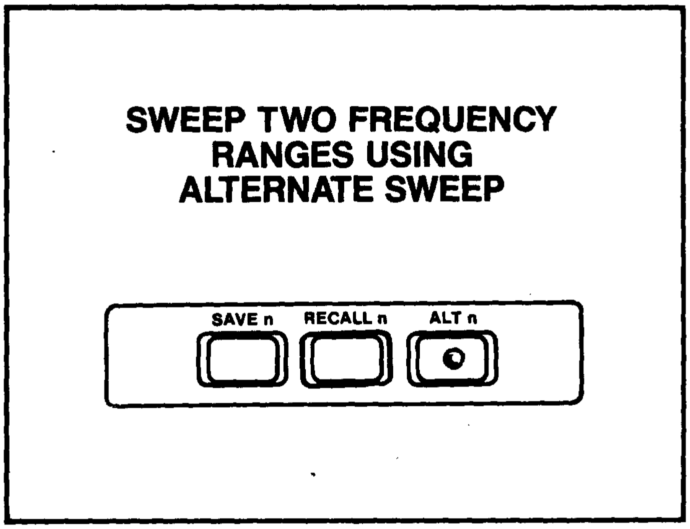
Good Detector Match

ADVANTAGE

Accurate Measurement of Low Insertion Loss (Pass band)

3229

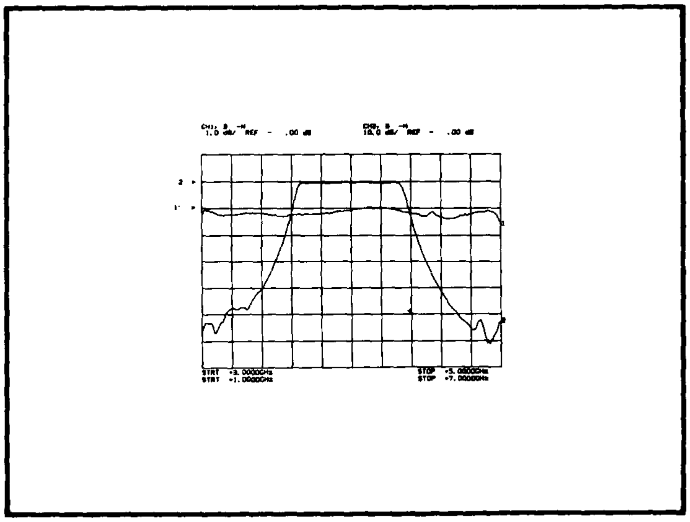
When measuring filters it is often useful to view two different frequency ranges simultaneously. This can be accomplished using the ALTERNATE SWEEP function of HP swept sources.



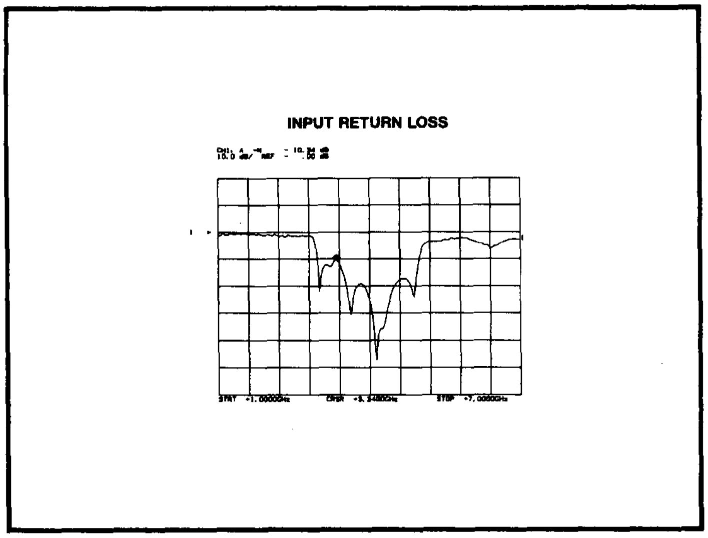
SWEEP TWO FREQUENCY RANGES USING ALTERNATE SWEEP

3231

Using ALTERNATE SWEEP, we can view the passband response (2 GHz sweep) and the wideband response (6 GHz sweep) at the same time. Both traces are "live" and will respond to device adjustments in real time. Tradeoffs between passband ripple and the slope of the filter skirts can be analyzed as adjustments are made.

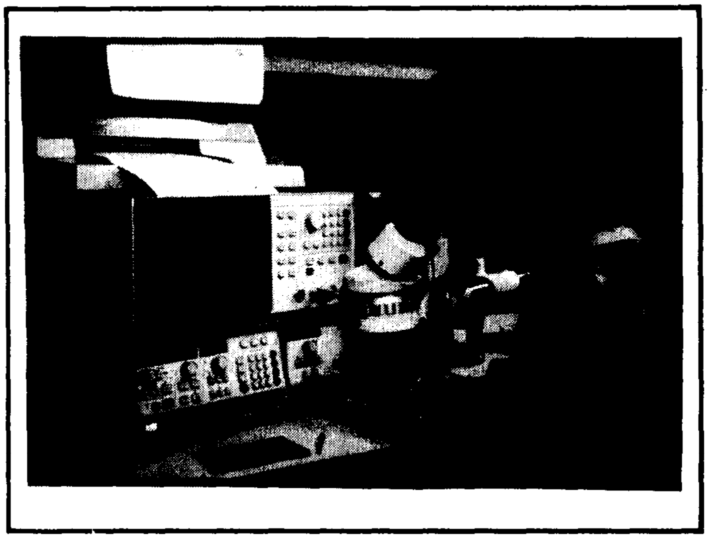


3232



3207

This plot shows input return loss of the filter. The example filter exhibits high return loss in the passband (20 dB), indicating good impedance match.



3406

Filters and other devices are often adjusted using the scalar analyzer's display of insertion loss or return loss as a guide. When making these adjustments it is often necessary to see the effects of the adjustments appear on the display "in real time" so that the operator can relate what the hand is doing with what the eye is seeing. It is therefore important to have fast sweeps so that the data is updated quickly.

FEATURE

Fast Sweeps

- Diode Detection
- AC Log Amps
- Fast Processing

ADVANTAGE

See the Effects of Adjustments

- In Real Time

  On Normalized Data

3236

As discussed in the fundamentals section, diode detection and AC log amplifiers are very fast at all power levels. With digital analyzers such as the HP 8757A and 8756A, the sweep time is not limited by the detectors or by the log amplifiers, but only by the analyzer's speed in digitizing and processing the data.

Fast sweeps allow the operator to see the effects of adjustments in real time and on normalized data.

This chart shows the sweep times that can be used with the HP 8757A and HP 8756A. Note that the HP 8757A sweep time depends on the horizontal resolution chosen by the user. With fewer data points (or fewer traces), it is possible to sweep faster, because less data is digitized and processed.

SWEEP TIMES

HP 8757A:

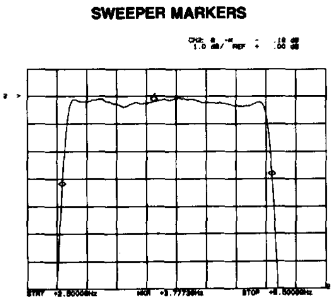
Number of Points	Minimum Sweep Time
101	50 ms
201	100 ms
401	200 ms
801	200 ms
1601	200 ms

HP 8756A:

Minimum Sweep Time: 200 ms

3237

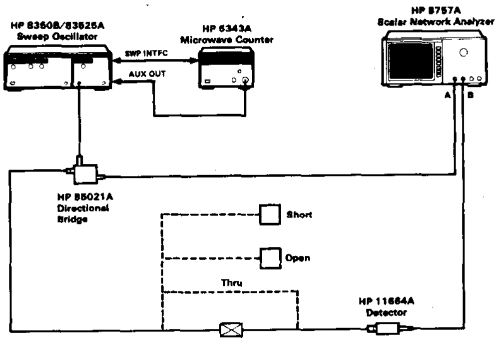
To get a readout of frequency, the operator has several choices. As we have already mentioned, the analyzer's cursor provides a quick reading of both magnitude and frequency. In addition, up to five sweeper markers are also available from HP sweep oscillators, and like the cursor, they can be dialed to any data point and both magnitude and frequency can be read.



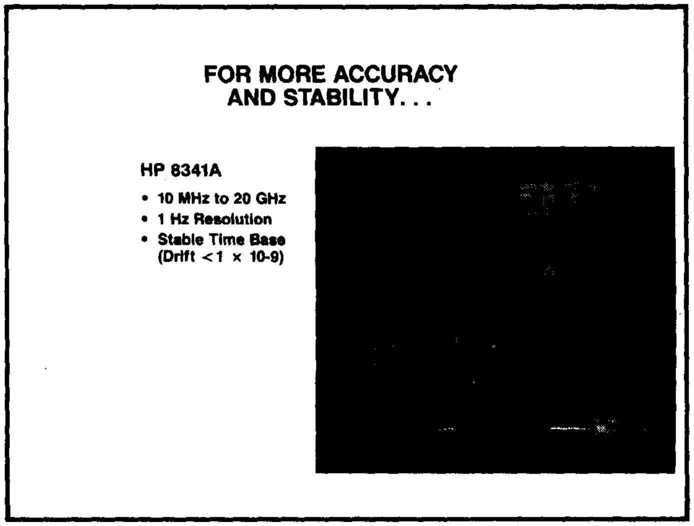
3239

In many filter applications it is necessary to make highly accurate measurements of marker frequencies, for example for 3-dB points. Using the HP 5343A microwave counter, sweeper markers can be counted precisely. A highly stable time base and a sweep oscillator interface allow the HP 5343A to make high resolution measurements of marker frequency.

COUNTING SWEEPER MARKERS



3240



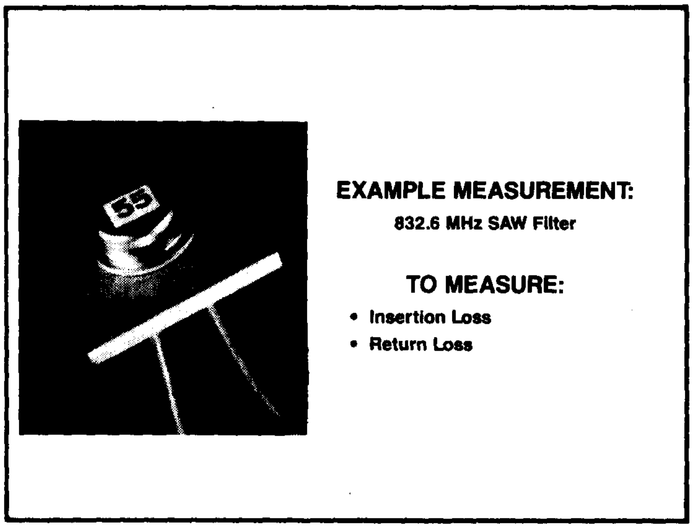
FOR MORE ACCURACY AND STABILITY...

HP 8341A

- **10 MHz to 20 GHz**
- **1 Hz Resolution**
- **Stable Time Base (Drift <1 × 10-9)**

3242

Some applications demand more frequency accuracy and stability than the HP 8350B can offer even with counted markers. One example is the measurement of a filter with a very narrow bandwidth. A synthesized sweeper is ideal for these applications.
The HP 8341A synthesized sweeper, for example, provides 10 MHz to 20 GHz frequency coverage with high resolution and stability. Let's look at an example application of a synthesized sweeper.



EXAMPLE MEASUREMENT:

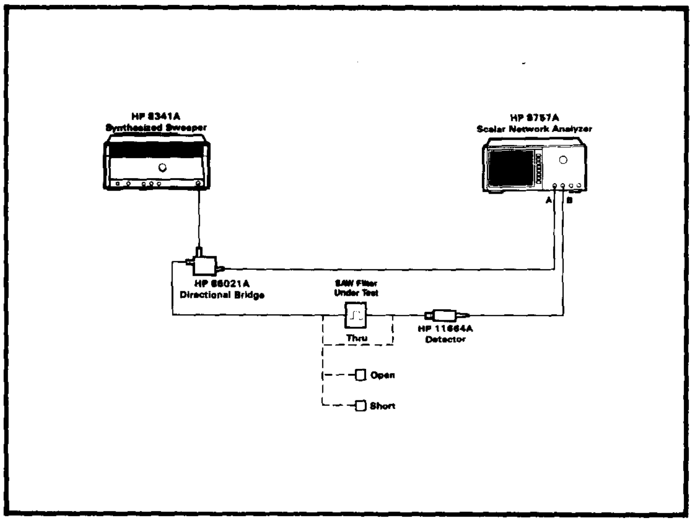
832.6 MHz SAW Filter

TO MEASURE:

- **Insertion Loss**
- **Return Loss**

3243

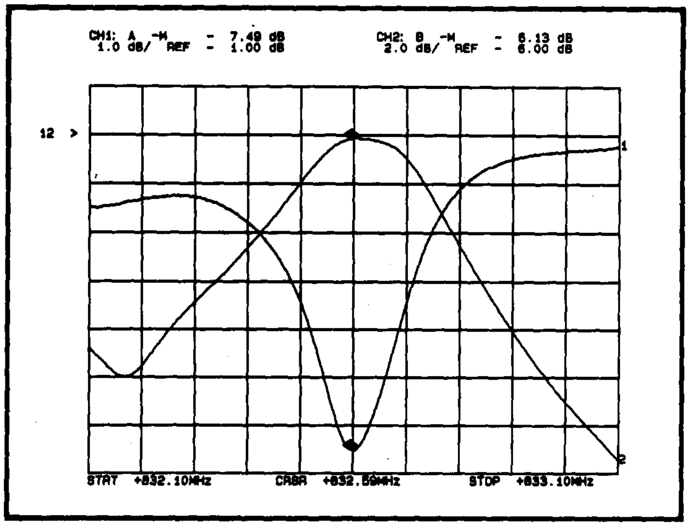
The next example filter is a surface acoustic wave (SAW) filter with very narrow bandwidth. We will perform a simultaneous measurement of insertion loss and return loss, and see why a synthesized sweeper is required in this application.



3244

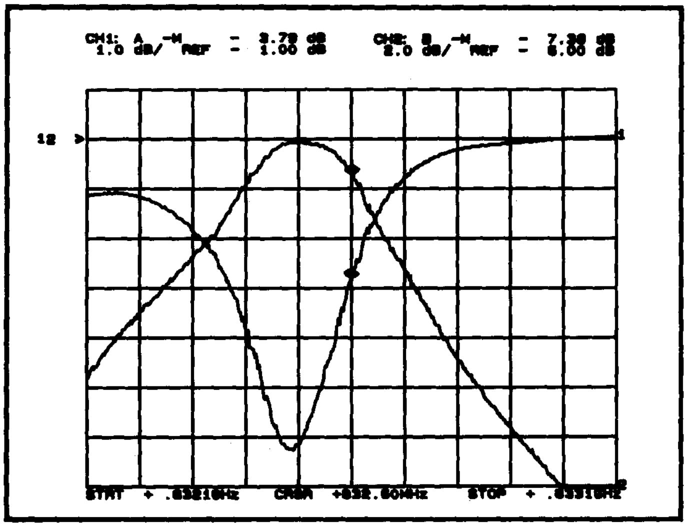
Except for the source and the frequency range, this measurement setup is identical to the one used for the 3-5 GHz bandpass filter.

This plot shows the device characteristics. Note that the frequency span is only 1 MHz. What would happen if we tried to make this measurement with the HP 8350B sweep oscillator?

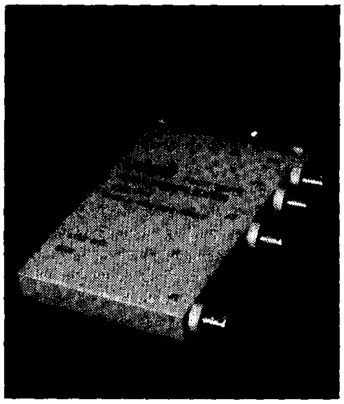


3245

This plot shows the same measurement with the HP 8350B as the source. Notice that the center frequency is offset slightly, and that the trace is distorted by the variations in the source frequency (residual FM) as the measurement is made. This narrowband device requires the frequency accuracy and stability of the synthesized sweeper.



At the start of this section we mentioned multiplexer measurements. A multiplexer is a combination of filters which allows a different frequency range to pass to each of several output ports. Here is a quadruplexer (4 output ports) that can be easily characterized with scalar network measurements.



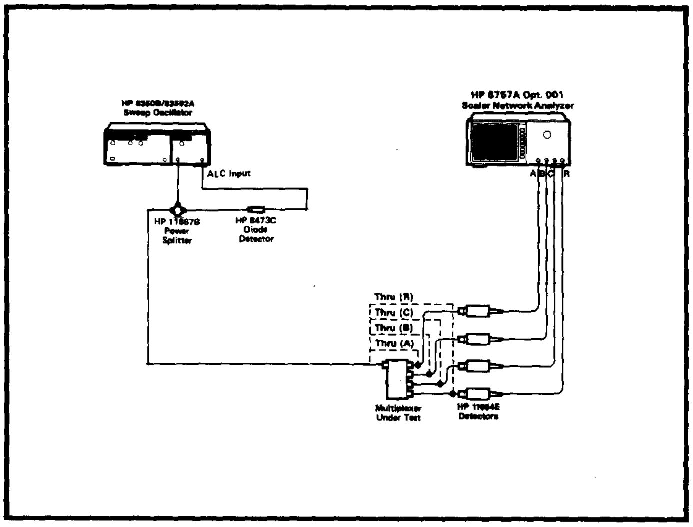
EXAMPLE MEASUREMENT:

Quadruplexer

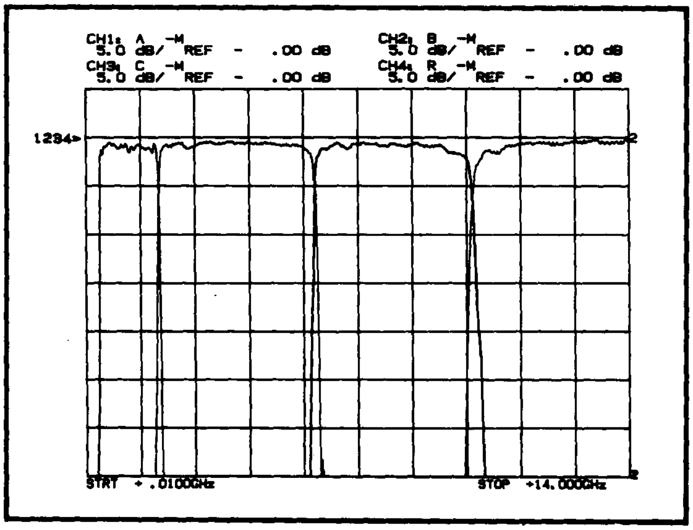
TO MEASURE:

Insertion Loss (4 Outputs)

3252



Using this test setup, and the HP 8757A option 001 (fourth detector input), we can measure the insertion loss of all four inputs simultaneously. Note that a separate "thru" calibration must be done for each detector. Improved source match is achieved using external source leveling.



This plot shows the response at all four quadruplexer outputs simultaneously. The cursor search and bandwidth functions can be used separately for each channel and real time adjustments can be made.

FEATURE

Four Detector Inputs

(HP 8757A Opt. 001)

Four Independent Display Channels

ADVANTAGE

View Insertion Loss of All Four Channels in Real Time

Four detector inputs and four display channels make this measurement very convenient.

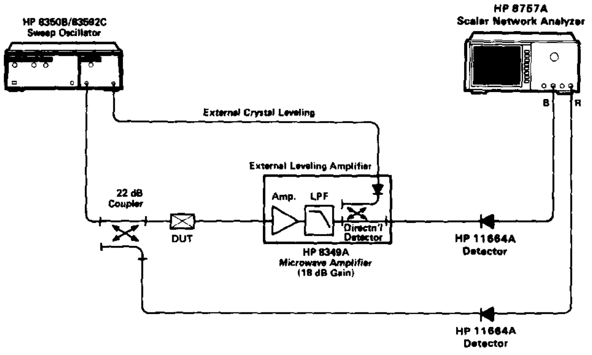
Some filter measurement applications require enhancements to the measurement system. For example some measurements demand more dynamic range than the standard scalar analyzer provides.

ENHANCEMENTS FOR FILTER MEASUREMENTS:

1. Extended Dynamic Range

Using an amplifier, it is possible to extend the effective dynamic range of a measurement. In the normal configuration without any amplifier, the dynamic range is limited to the dynamic range of one detector, for example only the B detector in a transmission measurement. Using an amplifier and external source leveling, it is possible to increase the dynamic range by combining the ranges of two detectors in a ratio measurement.

EXTENDED DYNAMIC RANGE



This extended dynamic range measurement is described in detail in HP application note 327-1.

The amount of dynamic range acheived using this method is summed up in this equation. The minimum dynamic range realized is Po-Sa+Ga, where Po is the maximum unleveled power available from the source (+8 dBm for HP 83592C), Sa is the minimum sensitivity of the B detector (-60 dBm for the HP 11664A and the HP 8757A), and Ga is the gain of the amplifier (+18 dB for the HP 8349A). This equation yields at least 86 dB of dynamic range for the HP 83592C, HP 11664A, and the HP 8349A.

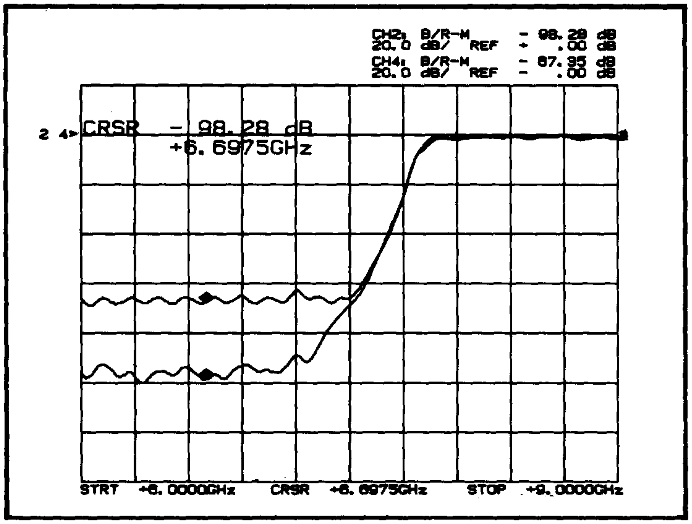
MINIMUM DYNAMIC RANGE

$$= P_o - S_a + G_a$$

Where P_o = Maximum Power of Source

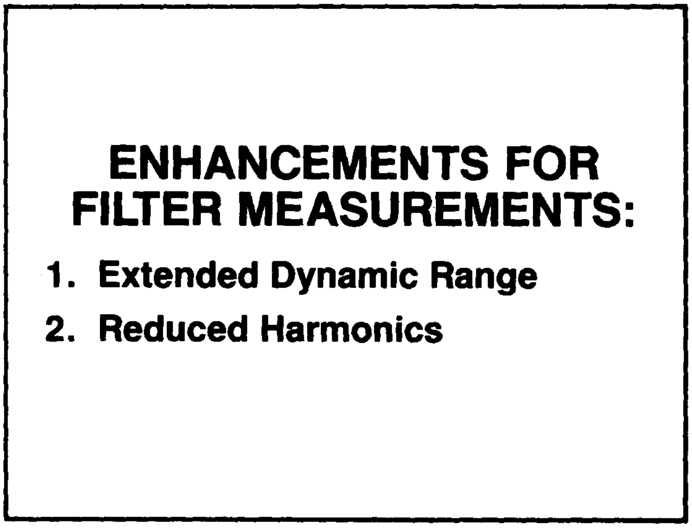
S_a = Sensitivity of Detector

G_a = Gain of Amplifier



3260

Here is an example of an extended dynamic range measurement of an 8-10 GHz bandpass filter. In this example we realize over 95 dB of effective dynamic range.



ENHANCEMENTS FOR FILTER MEASUREMENTS:

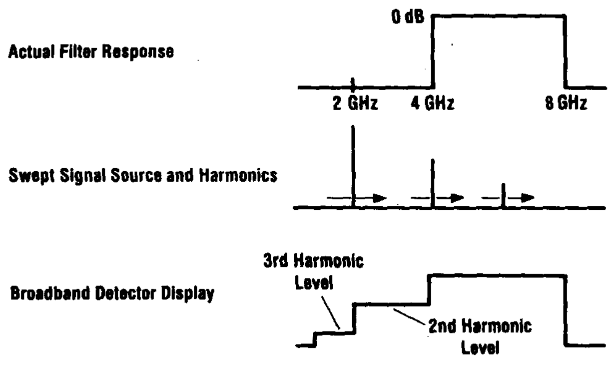
1. Extended Dynamic Range
2. Reduced Harmonics

3256

Another way to enhance filter measurements is to reduce the distortion due to the harmonics of the source. Before we discuss reduced harmonics, let's talk briefly about how harmonic distortion can affect a filter measurement.

HARMONIC DISTORTION:

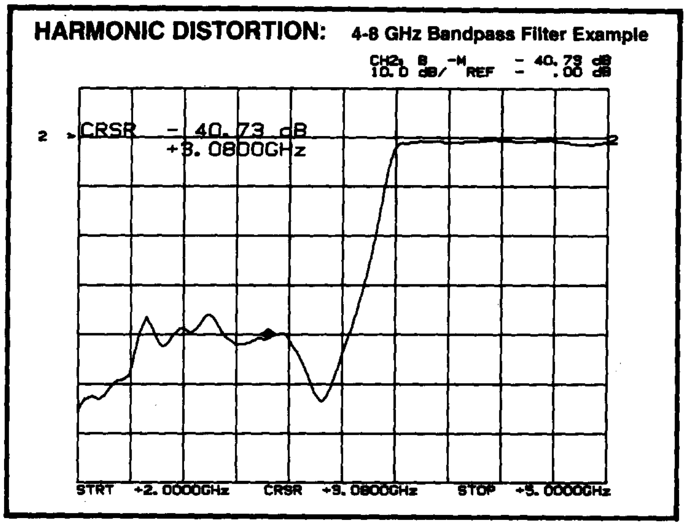
4-8 GHz Bandpass Filter Example



3261

In this example measurement of a 4-8 GHz bandpass filter, source harmonics cause a "staircase" response that is not the true filter response. This distortion is caused by the harmonics of the source which pass through the filter passband before the fundamental.

