A guide to Successful on Wafer Rf characterisation

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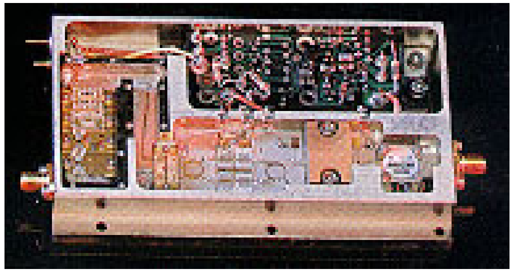
Agenda

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

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

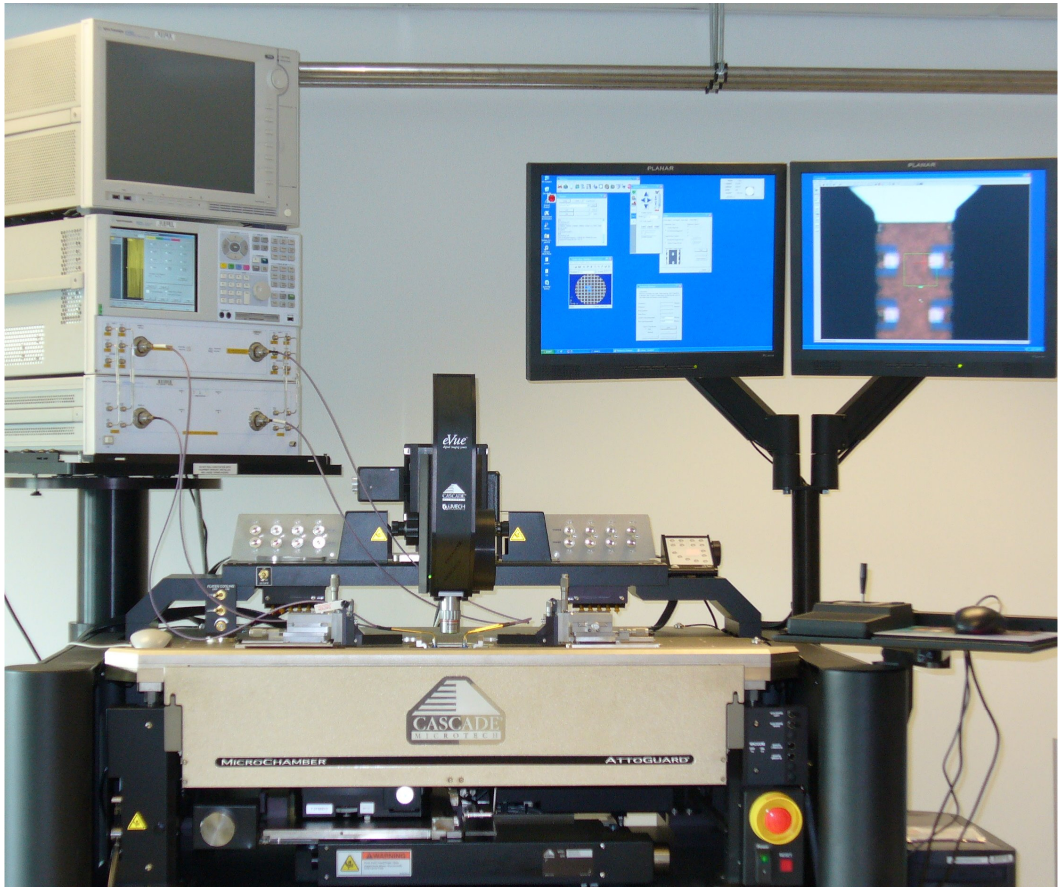
Probe station

Contact Substrate

Calibration Substrate

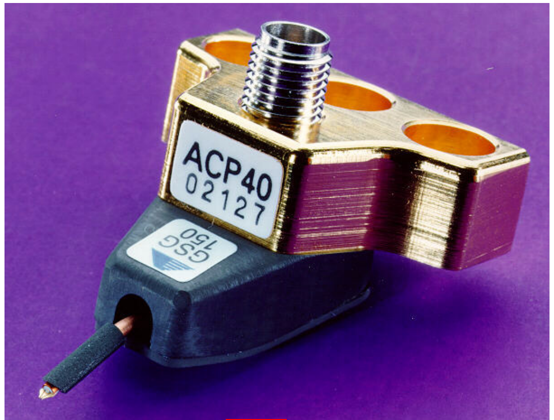
Calibration Software

Bias supply

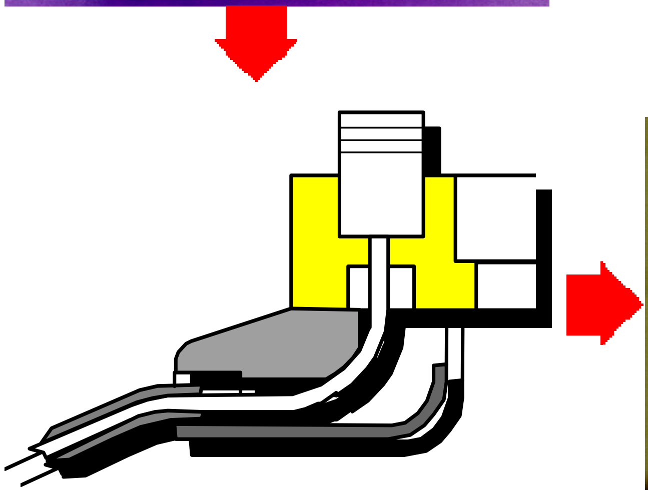


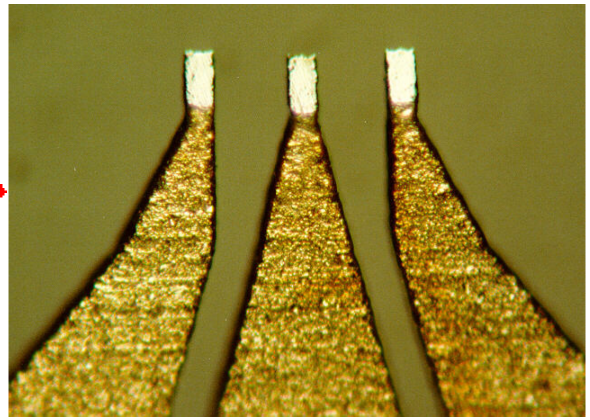
Microwave Probes

Air Co-Planar Transition

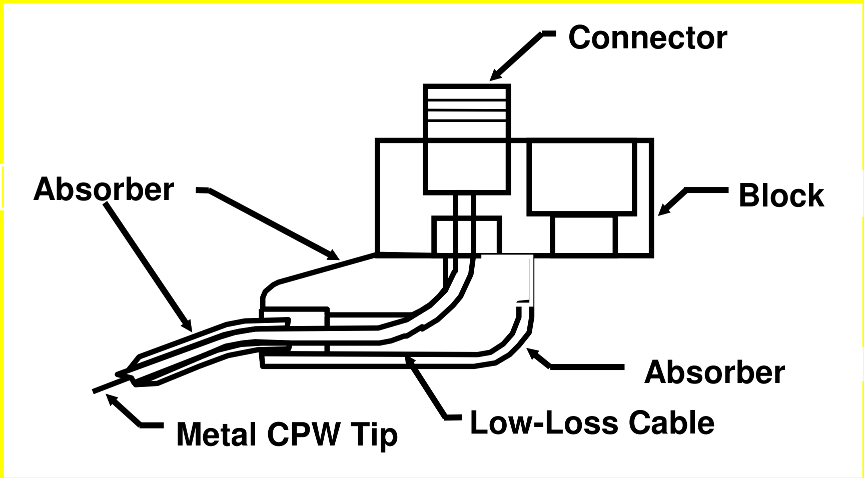


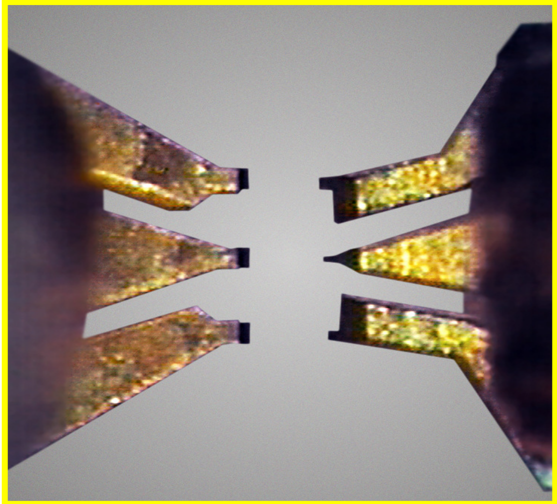
- Probe transitions from coaxial to co-planar waveguide
- Fabricated probe tips
  - Uniform and compliant probe contacts
  - Tight Impedance control





ACP Series Probe

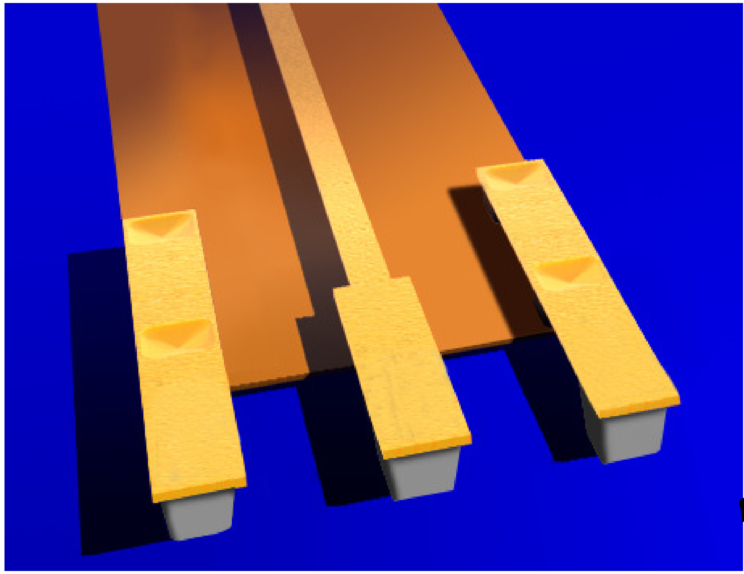


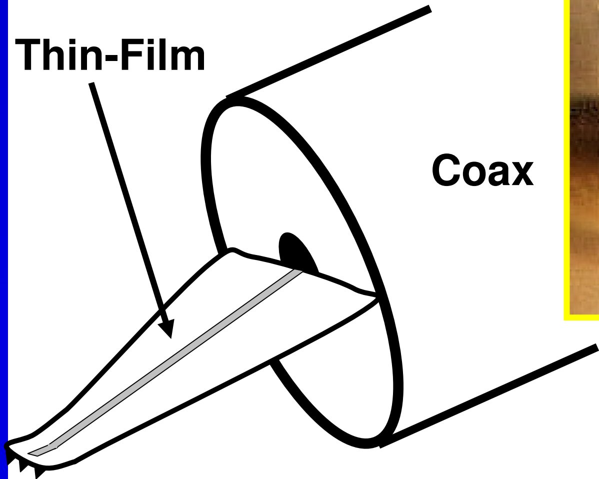


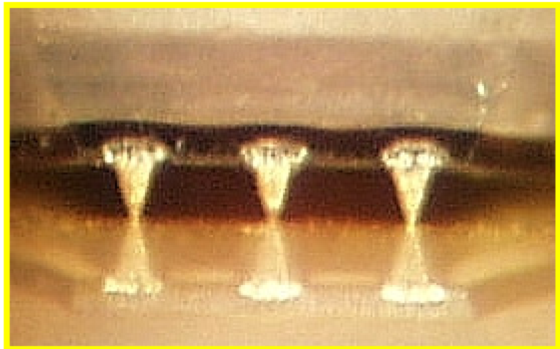
- Ideal for High Power
- Measurements up to 200degC
- Large 25um compliance between tips
- BeCu or W
- 15 W CW at 10 GHz
- 5 A DC current

Infinity Series Probe

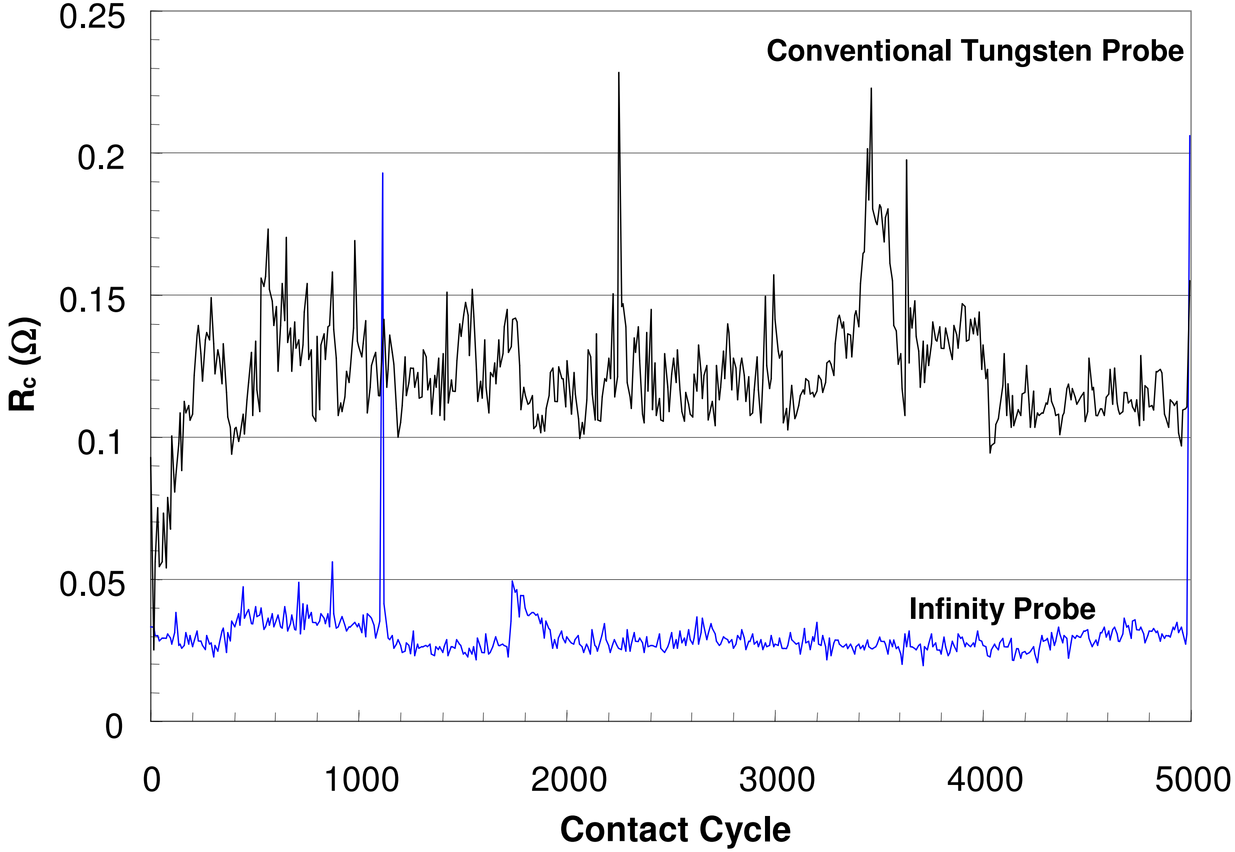
- Ultra Low Contact Resistance (30mΩ)
- Small Contact Area (12um)
- Improved Unsymmetrical Ground Performance
- Best Electrical Performing Probe







