A guide to Successful on Wafer Millimeter wave Rf characterisation

Cascade Microtech Europe Ltd

Gavin Fisher

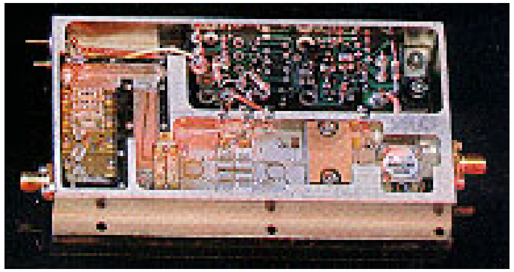
:: Agenda

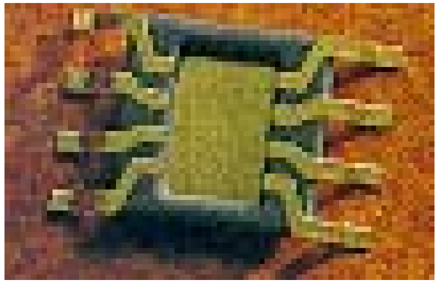
- The need for on-wafer S-parameter Measurements
- Typical system components and station specifics
- Microwave Probes
- Probe Station Essentials
- Probe Tip Calibration
- How to Calibrate
- Device for testability

:: Why do we need on Wafer Characterisation

:: 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 110 GHz System

Vector Network Analyzer

Cables

Probes

Probe positioners

Probe station

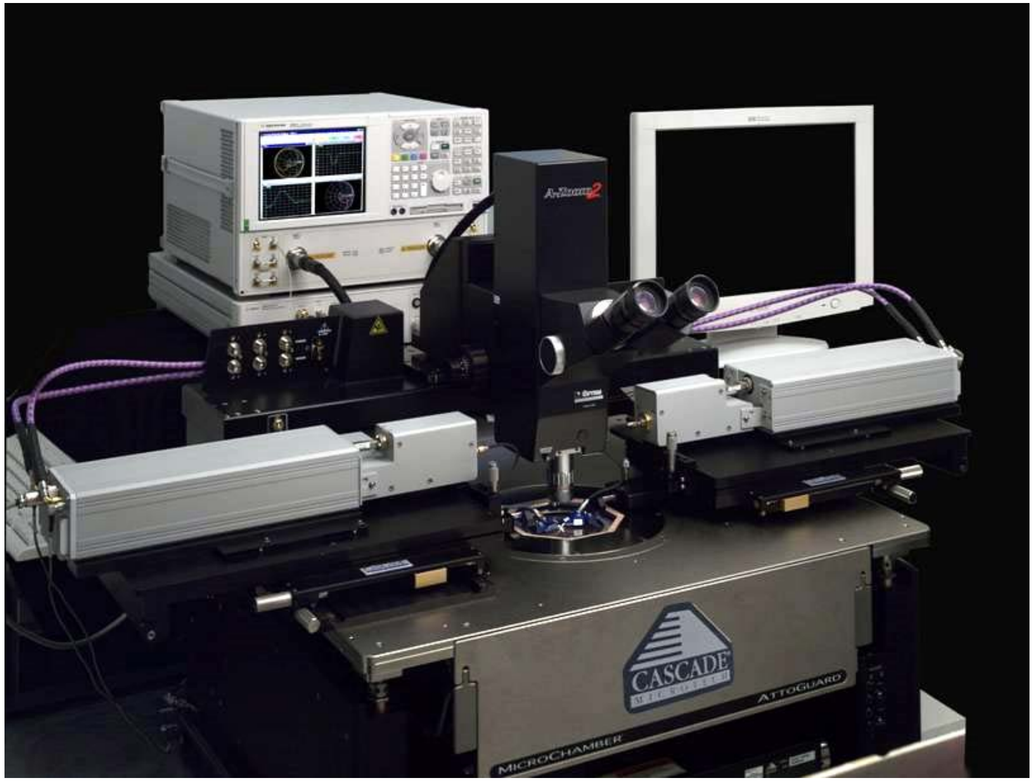
Contact Substrate

Calibration Substrate

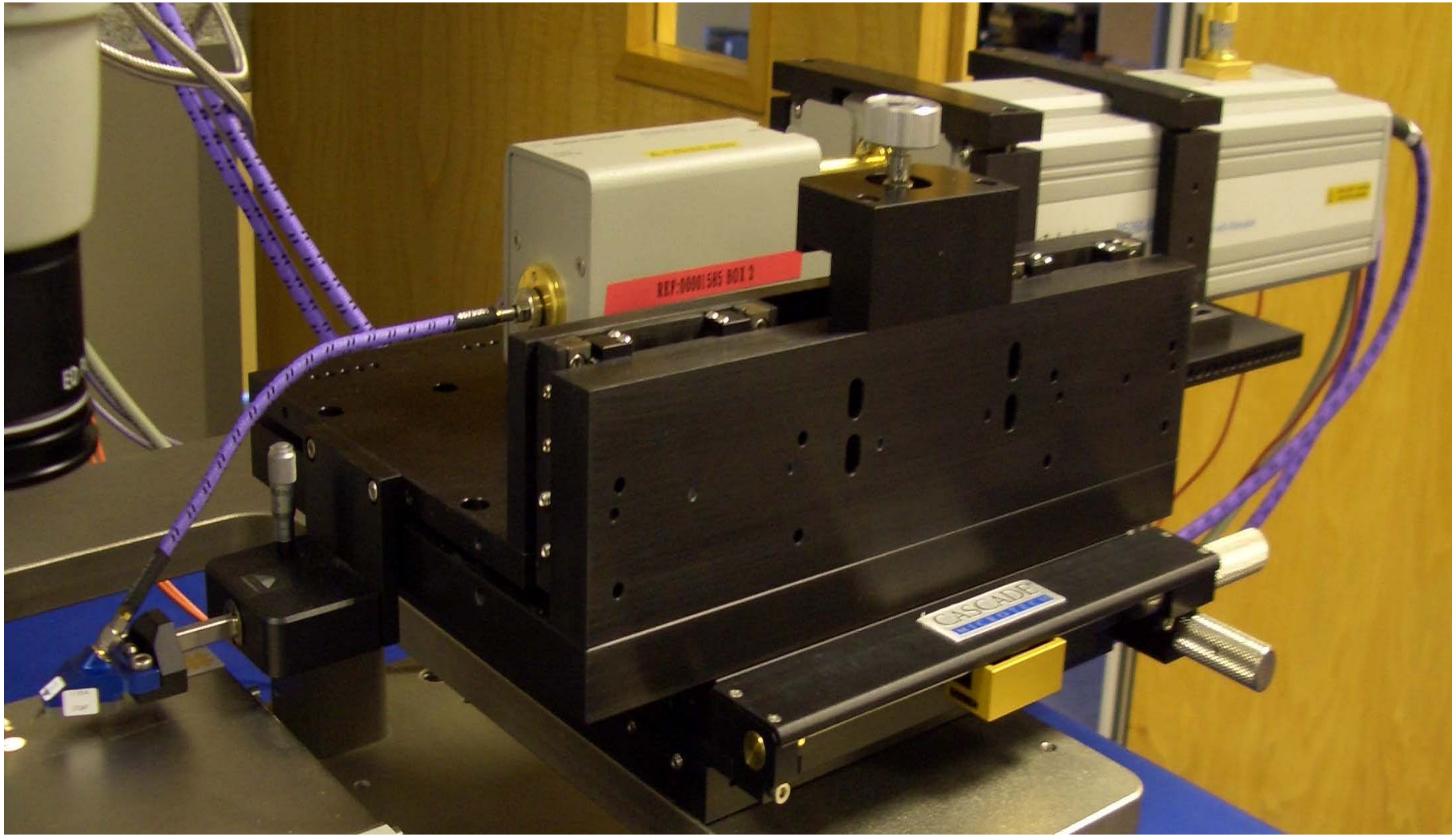
Calibration Software

Bias supply

Microscope



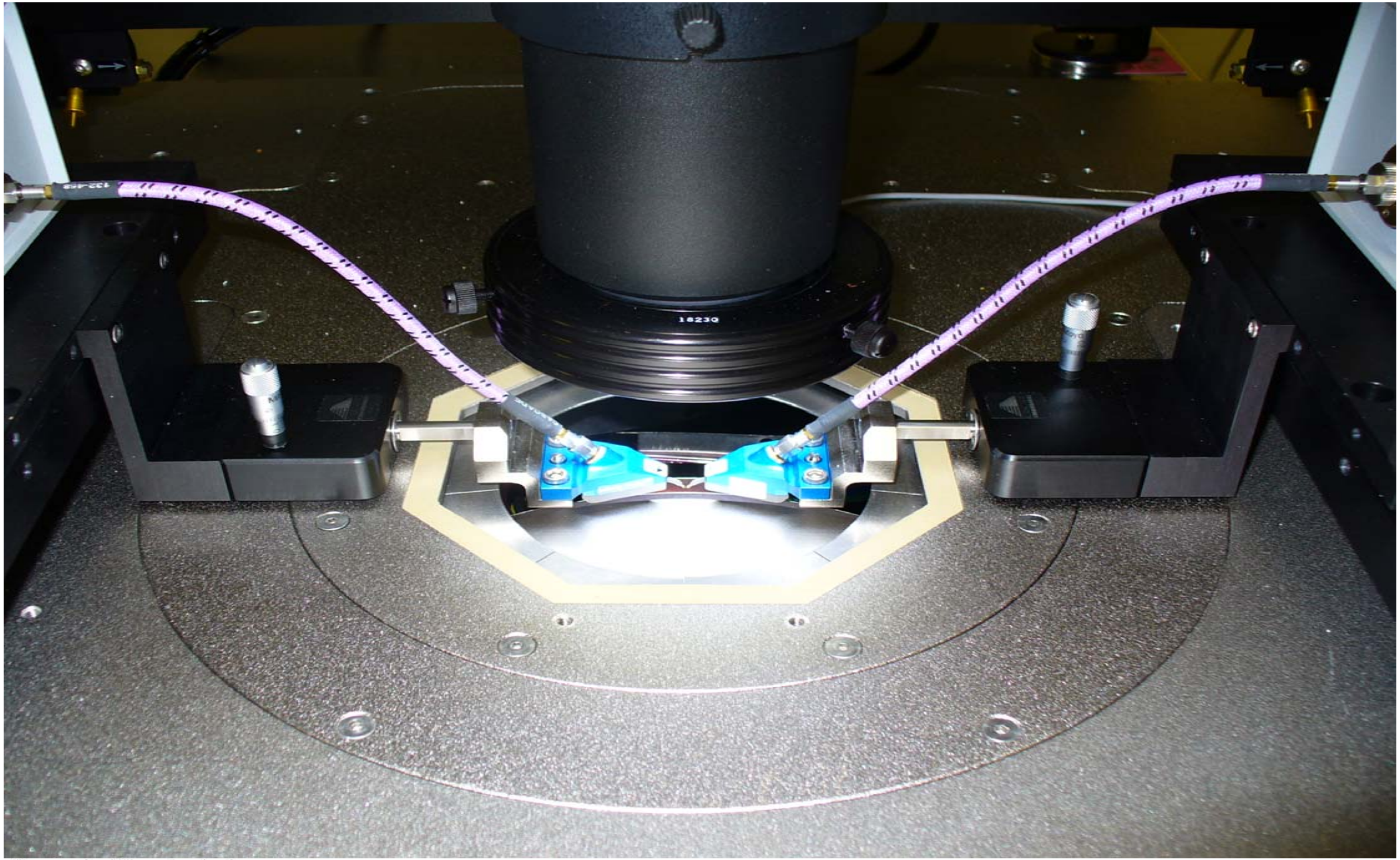
:: Large area linear lift positioner



:: 110 GHz Probes and Accessories

:: 220 GHz Probes / Waveguides

:: 110 GHz Probe connection scheme

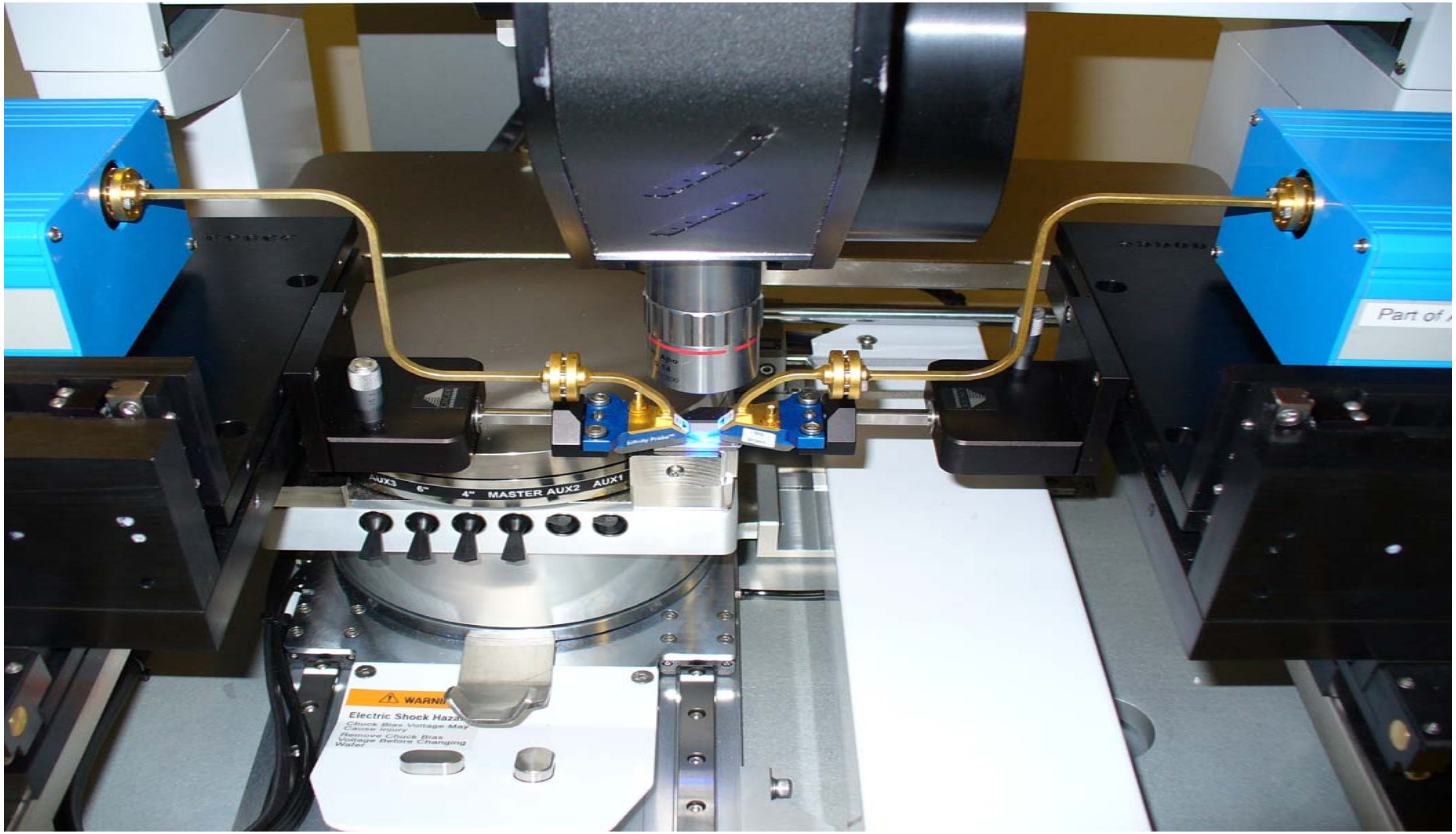


:: Semi-Automatic 220 GHz System

:: Manual 220 GHz System

- Quick release manual stage allows
- Evue microscope for rapid accurate probe set-up
- Deluxe anti-vibration table provides convenient monitor / keyboard mounts

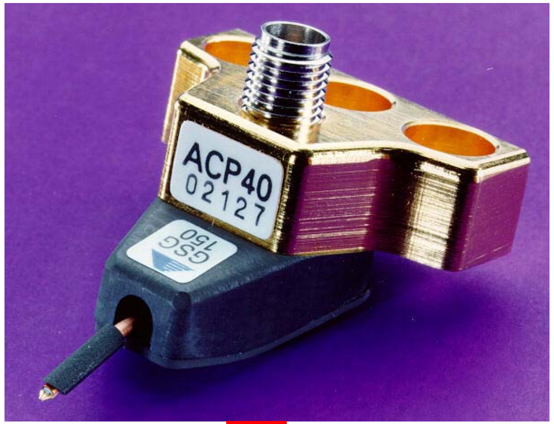
220 GHz Probe connection scheme

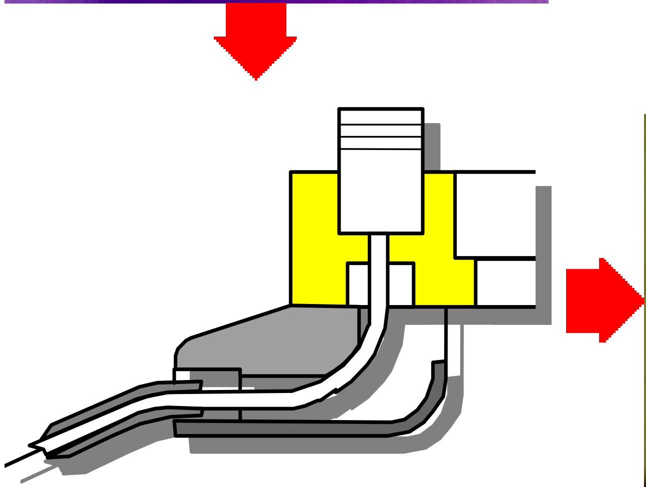


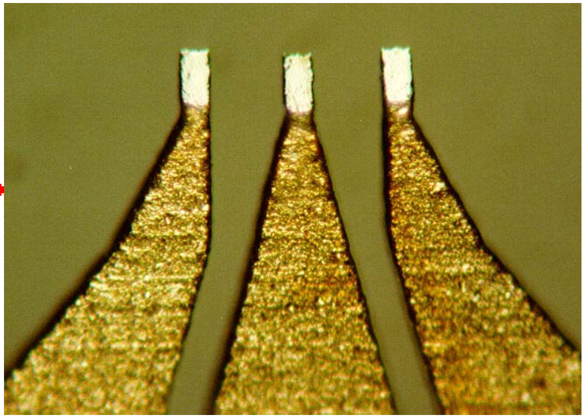
Microwave Probes

:: Air Co-Planar Transition

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

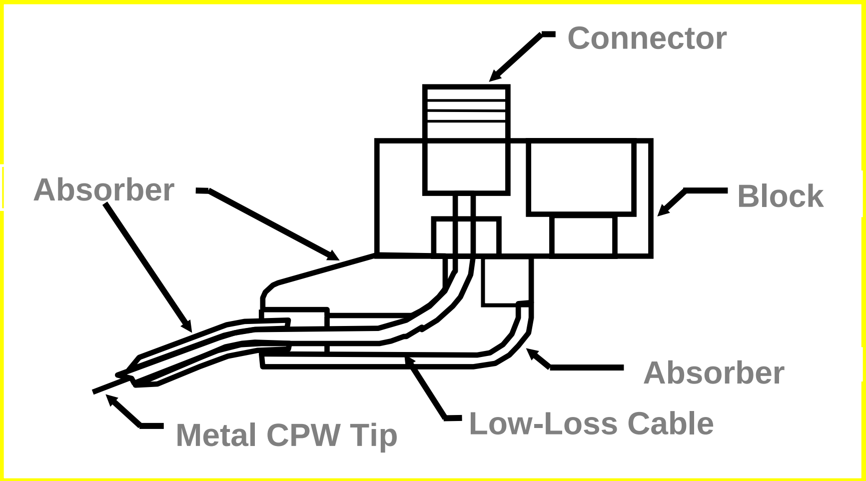




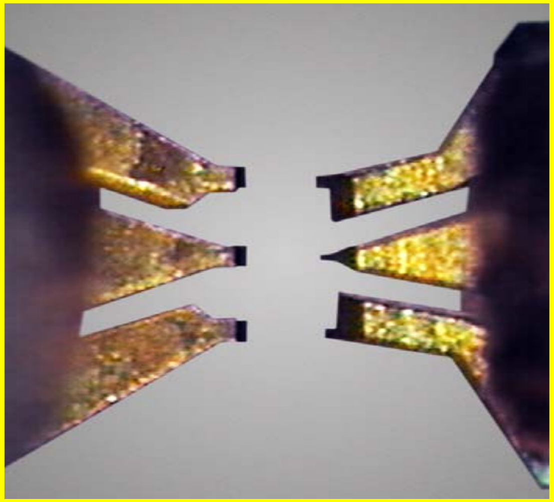


Cascade Microtech, Inc.