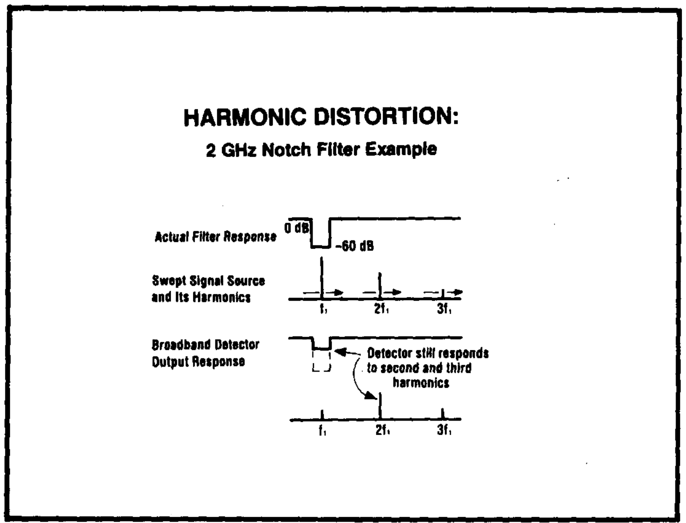
This plot shows this staircase on a 4-8 GHz bandpass filter.



HARMONIC DISTORTION: 4-8 GHz Bandpass Filter Example

3262

Another example shown here is a 2 GHz band-reject or notch filter. Since the harmonics are passed through the filter as the fundamental is in the reject band, the harmonics tend to fill in the notch, and distort the measurement of the true filter response.

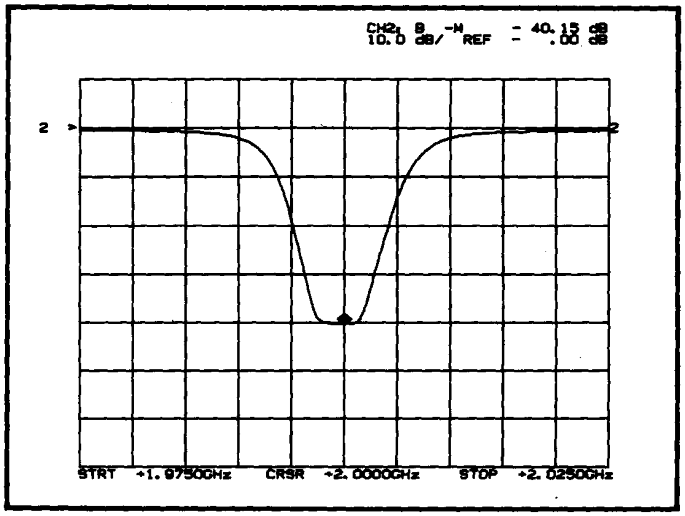


HARMONIC DISTORTION:

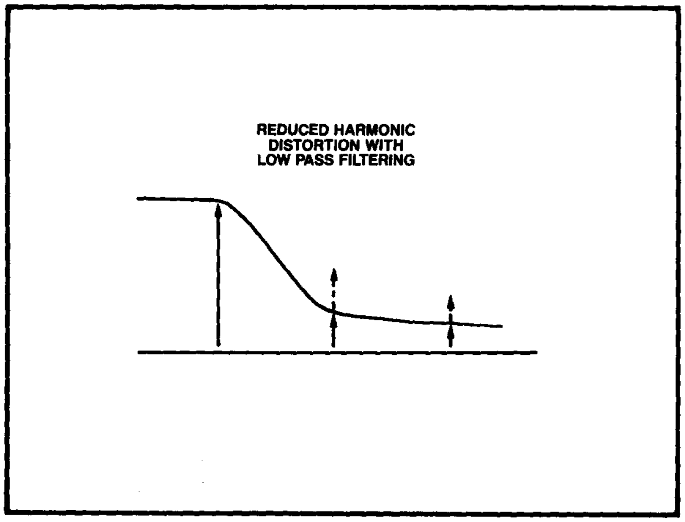
2 GHz Notch Filter Example

3263

Here is an actual plot of a 2 GHz notch filter. Although the filter's actual rejection is over 50 dB in the notch, this measurement shows only 40 dB.

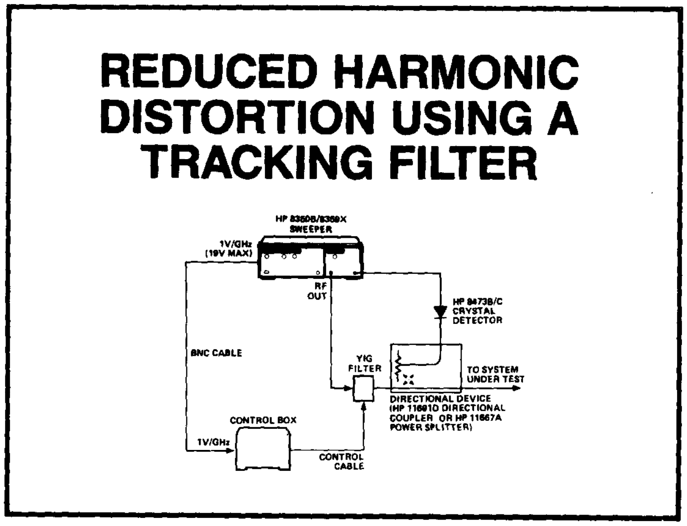


3264


REDUCED HARMONIC
DISTORTION WITH
LOW PASS FILTERING

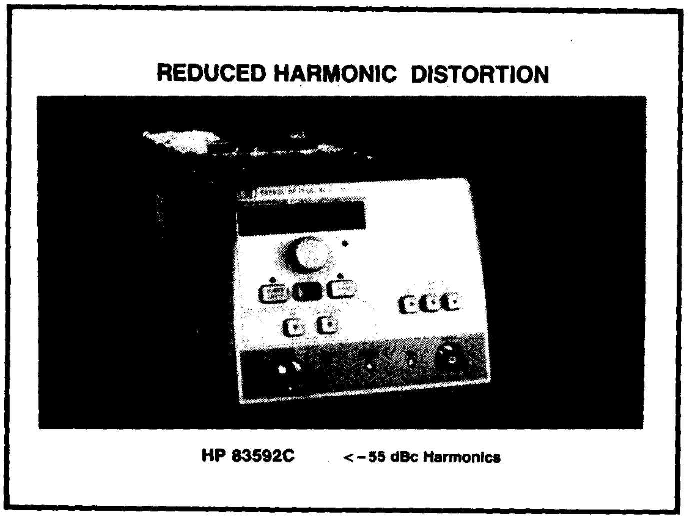
3265

There are several ways to reduce harmonic distortion. The first is simply to filter out the harmonics using a lowpass filter with a cutoff frequency that reduces the harmonics but does not affect the full sweep range of the fundamental. This method is often inconvenient for broad filters, such as the 4-8 GHz bandpass filter, because several filters would be necessary to cover the frequency range in steps. However lowpass filtering is a simple way to reduce harmonic distortion in many applications.


REDUCED HARMONIC DISTORTION USING A TRACKING FILTER

3267

A tracking filter can also be used to reduce harmonic distortion even over broad sweeps. This setup shows an example configuration using a tracking filter to provide <-55dBc harmonics.

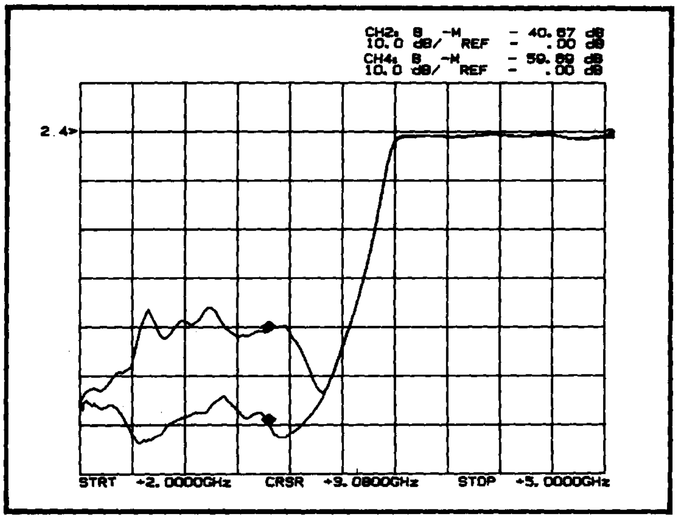

REDUCED HARMONIC DISTORTION

HP 83592C <-55 dBc Harmonics

3268

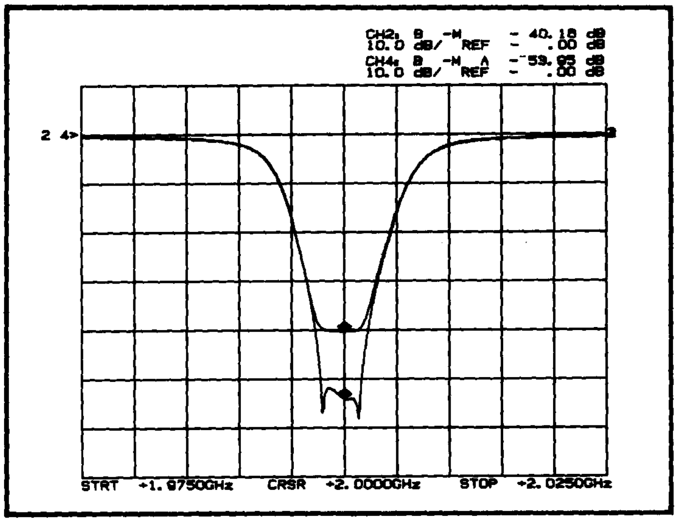
Another way to reduce harmonic distortion is to use a source with lower harmonic content. The HP 83592C plug-in for the HP 8350B sweep oscillator uses an internal tracking filter to provide <-55 dBc harmonics from 3.5 GHz to 20 GHz.

When harmonic distortion is reduced, the true filter response can be seen. This plot shows the measurement of the 4-8 GHz bandpass filter made with the HP 83592C. Notice that the staircase response is greatly reduced.



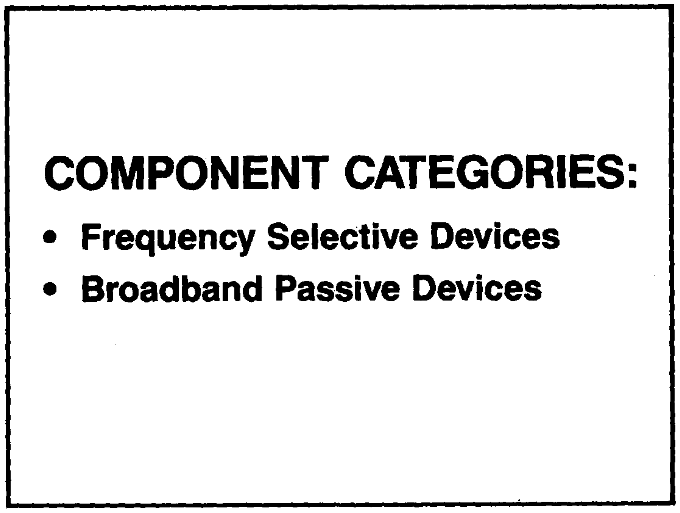
3268

This plot shows the notch filter measurement with the harmonic distortion removed. Notice that it is possible to see much farther into the notch.



3269

The next component category is broadband passive devices. These devices usually operate over a very broad frequency range and exhibit only small variations in response over that broad frequency range.



COMPONENT CATEGORIES:

- **Frequency Selective Devices**
- **Broadband Passive Devices**

3270

BROADBAND PASSIVE DEVICES:

- Transmission Lines
- Resistive Networks
- Terminations
- Isolators
- Attenuators
- Switches

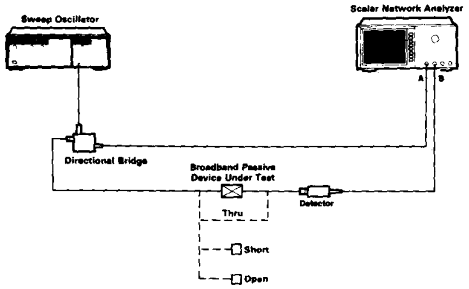
Transmission lines, resistive networks, terminations, isolators, attenuators, and switches are all examples of broadband passive devices.

BROADBAND PASSIVE DEVICE PARAMETERS:

- Insertion Loss
- Return Loss (SWR)
- Phase Linearity/Group Delay
- Phase Tracking

The parameters important to measure on broadband passive devices include insertion loss, return loss, phase linearity, and phase tracking. Again we will restrict ourselves to magnitude only (scalar) measurements.

TYPICAL SCALAR MEASUREMENT: BROADBAND PASSIVE



A typical reflection/transmission measurement of a broadband passive device is shown here. This is very similar to the filter measurement setup.

The measurement system necessary to characterize broadband passive devices must meet certain requirements. Wide frequency coverage (e.g. 10 MHz to 26 GHz) is often required. Because many broadband devices have low insertion loss, it is important to have good source and detector match to avoid the effects of re-reflections. Broadband devices also often have high return loss, so high directivity is important for accurate measurments. Switches and some attenuators require that the measurement system have a very wide dynamic range. Other parameters, such as low harmonics and high frequency accuracy are not usually required for measuring broadband passive devices.

The first example broadband passive device is a 10 dB attenuator. Attenuators such as this one are often used in preliminary measurements to verify the performance of the measurement system.

EXAMPLE MEASUREMENT:

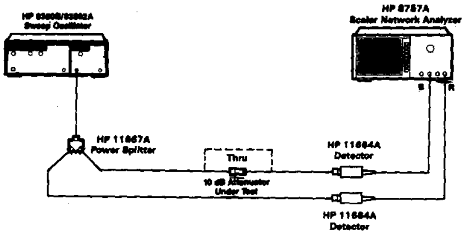
10 dB Attenuator

TO MEASURE:

- **Attenuation**

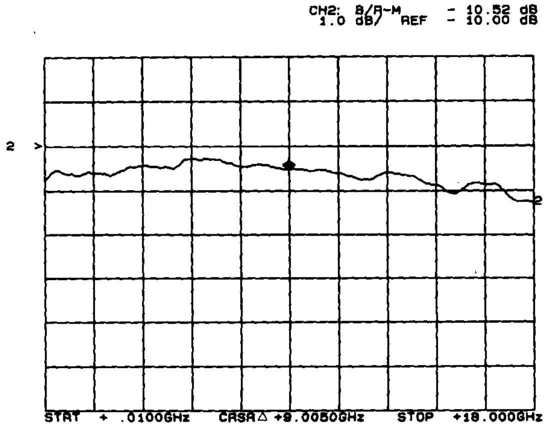
3276

This setup will provide a ratio measurement of insertion loss data from 10 MHz to 18 GHz. Remember that ratioing improves the effective source match by removing the effects of source power variations versus frequency. Note, however, that it is still necessary to perform the "thru" calibration to remove the effects of any differences in frequency response (tracking) between the two arms of the power splitter and between the two detectors.

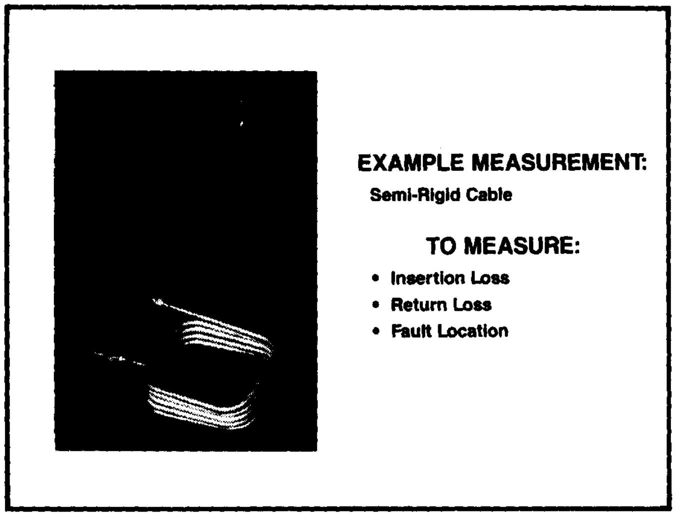


3278

This plot shows the normalized and ratioed frequency response (B/R-M). Note that the response variation is small over the entire frequency range.



3277



EXAMPLE MEASUREMENT:

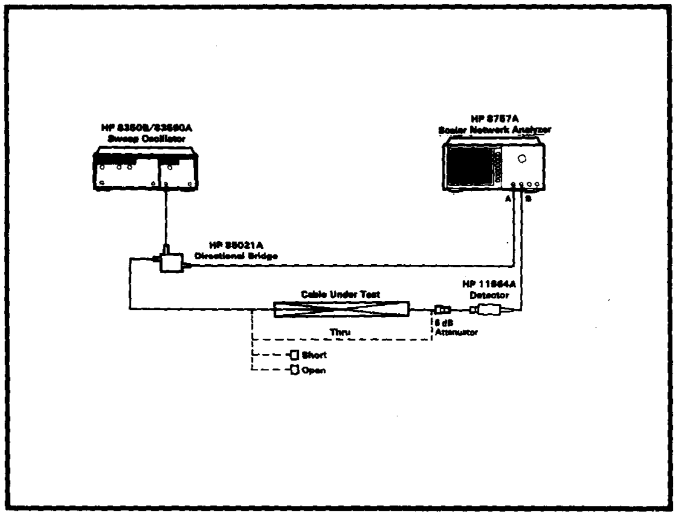
Semi-Rigid Cable

TO MEASURE:

- **Insertion Loss**
- **Return Loss**
- **Fault Location**

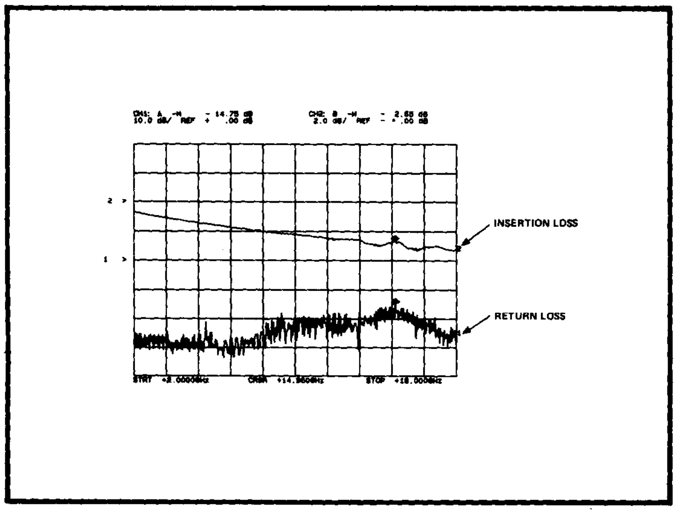
3280

The next example measurement of broadband passive devices is two sections of semi-rigid cable (RG-141) connected together. We will show the measurements of insertion loss and return loss and also show how fault location can be used to locate impedance mismatches along the line.



3281

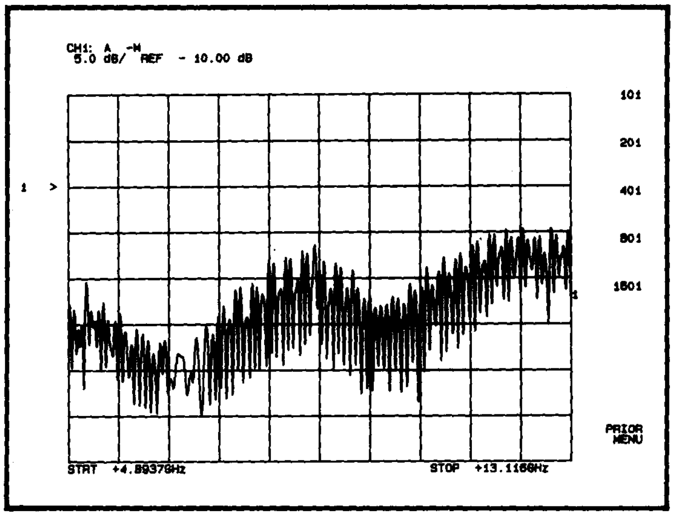
This setup is used to measure insertion loss and return loss simultaneously over a broad frequency range of 2-18 GHz. A 6 dB attenuator is used to isolate the detector and reduce the effects of re-reflections. (Effective detector match, remember, is particularly important when measuring low insertion loss devices.) The familiar thru and short/open calibrations are performed.



3282

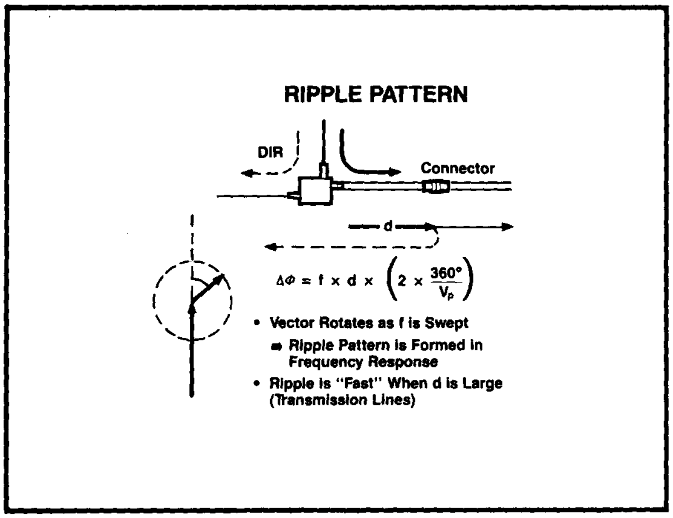
The resulting data is shown here. Note that the insertion loss is low, as it should be for any transmission line. Also note that return loss is high (near 25 dB), so high directivity is required to make this measurement accurately. The fast variation in the return loss plot is typical of many transmission line measurements and is worth some consideration.

This plot shows return loss over a narrower frequency span with 1601 point resolution. Note that the ripples are well-characterized. Let's discuss briefly the origin of this ripple.



3283

Signals reflected from various points within the line will combine vectorially to form the detected reflection response. When a signal travels down a line, it undergoes a phase shift that is proportional to both frequency and distance. In a long line (d large), the phase shift between signals reflected from various points in the line will vary rapidly with frequency. The result is the rapid ripple in the frequency response trace.



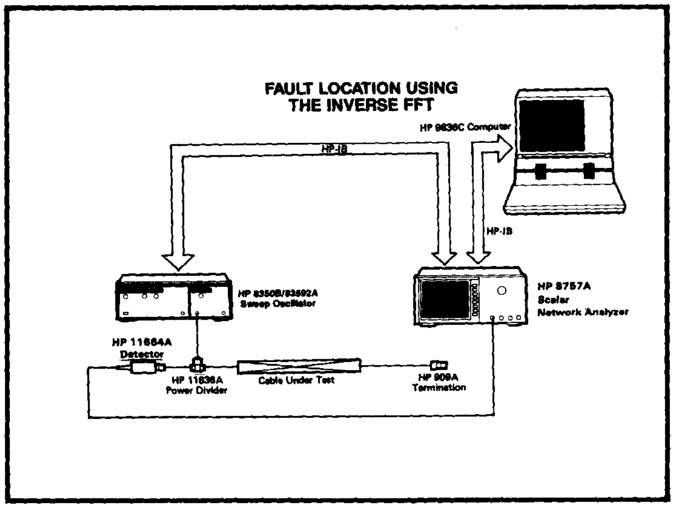
RIPPLE PATTERN

$$\Delta\Phi = f \times d \times \left(2 \times \frac{360°}{V_p}\right)$$

- Vector Rotates as f is Swept
  - ⇒ Ripple Pattern is Formed in Frequency Response
- Ripple is "Fast" When d is Large (Transmission Lines)

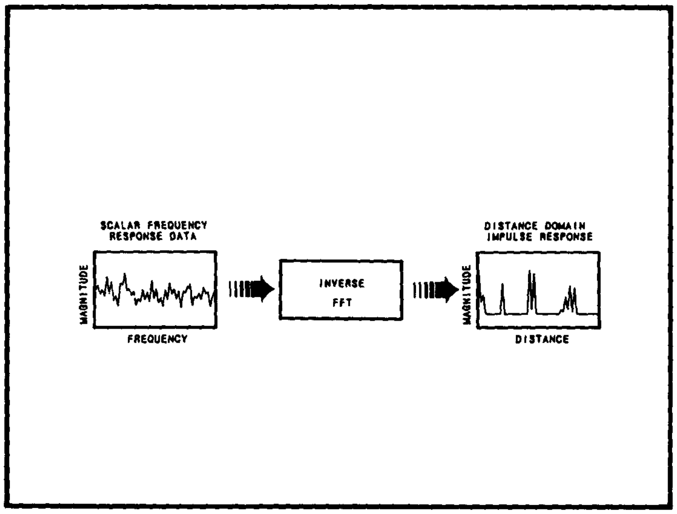
3283

It is possible to take advantage of the ripple pattern formed in transmission line measurements to perform another important measurement: fault location. The test setup shown here optimizes the formation of this ripple pattern, providing frequency domain data which can be converted to the distance domain using the inverse Fast Fourier Transform (FFT). This technique is called frequency domain reflectometry and it allows the operator to characterize impedance mismatches as a function of distance along the line. This is a valuable tool for troubleshooting lines, for example during installation and maintenance of communication, radar, or electronic countermeasure systems.



