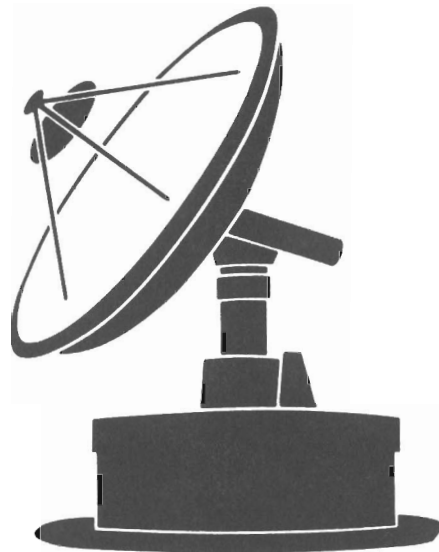# 40 GHz ON-WAFER MEASUREMENTS WITH THE HP 8510 NETWORK ANALYZER AND CASCADE MICROTECH WAFER PROBES

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RF & Microwave Measurement Symposium and Exhibition

HEWLETT PACKARD

Hewlett-Packard is pleased to have the opportunity to present this paper, written by Eric Strid, Reed Gleason, and Keith Jones, of Cascade Microtech, Inc., at the RF & Microwave Measurement Symposium and Exhibition.

Abstract:

The paper presents a system, consisting of the HP 8510 network analyzer and Cascade Microtech wafer probes, that is used to make RF measurements of microwave devices and ICs (MMICs) directly on-wafer for frequencies up to 40 GHz. The configuration of the system and the characteristics of the wafer probes are described. On-wafer calibration methods including the traditional open, short, load, and the newer thru, reflect, line (TRL) will be covered. Probe techniques for making the best possible on-wafer measurements will also be addressed, and a range of on-wafer measurement applications will be examined.
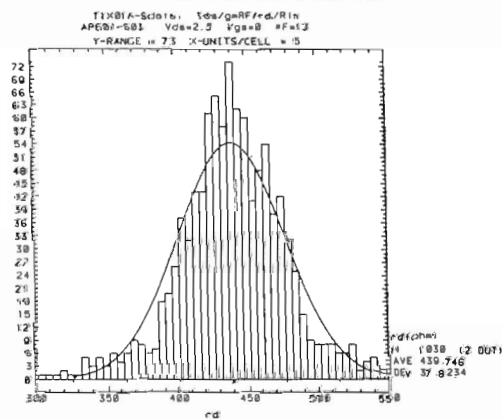
Biography:

Reed Gleason (M'68) was born in Portland, OR in 1945. He received the B.S. degree in electronic engineering from the California Institute of Technology, Pasadena, CA, in 1967. He joined the Naval Research Laboratory in 1967 where he worked on GaAs detector and mixer diodes, silicon TRAPATT diodes and GaAs and InP MESFETs. He joined Tektronix in 1978 where he worked on GaAs devices and integrated circuits. In 1983, he co-founded Cascade Microtech, Inc., where he now holds the position of Vice President of Engineering.

OUTLINE

1. Introduction

2. New equipment for 40 GHz on wafer measurements

3. Calibration and verification techniques
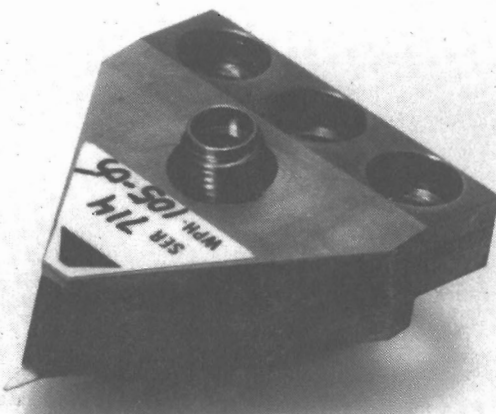
4. Probe care

5. Measurement examples

7151

In this paper, recent developments in wafer probing, including 40 GHz probes and test set for the HP 8510 Vector Network analyzer will be discussed. First, we will describe the available equipment and connections for 40 GHz on wafer measurements. The most recent techniques for accurate calibration and verification of the system will then be presented. Techniques for care and cleaning of the probe tips for maximum mechanical lifetime will be discussed and, finally, some measurement examples will be shown.

EXAMPLE DATABASE OF RF PARAMETERS

5355

Five years ago, microwave wafer probing was thought to be impossible. Today, microwave wafer probing is accepted as useful and necessary in microwave IC development. This is due to both the high resolution and repeatability of calibrations possible at the probe tips as well as the convenience and throughput possible when using wafer probes. Wafer probing now allows foundries and foundry users to develop a statistical data base of RF parameters on devices and IC's. This histogram shows a distribution of high-frequency GaAsFET drain source resistances measured on more than one thousand devices from more than fifty wafers from a foundry.

MICROWAVE PROBE HEAD

5326

A wide variety of high-frequency probe heads are available from Cascade Microtech. The WPH 0XX series are probe heads for measurements through 18 GHz which provide low loss low reflection 50 ohm characteristic impedance from the coax connection all the way to the probe tip. Eight footprint styles are available, including types with two 50 ohm lines per probe head. Three footprint styles are available in 26.5 GHz heads and one footprint style is available in probe heads applicable for 40 or 50 GHz measurements.

MULTI-CONTACT PROBE HEADS
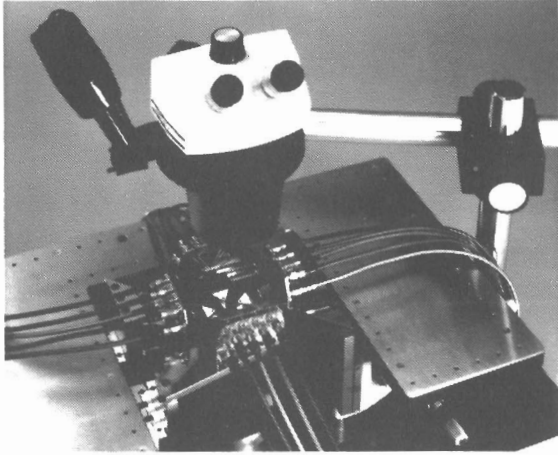
7152

For more probe contacts, the WPH-7XX series probe heads are available for up to eight contacts per head. These heads are useable to approximately 15 GHz and allow the user to specify the configuration of contacts. Any one contact can be chosen from a menu of a 50-ohm line, a 50 ohm line with a termination to ground at the probe tip, a 50 ohm line with a termination to a DC voltage at the probe tip, a ground, or a low impedance power supply connection. For low frequency non-bypassed connections, the WPH-9XX series of probe heads allows up to twelve needles on one probe head to be positioned en masse on the chip under test. For example a MMIC may use two ground-signal-ground probe heads such as the WPH-305, one 700 series head for high frequency bypassing on power supply connections and a 900 series head for control inputs.


