

A guide to Successful on Wafer Rf characterisation

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See it. Touch it. Measure it.



- The need for on-wafer S-parameter Measurements
- Typical system components
- Microwave Probes
- Probe Station Essentials
- Probe Tip Calibration
- How to Calibrate

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The need for on-wafer Characterisation?

- We want to know the true performance of the device and not the device plus package
 - De-embedding can be used but introduces additional errors and uncertainties
- We want to determine 'known good die' to reduce packaging cost and increase yields
 - Some RF packages can be very expensive and die yield can be low
- We want to automate the measurements
 - Being able to test wafers automatically can be cost effective and fast









Typical System

Vector Network Analyzer

Cables

Probes

Probe positioners

Probe station

Contact Substrate

Calibration Substrate

Calibration Software

Bias supply





Microwave Probes

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Air Co-Planar Transition



- Probe transitions from coaxial to co-planar waveguide
- Fabricated probe tips
 - Uniform and compliant probe contacts
 - Tight Impedance control







ACP Series Probe



- Ideal for High Power
- Measurements up to 200degC
- Large 25um compliance between tips
- BeCu or W
- 15 W CW at 10 GHz
- 5 A DC current







Infinity Series Probe



- Ultra Low Contact Resistance (30mΩ)
- Small Contact Area (12um)
- Improved Unsymmetrical Ground Performance
- Best Electrical Performing Probe







Typical results: Contact resistance



Contact resistance on un-patterned aluminum averages about 30 mΩ over 5000 contact cycles at ambient



New Infinity Waveguide Probe



-Waveguide/flange WR15 – 50-75GHz WB12 – 67-90GHz WR10 – 75-110GHz WR8 – 90-140GHz WR6 – 110-170GHz WR5 – 140-220GHz WR3 - 220-325GHz (end 2005)

Standard probe mount

Membrane

coupon

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GS pads fringe to the ground plane or chuck



Effects of Non-symmetrical Grounds

Non-symmetrical grounds can cause resonance loops even at frequencies <10GHz





DUT

Microstrip structure shields signal line better

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Probe Station Essentials

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MicroChamberTM Technology



- Dry, Frost Free environment
- Auxiliary Chucks
- Roll-out chuck
- Stable repeatable platen
- Top-Hat





MicroChamberTM Technology

- Completely Integrated
 Measurement Environment
 - FULL access to Positioners, Stage and Microscope
 - Roll-out stage Complete chuck, not just top layer
 - Easy, fast & safe wafer loading







- Triax connection panels
 - Easy power supply connections
 - Cable strain relief
- Goretm RF cables =
 - Low Loss
 - Phase stable
 - Flexible





Probe Tip Calibration

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Principle Calibration Techniques

- SOLT Short Open Load Thru
- SOLR Short Open Load Reciprocal
- LINE Reflect Match
- LRRM Line Reflect Reflect Match
- TRL Thru Reflect Line



Impedance Standard Substrate



Impedance Standard Substrate (Pitch: 100 – 250 um, Configuration: Ground-Signal-Ground) P/N: 101-190, S/N:



NIST Calibration Verification

- NIST Calibration and Verification Software
- Verification standards are GaAs CPW lines
- 45MHz to 40GHz
- LRRM compares with system drift limit
- SOLT /LRM
 - growing error w/freq
 - possible cal kit error
 - possible ref plane error





- Ensure that the probes are in place
- Clean and connect the cables and torque using relevant wrench
 - Use IPA and swab to clean connectors and allow to dry
- Visually inspect the probe tips and clean if contaminated
 - Use IPA and swab, brushing away from the probe body and allow to dry for ACP
 - Use probe clean for Infinity
- Planarize the probes on the Contact Substrate inspecting the probe marks for even GSG contacts
 - Adjust the positioner planarity until all tips make even contact







Planarizing the Probes

- Contact Substrate
 - PN 005-018
 - Dull gold finish
 - Bright contact marks
- Adjust planarity until equal marks from all probe contacts







Figure 1: Alignment marks

Figure 2: Images showing correct alignment and placement of probe tips of both ACP and Infinity style probes.