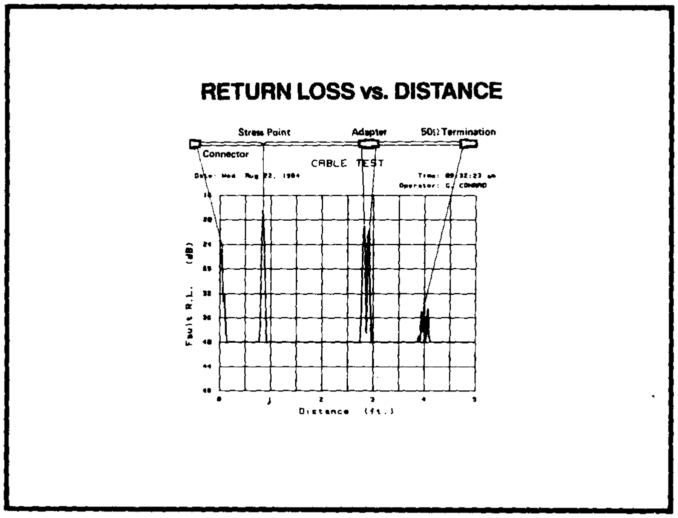
FAULT LOCATION USING THE INVERSE FFT

3285



3286

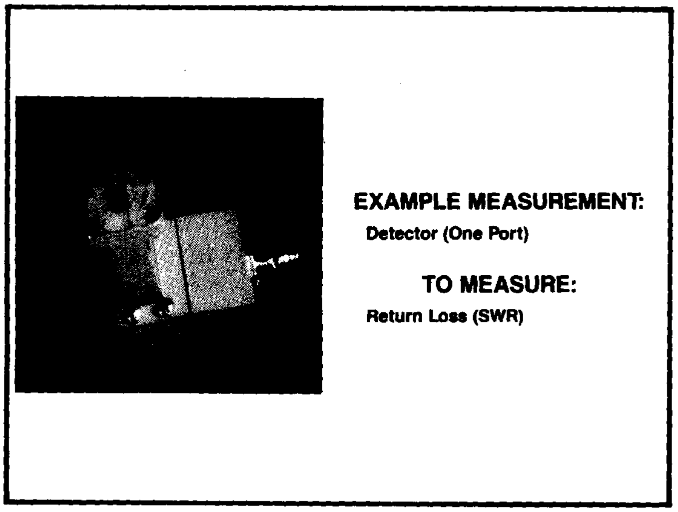
Fault location is accomplished by performing an inverse Fast Fourier Transform on frequency domain data. This converts the frequency domain information to its time domain equivalent. The time axis is then scaled by the velocity of propagation, and the result is the distance domain response. Mismatches appear as pulses whose location and magnitude are easy to read.



RETURN LOSS vs. DISTANCE

3287

Here we see the example cable with several mismatches lined up with its distance domain response. Notice how easily bad connections or faulty cable sections can be located. The HP 8757S automatic scalar network analyzer and the HP 85016A transmission line test software perform this measurement effectively.



EXAMPLE MEASUREMENT:

Detector (One Port)

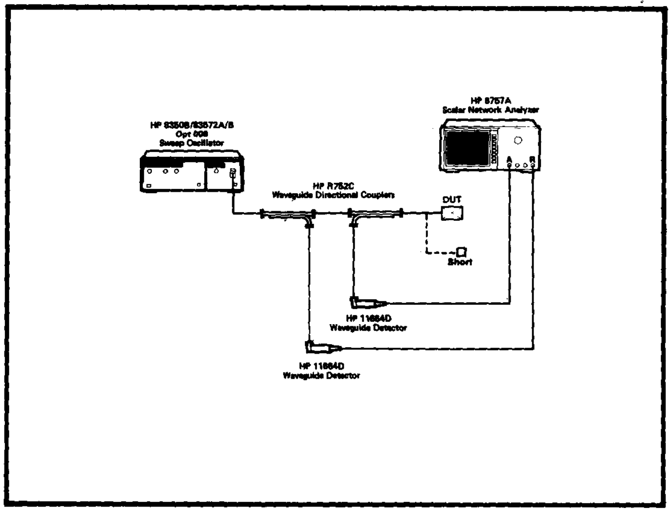
TO MEASURE:

Return Loss (SWR)

3288

Many broadband passive devices are one-ports, such as terminations and detectors. The next example is a 26.5-40 GHz detector, used to provide a DC voltage out proportional to the microwave signal at the input. Notice that the input is waveguide (WR-28). Since this is really only a one-port device, only a reflection measurement can be made.

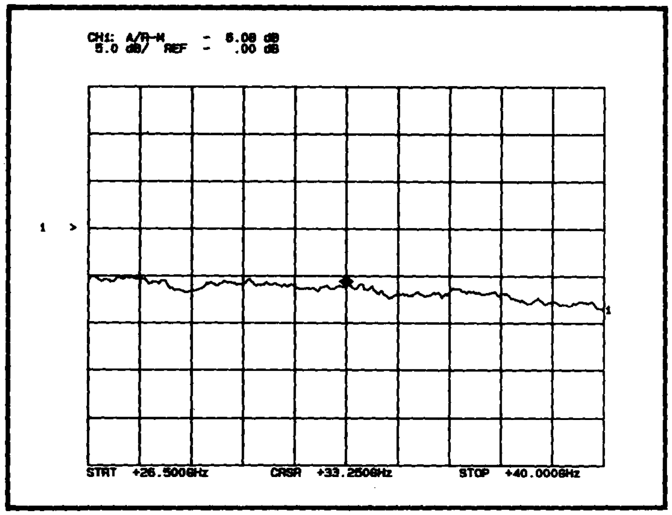
This measurement uses two waveguide directional couplers to provide the reference channel (R) and to couple off the reflected signal (A). Calibration is done with a short only, and not with a short/open. Since an open does not provide 0 dB return loss in waveguide, the short/open average cannot be used to eliminate the calibration error ("B" term in reflection uncertainty equation).



3289

Note: It is possible to use an adjustable short, and to simulate an open as a 180 degree offset from a short. However, because of waveguide dispersion, this offset will be different at each frequency, and would not apply over the entire 26.5-40 GHz range.

The return loss plot is shown here, normalized to the response of a short.



3290

The next broadband passive device example is another attenuator, this time, a voltage controlled attenuator. The attenuation is adjusted by simply adjusting the control voltage on the tuning input. The two measurements we wish to make on this device are attenuation versus frequency and attenuation versus control voltage.

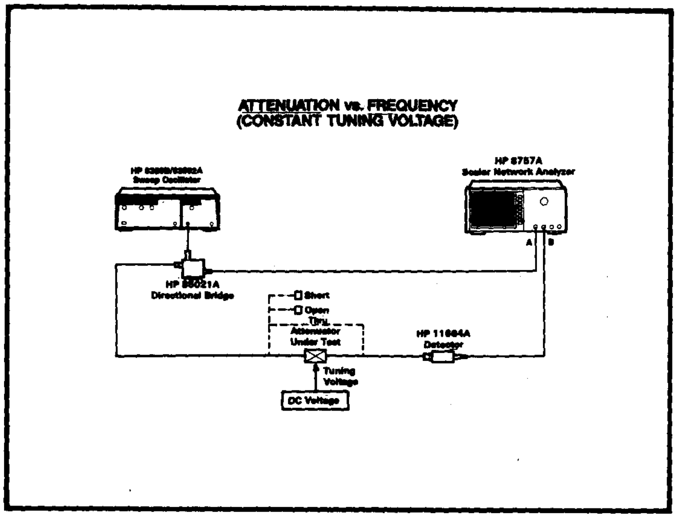
EXAMPLE MEASUREMENT:

Voltage Controlled Attenuator

TO MEASURE:

- **Attenuation vs. Frequency**
- **Attenuation vs. Tuning Voltage**

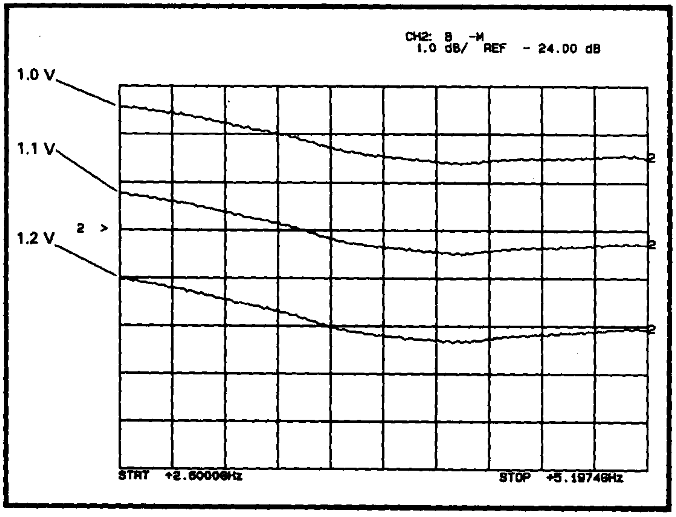
3291



ATTENUATION vs. FREQUENCY (CONSTANT TUNING VOLTAGE)

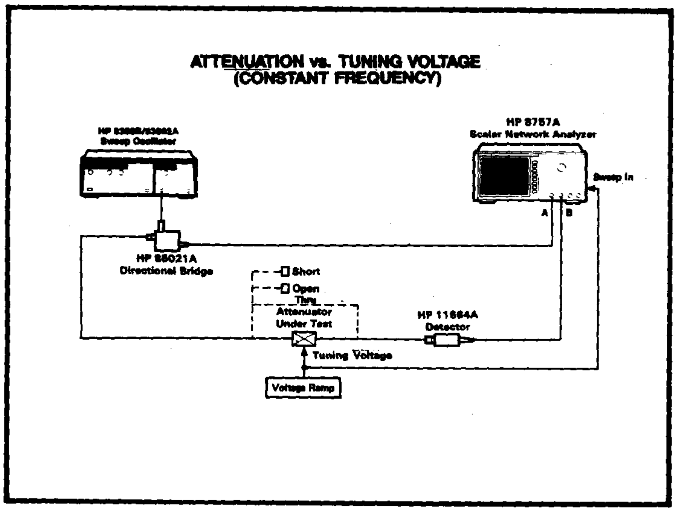
3292

The first measurement is of frequency response at a constant tuning voltage. This attenuator operates from 2.6-5.2 GHz.



3293

Shown here is the attenuation vs. frequency for several values of tuning voltage. The entire frequency range can be observed as the tuning voltage is adjusted.



ATTENUATION vs. TUNING VOLTAGE (CONSTANT FREQUENCY)

3294

Another way of characterizing this device is by observing the swept voltage response while the microwave source is held at a constant frequency. The HP 8757A non-standard sweep mode is very useful here. On request, the HP 8757A can scale any voltage ramp in the 0-10 V range for full screen display. In this example, a 1-4 V triangle wave from a function generator is used to drive not only the VCA tuning input, but also the HP 8757A sweep input. The microwave source remains at one frequency.

FEATURE

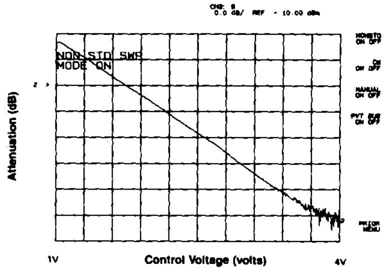
Non-Standard Sweep (Voltage Ramp Scaling)

ADVANTAGE

Easy Full Screen Measurement of Voltage Controlled Devices

3296

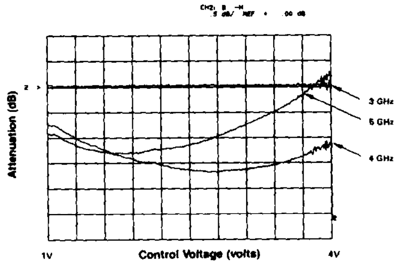
The measurement shows how the attenuation increases linearly as the voltage increases. But this only shows the response at one frequency. If the frequency of the source was now varied, you could see how this voltage response changed. But it would be difficult to see variations in a sloped line on this scale.



3295

An even better way to view frequency response is to normalize the response to one particular frequency and then adjust the frequency. This shows voltage response variations with frequency on a much greater vertical resolution. In this plot the response at 3 GHz was stored in memory, and the normalized responses at 4 GHz and at 5 GHz were recorded.

ANOTHER WAY TO VIEW THE FREQUENCY RESPONSE:



3297

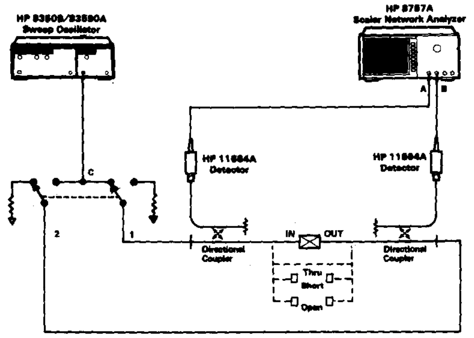
EXAMPLE MEASUREMENT:
Isolator

TO MEASURE:

- **Insertion Loss (Forward and Reverse)**
- **Return Loss (Input and Output)**

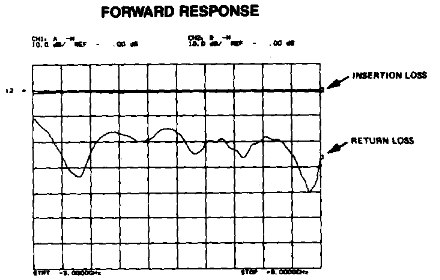
3098

An isolator is a broadband passive device which is designed to provide good output match with high reverse isolation. In this example, the input and output characteristics of this isolator will be measured in one setup.



3298

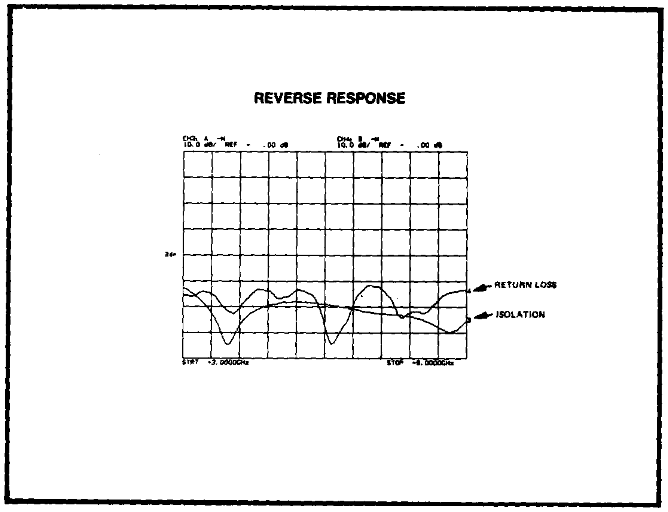
This setup uses a switch and two directional couplers to provide two different paths of signal flow. When terminal 1 is connected to terminal C, the signal is incident on the input of the isolator, and the input return loss and forward insertion loss can be measured. When terminal 2 is connected to terminal C, the signal is incident on the output of the device and the output return loss and reverse isolation can be measured. Note that this switch provides termination for the unconnected switch position, which is necessary to avoid re-reflections.



3299

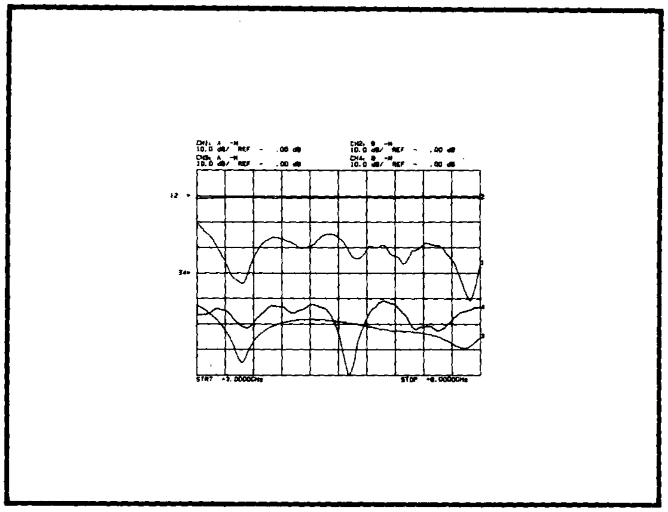
This plot shows the forward response (C-1), return loss and insertion loss. Note that the forward insertion loss is relatively low.

This plot shows the reverse response (C-2), output return loss and reverse isolation. Note that the isolation is relatively high (20 dB).

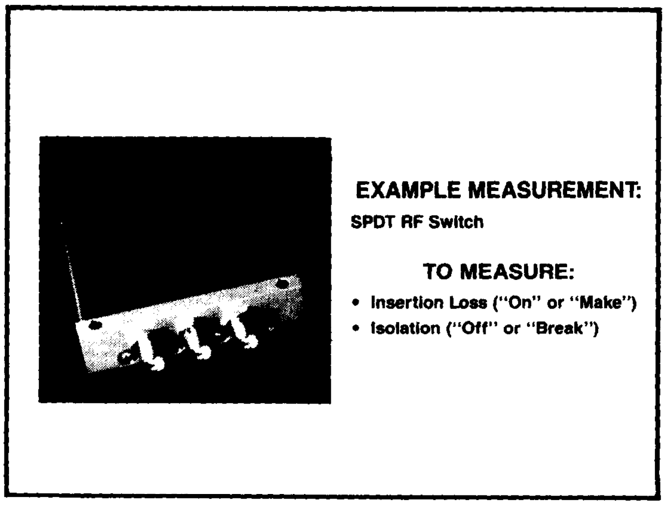


REVERSE RESPONSE

With the HP 8757A in this setup, it is possible to display all four parameters simultaneously.



Our last broadband passive device example is a single pole double throw switch to be tested from 2-18 GHz. We will measure the parameters at one terminal only, both insertion loss (with that terminal connected) and isolation (with that terminal unconnected).



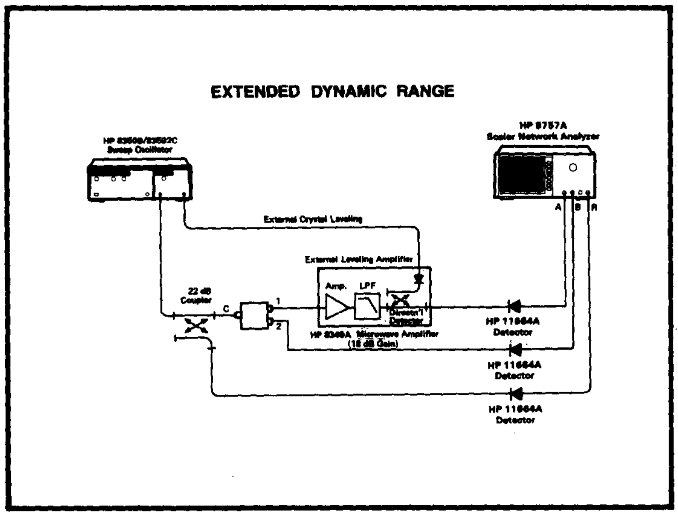
EXAMPLE MEASUREMENT:

SPDT RF Switch

TO MEASURE:

- **Insertion Loss ("On" or "Make")**
- **Isolation ("Off" or "Break")**

3097



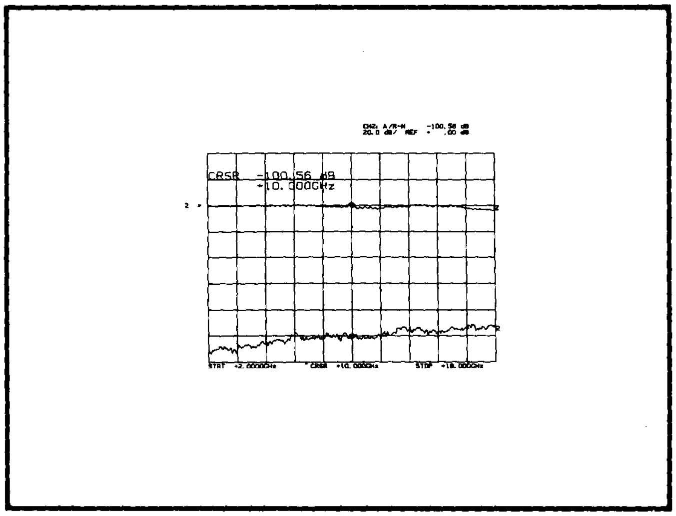
EXTENDED DYNAMIC RANGE

3301

Since switch isolation is often very high (>100 dB), an extended dynamic range setup is required to make this measurement. In this setup, an HP 8349A amplifier is inserted in the path of the switch position being measured (position 1 in this diagram).

With the C-1 connection made, we can measure the "on" insertion loss of position 1 as the ratio A/R.

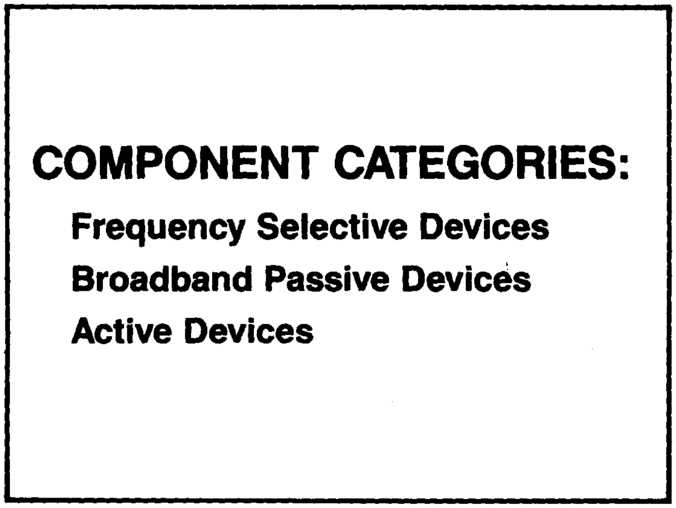
With the C-2 connection made, we can measure the "off" isolation of position 1, still the ratio A/R.



3305

This plot shows the resulting data, measuring 100 dB of isolation.

Note that the same measurements could be made for switch position 2 by inserting the amplifier between switch position 2 and the B detector.



COMPONENT CATEGORIES:

Frequency Selective Devices

Broadband Passive Devices

Active Devices

3306

The next device category is active devices.

The most common active devices are amplifiers, and 3 common types of amplifiers are shown here. GaAsFET amplifiers have been designed to operate to very high frequencies (>40 GHz) and have good noise performance. Bipolar amplifiers typically provide higher output power, but the noise performance and frequency coverage are not as good as GaAsFET amplifiers. Travelling wave tube (TWT) amplifiers operate at very high power levels (e.g. 10 Watts).

AMPLIFIERS

- **GaAsFET**
- **Bipolar**
- **TWT**

3307

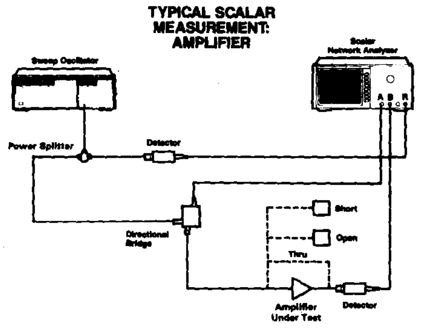
Amplifiers are characterized by many performance parameters, some of which are listed here. It is necessary to characterize amplifiers not only as a function of frequency, but also as a function of input power level. Some frequency and power response parameters can introduce distortion, but there are also other distortion parameters, such as harmonic and intermodulation distortion and noise figure. This discussion will include measurements of the scalar frequency response parameters and gain compression.

AMPLIFIER PARAMETERS

- **Gain and Gain Flatness**
- **Power**
- **Return Loss**
- **Reverse Isolation**
- **Phase Linearity/Group Delay**
- **Gain Compression (Saturation)**
  - **— Swept**
  - **— CW**
- **Harmonics**
- **Intermodulation Products**
- **Noise Figure**

3308

A typical scalar measurement of an amplifier is shown here. Note that ratioing is used so that calibration can be maintained as the power level to the input is changed. Since the power change will appear in both output arms of the power splitter, the ratio remains unaffected. Without ratioing, the system would have to be recalibrated each time the power level was changed.



3212

EXAMPLE MEASUREMENT:

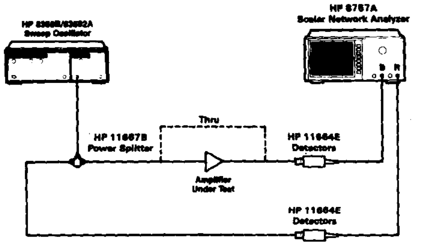
10 MHz to 2 GHz Bipolar Amp

TO MEASURE:

- Gain and Gain Flatness
- Gain Compression
- Power
- Return Loss (SWR)

3089

The first example measurement is a bipolar amplifier with about 40 dB of gain. We will use this example to illustrate many of the amplifier measurements.



3314

The measurement of gain is made with this setup. Notice that the calibration and the measurement will present different power levels to the B detector. The difference is the gain of the amplifier. It is important that the detectors' response not vary significantly as the incident power level is changed. This is specified as the dynamic accuracy of the detector and receiver.

FEATURE

Good Dynamic Accuracy

(Low Detector Response Variations with Power Level)

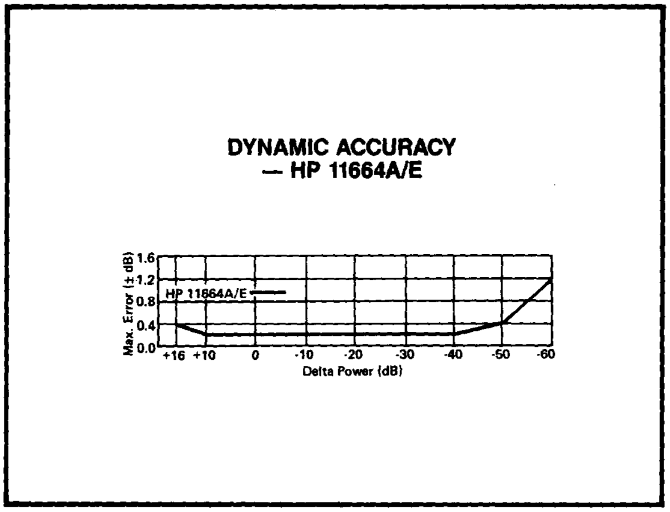
ADVANTAGE

Calibration Power Level and Measurement Power Level Can Be Different Without Adversely Affecting the Measurement

3316

Good dynamic accuracy is an essential feature in amplifier measurement applications so that the difference in power level between the calibration and the measurement will not cause significant measurement error.