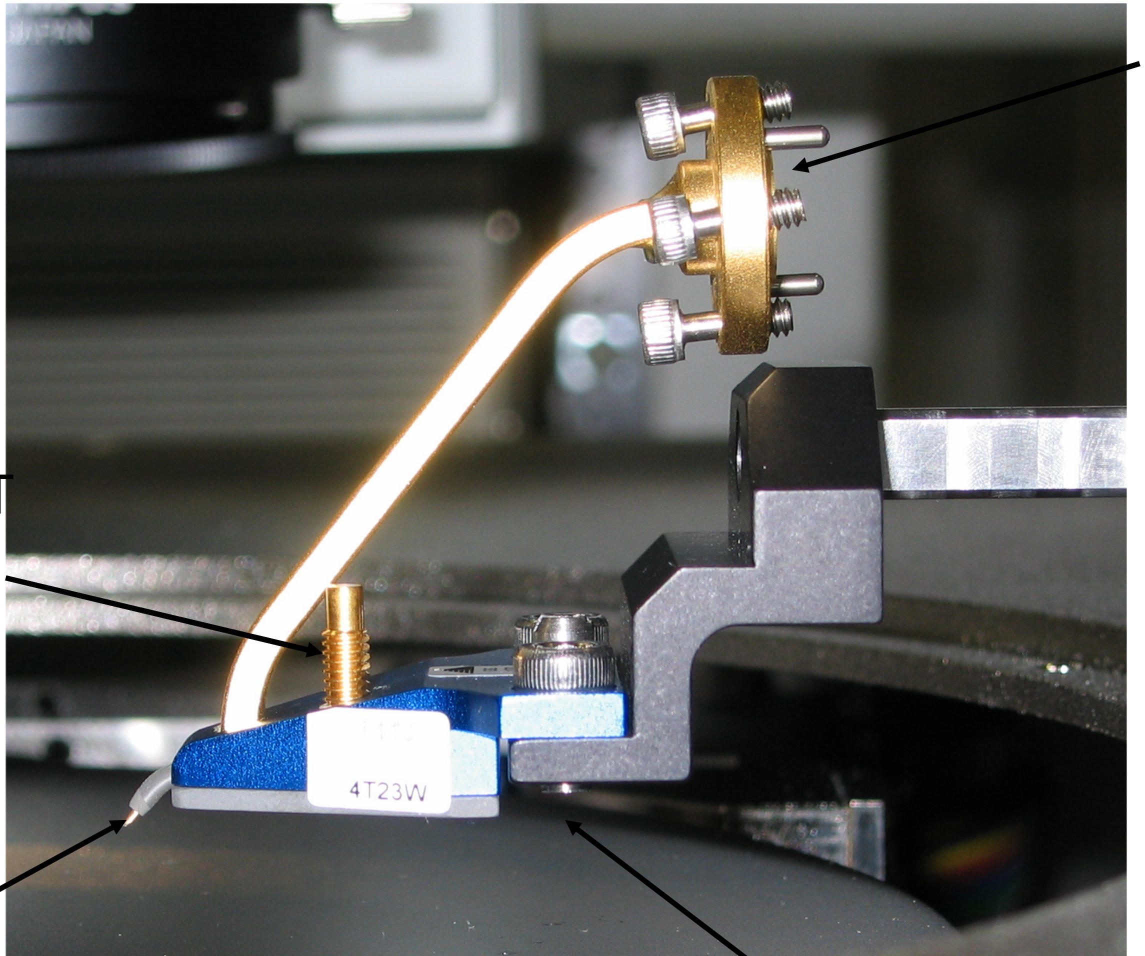
Typical results: Contact resistance



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

Repeatability

New Infinity Waveguide Probe



SSMC bias T connector

Membrane coupon

Waveguide/flange

WR15 – 50-75GHz

WR12 – 67-90GHz

WR10 – 75-110GHz

WR8 – 90-140GHz

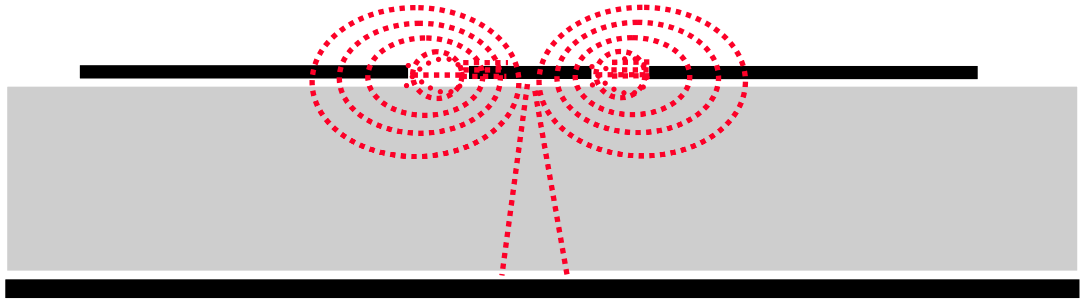
WR6 – 110-170GHz

WR5 – 140-220GHz

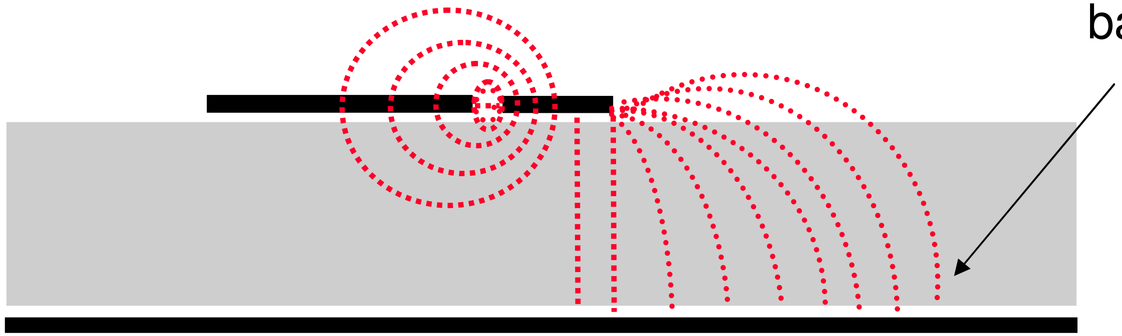
WR3 - 220-325GHz (end 2005)

Standard probe mount

Non-symmetrical Grounds



GSG pads shield like CPW



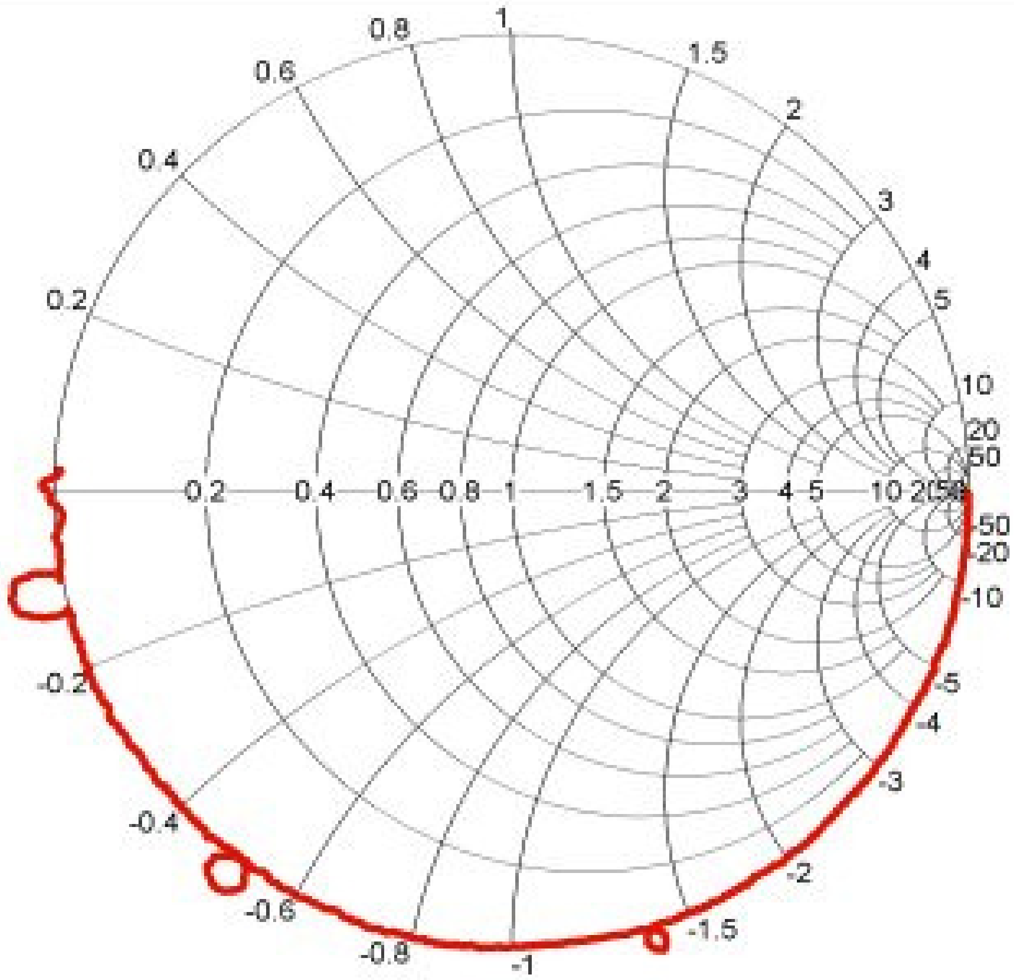
Fields terminate on backside of wafer on one side

GS pads fringe to the ground plane or chuck

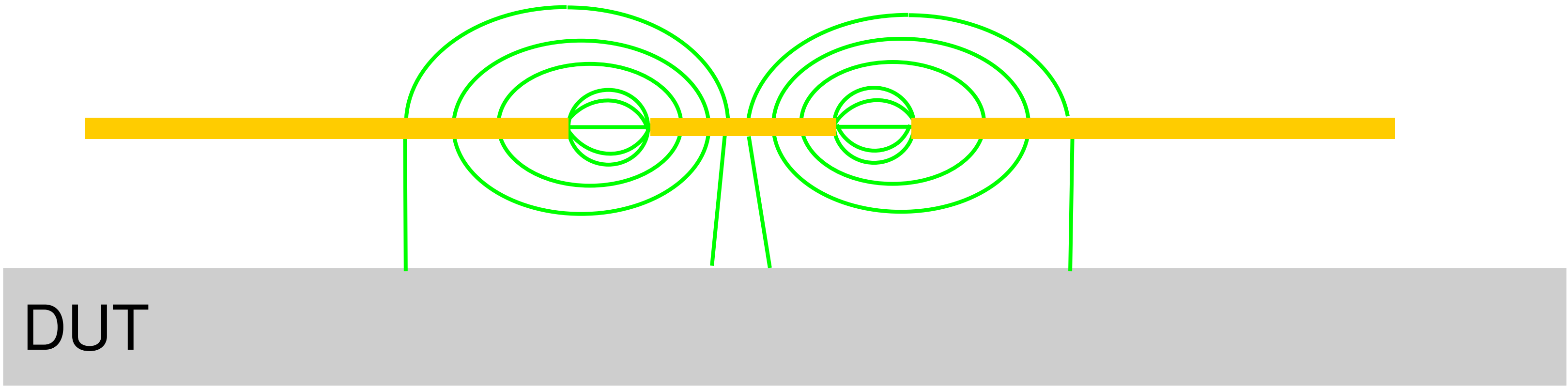
Effects of Non-symmetrical Grounds

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

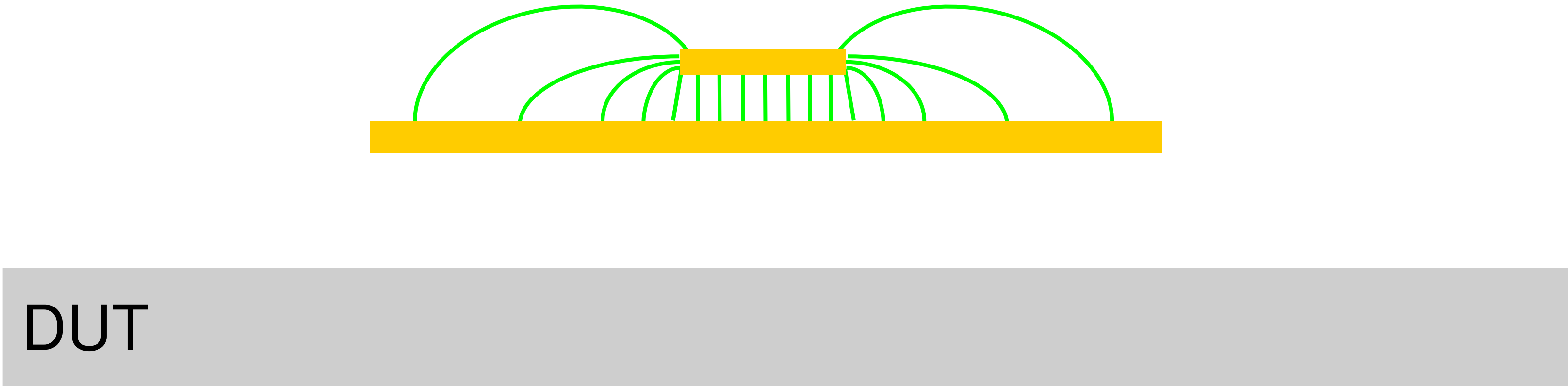
S11



Infinity Probe Tip Shielding



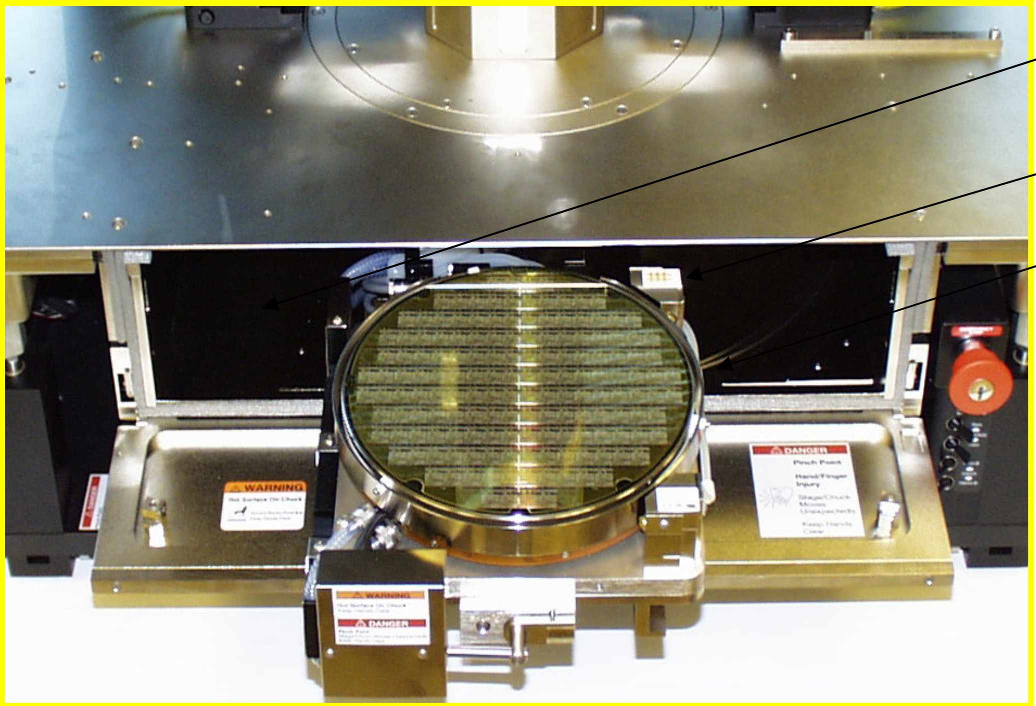
Coplanar probe tips do not shield from the DUT



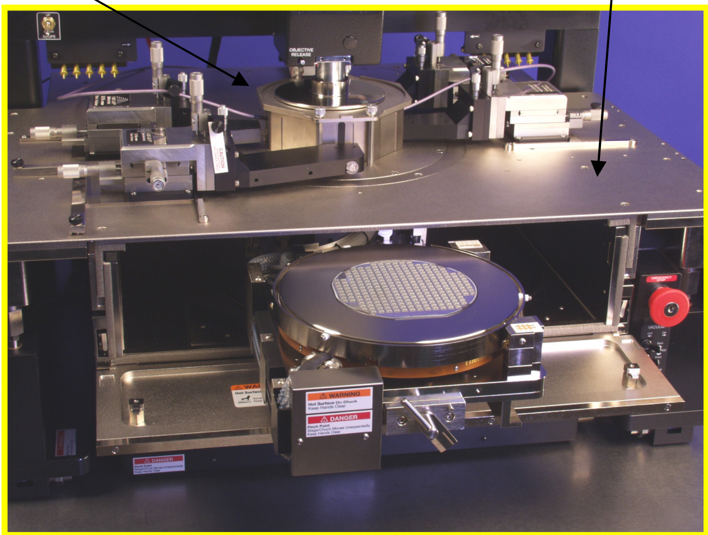
Microstrip structure shields signal line better

