Layout Rules for GHz-Probing

Overview

Coplanar GHz probes have been available only since 1983, and have significantly advanced wafer probing capabilities. Wafer probing at GHz frequencies has developed over the past several years from a simple R&D toy to a sophisticated high-volume manufacturing tool used in GaAs, silicon, packaging, and hybrid industries. Successful GHz probing requires that consideration be given to layout and design before design completion and mask fabrication. Failure to observe specific layout requirements can result in the inability to test devices with GHz probes.

This Application Note focuses on layout and testing issues as they apply to the use of GHz coplanar probes, Discussed first are specific mechanical and electrical layout rules, rules that will to assure that a fabricated device can be successfully probed. Following the layout rules are design/layout guidelines for current major applications of GHz-wafer-probing technology-microwave monolithic integrated circuits (MMICs), high-speed digital ICs, individual characterization devices for process characterization and modeling, and high-speed hybrids and packages. The rules in this Application Note will help you achieve the best possible tests.

It is useful to stop and consider what you really wish to measure. When GHz probes are used with a network analyzer (after calibration), what is measured will be what is contacted by the probe tips. This includes the pad parasitics, and parasitics associated with the interconnects from the pad to the other devices on your substrate. If you want to measure a device independent of the pad effects, then it is useful to make the pads small, so their effects will be negligible or easily subtracted from the measured data. In any event, it is important to be clear that when using a network analyzer you will be measuring everything past the end of the probe tips, unless you use special calibration/correction techniques. In most applications this is exactly what you want; a measurement of the circuit's electrical performance.

This Application Note applies to the following FormFactor probe series:

- WPH-Oxx- 18 GHz probes
- WPH-1xx- 26 GHz probes
- RTP-105-xxx- 26 GHz replaceable-tip probes l WPH-2xx-50 GHz probes
- WPH-3xx - 40 GHZ probes
- WPH-7xx - multicontact probes
- WPH-9xx - multiple-needle probes

The S channels (red tips) can be adjacent to other types of channels (red or blue tips), forming various RF signal configurations, such as ground-signal (GS), signal-ground (SG), ground-signal-ground (GSG), ground-signal-signal (GSS), differential signal-signal pairs without grounds (SS). In some cases, the bypassed powers (P) are used in place of grounds (G) such as in PS, GSP. In this document, Ps used this way will be referred to as Gs unless stated otherwise. The network analyzer calibrates these variously configured channels, treating them individually as ports. If N is the total number of these ports, the network analyzer regards the DUT as an N-port network. Note that the differential SS configuration is counted as a single port, since the differential pair will be connected to a single port of the network analyzer through a balun outside the probe. The technique described in this application note is called the N+1 Port SOLT/SOLR calibration, where N is the number of ports in the test set-up that need to be calibrated and the N+1'th port is assigned to an additional RF channel for common thru pair measurements. However, this does not mean that one necessarily needs a VNA with N+1 ports, as described later in this application note.

Probe Features Affect Layout

A coplanar probe's features (Fig. 1) include the probe body, the coaxial connector, the probe tip, and the contacts at the probe tip end. Coplanar transmission lines carry the signal between the coaxial connector and the probe tip contacts.
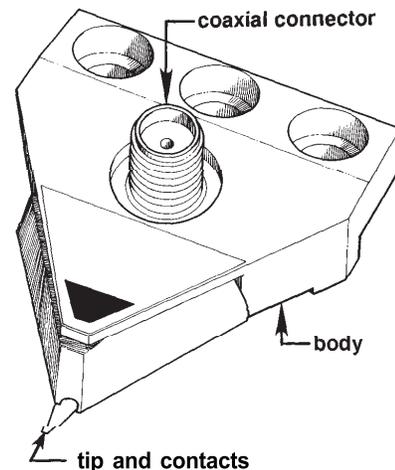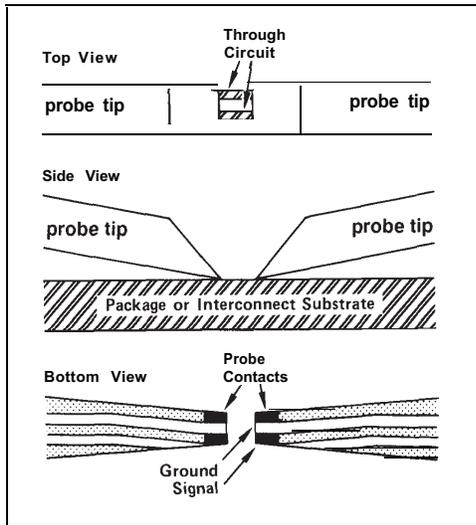

Figure 1. Coplanar probe

Figure 2. Probe tip: top, bottom, and side view.

The transition from coaxial, with a radial electrical field pattern (Fig. 3a), to a coplanar transmission line with a much different electrical field pattern (Fig. 3b) is made within the probe. This is a difficult transition to make at GHz frequencies, and presented difficulties in successfully designing this type of probe. The best DUT tests result if the electric field patterns at the probe tip are similar to the field patterns in the DUT. If transitions are necessary, they should be made cleanly.

The typical probe contact is a signal (S) or ground (G) contact. The signal contacts are electrically connected to a coaxial connector center pin, and the ground contacts are electrically connected to the coaxial-connector body. At high frequencies the ground is not an equipotential reference, as in low frequency circuits, but is a part of a transmission line that contains time-varying electric fields. The 700-series multicontact probes also permit specified contacts to be bypassed ("P"-discussed later in this Application Note), and terminated ("T"). (See the Probe Selection Guide for additional details).
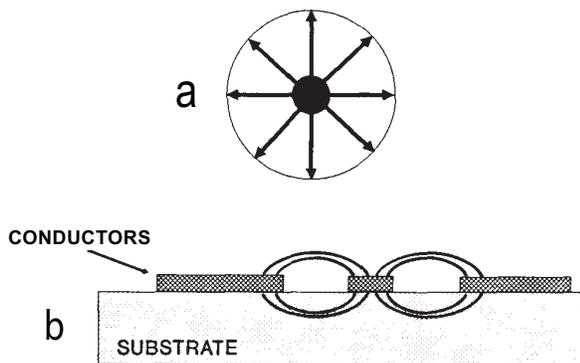
Figure 4 shows an example MMIC pad footprint. Note the input is on the left, the output on the right, and that the power and control signals at the top are provided by low-frequency needle-type probes. The GHz probes are GS (ground-signal) probes, useful to 26 GHz. The bottom row of pads are on the same bus, providing a low-impedance ground for the two GHz probe ground contacts. When packaged, there will be several bond wires connecting the ground buses to the package ground. This minimizes common-ground inductance. Also, note that the amplifier is positioned close to the ground bus in order to minimize common-ground inductance. In practice, the individual transistors would be positioned very close to the ground bus.
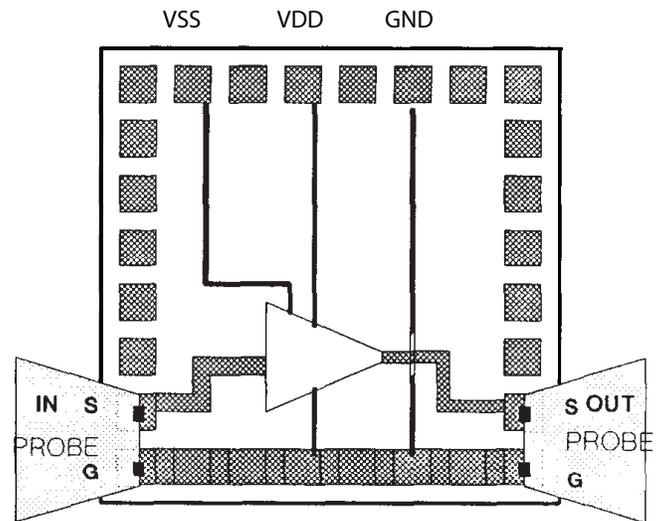

Figure 4. Typical MMIC padout, ground-signal probes in contact

There are several physical features of coplanar probes that affect the layout. The first of these (Fig. 5) is the extension of the probe tip substrate material past the center of the contact closest to the edge. This dimension is typically 100 µm. Probes must not be allowed to collide, so this 100 µm extension must be considered when laying out pads.