COMPLETE PROBE STATION
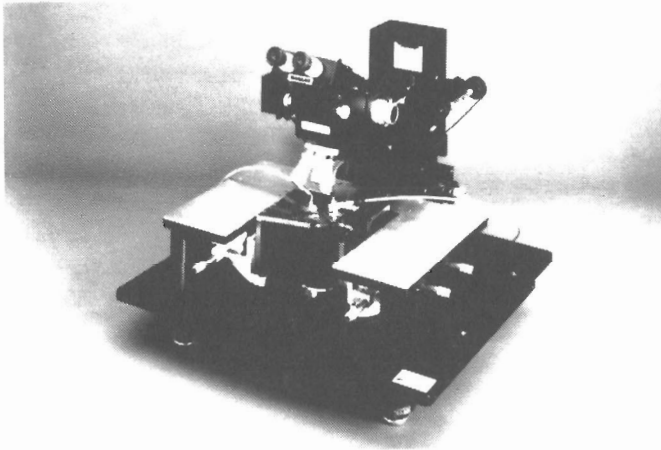
7153

The recommended holders for such probes include probe cards, autoprober top plates, or full manual stations. The Cascade Model 44 and Model 42 manual probe stations are optimal for research and development or die-sorting applications. These stations allow the probe heads to be individually positioned in X, Y, and Z with very rigid and planar holders, suitable for supporting large coaxial cables, tuners, noise sources, etc.
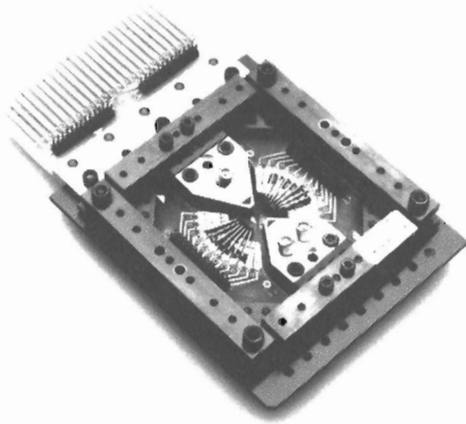

AUTOPROBER TOP PLATE
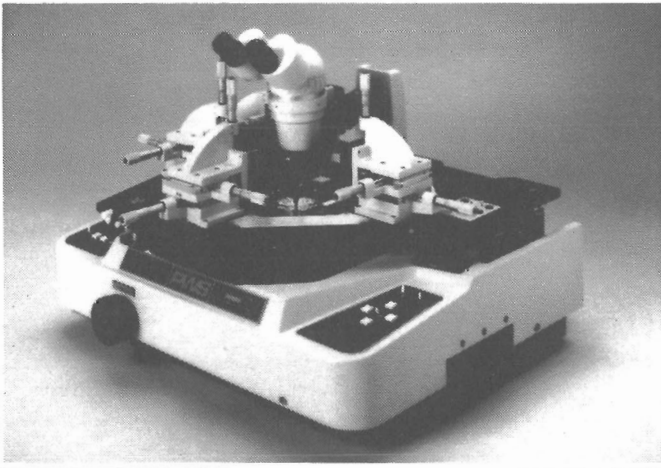
7154

Autoprober top plate models 54, 64, and 74 are optimal for measurements requiring probehead interchangeability. Each of these top plates allows up to four probeheads to be positioned around a die and the autoprober supplies X, Y, and Z automated motion for positioning of the wafer.

PROBE CARD

7155

Series 1000 and Series 2000 probe cards are available for fixed footprints. One to four of the above mentioned probe heads can be mounted in a probecard frame which then fits into almost any manual or autoprober station. The probecards allow fast reconfiguration of fixed probe footprints by production personnel.


GETTING THE BEST ELECTRICAL PERFORMANCE FROM YOUR PROBE SYSTEM

- Equipment setup
- Basic calibration
- Locating the reference planes
- Probe placement and repeatability
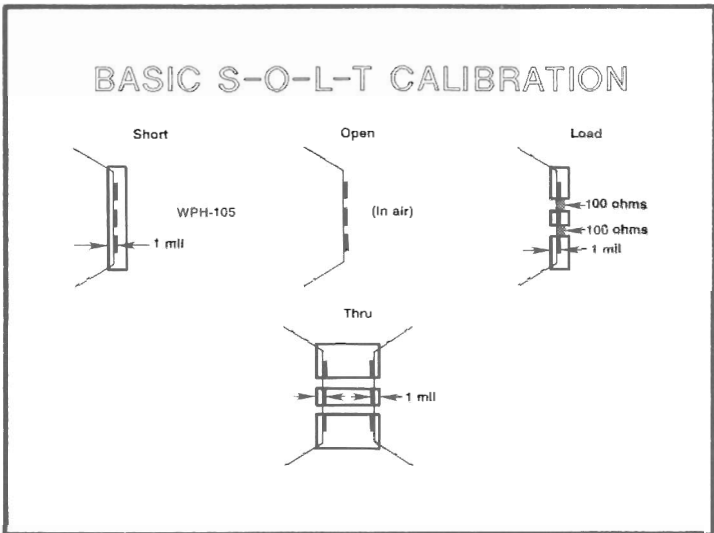- Probe crosstalk measurements

7156

You'll get the best electrical performance from the probe system with the correct equipment setup, a thorough understanding of the calibration standards and how they relate to the resulting measurement reference planes, a realization that accurate probe placement is necessary for repeatability and an idea of the level of cross-talk to expect in probe measurements.

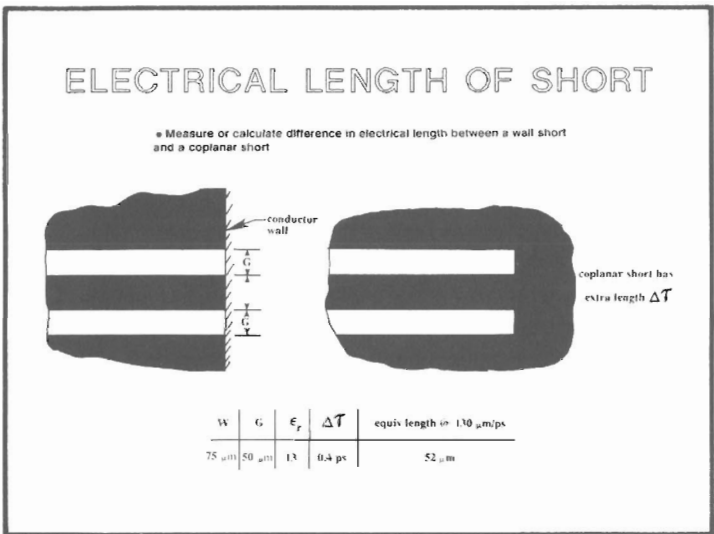## MEASUREMENT SYSTEM BLOCK DIAGRAM
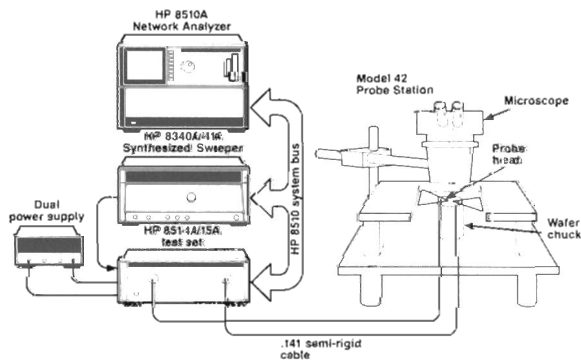
5330