Probe Station Essentials

MicroChamber™ Technology



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

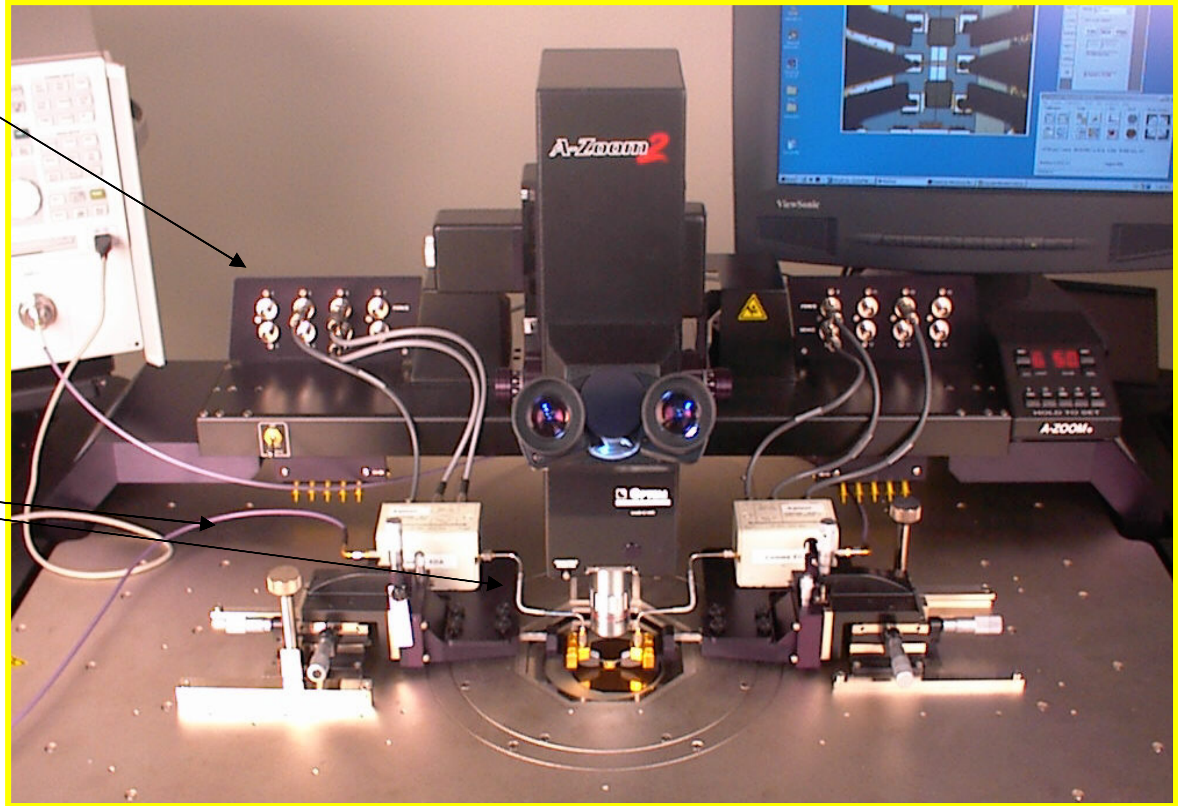


MicroChamber™ Technology

- 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

RF & DC Cabling

- Triax connection panels
  - Easy power supply connections
  - Cable strain relief
- Gore^{tm} RF cables
  - Low Loss
  - Phase stable
  - Flexible



Probe Tip Calibration

Principle Calibration Techniques

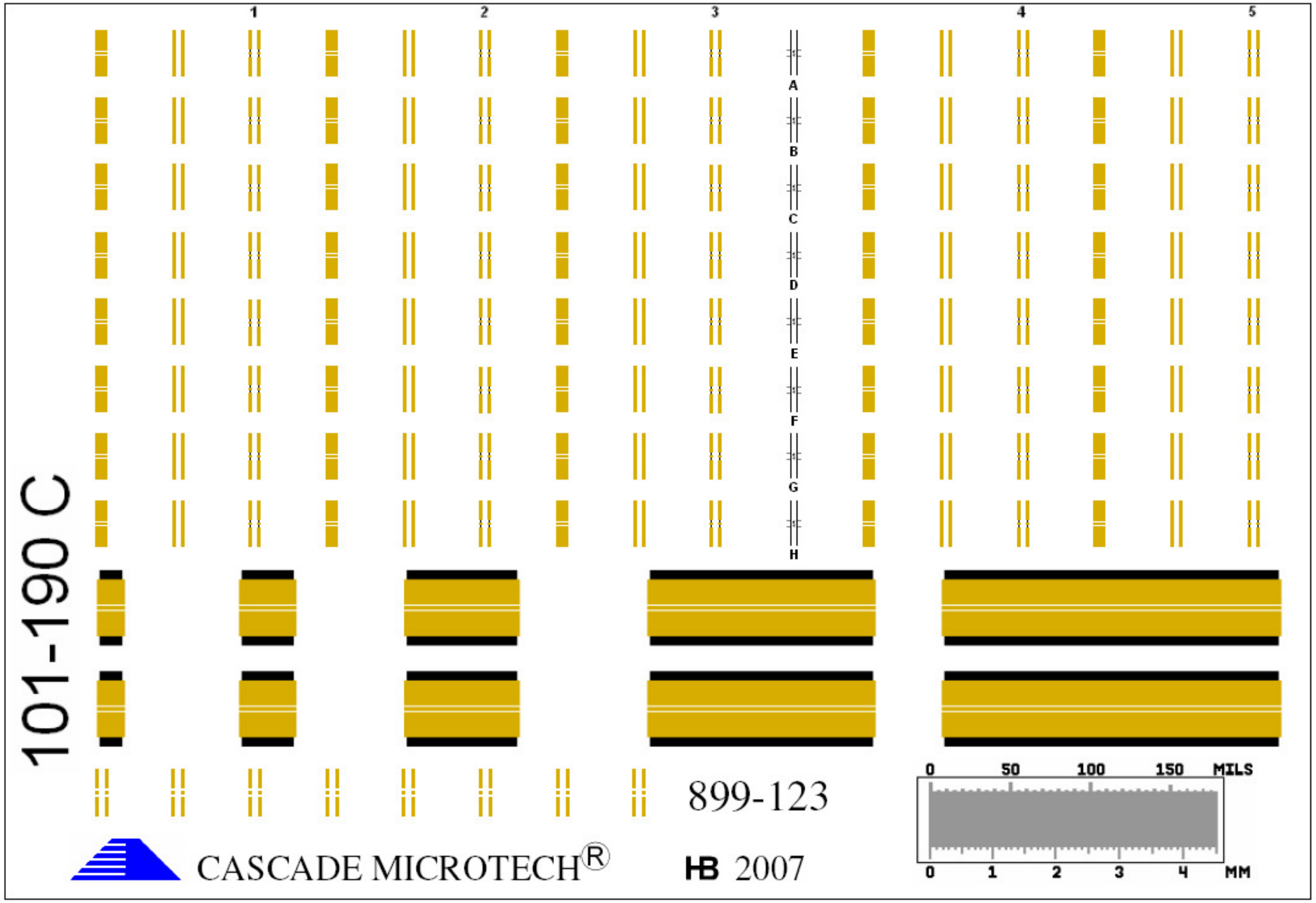
- **SOLT** — **S**hort **O**pen **Load Thru**
- **SOLR** — **S**hort **O**pen **Load Reciprocal**
- **LRM** — **L**ine **R**eflect **M**atch
- **LRRM** — **L**ine **R**eflect **R**eflect **M**atch
- **TRL** — **T**hru **R**eflect **L**ine

Impedance Standard Substrate

Impedance Standard Substrate

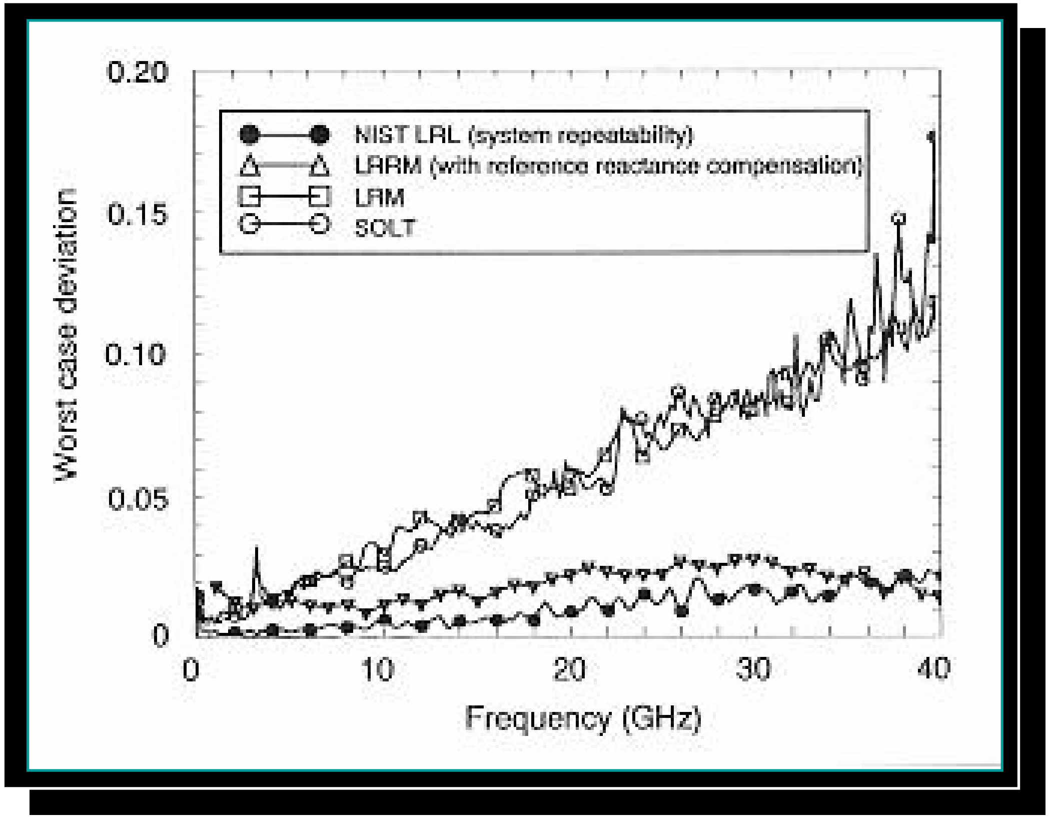
(**Pitch:** 100 – 250 um, **Configuration:** Ground-Signal-Ground)

P/N: 101-190, S/N:



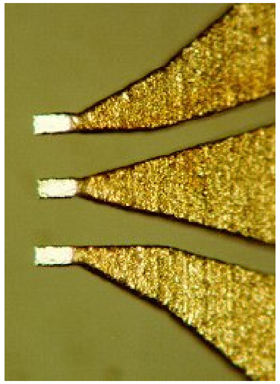
NIST Calibration Verification

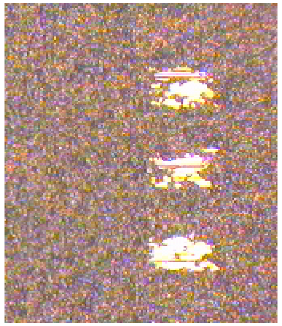
- NIST Calibration and Verification Software
- Verification standards are GaAs CPW lines
- 45MHz to 40GHz
- LRRM compares with system drift limit
- SOLT /LRM
  - growing error w/freq
  - possible cal kit error
  - possible ref plane error



How to calibrate

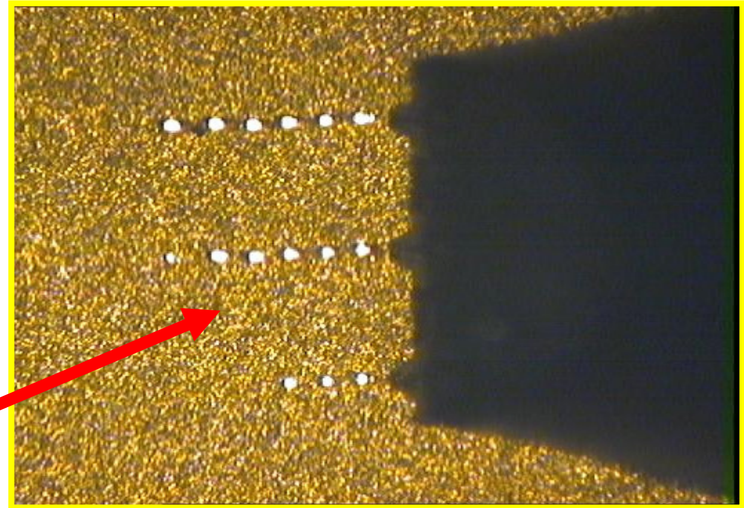
- Ensure that the probes are in place
- Clean and connect the cables and torque using relevant wrench
  - Use IPA and swab to clean connectors and allow to dry
- Visually inspect the probe tips and clean if contaminated
  - Use IPA and swab, brushing away from the probe body and allow to dry for ACP
  - 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