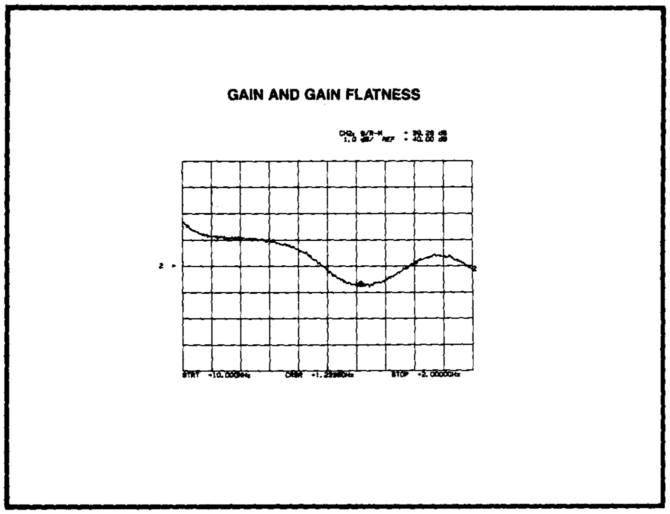
Shown here is the dynamic accuracy specification of the HP 11664A/E detectors when used with the HP 8757A scalar network analyzer. Note that even over a wide range in power, there is small response variation (<0.2 dB). Even wider ranges in power can be accomodated with only small measurement errors.


DYNAMIC ACCURACY
— HP 11664A/E

3317

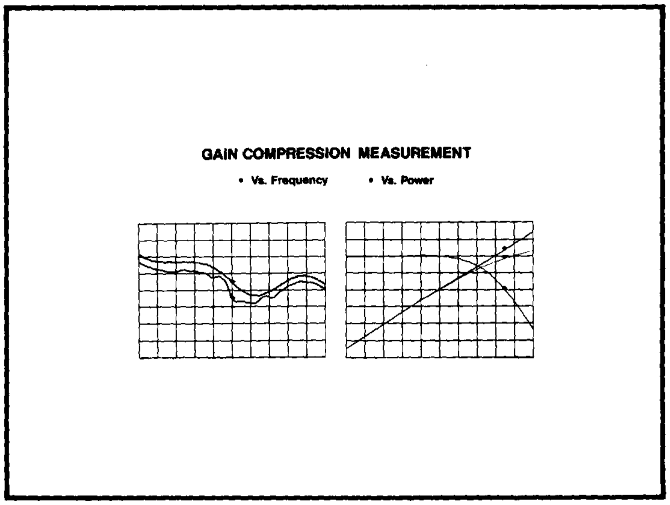
It is possible to avoid dynamic accuracy errors when measuring amplifiers with very high gain by inserting an attenuator after calibration. This can be used to minimize the change in power level between calibration and measurement. However, since the calibration does not include this attenuator, the frequency response of the attenuator will affect the normalized measurement.

This plot shows gain versus frequency. Cursor functions are useful in this measurement to determine max, min and peak-to-peak ripple.


GAIN AND GAIN FLATNESS

3315

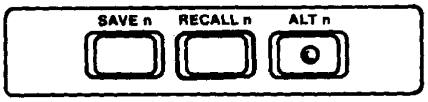
The next parameter to measure on this amplifier is gain compression or how the amplifier behaves in saturation. There are several ways to characterize gain compression. First, swept gain compression measurements can be made by simply increasing the power level at the input of the amplifier and observing how the gain trace falls. Another way to view this response is to sweep the input power while remaining at a constant frequency. Let's perform these measurements on the bipolar amplifier.


GAIN COMPRESSION MEASUREMENT

- Vs. Frequency
- Vs. Power

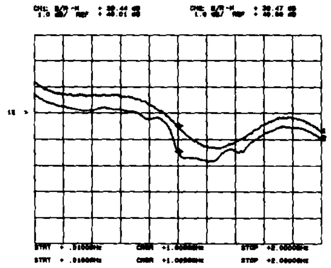
3320

SWEPT GAIN COMPRESSION MEASUREMENT USING ALTERNATE SWEEP



3321

To make the measurement of swept gain compression, the alternate sweep function is very convenient. Recall that alternate sweep allows you to view the response for two different front panel states. In measuring filters, we found that alternate sweep enabled us to view two frequency ranges simultaneously in real time. For the amplifier application, we sweep the same frequency ranges at two different power levels.



3322

The result is that you can view small signal gain and saturated gain at the same time. The source power simply toggles between two levels, and each response appears on one channel. As the power level is increased on one channel, you can see the gain trace drop as the amplifier saturates. At the same time you can still view the small signal gain in real time on the other channel. This makes gain compression measurements easy.

FEATURE

Alternate Sweep

ADVANTAGE

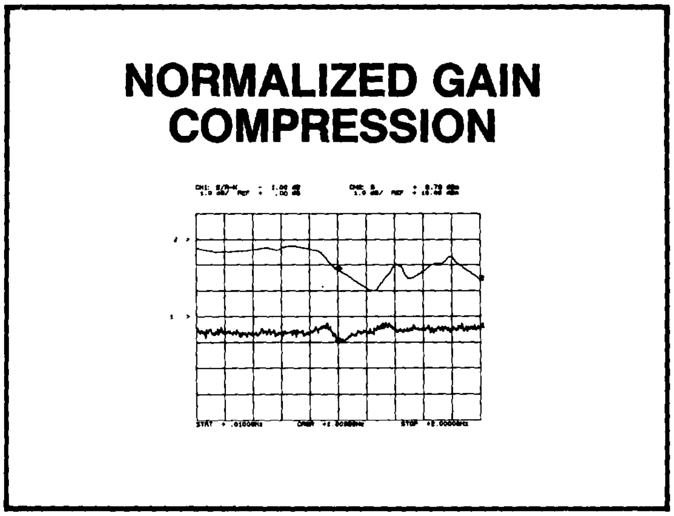
View Small Signal and Large Signal Gain
- **Simultaneously**
- **In Real Time**

Read Frequency Where 1 dB Compression First Occurs
Read Power (dBm) at 1 dB Compression on a Separate Channel

3323

The alternate sweep function allows simutaneous measurement of small signal gain and large signal (saturated gain) in real time. If adjustments or changes are made on the device, the operator can see how both the small and large signal gain are affected. The 1 dB gain compression point is often specified on amplifiers. This is the output power level at which the gain decreases by 1 dB. Using this measurement it is possible to see at which frequency gain compression first occurs. Using a third channel, the amplifier's maximum output power can be measured.

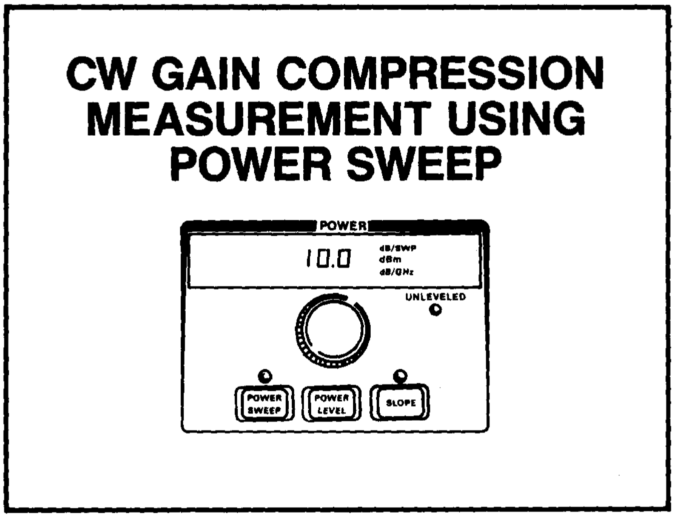
Swept gain compression can also be measured without using alternate sweep. By normalizing with respect to small signal gain, and then increasing the power level, you can see the gain trace drop from down from a horizontal line. This normalization makes it easier to see the gain compression, and is very useful in final test applications. Again the frequency and power level at 1 dB gain compression can be read easily.



NORMALIZED GAIN COMPRESSION

3324

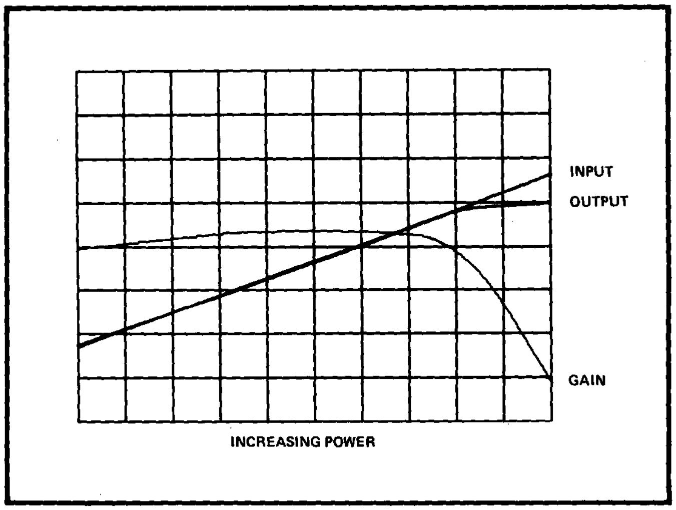
CW gain compression measurements can be made using the power sweep function of many HP swept sources. The power out of the source is swept linearly as the RF frequency remains constant.



CW GAIN COMPRESSION MEASUREMENT USING POWER SWEEP

3325

Now it is easy to see the rolloff in the gain, and the point at which the output power no longer linearly tracks the input power.



3326

FEATURE

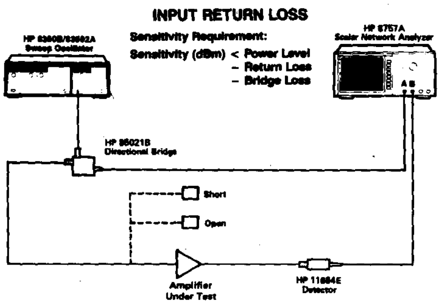
Power Sweep

ADVANTAGE

Show Gain vs. Input Power Level
Read Power (dBm) at 1 dB Compression

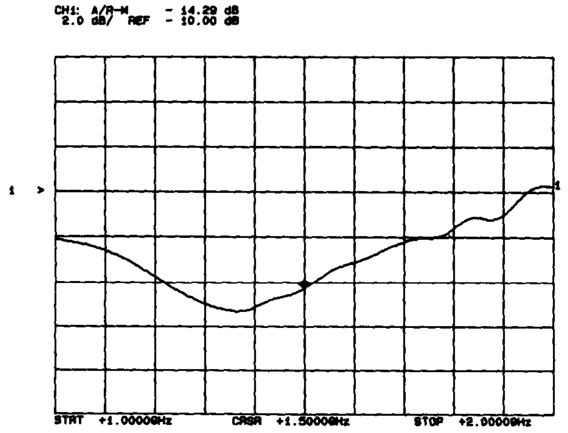
3328

The power sweep feature gives you the capability of making effective gain compression measurements at a single frequency. Use alternate sweep to locate the first frequency to compress by 1 dB, and then power sweep to read the compression power level.



3330

Amplifier input and output return loss are other important amplifier parameters that can be measured with scalar network analyzers. The setup for measuring input return loss is shown here. If the input return loss measurement is made at a very low power level (for example when measuring an amplifier with very high gain), the measurement can be limited by the sensitivity of the detectors used. The reflected signal being detected must be greater than the sensitivity of the bridge (or detector) that is detecting the reflected signal. This equation summarizes the sensitivity requirement. "Power level" is the test port power level, and "bridge loss" is any loss in the signal from the amplifier input to the detector (6 dB for a directional bridge).

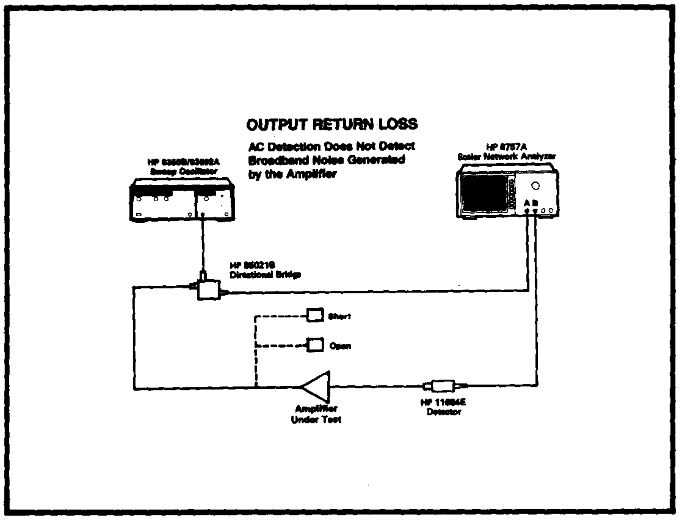


3331

For the example amplifier, sensitivity was not a limitation, since the signal being detected (-45 dBm) is larger than the bridge sensitivity (approx. -60 dBm). If it were a limitation (e.g. for a higher gain amplifier tested at lower input power level), it may be necessary to test input return loss at a higher input power level. The amplifier may go into saturation, and we must assume that the amplifier has the same return loss in saturation. This assumption may not be valid.

Measurements of output return loss can also be made using this setup. Note that the amplifier is just turned around.

In some measurements, the broadband noise generated by the amplifier (not present in the source) may degrade the signal detected by the bridge. However, this is only a problem for DC detection since all signals present are detected, including the broadband noise. With AC detection, the noise is not modulated, so it is not detected, and accurate gain measurements are achieved.



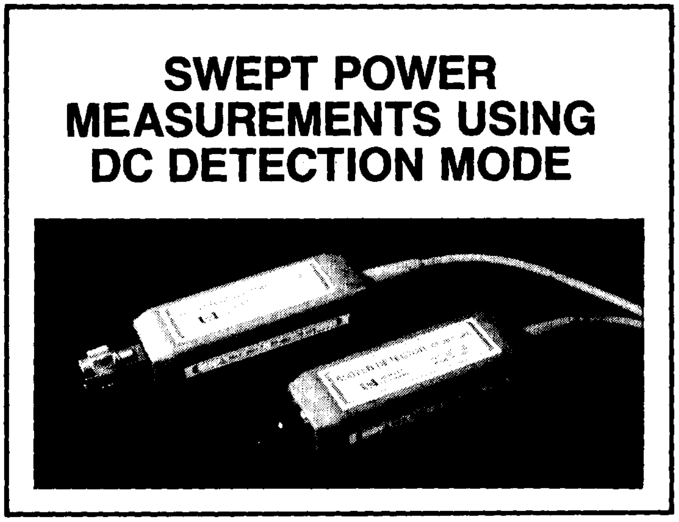
OUTPUT RETURN LOSS

AC Detection Does Not Detect Broadband Noise Generated by the Amplifier

3332

Another common amplifier measurement is the measurement of output power (dBm) versus frequency. This measurement can be made accurately and quickly using the HP 85025A/B detectors in DC detection mode. A power meter still provides the more accurate power measurements, but the scalar analyzer provides swept frequency power measurements which can be accomplished more quickly.

(Power measurements can also be made in AC detection mode, but this is dependent on the RF modulation, which may vary.)

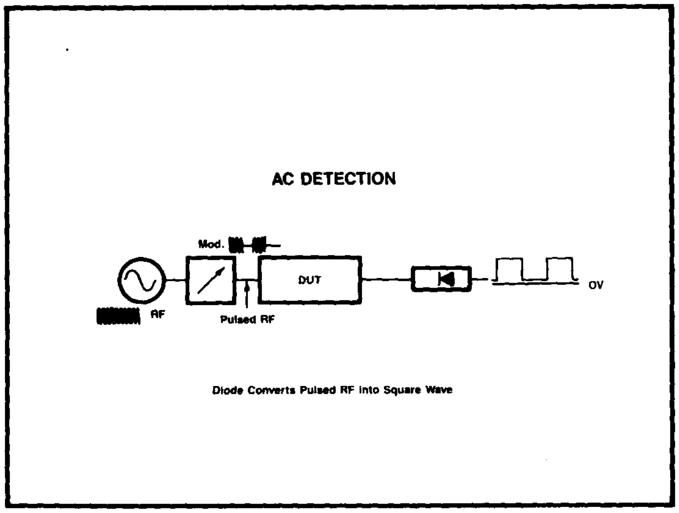


SWEPT POWER MEASUREMENTS USING DC DETECTION MODE

3329

A review of AC/DC detection is helpful at this point to see which mode is more appropriate in amplifier measurements.

With AC detection, the detector responds only to signals that are modulated by a specific frequency (27.8 kHz for the HP 8757A/56A). Any unmodulated signals are not detected.



AC DETECTION

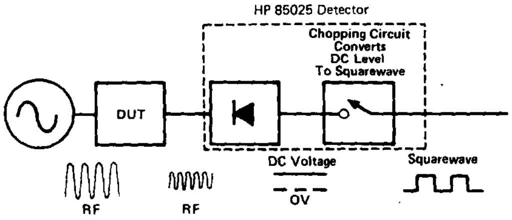
Diode Converts Pulsed RF Into Square Wave

AC DETECTION

- **For Accurate Ratio Measurements Even in the Presence of:**
  - **Spurious Signals**
  - **Broadband Noise**
  - **Thermal Drift**

AC detection mode is ideal for accurate ratio measurements, and for measurements in the presence of broadband noise or other spurious signals. The effect of thermal drift is virtually eliminated.

DC DETECTION



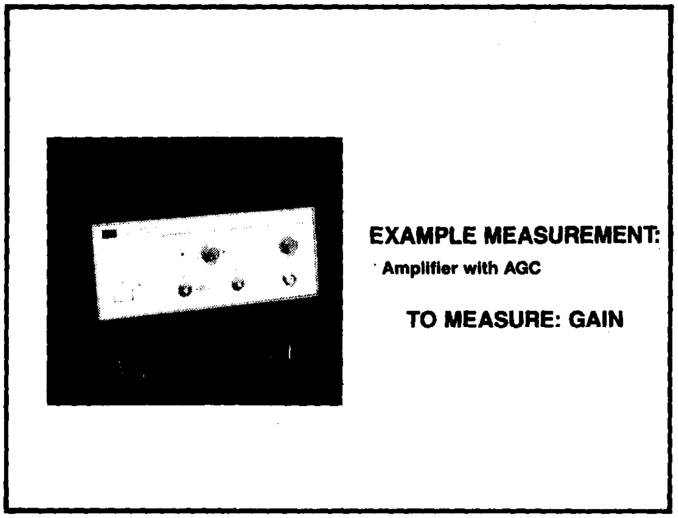
In DC detection mode, the diode provides a DC output voltage proportional to the power of all signals at the input, modulated or not. This signal is then chopped at a 27.8 kHz rate to simulate the signal provided by AC detection. This method of DC detection permits the use of the receiver's AC log amplifiers which provide fast response time in either AC or DC mode.

DC DETECTION

- **For Accurate Swept Power Measurements**
- **When Modulation Affects the Measurement**
  - **— Amps with Automatic Gain Control (AGC)**
  - **— Amps that are Sensitive to Average RF Power (TWTA's, Temperature Sensitive Amps)**
  - **— Amps with Gain at Low Frequency (<1 MHz)**
  - **— Self-Biasing Amplifiers**

DC detection is very useful for swept frequency power measurements, as already discussed, and for measurements that are adversely affected by modulation. Some examples are listed here. One of these examples is an amplifier with automatic gain control (AGC). Let's take a closer look at how modulation affects this measurement.

This amplifier includes an AGC. The user controls the output power with a front panel knob, and the amplifier adjusts its gain to provide that power at its output.



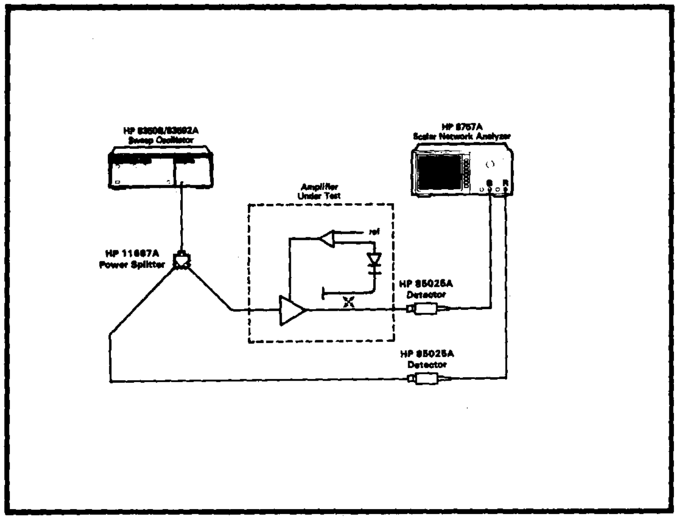
EXAMPLE MEASUREMENT:

· Amplifier with AGC

TO MEASURE: GAIN

3336

Again, ratioing is done to improve the source match and normalization is done with a "thru" connection. Within the amplifier, a sample of the output power is detected and compared to a reference voltage. The amplifier's gain is adjusted to provide the desired output power level over a whole range of input power levels. Note that we are using an HP 85025A detector to perform the gain measurement in both AC and DC detection modes.

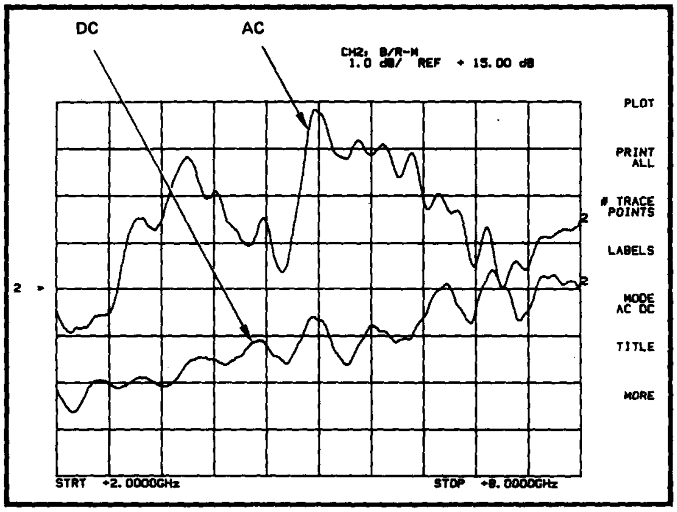


3337

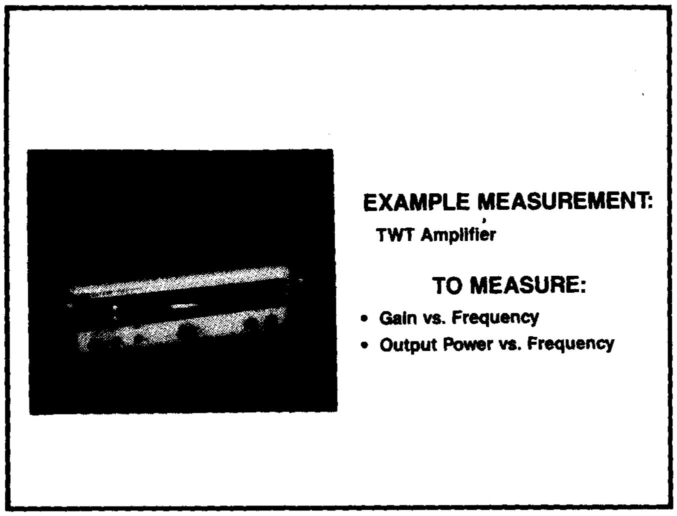
In DC mode, the amplifier input and output are unmodulated. The detector chops this signal to form a 27.8 kHz square wave for the receiver.

In AC mode, the input to the amplifier is square wave modulated. The AGC tries to adjust its gain to track the modulation, but fails. The result is that a distorted square wave is sent back to the receiver, and errors result in the measurement.

This plot shows the data measured in both AC and DC modes. The higher reading in AC mode is the result of overshoot and ringing in the detected signal. DC detection provides a more accurate measurement in this application.



3338



EXAMPLE MEASUREMENT:

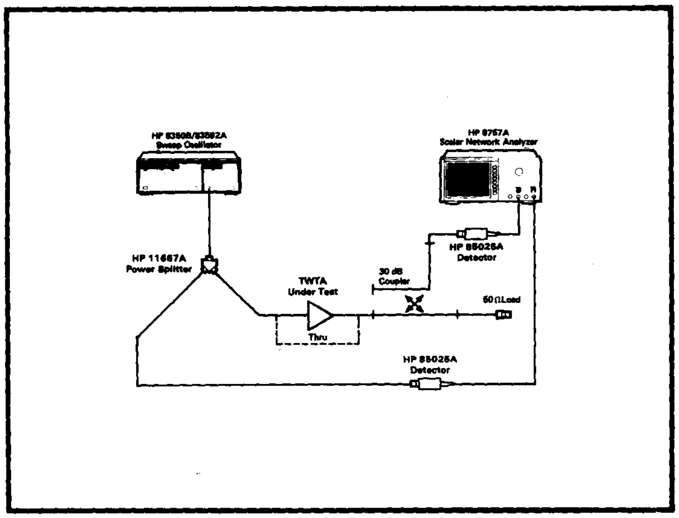
TWT Amplifier

TO MEASURE:

- **Gain vs. Frequency**
- **Output Power vs. Frequency**

3339

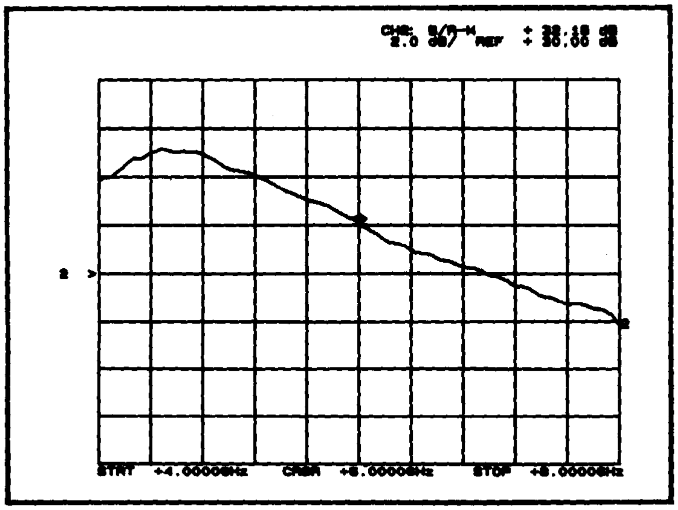
The last active device measurement is of a 4-8 GHz traveling wave tube amplifier (TWTA). For this example, we will measure gain.



3340

This is the setup used for this measurement. Since the output power of the TWTA is so high (1W or +30 dBm), the output is sampled with a 30 dB coupler to avoid overdriving the B detector. Notice that the coupler's response is included in the calibration.