A typical setup for network analyzer measurements at the probe tips connects the HP 8514B, 8515A, or 8516A test set through cables to the probe heads. The cables should have low reflections and good repeatability. 0.141 inch semi-rigid coaxial cable is recommended for measurement frequencies through 26 GHz and 0.086 inch semi-rigid coaxial cable is recommended for measurement frequencies up to 40 GHz. The bias for the FET's or other active devices can be supplied through the bias tees in the test set. Normal connections between the HP 8510 and the sweeper or synthesizer are used. When using the HP 8516A test set through 40 GHz, it is important to use cables with low loss. Approximately 18 inches is the maximum length recommended for the 0.086 semi-rigid cables from the test set to the probeheads. This sometimes requires that the test set be placed on either side or in back of the probe station for connection to the probeheads. A good system check is to compare the uncorrected return loss of a short or an open at the probe tips, with the return loss of a 50 ohm load at the probe tips. There should be at least approximately 6 dB of return loss difference between the short or open and the load.

5

BASIC S-O-L-T CALIBRATION

Short
WPH-105
← 1 mil

Open
(In air)

Load
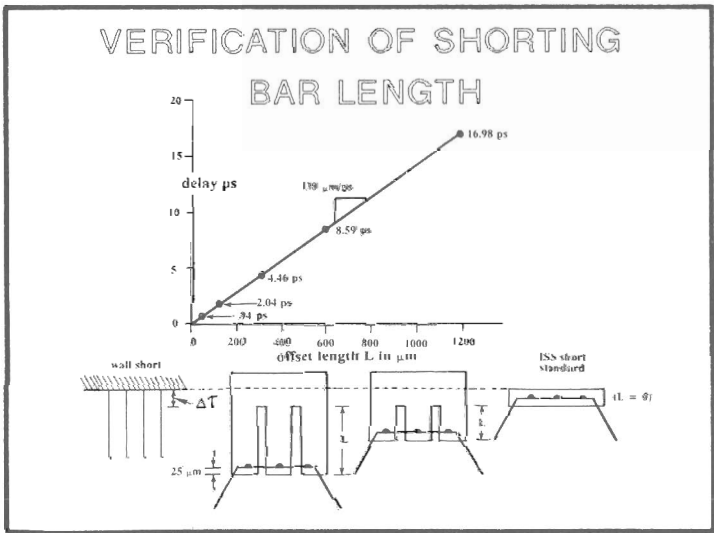→ 100 ohms
→ 100 ohms
← 1 mil

Thru
← 1 mil

7157

The basic reflection calibration for a ground-signal-ground probe head is illustrated here. The short circuit standard shorts the three contacts on a 50 micron wide conductor bar where an overlap of 25 microns on the bar is recommended. The open circuit standard is the probe lifted in air. The 50 ohm load for a ground-signal-ground probe uses a parallel pair of trimmed 100 ohm resistors that are each about 50 microns long, making a minimum size 50 ohm load. For two-port calibrations, a very short 50 ohm coplanar waveguide thru connection is used. The following slides discuss the verification of the electrical lengths of these standards.

ELECTRICAL LENGTH OF SHORT

• Measure or calculate difference in electrical length between a wall short and a coplanar short

conductor wall

G

G

coplanar short has extra length ΔT

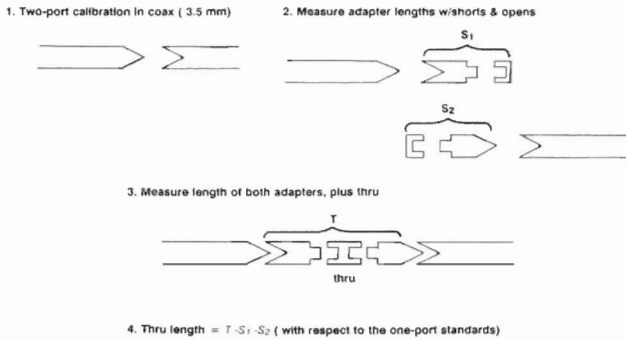| W	G	ϵ_r	ΔT	equiv length @ 130 μm/ps
75 μm	50 μm	13	0.4 ps	52 μm

7158

The electrical length of a coplanar short can be calculated or measured. In this example, the coplanar short was compared with a coplanar waveguide which was shorted by a conductor wall normal to the wave propagation to approximate a short circuit whose physical and electrical length are the same. The extra length of the coplanar short is a fringing inductance which is the electromagnetic dual of the open-circuit capacitance of an open microstrip line. In this case, the extra electrical length was 0.4 pico seconds. By knowing the phase velocity of the wave on the coplanar line, a location of the reference plane beyond the physical short length can be calculated.

VERIFICATION OF SHORTING BAR LENGTH

delay ps

20

15

10

5

0

0   200   400   600   800   1000   1200
offset length L in μm

16.98 ps
139 μm/ps
8.59 ps
4.46 ps
2.04 ps
.94 ps

wall short
ΔT
25 μm

ISS short standard
(L = 0)

7159

The electrical lengths of various offset shorts were measured with a constant 25 micron overlap of the probe on the offset short patterns. The electrical length of the offset short was verified to be proportional to the physical length of the offset short. The 50 micron wide short standard on the Cascade ISS is then interpreted as a 0 length offset short, which puts the reference plane for this coplanar waveguide media at 52 minus 25 or 27 microns in front of the probe tip.

6

MEASUREMENT of TRANSMISSION
and REFLECTION REFERENCE PLANES
FROM A COAXIAL REFERENCE

1. Two-port calibration in coax (3.5 mm)   2. Measure adapter lengths w/shorts & opens

3. Measure length of both adapters, plus thru

4. Thru length = $T - S_1 - S_2$ (with respect to the one-port standards)

7160

An independent verification of the reference planes can be achieved by comparing the probe standards with a reference calibration in coax. The coaxial calibration uses shorts and thru connections which have electrical lengths which can be predicted from physical dimensions. If the coax calibration is used to measure the length of the adapter, in this case the probe head with a short or open terminating the adapter, then the adapter length can be measured. Then the transmission length of both probes, while contacting a thru connection, can be measured and the length of the thru connection is then simply the difference between the thru measurement and the length of each adapter as measured by a short or open.