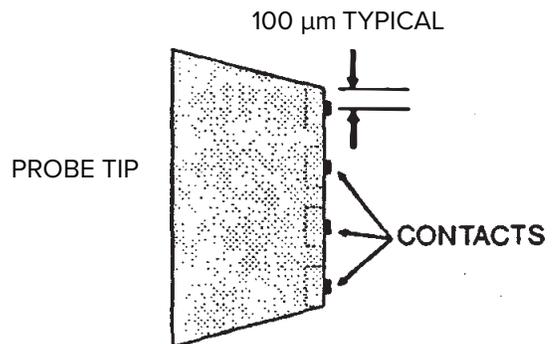Figure 3. Electric field patterns in coaxial and coplanar transmission lines.

Figure 5. Substrate extension is typically 100 µm. probes in contact.

Another physical layout consideration is the probe contact size (Fig. 6), typically 50 x 50 μm. Note that these contacts are much larger than needle probes, and the passivation windows must be large enough to accommodate these contacts plus typical probe system variations.
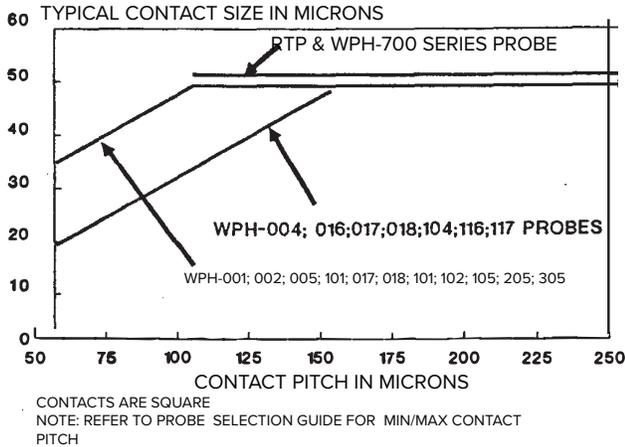

CONTACTS ARE SQUARE
NOTE: REFER TO PROBE SELECTION GUIDE FOR MIN/MAX CONTACT PITCH

Figure 6. Contact size as a function of contact pitch and probe type.

The final consideration is the probe skating distance. For every 50 μm of overtravel (overtravel is the continued downward movement after the probe tip has made initial contact with the wafer) the probe contacts will skate laterally 1 o μm. If the probes are too close together, they could skate into each other and be damaged. The layout rules will help you prevent probe collisions.

Sequence of Layout Events

The following are guidelines to the typical sequence of events involved in layout for testing with GHz probes. In many cases these guidelines will improve the packaged device performance. Specific requirements may result in these guidelines being altered.

1. Select basic pad footprint for signal, power, control, and ground pads to be consistent with input/output type (see step 2) and package requirements. Example pad footprints are shown throughout this Application Note.

2. Select high frequency input/output type to meet your specific frequency, design, and signal count requirements; either signal-ground (SG) or ground-signal-ground (GSG), or signal-signal (SS).

3. Orient high-gain signal pads away from each other. Typical microwave circuits place inputs on the left, and outputs on the right.

4. Use at least one ground pad for each GHz probe. The ground pads tor each GHz probe must be electrically connected together on the OUT to provide a low-impedance, common-groundnode.

5.Use additional ground pads between signal pins to obtain reduced crosstalk (as required) within multicontact GHz probes.

6. Verify that pad pitch matches available probe pitch (see Probe Selection Guide). Also, verify that the pad footprint meets packaging requirements.

7. Call the FormFactor Applications Group to verify that the footprint is agood layout for probing. If you want to violate some of therules, please call the FormFactor Applications Group regarding the trade-offs. Most of the rules can be successfully violated, provided you meet certain conditions.

Layout Rules, Mechanical

This section describes the mechanically related rules regarding probe pad placement and sizing. In most designs the probe pads are also used as bond pads, so the final layout should satisfy requirements for both probing and bonding. A good layout for GHz probing is usually also a good layout for packaging.

There are two important GHz-probe mechanical parameters which directly affect the mechanical layout rules; the contact dimensions and the substrate extension past the contact. Typical contact size for WPH-series probes (Fig. 6) is 50 x 50 μkm for contact pitch greater than 100 μpm,tapering to 35 x 35 μkmmas the contact pitch approaches 50 μbmrn. The contact size is important because the passivation window must be large enough to allow the entire contact to touch the pad. The substrate extension is typically 100 μpm past the contact center (Fig. 5).

Coplanar-waveguide GHz probes are constructed with all contacts in a straight line, and with equal spacing between contacts. This means that all pads, arranged for an individual GHz probe measurement, must be in a straight line, have equal pitch, and be on the substrate top. Non-square or very large pads may be laid out more randomly, as long as there is a minimum-size land area, spaced at an equal pitch for the probe contacts to land on.

Top-side pads connected to substrate vias must be used to contact backside grounds. All pads must have as small as possible height variation, because the GHz-probe construction allows little contact height variation.

If GHz probes crash into each other, they can be damaged. The pad layout must allow for sufficient damage-avoidance space between GHz probes. Provide sufficient space for probes that are oriented 90 degrees to each other, as well as between probes that face each other. There must be sufficient space between probes to allow for probe skating. The following pad layout rules allow for vertical overtravel of 20 mils (500 µm). Note that 20 mils is the maximum rated overtravel for FormFactor GHz probes, and that the recommended nominal overtravel (to achieve assured contact) for the typical probe is 2-4 mils (50-l00 µm).

The mechanical layout rules are given three-digit numbers, starting with 100. This number also indicates the applicable dimension within the referenced figures. Note that the minimum and maximum values given are the recommended values for general testing conditions. If you have a specific need outside these values, please call the FormFactor Applications group for consultation.

Rule 100 Pad Size: The minimum pad size is 50 x 50 µm (Fig. 7). The recommended minimum pad size for general use is 100 x 100 µm. Note that because the probe contacts are fairly large, in many situations pads smaller than 50 x 50 µm can be successfully probed. Unless you have a good reason to do otherwise, use 100 x 100 µm pads with a 150 µm pitch. This provides for easy probing, and parasitic are low enough for many applications.
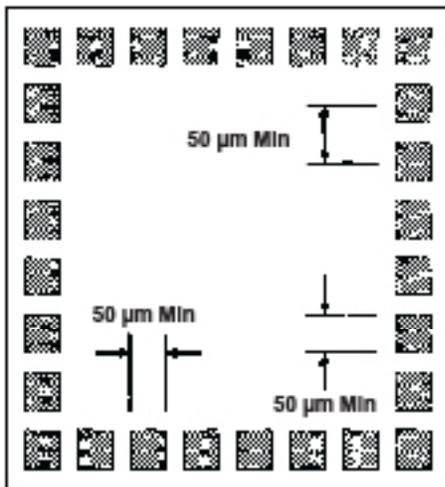
Rule 101 Passivation Window: The minimum passivation km window size is 96 x 96 µm (Fig. 8). Smaller passivation windows are acceptable for probe pitch values less than 100 µm because the contact size decreases as contact pitch becomes less than 100 (Fig. 6). Note that for small pad sizes, the passivation window will be significantly larger than the pad. If the pad metalization is above the final passivation layer, this rule does not apply.
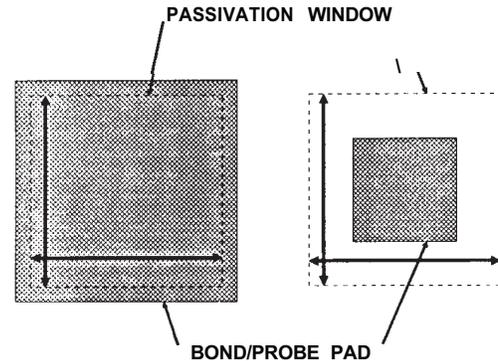

PASSIVATION WINDOW

BOND/PROBE PAD

Figure 8. Rule 101. Minimum passivation window size is 96 x 96 µm

Rule 102 Pad pitch: The minimum center-to-center pad pitch is 50 µm minimum pitch (Fig. 7). The recommended minimum is 150 µm. Note that many probes have a 100 µm specification. (See the Probe Selection Guide for additional details.)