ACP Series Probe

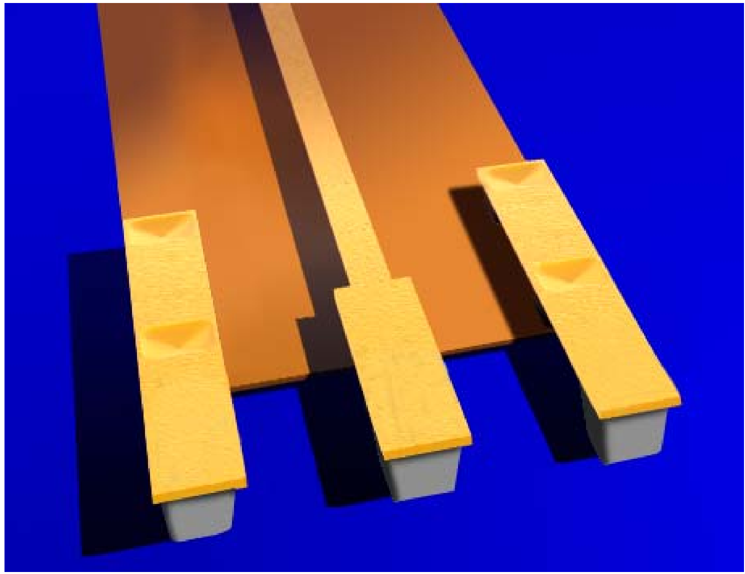


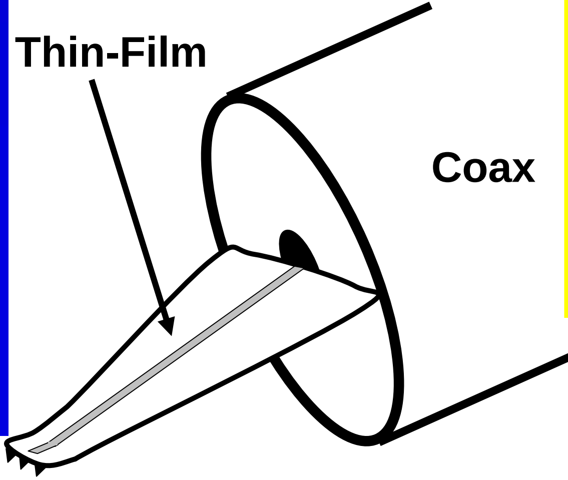
- Ideal for High Power
- Measurements up to 200degC
- Large 25um compliance between tips
- BeCu or W
- 15 W CW at 10 GHz
- 5 A DC current



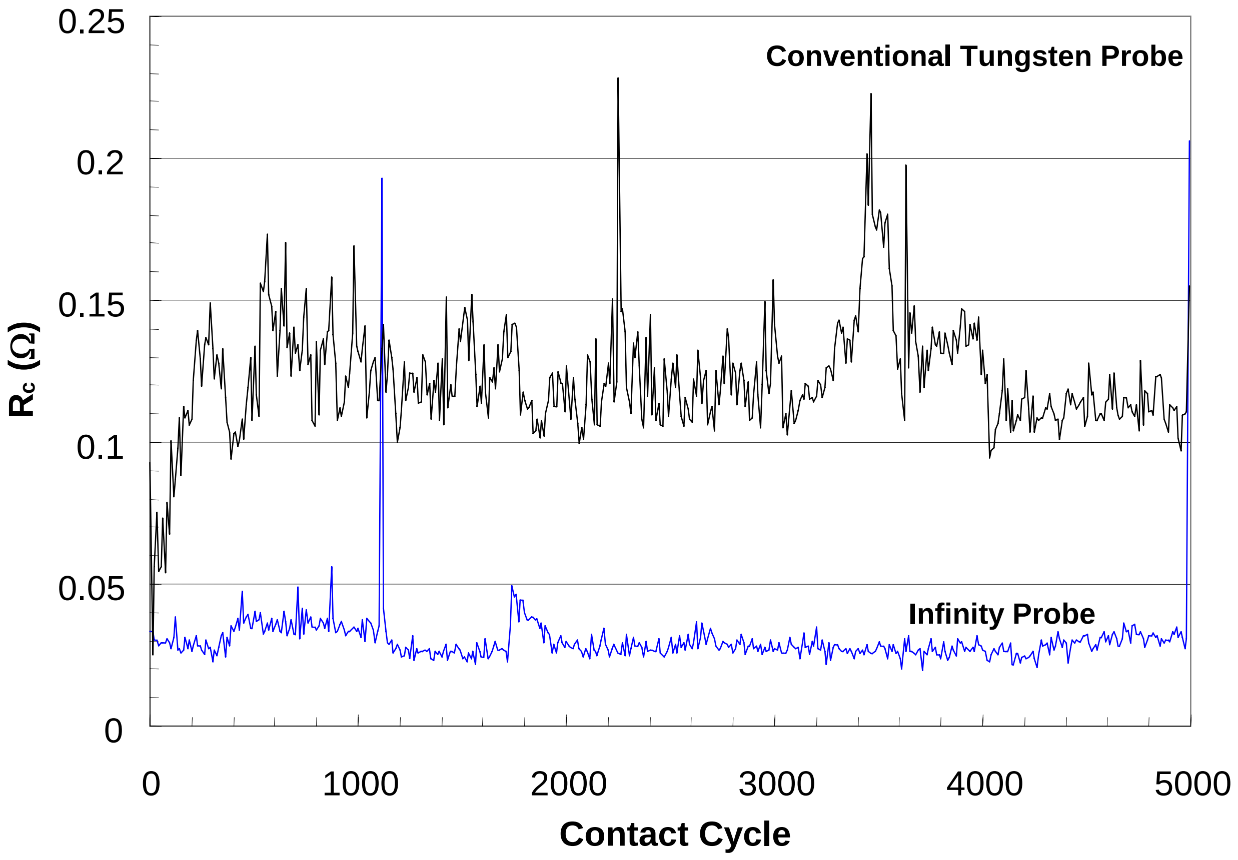
:: Infinity Series Probe

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





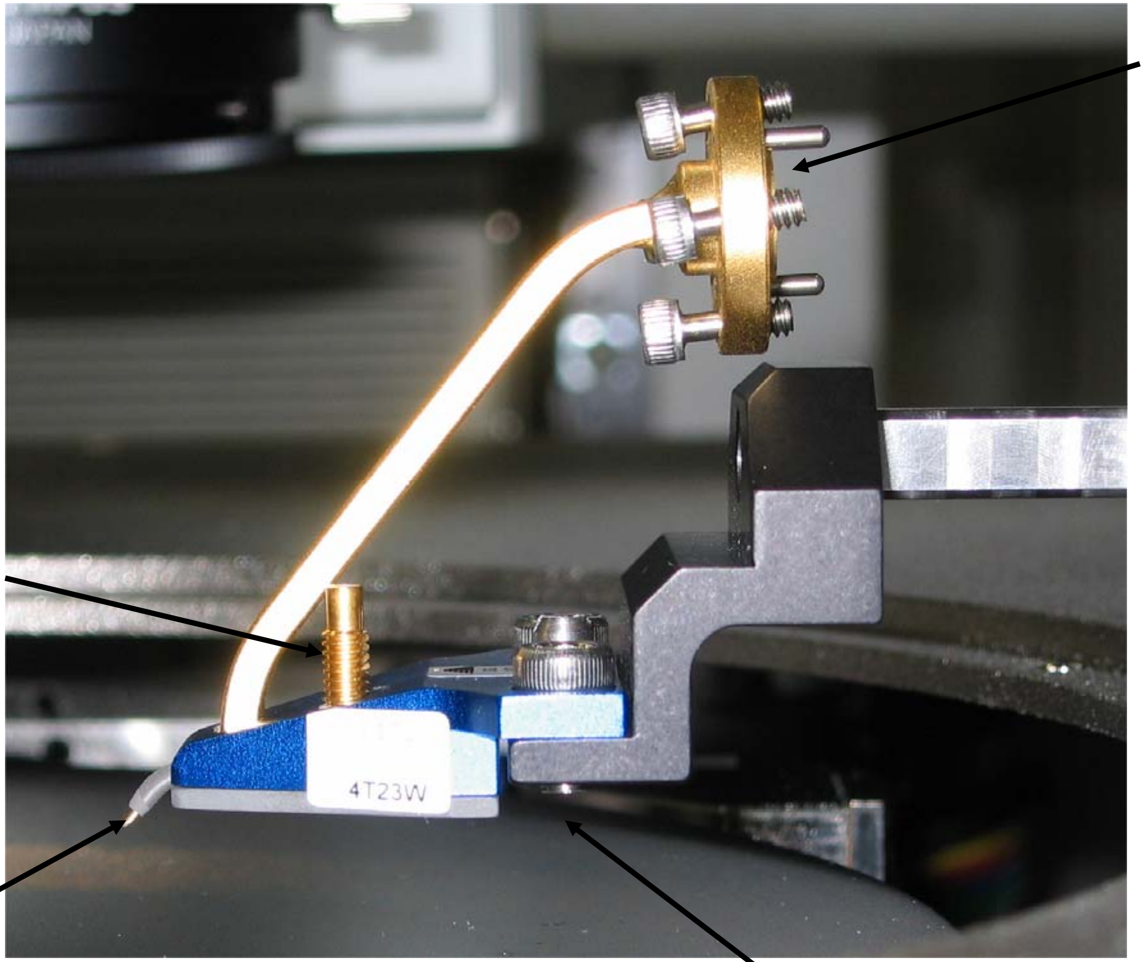
Typical results: Contact resistance



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

Repeatability

:: New Infinity Waveguide Probe



Waveguide/flange

WR15 – 50-75GHz

WR12 – 67-90GHz

WR10 – 75-110GHz

WR8 – 90-140GHz

WR6 – 110-170GHz

WR5 – 140-220GHz

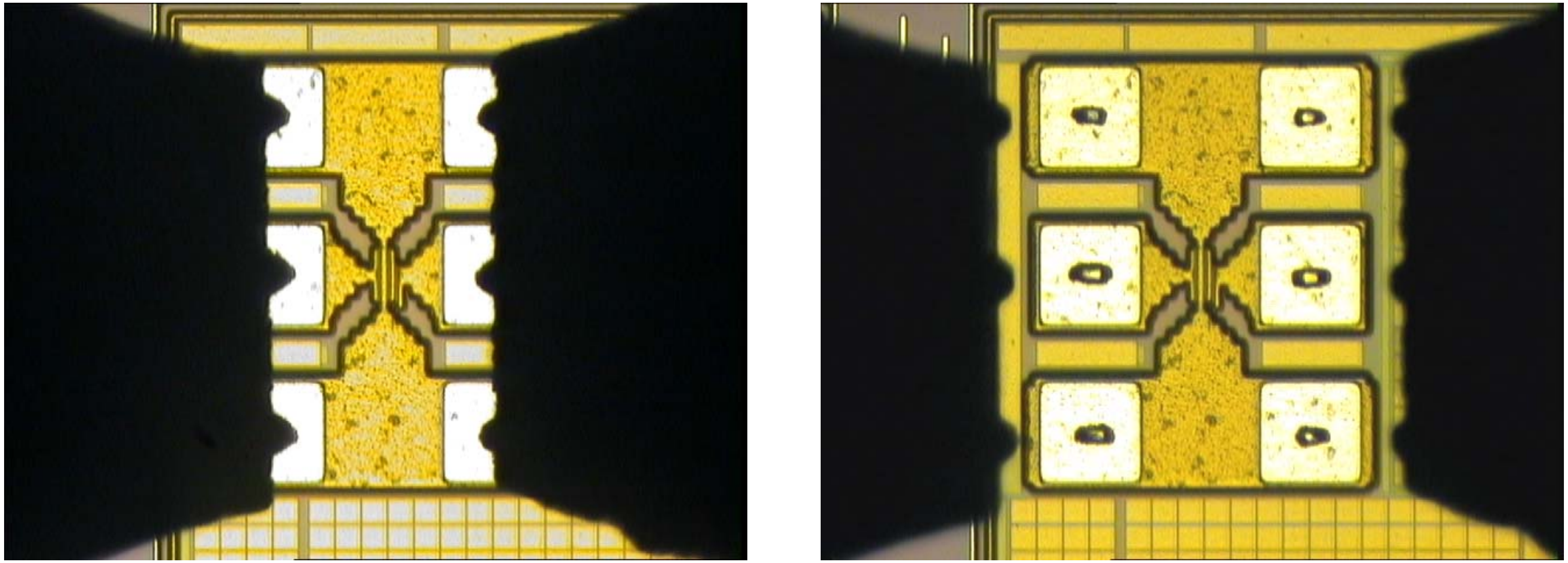
WR3 - 220-325GHz (en 2005)

SSMC bias T connector

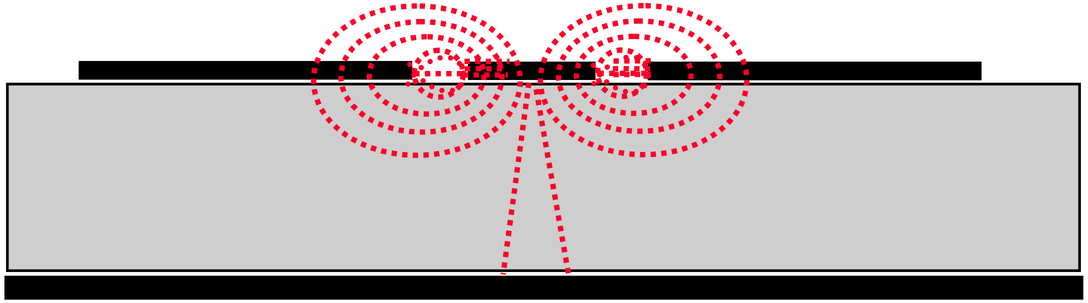
Membrane coupon

Standard probe mount

:: Contact Marks on Aluminum Pads

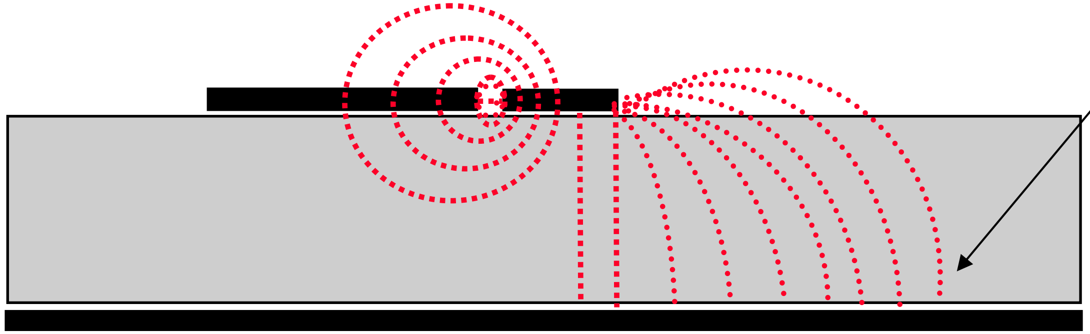


:: Non-symmetrical Grounds



GSG pads shield like CPW

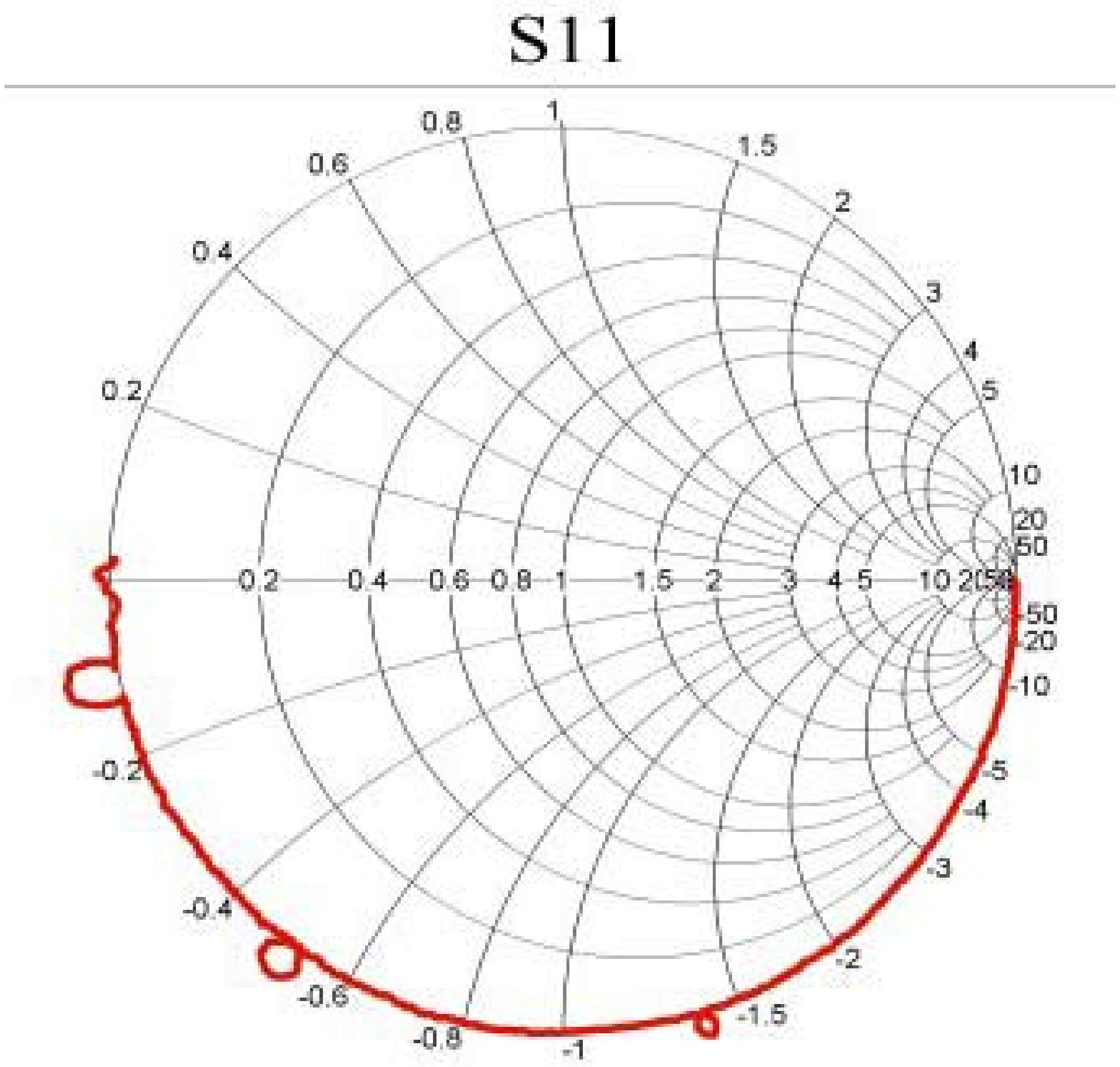
Fields terminate on
backside of wafer
on one side



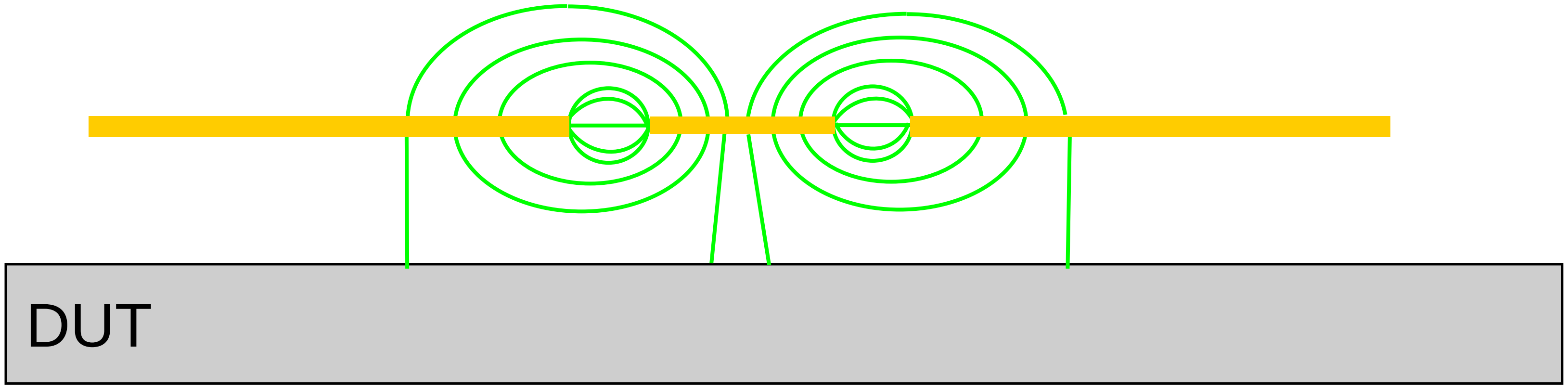
GS pads fringe to the ground plane or chuck

Effects of Non-symmetrical Grounds

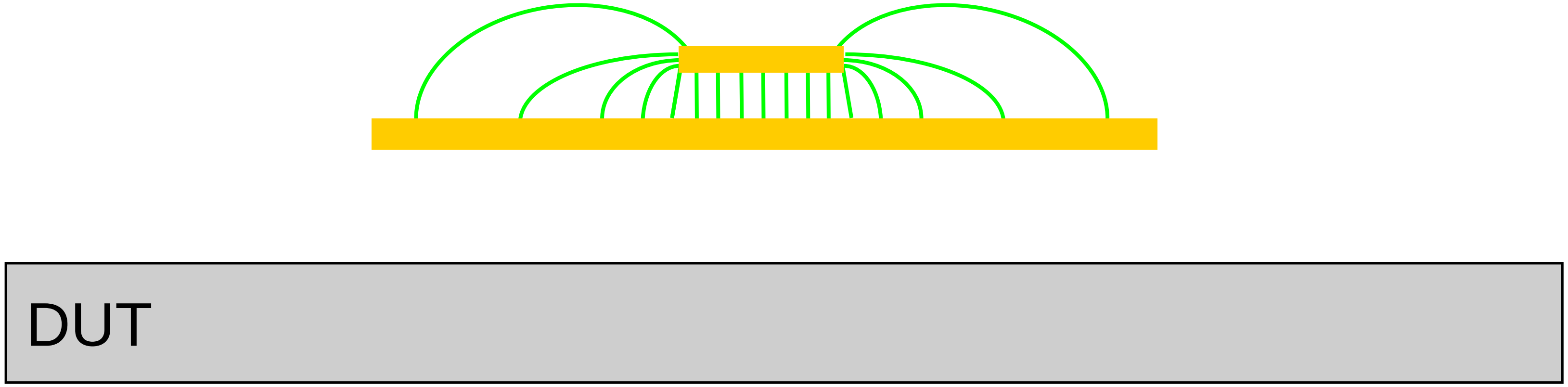
Non-symmetrical grounds can cause resonance loops even at frequencies <10GHz



Infinity Probe Tip Shielding



Coplanar probe tips do not shield from the DUT

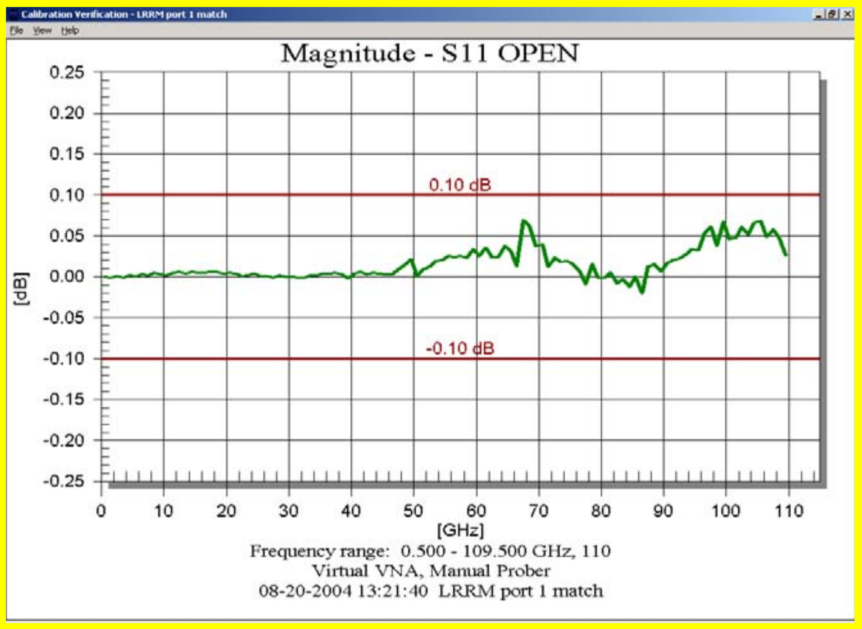


Microstrip structure shields signal line better

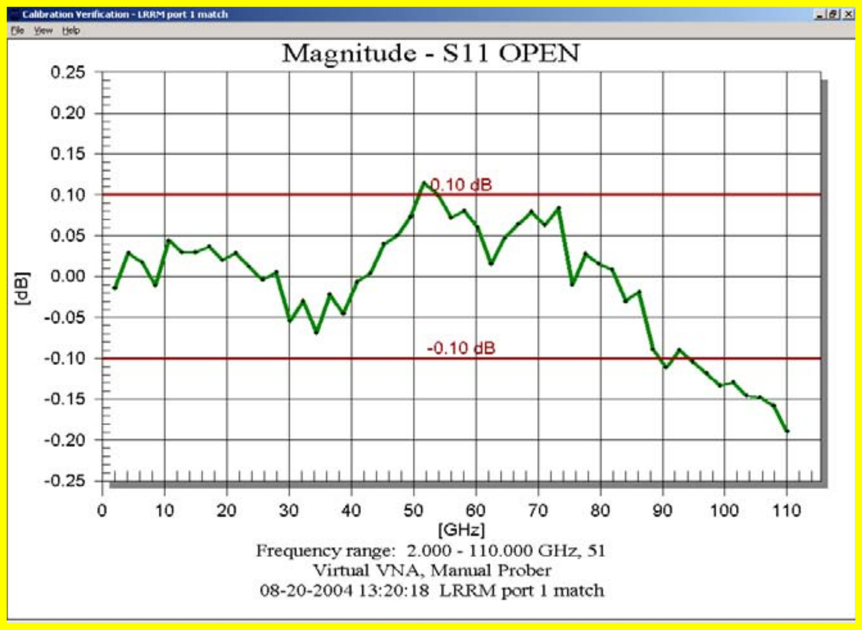
110GHz Cal - ACP versus Infinity

- Much lower uncertainty due to lower mode content in Infinity Probe

InfinityCal Response



Frequency range: 0.500 - 109.500 GHz, 110
Virtual VNA, Manual Prober
08-20-2004 13:21:40 LRRM port 1 match