DC detectors are used to avoid using modulation which may affect the behavior of the TWTA.



3341

The resulting gain data is shown here.

The next component category is frequency translation devices. These are devices that change the frequency of an input signal.

COMPONENT CATEGORIES:

- Frequency Selective Devices
- Broadband Passive Devices
- Active Devices
- Frequency Translation Devices

Mixers are the main focus of this discussion on frequency translation devices They provide a signal at the output whose frequency is the sum or difference of the signals on the two inputs. Another device that translates frequency is the multiplier, which is used to provide a signal at its output whose frequency is double or triple the frequency at its input.

FREQUENCY TRANSLATION DEVICES

- Mixers
  - Upconverters
  - Downconverters
- Multipliers
  - Doublers
  - Triplers

The mixer parameters we will discuss here are very similar to the amplifier parameters. The frequency response parameters include conversion loss (the power loss associated with the frequency translation) and return loss on all ports.

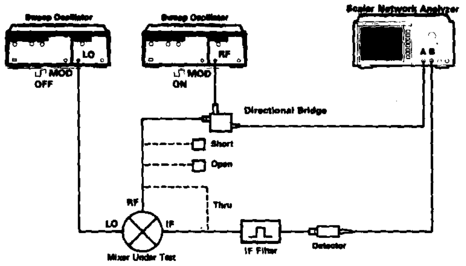
Like an amplifier, a mixer will saturate when the input power is increased. This causes the conversion loss to increase. This conversion compression can be measured in the same way gain compression is measured on amplifiers, either swept or CW.

Harmonics, intermodulation products, and noise performance of mixers can also be characterized with a spectrum analyzer and noise figure meter.

MIXER PARAMETERS

- Conversion Loss
- Power Out
- Isolation (e.g. LO Feedthrough)
- Return Loss (SWR)
- Phase Linearity/Group Delay
- Conversion Compression
  - Swept
  - CW
- Harmonics
- Intermodulation Products
- Noise Figure

TYPICAL SCALAR MEASUREMENT: MIXER



Shown here is a typical scalar measurement made on a mixer. Notice the need for two RF sources to stimulate two of the mixer ports. For example, if the mixer under test is being tested as a downconverter, then two sources are required, one to simulate the RF and one to simulate the LO (local oscillator). The mixing products will appear at the IF port. It may then be necessary to filter the IF before detection. (For more information on this "two tone" configuration, refer to HP Application Note 312-1.)

EXAMPLE MEASUREMENT:

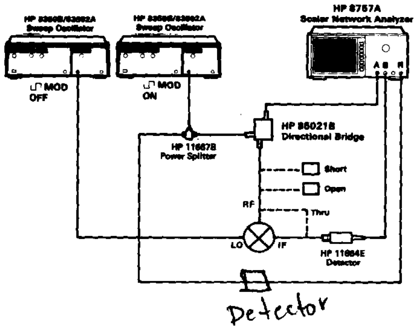
Downconverting Mixer

TO MEASURE:

- Conversion Loss (Fixed LO)
- Conversion Loss (Fixed IF)
- Conversion Compression
- Return Loss (Input and Output)

Note that the RF is modulated but the LO is not. AC detection mode will detect only the modulated signal, that is the signal from the RF port. The signal from the LO port (LO feedthrough) will be ignored. This makes AC detection a significant advantage in many mixer measurement applications.

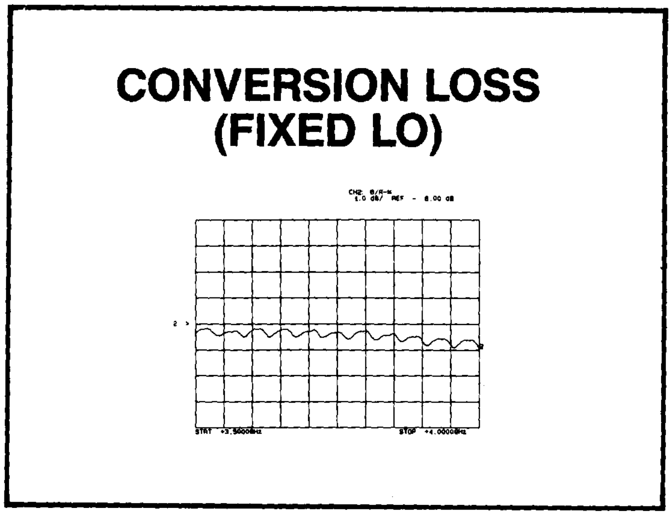
This mixer's RF and LO operate from 2-12 GHz, and the IF operates from 10 MHz to 1 GHz. We will test the mixer for its use as a downconverter. We will show two kinds of conversion loss measurements. The first uses a fixed LO and a swept RF to produce a swept IF at the detector. In the second measurement, the IF is held constant by causing the RF and LO to sweep in unison with a fixed frequency offset.



This setup is used to perform conversion loss and return loss measurements.

Notice also that the calibration is done at a different frequency than the measurement. This means that the frequency response of the detectors will be different between calibration and measurement. It is therefore essential that the detector flatness (vs. frequency) be very good so that this error is minimized.

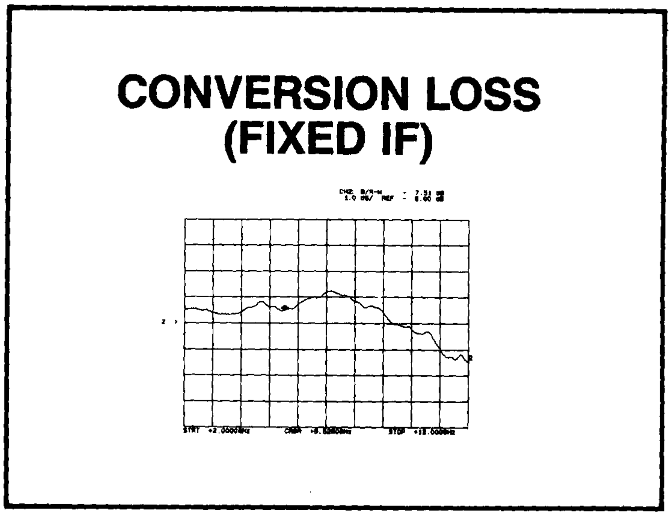
In this measurement the LO is fixed at 3 GHz, and the RF is swept from 3.5 to 4.0 GHz. This sweeps the IF (the difference between the LO and the RF) from 500 MHz to 1 GHz. Note that the frequency annotation is for the RF and not for the IF, even though it is the IF that is actually being detected.



CONVERSION LOSS (FIXED LO)

3351

Since the IF range is only 10 MHz to 1 GHz, complete characterization of the mixer using the fixed LO method would require many steps to cover the entire 2-12 GHz range. By causing the RF and the LO to sweep together offset by a constant frequency (the IF), it is possible to make broadband sweeps. Here the IF is fixed to 100 MHz, with the LO sweeping from 2.1-12.1 GHz and the RF sweeping from 2-12 GHz. (A communication interface between the sweepers controls this dual sweep.)

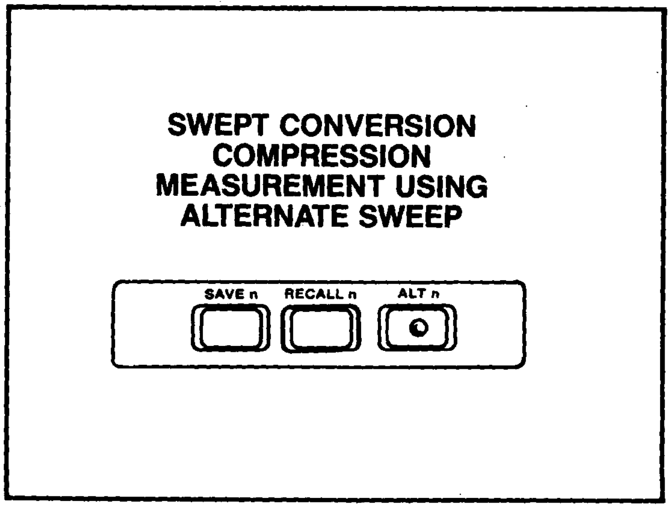


CONVERSION LOSS (FIXED IF)

3352

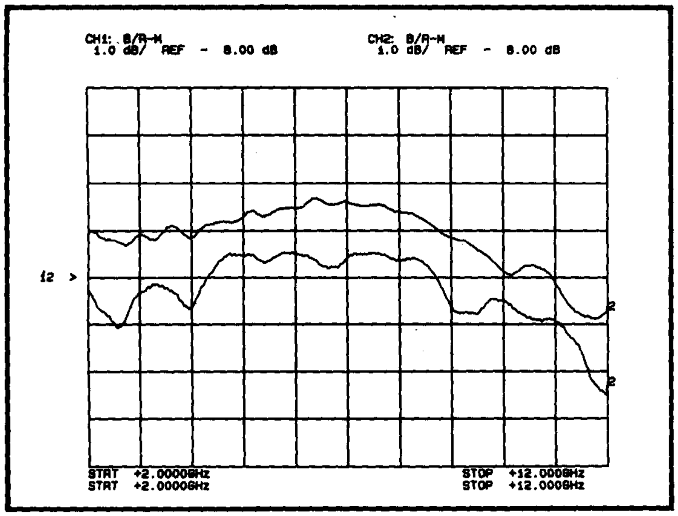
Now let's see how the conversion loss increases as the power level is increased.

Just as in the amplifier example, we can measure swept conversion compression or compression versus input power level at a single frequency. Using alternate sweep we can alternate between small signal and large signal compression.



SWEPT CONVERSION COMPRESSION MEASUREMENT USING ALTERNATE SWEEP

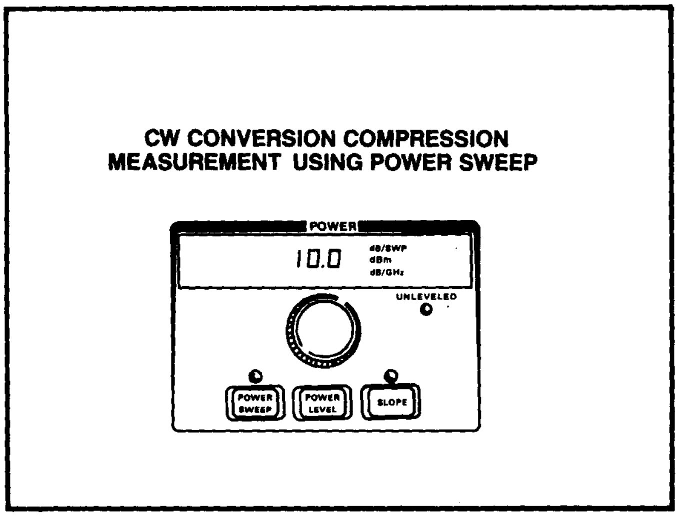
3354



3355

Here we can see the conversion loss over frequency at two power levels, one trace is the small signal conversion loss and the other shows saturation and increased conversion loss.

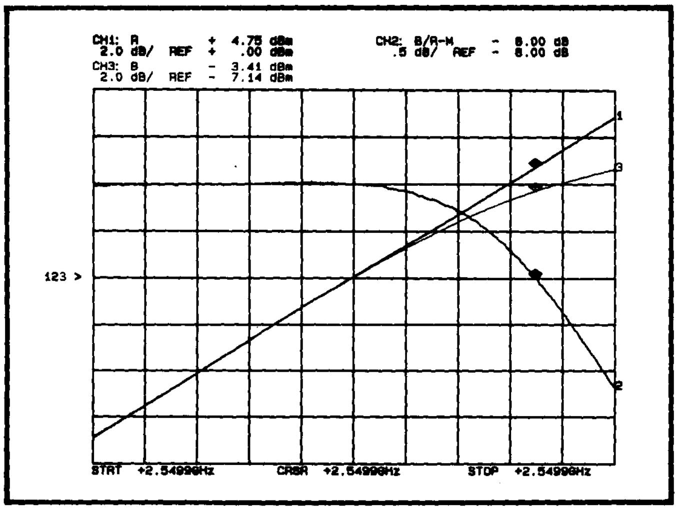
Again, alternate sweep allows the operator to view both responses in real time, and to read the frequency at which compression first occurs.



CW CONVERSION COMPRESSION MEASUREMENT USING POWER SWEEP

3458

When the RF and LO are each kept at a single frequency, we can use the power sweep function to characterize conversion compression versus power level.



3459

With power sweep, the RF power is increased linearly and conversion loss can be viewed as a function of power. Note that when saturation is reached, the IF power (B) no longer tracks the RF power (R), and the conversion loss (B/R) increases.

Oscillators are the next component category.

COMPONENT CATEGORIES:

- Frequency Selective Devices
- Broadband Passive Devices
- Active Devices
- Frequency Translation Devices
- Oscillators

There are three common types of oscillators: YTO's, VTO's, and fixed oscillators.

OSCILLATORS

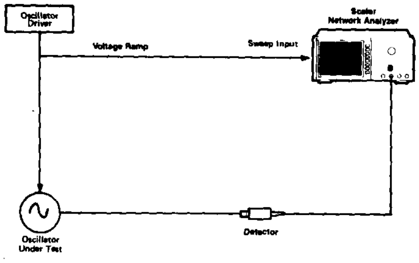
- YIG Tuned Oscillators (YTO)
- Varactor Tuned Oscillators (VTO)
- Fixed Oscillators (e.g. Dielectric Resonators)

Some of the common oscillator parameters are shown here. Scalar network measurements are best suited for the measurement of swept output power as a function of tuning voltage or current.

OSCILLATOR PARAMETERS

- Power Output (e.g., vs. Tuning Voltage)
- Frequency (e.g., vs. Tuning Voltage)
- Phase Noise
- Impedance

TYPICAL SCALAR MEASUREMENT: OSCILLATOR



3364

This set-up shows the typical configuration for an oscillator measurement. Note that no external source is required to stimulate the device since the oscillator generates its own RF power.

Power measurement accuracy is perhaps the most critical feature of an oscillator measurement system. A feature that offers great convenience for testing tuned oscillators is the ability to use any voltage ramp to drive the display of the analyzer. The HP 8757A non-standard sweep function is ideal for this application.

EXAMPLE MEASUREMENT:

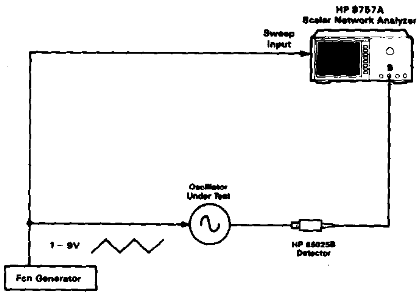
VTO (3.7-4.2 GHz)

TO MEASURE:

Swept Power Out
vs. Tuning Voltage

3099

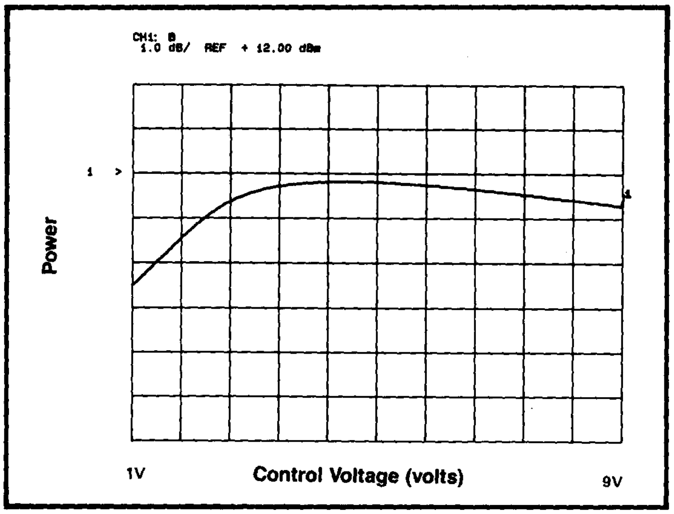
This example is a varactor tuned oscillator, and will be characterized by output power versus tuning voltage.



3366

The set-up includes a function generator to provide the volage ramp (triangle wave) for the tuning input of the oscillator and for the sweep input of the analyzer. Notice that DC detection is used since the oscillator output is not modulated.

The resulting plot shows power versus tuning voltage. A frequency counter could be used to see how frequency varies with tuning voltage. If the oscillator frequency is a linear function of tuning voltage, then the power versus voltage plot could be scaled to show power versus frequency.



3367

The final device category is antennas.

COMPONENT CATEGORIES:

- Frequency Selective Devices
- Broadband Passive Devices
- Active Devices
- Frequency Translation Devices
- Oscillators
- Antennas

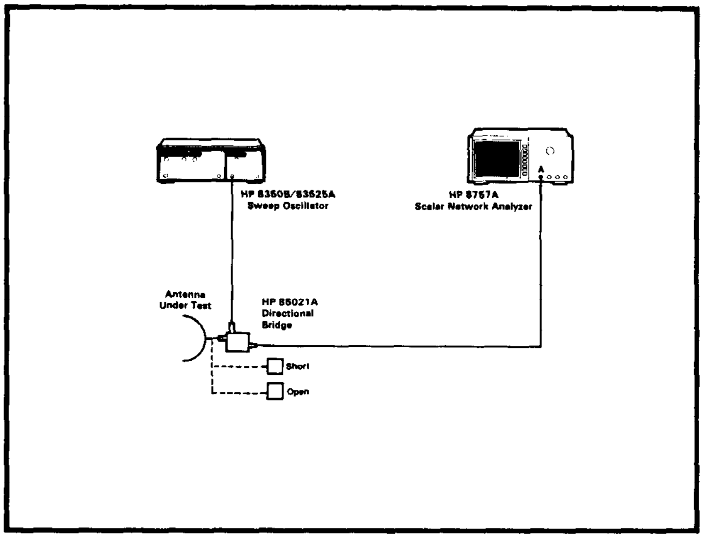
3368

Antennas are characterized by return loss and radiation pattern. Swept return loss measurements can be made using scalar network analysis.

ANTENNA PARAMETERS

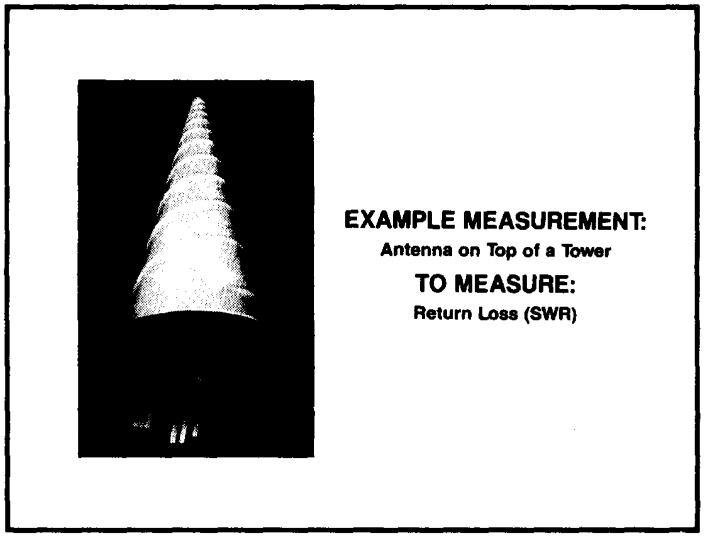
- Return Loss
- Radiation Pattern

3369



3515

A typical antenna return loss measurement is shown here. Because antenna measurements are often made in the presence of spurious signals, AC detection provides a significant advantage. Since spurious signals are not modulated by 27.8 kHz, they will not be detected in AC detection mode.



EXAMPLE MEASUREMENT:

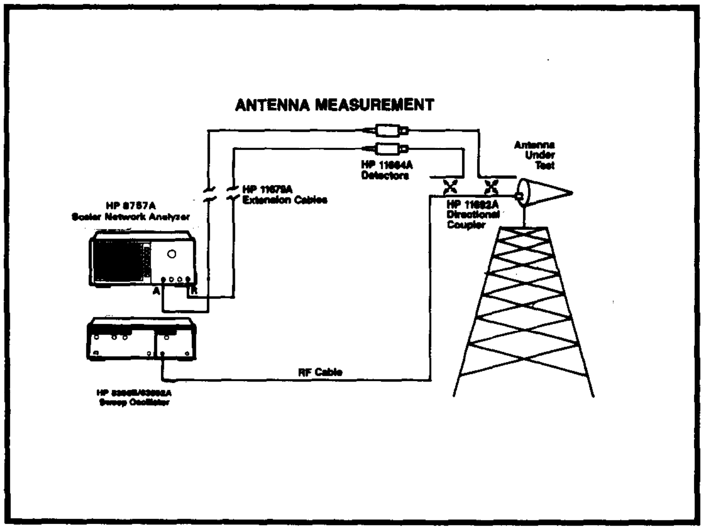
Antenna on Top of a Tower

TO MEASURE:

Return Loss (SWR)

3426

As an example, we will measure the return loss of this antenna. The antenna is situated in a remote location, about 20 feet from the test equipment.

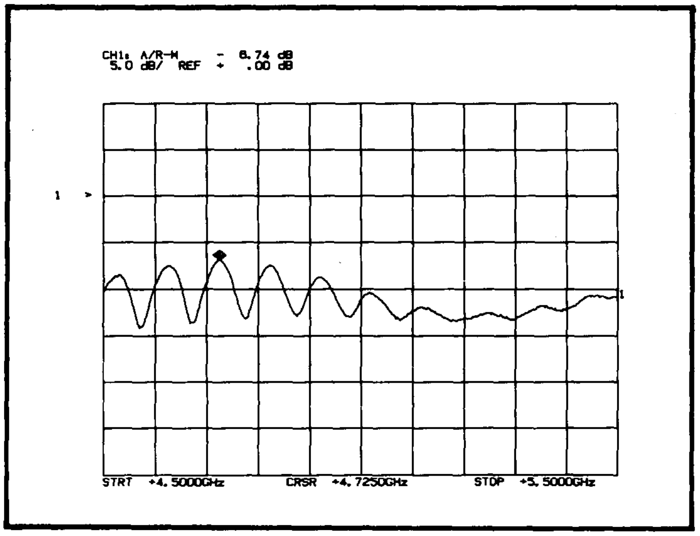


ANTENNA MEASUREMENT

3461

As shown here, the antenna is tested, without the need to lift heavy instruments up the tower to the antenna. The detector extension cables allow the detectors to be located far from the instruments with no degradation in performance. Note also that the incident and reflected signals are sampled using a dual directional coupler. In this application, ratioing removes the effects of the RF cabling from the source to the coupler.

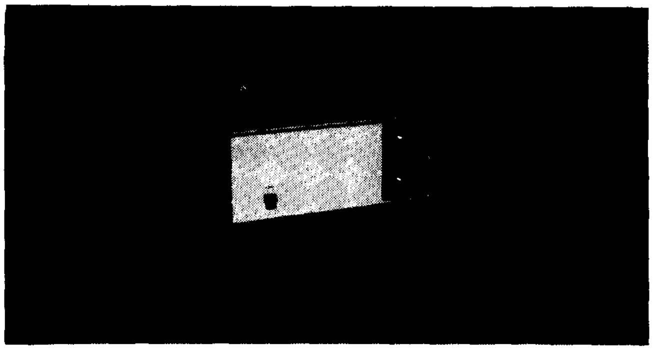
The resulting data plot shows the return loss from 4.5 to 5.5 GHz. This is a very important check to make sure that the antenna is not shorted before high power is delivered to it.



3374

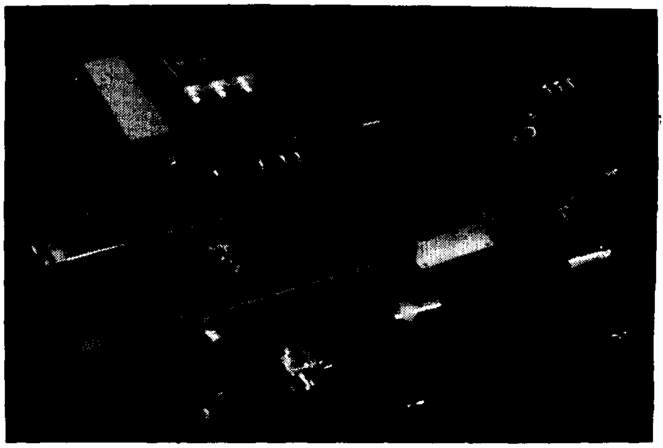
If higher power is required at the test port, an amplifier such as the HP 8349A can be used. The HP 8349A microwave amplifier can deliver up to +20 dBm from 2-20 GHz.