Rule 103 Orthogonal-row pad spacing: The minimum center-to-center pad spacing for orthogonally oriented probes (in a corner) is 200 µm (Fig. 9). Sufficient clearance is often achieved by eliminating the corner pad (Fig. 15).
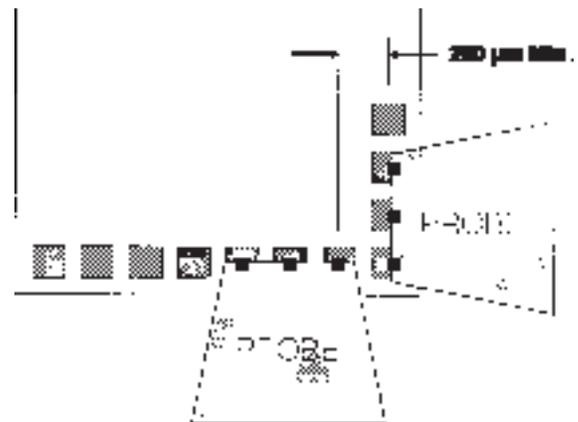

Figure 7. Rules 100 and 102. Minimum pad size is 50 x 50 µm. Minimum pad pitch is 50 µm

Figure 9. Rule 103. minimum center-to-center pad spacing in a corner is 200 µm.

Rule 104 Single-row pad spacing: The minimum center-to-center pad spacing for opposing, side-by-side probes that are contacting the same line of pads, (Fig. 10) is 200 µm.
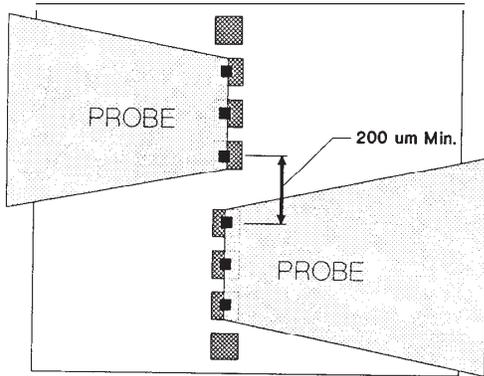

Figure 10. Rule 104. minimum pads spacing with opposing, side-by-side probes is 200 µm.

Rule 105 Parallel-row pad spacing: The minimum center-to-center pad spacing between facing probes on parallel rows of pads (Fig. 11) is 200 µm. Note that this spacing is based on the assumption of 20 mils (500 µm of probe over-travel. If the probe overtravel can be limited to 10 mils (250 µm) then the minimum spacing is 100 µm.
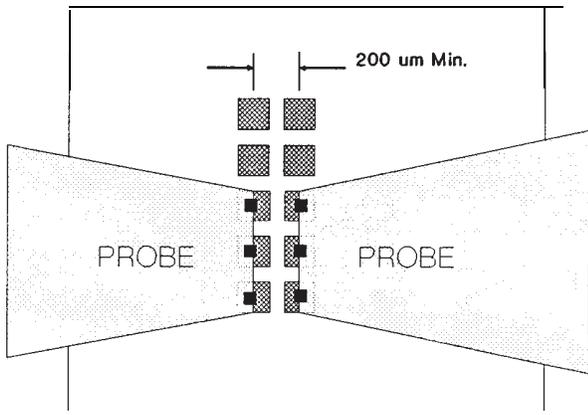

Figure 11. Rule 105. Minimum center-to-center pad spacing for parallel rows of pads with facing probes is 200 µm.

Rule 106 Pad height variation The maximum pad height variation in a row of pads contacted by one probe is 0.5 km (Fig. 12). Pad height variation usually occurs because pads are constructed with different metal stacks. Be sure to use the same metal layers to construct all pads.
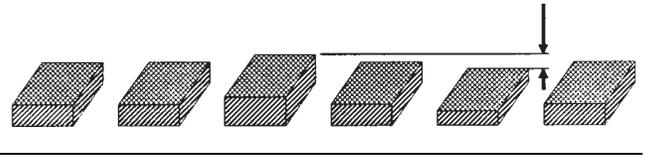

Figure 12. Rule 106. Maximum pad height variation in a row of pads contacted by one probe is 0.5 pm.

Rule 107 Planarity requirements: The maximum overall planar deviation of a row of pads contacted by one probe, with respect to the backside of the substrate, is 2 parts per 1,000 for WPH-700 series multicontact probes, and 5 parts per 1,000 for other probes (Fig. 13). Non-planarity can be caused by using different metal stacks for the pads within a row, or incorrectly backlapping a wafer. Also note that during probing, non-planarity between the probe contacts and the pads should not exceed these maximum planar deviations.
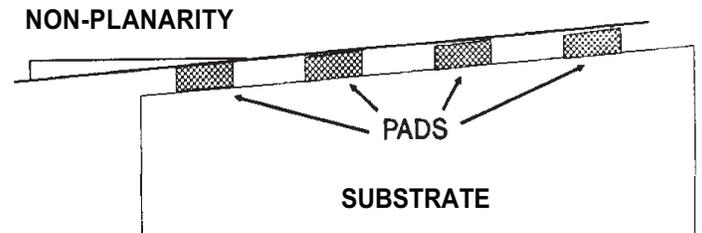

Figure 13. Rule 107. Maximum non-planarity from a row of pads to the backside of substrate is 2/1,000 for WPH-700 probes, and 5/1,000 for all other probes.

Rule 108: Pads at 90 degrees only. Rows of pads meeting at an angle (Fig. 14) must be orthogonal (at 90 degrees).

Rule 109: Pads are collinear All pads contacted by an individual probe must be collinear (Fig. 14).
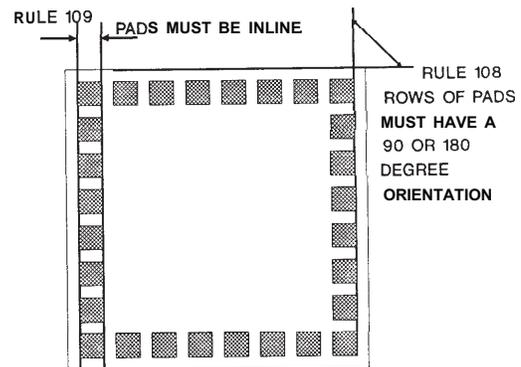

Figure 14. Rule 108- ROWS of pads meeting at an angle must be at 90 degrees. Rule 109- Pads contacted by one probe must be collinear.

Rule 110 Pads have equal pitch: All pads contacted by an individual probe must have constant pitch. Note that the WPH-700 series multicontact probes allow for contact removal, and therefore pad removal.

Rule 111: Pads on top all pads must be on the substrate top.

Layout Rules, Electrical

This section describes the electrically related rules regarding pad placement and sizing. In most designs the pads are also used as bond pads, so the final layout should satisfy requirements for both probing and bonding. The following rules are given three-digit numbers starting with 200.

Compared with mechanically related layout rules, the electrical considerations are more complex. Included in the electrical considerations are:

- Probe grounds;

- Signal input/output;

- Crosstalk between probes;

- Crosstalk between signal lines within a probe;

- Maximum operating frequency for each probe type;

- Power and ground to DUT during probing;

- Maximum current per contact.

Rules 200-205

Rule 200 Pads on top: All pads must be on the substrate top surface, and all nodes to be measured or stimulated must connect to these pads.

Rule 201 Probe Grounds: Each probe must have at least one ground contact.