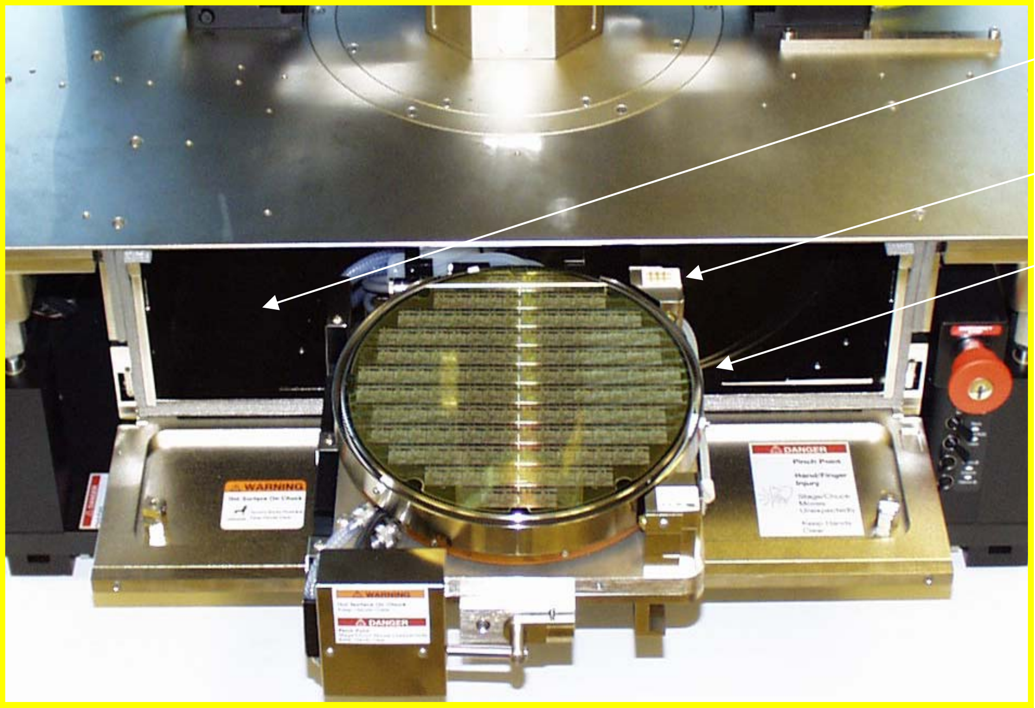


Frequency range: 2.000 - 110.000 GHz, 51
Virtual VNA, Manual Prober
08-20-2004 13:20:18 LRRM port 1 match

ACP Cal Response

Probe Station Essentials

MicroChamber™ Technology



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

:: Shielded Environment

Shielding Technology

- EMI Gaskets
- Silver loaded slits
- Steel lens cover
- Steel top hat cover

MicroChamber™ Technology

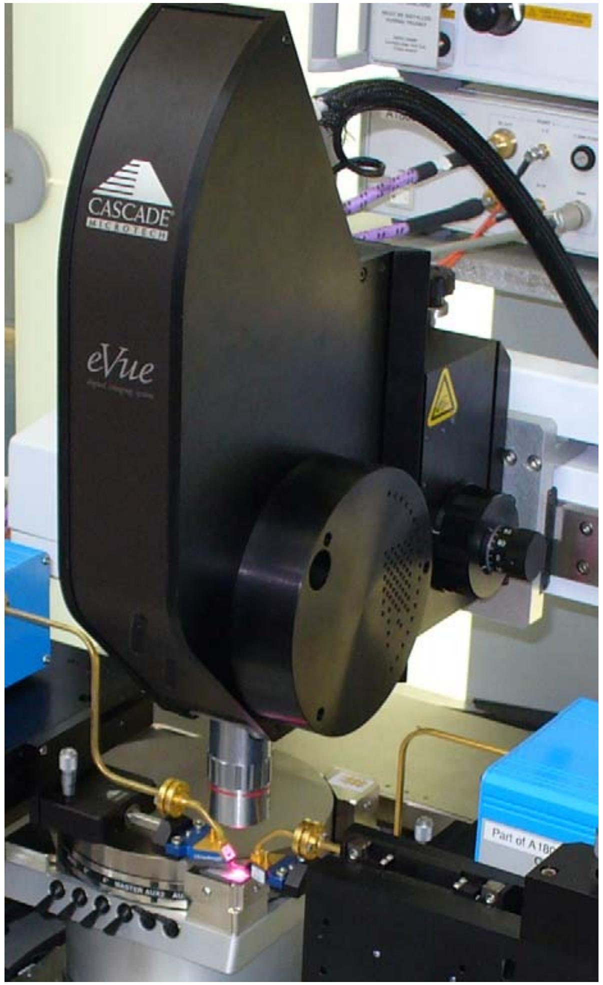
- **Completely Integrated Measurement Environment**
  - FULL access to Positioners, Stage and Microscope
  - Roll-out stage – Complete chuck, not just top layer
    - Easy, fast & safe wafer loading

RF & DC Cabling

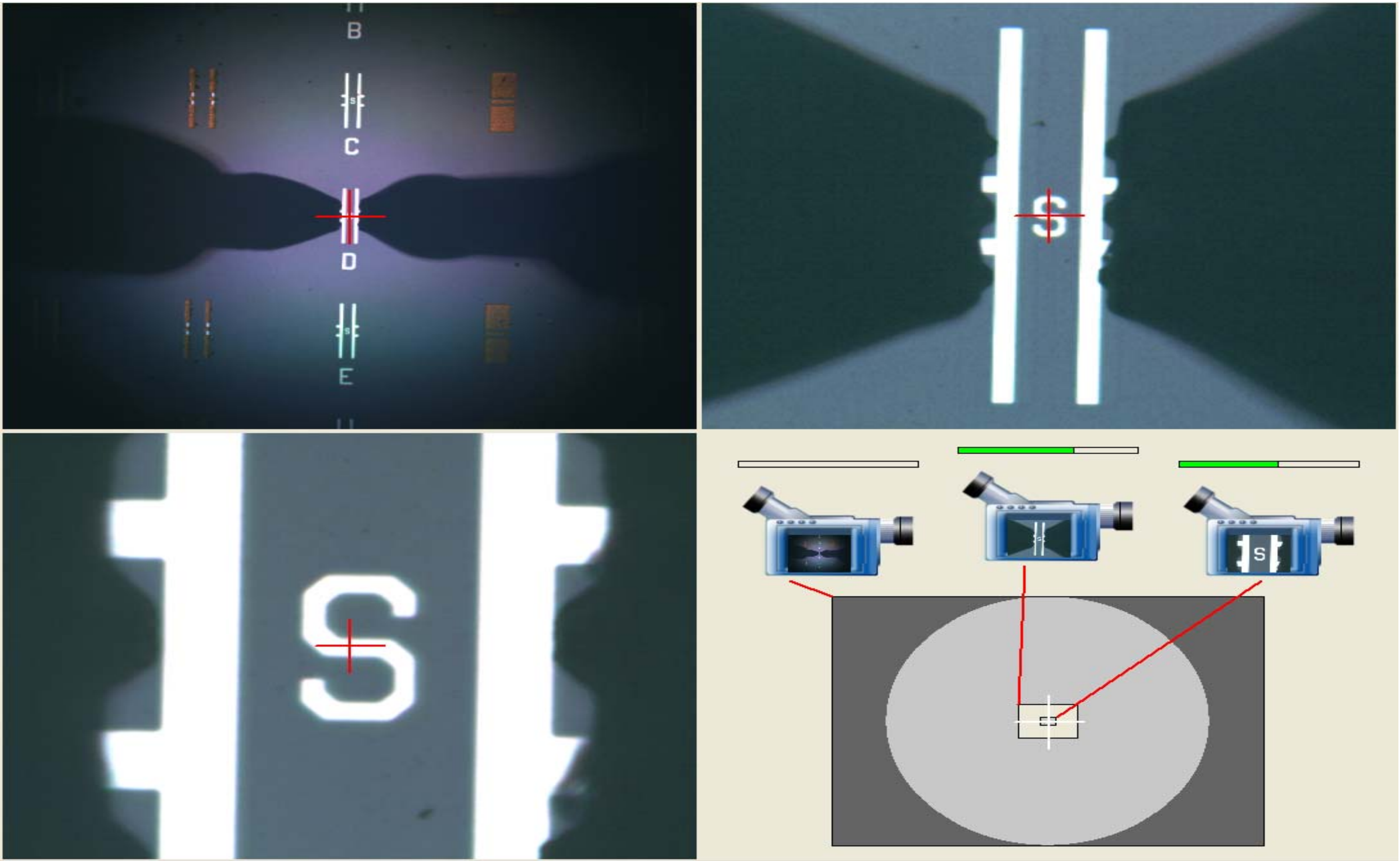
- **Triax connection panels**
  - Easy power supply connections
  - Cable strain relief
- **Gore^{tm} RF cables**
  - Low Loss
  - Phase stable
  - Flexible
- **N5250 110 GHz pna has in-built triaxial bias tees as option**
- **Waveguide Infinity probe has bias tee built in as ar option**

:: Evue Microscopy

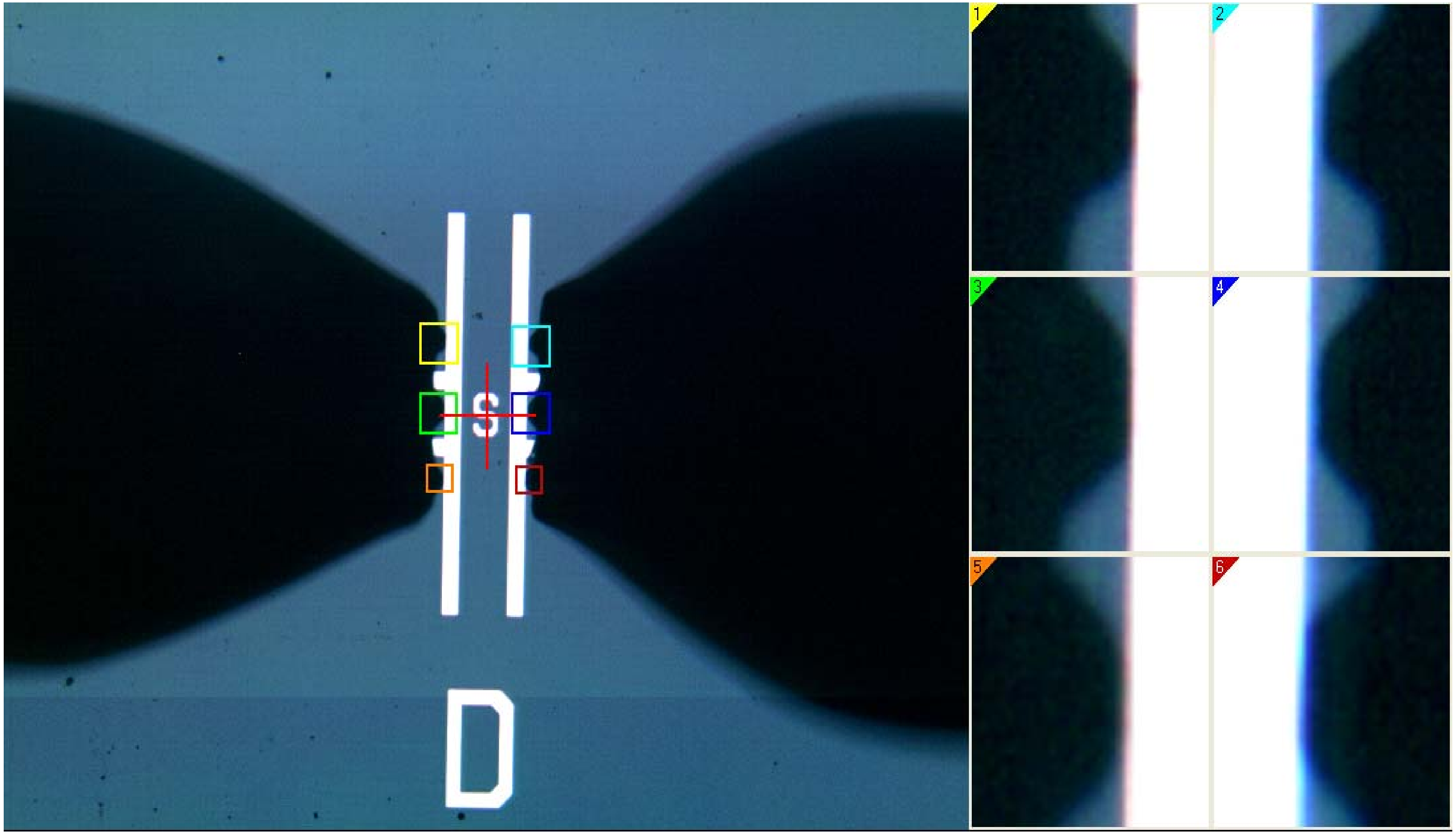
- Alignment of probes for mmw work is extremely important
- Accuracy better than 5 um required
- Simultaneous view of high and low magnification helps ensure safety of valuable mmw probes
- Auto z helps ensure that repeatable contact is maintained on warped thinned wafer



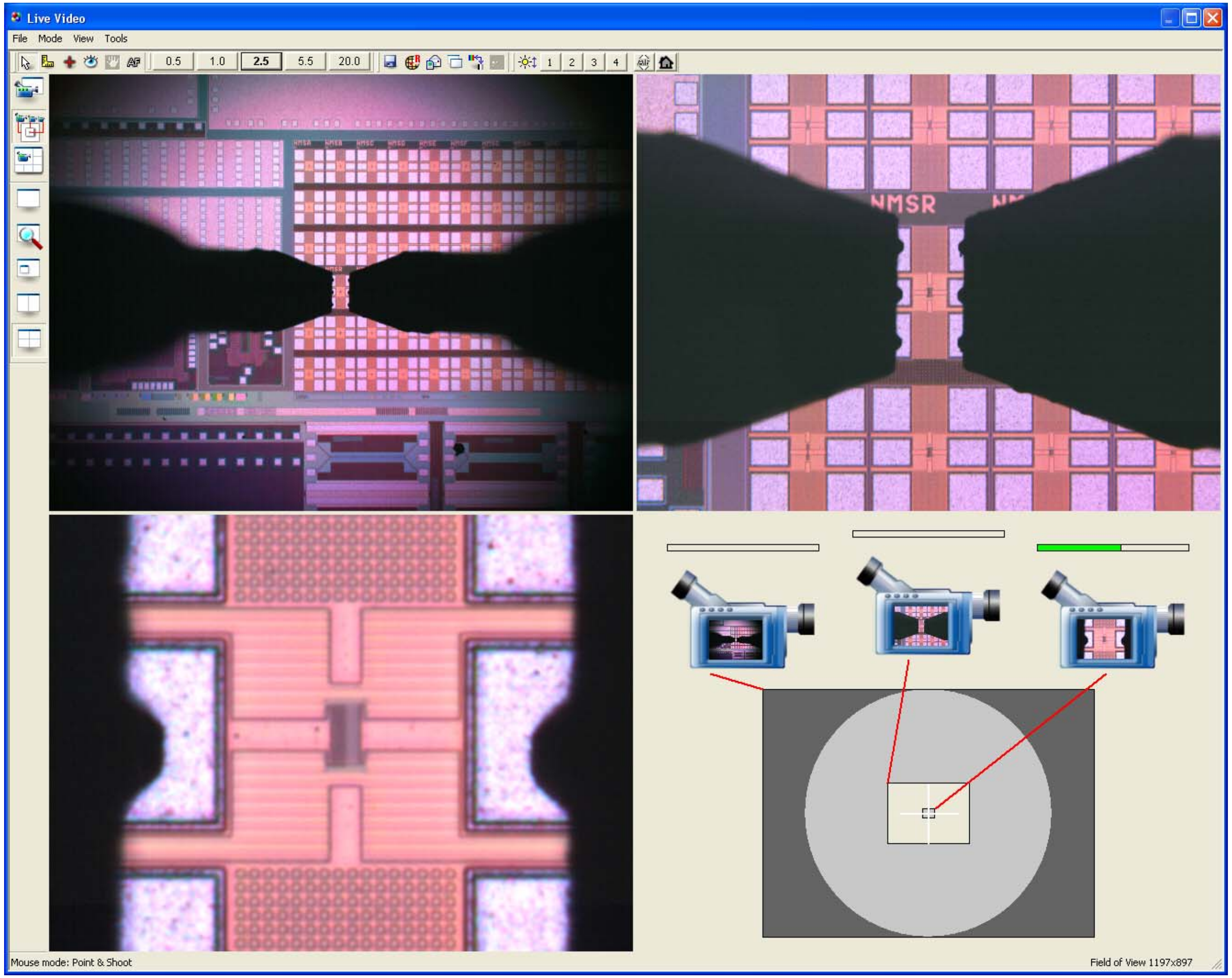
:: Evue – three simultaneous views



:: Evue – Positioning assessment



:: Evue – device identification

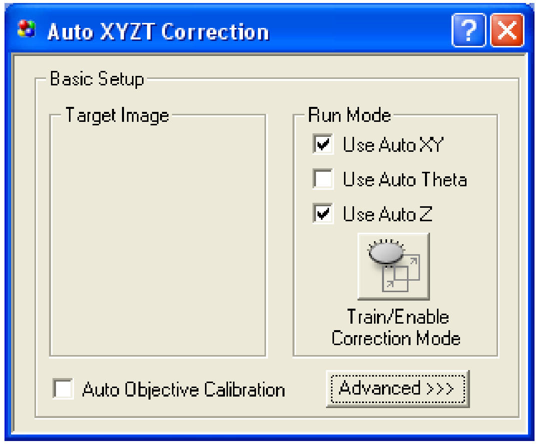


Mouse mode: Point & Shoot

Field of View 1197x897

:: Evue – Auto xyz

- Auto xyz asesses contact X/Y/Z changes die by die using evue
- Wafer profiling automatically profiles the whole wafer using evue in a single one time operation prior to test



Auto XYZT Correction

Basic Setup

Target Image

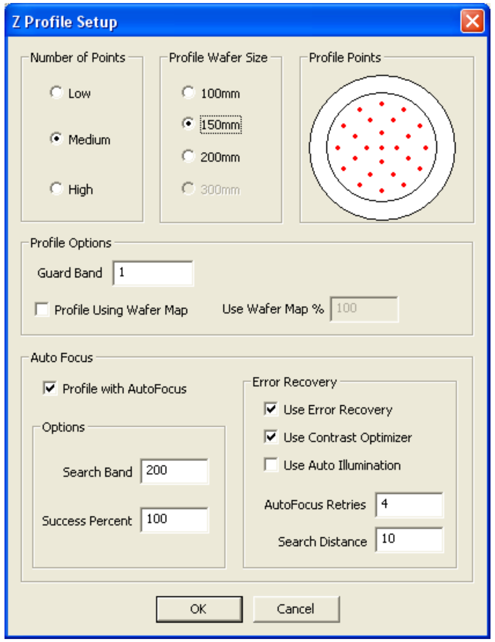
Run Mode

☑ Use Auto XY

☐ Use Auto Theta

☑ Use Auto Z

☐ Auto Objective Calibration



Z Profile Setup

Number of Points

○ Low

● Medium

○ High

Profile Wafer Size

○ 100mm

● 150mm

○ 200mm

○ 300mm

Profile Points

Profile Options

Guard Band: 1

☐ Profile Using Wafer Map

Use Wafer Map %: 100

Auto Focus

☑ Profile with AutoFocus

Options

Search Band: 200

Success Percent: 100

Error Recovery

☑ Use Error Recovery

☑ Use Contrast Optimizer

☐ Use Auto Illumination

AutoFocus Retries: 4

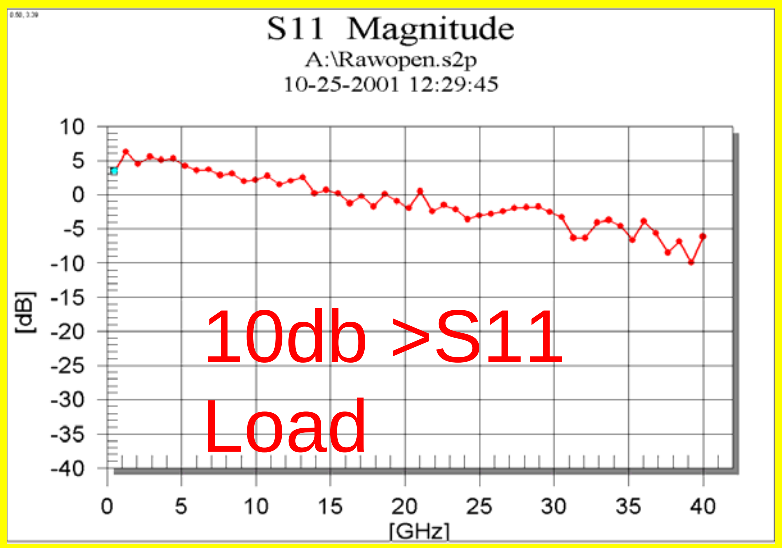
Search Distance: 10

Probe Tip Calibration

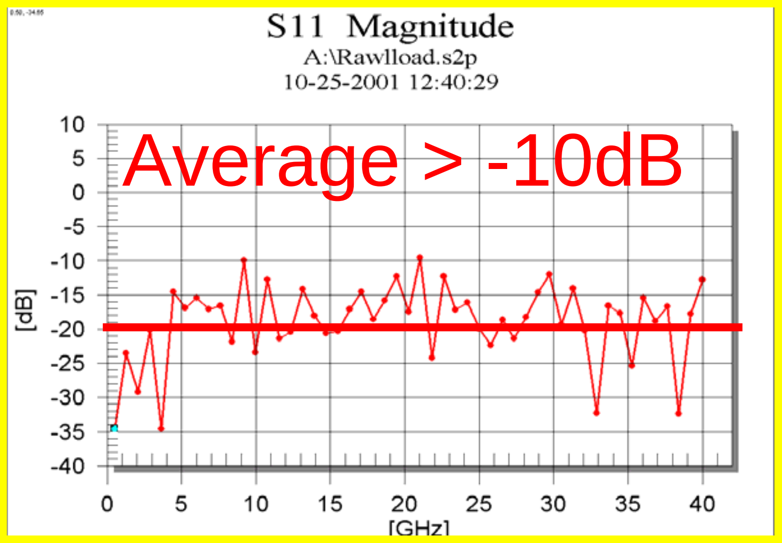
:: Principle Calibration Techniques

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**

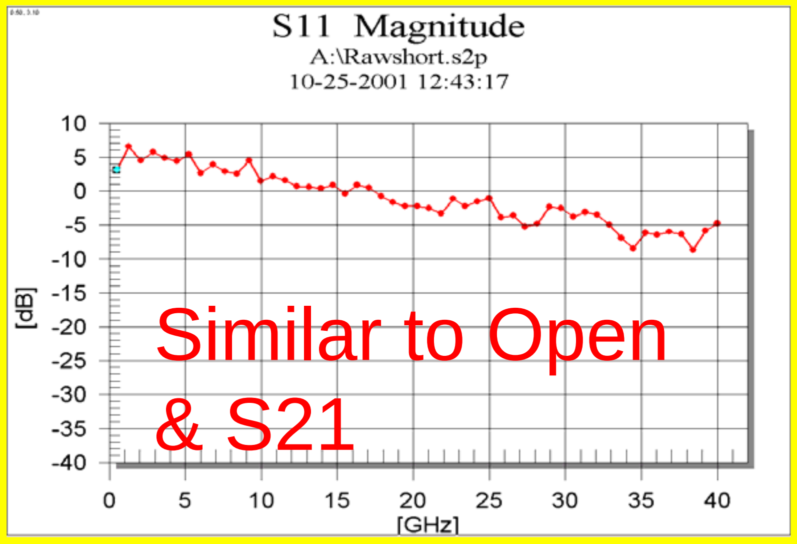
:: Uncorrected VNA



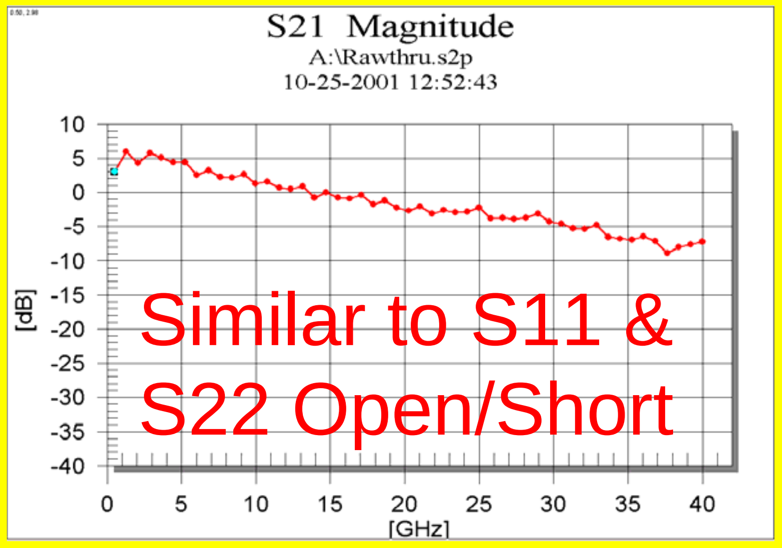
10db >S11 Load



Average > -10dB



Similar to Open & S21



Similar to S11 & S22 Open/Short

:: General PNA Recommendations

- **Signal-to-noise ratio degrades calibration**
  - Use ≤ 300Hz IF bandwidth with no averaging
    - Can be increased after calibration
  - Use high RF Power
    - Stay within DUT linear output limits
  - Use the least amount of necessary attention
    - Port 1 normally ≤ 10dB for SS gain devices
    - Port 2 normally Zero for SS gain devices
  - Use shortest possible low loss cables
    - Gore is best
- **Maintain constant temperature**