- Sets probes overtravel & spacing for calibration
- Initial Contact (zero overtravel)
 - Line the edges of the probes to edge of flags
 - Center the contacts with X & Y micrometers
- Final Contact (2 –3 mils overtravel)
 - Tips lined up with flag centers
 - Center the contacts with Z micrometer only



- Tools for the novice
 - Guided Wizards
 - Multi-media Tutorials
 - Intelligence in setups
- Tools for expert
 - Enhanced verification
 - Real time measurement validation
 - Enhanced reports





System Setup

- Measurement System Setup
 - Define the measurement system
 - VNA, prober, ISS and probes
 - VNA Qualification
 - Test that the VNA is functional and repeatable
 - Probe Qualification
 - Check that the probe is making contact
 - ISS management
 - What structures to use
 - Is a structure good?

Description					
Description	<enter description="" h<="" td=""><td></td><td></td><td></td><td></td></enter>				
Num Ports	4				
Drift & Noise					
Enable Noise	True				
Noise Level	0.05%				
Noise Level (F)	0.0125%				
Enable Drift	False				
Drift Level(t)	0.01%				
Drift Level (t*f)	1%				
Frequency List					
Sweep Mode	Lin				
Num Seaments	1				
	Start Freq	Stop Frea	Num Points		
Item 1	300 KHz	20 GHz	201		
Source Files					
Num Source Files	1				
	File Name	File Sweep Mode	Cal Symbolic Name	File Freg Range	
Source File 1	VnaVirtual.S4P	DirectFromFile		300 KHz 20 GHz 20	
/					>
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Sten 1	Add Substrate To System
1	And outstrate its bystein
Subst	rates:
104-7	783A W-BAND GSG 75-1 🕶
A	dd
	ad Save
Rotate	e Substrate:
Step 2:	Define Stage Position of Reference for 104-783A SN 1111
2	Select Reference Structure Record Current Location
-	Move to Reference
Step 3:	Set Software Alignment Angle for 104-7834 SN 1111
Step 3:	Set Software Alignment Angle for 104-783A SN 1111
Step 3:	Set Software Alignment Angle for 104-783A SN 1111 Use Hardware Angle Deg Zero Align
Step 3: 3	Set Software Alignment Angle for 104-783A SN 1111 Use Hardware Angle Deg Zero Align
Step 3:	Set Software Alignment Angle for 104-783A SN 1111 Use Hardware Angle Deg Zero Align



Using Wincal XE to Prepare the calibration

Station Probes Standards Port Map	Description				
tion	Description	From VNA 10/16/2			
m Value	Frequency List and				
ufacturer Agilent Technologies	Sweep Mode	Lin			
E8361A US43140785	Num Segments	1			
n A.07.12.03		State	Start Freq	Stop Freq	Num Points
s "550,PU2,UNL,U16,U14" ing Terms Available	Freq Segment 1	On	100 MHz	67 GHz	201
	IF Bandwidth	50 Hz			
	Averaging	Off 🗸 🗸			
VA.	Num Average	1			
PIB) 💌	Independent IF Ban	Disable			
nication Channel	Independent Power	Disable			
ddr: 16 VNA GPIB Setup	Misc				
	Alternate Sweeps	Off			
	Interpolation	On			
onfirm Vna Settings Stimulus Settings	Port Extensions				
	Port Extensions	Disable			
	Offset Port 1	0 ps			
(0 (ohms) 50	Offset Port 2	0 ps			
	Velocity	1			
	Power and Attenua				
	Port Power Coupled	On			
	Port 1 Power	-30 dBm			
	Port 2 Power	-12 dBm			
OK Cancel Apply Help	<u> </u>	Send to Vna Get From \	/na Compa	ire with Vna	Set To Recomme

 Important to initialise instrument settings paying attention to power, number of points, Start and stop and particularly IF bandwidth



Probe Set-up

👼 System Setup 📃 🗖 🔀
VNA Station Probes Standards Port Map
Quick Setup
VNA Port 1 VNA Port 2
Base Probe Signal Config Options Pitch
infinity 🖌 GSG 🔽 40/50/67 🔽 125 🛩
Orientation N W ○ ○ E S E Differential +/- Differential -/+
Port 1 Probe: (SN undefined) WEST infinity-GSG 40/50/67 125 Port 2 Probe: (SN undefined) EAST infinity-GSG 40/50/67 125 STATION: Nucleus (This Computer) VNA: PNA (GPIB) Impedance Standard Substrate(s): 101-190B (SN 1111) No rotation, not aligned
OK Cancel Apply Help

- Probe characteristics are displayed both graphically and numerically. Probes can be identified by serialisation
- Probe data required to check calibration compatability and where necessary provide lumped element data