Rule 202 All grounds connected: All probe ground contacts must be electrically connected together on the DUT (Fig 15) This connection should be as short a connection as possible, presenting a low impedance at high frequencies. A useful method for connecting probe grounds is shown in Fig. 16. This approach uses L-shaped metalization to connect the probe grounds. Note that this method requires the edge contacts to be defined as ground for each probe.
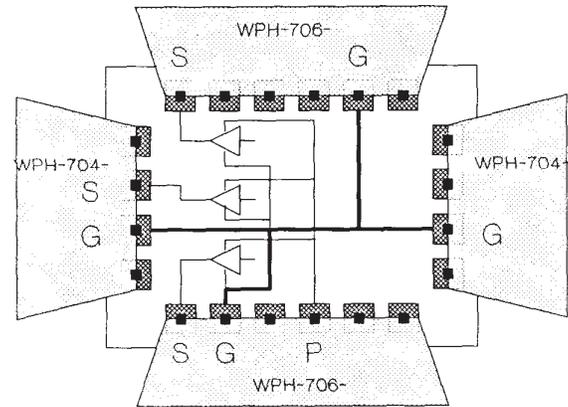

Figure 15. Rule 201 - All probes must have at least one ground. Rule 202-All probe grounds must be connected together on the DUT.
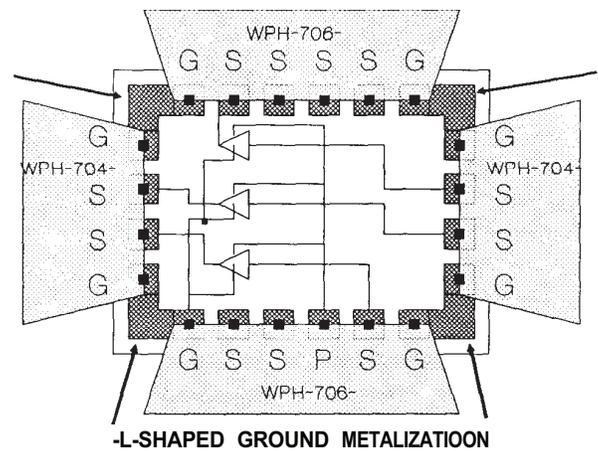

-L-SHAPED GROUND METALIZATIOON

Figure 16. Alternative method of connecting the probe grounds together, using L-shaped metalization connecting ground pads. Requires probes with outside contacts defined as ground.

Rule 203 Signal input/output: Signal input/outputs are either signal-ground (SG), ground-signal-ground (GSG), or signal-signal (SS). Any of these input/outputs may be used for measurements up to 18 ghZ The GSG arrangement is advised for measurements beyond 18 ghZ, and required beyond 26 GHz. The SS input/output requires differential signals and a mirrored layout, resulting in a virtual ground. The WPH-700 series probes can be factory programmed to provide a wide variety of contact sequences, including signal, ground, bypassed power, and terminated signal. (See the Probe Selection Guide for details.)

Rule 204 High dynamic-current grounds: The lowest impedance ground return for high dynamic-current outputs must be connected to the same probe head that is providing the power to those outputs (Fig 17).
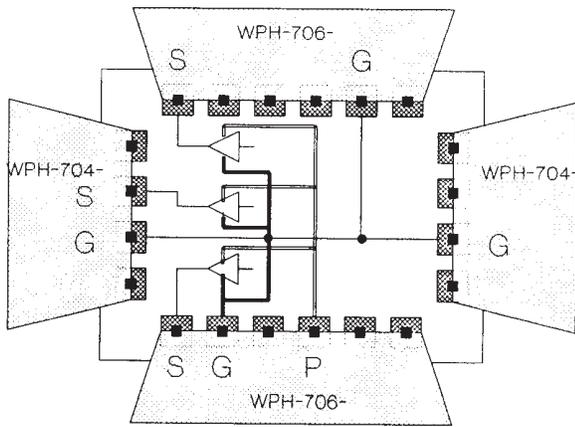
Figure 17. Rule 202. Where high dynamic currents exist, provide low-impedance grounds to the same probe which supplies the power.

Rule 205 Maximum rated current: The maximum dc current per contact is one-half ampere. Do not apply more than 1 ampere total to a probe that is in continuous contact, i.e., no make and break contact.

Crosstalk

If there is good shielding design, crosstalk is generally not a problem, except when testing very high gain amplifiers, A/D and D/A circuits, or when there are severe reverse isolation requirements. When using coplanar probes, crosstalk may be observed in the following situations:

Crosstalk between probes:

• Capacitive or radiative coupling between probes.

• Common ground inductance in DUT.

Crosstalk between signal lines within a probe:

• Common ground inductance in probe.

• Mutual coupling between signal lines within a probe.

There are layout decisions that will affect crosstalk:

• Spacings between input and output pads will affect probe-to-probe crosstalk.

• Common-ground inductance in the device layout will affect probe-to-probe crosstalk.

• There is the question of whether or not to place an intervening ground pad between signal pads when laying out circuits to be probed by the WPH-700 series multicontact probes. The addition of the intervening ground pad will require a corresponding ground contact in the probe, and therefore will reduce crosstalk between signal lines within the probe.

Crosstalk Between Probes

The crosstalk between probes due to capacitive and radiative coupling is shown in Fig. 18. Note that the crosstalk depends on the spacing between probes, and the material on which the probes are landed. When laying out circuits where crosstalk between probes is important, space the pads as far apart as possible.
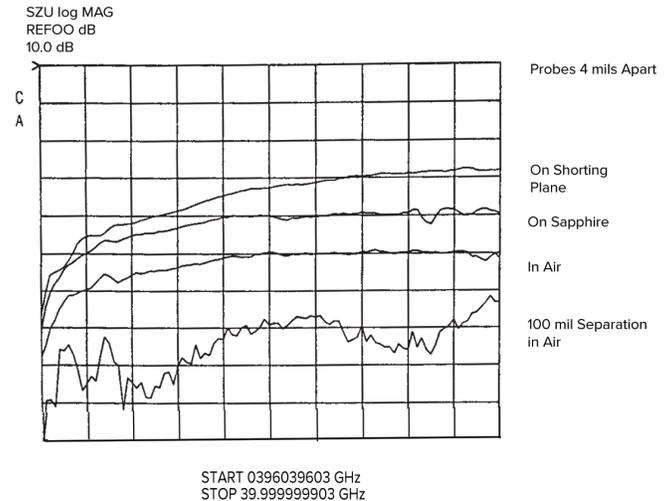

Figure 18. Crosstalk between two GSG probes.

Another factor affecting probe-to-probe crosstalk is the common ground inductance, as shown in Fig. 19. Current from both the input and output will flow through the common inductance, resulting in a voltage drop across the common inductance, and part of the output signal will appear at the input, and vice versa. This internally generated crosstalk cannot be corrected by calibration or probing techniques. The guideline for layout is to make the common ground metalization as short and as wide as possible to minimize inductance.
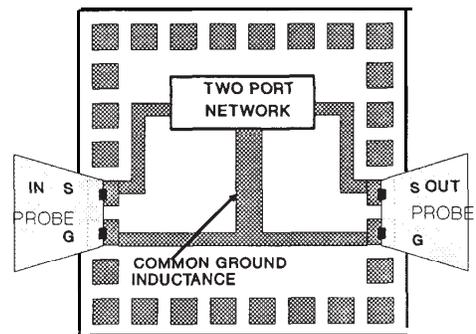

Figure 19. Schematic layout showing common-ground inductance, resulting in crosstalk between input and output probes.

Contact sequence and crosstalk Crosstalk between signals within a probe is generally a consideration only with the WPH-700 series multicontact probes. The main contribution to crosstalk within a probe, over which you have some control, is the contact sequence. Specifically, do you place an intervening ground between adjacent signals? For example, one can specify the following sequences for a WPH-708 multicontact probe (eight contacts): (1) GSSSSSSG, (2) GSSGSSGP, and (3) GSGSGSGS. An intervening ground will obviously lower the crosstalk between the signal lines.