:: SOL 1-Port Calibration

- Only calibration technique
- Works on all PNAs
- PNA front panel supported
  - Requires PNA cal kit
- WinCal supported
- Requires rigorous definitions

:: SOLT 2-Port Calibration

Works on all PNAs

Oldest calibration technique

PNA front panel supported

    Requires PNA cal kit

WinCal supported

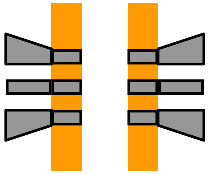
Requires rigorous definitions

Looks best after calibration

Less accurate than LRM & LRRM

SOLT Calibration

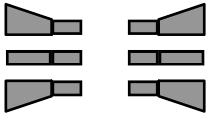
Short



L_{short}

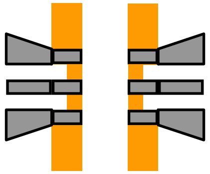
Open

(probes in air)



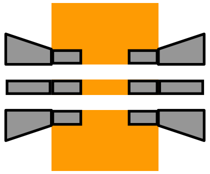
C_{open}

Load



L_{term}

Thru



$Delay_{Thru}$

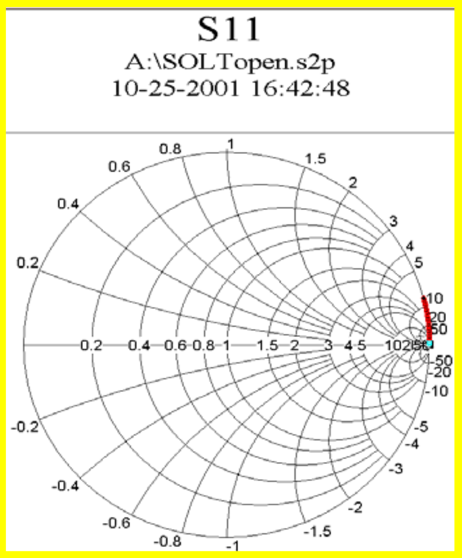
- **All standards must be perfectly known**
  - Available every vector network analyzer (CalKit required)
  - Open has capacitance (often negative)
  - Short and load have inductance
- **Sensitive to probe placement**
- **Mathematically over-determined**
- **Unpredictable behavior**

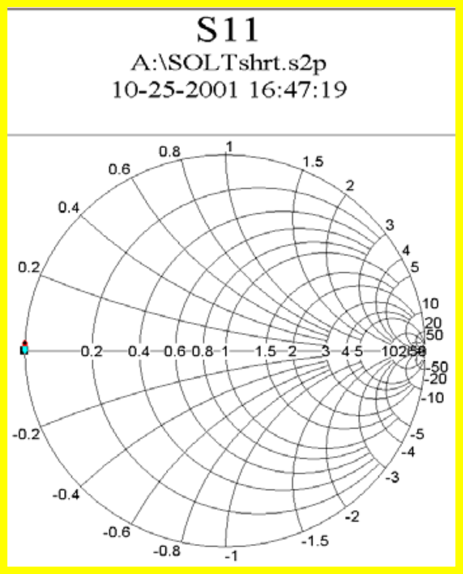
:: SOLT Calibration Results

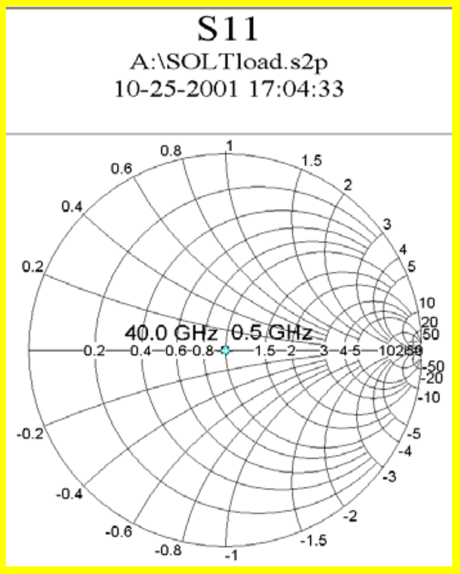
All standards match their cal kit definitions

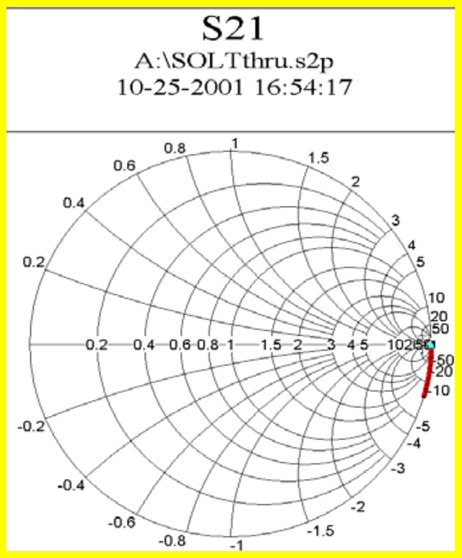
Even bad standards will look good

- Must verify with other devices


S11
A:\SOLTopen.s2p
10-25-2001 16:42:48


S11
A:\SOLTshrt.s2p
10-25-2001 16:47:19


S11
A:\SOLTload.s2p
10-25-2001 17:04:33


S21
A:\SOLTthru.s2p
10-25-2001 16:54:17

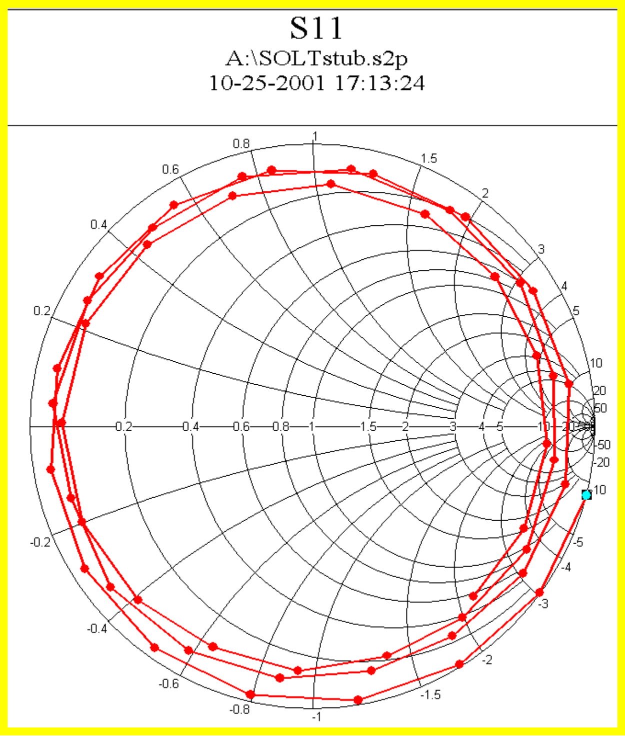
:: SOLT Calibration Results

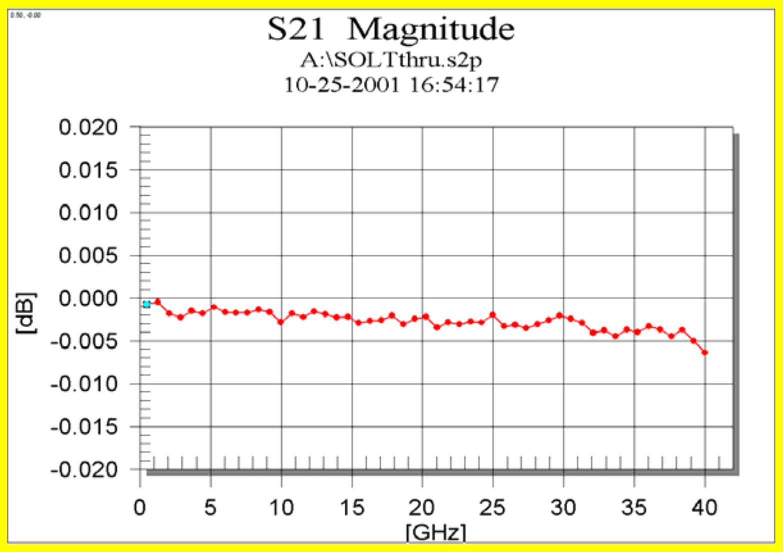
Open stub

- Not centered on the Smith chart
- Lines crossing

S21 always exhibits ripple

- Bad artifact of the SOLT cal





:: SOL-R 2-Port Calibration

Works on PNAs

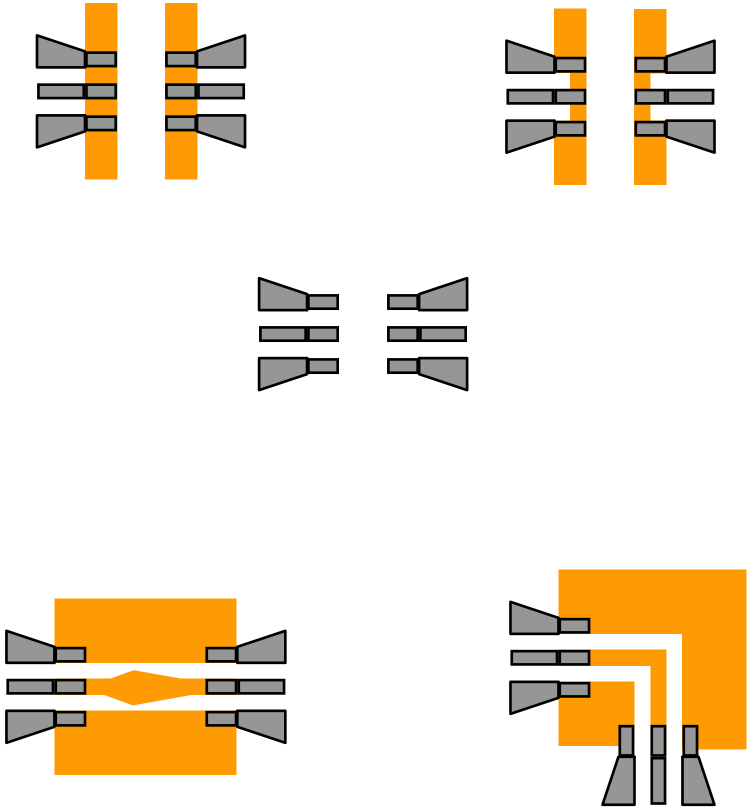
Not PNA front panel supported

WinCal supported

Requires no THRU definition

Recommended for dual probes, right angle probes & probe cards

SOL-R Calibration

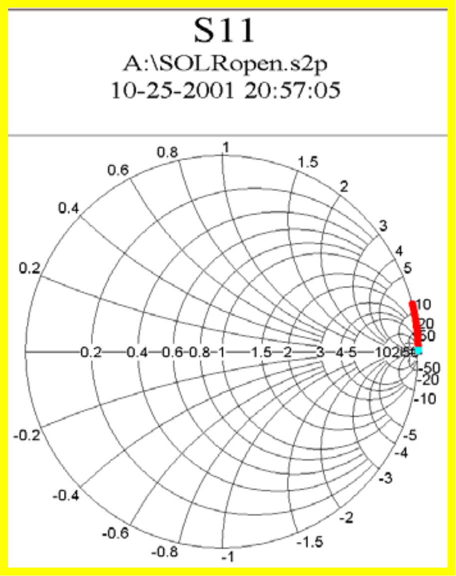


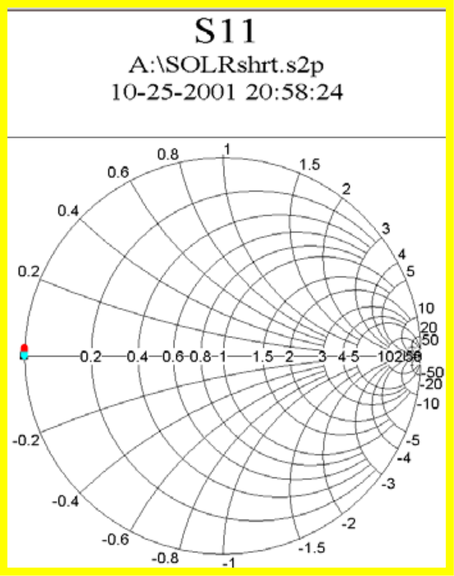
Short-Open-Load-Reciprocal Thru

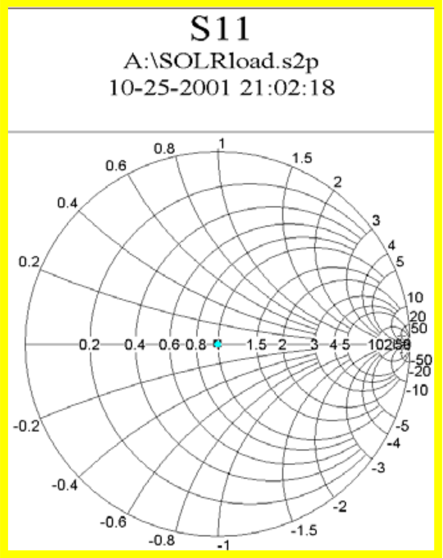
- Reciprocal Thru requires only S12 = S21
- Tolerant to lossy or highly reactive insertion standard
- Convenient for use with fixed probe spacing in probe cards
- Does not require a custom Thru
- Convenient for use when DUT terminals are orientated at 90°
- Available in WinCal (not front panel)

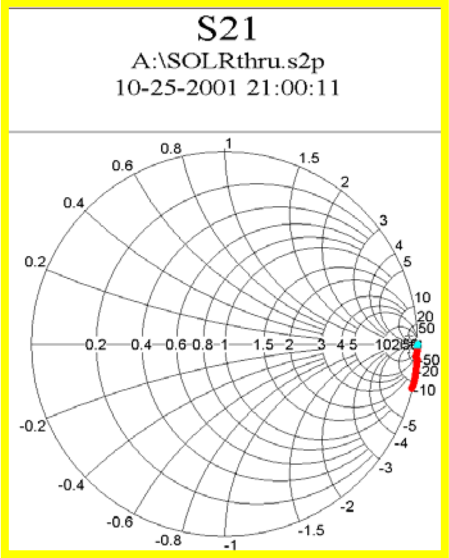
:: SOL-R Calibration Results

Short, Open & Load match the SOL definitions





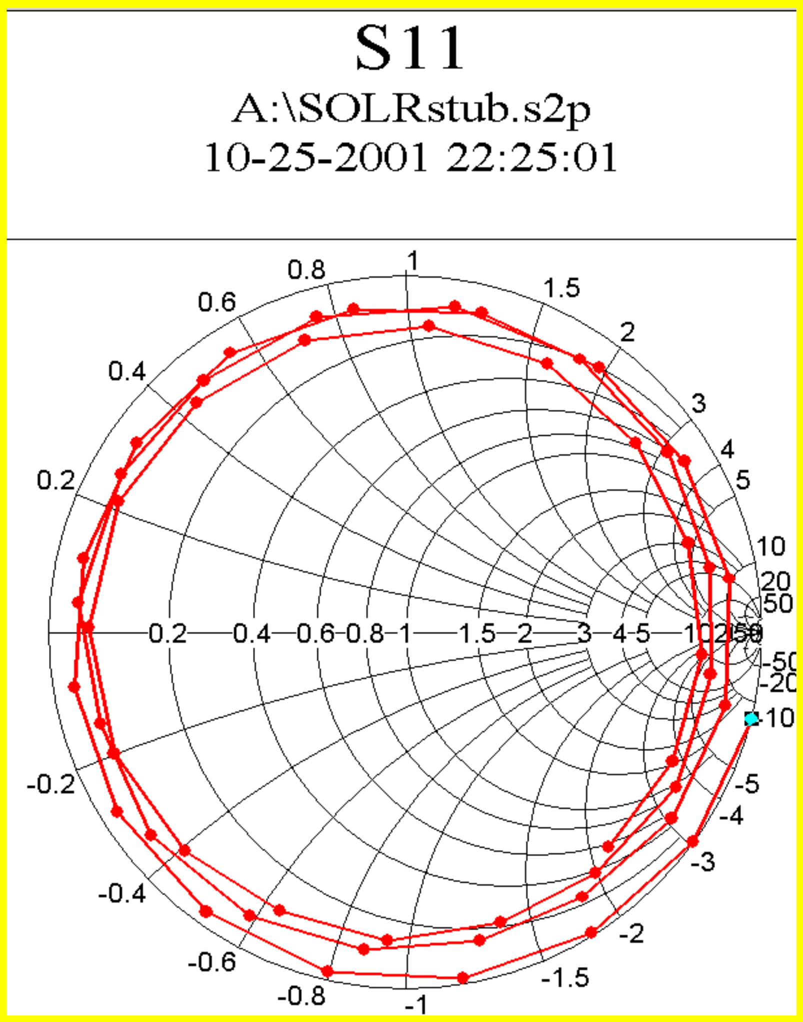




:: SOL-R Calibration Results

Open Stub

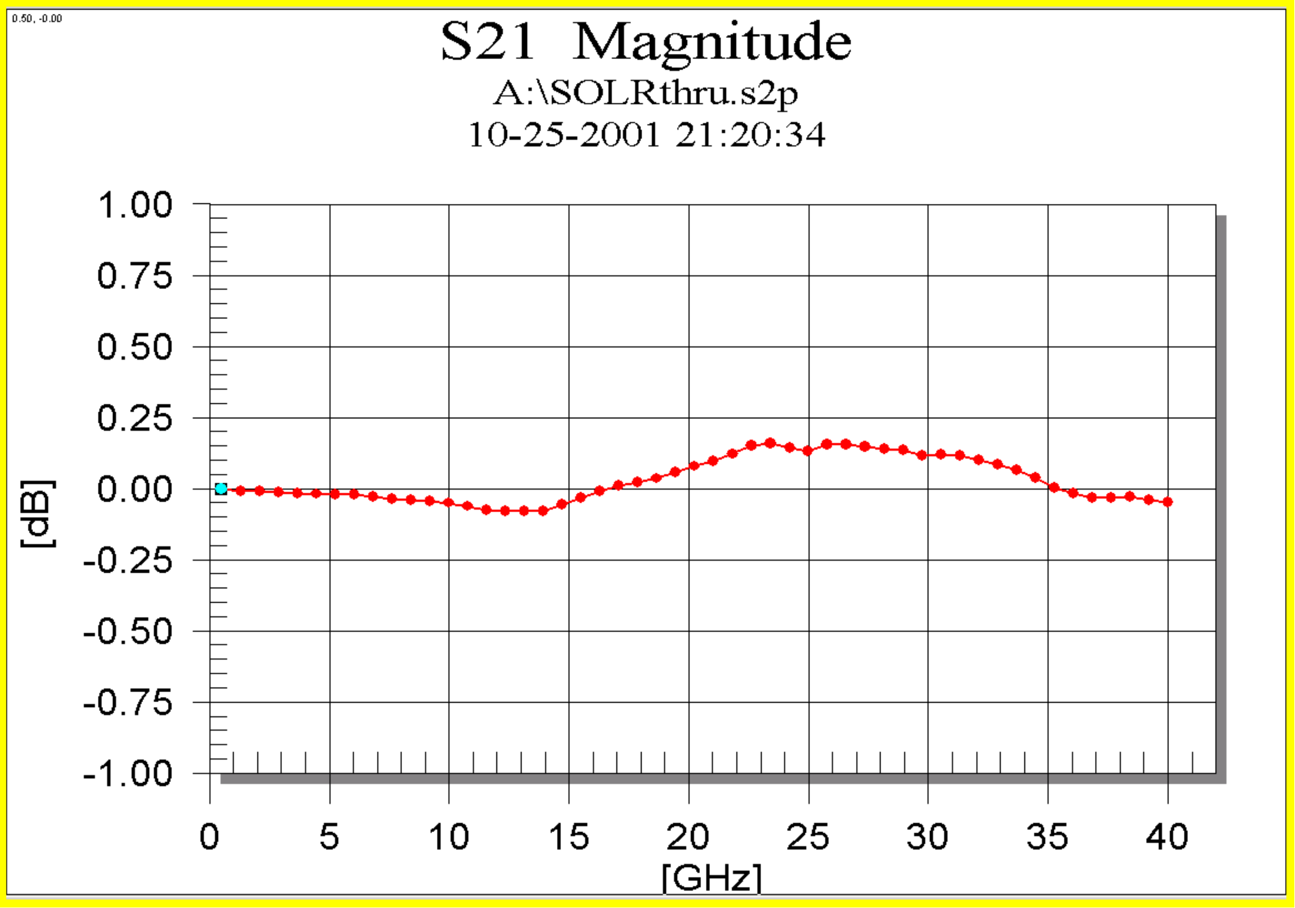
- Not centered on the Smith chart
- Lines are crossing