APPROXIMATE UNTERMINATING

Objective: determine S_{21} of adapter
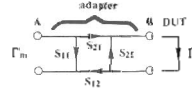
1. Calibrate in media A

2. Measure & store Γ_m with r = 1 (open)

Γ_{m1} $S_{11} + S_{21}^2 S_{22} + S_{21}^2$

(assume $S_{22} << 1$)

3. Measure & store Γ_m with r = -1 (short)

Γ_{m2} $S_{11} + S_{21}^2 S_{22} - S_{21}^2$

4. Subtract short from open

$\Gamma_{m1} - \Gamma_{m2}$ $2 S_{21}^2$

7161

There is a problem, however, with directly measuring the adapter length with a short or open on it:
The reflections in the adapter cause the phase and, therefore, the delay measurement to be noisy. The S-parameters of the adapter can be measured by unterminating the adapter with three known standards as is done in a one-port VNA calibration. Alternatively, an approximate solution is possible by using the short and open standards and assuming that the S22 of the adapter is relatively small. Then the measured reflection coefficient of the adapter with the short circuit is subtracted from the measured reflection coefficient with an open circuit. This can be done using the display math function on the HP 8510. The resulting difference has the first order reflections removed. The phase versus frequency of the S21 is caused by the dispersion of the coplanar waveguide. This shape matches the transmission phase of two adapters with a thru very accurately so that measurements of electrical lengths within about 0.1 picoseconds are possible. The location of the reference planes can then be calculated from the phase velocity of the coplanar waveguide in the thru standard.
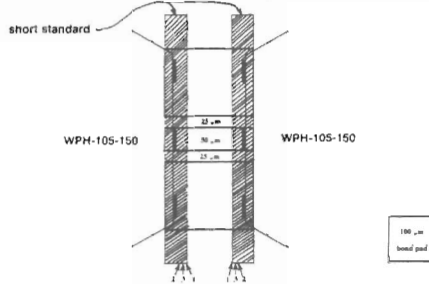

TRL (LRL) CALIBRATION
AT PROBE TIPS

THRU   REFLECT   LINE

cal kit
tips   probe in air
(NA)   25 ps
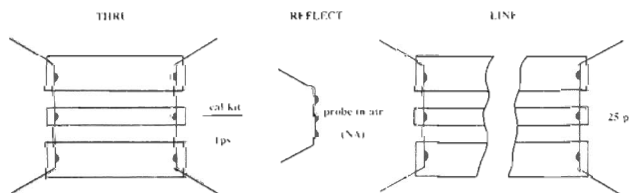
• Reference plane is placed in midpoint of shorter line, then rotated out 0.5 ps each.

• Know reference planes from Vp, e.g., 0.5 ps x 130 μm/ps = 65 μm from midpoint.

7162

The HP 8510B can be used for TRL calibrations at the probe tips. The standards used, in this case from 0.5 to 18 GHz, are a thru connection, a coplanar transmission line (which was about 25 picoseconds long), and a reflect standard which was the probe raised in air. The TRL calibration technique solves for the reference plane being at the center of the shorter line. Then the delay used in the cal kit defining the thru moves the reference planes to the desired position. As in the previous verification, the reference plane location can be physically located by using the phase velocity on the thru line. Comparison measurements of opens and shorts agree very well with the short-open-load-thru calibration standards.
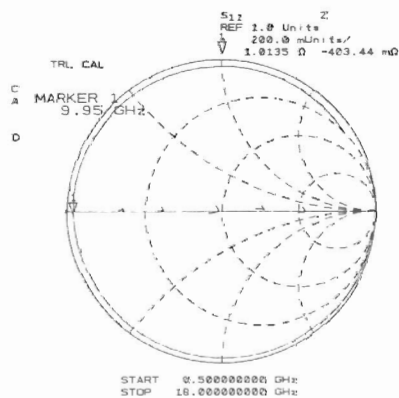
REFERENCE PLANE
DETERMINATION RESULTS

Method	Reference	Reference Plane measured location (in front of probe tip)
1. offset shorts	wall short = zero length	+ 27 μm
2. coax cal w/ unterminating	TEM stds set reference plane	+ 4 μm
3. TRL (LRL)	Γreflect1 = Γreflect2	+ 10 μm

short standard

WPH-105-150   WPH-105-150

100 μm bond pad

7163

The results of these reference plane experiments are summarized here. The measurement of the electrical length of a coplanar short resulted in the reference plane location 27 microns in front of the probe tip. The coaxial calibration and approximate unterminating approach predicted the reference plane to be 4 microns in front of the probe tip and the TRL calibration predicted the reference plane to be 10 microns in front of the probe tip. This figure shows these relative locations superimposed over the short circuit standard and a thru standard.
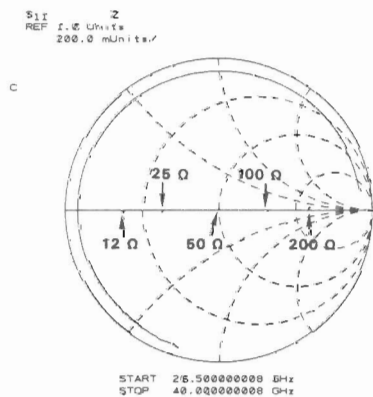

ONE-PORT STANDARDS
MEASURED FROM TRL CAL

S11   Z
REF 1.0 Units
     200.0 mUnits/
     1.0135 Ω -403.44 mΩ

TRL CAL

C
A   MARKER 1
    9.95 GHz

D

START   0.500000000 GHz
STOP   18.000000000 GHz

7164

The TRL calibration approach uses the characteristic impedance of the longer transmission line as the reference impedance for all of the parameters. This figure shows one port measurements of a short, a 12 ohm resistor, a 25 ohm resistor, a 50 ohm resistor, a 100 ohm resistor, a 200 ohm resistor, an open and the transmission line used in the TRL calibration measured as a one port. Since the characteristic impedance of a coplanar line (or microstrip line) changes with frequency, the lumped resistor standards have a resistance which appears to change with frequency. However, the open stub measurement is very accurate.