Select the contact sequence that meets your requirements. Typical voltage crosstalk performance (measured with an HP 54120 digitizing oscilloscope, and using 100 ps rise time signals for all data):

sequence*	crosstalk (%), signal-signal	termination
GSGSG	1.0%	sig lines open
GSSG	4.0%	sig lines open
GSGSG	0.3%	sig lines 50 Ω-gnd
GSSG	3.5%	sig lines 50 R-gnd
GSGSG	2.0%	sig lines short-gnd
GSSG	14.0%	sig lines short-gnd

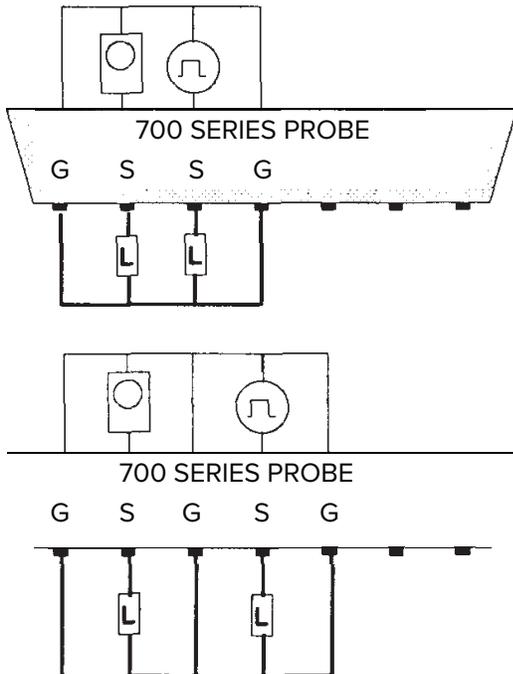*See Fig. 20 for a test circuit schematic.

Figure 20. Circuit used to measure crosstalk between S1 and S2 in WPH-700 series multicontact probes. Load L was either an open, short, or 50 ohms.

Probe ground-line common inductance: Another factor affecting signal-to-signal crosstalk within a probe is the common inductance in the probe ground line. This situation is analogous to the common-ground inductance in a DUT, as previously discussed. Figure 21 shows a simplified equivalent circuit of a two-signal probe with common lead inductance Zg12. The amount of crosstalk is shown in Fig. 22 as a function of frequency and common-lead inductance value.
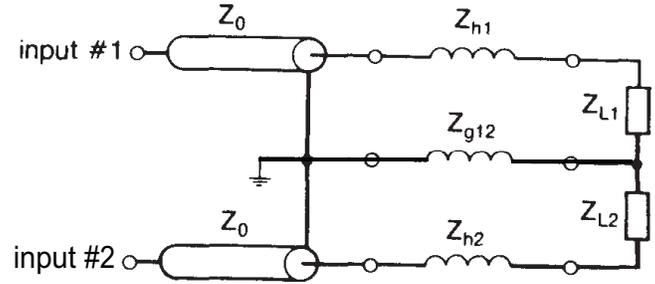

Figure 21. Simplified equivalent circuit of a SGS probe, showing how common ground inductance Zg12 contributes to crosstalk between the two signal lines.
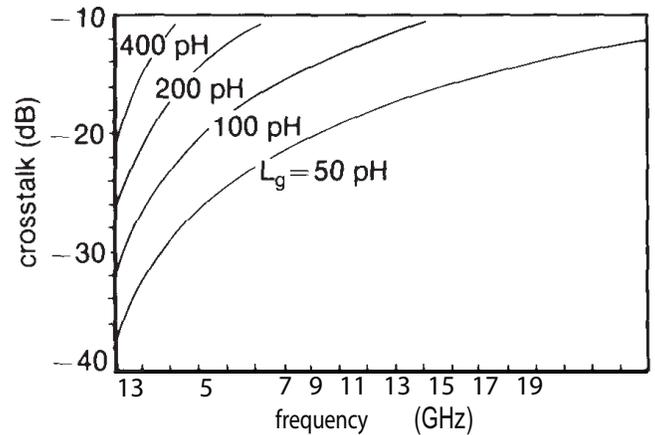

Figure 22. Common-ground inductance affects crosstalk between signal lines within a probe.

The guideline in this situation is to be aware of this source of crosstalk, choose probe families which meet your needs, and to lay out your IC accordingly. The probe families have different common-lead inductance values and you need to review the Probe Selection Guide as you make your decisions. Note that these considerations also apply to bonding wires used in packaging. The 0.3 nH of the WPH-700 series multicontact probe ground inductance corresponds to a bonding wire 300 µm (12 mils)klomng. Also note that multiple grounds and power contacts reduce the probe's equivalent common- ground inductance.

Layout Rules for GHz Probing

DUT Power

There are four typical methods to provide power to the DUT during probing: (1) Bias tee, (2) WPH-900 multiple-needle probes, (3) WPH-700 multicontact probes, and (4) single-needle positionable probes. Bias tees, which are high-frequency chokes, are typically used when probing individual transistors or FETs, and allow the signal lines to be dc biased. Bias tees that have been installed in the S-parameter test set are usually used to characterize individual transistors or FETs.

WPH-900 needle-type probes are typically used to provide power to ICs being probed (Fig. 23). They work well, except when their inductance (8 nH typical) affects the circuit performance. An inductance of 8 nH will adversely affect many circuits (model your circuit to check the result), including high-gain amplifiers and fast digital devices. In these cases, the WPH-700 multicontact probes are recommended, because one of the available contact configurations has internal power-supply bypassing right at the probe tip (Fig. 24). The bypassing network has been specifically designed to be non-resonant over a very wide frequency when probing ICs. The typical impedance is 0.01 µF in series with 4 FF ohms and 300 pH. See the WPH-700 multicontact probe brochure for additional details on how to select and use these probes for this application.

Note that in Fig. 24, the inductance associated with the VSS, VDD and GND metalization will be about 1 nH each, which is three times that of probe inductance. If you need lower inductance, use much wider lines, or make the die smaller, or move the WPH-700 multicontact probe to the side of the chip.
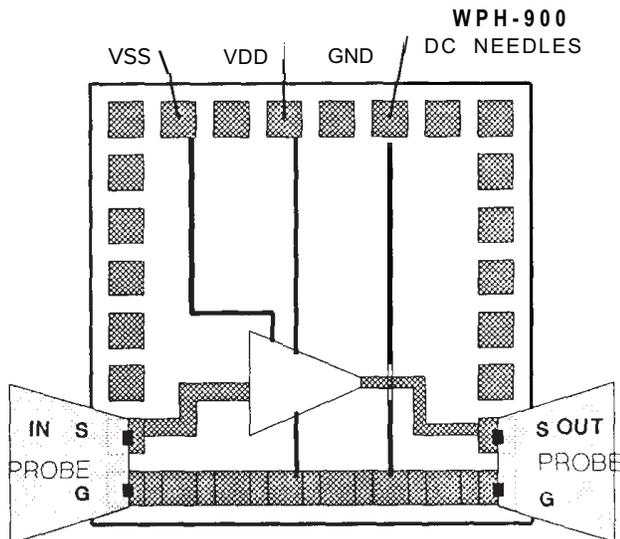

Figure 24. Typical MMIC with WPH-700 series probes, configured to provide bypassed dc power.

Specific Applications

MMICs

The use of FormFactor probes to measure MMIC performance is a natural application. There are four different MMIC layout topologies which encompass most of the MMICs being manufactured today: (1) coplanar waveguide, (2) lumped element, (3) microstrip, and (4) differential or balanced. For the examples shown here, the typical pad size is 100 x 100 µm.

A schematic representation of a coplanar waveguide (CPW) topology is shown Fig. 25. This topology is very easy to probe by using FormFactor probes, and the FETs have minimal ground inductance because both the circuit and the probe are fabricated with CPW topology. The signal input/output should always be GSG (Fig. 25). The circuit is biased either through the signal lines with bias tees, or through separate pads contacted with either the WPH-900 multiple-needle probes or the WPH-700 series multicontact probes. Note the second-level metal crossovers connecting the grounds together, eliminating ground moding.

Figure 23. Typical MMIC with WPH-900 probe needles providing power and ground. The needle inductance can result in circuit malfunction.