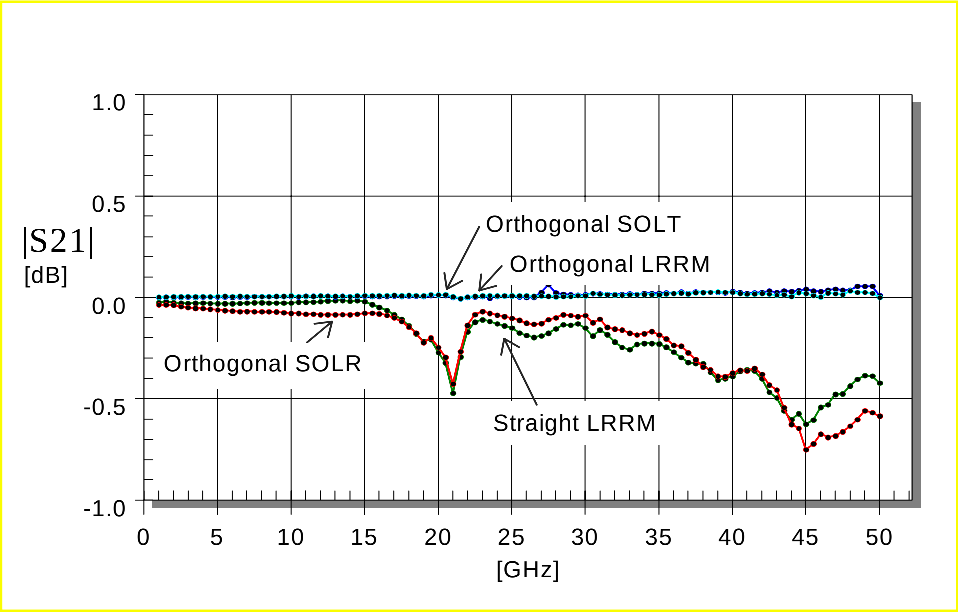
:: SOL-R Calibration Results

Thru is least accurate of all calibration types

- Best method for right angle probing and probe cards



Right Angle Measurements



Carefully constructed right angle ‘Thru’ standard

Thru is non-ideal, large dip at 20 GHz

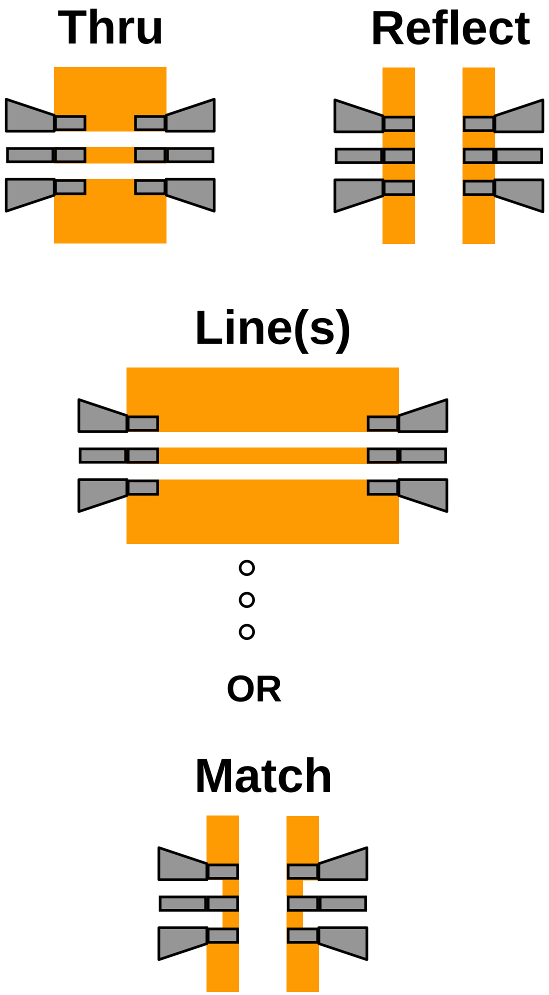
Errors in standard cal’s

SOLR immune to Thru errors

:: TRL 2-Port Calibration

- **Preferred by engineers for on-wafer microstrip embedded devices**
  - Cannot realize 50 Ohm lines exactly
- **Most popular for mmW GaAs**
- **Hard to get broadband standards**
  - Dispersive below 5 GHz
  - Long lines require too much wafer real estate

TRL/LRM Calibration



Thru-Reflect-Line

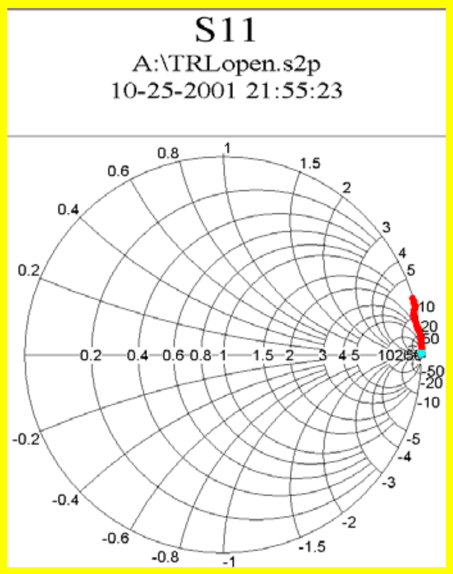
- Requires least info about standards
- S-parameters referenced to line Zo
- Reference plane at center of Thru
- Requires multiple probe spacings
- Zo is inherently complex at low frequencies
- Not suitable for fixed spacing probes (e.g., probe card)

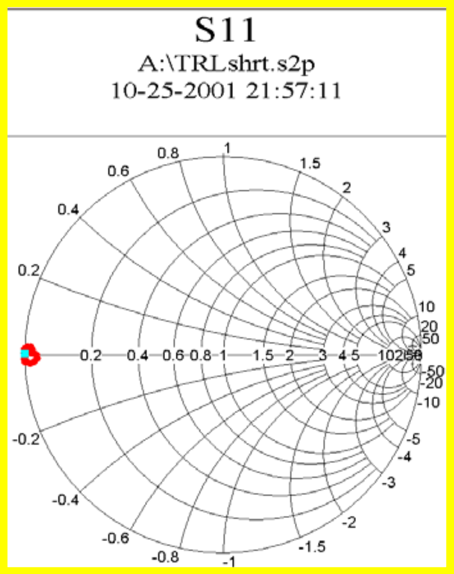
Line-Reflect-Match

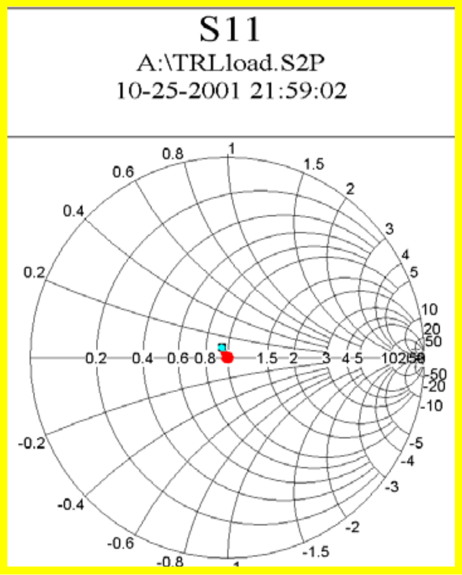
- Referenced to Zmatch

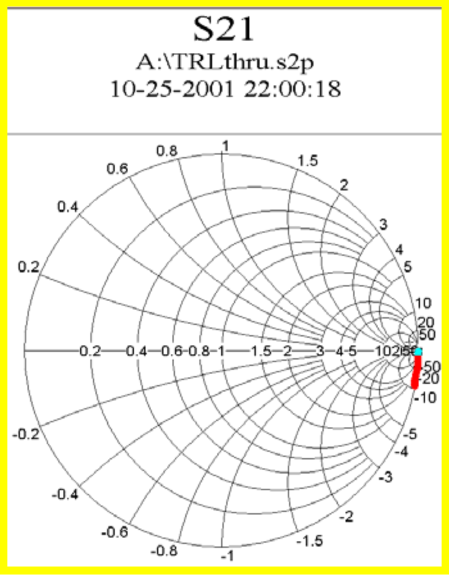
:: TRL Calibration Results

All standards exhibit large anomalies





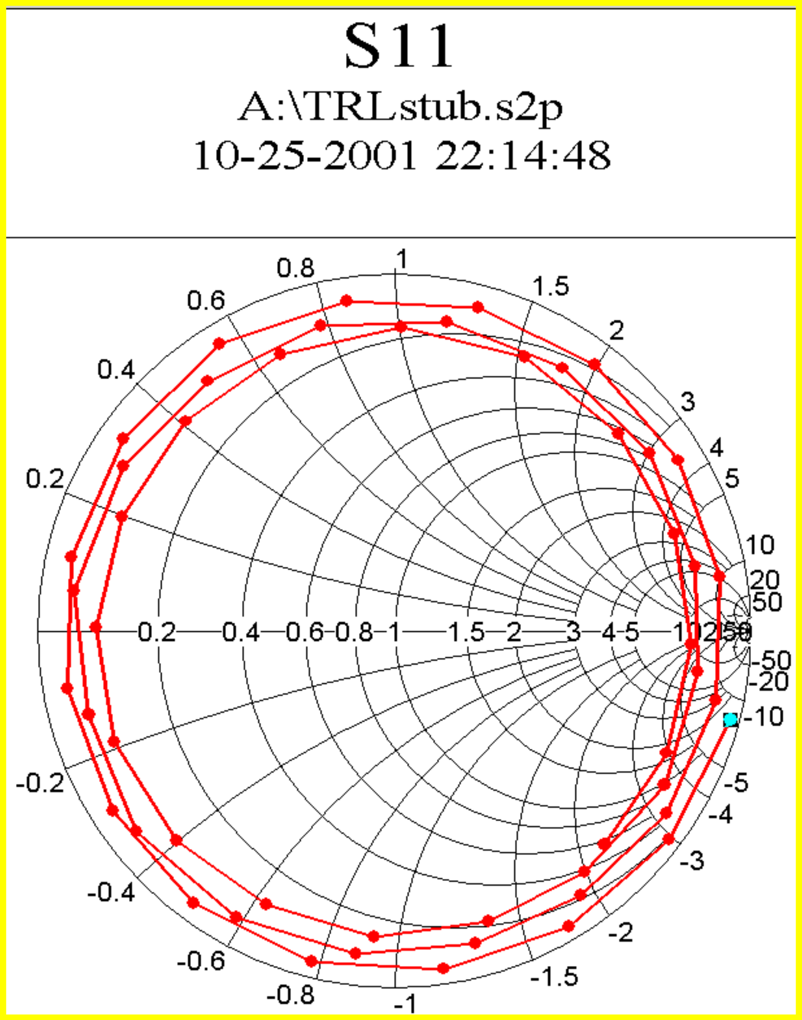




:: TRL Calibration Results

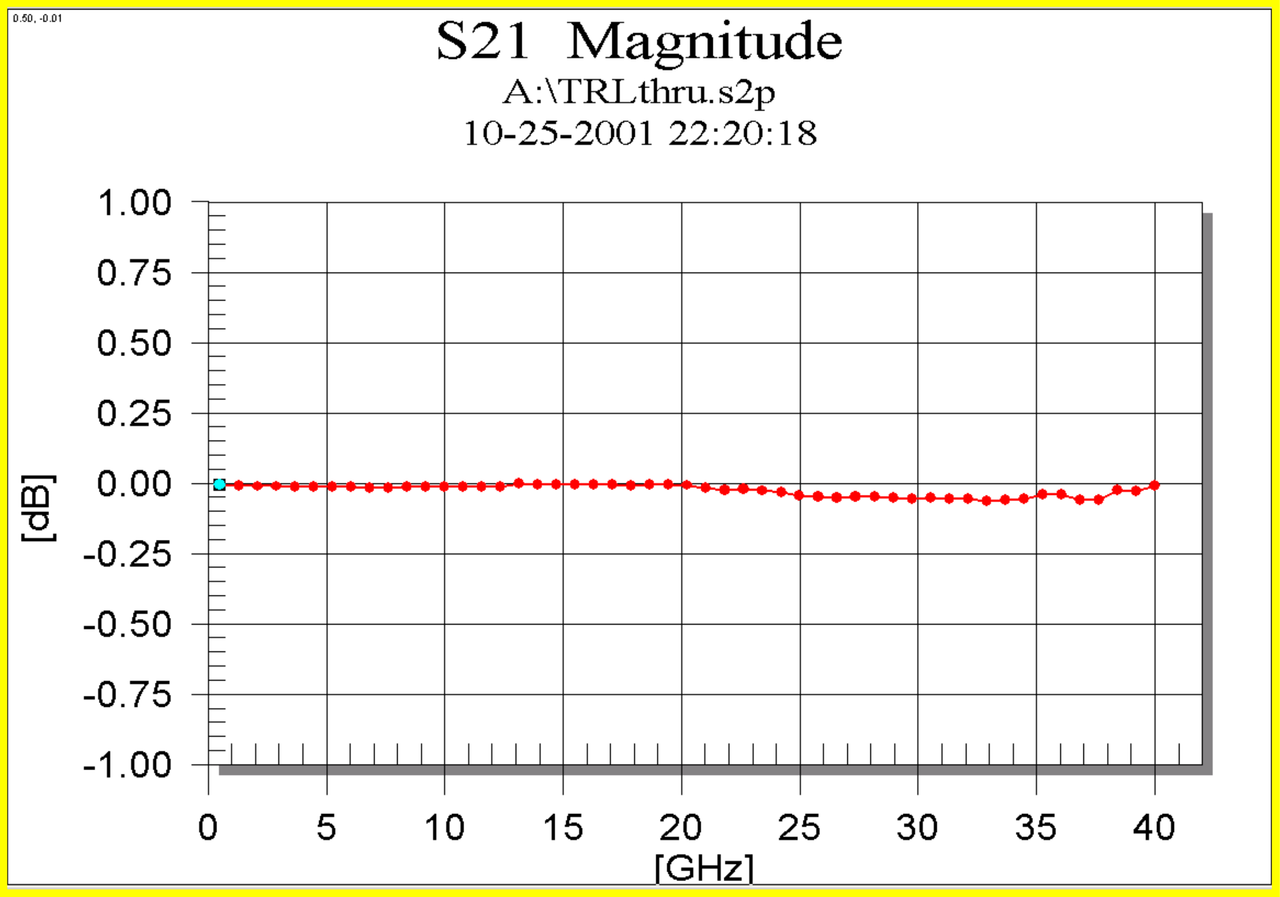
Open stub is well centered on the Smith chart

No lines are crossing



:: TRL Calibration Results

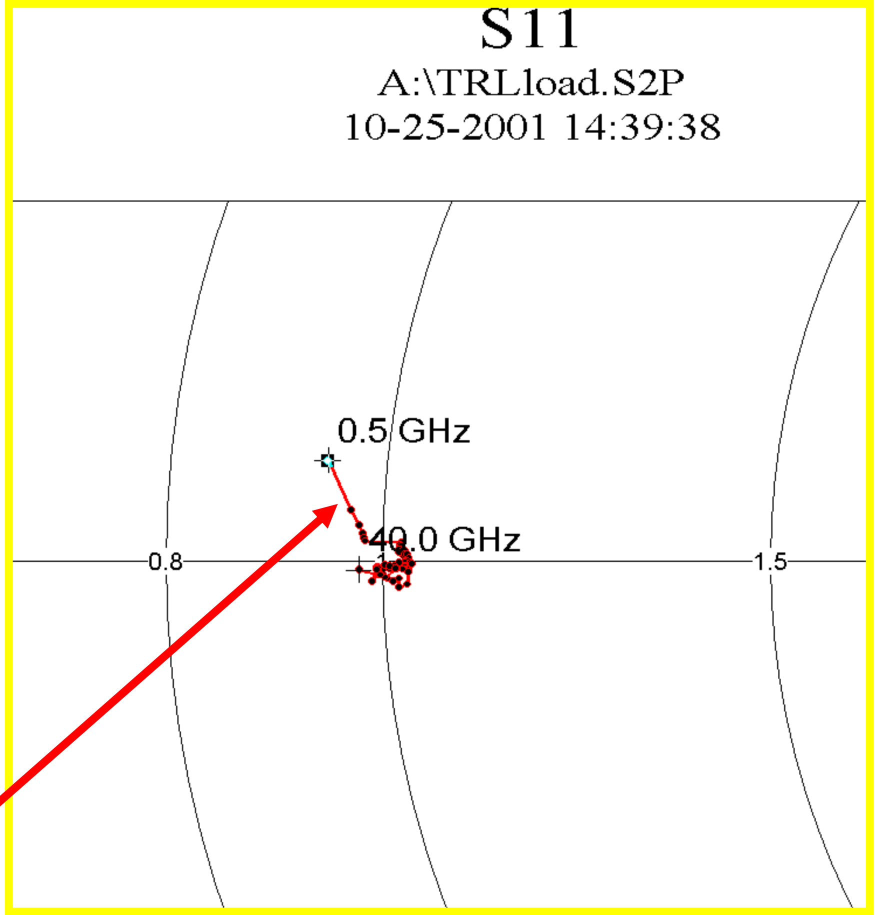
Thru line exhibits excessive loss



:: TRL Measurement Problems

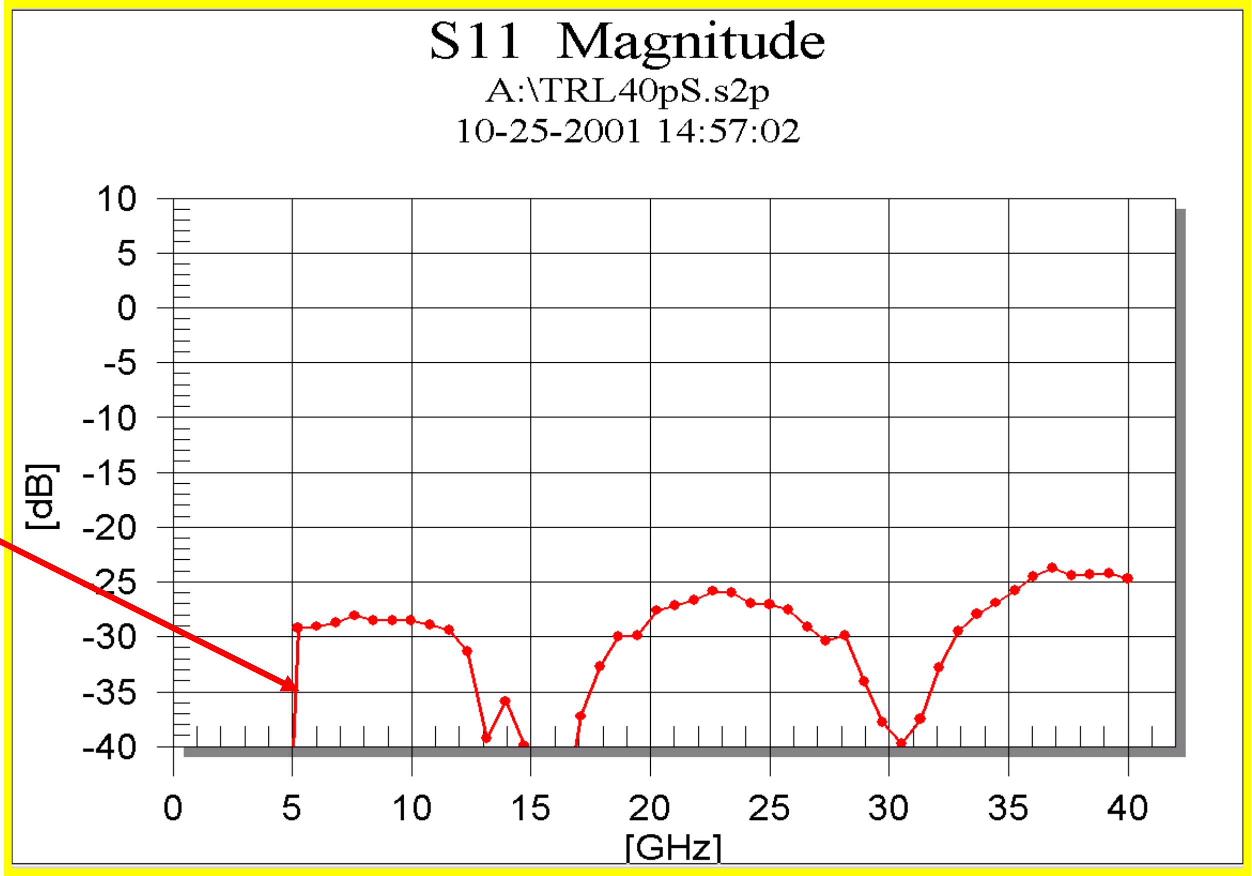
Very poor below 5 GHz

Propagation not constant for thin film structures



Apparent dispersion of a lumped element

:: TRL Measurement Problems



Discontinuities
at the delay line
definitions

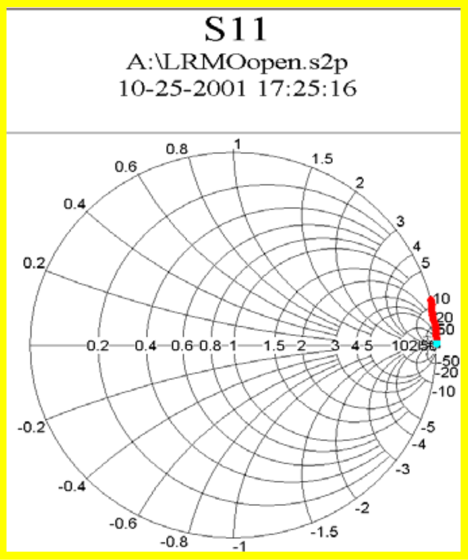
:: LRM 2-Port Calibration

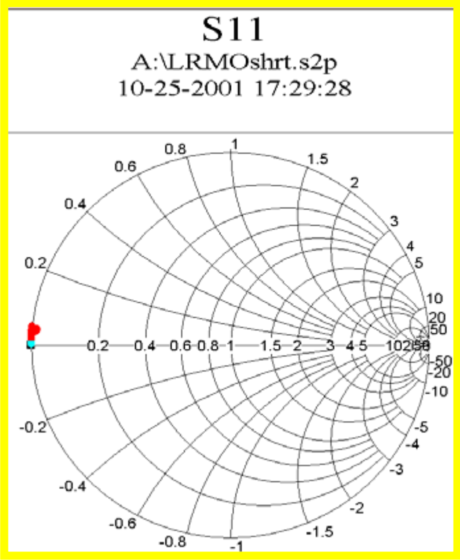
- **Works on all PNAs**
- **PNA front panel supported**
  - Requires VNA cal kit
- **WinCal supported**
  - Automatic load inductance enhanced
- **Better than SOLT**