Use the HP 8349A Amplifier (2-18 GHz) for Higher Power at the Test Port



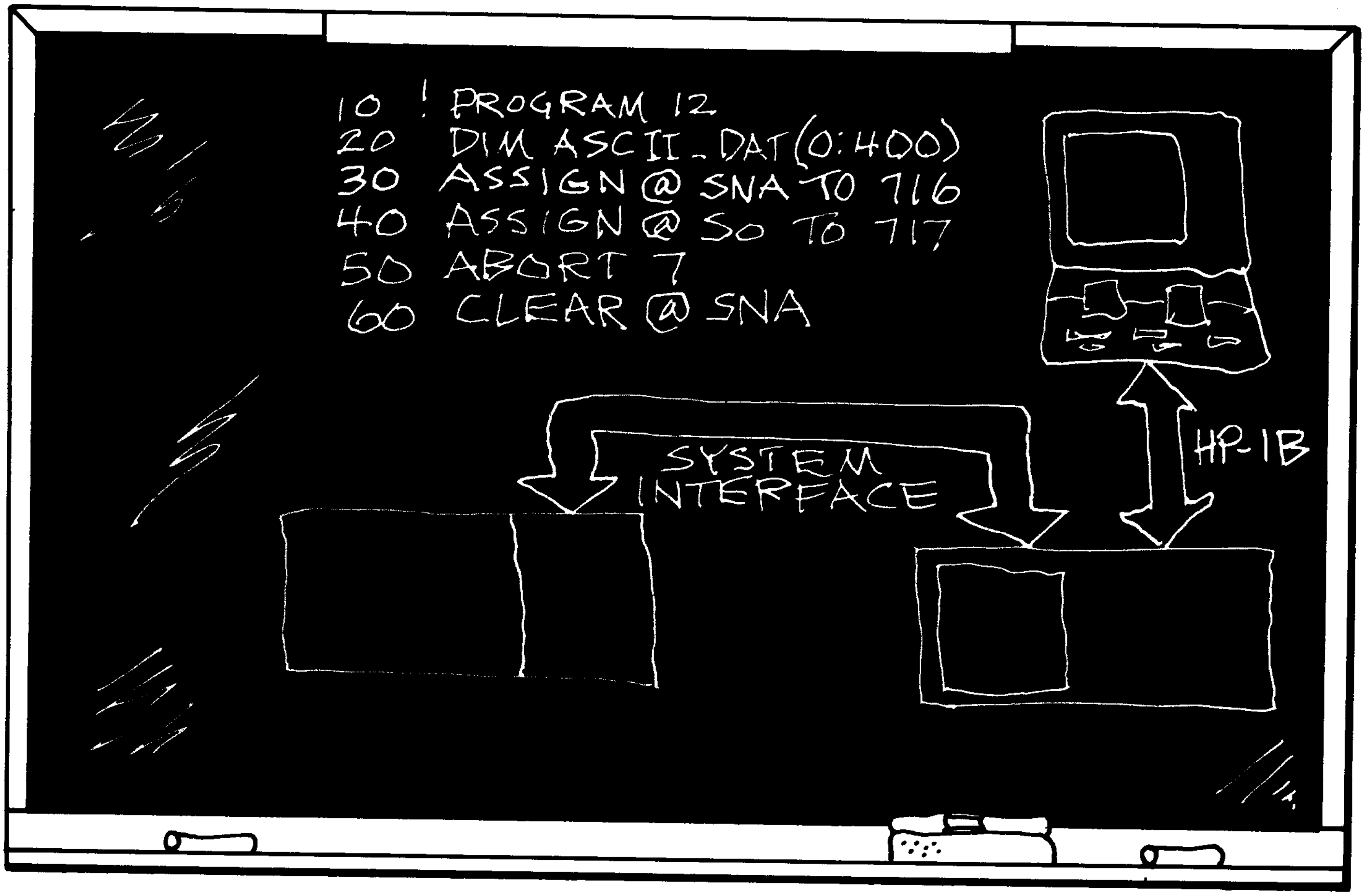
3375

There are many applications of scalar measurements. This section of the seminar has shown some of them. In the next section, we will see how automating scalar measurements can improve efficiency and provide more accurate results.



3087

Automatic Systems



```
10 ! PROGRAM 12
20  DIM ASCII_DAT(0:400)
30 ASSIGN @ SNA TO 716
40 ASSIGN @ So TO 717
50 ABORT 7
60 CLEAR @ SNA
```

Today's manufacturer of microwave components is faced with meeting increased demand for his products as the microwave industry continues its rapid growth. He must also find ways to consistently make his product so that it meets specification. And he must find ways to improve his process so that he can reduce costs and/or increase performance. Thus, the three biggest challenges facing today's manufacturer of microwave components are:

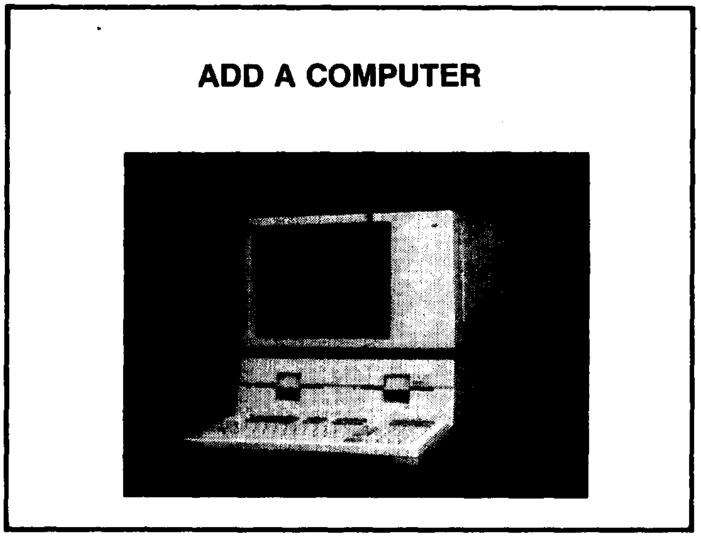
Productivity
Quality
Competitiveness.

TODAY'S CHALLENGES

- Productivity
- Quality
- Competitiveness

3110

One of the best ways to meet all three of these challenges is to add a computer to your measurement system.



ADD A COMPUTER

3111

Automating your measurement system offers these four main advantages. Let's take a look at each of these individually.

ADVANTAGES

- Measurement Speed
- Data Management
- Increased Accuracy
- Additional Measurement Capabilities

ADVANTAGE

Measurement Speed

3112

By increasing your measurement speed, you decrease test time. Many of our customers in the past have realized more than a tenfold decrease in their test times by automating their measurement systems. Let's look at several ways to reduce measurement time.

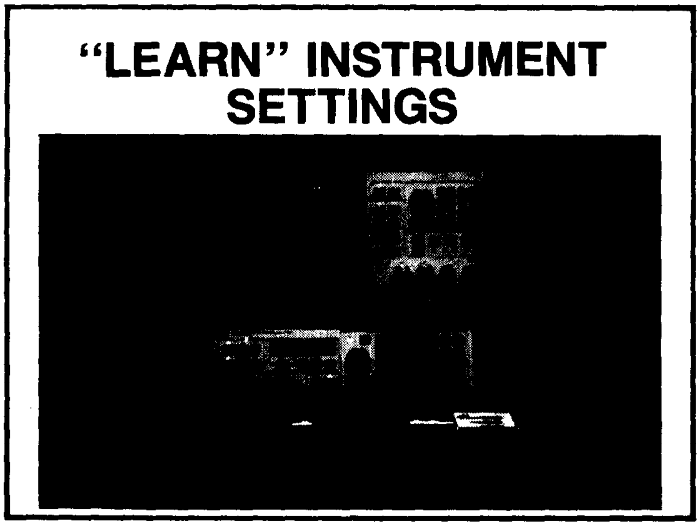
MEASUREMENT SPEED

Fast Setup of the Measurement

Increased Throughput

3114

Measurement Speed can be increased by two separate techniques. The first technique is to set up all of the test equipment to make the desired measurement. The second technique is to aid the test technician in either adjusting the device under test or verifying that the device meets specification. Let's take a closer look at these two techniques.

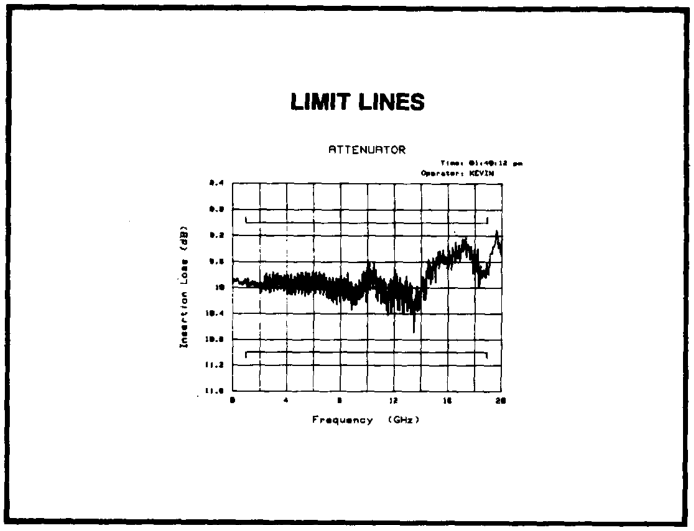


"LEARN" INSTRUMENT SETTINGS

3546

Save/recall registers of the source and analyzer allow several test configurations to be stored inside the equipment. A computer can learn each of these settings via a Learn String. Later this Learn String can be input to both instruments to restore these settings. The Learn String is usually much faster than sending individual programming commands; but both are significantly faster than performing the measurement setup manually.

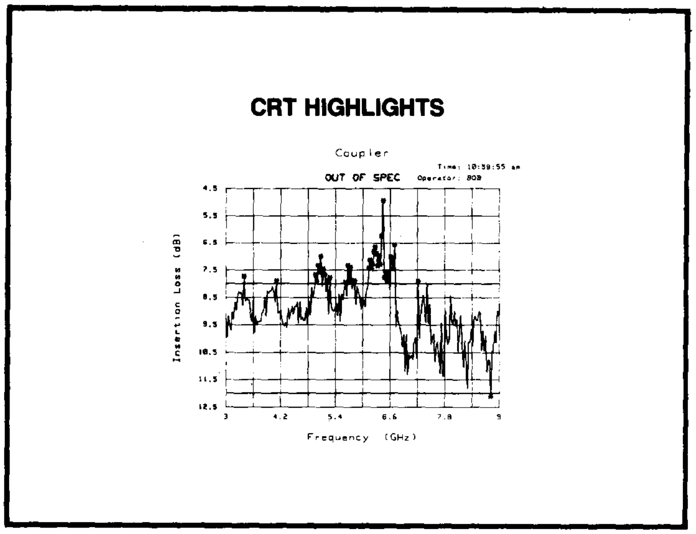
The use of Limit Lines is a graphical technique which allows the test technician to quickly compare his/her test data to the specification data.



LIMIT LINES

3117

The use of CRT highlights is an enhancement to the use of limit lines. Here, any data points which are out of spec are highlighted for even easier recognition by the test technician.



CRT HIGHLIGHTS

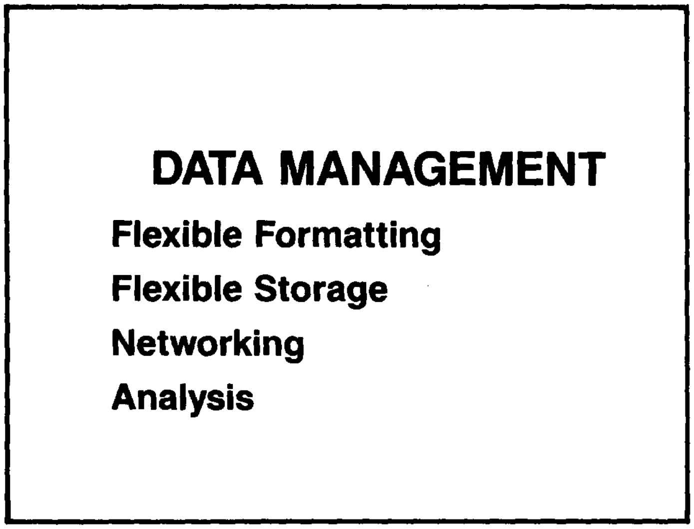
3118

The second major advantage of automating your measurement system is Data Management. Let's take a closer look at the enhancements offered by Data Management.

ADVANTAGES

- **Measurement Speed**
- **Data Management**

3112

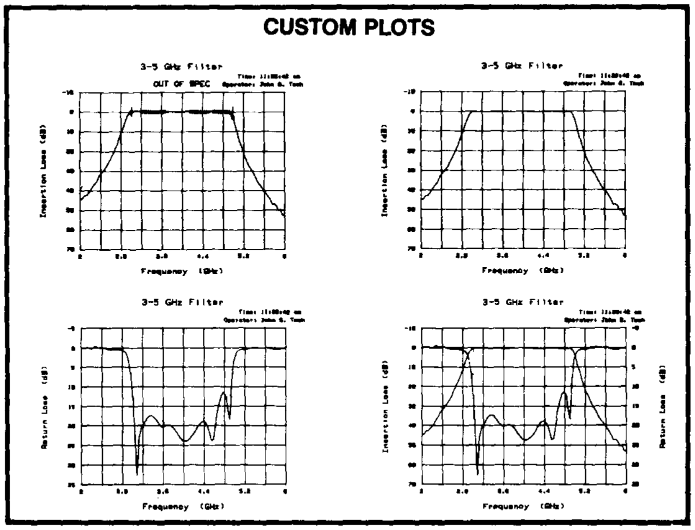


DATA MANAGEMENT

- Flexible Formatting
- Flexible Storage
- Networking
- Analysis

3122

Data Management can be integrated into an automatic measurement system by each of these techniques.

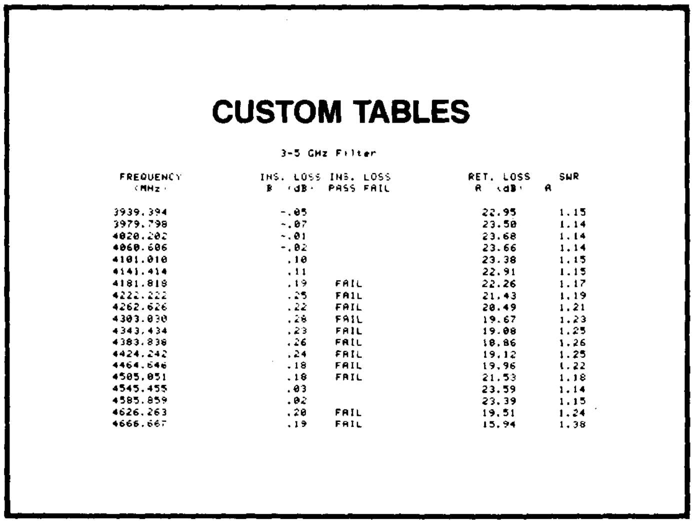


CUSTOM PLOTS

3124

Flexible Formatting is achieved by two features of an automatic system; custom plots and custom tables.

Here is an example of a custom plot. The operator can choose what data he wishes to plot, how to scale the plots, how many plots to place on a single page, and even operator name and time.



CUSTOM TABLES

3-5 GHz Filter

FREQUENCY (MHz)	INS. LOSS B (dB)	INS. LOSS PASS FAIL	RET. LOSS A (dB)	SWR A
3939.394	-.05		22.95	1.15
3979.798	-.07		23.50	1.14
4020.202	-.01		23.68	1.14
4060.606	-.02		23.66	1.14
4101.010	.10		23.38	1.15
4141.414	.11		22.91	1.15
4181.818	.19	FAIL	22.26	1.17
4222.222	.25	FAIL	21.43	1.19
4262.626	.22	FAIL	20.49	1.21
4303.030	.28	FAIL	19.67	1.23
4343.434	.23	FAIL	19.08	1.25
4383.838	.26	FAIL	18.86	1.26
4424.242	.24	FAIL	19.12	1.25
4464.646	.18	FAIL	19.96	1.22
4505.051	.18	FAIL	21.53	1.18
4545.455	.03		23.59	1.14
4585.859	.02		23.39	1.15
4626.263	.20	FAIL	19.51	1.24
4666.667	.19	FAIL	15.94	1.38

3125

Here is an example of a custom tabular printout. Once again, the operator can choose what data he wishes to print and how to organize it on a page. Specifying the pass/fail frequencies aids the technician.

Another technique of Data Management is Networking. Networking is the sharing of data, test programs, and peripherals.

The sharing of data allows the operator to perform analysis on a process and maintain better control.

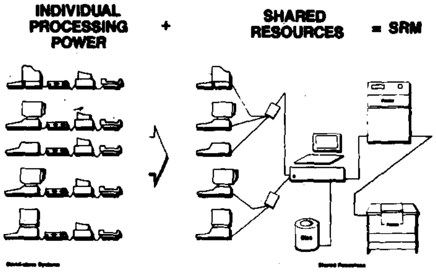
The sharing of programs allows each test station to share the same programs. Thus, if a change needs to be made, it can be done centrally and not at each individual station.

NETWORKING

SHARING OF:

- **Data**
- **Programs**
- **Peripherals**

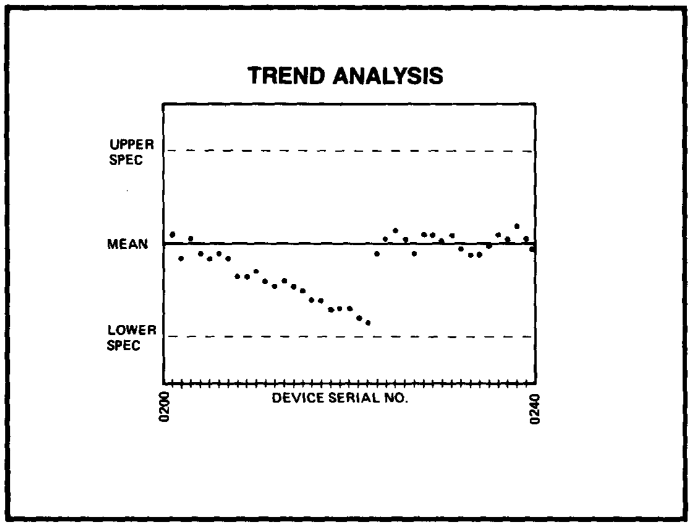
The sharing of peripherals allows operators to store data on a central disk and to share printers and plotters, thus saving equipment and overhead costs. An example of networking is a product sold by HP called Shared Resource Management or SRM. SRM is both the hardware and software needed to link many individual stations together into one system.



The final technique of Data Management is Data Analysis. An example of Data Analysis is Trend Analysis Control. Trend Analysis is a straightforward technique which allows you to monitor a manufacturing process. It allows you to observe any negative trends in a process and make changes before the problem gets out of hand.

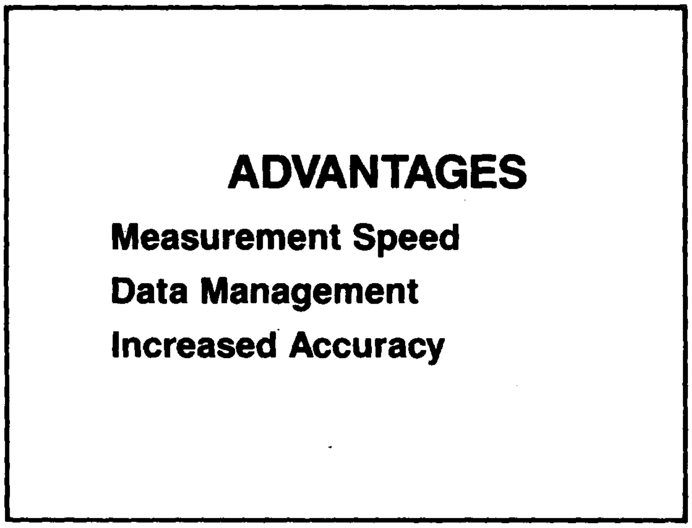
TRENDANALYSIS

Observing the Changes in a Process and Making Appropriate Corrections When Necessary



3132

Here is an example of trend analysis. In this case, the production engineer saw that the test data was drifting toward being out of spec. He then located and corrected the problem before any devices failed to meet specification.

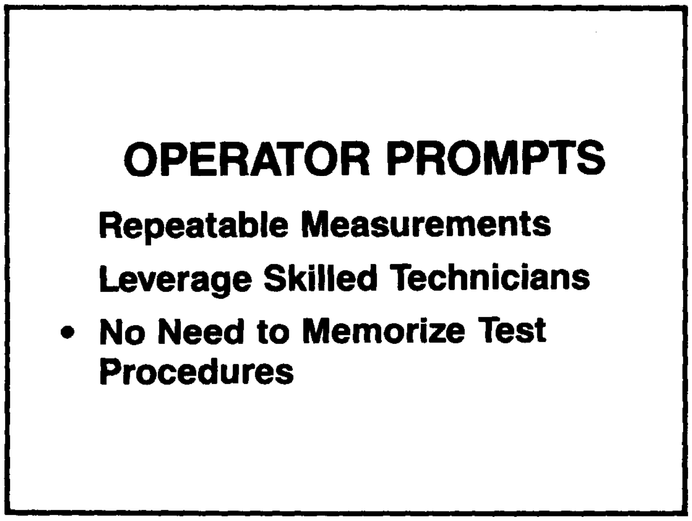


ADVANTAGES

Measurement Speed
Data Management
Increased Accuracy

3112

The third major advantage of automating your measurement system is Increased Accuracy.



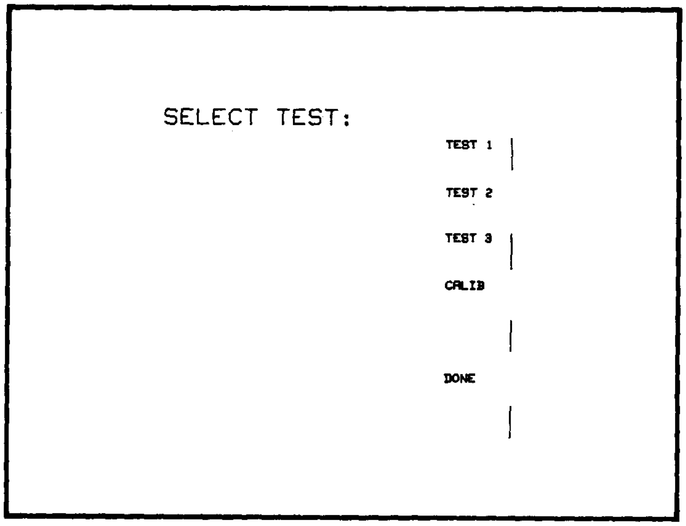
OPERATOR PROMPTS

Repeatable Measurements
Leverage Skilled Technicians
- No Need to Memorize Test Procedures

3142

Operator prompts are messages or instructions which can be displayed on the CRT. This results in more repeatable measurements because tests are not accidentally omitted or performed out of sequence. Operator Prompts can also allow less skilled technicians to perform complicated measurements and free your highly skilled technicians for more technical tasks. Operator Prompts also alleviate the need to memorize test procedures. This allows both the frequent and infrequent operator to perform complicated measurements without reading a test procedure manual.

The analyzer's CRT can be used as a terminal as opposed to the computer's display. Start by defining your own soft key labels, then detecting which front panel soft key was pressed. Here a complete selection of tests is presented to the operator. Guide the operator through each test by labelling the soft keys with the appropriate choices.



SELECT TEST:

TEST 1

TEST 2

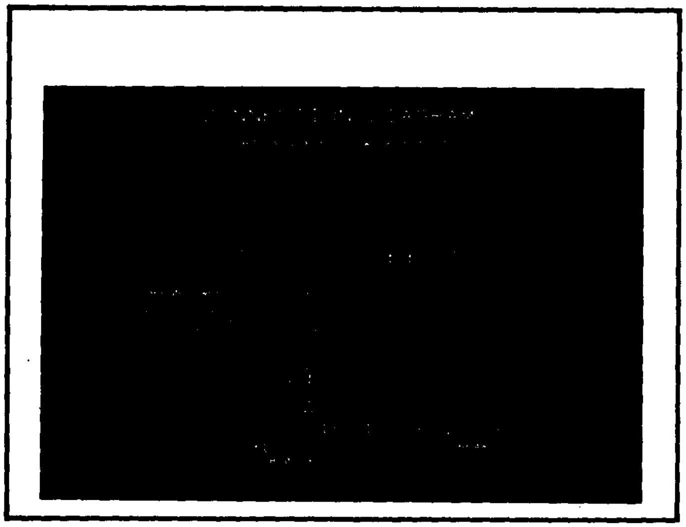
TEST 3

CALIB

DONE

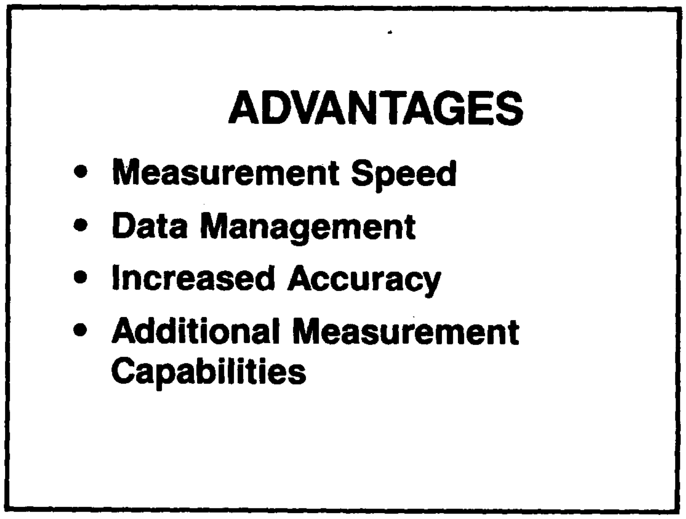
3545

Here is an example of the use of CRT Graphics. In this case, an equipment connection diagram was drawn directly on the CRT of the scalar network analyzer. Programmable analyzers like the HP 8756A and HP 8757A let the user do connection diagrams, redisplay data, and display operator prompts on their CRT's.



3153

The fourth major advantage of automating your measurement system is Additional Measurement Capabilities.



ADVANTAGES

- Measurement Speed
- Data Management
- Increased Accuracy
- Additional Measurement Capabilities

ADDITIONAL MEASUREMENT CAPABILITIES

HP-IB Only Functions

Signal Processing

3151

An automatic measurement system can provide additional measurement capabilities through the use of HP-IB Only Functions and Signal Processing. HP-IB is the Hewlett-Packard Interface Bus, a system that standardizes the hardware interface (e.g. connector) for programming instruments. It is now commonly referred to as IEEE-488, IEC-625, and GP-IB.

HP-IB FUNCTIONS

Detect Softkey Pressed

Status Byte

CRT Graphics

Learn String

3544

Special HP-IB Only functions allow the scalar network analyzer to tell the computer when it has completed an operation, such as a plot. Remember, a computer can't "see" the CRT, it must rely on additional help. The status byte is a storage register within the scalar network analyzer that can indicate the status of many internal conditions. Also control the CRT graphics and the soft key labels. Learn strings are similar to the save/recall registers except the computer stores the information, not the analyzer.

FAULT LOCATION

Convert Frequency Domain Data
into Distance Domain Data

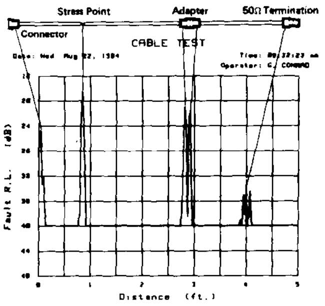
3156

An automatic measurement system can provide additional measurement capabilities thru the use of Signal Processing. One example of Signal Processing is "Fault Location."

Stated simply, Fault Location is a technique that converts frequency domain data into distance domain data.