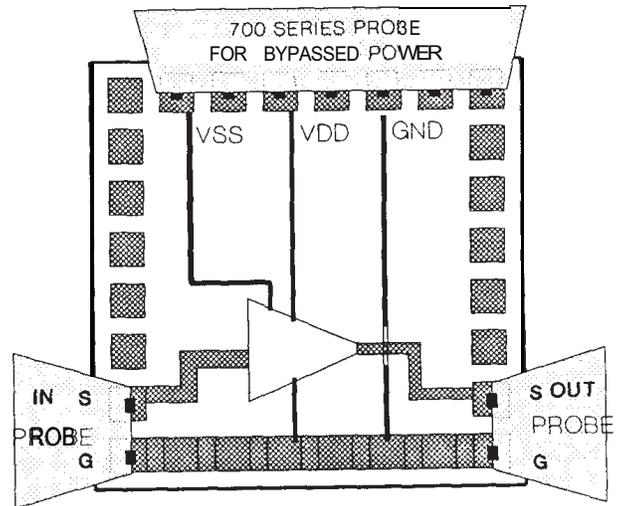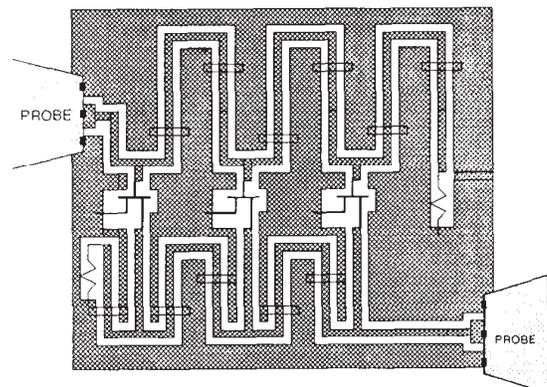Figure 25. MMIC layout, with padouts for probes.

Layout Rules for GHz Probing

A simplified layout of a lumped-element MMIC topology is shown in Fig. 26. Note that in this topology lumped inductors, capacitors, and resistors are used, rather than transmission lines. The interconnects on the die are modeled as inductors. Because lumped element designs are typically used below 18 GHz, the input/output of Fig. 26 is GS. If you wish to use a GSG input/output, the other ground should be connected to the DUT ground bus with a large, minimum length of metal (Fig. 27). Power is provided with WPH-900 multiple-needle probes (Fig. 27) or WPH-700 multicontact probes (Fig. 26).
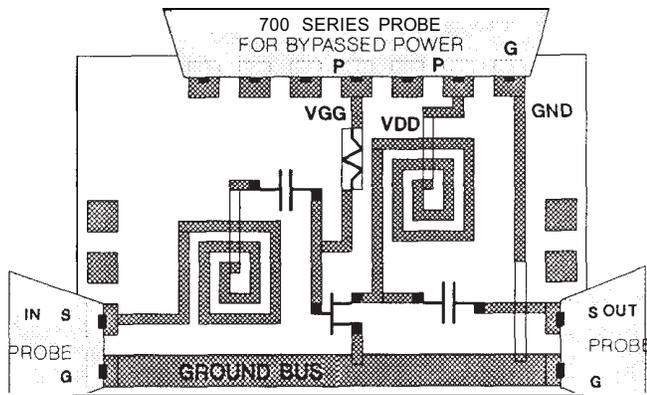

Figure 26. Schematic of lumped-element MMIC. WPH-700 multicontact probe provides power, and GS probes provide measurements.
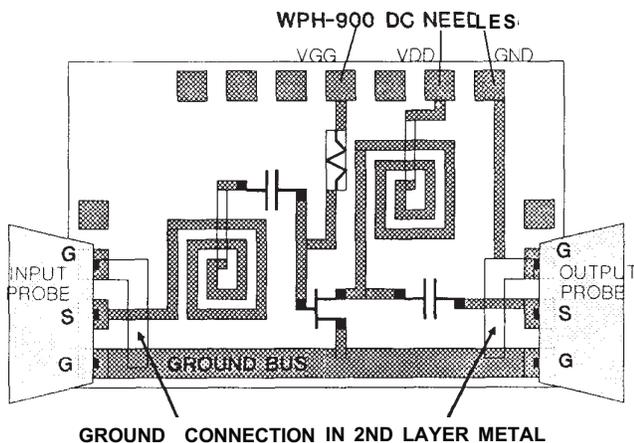

Figure 27. Schematic of lumped-element MMIC. WPH-900 needles provide power, and GSG probes provide measurements. Note short, wide metal used to connect the two ground pads.

When these die are packaged, multiple-bond wires are used to connect the die ground bus to the package ground. Additionally, bond wires will connect the input and output pads to the appropriate package pins. None of these inductive bond wires will be present during probing, and their effect on circuit performance will not be included in the measurements. The guideline is to model your circuit without the package and bond wire parasitics present, and this is what you should measure with the probes.

A simplified example of a microstrip layout is shown in Fig. 28. Microstrip designs always have a backside ground, and usually have substrate vias to connect the top-side devices to ground. Because the FormFactor probes require ground and signal to be in the same plane, substrate vias are necessary to launch signals into a microstrip design.

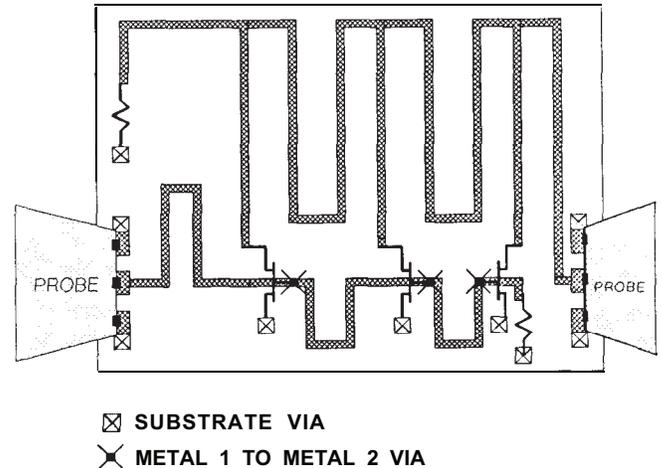⊠ **SUBSTRATE VIA**
✕ **METAL 1 TO METAL 2 VIA**

Figure 28. Typical microstrip-MMIC layout. Substrate vias are required to connect the probe grounds to the IC backside ground.

The parasitic inductance in the coplanar-to-microstrip transition should be minimized by making the metal lines to the via as short as possible. Do not land on the substrate vias, as they are typically not flat enough for a probe to reliably contact the vias and a pad at the same time. Note that you will measure, using the probes, the MMIC performance and the coplanar-to-microstrip transition formed by the substrate vias. A correction can be done by measuring and removing the effects of this transition; or you can use a TRL calibration technique, by moving the reference plane just past the transition so it will not be included in the measurement. If substrate vias are not available, a technique using capacitive coupling to the backside is available [1]. Power and control signals are typically sent through the signal lines with bias tees, or WPH-900 multiple-needle probes, or WPH-700 multicontact probes.

An example of a differential-layout MMIC is shown in Fig. 29. The unique feature of this layout is the mirrored symmetry, which results in a virtual ground. Differential input and output signals are typically used without any ground. Single-ended input signals, output signals, and power sources require grounds. The use of balanced topologies results in balanced current requirements, easing power supply bypassing requirements. This topology has been successfully probed up to 18 GHz. This technique's limitation is that it requires accurately balanced signals. This is generally a limitation with the signal generation equipment, and not of the probe phase match. For WPH-003 18 GHz probes, the phase match is better than 1 ps, and better than 5 ps for WPH-700 multicontact probes.
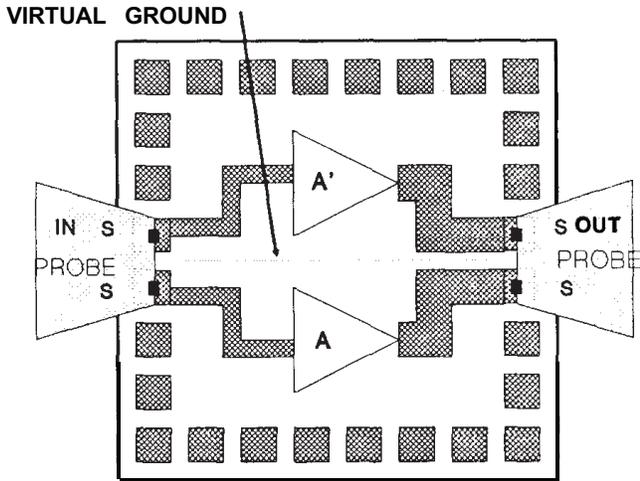
VIRTUAL GROUND

A' IS MIRROR IMAGE OF A

Figure 29. A differential layout. Circuit A is mirror-imaged about the virtual ground to give circuit A'. The SS input requires differential signals.