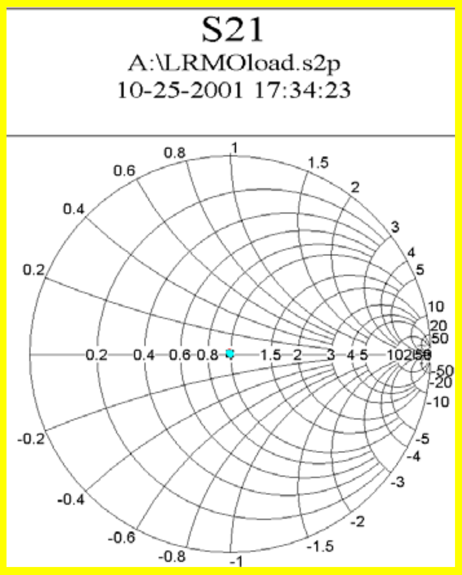
:: LRM Calibration Results

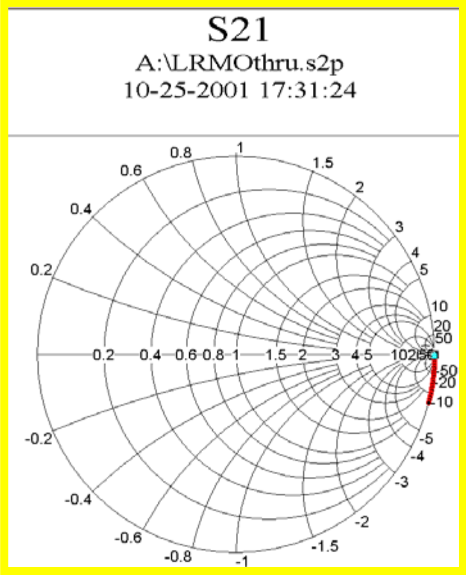
All standards have visibly small anomalies

Results approximate SOLT cal definitions







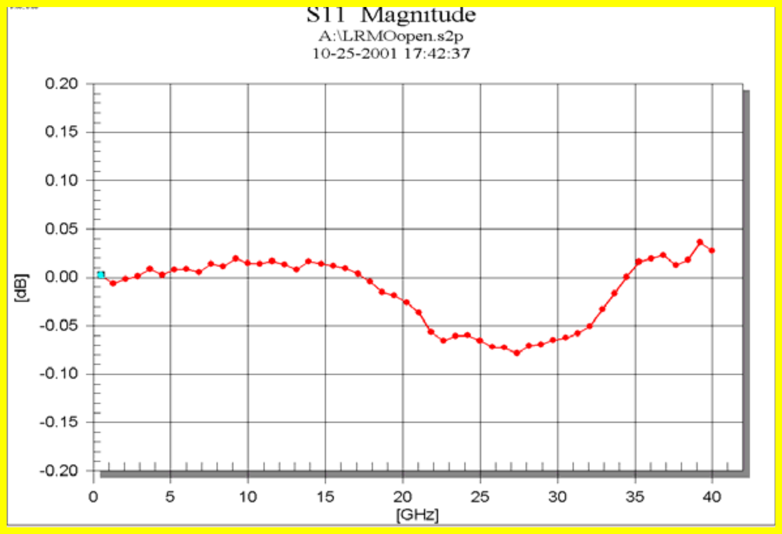


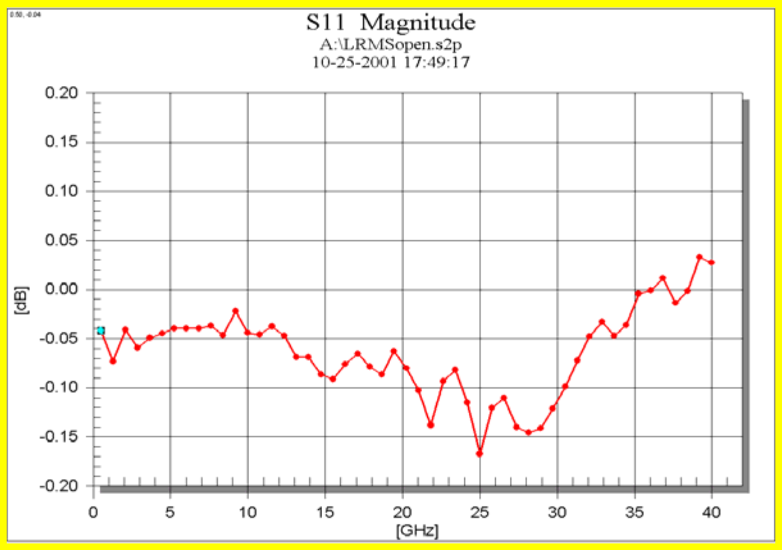
:: LRM Calibration Results

Opens from LRM (open – load) exhibit non-linear characteristics

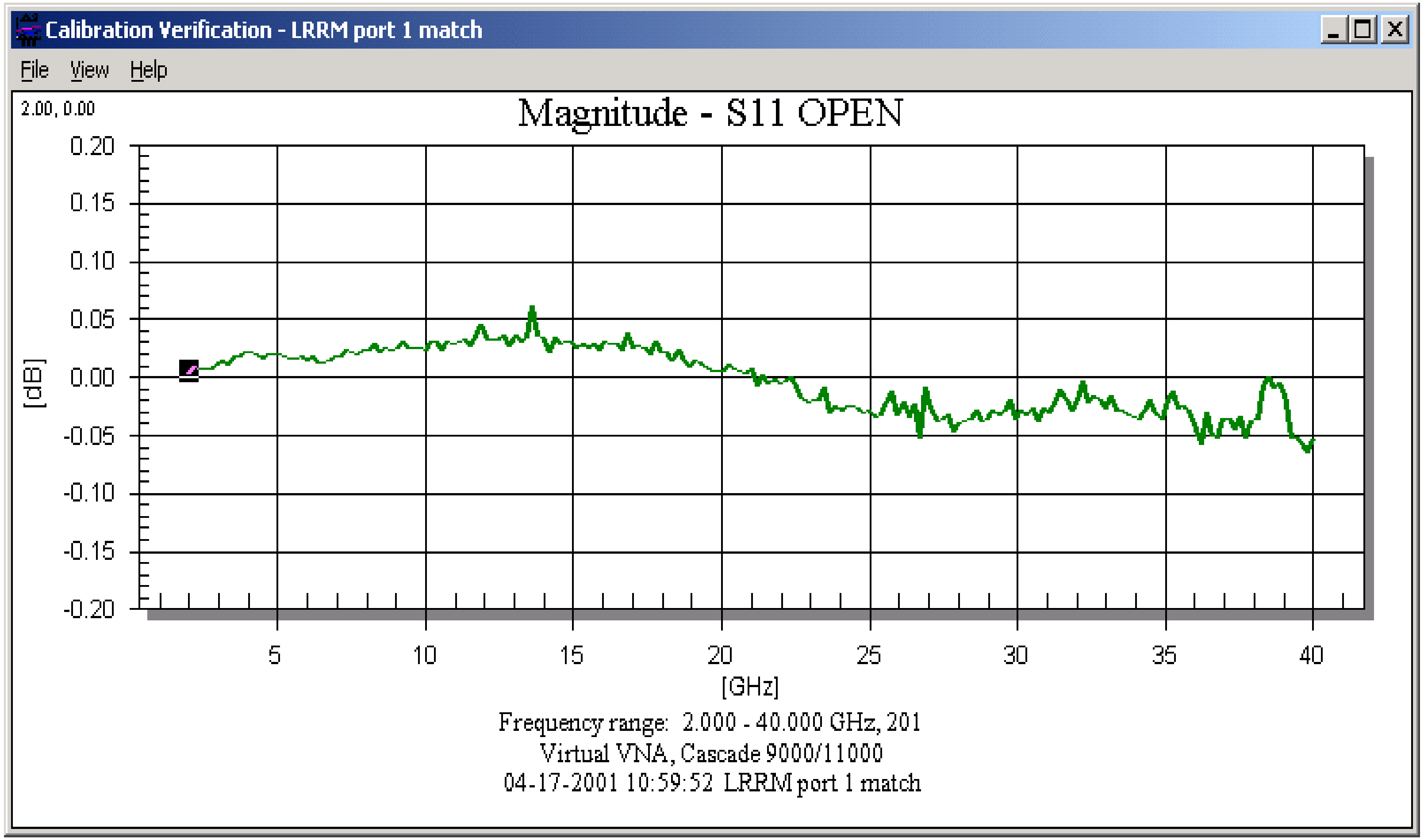
Opens from LRM (short – load) introduce additional ripple

Recommend LRM (open – load)





Open Response After LRRM/LRM Calibration – ACP Probes



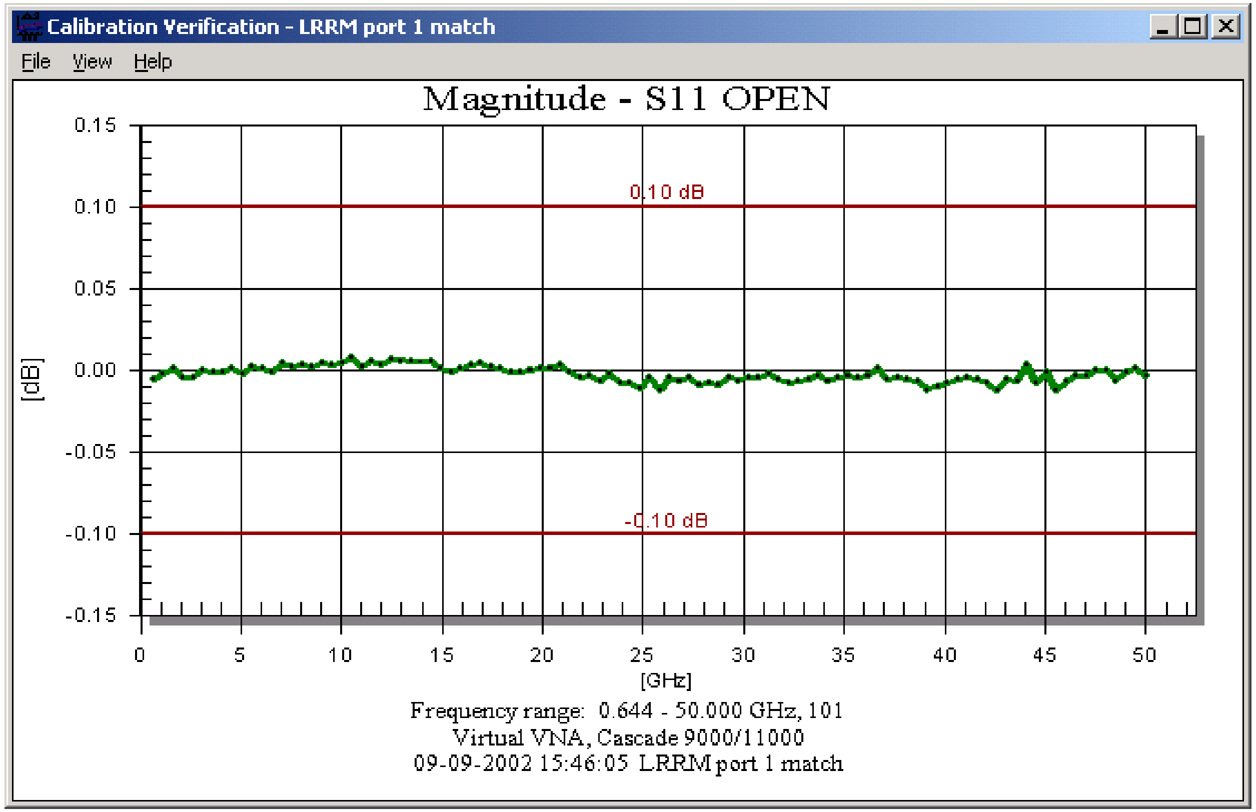
Frequency range: 2.000 - 40.000 GHz, 201
Virtual VNA, Cascade 9000/11000
04-17-2001 10:59:52 LRRM port 1 match

Open Response After LRRM/LRM Calibration – Infinity Probes

Almost ideal

2 to 10 X better than ACP or GGB

SOLT always yields perfect response

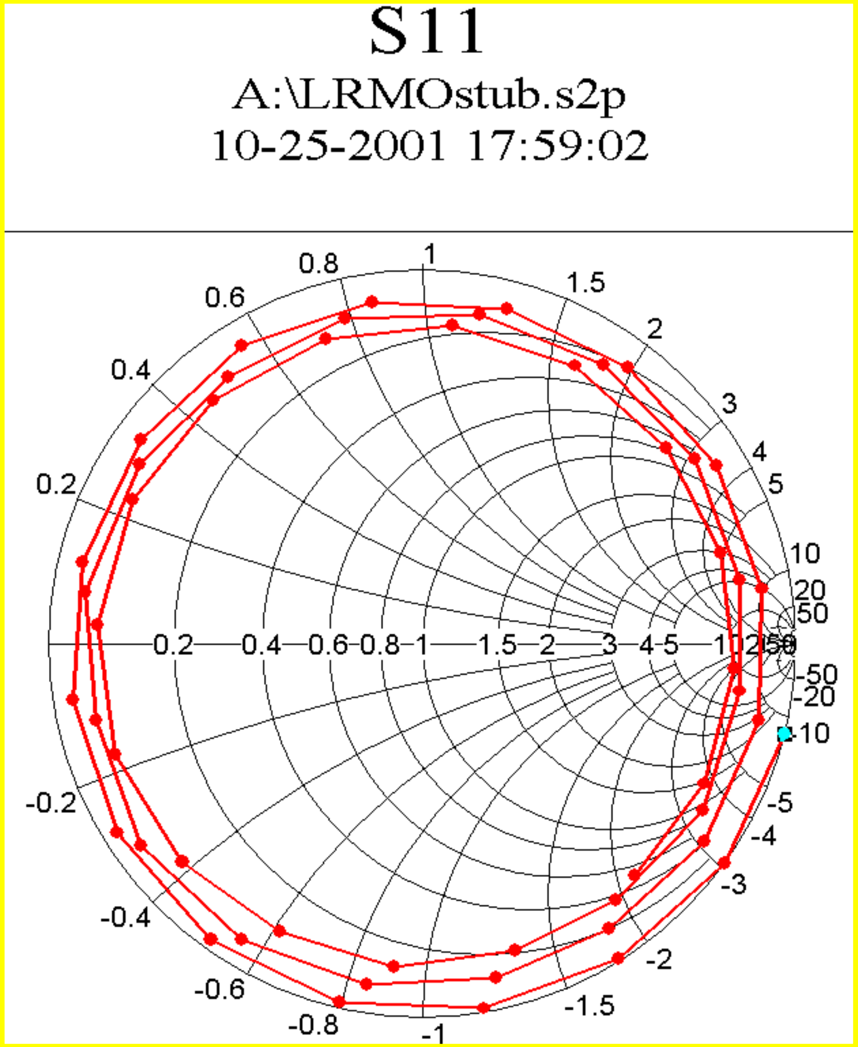


Frequency range: 0.644 - 50.000 GHz, 101
Virtual VNA, Cascade 9000/11000
09-09-2002 15:46:05 LRRM port 1 match

:: LRM Calibration Results

Open stub is well centered on the Smith chart

No lines are crossing



S11

A:\LRMOstub.s2p

10-25-2001 17:59:02

:: LRM Recommendations

Best PNA front panel cal

- Does not require WinCal

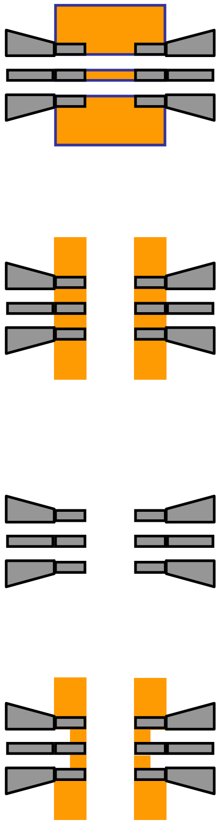
Gives better results than SOLT

- Less fine grain ripple artifacts
- Less sensitive to probe placement errors

WinCal LRM open-load with automatic load inductance

- Better than PNA front panel LRM

LRRM



Cascade Microtech Calibration Research

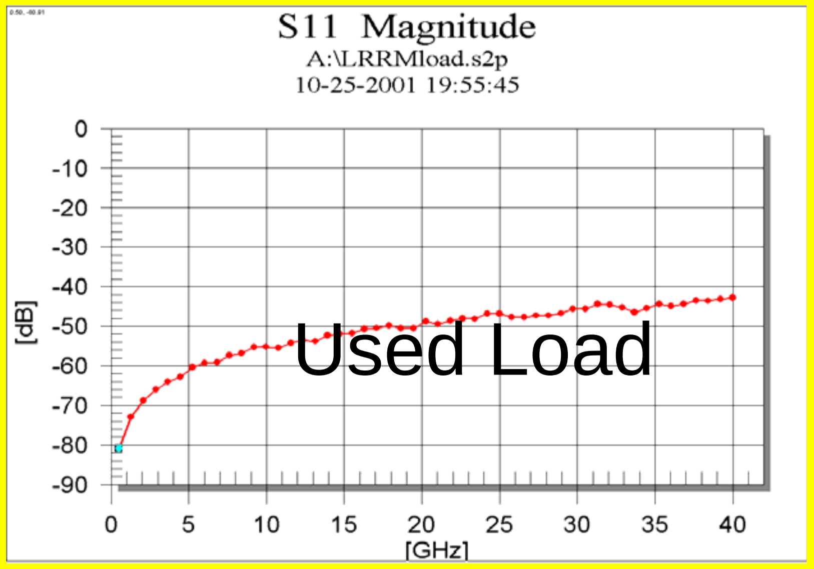
Line-Reflect-Reflect-Match Calibration

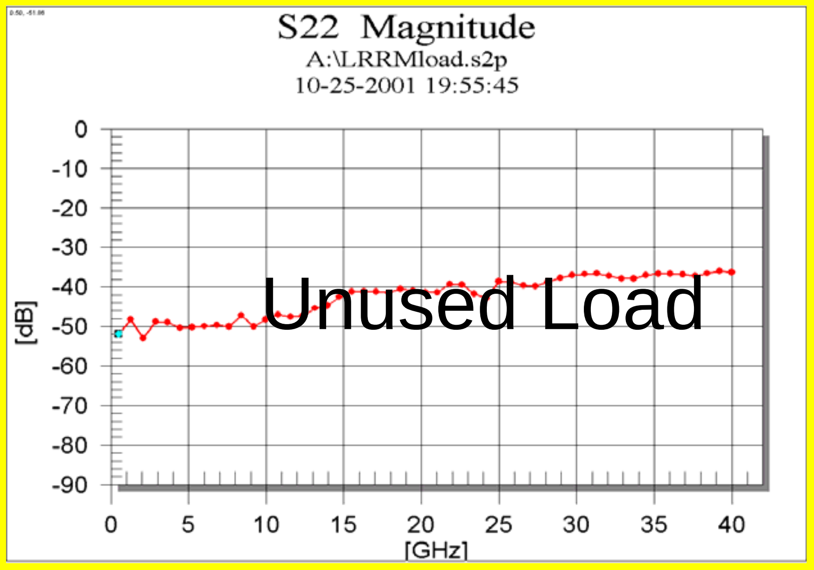
- TRL only Match acts as infinitely high loss line
- One transmission line standard only allows fixed probe spacing calibration
- Thru (line) delay, Match resistance must be known
- Measurements referenced to trimmed resistor
- Required measurement of only one load standard
- Patented load inductance compensation
- Uses off-wafer standards (ISS)
  - Same standards as SOLT only no need for cal kit
- Available in WinCal only (not front panel)

:: LRRM Requires only 1 Load

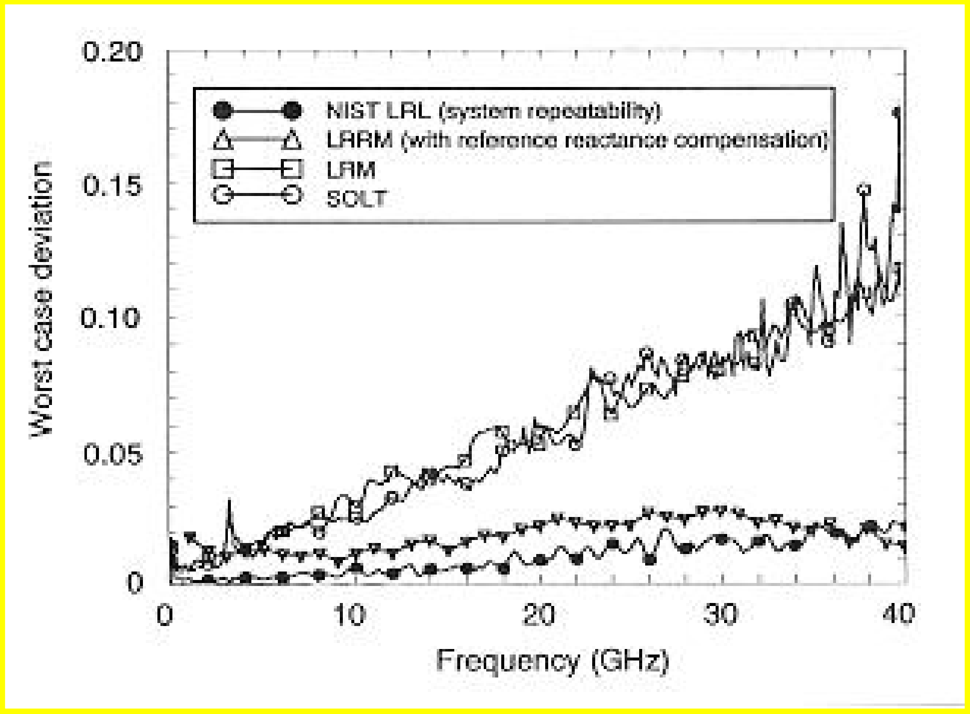
Easier to put standards on the wafer

- Only the dc (kelvin) resistance required
- LRM requires two matched loads





NIST Verification



System drift baseline

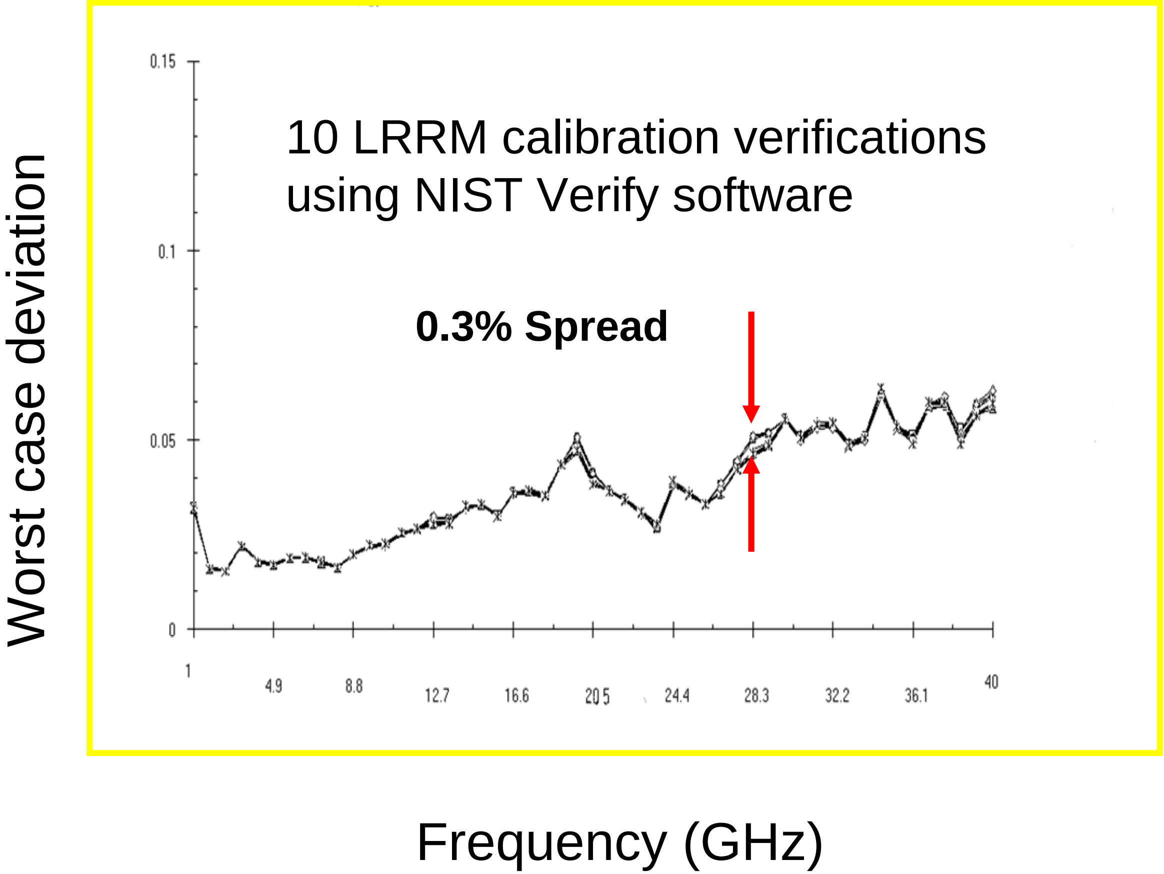
LRRM compares with system drift limit

- best fixed probe position calibration

SOLT /LRM

- growing error w/freq
- possible CalKit error
- possible ref plane error

How repeatable is my calibration?