ONE-PORT STANDARDS
MEASURED FROM SOL CAL

S11   Z
REF 1.0 Units
    200.0 mUnits/

C

25 Ω   100 Ω

12 Ω   50 Ω   200 Ω

START 26.500000000 GHz
STOP   40.000000000 GHz

7165

This figure shows the same standards measured through 40 GHz with a short-open-load one port calibration. Now the verification resistor measurements show lumped element behavior as expected. For the short- open-load calibration, the electrical length of the short and open must be accurately specified and the probe tips must be correctly placed to assure correct reflection coefficient measurements. [1]

8

PROBE CALIBRATION TECHNIQUES

	advantages	disadvantages
SOLT	• Z_0 reference set by trimmed resistor	• More standards to connect and verify • Open and short lengths must be derived indirectly
TRL (LRL)	• Simple standards • Electrical lengths are more self-consistent	• Requires precision line Z_0 • Requires moveable probes

7166

The short-open-load-thru calibration has the advantage that the impedance reference of the measurement can be set by an accurately trimmed resistor. The disadvantages are that more standards are required to achieve a calibration and the electrical lengths of the open and short must be derived and verified indirectly. The advantages of the TRL calibration approach for wafer probes are that fewer standards are needed and the calibration technique inherently keeps the reference planes of reflection and transmission parameters self-consistent. The disadvantages of the TRL calibration are that the reference impedance is set by the characteristic impedance of the longer line and, in some cases, the probes must be movable to contact both ends of both transmission lines.

SHORT STANDARD REFERENCE PLANE vs OVERLAP DISTANCE
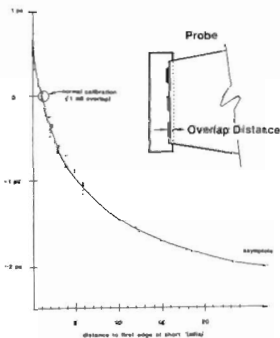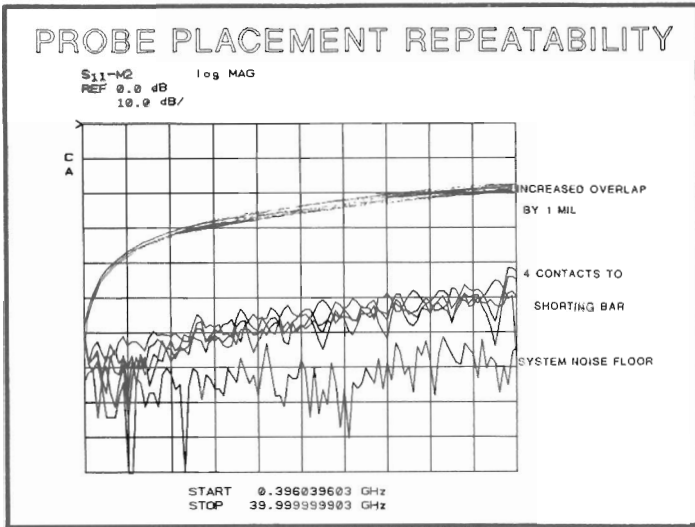

5340

The placement of the probe tip on a short standard affects the electrical length of the measured short. This plot shows the change in delay as a function of how much the edge of the short standard is overlapped. Note that the length can be accurately repeated and that there is a maximum of about two picoseconds of shortening when the probe overlaps a very large short by more than about 20 mils. Since the placement will affect the electrical length of the short, the probe must be accurately placed for each calibration. The recommended overlap is 25 microns (1 mil) on the 50 micron wide short standard.

REFLECTION MAGNITUDE OF AN OPEN STUB
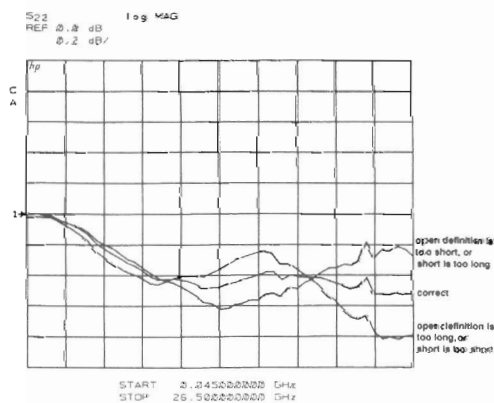
7167

A magnified plot of the magnitude of the relection coefficient of an open stub is shown here. If the relative lengths of the short and open standards are incorrect, then the reflection coefficient magnitude will be correlated to the reflection coeffiecient's phase. The center line shows a correct relative length of the short and open resulting in a monotonically increasing loss of the stub with frequency.

PROBE PLACEMENT REPEATABILITY

S11-M2   log MAG
REF 0.0 dB
   10.0 dB/

C
A

INCREASED OVERLAP
BY 1 MIL

4 CONTACTS TO

SHORTING BAR

SYSTEM NOISE FLOOR

START   0.396039603 GHz
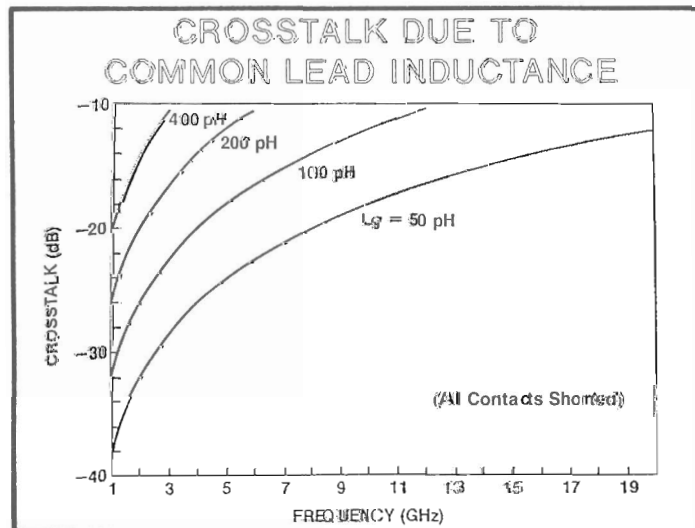STOP   39.999999903 GHz

7168

This plot shows the effect of probe placement and placement repeatability. The lowest trace is the noise floor of the network analyzer, the middle traces show the repeatability when lifting the probe from a short circuit and replacing the probe in the same position on the short. The top traces show multiple measurements of the same short circuit, but overlapped by an extra 25 microns. The short circuit is the worst possible case of a reflection coefficient changing with probe placement. For example the effect of placement on a 50 ohm load is one fourth as great or 12 dB better repeatability. Note that even through 40 GHz, a careful placement of the probe results in about 50 dB repeatability from measurement to measurement.