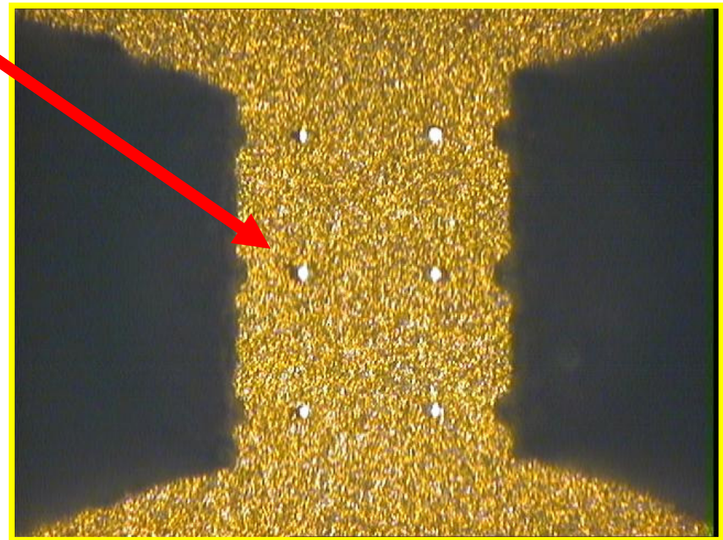




Planarizing the Probes

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





ISS Alignment Marks

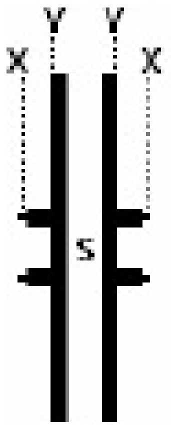


Figure 1: Alignment marks

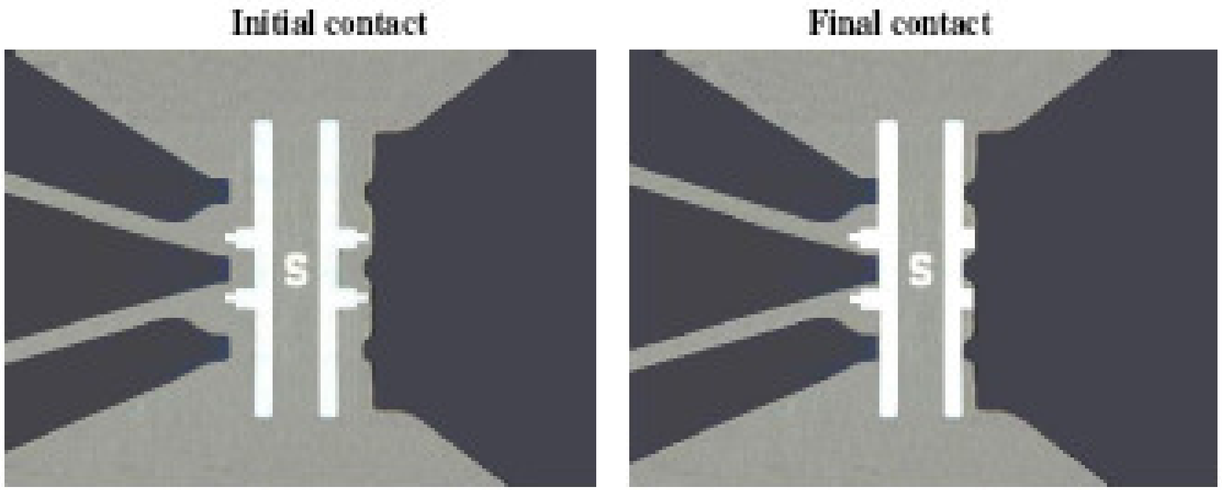
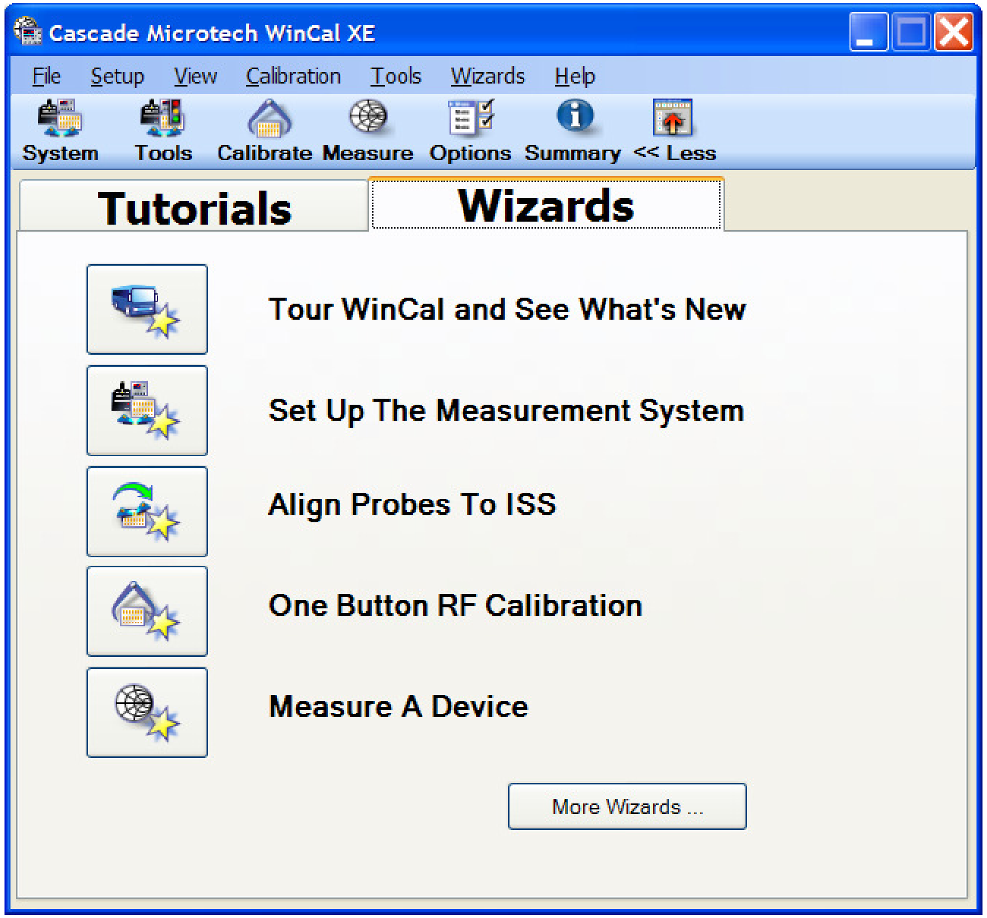


Figure 2: Images showing correct alignment and placement of probe tips of both ACP and Infinity style probes.

- 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

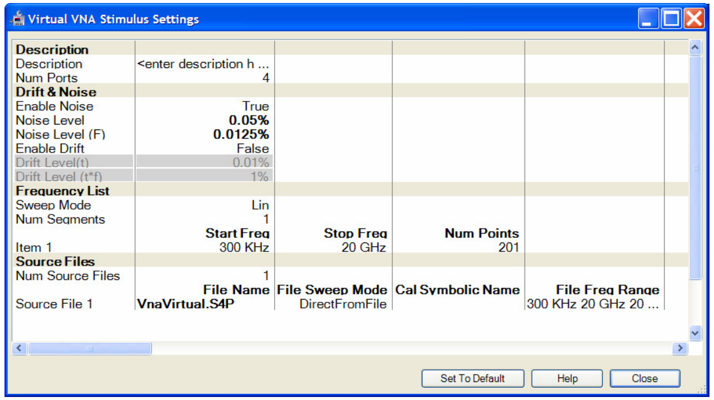
WinCal XE

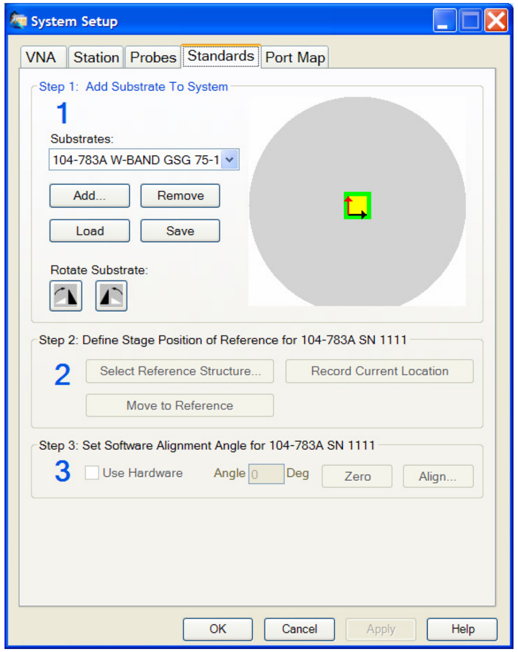
- Tools for the novice
  - Guided Wizards
  - Multi-media Tutorials
  - Intelligence in setups
- Tools for expert
  - Enhanced verification
  - Real time measurement validation
  - Enhanced reports



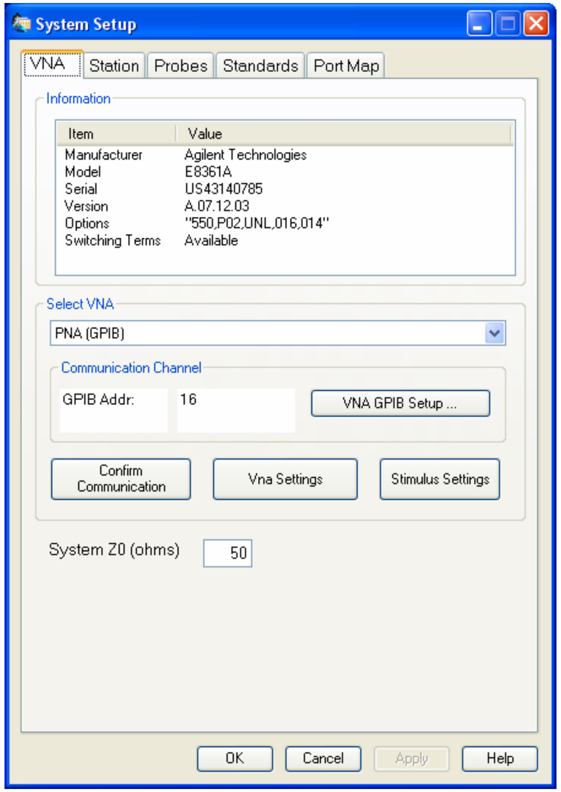
System Setup

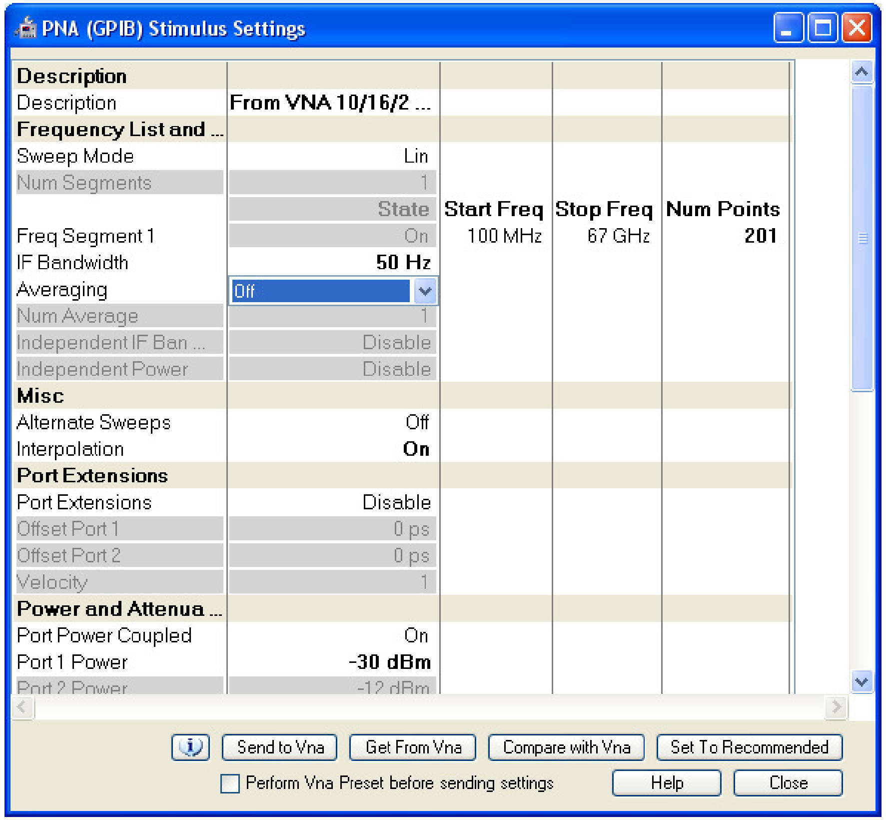
- Measurement System Setup
  - Define the measurement system
    - VNA, prober, ISS and probes
  - VNA Qualification
    - Test that the VNA is functional and repeatable
  - Probe Qualification
    - Check that the probe is making contact
    - ISS management
    - What structures to use
    - Is a structure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





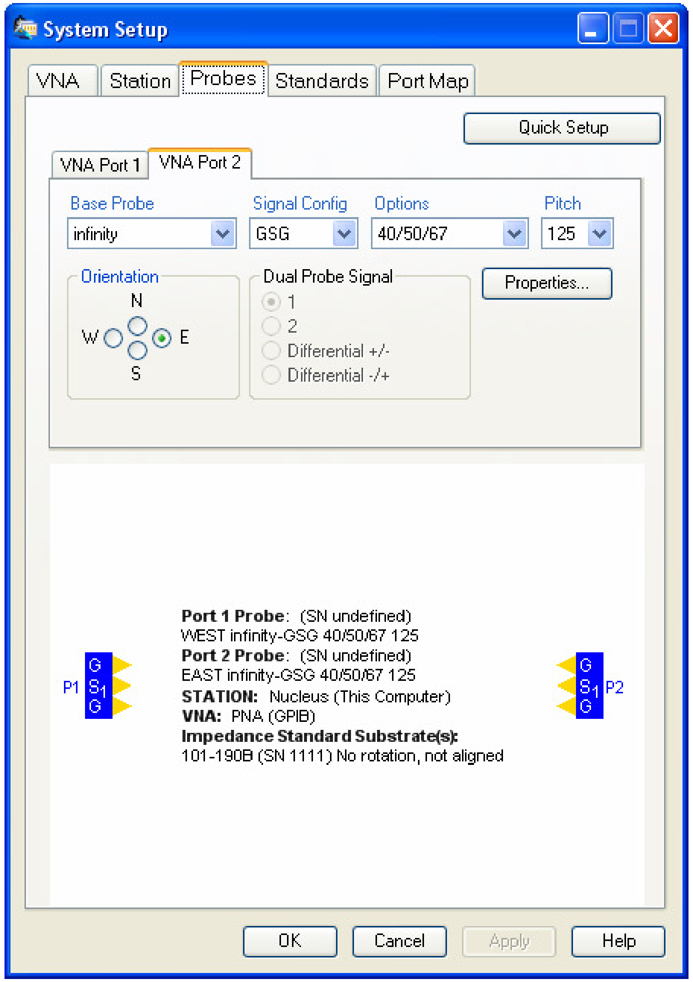
Using Wincal XE to Prepare the calibration





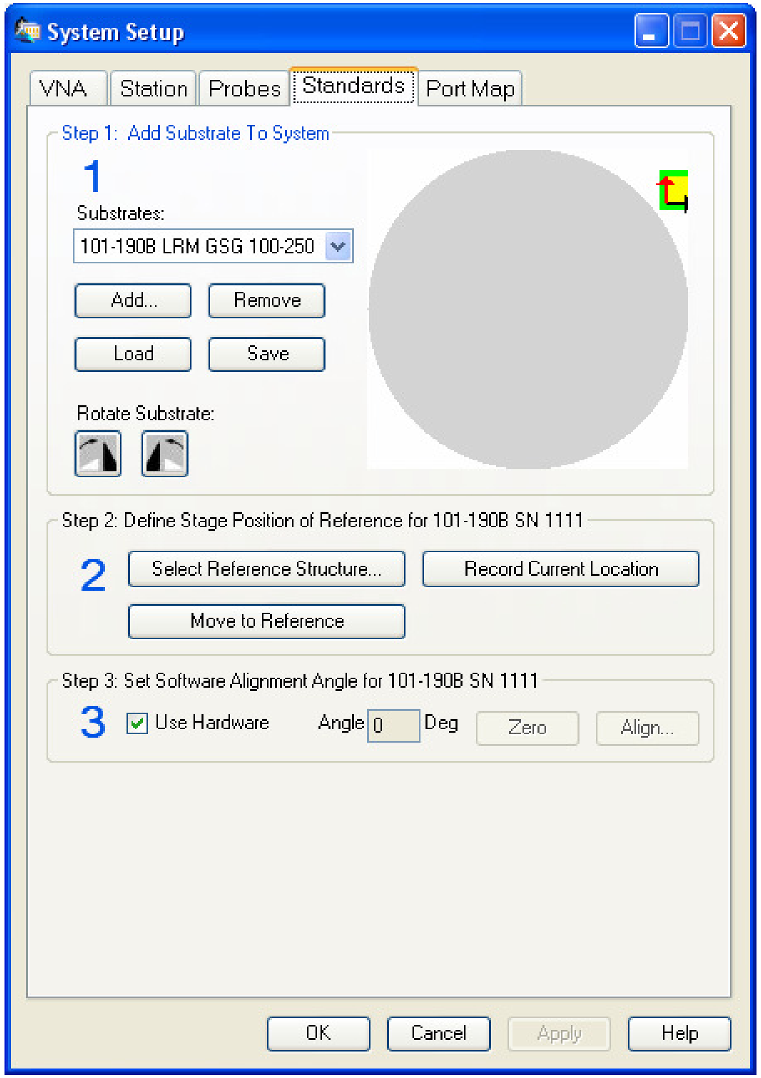
- Important to initialise instrument settings paying attention to power, number of points, Start and stop and particularly IF bandwidth