10 LRRM calibration verifications using NIST Verify software

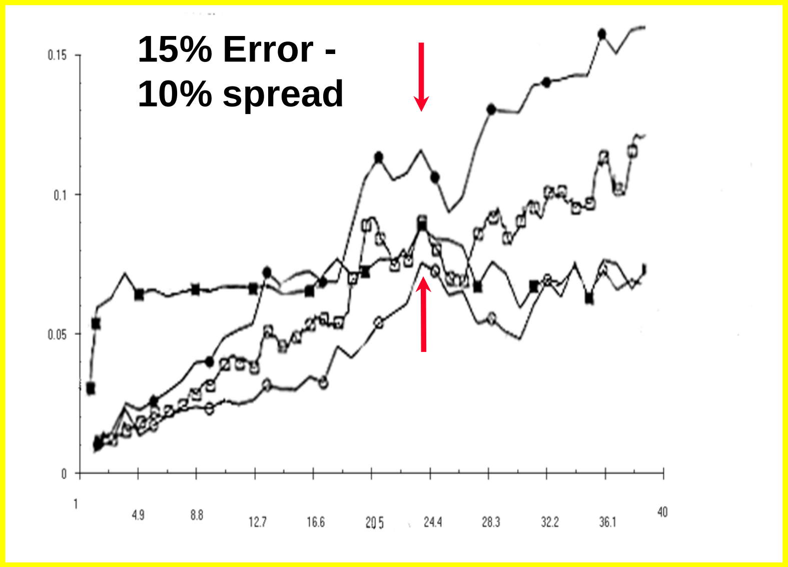
0.3% Spread

LRRM automatic calibration is VERY repeatable

How does a manual calibration compare to an automatic calibration?

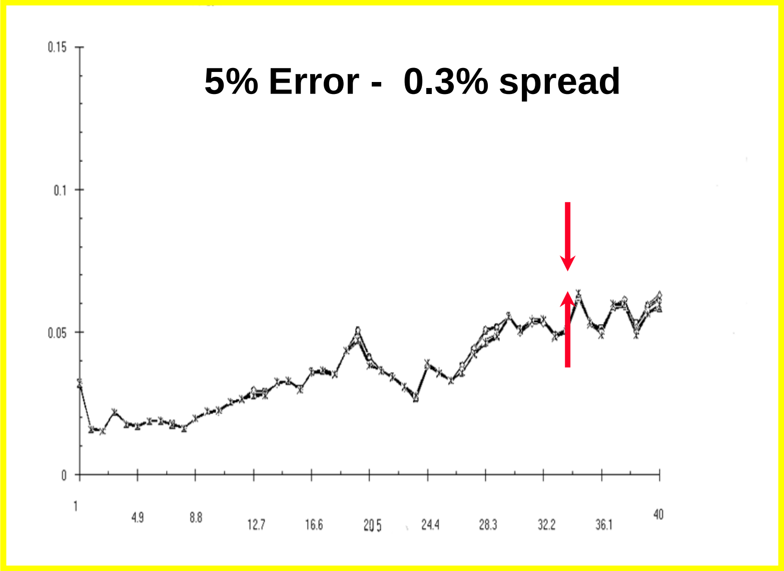
Worst Case Accuracy to 40GHz

Four Manual Calibrations



15% Error -
10% spread

Ten Semi-Auto Calibrations

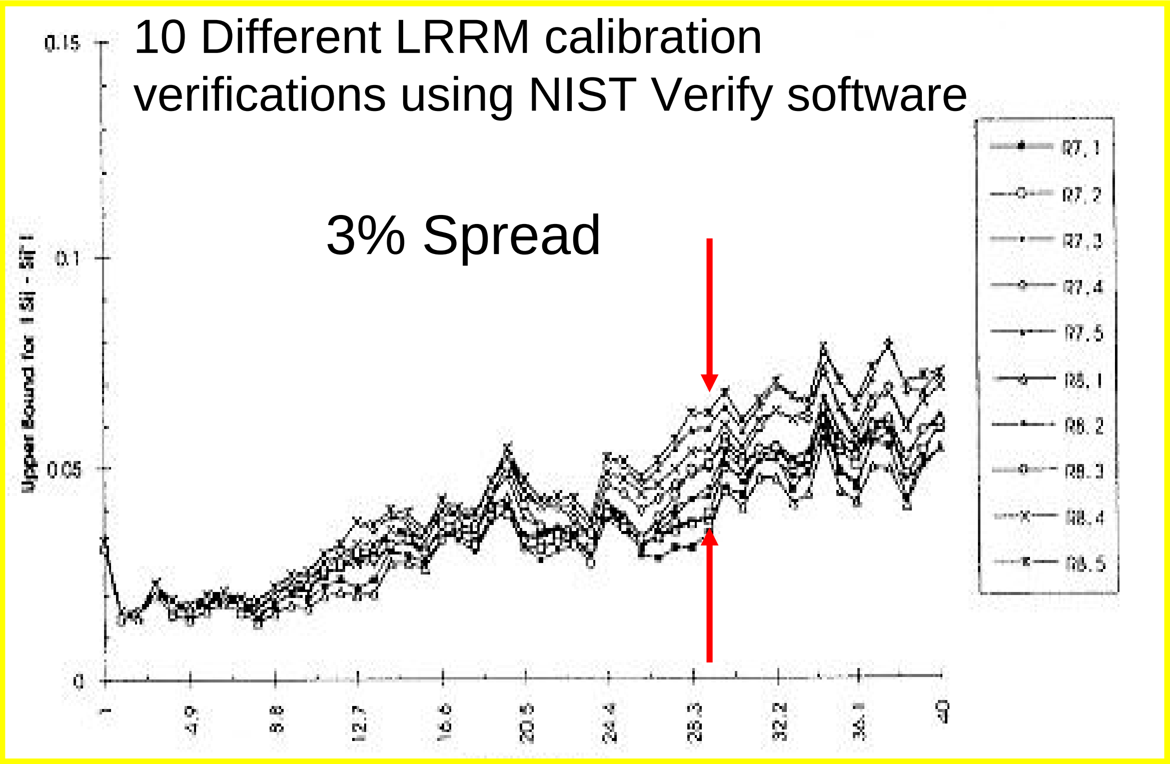


5% Error - 0.3% spread

Semi-auto Prober is faster and far more repeatable!

How repeatable are the calibration standards?

Worst case deviation



10 Different LRRM calibration verifications using NIST Verify software

3% Spread

Frequency (GHz)

Impedance Standard Substrate Standards are very repeatable

:: Which Calibration Technique is Best?

SOLT

- All Hi-Q measurements <20GHz
- Most measurements requiring attenuation
- Most measurement <-10dBm input power

SOLR

- All probe card applications
- All dual signal probe applications
- Right angle probe applications

:: Which Calibration Technique is Best?

LRM (with auto load inductance)

- Most accurate attenuation measurements
- Some on-wafer standards

LRRM (with auto load inductance)

- Best for broadband mmW transistors
- On-wafer standards with a single load

TRL

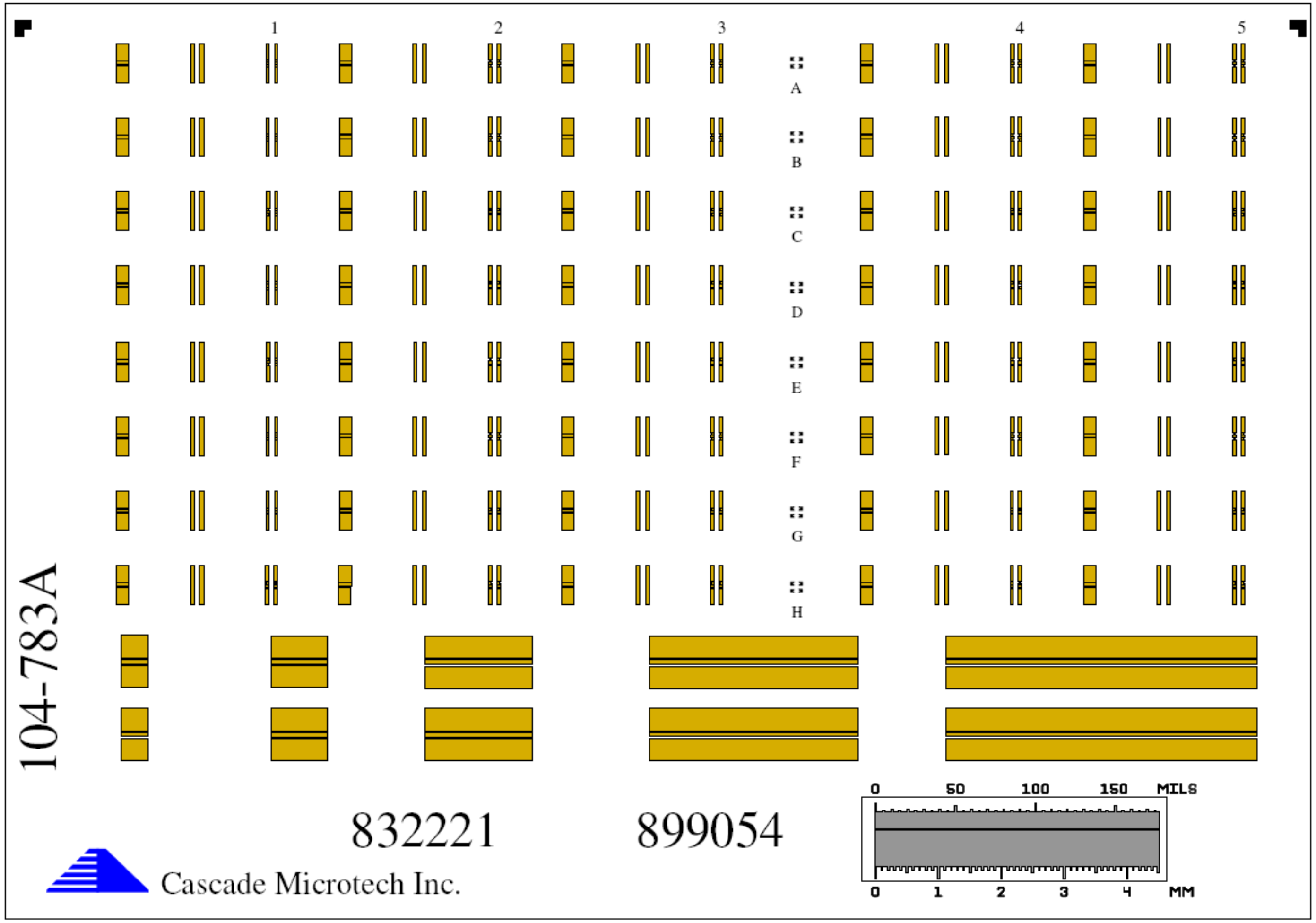
- Microstrip mmW device characterization
- Waveguide banded measurements
- III-V on-wafer mmW microstrip standards

:: Impedance Standard Substrate

W-band Impedance Standard Substrate

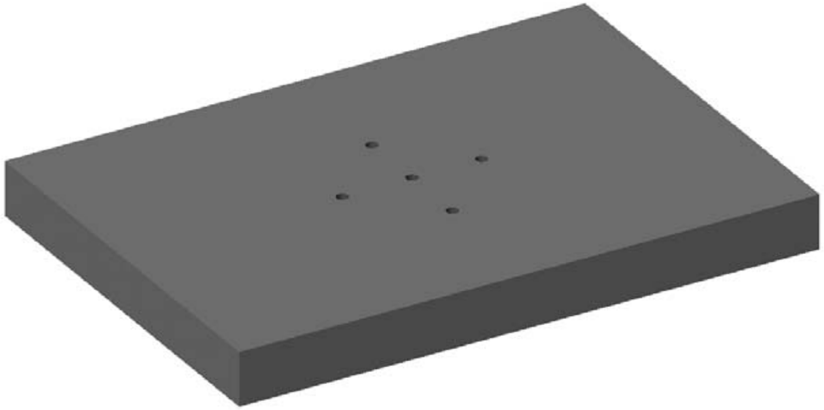
(**Pitch:** 75 µm – 150 µm, **Configuration:** Ground-Signal-Ground)

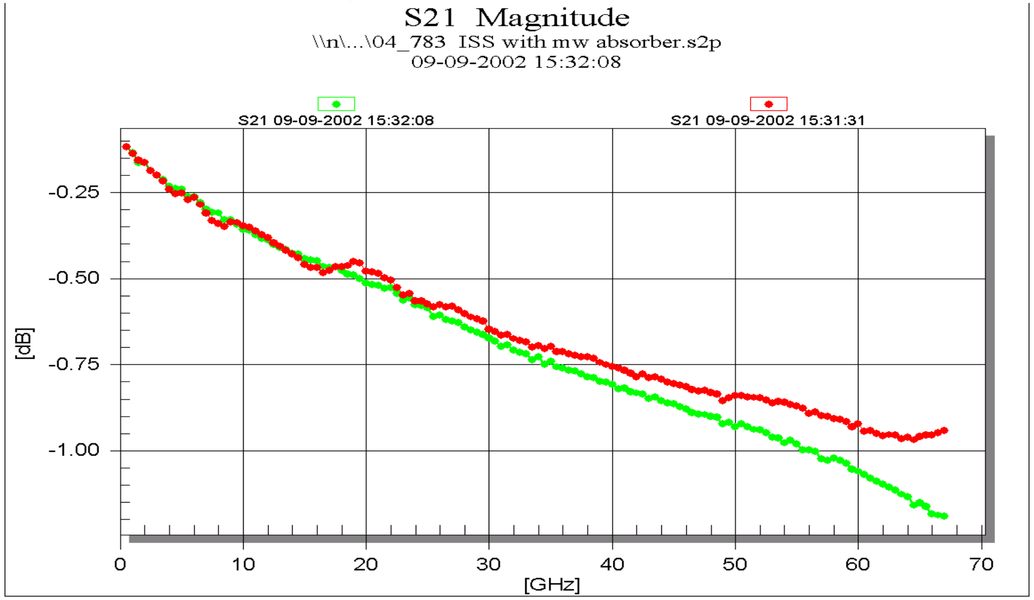
P/N: 104-783 ; **S/N:**



Absorbing ISS holder

- **Measurements > 50 GHz, unwanted modes are excited**
- **Microwave absorbing ISS holder reduces unwanted modes (PN 116-344)**
  - Ideal for LRRM, LRM & SOL-R calibrations
- **ISS enhanced for CPW transmission mode –thinned to 10 mils (PN 104-783)**

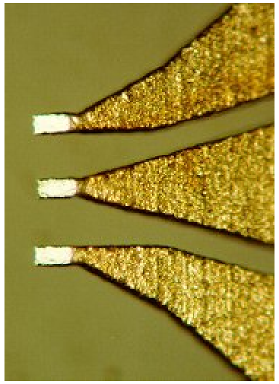


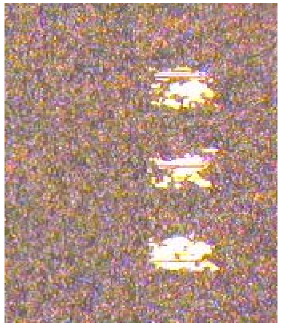


How to calibrate

:: How to calibrate

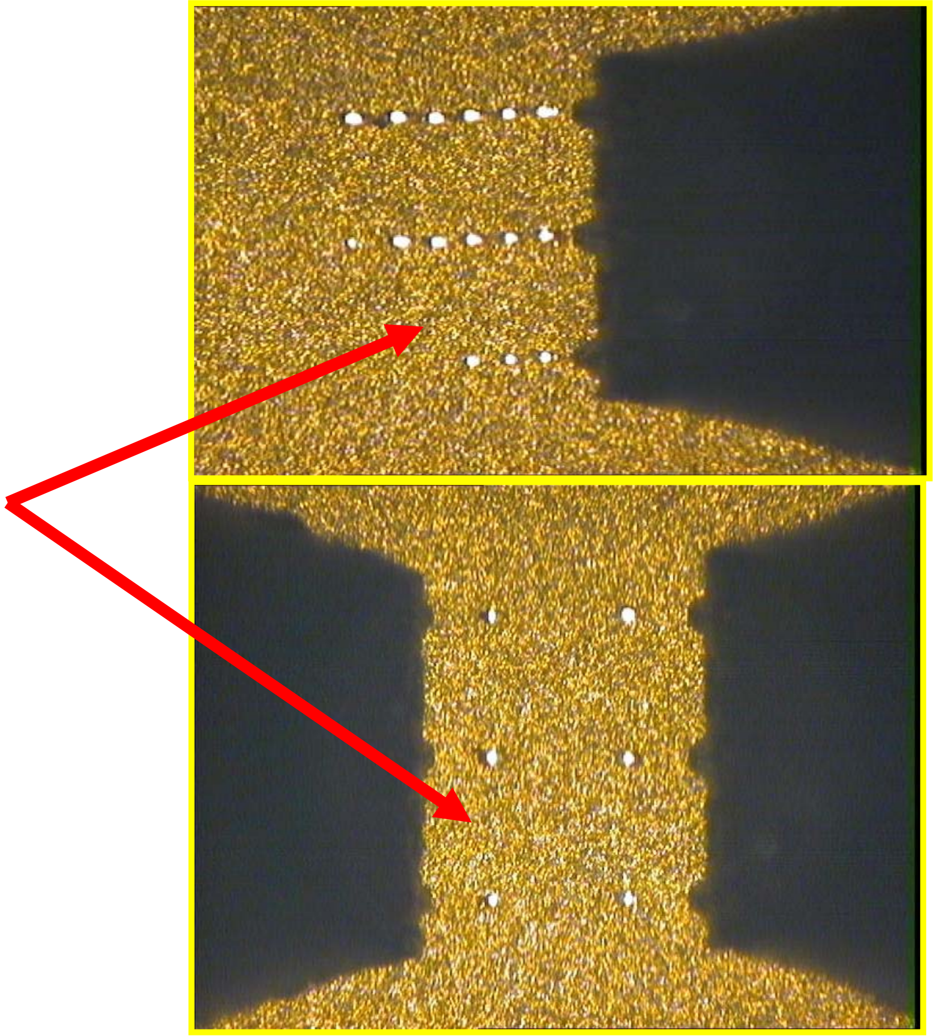
- **Ensure that the probes are in place**
- **Clean and connect the cables and torque using relevant wrench**
  - Use IPA and swab to clean connectors and allow to dry
- **Visually inspect the probe tips and clean if contaminated**
  - Use IPA and swab, brushing away from the probe body and allow to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



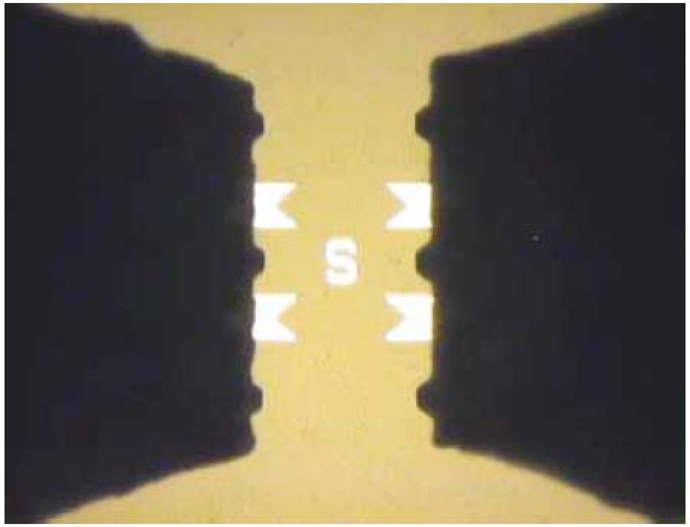


Planarizing the Probes

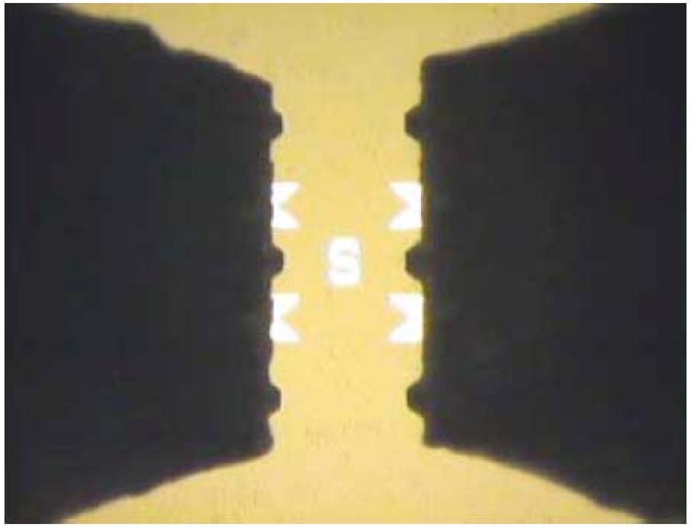
- **Contact Substrate**
  - PN 005-018
  - Dull gold finish
  - Bright contact marks
- **Adjust planarity until equal marks from all probe contacts**