PROBE EQUIVALENT CIRCUIT

Input
#1

Z_0 Z_1

Z_{g12}
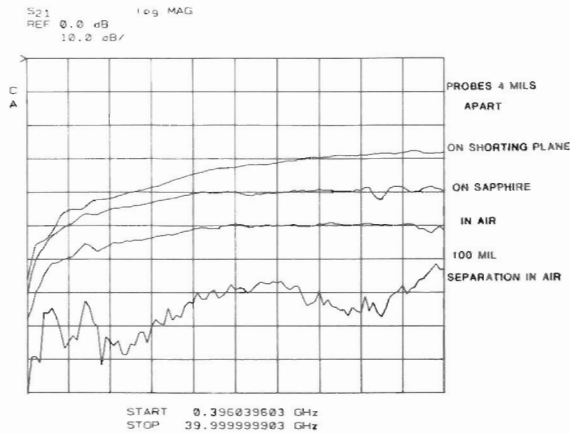
Z_{L1}

Z_0 Z_2

Z_{L2}

Input
#2
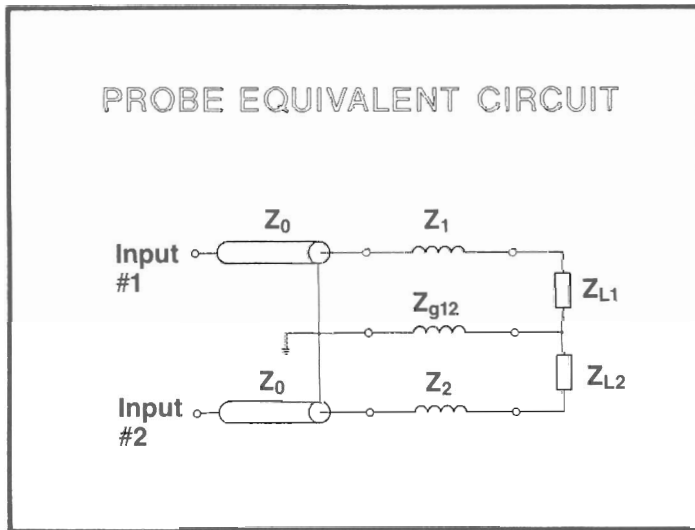
5321

At microwave frequencies, common lead inductance in either the probe or the circuit under test, will have large effects on measured data. This is a simple first order equivalent circuit of a pair of probes. The first troublesome parasitic with a 50 ohm system is normally the common lead inductance ZG12. ZG12 can be measured by making ZL1 and ZL2 low impedances and measuring the transmission from input number one to input number two. Transmission will be a strong function of ZG12.

CROSSTALK DUE TO COMMON LEAD INDUCTANCE

-10

400 pH
200 pH
100 pH

Lg = 50 pH

-20

-30

(All Contacts Shorted)

-40
1   3   5   7   9   11   13   15   17   19
FREQUENCY (GHz)

CROSSTALK (dB)

5322

For the worst case of the probe tips shorted together, this slide shows the calculated crosstalk from port one to port two. Note that a common lead inductance of only 50 picohenries provides only 12 dB of isolation at 20 GHz. A typical bond wire or needle probe has about one nanohenry of inductance per millimeter of length, so the crosstalk due to common lead inductance is a very significant problem for needle probes.

10

PROBE CROSSTALK
MEASUREMENTS (ISOLATION)

S21   log MAG
REF 0.0 dB
     10.0 dB/

C
A

PROBES 4 MILS
APART

ON SHORTING PLANE

ON SAPPHIRE

IN AIR

100 MIL
SEPARATION IN AIR

START   0.396039603 GHz
STOP   39.999999903 GHz

7169

We show here a measurement of the crosstalk between two WPH-305 probe heads. The top trace shows the case where both probes are contacting a short circuit. The next line shows the case where both probes are contacting the surface of the sapphire dielectric of the ISS, and the next line shows the case where the probes are in air separated by 4 mils. The bottom trace shows the noise floor of this particular measurement system. Other measurements have shown that at least 50% of the crosstalk vector shown here is due to cross-talk between the standards being contacted in the measurement. For example, the short circuits should have a mutual inductance coupling them and the open circuits should have a mutual capacitance between the signal contacts.

GETTING THE BEST
MECHANICAL PERFORMANCE
FROM YOUR PROBES

- How to get 1,000,000 cycles from your probes

- Overtravel limits

- Protect from current overloads
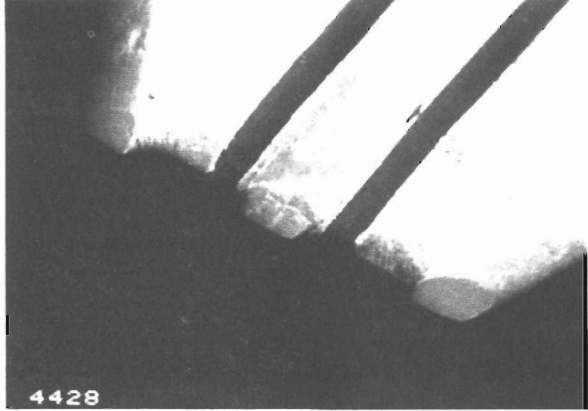
7170

PROBE LIFE DEMONSTRATION
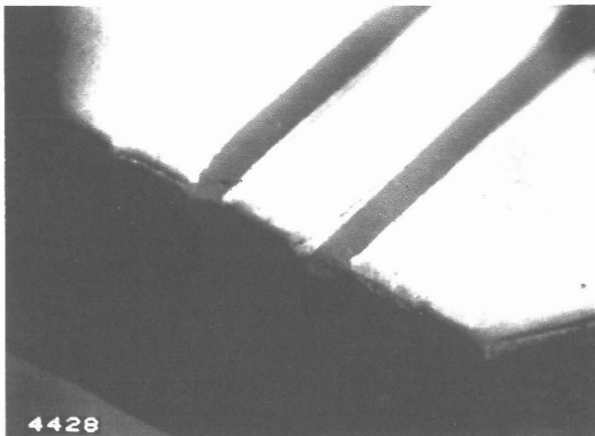
4428
Probe serial no. 4428 before use.

7171

Probe life is directly related to overtravel (continued downward vertical movement once the DUT is contacted by the probe tip), the DUT material, and the electrical power applied to the tips.
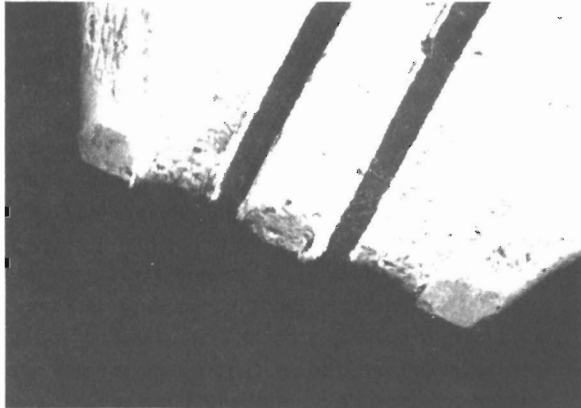
11

PROBE LIFE DEMONSTRATION

4428

SN 4428 after 360,000 cycles with .002" overtravel and 10 ma test current (power off between cycles).

7172

This example of a typical Cascade probe shows < 20% wear after 360,000 contacts on Au pads with 2 mils overtravel and cold probing (power OFF).

## PROBE LIFE DEMONSTRATION

Probe serial no. 3004 after 105,000 cycles, hot probing with 1/2 amp and .010" overtravel.