Probe Set-up



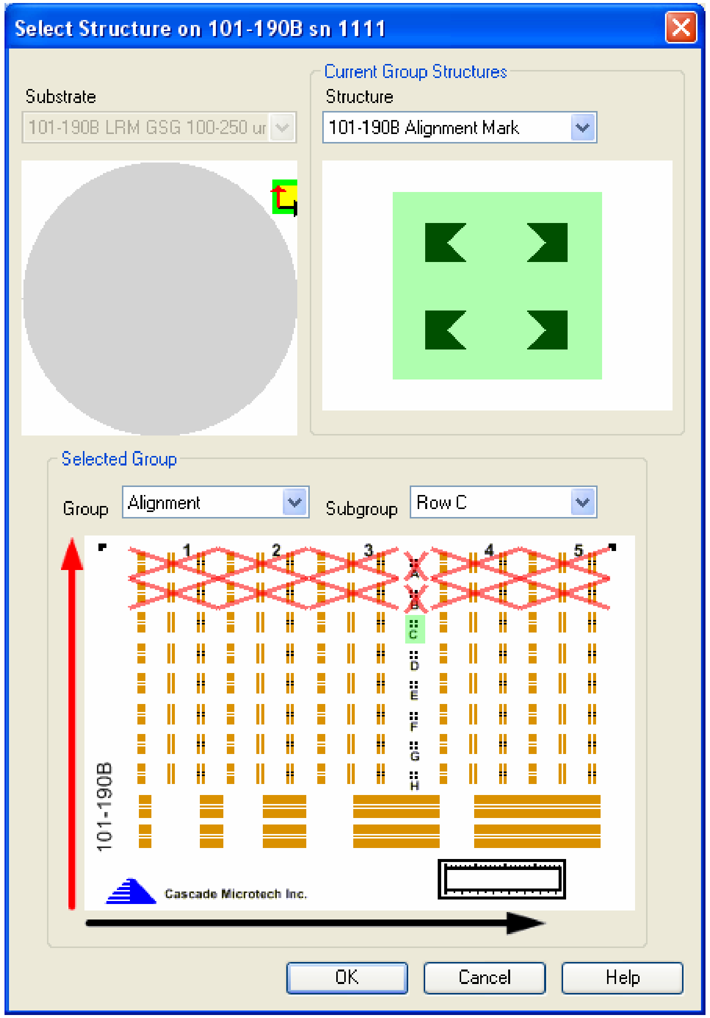
- Probe characteristics are displayed both graphically and numerically. Probes can be identified by serialisation
- Probe data required to check calibration compatability and where necessary provide lumped element data

ISS Set-up for Auto calibration



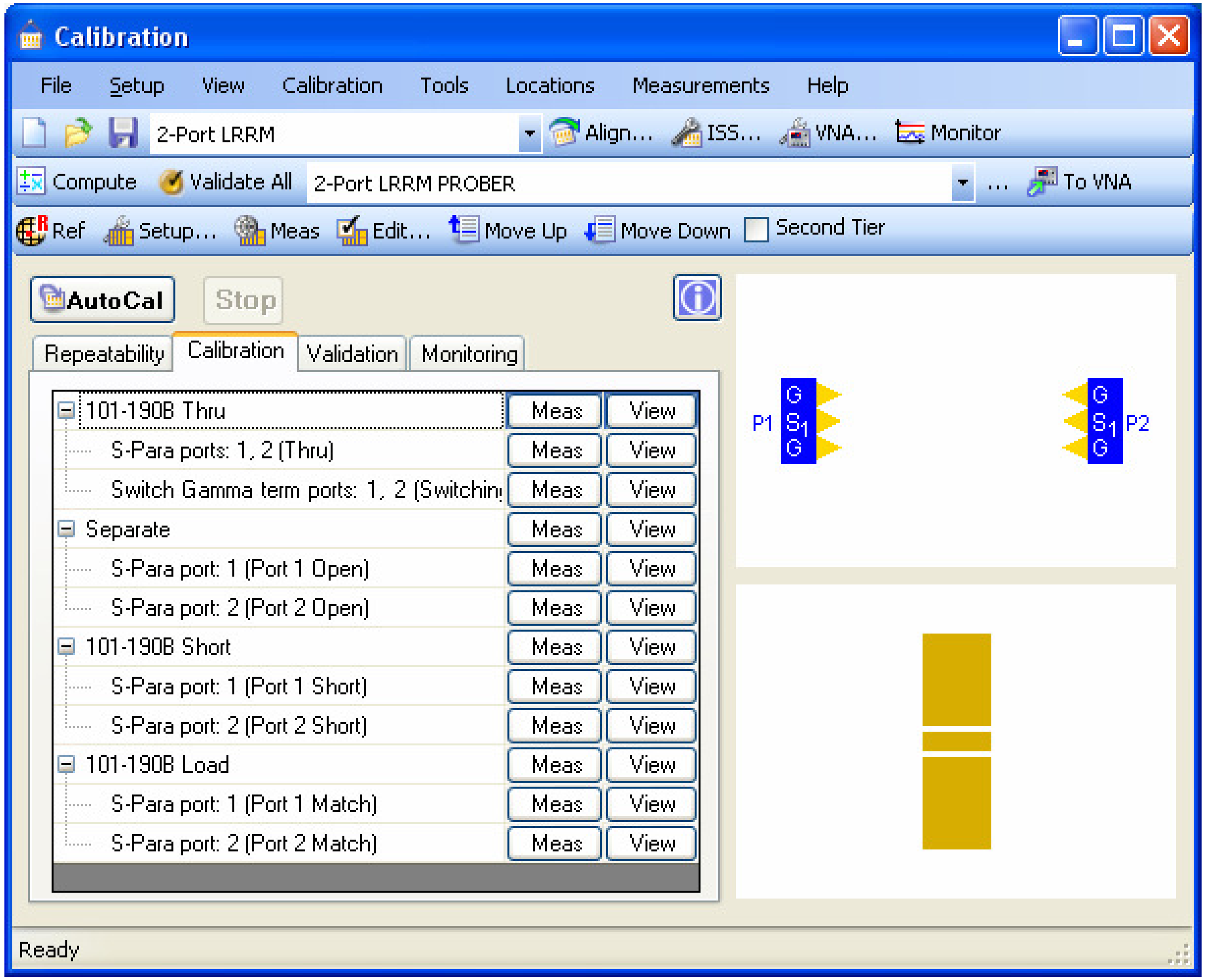
- Individually serialised iss data can be loaded
- This information is important to keep track of correct iss for calibration and determine location of alignment structure

ISS Alignment structure location



- 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

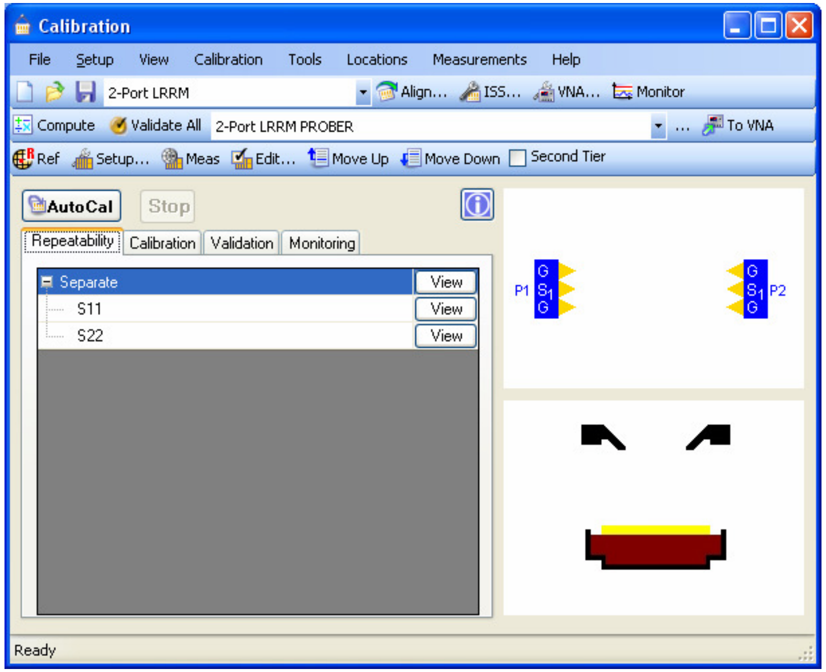
Automatic Calibration

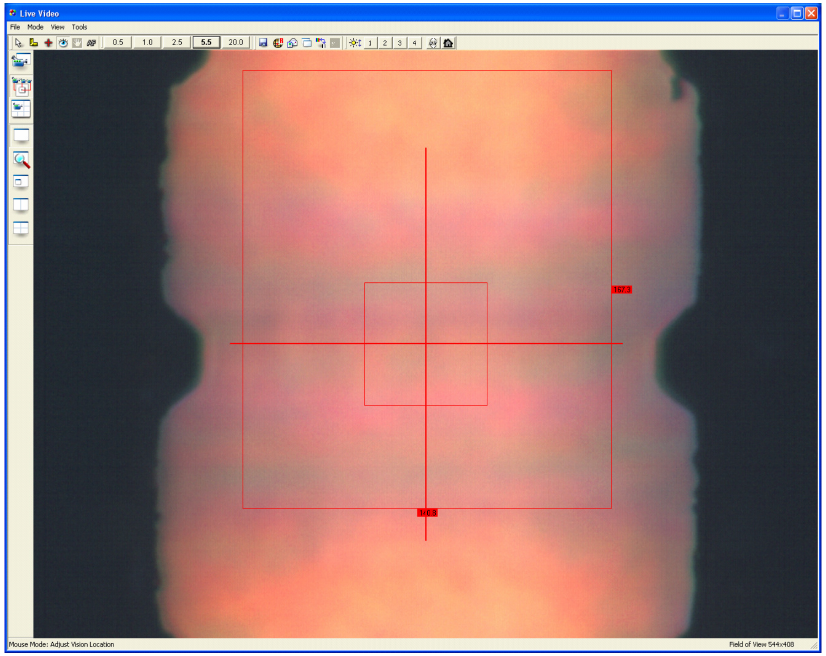


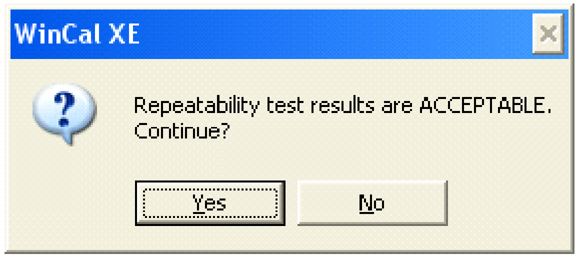
Calibration Procedure

- 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

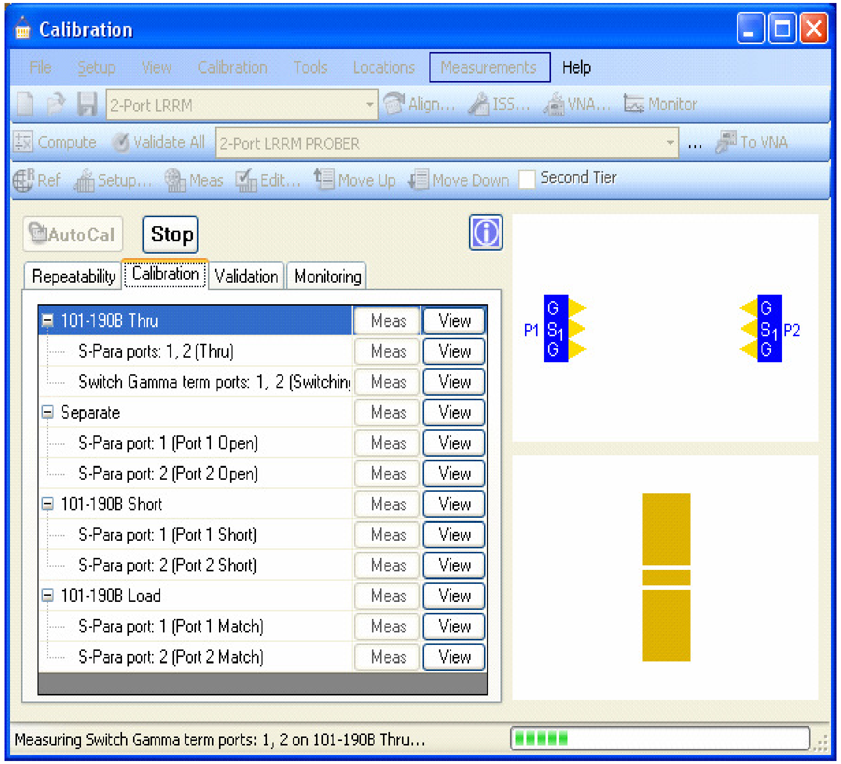


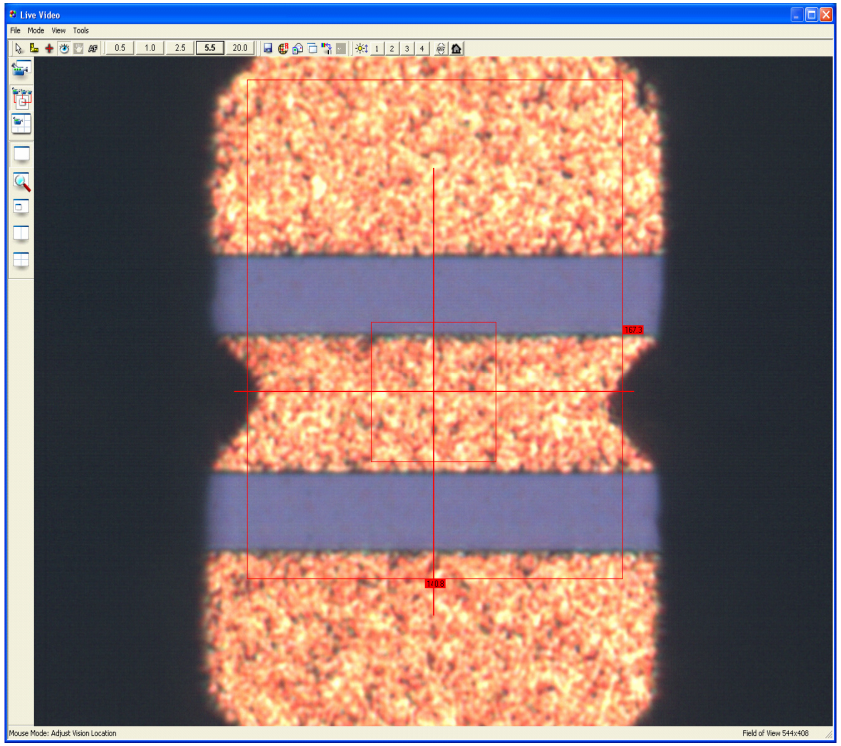




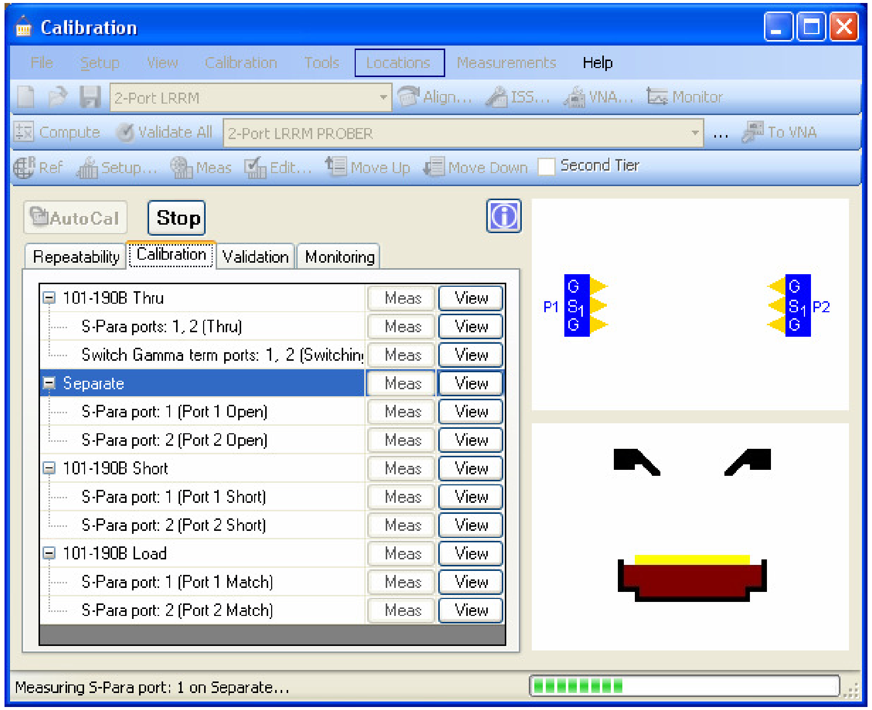
Wincal measures open to check repeatability of measurement system