This display of Return loss versus Distance is the main contribution of fault location. Here the computer has converted a swept return loss measurement into a useful troubleshooting tool to locate faults along a cable.

RETURN LOSS vs. DISTANCE



3411

Now that we have seen the benefits of automating a measurement system, let's take a look at what is required to construct an automatic system. There are three major areas which we need to address in order to construct an automatic system. Let's take a look at each of these areas separately.

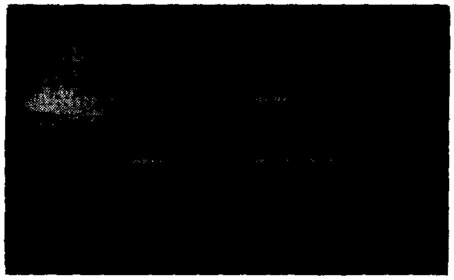
CONSTRUCTING AN AUTOMATIC SYSTEM

- **Measurement Equipment**
- **Computational Equipment**
- **Programming Language and Software**

3159

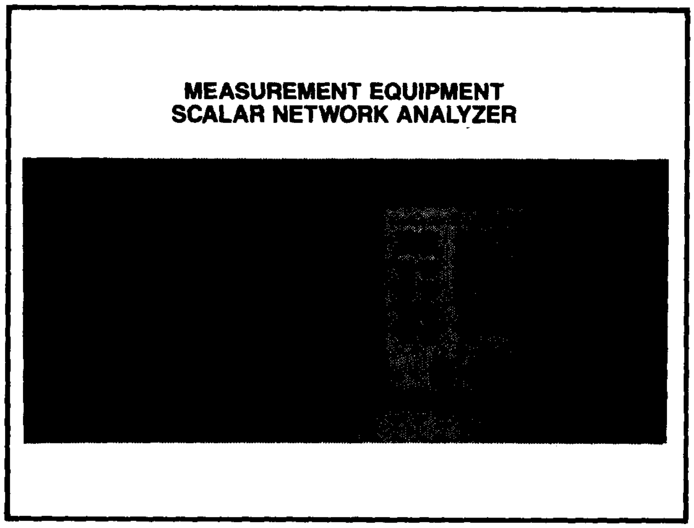
Here's an extensive automated test system that includes an assortment of measuring equipment. This complex system is similar to very simple, small systems in that building the system is the simple part. The importance of controlling each instrument to achieve the desired result is the difficult part.

EXAMPLE AUTOMATIC MEASUREMENT SYSTEM



- **Develop Your Own**
- **Contract HP to Develop It**

3203



MEASUREMENT EQUIPMENT
SCALAR NETWORK ANALYZER

3163

The first area of concern is the measurement equipment we choose for the system. For scalar measurements we need an HP-IB programmable scalar network analyzer. The HP 8756A and HP 8757A Scalar Network Analzyers offer versatile front panel and HP-IB capabilities.

MEASUREMENT EQUIPMENT

Sweep Oscillator or Synthesized Sweeper
- Scalar Network Analyzer

Spectrum Analyzer
Power Meter
Noise Figure Meter
Others

3161

To complete our measurement equipment, we will need at least a swept source. We may need several instruments to accomplish all of our measurement goals. HP has a broad offering of programmable instrumentation which will satisfy most users' needs.

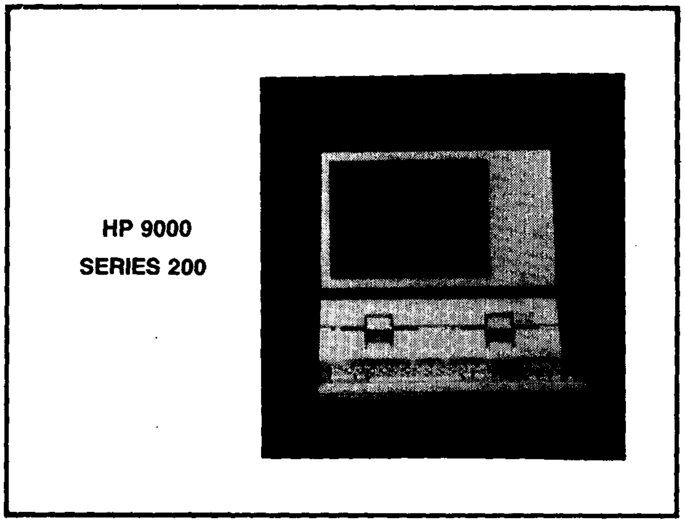
COMPUTATIONAL EQUIPMENT

HP 9000 Series 200
HP Series 80
HP 1000 A/E/F Series
Peripherals

3168

Next we need to add an HP-IB controller -- a computer that can control and program HP-IB instruments. HP offers several computers that perform these tasks. The HP 9000 series 200 are high speed desktops, and the HP series 80 are economical and portable computers.

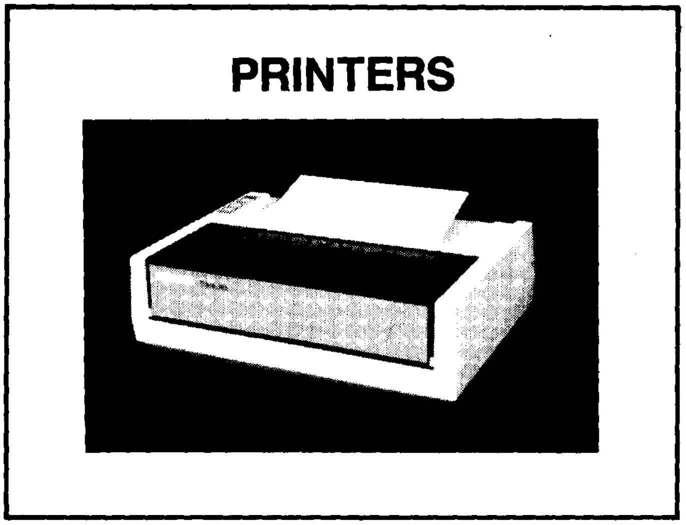
HP's most popular family of instrument controllers is the HP 9000 Series 200. There are several models to choose from in all. These are high performance technical computers and are the most common choice for use as an instrument controller.



HP 9000
SERIES 200

3169

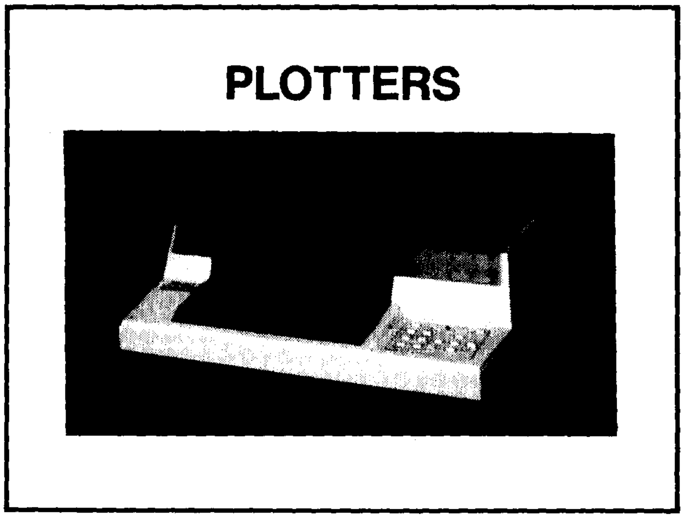
We need to choose the appropriate peripherals in order to complete the hardware for our automatic system. Once again, HP has a broad offering of peripherals to choose from. This is an HP 2225A printer, also known as the "ThinkJet". It is capable of tabular and graphics printouts.



PRINTERS

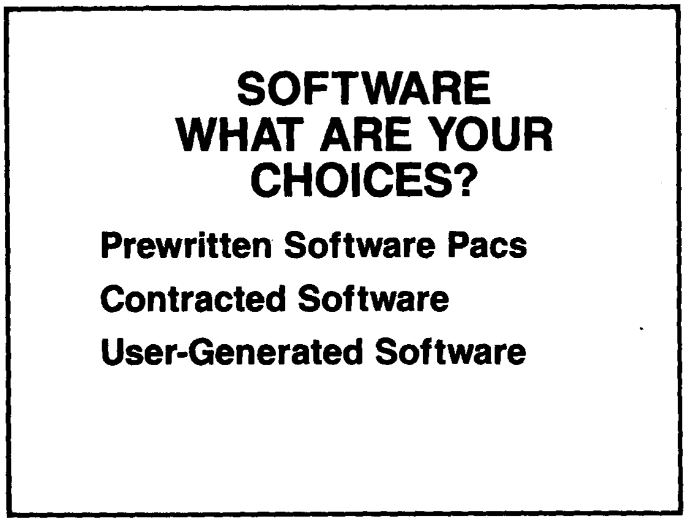
3173

For multi-color graphs, a multi-pen graphics plotter like this HP 7470A is desirable. Its plotting speed and size are advantages in a production or lab environment.



PLOTTERS

3174

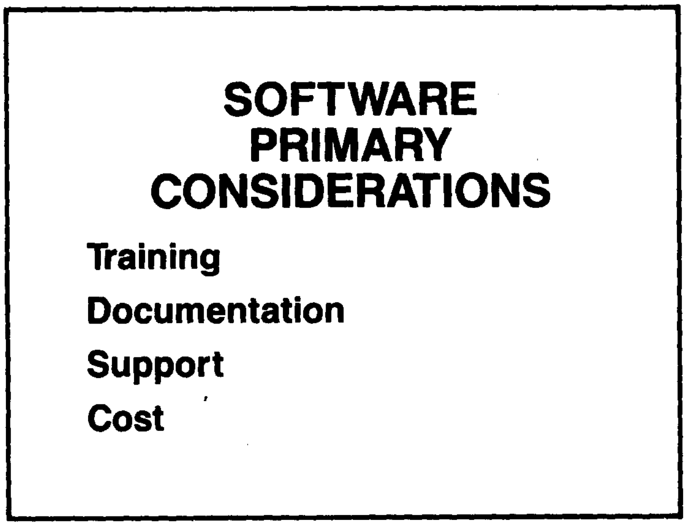


SOFTWARE
WHAT ARE YOUR
CHOICES?

Prewritten Software Pacs
Contracted Software
User-Generated Software

3180

The third area of concern when constructing an automatic system is the selection the software. Shown here are the three choices that the user has in selecting software. But, before we examine the merits of each of these choices, let's look at the criteria for making a decision.

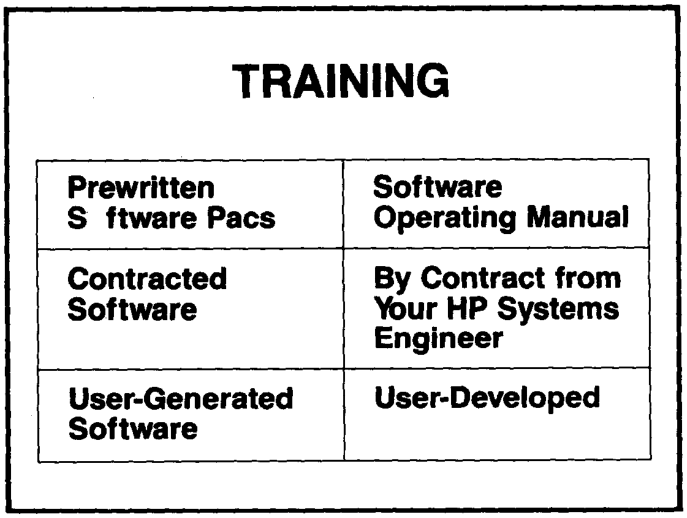


SOFTWARE
PRIMARY
CONSIDERATIONS

Training
Documentation
Support
Cost

3181

The four primary points to consider when making a decision on software are shown here. Training involves not only the test technician who will use the software, but also the responsible Production Engineer. Documentation of how the software works is also very important for keeping the test station operational. Support can be very important for finding and fixing bugs as well as making modifications as needs change. And finally, cost can be the biggest decision maker of all.



TRAINING

Prewritten Software Pacs	Software Operating Manual
Contracted Software	By Contract from Your HP Systems Engineer
User-Generated Software	User-Developed

3182

Prewritten Software offer very thorough training in the form of a software operating manual.

Training on Contracted Software can be performed by your HP Systems Engineer.

Training on User Generated Software is left to the user to develop.

Prewritten Software also come with thorough documentation in the form of an operating manual.

Documentation of Contracted Software can be provided by your HP Systems. Engineer.

Documentation of User Generated Software is left to the user to develop.

DOCUMENTATION

Prewritten Software Pacs	**Software Operating Manual**
Contracted Software	**By Contract from Your HP Systems Engineer**
User-Generated Software	**User-Developed**

3183

Prewritten Software have the advantage of that the Operating Manual is frequently updated.

Support of Contracted Software can be provided by your HP Systems Engineer.

Support of User Generated Software is left to the user to develop.

SUPPORT

Prewritten Software Pacs	**Manual Change Sheets**
Contracted Software	**By Contract from Your HP Systems Engineer**
User-Generated Software	**User-Developed**

3184

The cost of Prewritten Software is almost always the most economical choice if the software meets your measurement needs.

Contracted Software is usually more expensive than the Prewritten software, but the software is written specifically for your application. Contracted Software is usually more economical than User Generated Software because it is written by experienced programmers.

User Generated Software is usually the most expensive. Let's take a closer look at why this is true.

COST

Prewritten Software Pacs	**Low**
Contracted Software	**Medium**
User-Generated Software	**High**

3185

COST

10 Lines / Day

$30 / Line

2000-Line Program = $60K

Months to Complete

An industry average for software development is 10 lines of documented, debugged code per day. And a conservative estimate of a loaded engineer (salary plus overhead) at $300 per day results in a line of code costing $30 each. And if we priced a medium sized program of 2000 lines, this would cost approximately $60,000. In addition, this would take 10 man-months to complete.

EXAMPLE AUTOMATIC MEASUREMENT SYSTEMS

HP 85015 System Software

HP 85016 Transmission Line Test Software

Amplifier Test System

3187

We have seen how to construct an automatic system and how important software is. Let's take a look at some examples at how two HP offerings can solve your software problems.

EXAMPLE AUTOMATIC MEASUREMENT SYSTEMS

HP 85015 System Software

3188

We'll start off by looking at the HP 85015 System Software. This software can be used on any HP 9000 Series 200 computer. The required measurement equipment is an HP Scalar Network Analyzer and an HP Swept Source. A printer and/or plotter may also be added to round out the system.

The HP 85015 System Software can quickly and easily measure any or all of these parameters. It measures all of the standard scalar parameters.

85015A APPLICATIONS

- Production Line
- Final Test
- Research & Development
- Incoming Inspection

Here are the HP 85015's key features. It is designed to be customized without the user doing any programming. The program provides the user numerous options and selections at each point of the measurement process. Let's look at each of these individually.

HP 85015 SYSTEM SOFTWARE

AUTOMATICALLY MEASURE:

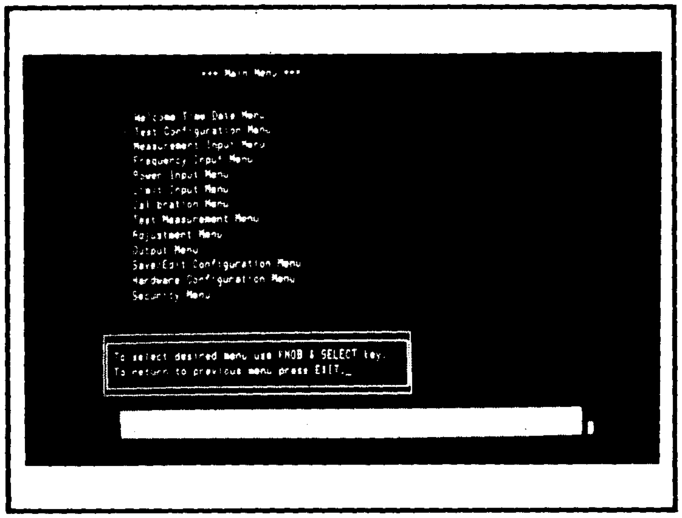
- SWR
- Return Loss
- Insertion Loss
- Gain
- Power

3188

The HP 85015 Software can be applied to increase productivity throughout a microwave facility. It is ideal for incoming inspection, production test, and final QA. All of these areas require specific measurements to be made repeatedly.

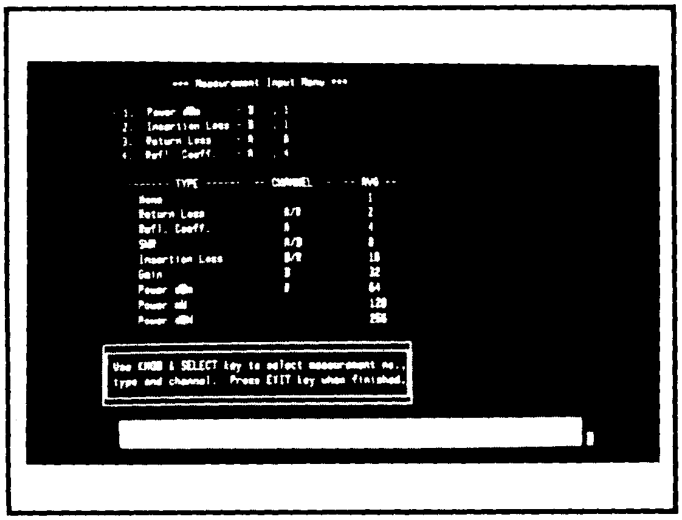
85015A
SOFTWARE FEATURES

- Simple Menu Operation
- Easily Customized Measurements
- Real-Time Limit Testing
- Flexible Plot & Print Formats



To select desired menu use KNOB & SELECT key.
To return to previous menu press EXIT._

The simple menu operation of this software leads you step-by-step through the measurement process. You are presented with a selection list, you make your choice by moving the arrow cursor to the desired action.

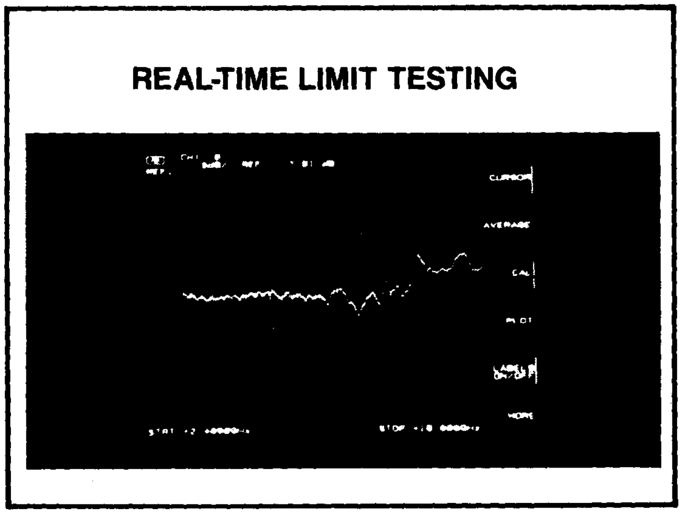


1. Power dBm - B , 1
2. Insertion Loss - B , 1
3. Return Loss - A , 8
4. Refl. Coeff. - A , 4

TYPE	CHANNEL	AVG
None		1
Return Loss	A/B	2
Refl. Coeff.	A	4
SWR	A/B	8
Insertion Loss	B/R	16
Gain	B	32
Power dBm	R	64
Power mW		128
Power dBW		256

Use KNOB & SELECT key to select measurement no., type and channel. Press EXIT key when finished.

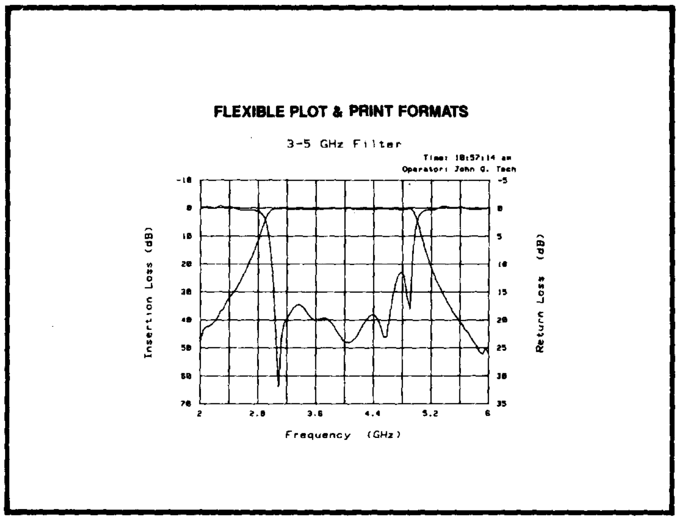
The operator can easily create custom measurements for his/her special testing needs. Note here that you have complete control of what measurements are made and at any test detector. You can make up to four measurements simultaneously.


REAL-TIME LIMIT TESTING

3189

Limit Lines can be drawn on the CRT and adjustments made in Real-Time. Out of limit frequencies can be noted with an audible beep and/or a display indicator.

In addition, there is a great amount of flexibility in creating an appropriate plot or print format. Since the output formats are the areas users like to customize the most, the HP 85015 lets you do it without doing any programming. Specify the number of plots, what to plot, and even where to plot it. In printouts, you can specify what data is printed in which column and whether it passes or fails the limit tests.


FLEXIBLE PLOT & PRINT FORMATS

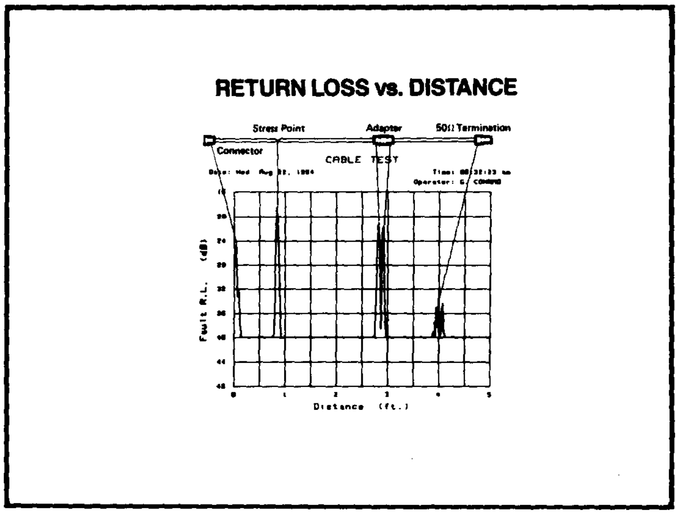
3190

A second example system is the HP 85016 Transmission Line Test Software. It runs on the same hardware as the HP 85015 Software. The HP 85016 is a superset of the measurement capability that the HP 85015 provides.

EXAMPLE AUTOMATIC MEASUREMENT SYSTEMS

- **HP 85015 System Software**
- **HP 85016 Transmission Line Test Software**

The HP 85016 provides the ability to locate faults in cables and waveguide, in addition to characterizing insertion loss and return loss. Here you can see specific mismatches along this cable. Some may be expected, others not.


RETURN LOSS vs. DISTANCE

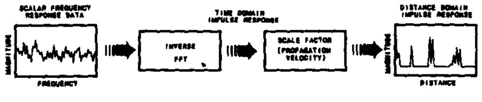
3411

HP 85016 APPLICATIONS

- Installation
- Maintenance
- Manufacturing
- Engineering

3198

Cable test is important in many companies. It may range from testing cables or waveguide on a roll at incoming inspection to the installation and maintenance of cables used in antenna feeds, aircraft, and/or ships.



3157

Fault location involves converting a swept return loss measurement into a return loss versus distance display. The software takes the return loss data from the analyzer, converts to the time domain via the Inverse Fourier Transform, then scales the data to be in the distance domain. The goal is to determine whether a fault exists and at what distance.

FAULT LOCATION

High Resolution

Automatic Data Correction

3193

The operator is given the ability to choose the desired resolution as a function of the total cable or waveguide length. Likewise, the software can correct for some losses in the system.

Why would anyone not select the highest possible resolution? Because increased resolution requires trade-offs in frequency bandwidth and increased computational time. For better resolution we must sweep a broader frequency range. This may be difficult for our test setup. For example, to halve the distance resolution requires doubling the span.

HIGH RESOLUTION

Selectable Resolution
  2.0% of Line Length
  1.0%
  0.5%

Trade-offs
  Frequency Bandwidth
  Computational Time

3194

Automatic Data Correction is another significant feature of the HP 85016 Software. Without correcting for coaxial losses, significant errors can be introduced into the measurement.

Waveguide dispersion can also cause significant measurement errors. Dispersion can cause errors in the magnitude and the location of a fault in waveguide.

AUTOMATIC DATA CORRECTION

- **Coaxial Losses**
- **Waveguide Dispersion**

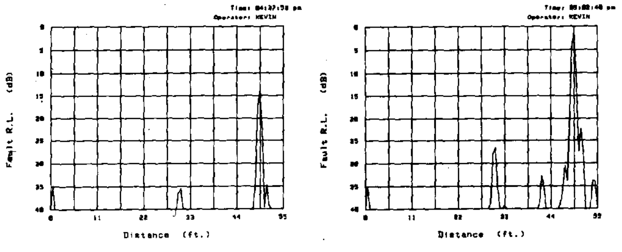
3195

Here is an example of how coaxial losses can effect the accuracy of a fault location measurement. The device under test is a 50 foot length of coaxial cable terminated by an open circuit.

The first graph shows that without correction for coaxial losses, the open circuit appears to be a fault with 13 dB return loss.

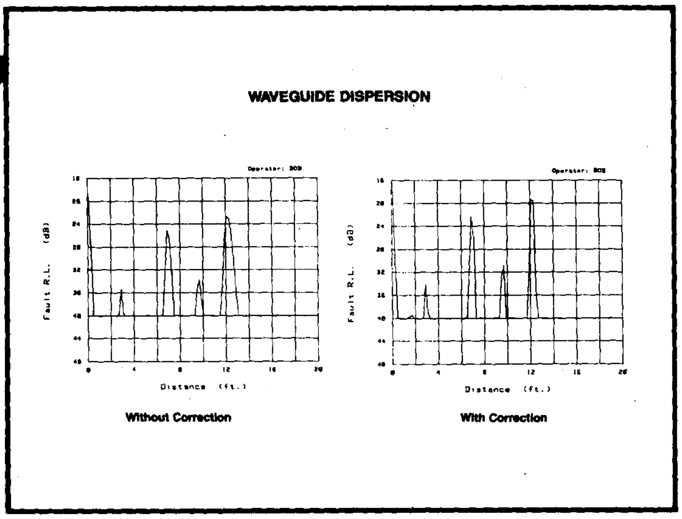
The second graph shows that with correction for coaxial losses, the open circuit appears to be a fault with approximately 0 dB return loss.