7173

Increasing the overtravel to 10 mils (recommended working maximum) and hot probing (power kept ON) with 0.5amps current increases the contact wear. This combination of overtravel and hot probing exhibits the same wear after 105,000 cycles as the previous example. Even at these extremes the useful probe life should exceed 500,000 contacts.

PROBE PROTECTION CIRCUIT

power supply

I limit ≤ 500 mA

+

+ sense

- sense

-

R_{limit}

$100\ \Omega$
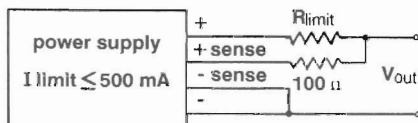
V_{out}

$$R_{limit} \geq \frac{V_{out}}{500\ mA}$$

7174

Instantaneous overload effects caused by making and breaking contact with power applied can reduce probe life to a few thousand cycles. If the probe tip contacts a low impedance with bias applied, the maximum current will be determined by the size of the output capacitor and the current limiting resistor. At the same time, if contact is broken with a large current flowing, any inductance in the power supply will cause arcing at the probe tip. Installing this current limit/sense circuit will help alleviate these problems. Be sure to use low inductance resistors for this protection circuit.

EXTENDING PROBE CONTACT LIFE

- Limit overtravel to 4 mils or less

- Avoid instantaneous current overloads

- Follow care & cleaning procedures

7175

Cascade recommends probing with 4 mils of overtravel or less. Reliable contact to the DUT usually can be established at 2 mils of overtravel. Reducing overtravel will also help to minimize the amount of metal picked up by the probe tips and thus reduce the need for cleaning. Procedures for care and cleaning of Cascade probes can be found in all Cascade probe station and top plate manuals. Additional information is available in the "Proper Care & Cleaning of Cascade Microtech Microwave Probe Heads," application note.

MEASUREMENT EXAMPLES

- FET measurement

- MMICs measurements

- Corrections for noise and power measurements

7176

Now we show some examples of probe measurements through 40 GHz made using an HP 8510B network analyzer with an HP 8516A 40 GHz test set and Cascade 50 GHz probes. First, FET measurements and parameter extraction is shown. Then, examples of MMIC measurements and corrections using the HP 8510 to correct noise and power measurements are discussed.

40 GHz FET MEASUREMENT

300-MICRON FET EXAMPLE 3V, -1V, 18.9 mA
V 8510=0.00 V 17-FEB-88 12:43
MEASURED X   COMPUTED O

```
---  S12  RADIUS: 0.20
- -  S21  RADIUS: 10.00
     S22
0.396 - 40.00 GHz
E11      2.01 %
E12     13.98 %
E21      3.23 %
E22      2.96 %
Ft      32.05 GHz
gm/C    29.96 GHz
gmextr  74.64 mS
gm      81.36 mS
Cgs    365.11 fF
Cgd     73.27 fF
Cds     90.33 fF
Tt       2.04 pS
Rg       0.26 ohm
Rgs      1.68 Kohm
Rin      2.25 ohm
Rs       1.11 ohm
Rds    127.27 ohm
Rd       6.48 ohm
Lg      18.8 pH
Ls       1.2 pH
Ld       1.5 pH
```
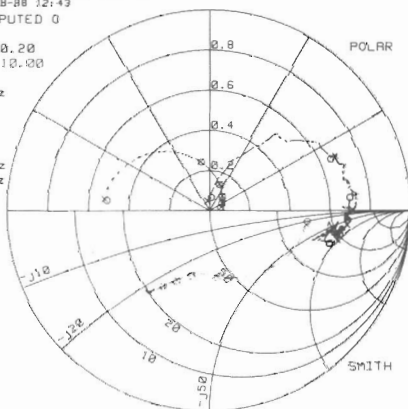
POLAR

SMITH

7177

This is a measurement of a 300 micron millimeter wave GaAsFET. In this plot the X's refer to the measured data and the O's refer to a lumped equivalent circuit whose calculated S-parameters are plotted over the measured data. This measurement was taken with an asymmetric HP 8516A Opt. 003 test set as opposed to the standard HP 8516A test set which has symmetric dynamic range for both transmission measurements. This assymmetry resulted in the slightly more noisy S12 measurement. As can be seen here, the measured data matches a lumped equivalent circuit for the FET quite well over the entire frequency range.

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PROBE PLACEMENT COMPARISON
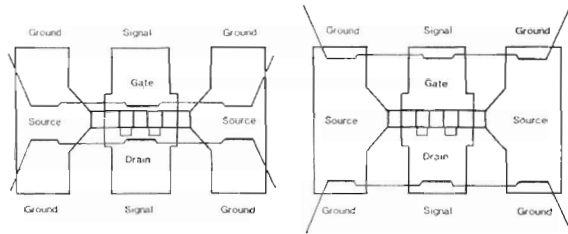
7178

The effect of different probe placements on DUT pads has been investigated. In this comparison, the same FET at the same bias condition was measured with the probes at the inner and then at the outer edges of its bond pads.
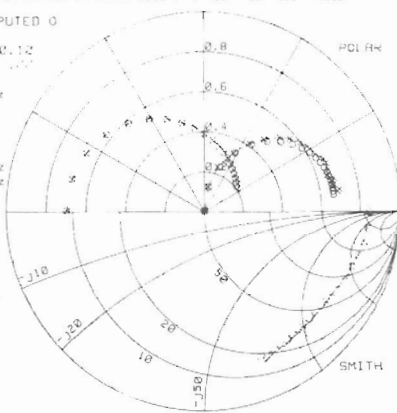
FET PROBED AT INNER EDGE

10/22/86 300 MICRON FET PROBED AT INNER EDGE OF 2 MIL PADS (GSG PROBES)

MEASURED X   COMPUTED O

— · S12   RADIUS: 0.12   POLAR
· · S21   RADIUS: 0.08

0.045 - 20.15 GHz
E11   0.68 %
E12   7.39 %
E21   2.10 %
E22   1.77 %
Ft   15.59 GHz
gm/C   14.82 GHz
gmextr   37.98 mS
gm   38.90 mS
Cgs   390.44 fF
Cgd   19.66 fF
Cds   87.48 fF
Tt   4.87 pS
Rg   0.50 ohm
Rgs   21.90 Kohm
Rin   4.50 ohm
Rs   0.62 ohm
Rds   586.85 ohm
Rd   0.00 ohm
Lg   23.3 pH
Ls   1.5 pH
Ld   16.9 pH

SMITH

7179

The measurement with the probe on the inner edge of the pads is shown here.