ISS Set-up for Auto calibration

🄄 🗖 🗶
System Setup VNA Station Probes Standards Port Map Step 1: Add Substrate To System 1 Substrates: 101-190B LRM GSG 100-250 Image: Comparison of the system Add Remove Load Save Rotate Substrate: Image: Comparison of the system
Step 2: Define Stage Position of Reference for 101-190B SN 1111 2 Select Reference Structure Move to Reference Step 3: Set Software Alignment Angle for 101-190B SN 1111
3 V Use Hardware Angle Deg Zero Align
OK Cancel Apply Help

- Individually serialised iss data can be loaded
- This information is important to keep track of correct iss for calibration and determine location of alignment structure



ISS Alignment structure location

Select Structure on 101-190B	sn 1111 🛛 🔀
Substrate	Current Group Structures Structure
101-190B LRM GSG 100-250 ur 💌	101-190B Alignment Mark 🔽
Selected Group	
Group Alignment 🗸	Subgroup Row C
BO6 	
	OK Cancel Help

- ISS Reference location determines the correct orientation and alignment of the probes with respect to the entire iss
- A similar tool is used to inform the software of damaged or untrimmed lcations



Automatic Calibration

â Calibration		×
File Setup View Calibration Tools I	Locations Measurements Help	
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💷 Compute 🛛 Validate All 🛛 2-Port LRRM PROBER	ER 🗾 🗾 🗾 To VNA	
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📮 101-190B Thru	Meas View P1 S1	2
S-Para ports: 1, 2 (Thru)	Meas View G	
Switch Gamma term ports: 1, 2 (Switchin)	ni Meas View	
📮 Separate	Meas View	
S-Para port: 1 (Port 1 Open)	Meas View	
S-Para port: 2 (Port 2 Open)	Meas View	
📮 101-190B Short	Meas View	
S-Para port: 1 (Port 1 Short)	Meas View	
S-Para port: 2 (Port 2 Short)	Meas View	
📮 101-1908 Load	Meas View	
S-Para port: 1 (Port 1 Match)	Meas View	
S-Para port: 2 (Port 2 Match)	Meas View	
Ready		



Calibration Procedure

- Automatic calibration will use the prober to automatically move from standard to standard
- On pressing autocal the procedure is as follows
 - Repeatability check measures raw open multiple times in order to check the system is repeatable (often picks up problems relating to cabling, system directivity, Excessively high If bandwidth)
 - Calibration moves though all standards for the calibration, computes calibration and sends to instrument
 - Verification will look at a verification standard to compare against known values (typically an open)
 - Monitoring measurement will store data for future checks against system stability (is cal still good)



Repeatability Check



Wincal measures open to check repeatability of measurement system

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Calibration measurements for LRRM -Thru

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101-1908 Thru S-Para ports: 1, 2 (Thru) Switch Gamma term ports: 1, 2 (Switchin) Separate S Para port: 1 (Port 1 Open)	Meas View Meas View Meas View Meas View	P1 S1 G	6 81 6 6	
S-Para port: 2 (Port 2 Open)	Meas View			
□ 101-190B Short	Meas View			
S-Para port: 1 (Port 1 Short)	Meas View			
S-Para port: 2 (Port 2 Short)	Meas View			2 10 / 1 2 10 10 20 10 10 20 10 10 10 10 10 10 10 10 10 10 10 10 10
📮 101-190B Load	Meas View			
S-Para port: 1 (Port 1 Match)	Meas View			
S-Para port: 2 (Port 2 Match)	Meas View			
Measuring Switch Gamma term ports: 1, 2 on 101-19	908 Thru		.;;	Mause Moder: Adjust Vision Location Frield of View 544-4400



Calibration measurements for LRRM – Open



 System re-measures open for the calibration. At times the open measurement uses substrate opens hence the need for remeasurement



Calibration Measurements for LRRM - Short





Calibration Measurements - Load

💼 Calibration				
File Setup View Calibration Tools I	ocations	Measurem	ents Help	
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S-Para port: 2 (Port 2 Open)	Meas	View		
□ 101-190B Short	Meas	View		
S-Para port: 1 (Port 1 Short)	Meas	View		
E 101-1908 Load	Meas	View		
S-Para port: 1 (Port 1 Match)	Meas	View		
S-Para port: 2 (Port 2 Match)	Meas	View		
			Shows at	stract visual representation o
Measuring S-Para port: 2 on 101-1908 Load				