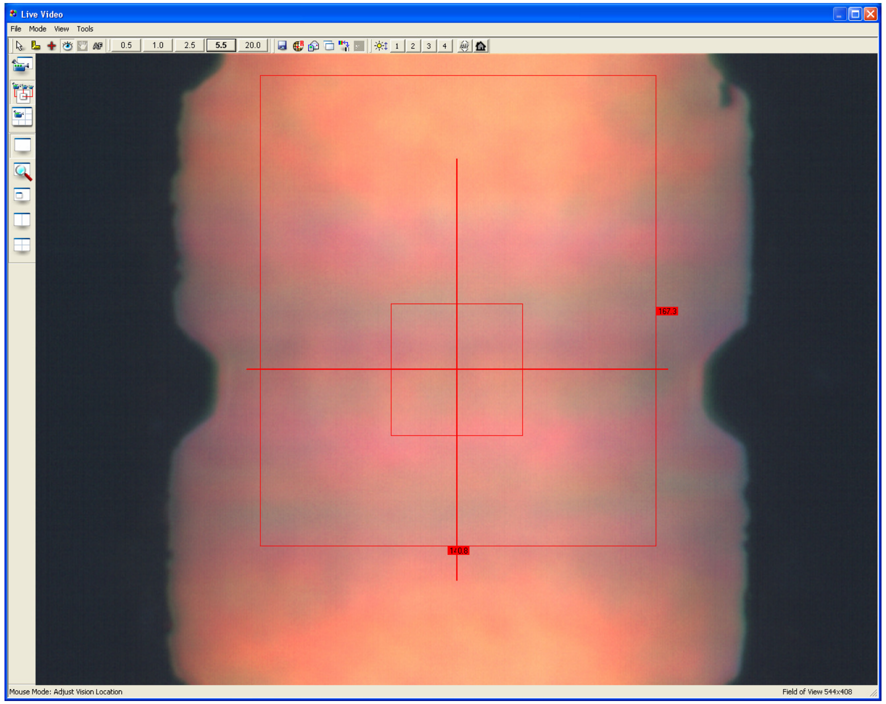
Calibration measurements for LRRM - Thru





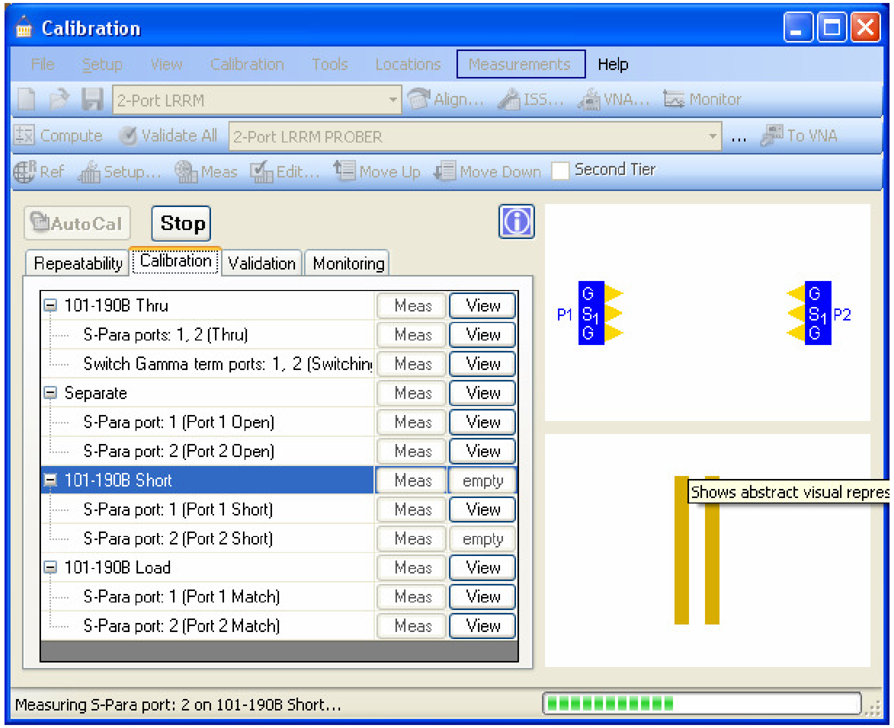
Calibration measurements for LRRM – Open

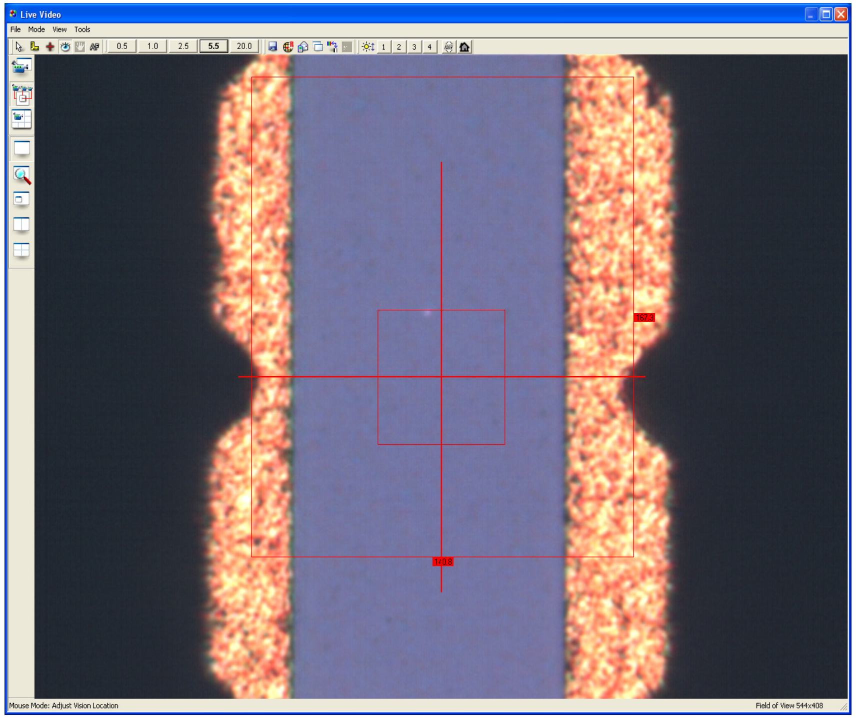




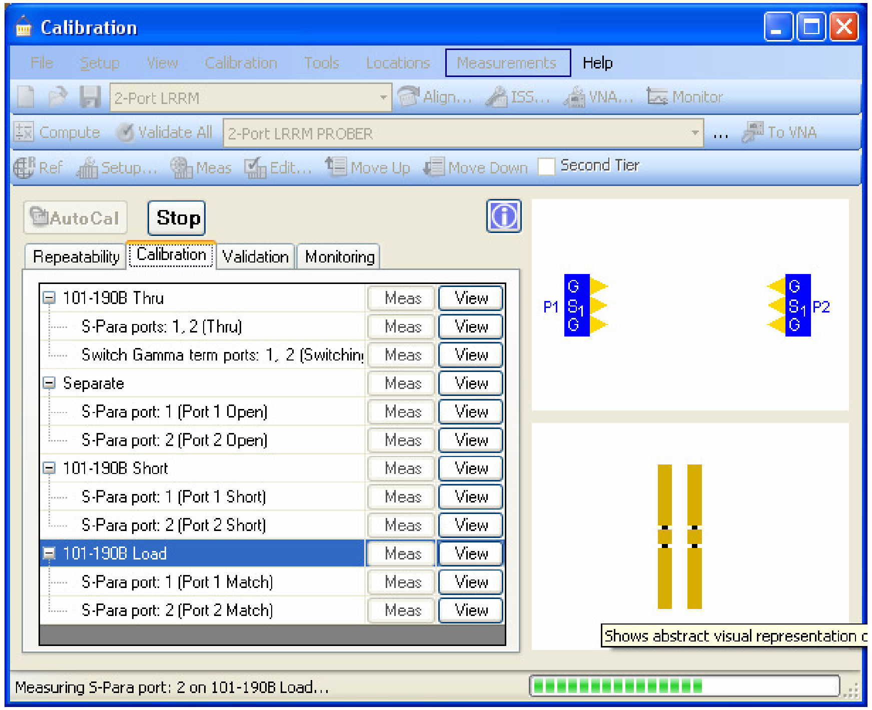
- System re-measures open for the calibration. At times the open measurement uses substrate opens hence the need for remeasurement

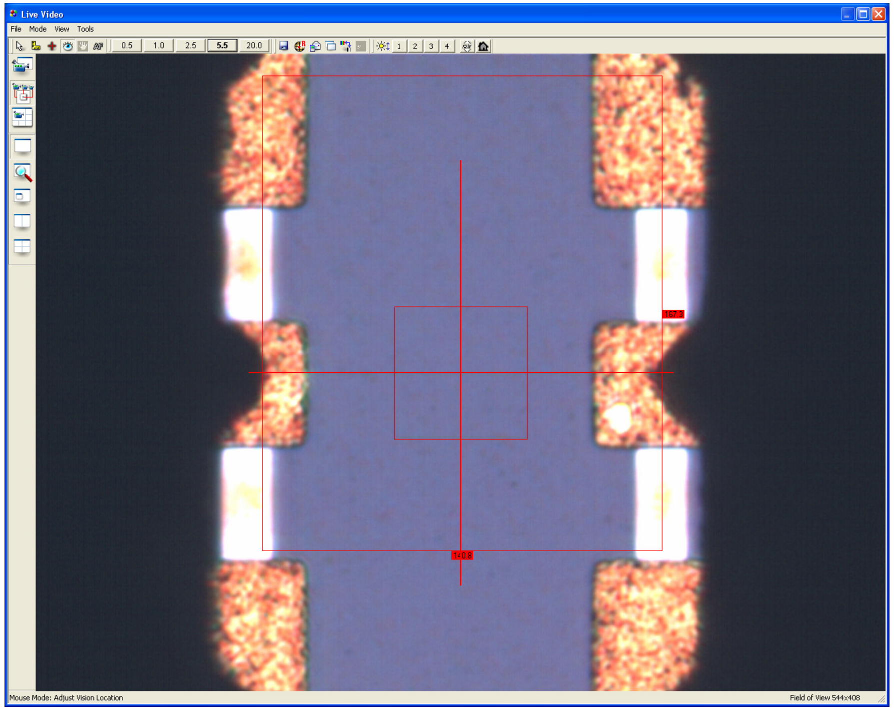
Calibration Measurements for LRRM - Short





Calibration Measurements - Load



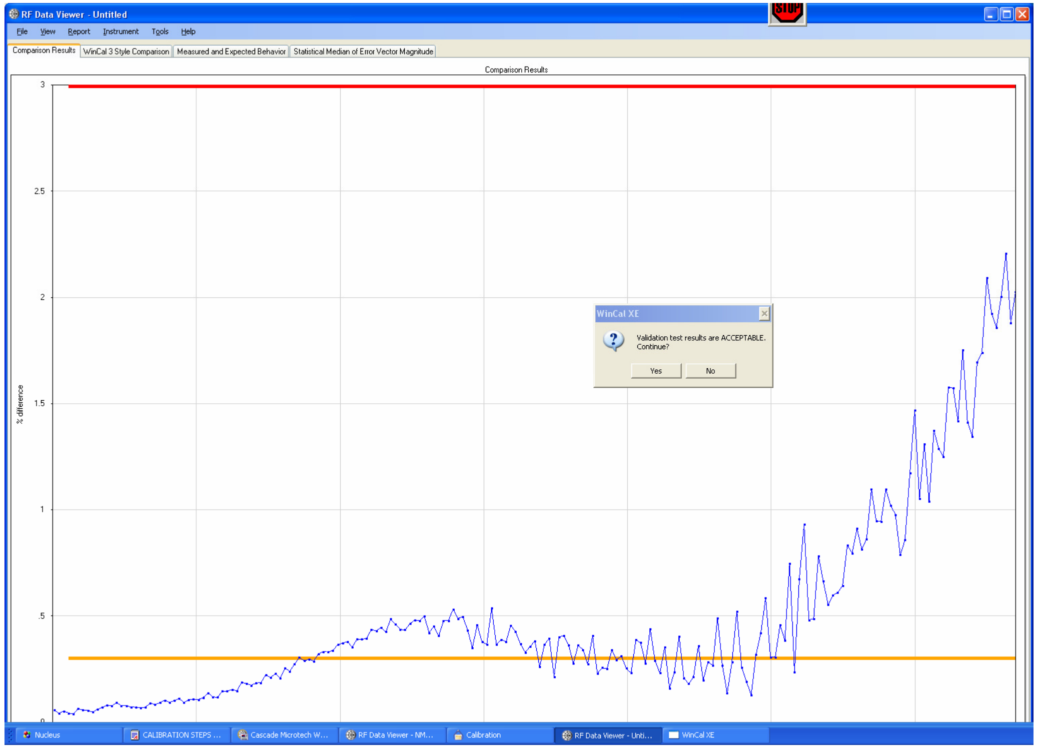


- It is important that only 50 ohm loads are used for this part of the calibration

Calibration – Computation and sending of error coefficients

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

Calibration - Validation



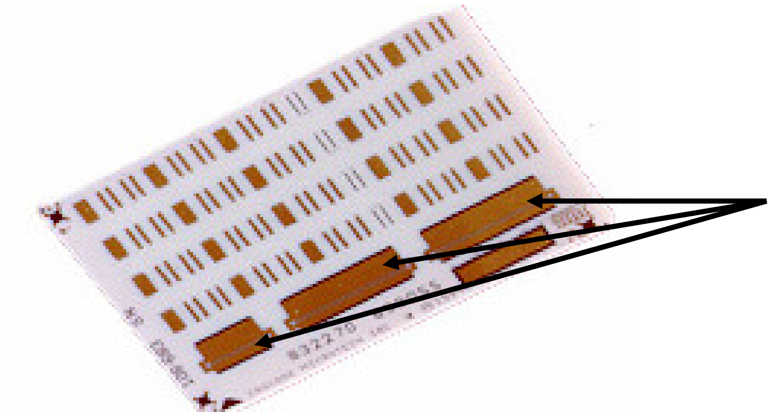
- Following calibration a validation is carried out against a known standard. Typically this is an open whose capacitance is known by the probe pitch, but can be a golden dut whose characteristics are pre-measured and stored. For Irrm the open is the raw open measured during the cal and corrected by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

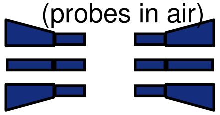
- As well as re-measuring the calibration standards, other verification standards can be measured to determine successful calibration
  - These include open stubs and transmission lines
  - Open stubs and lines of varying lengths are found on the calibration standards