COAXIAL LOSSES



Without Correction **With Correction**

3196



WAVEGUIDE DISPERSION

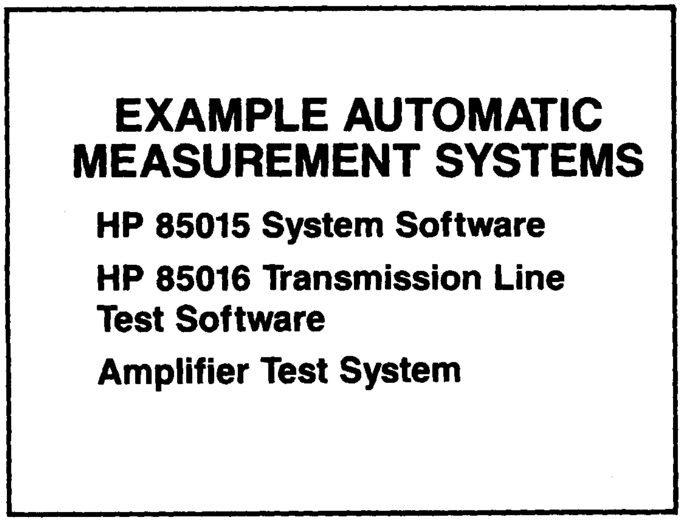
Without Correction

With Correction

3197

Here is an example of how waveguide dispersion can effect the accuracy of a fault location measurement in waveguide. The inaccuracies are caused by the velocity of propagation in waveguide is not constant as a function of frequency.

These two graphs show that without correction, the amplitude of the fault is decreased and its position is skewed to the right. The effects of dispersion increase greatly as the length of the waveguide run increases.



EXAMPLE AUTOMATIC MEASUREMENT SYSTEMS

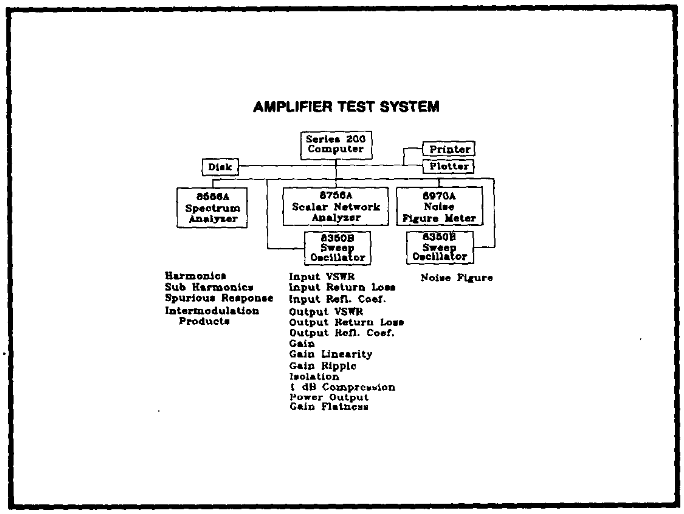
HP 85015 System Software

HP 85016 Transmission Line Test Software

Amplifier Test System

3187

Let's see how these two HP software offerings can be leveraged into larger test systems. For example, an amplifier test system may require more tests than our scalar analyzer can provide.



AMPLIFIER TEST SYSTEM

Harmonics
Sub Harmonics
Spurious Response
Intermodulation Products

Input VSWR
Input Return Loss
Input Refl. Coef.
Output VSWR
Output Return Loss
Output Refl. Coef.
Gain
Gain Linearity
Gain Ripple
Isolation
1 dB Compression
Power Output
Gain Flatness

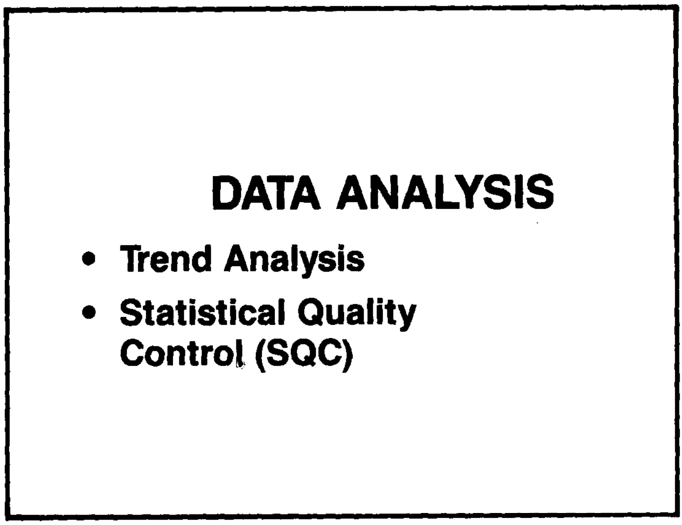
Noise Figure

3200

This is an example test system. The test station is fully automated, and several stations can be linked together via the Shared Resource Manager. The HP 85015 or HP 85016 software can be a subset of the total measurement software.

Let's cover one last topic that is important to many trying to improve their productivity.

We have already discussed the importance of data analysis in an automated test sytem. Trend Analysis provides us with information on how a process or specification does versus time. Statistical Quality Control is another example of Data Analysis. It's a bit more complicated than Trend Analysis, but it can provide even more information.

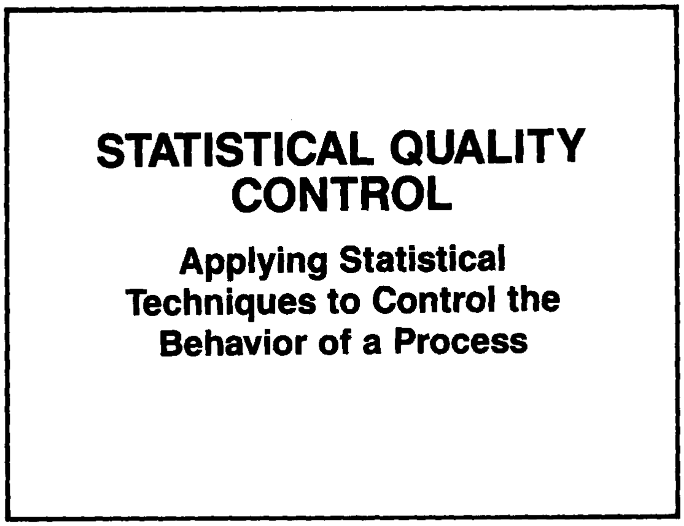


DATA ANALYSIS

- **Trend Analysis**
- **Statistical Quality Control (SQC)**

3130

SQC relies on using statistical tools to determine whether or not a process has a problem. For example, it can tell us what effect a change in a production test procedure or component may have in the manufacture of a device.

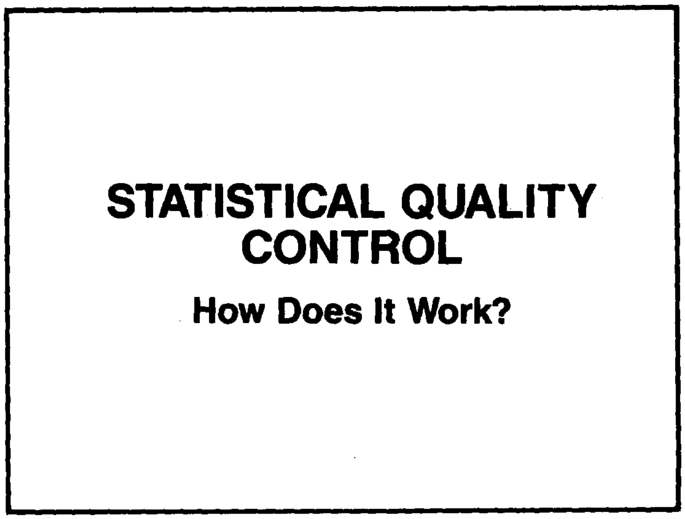


STATISTICAL QUALITY CONTROL

Applying Statistical Techniques to Control the Behavior of a Process

3133

Statistical Quality Control sounds rather complicated, but if we approach it step-by-step, it's easy to understand.



STATISTICAL QUALITY CONTROL

How Does It Work?

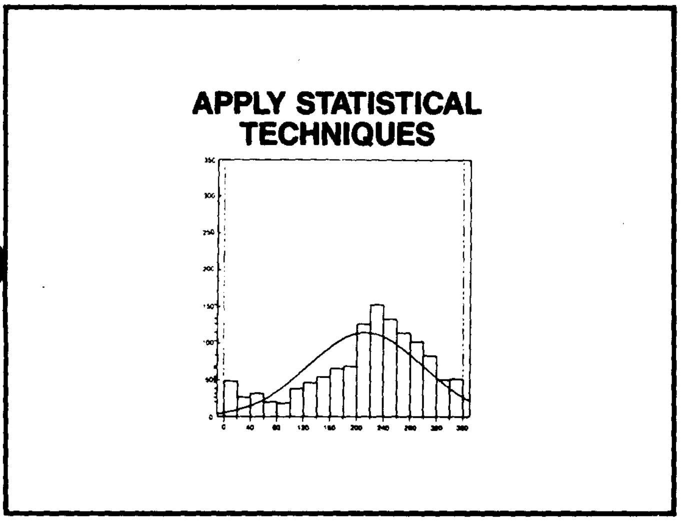
3134

COLLECT DATA

FREQUENCY (MHz)	INS. LOSS B (dB)	INS. LOSS PASS FAIL	RET. LOSS A (dB)	SWR A
3939.394	-.05		22.95	1.15
3979.798	-.07		23.50	1.14
4020.202	-.01		23.68	1.14
4060.606	-.02		23.66	1.14
4101.010	.10		23.38	1.15
4141.414	.11		22.91	1.15
4181.818	.19	FAIL	22.26	1.17
4222.222	.25	FAIL	21.43	1.19
4262.626	.22	FAIL	20.49	1.21
4303.030	.28	FAIL	19.67	1.23
4343.434	.23	FAIL	19.08	1.25
4383.838	.26	FAIL	18.86	1.26
4424.242	.24	FAIL	19.12	1.25
4464.646	.18	FAIL	19.96	1.22
4505.051	.18	FAIL	21.53	1.18
4545.455	.03		23.59	1.14
4585.859	.02		23.39	1.15
4626.263	.20	FAIL	19.51	1.24
4666.667	.19	FAIL	15.94	1.38
4707.071	.26	FAIL	13.44	1.54
4747.475	.30	FAIL	11.91	1.68
4787.879	.38	FAIL	11.35	1.74

3135

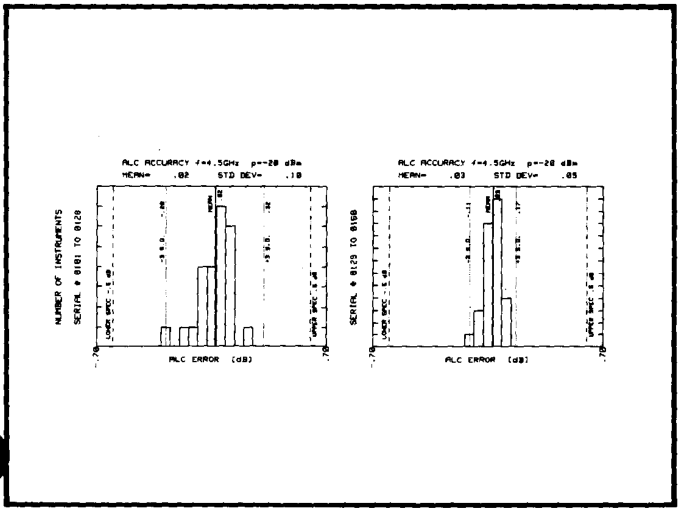
The first step is to collect test data. Automatic systems are ideal for gathering test data on performance specifications.



APPLY STATISTICAL TECHNIQUES

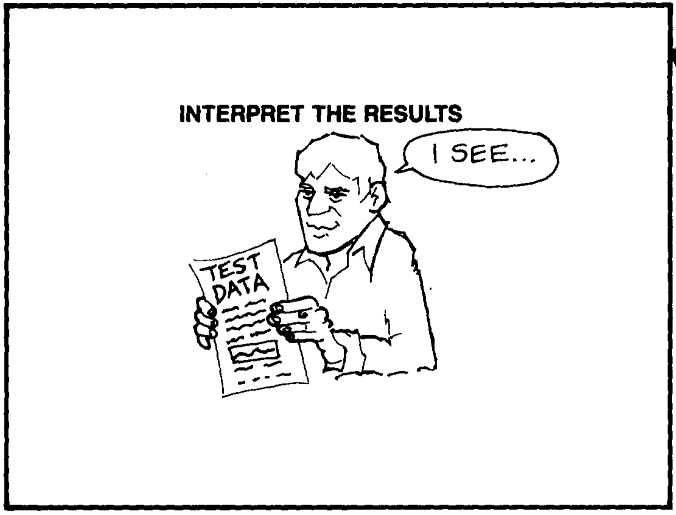
3136

The second step is to apply some basic statistical techniques to the test data. This is usually done by placing the data in a graphical form which is easier to interpret. The goal here is to determine how broad the distribution of test data is, for we will need to make this a figure of merit.



As an example, we have observed on our production line certain specifications of our sources. This slide is an analysis of the ALC error in one source. It shows the distribution of the data before and after a process change. This type of quick, graphic feedback is extremely important in using our production engineering resources efficiently. This is why we use this as a figure of merit -- it tells us whether or not we succeeded in improving the process.

Step three is to interpret the test data. This allows you to identify where a problem may exist in the production process. You may determine that either a problem doesn't exist, or that you are looking at too big of a problem.

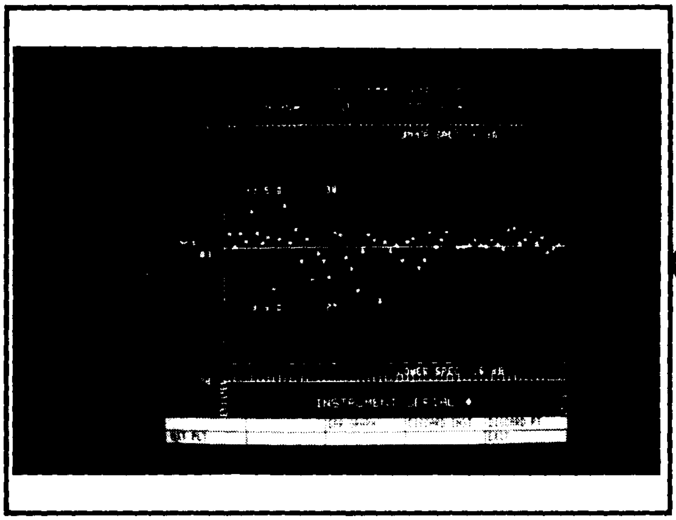


INTERPRET THE RESULTS

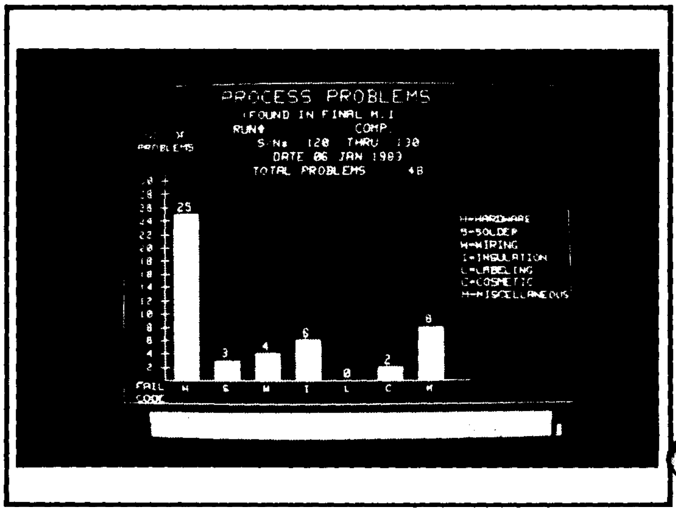
3137

Here is an example of measuring process performance. This is a scattergram of the data from our source production test again. If you are familiar with SQC, you will recognize this as a control chart. Along the horizontal axis is the serial number of the device. The vertical axis is the actual value of the parameter, in this case ALC error.

You will see that about half way through this block of instruments, the distribution of the data becomes more closely packed around the mean value. This is the result of making a process change. It was very valuable to quickly see that the change indeed improved the process.

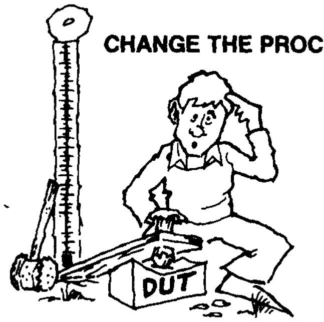


Here we have a histogram presentation of the data showing the relative contribution of the various components that contribute to our test specification. This allow us to determine if a specific component, adjustment, or tolerance is the area we want to improve.



PROCESS PROBLEMS
(FOUND IN FINAL M.I
RUN# COMP.
S/N# 120 THRU 130
DATE 06 JAN 1983
TOTAL PROBLEMS 48

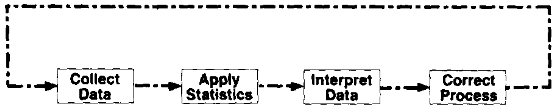
CHANGE THE PROCESS



3138

Step four is to change the process once you have identified the problem.

THE SQC PROCESS


Collect Data → Apply Statistics → Interpret Data → Correct Process

3539

Once you have changed the process, you will probably want to repeat steps one, two, and three to make sure that the change had a positive effect and not a negative one.

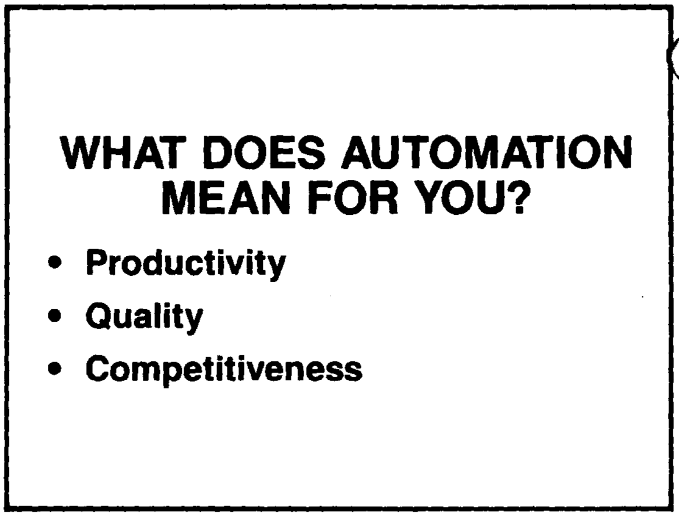
AUTOMATION SUMMARY

Advantages
Composing a System
HP Software Solutions
SQC Tutorial

3540

In review, we've covered why automation is important and how to build an automated test system. The HP software offerings discussed overcome the difficulty of generating your own software, obviously the most critical part of your system. Once your system is functional, you can use SQC to improve your productivity and detect production problems.

The benefits of automation are obvious, and Hewlett-Packard is ready to help you meet today's challenges. We can provide you the manual and automatic tools to solve your measurement problems and to improve productivity.



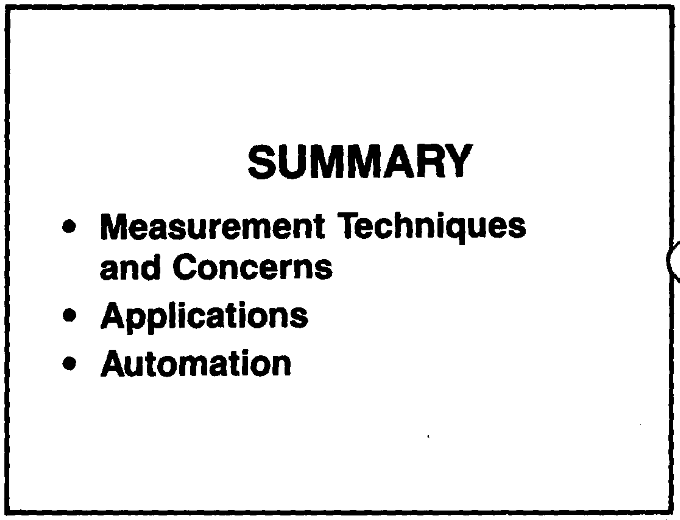
WHAT DOES AUTOMATION MEAN FOR YOU?

- Productivity
- Quality
- Competitiveness

3204

Now that we've covered the advantages of automation, we have come to the end of our discussion on component measurements.

We have discussed measurement techniques and concerns, specific applications, and the impact of automation. Let's have a brief review of some key messages.

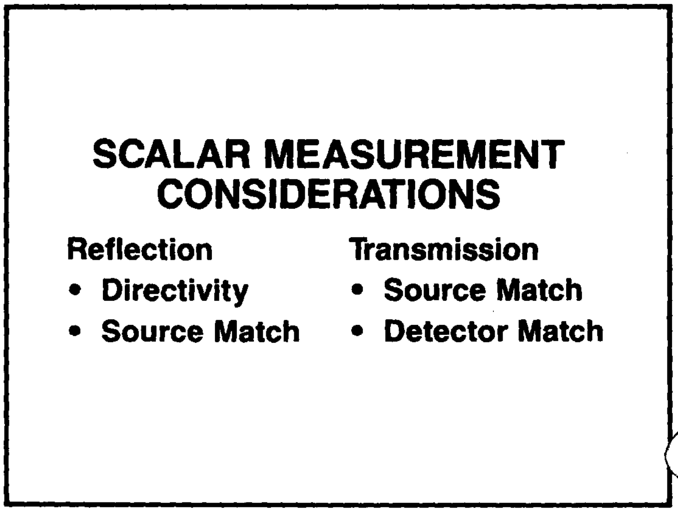


SUMMARY

- Measurement Techniques and Concerns
- Applications
- Automation

3541

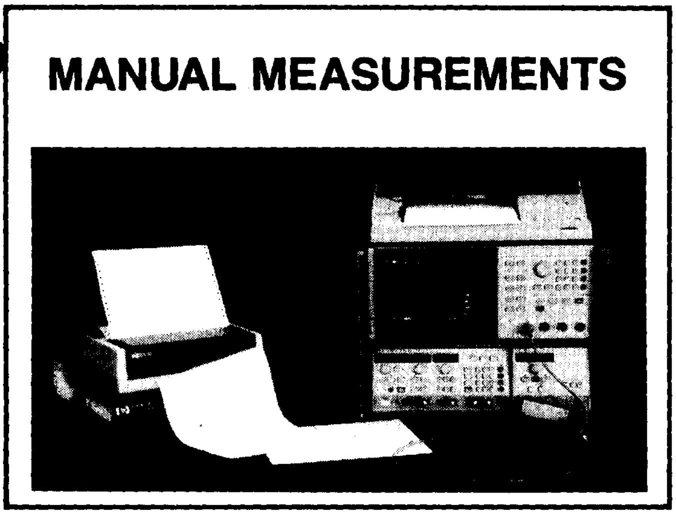
Directivity is important in low reflection measurements, source match in high reflection measurements. Source match and detector match are critical in transmission measurements.



SCALAR MEASUREMENT CONSIDERATIONS

Reflection	Transmission
• Directivity	• Source Match
• Source Match	• Detector Match

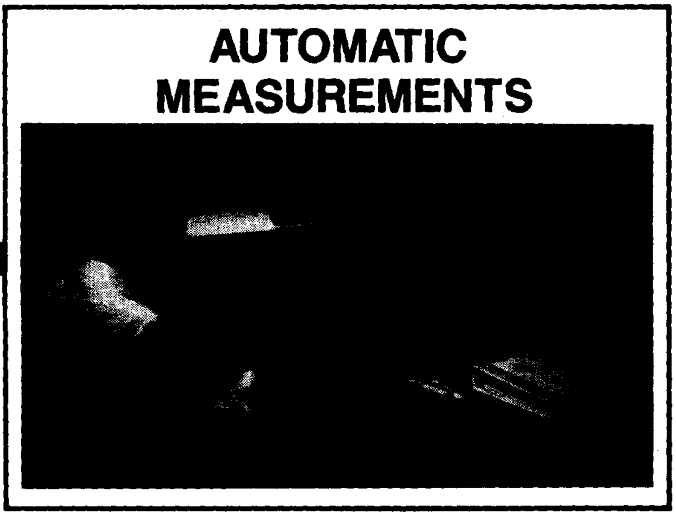
3542



MANUAL MEASUREMENTS

3397

A manual scalar measurement system must be versatile in measurement capability plus be accurate. HP scalar network analyzers and swept sources are designed to provide you the best system possible.



AUTOMATIC MEASUREMENTS

3543

By automating a manual system, we can gain in productivity and accuracy. However, the software to meet our needs can be expensive. HP software products are designed to allow you the customization necessary to meet your needs, today and in the future.

APPENDIX A

DECIBELS

The decibel is a logarithimic unit of measure for comparing two power levels.

$dB = 10 \log_{10} P_1/P_r$

P_r - reference power level

Decibels are also used to indicate absolute power levels (by adding a third letter to the notation). Absolute power levels can be obtained by assigning the reference power level some absolute power (e.g. 1 milliwatt, 1 watt). Decibels above 1 mw would be dBm (P_r = 1 mw).

$dBm = 10 \log_{10} P_1/(1\ mw)$

$P_r = 1mw$

Decibels in voltage can be derived from the original equation.

$P_1/P_r = [V_1{}^2/R_1]/[V_r{}^2/R_r]$

$dB = 10 \log_{10} [V_1/V_r]^2 * [R_r/R_1]$

$dB = 20 \log_{10} V_1/V_r - 10 \log_{10} R_1/R_r$

$dB = 20 \log_{10} V_1/V_r$ when $R_1 = R_r$

In addition:

$dBV = 20 \log_{10} V_1$ when $V_r = 1$ volt