The preceding examples show typical ways of providing power and ground to the DUT. In many cases, such as high-gain amplifiers, the use of WPH-900 multiple-needle probes to provide power will result in unwanted oscillations during probing, due to the inductance of the needle (typically 8 nH0. In such cases, use WPH-700 multicontact probes to provide power.

Additionally, remember that when probing your ICs you will be measuring the IC performance without the package and bond wires, and that the measured performance in the package will be slightly different than measured on the wafer.

Digital Devices

Most digital GHz-probing applications involve GaAs ICs, high-speed ECL, or mixed analog/digital with high-speed digital inputs or outputs. Most digital DUTs are probed with WPH-700 multicontact probes, because of the larger number of required contacts. Additional reasons to use the WPH-700 multicontact probes are the availability of bypassed non-resonant power, and ECL output terminations (50 ohms to VTT). A typical, and recommended, padout is shown in Fig. 30, with typical pad size being 100 x 100 µm. Note that all pm. probe grounds are connected together on the DUT (Fig. 15), and that the high-current output driver grounds are connected by the lowest impedance path to the same probe which supplies the power to these drivers (Fig. 17). If situations arise where high input/output isolation is required, lay out the IC so that the inputs and outputs are contacted by separate probes (Fig. 31).
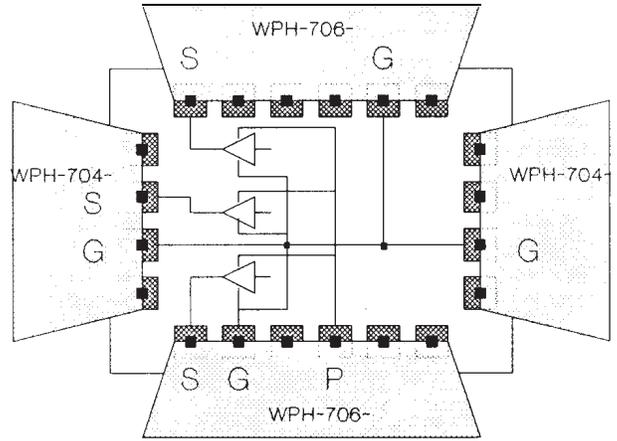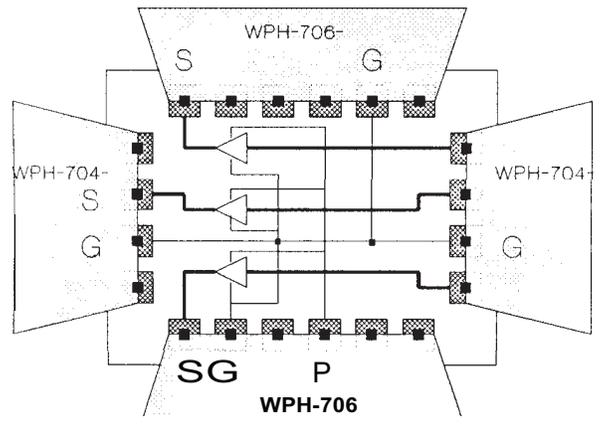

Figure 30. Typical digital IC padout

Figure 31. Digital IC example, showing inputs on a probe separate from the outputs. This maximizes isolation between inputs and outputs.

Characterization Devices

Individual FETs, transistors, capacitors, and inductors are often measured in order to develop models, or as part of wafer qualification. In laying out these devices it is important to minimize parasitics associated with the interconnects to these devices, and the pads. In general, if one is measuring low-impedance devices, then the series-inductance parasitics should be minimized by using fat, short bars of metal. If high-impedance devices are to be measured, then the parallel-capacitance parasitics should be minimized by using narrow interconnects and small pads. Also, the substrate will affect the final layout. For example, the parasitic capacitance to ground is much smaller with semi-insulating GaAs substrates than for conductive silicon substrates.

Layout Rules for GHz Probing

The GaAs industry typically measures fairly large devices Layout Rules for GHz-Probing 13 (300 μm gate length) as characterization devices. Many km device layouts are constructed with 100 x 100 μm pads, and wide metal buses connecting the pads to the DUT, as shown in Fig. 32a and b. However, within the silicon community the characterization devices are often minimum-size devices, presenting high impedances to the test system. This requires that parasitic capacitances be minimized. To minimize parasitic capacitance to the substrate (Fig. 32c and d) the pads are small, usually 50 x 50 μm and the interconnects from the pads to the DUT are Km, narrow. Note that with GSG configurations the DUT should connect the two ground buses together (Fig. 32a and c).
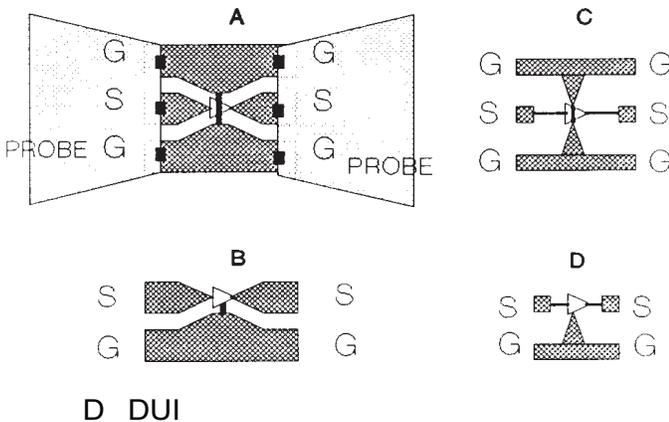

Figure 32. Layout examples of active characterization devices.

Figure 33 shows typical optimization steps in laying out a characterization pattern for a GaAs FET. Figure 33a shows the initial layout. The initial layout has the problems of narrow, high-inductance, connections to the gate and drain, and the common-ground inductance in the source connection has not been minimized. In Fig. 33b these problems have been resolved by repositioning the DUT, and by widening the interconnect metal to the gate and drain. Finally, in Fig. 33c the pads are moved closer together to further minimize the series-inductance parasitics associated with the metal connecting the gate and drain to the pads. Larger interdigitated FETs are typically measured as shown in Fig. 34.
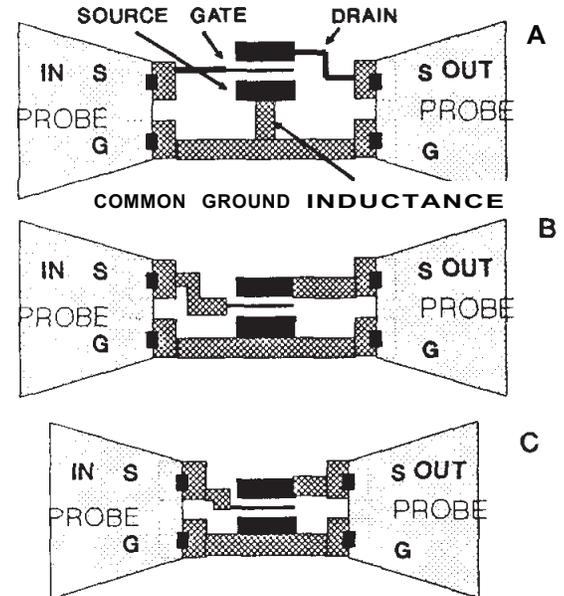

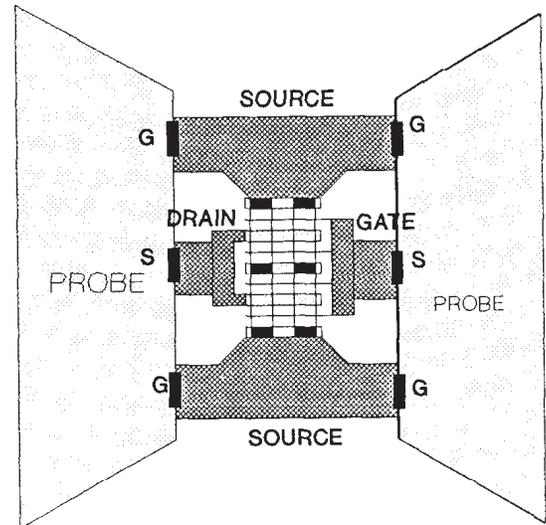Figure 33. Optimization of large GaAs FET characterization device

Figure 34. Example layout of four-gate interdigitated GaAs FET. Note the second-layer metal connecting the sources together.