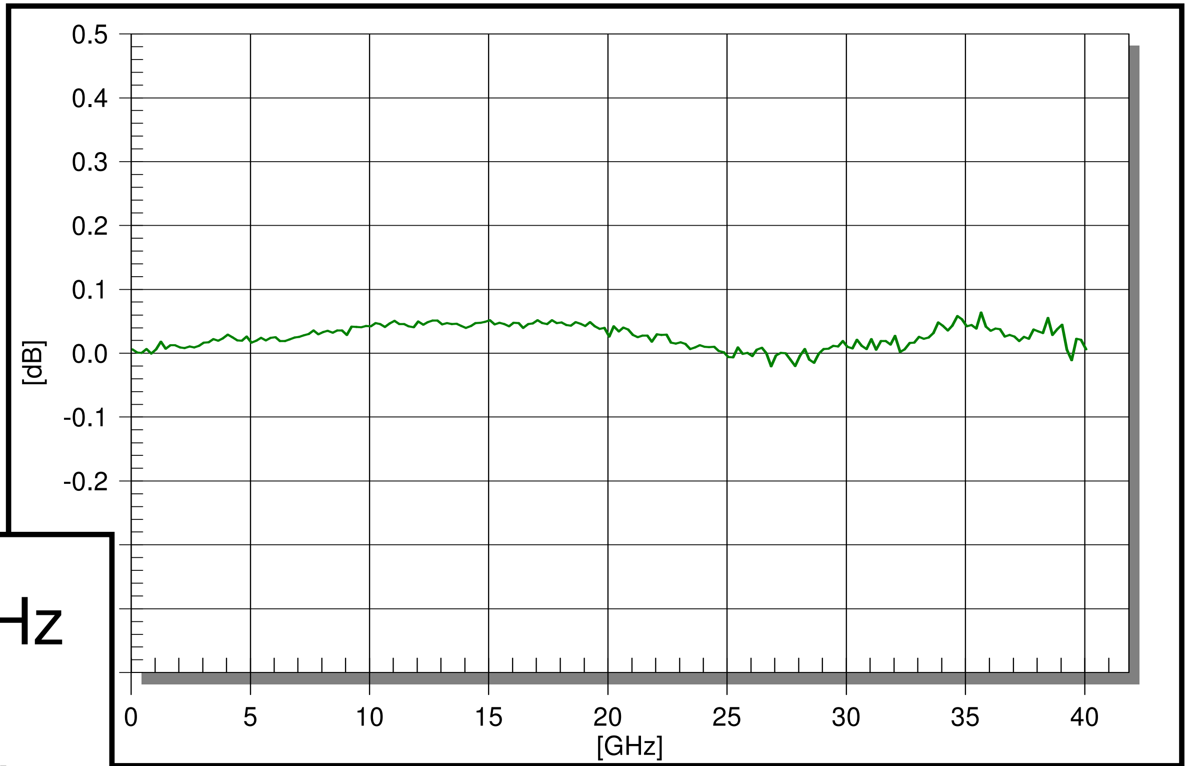


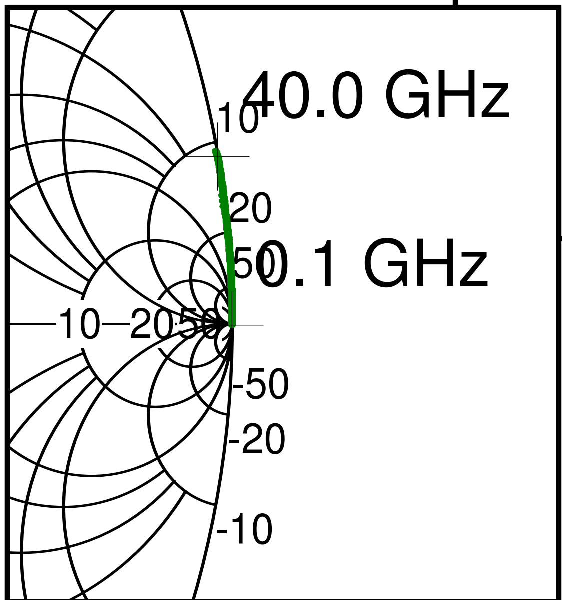
Various lengths of transmission lines

Calibration Verification Standards

Reflect
(probes in air)



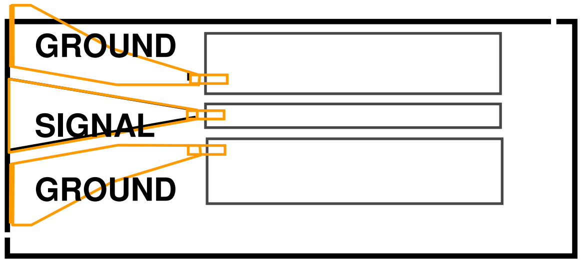


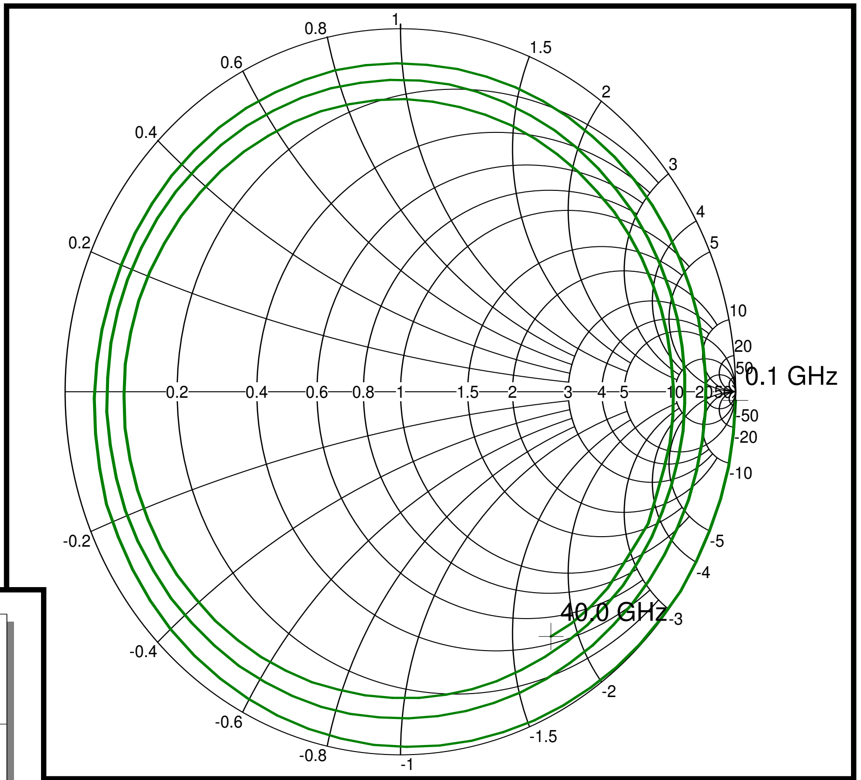


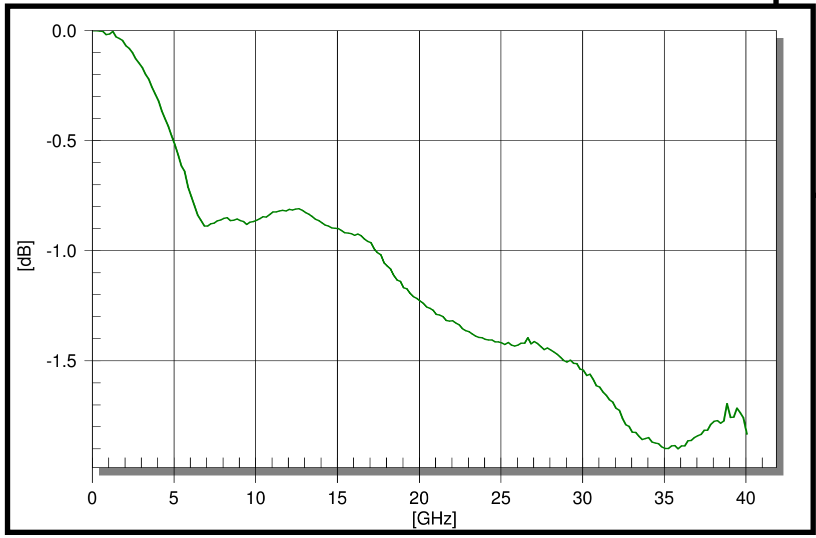
- Unity Gain
- Negative Capacitance
  - Due to wave propagation being faster in air than on the Alumna substrate

Independent Verification Standards

Open stub



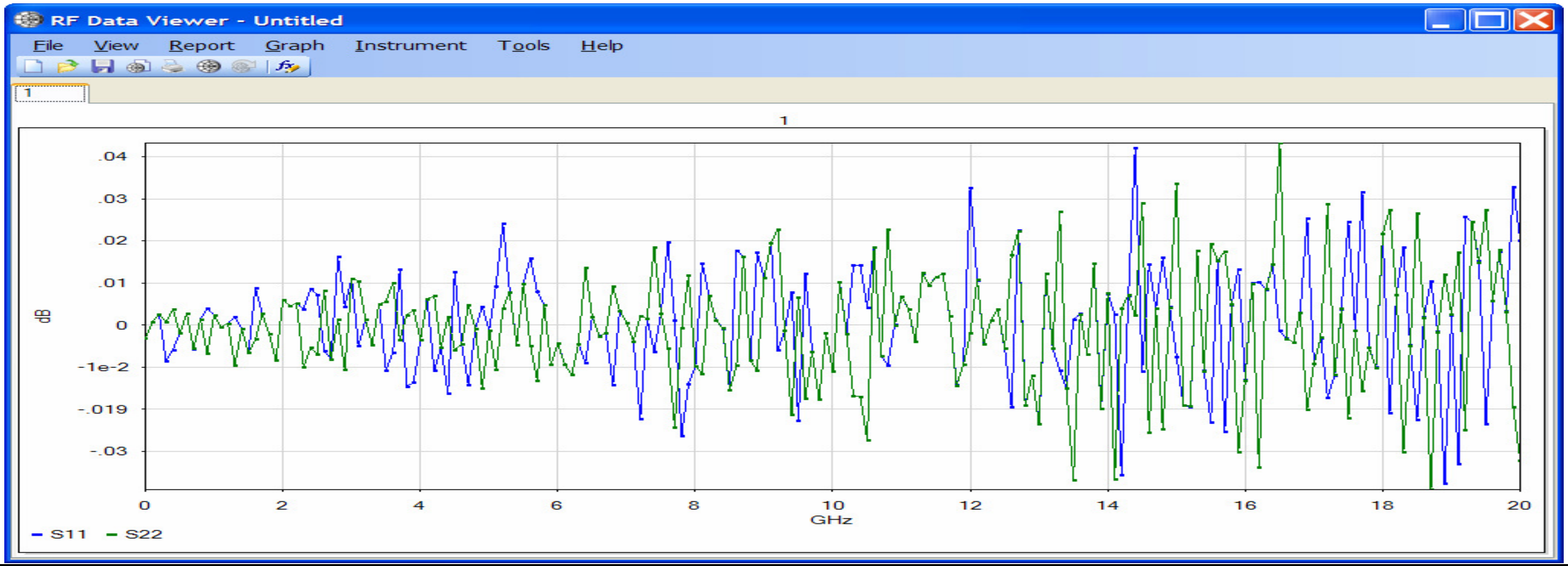




- Linear Phase Lag
- 50ohm to stub Z miss-match
- Fringing C at stub open end

Calibration Drift

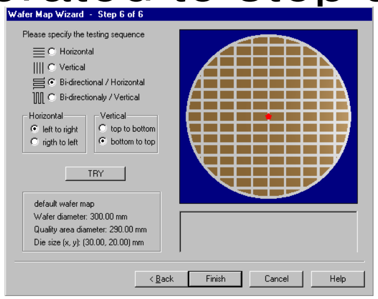
- WinCal 2006 Calibration software has a feature called monitoring
- Monitoring allows the user to capture calibrated reference data immediately after a calibration has been performed. At a later time, you can re-measure the previously-acquired references (by selecting Calibration>Monitor in the Calibration 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.

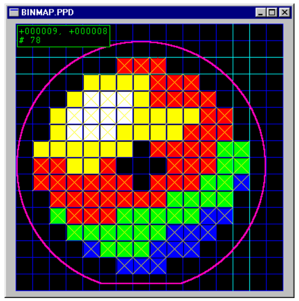


Device Layout

Design for Testability

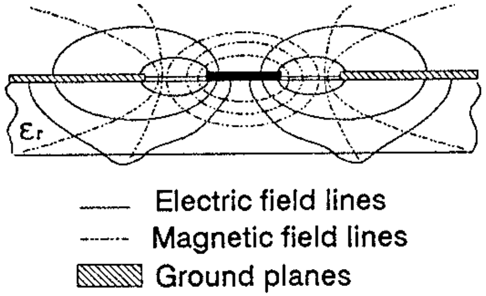
- Do you want to test the device at wafer level?
  - If yes, you will need to have a pad layout which conforms with possible probe configurations.
- How much money do you want to spend on probes?
  - Complex designs may require an RF/Microwave probe card
  - Well designed circuits may be able to use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

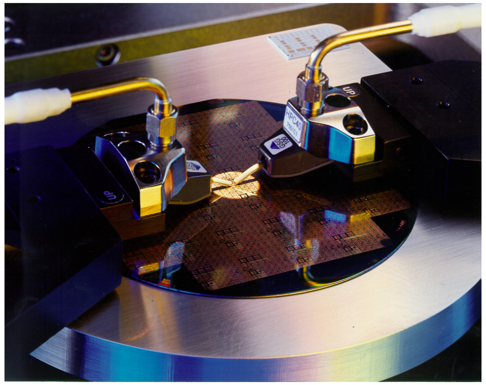


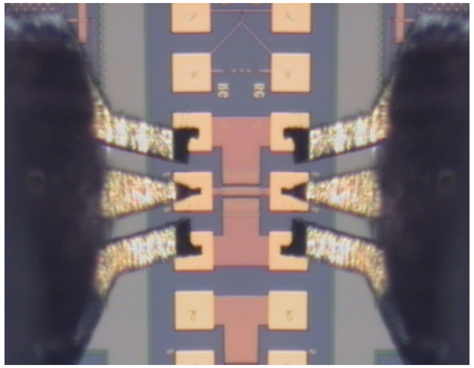


Think About Testing Before Design

- 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

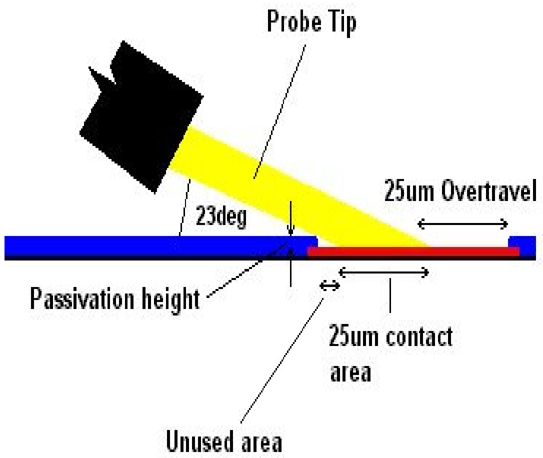


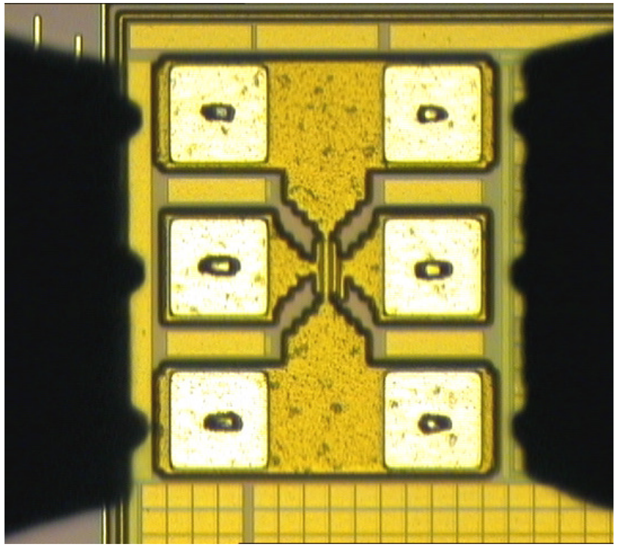




Pad Sizes

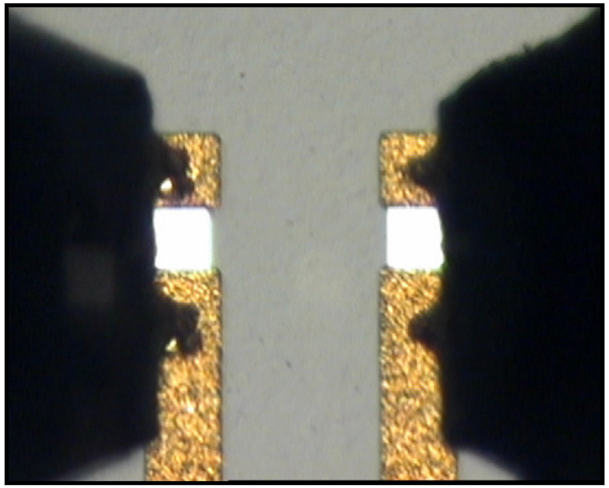
- Recommended minimum pad is 80um x 80um for ACP Probes
- **Infinity Probe Allows 50um x 50um probing**
- Passivation height must be considered
- Pad height variation must not exceed 25um for ACP or 0.5um for Infinity