 It is important that only 50 ohm loads are used for this part of the calibration



PNA Settings
Cal Set Control
Set the description for this Cal Set to send to the PNA.
Use %S to insert cal algorithm name. Use %U to insert user's name.
Cal Set Description
%S %U
Show this dialog when sending Cal Set
Save VNA State After Sending
WinCal01 .CST
OK Cancel Help

 Wincal applies the selected calibration to the measured data (typically we recommend LRRM) and error set is sent to the instrument



Calibration - Validation



Following calibration a validation is carried out against a known standard. Typically this
is an open whose capacitance is known by the probe pitch, but can be a golden dut
whose characteristics are pre-measured and stored. For Irrm the open is the raw open
measured during the cal and corrected by the calibration (post corrected)



Calibration Verification

- What defines a good calibration?
 - Ideally a reflection measurement after calibration should be 0.0dB
 - LRRM type calibration is self-consistent and will never look perfect as it will show any errors as a magnitude on a reflection measurement
 - A guide would be to ensure that the magnitude of the reflection error is less than 0.1dB for measurement to 67GHz and 0.2dB to 110GHz
 - Note this does not apply to an SOLT or SOL calibration as these are not self consistent and will be forced to look like a perfect reflection standard
 - Independent standards will need to be measured for verification



Independent Verification

- As well as re-measuring the calibration standards, other verification standards can be measured to determine successful calibration
 - These include open stubs and transmission lines
 - Open stubs and lines of varying lengths are found on the calibration standards



Various lengths of transmission lines



Calibration Verification Standards



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- WinCal 2006 Calibration software has a feature called monitoring
- Monitoring allows the user to capture calibrated reference data immediately after a calibration has been performed. At a later time, you can re-measure the previously-acquired references (by selecting Calibration>Monitor in the Calibration menu), compare the data to the reference data, and determine if any portion of the measurement system has changed. Measurements and structures used in calculating the monitoring data are listed in the Monitoring tab.



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Device Layout

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Design for Testability

- Do you want to test the device at wafer level?
 - If yes, you will need to have a pad layout which conforms with possible probe configurations.
- How much money do you want to spend on probes?
 - Complex designs may require an RF/Microwave probe card
 - Well designed circuits may be able to use existing probes
- Do you want to automate die-to-die testing?
 - Can a wafer map be generated to step across a wafer?







Think About Testing Before Design

- RF Performance
 - Pad configuration (GS Vs GSG)
 - Probe pitch
- Ability to Physically Probe
 - Pad size
 - Pad height
 - Distance between probes
 - Number of contacts per side
- Calibration
 - Paths
 - Best calibration methods
 - De-embedding devices











- Recommended minimum pad is 80um x 80um for ACP Probes
- Infinity Probe Allows 50um x 50um probing
- Passivation height must be considered
- Pad height variation must not exceed 25um for ACP or 0.5um for Infinity







Probe Configuration

- Whenever possible use GSG
 - Use GSG above 10GHz
- Probe pitch affects S-parameters
 - Use smallest practical pitch
 - $1/50^{\text{th}} \lambda$ of highest frequency for GS
 - $1/20^{th} \lambda$ of highest frequency for GSG





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DC bias, ground and control pads





Probe Pad Positioning



- RF probes should have more than 200um separation to avoid crosstalk
- All pads must be on top surface
- All grounds should be connected together
- Adjacent devices should be >500um away for mm-wave measurements (>250um for Infinity)

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Maximum Probe Contacts

- The maximum number of RF & DC contacts per side depends on the type of probe used to test the DUT
 - Only 1 standard RF or DC series probe head can be mounted on each side
 - A dual signal RF probe allows a GSSG/GSGSG probe on each side
 - A multi contact RF probe allows up to 3 RF contacts, or mixed RF and DC on each side
 - RF probe cards allows many RF and DC contacts on any side (but expensive if not in production)







- Conductive substrate increases parasitic reactance
 - Pad and interconnect capacitance and inductances become more significant during device measurement
 - De-embedding of pads and interconnects is required
- Limitations of Pad Parasitic Removal methods
 - The larger the pads and smaller the device, makes de-embedding more difficult to achieve



De-embedding Techniques

- Open and Short 'dummy' devices need to be measured
- S-parameters are transformed to Y, Zparameters
- The dummy devices can be subtracted from the actual device
- The resulting Y, Zparameters can be transformed and displayed





Dummy Devices



GSG test device

Open pads & Short Dummy metal Dummy



Thankyou for listening

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