In Fig. 35 the analogous situation is shown for minimum- size transistors on silicon substrates. In Fig. 35a the layout contains large (100 x 100 μm pads, very closely spaced together. This layout, while excellent for FETs on GaAs is not workable for minimum-size devices on silicon. The problems with this layout are the parasitic capacitances (Fig. 35b). Because silicon is conductive, the parasitic capacitances are much higher than with GaAs or alumina substrates, and can contribute to significant measurement errors, a - 50% error in ft, for example. See the paper "GHz On-Silicon-Wafer Probing Calibration Methods" [2] for more details.
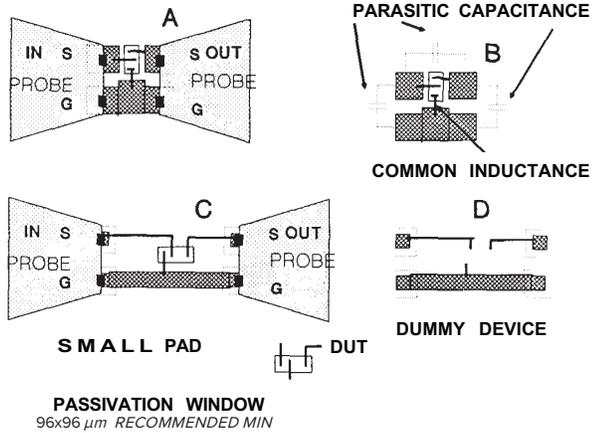
Figure 35. Optimization of small silicon transistor characterization device. Dummy device is used to correct measurement for remaining parallel-capacitive parasitics.

Parasitics are minimized in the Fig. 35c layout by using smaller pads (50 x 50 μm spacing the pads out further (150 to 250 μm center-to-center spacing), and narrowing the metal lines to minimize capacitance to ground. The DUT is located near the probe ground bus to minimize the common inductance. Also note that when laying out 50 μm pads, the passivation window should be at least 96 x 96 km, and preferably larger, to accommodate the 50 x 50 μm probe contacts, plus typical placement errors. (References 2 and 3 describe techniques to correct measurement errors due to parasitic capacitances.)

The recommended method of minimizing parasitics involves the use of a "dummy" device, which is simply the DUT layout without the DUT (Fig. 35d) [3]. It is recommended that a dummy device be included with each group of DUTs. In this way the wafer variations affecting the parasitic capacitances, such as oxide thickness variations, will also be corrected.

When laying out passive-characterization devices for probing, the above discussion applies. The simplest layout is shown in Fig. 36a, using one probe. With this layout, however, part of the DUT parasitic capacitance to ground will not be measured (Fig. 36b). The solution is to lay out the DUT so that a two-port measurement can be made (Fig. 36c).
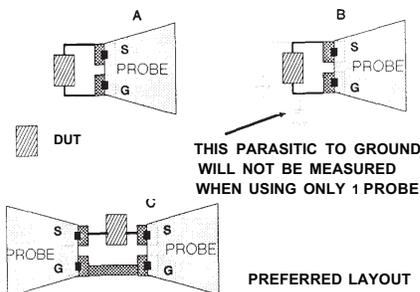

Figure 36   Layout examples of passive characterization   devices.

Figure 36. Layout examples of passive characterization devices

One final tip. To obtain maximum repeatability, use a dielectric etch to mark where the front of the probe tips should land (Fig. 37).
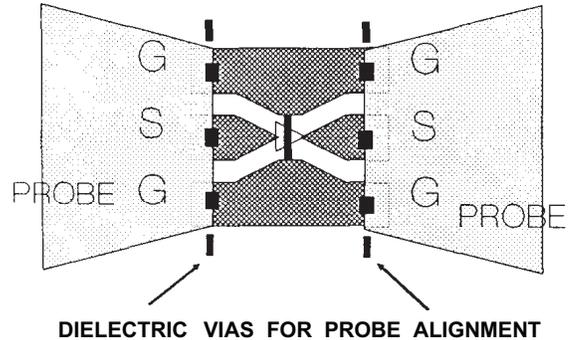

Figure 37. Dielectric vias for probe alignment marks, used to increase measurement repeatability.

Hybrids and Packages

The typical pad and interconnect dimensions in packages and hybrid substrates are much larger than with ICs. The larger pad and interconnect dimensions require short-length DUT connections, especially the ground connections, for good GHz-probing. The probe contacts do not need to land in the center of pads, but can land near the edge (Fig. 38). Be sure that the passivation has been removed from where the probes will land. Also, refer to the Probe Selection Guide to verify that probes with a wide enough pitch are available.
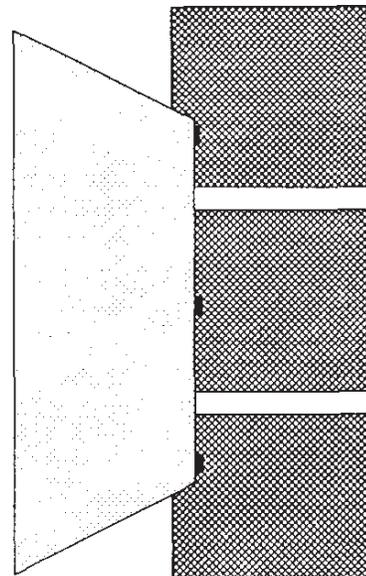

Figure 38. Off-center probe landing on large hybrid or package pads.

Layout Rules for GHz Probing

Probing into wells has a potential problem (Fig. 39). The probe can collide with the top corner of the well. If you have a potential situation like this, please call the FormFactor Applications group and request a side view of the probe you plan to use. Generally the WPH and RTP line of probes approach the DUT at about an 11 degree angle.
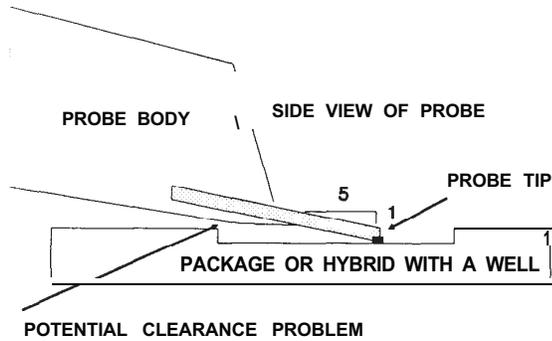
PROBE BODY   **SIDE VIEW OF PROBE**

5

PROBE TIP

1

PACKAGE OR HYBRID WITH A WELL   1

POTENTIAL CLEARANCE PROBLEM

Figure 39. Side view of probe and package with a well, illustrating potential clearance problem.

Note:
The signal lines that are to be calibrated are represented in bolded-black fonts.
The list only shows one representing both of the two mirrored cases, e.g., GSP also represents PSG.
The under-bar can be any channel except for G or P, or can represent the edges (outside the first and last channels of the probe).

Table 3. Calibration coefficients for InfinityQuad probes.

Note:
The under-bar can be any channel except for G or P, or can represent the edges (outside the first and last channels of the probe).
* The calibration coefficients are those used when the R-term and the reference impedances are defined as 50 Ω, and not 100 Ω.

Summary

This Application Note is intended to help you lay out your IC hybrid, or package so that FormFactor coplanar probes can be used for testing. These probes are widely used to test individual devices, MMICs digital ICs hybrids, and packages. If you have any questions pertaining to layout or testing please call the FormFactor Applications Group.

References

[1] Williams, Dylan F.; and Miers, Tom H.; "A Coplanar Probe to Microstrip Transition;" IEEE Transactions on Microwave Theory and Techniques; Vol. 37, No. 7, July 1988, pp 1219-1223.

[2] Fraser, A.; Gleason, Reed; Strid, Eric; "GHz On-Silicon-Wafer Probing Calibration Methods: "7988 Proceedings of the 1988 Bipolar Circuits and Technology Meeting; pp 154-I 57.

[3] P. J. van Wijnen, et al.; "A New Straightforward Calibration and Correction Procedure for 'On Wafer' High Frequency S-parameter Measurements (45 MHz-I 8 PGrHozc)e;e" dings of the Bipolar Circuits and Technology Meeting: 1987.

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