FET PROBED AT OUTER EDGE

10/22/86 300 MICRON FET PROBED AT OUTER EDGE OF 2 MIL PADS (GSG PROBES)

MEASURED X   COMPUTED O

— · S12   RADIUS: 0.13   POLAR
· · S21   RADIUS: 0.08

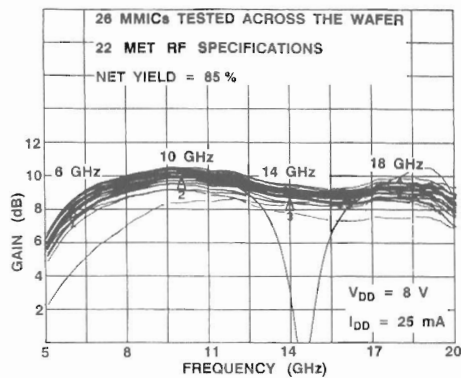0.045 - 20.15 GHz
E11   0.79 %
E12   5.08 %
E21   2.40 %
E22   2.10 %
Ft   15.76 GHz
gm/C   14.64 GHz
gmextr   37.90 mS
gm   38.60 mS
Cgs   400.33 fF
Cgd   19.85 fF
Cds   87.10 fF
Tt   4.81 pS
Rg   0.50 ohm
Rgs   32.03 Kohm
Rin   4.62 ohm
Rs   0.48 ohm
Rds   592.59 ohm
Rd   0.00 ohm
Lg   50.3 pH
Ls   2.3 pH
Ld   47.6 pH

SMITH
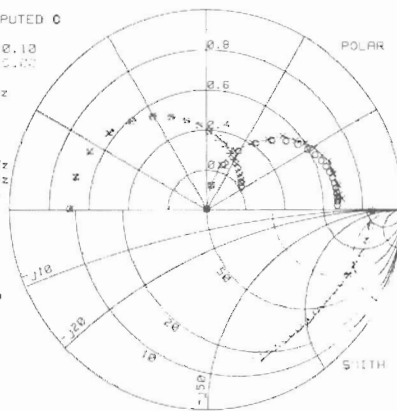
7180

The remeasurement of this FET with the probes 2 mils farther out on the bond pads results in similar S-parameters, except with more electrical length on each parameter. Note that the extracted equivalent circuit is very similar in the two cases with the exception of the series inductances, L_g and L_d. In the first case, L_g and L_d are about 20 pico-henries. In the second case, they are about 50 pico-henries. From measurements such as these, the connection parasitic to the device is relatively easy to extract from the total device measurement.
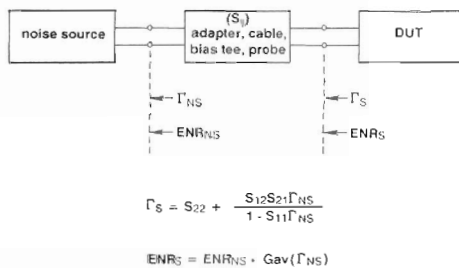
GAIN vs FREQUENCY

26 MMICs TESTED ACROSS THE WAFER

22 MET RF SPECIFICATIONS

NET YIELD = 85 %

V_{DD} = 8 V

I_{DD} = 25 mA

GAIN (dB) vs FREQUENCY (GHz)

6 GHz   10 GHz   14 GHz   18 GHz

7181

This is a plot of gain versus frequency of a 6 to 18 GHz MMIC chip (courtesy of Pacific Monolithics, Inc.). The on-wafer measurement system is very convenient for measurements and comparisons of devices or circuits across a wafer. In this case, gain measurements were taken on many devices on a wafer and plotted on top of each other for a quick comparison.
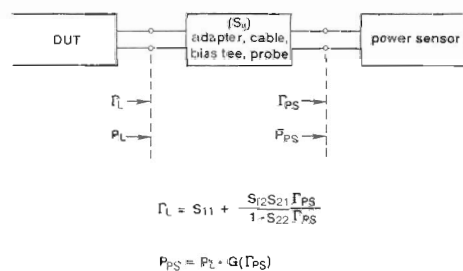
CORRECTING NOISE MEASUREMENTS FOR ADAPTER LOSSES AND REFLECTIONS

noise source — (S$_{ij}$) adapter, cable, bias tee, probe — DUT

$\leftarrow \Gamma_{NS}$ $\Gamma_S \rightarrow$

$\leftarrow$ ENR$_{NS}$ ENR$_S \rightarrow$

$$\Gamma_S = S_{22} + \frac{S_{12}S_{21}\Gamma_{NS}}{1 - S_{11}\Gamma_{NS}}$$

$$ENR_S = ENR_{NS} \cdot Gav(\Gamma_{NS})$$

7182

On wafer noise figure measurements are also common with the Cascade probes. An HP 8510 system can be used to measure the S-parameters of any adapters, cables, bias tees or probes between the noise source and the probe tip. The approximate unterminating technique, as discussed earlier, can be used to measure losses in the adapter. For more accuracy, a full unterminating can be done with three known standards or alternatively, the HP 8510B adapter removal feature can be used to measure the S-parameters of the adapter. The corrections to the noise source ENR and reflection coefficient are shown here. The reflection coefficient seen by the DUT is now modified by the adapter and the excess noise ratio (ENR) is attenuated by the available gain of the adapter. Note that the available gain of the adapter is a function of the reflection coefficient of the noise source, but not a function of the DUT parameters. In this set up, the DUT's noise figure will be the noise figure when the DUT is terminated in gamma sub S. To relate the noise figure at gamma sub S to the noise figure in a 50 ohm system, the noise parameters of the DUT must approximately be known [2].

CORRECTING POWER MEASUREMENTS FOR ADAPTER LOSSES AND REFLECTIONS

DUT — (S$_{ij}$) adapter, cable, bias tee, probe — power sensor

$\Gamma_L \rightarrow$ $\Gamma_{PS} \rightarrow$

$P_L \rightarrow$ $P_{PS} \rightarrow$

$$\Gamma_L = S_{11} + \frac{S_{12}S_{21}\Gamma_{PS}}{1 - S_{22}\Gamma_{PS}}$$

$$P_{PS} = P_L \cdot G(\Gamma_{PS})$$

7183

Corrections for on-wafer power measurements are analogous to those for noise figure measurements. In the case of power, the device under test is terminated by gamma sub L which is a combination of the adapter and power sensor parameters, and the power delivered from the DUT into the adapter and power sensor is attenuated by the gain of the adapter before reaching the power sensor. The gain in this case is the ratio of the delivered powers, which is a function of the reflection coefficient of the power sensor, but not of the DUT parameters. Here again, the actual power of the DUT operating into a 50 ohm environment is not deducible from this measurement if the device is significantly non-linear.

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SUMMARY

- 40 GHz wafer characterization using the HP 8516A & Cascade probes

- Reference planes can be located within +/- 0.1 pS

- 50 dB repeatability demonstrated through 40 GHz with the WPH-305 Wafer Probe

- >1,000,000 contacts can be achieved with proper probe care

7184

Reference #1:

Model 42 Instruction Manual. Cascade Microtech, copyright 1987.

Reference #2:

E.W. Strid, "Measurement of Losses in Noise-Matching Networks." IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-29, #3, March 1981.