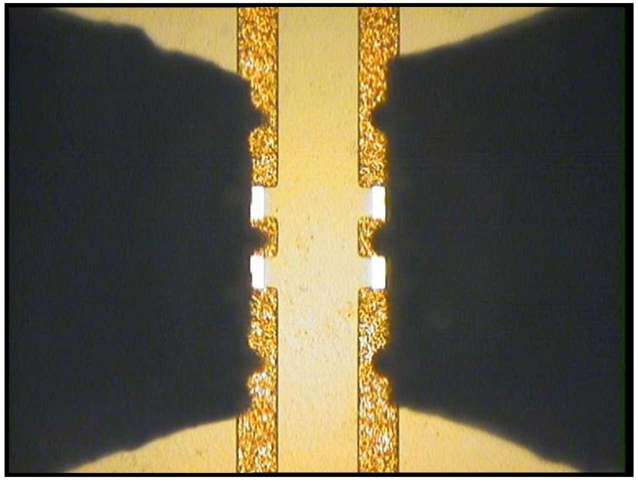




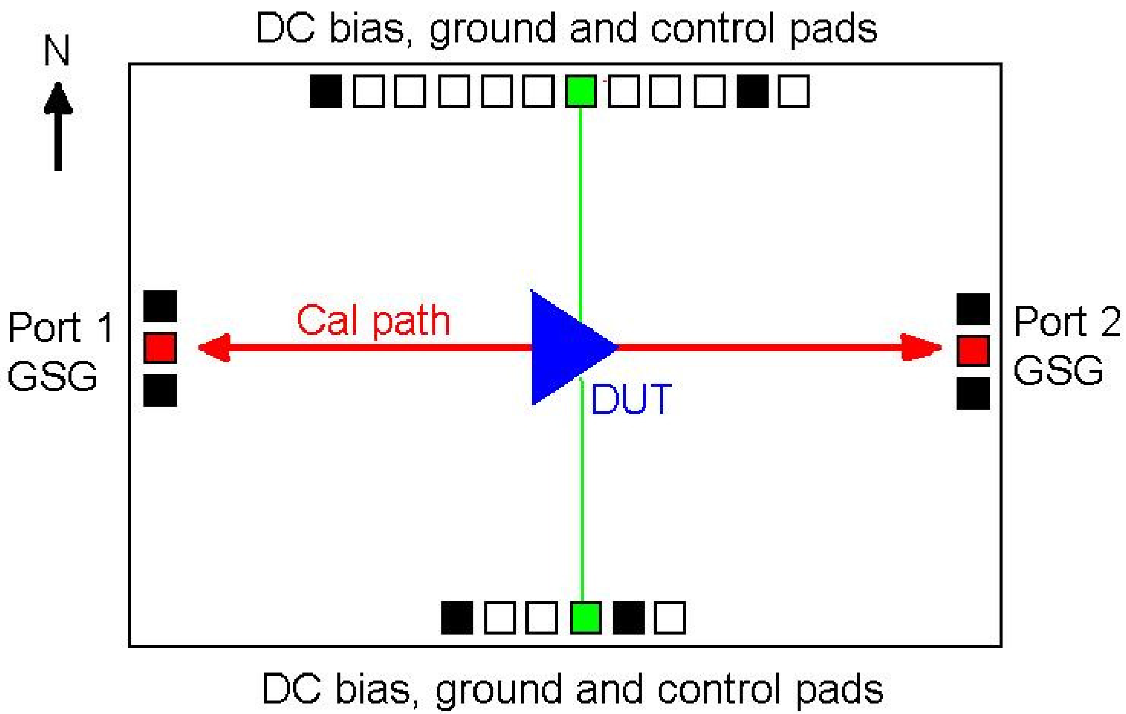
Probe Configuration

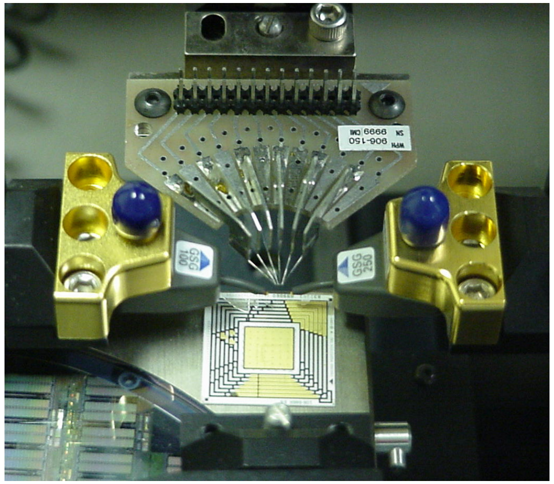
- Whenever possible use GSG
  - Use GSG above 10GHz
- Probe pitch affects S-parameters
  - Use smallest practical pitch
    - 1/50th λ of highest frequency for GS
    - 1/20th λ of highest frequency for GSG



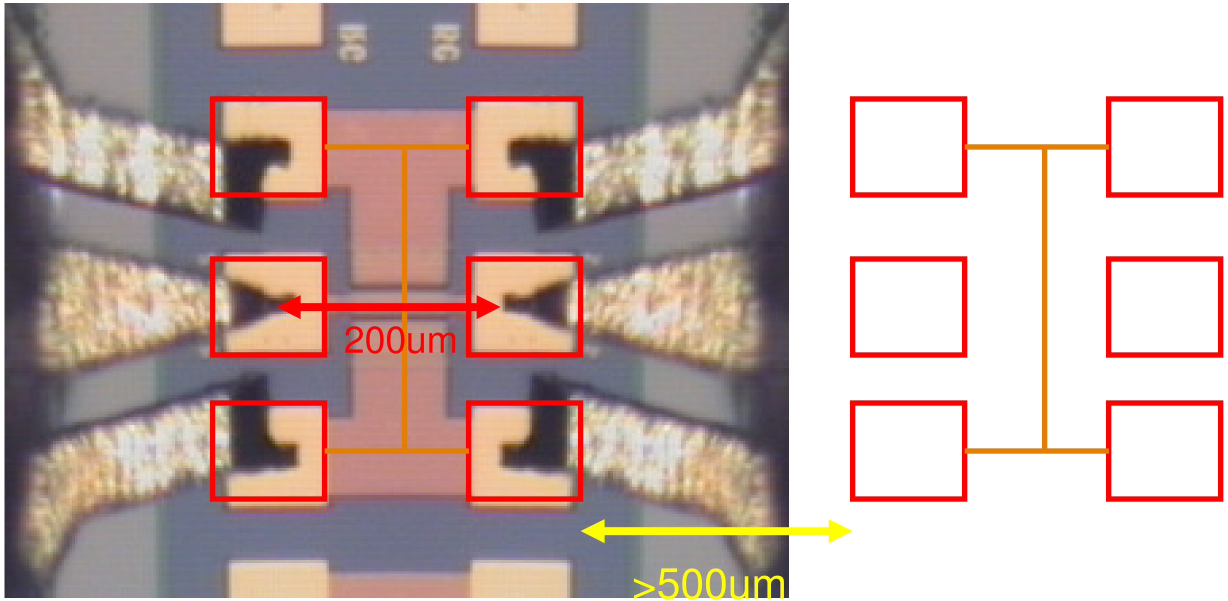


Device Pad Layout





Probe Pad Positioning

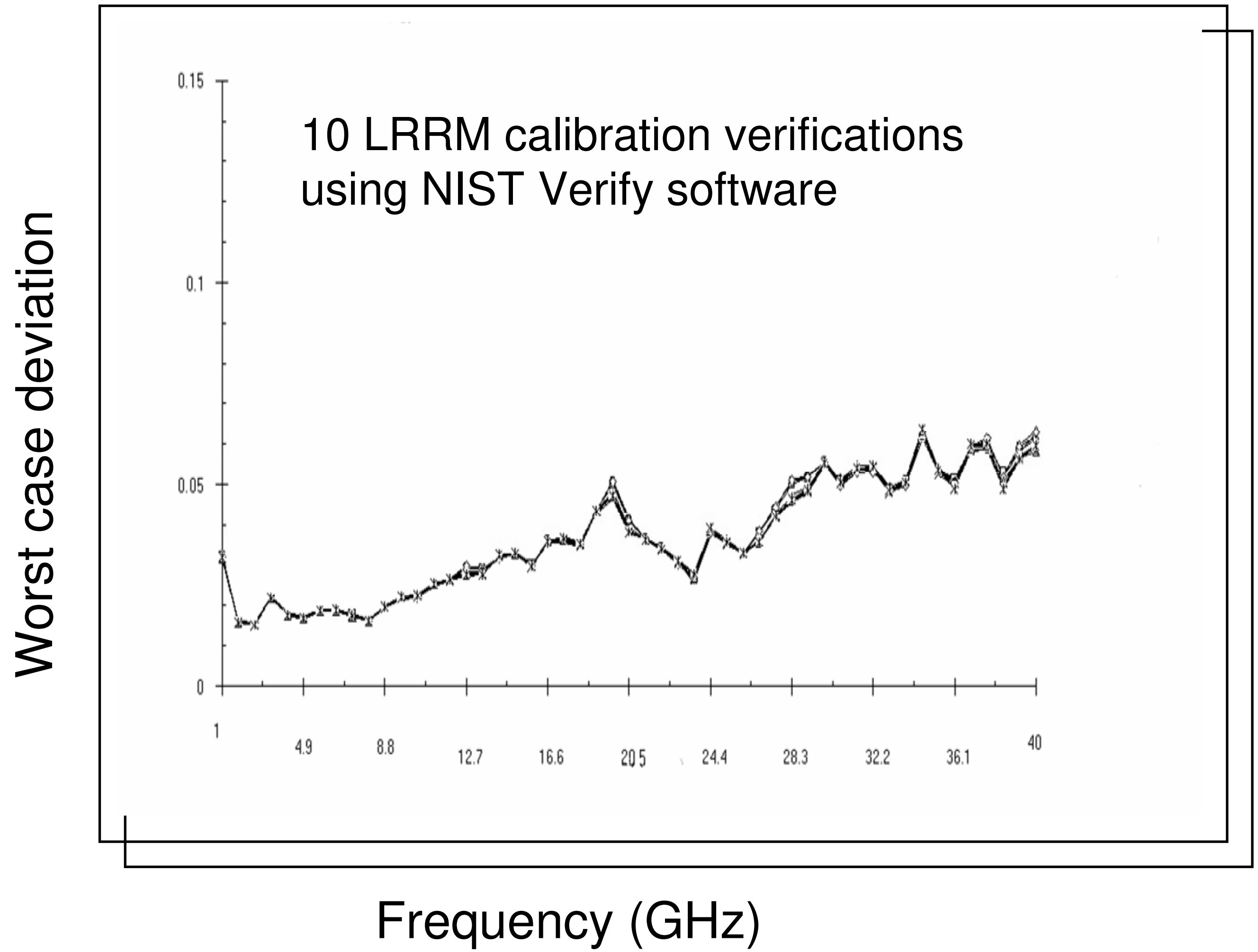


- RF probes should have more than 200um separation to avoid cross-talk
- All pads must be on top surface
- All grounds should be connected together
- Adjacent devices should be >500um away for mm-wave measurements (>250um for Infinity)

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)

Calibration Repeatability



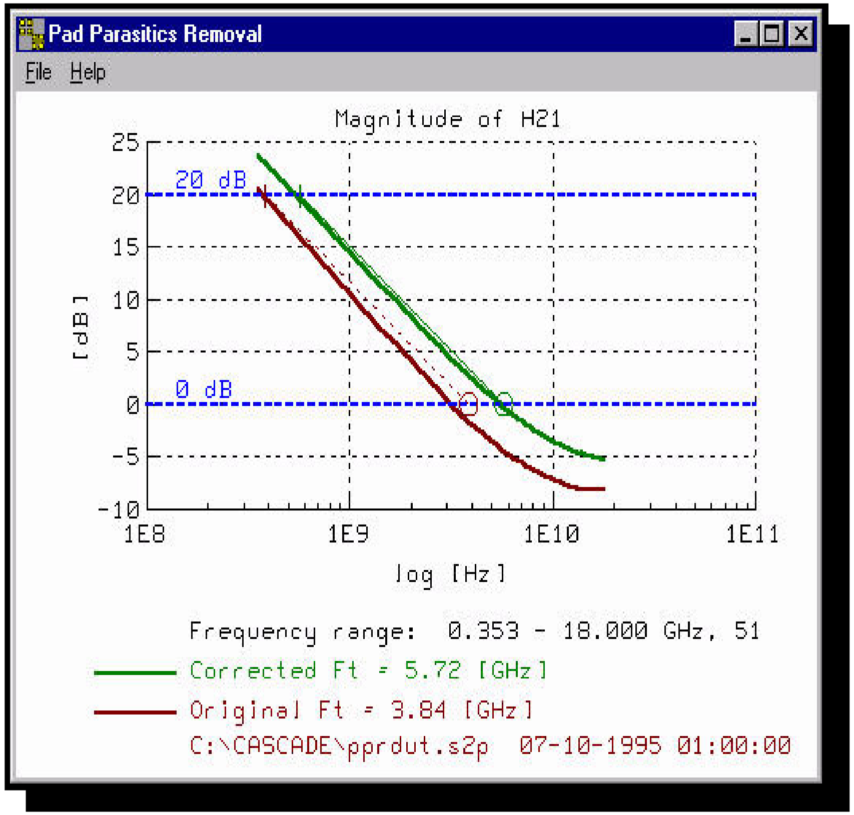
- LRRM automatic calibration is VERY repeatable

Pad Parasitic Removal

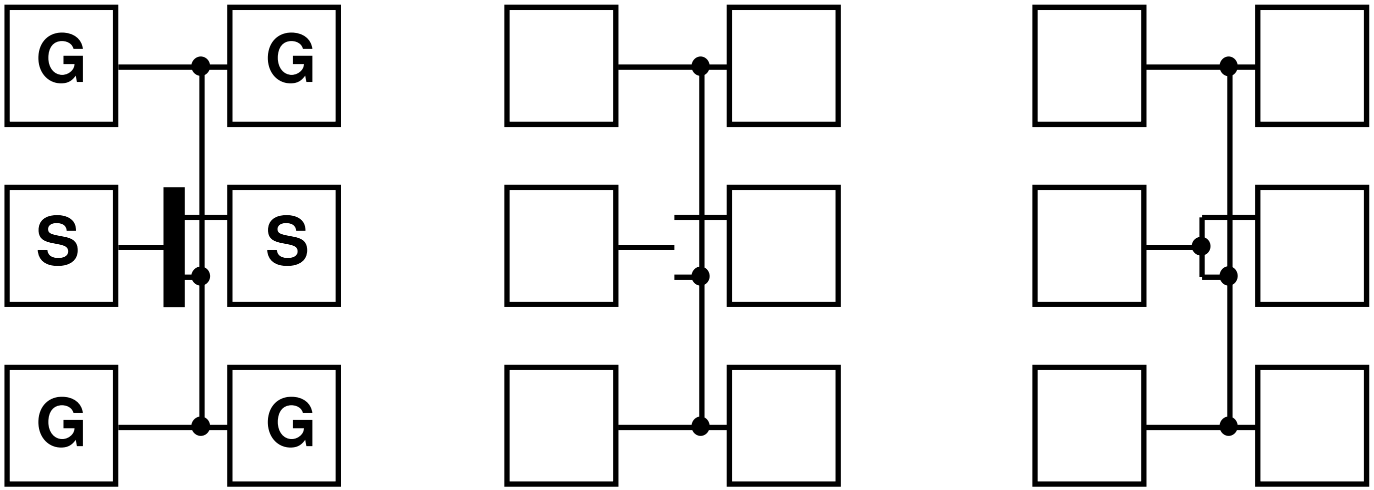
- Conductive substrate increases parasitic reactance
  - Pad and interconnect capacitance and inductances become more significant during device measurement
    - De-embedding of pads and interconnects is required
- Limitations of Pad Parasitic Removal methods
  - The larger the pads and smaller the device, 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, Z-parameters
- The dummy devices can be subtracted from the actual device
- The resulting Y, Z-parameters can be transformed and displayed



Dummy Devices



GSG test device

Open pads & metal Dummy

Short Dummy

CASCADE MICROTECH

Thankyou for listening

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