ISS Alignment Marks



Initial Contact

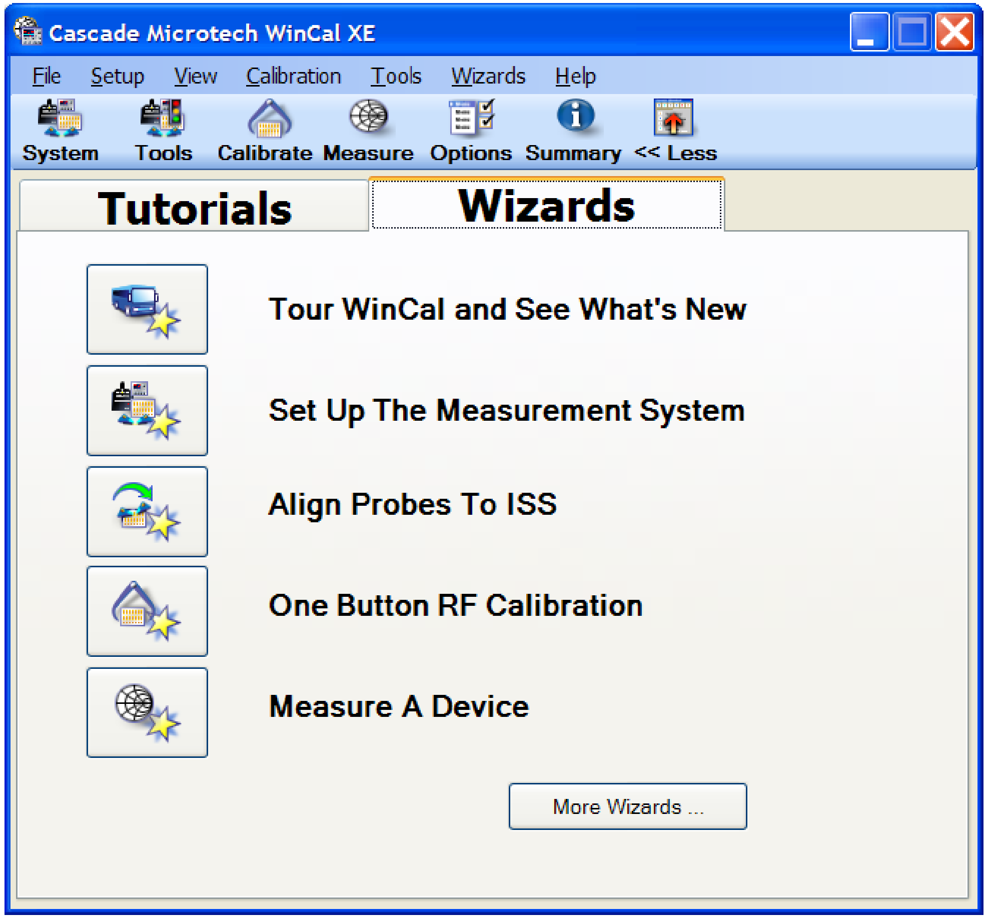


Final Contact

- **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

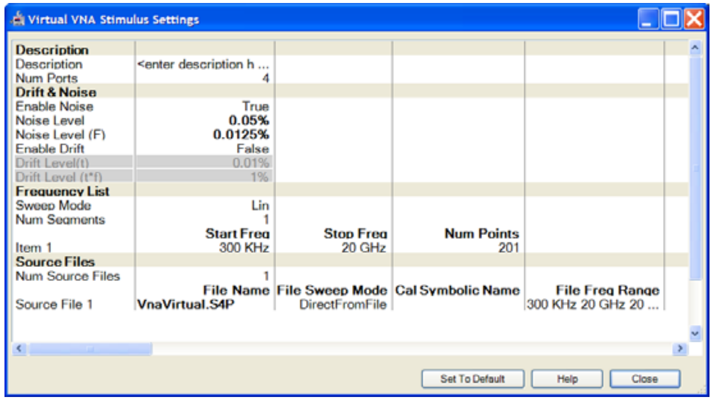
WinCal XE

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

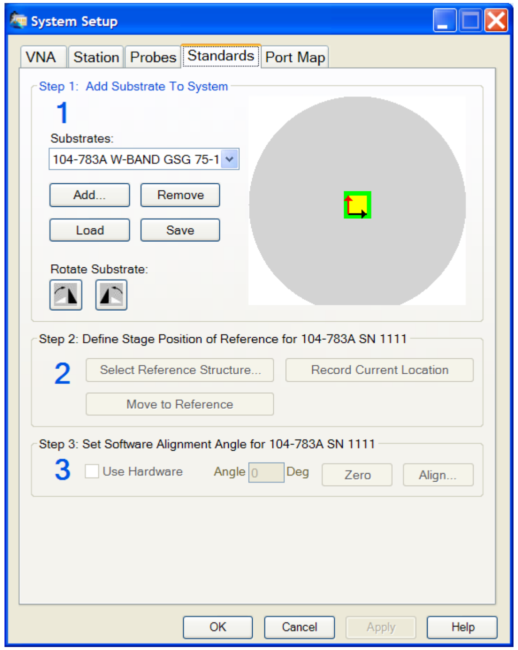


System Setup

- **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?



Description				
Description	<enter description h ...			
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 Segments	1			
	Start Freq	**Stop Freq**	**Num Points**	
Item 1	300 KHz	20 GHz	201	
Source Files				
Num Source Files	1			
	File Name	**File Sweep Mode**	**Cal Symbolic Name**	**File Freq Range**
Source File 1	**VnaVirtual.S4P**	DirectFromFile		300 KHz 20 GHz 20 ...



Step 1: Add Substrate To System

1

Substrates: 104-783A W-BAND GSG 75-1

Rotate Substrate:

Step 2: Define Stage Position of Reference for 104-783A SN 1111

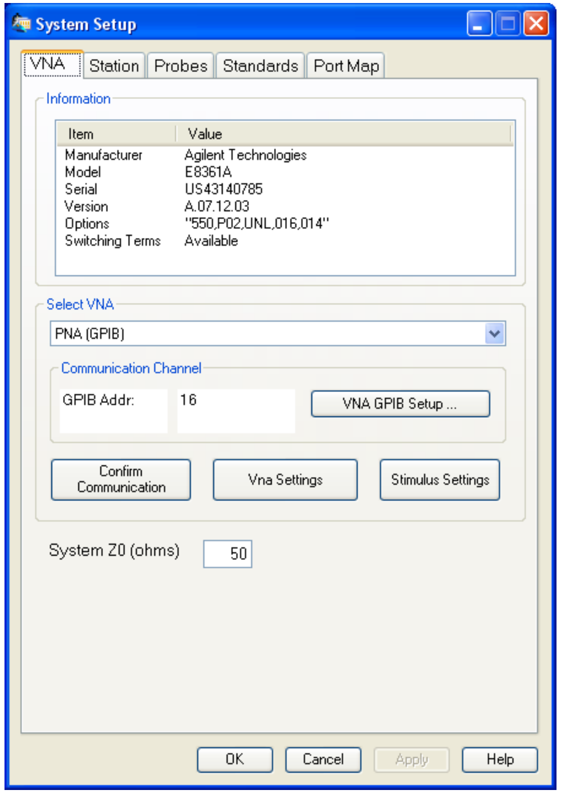
2

Step 3: Set Software Alignment Angle for 104-783A SN 1111

3

☐ Use Hardware Angle 0 Deg

:: Using Wincal XE to Prepare the calibration



Information

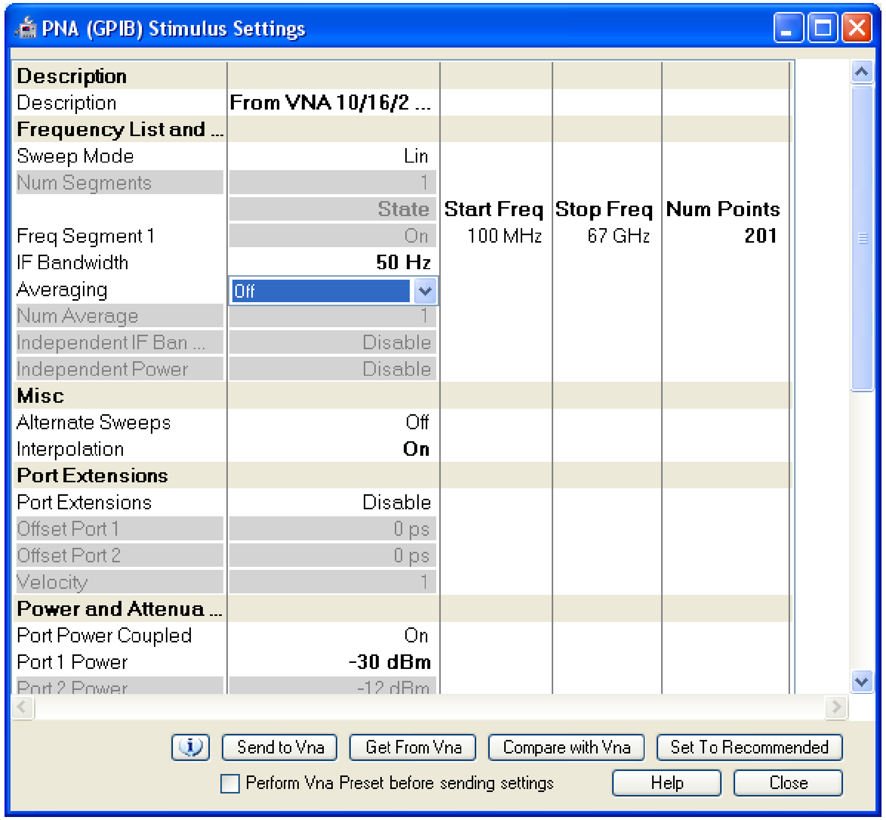
Item	Value
Manufacturer	Agilent Technologies
Model	E8361A
Serial	US43140785
Version	A.07.12.03
Options	"550,P02,UNL,016,014"
Switching Terms	Available

Select VNA: PNA (GPIB)

Communication Channel

GPIB Addr: 16

System Z0 (ohms) 50

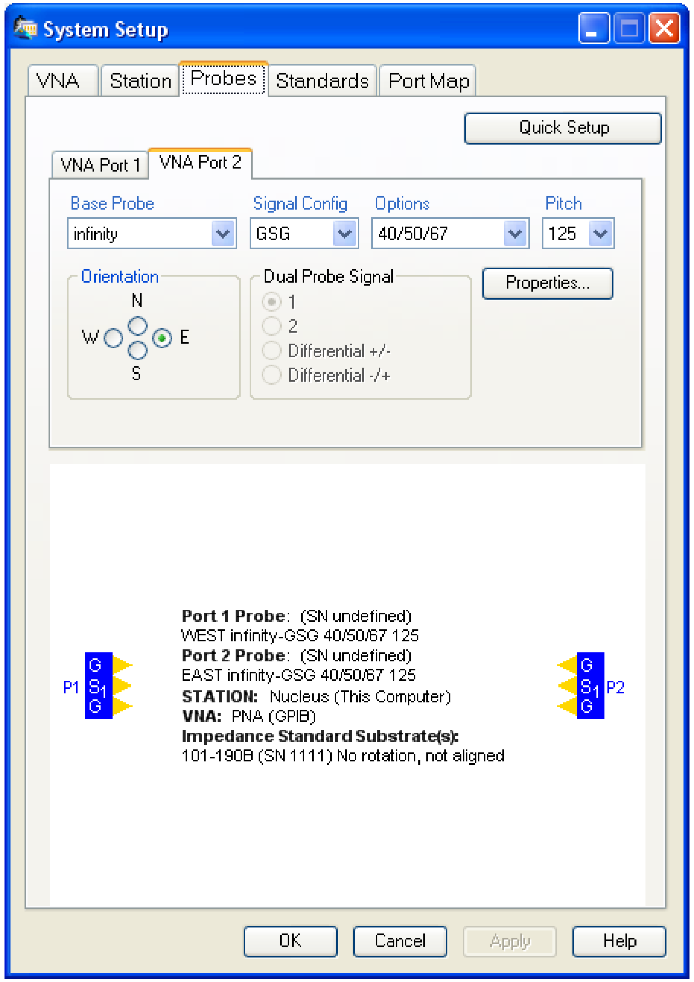


Description				
Description	**From VNA 10/16/2 ...**			
Frequency List and ...				
Sweep Mode	Lin			
Num Segments	1			
	State	**Start Freq**	**Stop Freq**	**Num Points**
Freq Segment 1	On	100 MHz	67 GHz	**201**
IF Bandwidth	**50 Hz**			
Averaging	Off			
Num Average	1			
Independent IF Ban ...	Disable			
Independent Power	Disable			
Misc				
Alternate Sweeps	Off			
Interpolation	**On**			
Port Extensions				
Port Extensions	Disable			
Offset Port 1	0 ps			
Offset Port 2	0 ps			
Velocity	1			
Power and Attenua ...				
Port Power Coupled	On			
Port 1 Power	**-30 dBm**			
Port 2 Power	-12 dBm			

☐ Perform Vna Preset before sending settings

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

:: Probe Set-up



Base Probe: infinity
Signal Config: GSG
Options: 40/50/67
Pitch: 125

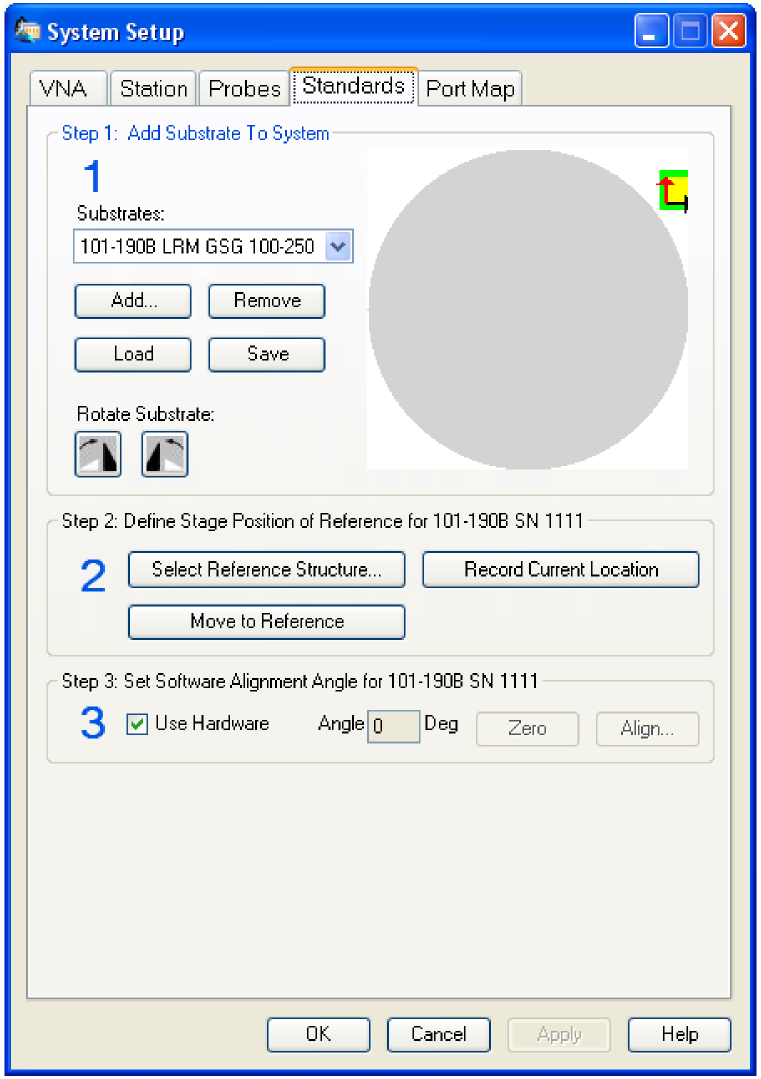
Orientation
N
W ○ ○ ● E
○
S

Dual Probe Signal
● 1
○ 2
○ 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

- 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



Step 1: Add Substrate To System

Substrates: 101-190B LRM GSG 100-250

Step 2: Define Stage Position of Reference for 101-190B SN 1111

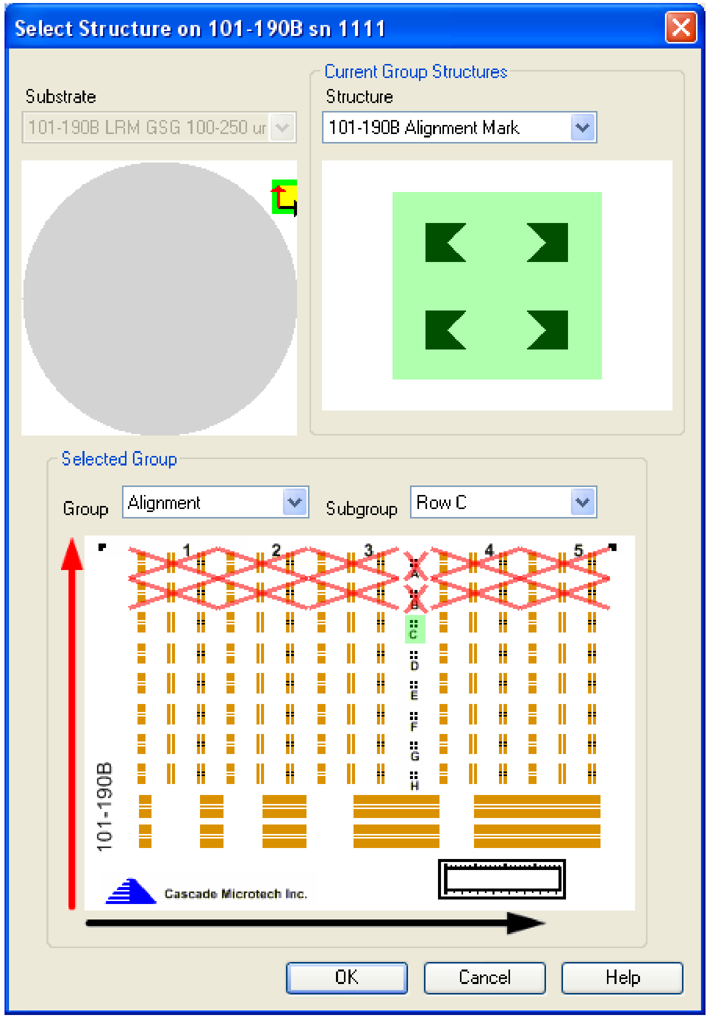
Step 3: Set Software Alignment Angle for 101-190B SN 1111

☑ Use Hardware

Angle 0 Deg

- 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: 101-190B LRM GSG 100-250 ur

Current Group Structures

Structure: 101-190B Alignment Mark

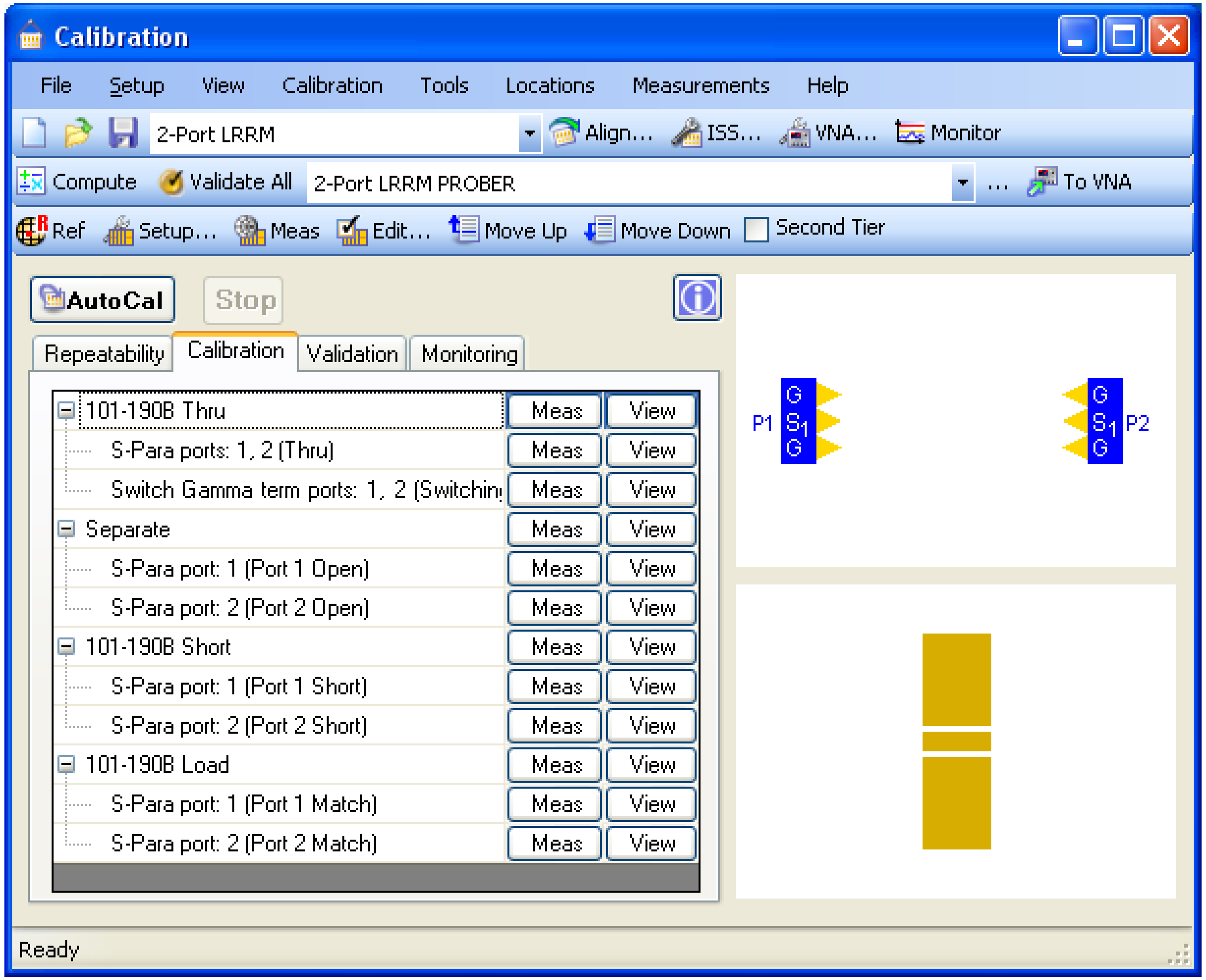
Selected Group

Group: Alignment

Subgroup: Row C

- 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



2-Port LRRM

2-Port LRRM PROBER

- 101-190B Thru
  - S-Para ports: 1, 2 (Thru)
  - Switch Gamma term ports: 1, 2 (Switching
- Separate
  - S-Para port: 1 (Port 1 Open)
  - S-Para port: 2 (Port 2 Open)
- 101-190B Short
  - S-Para port: 1 (Port 1 Short)
  - S-Para port: 2 (Port 2 Short)
- 101-190B Load
  - S-Para port: 1 (Port 1 Match)
  - S-Para port: 2 (Port 2 Match)

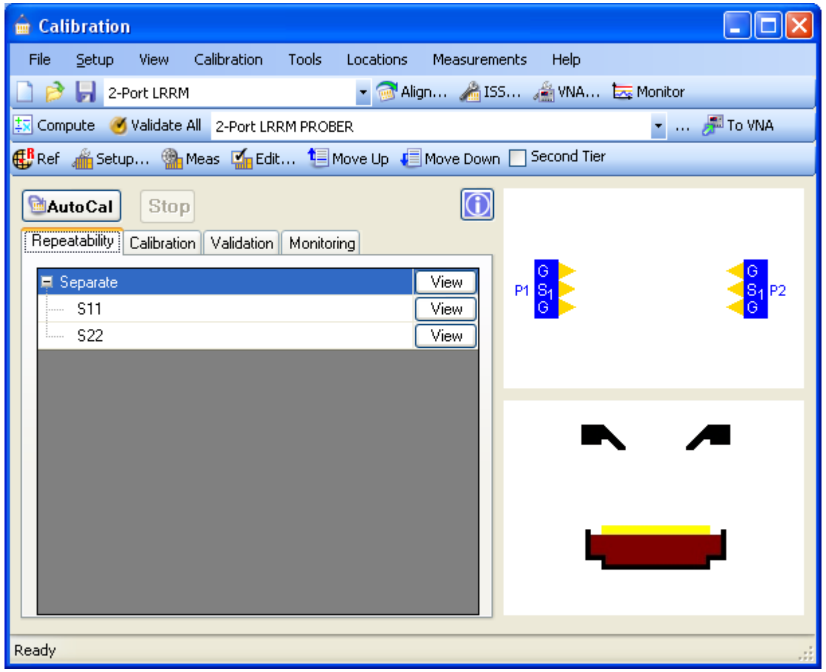
Ready

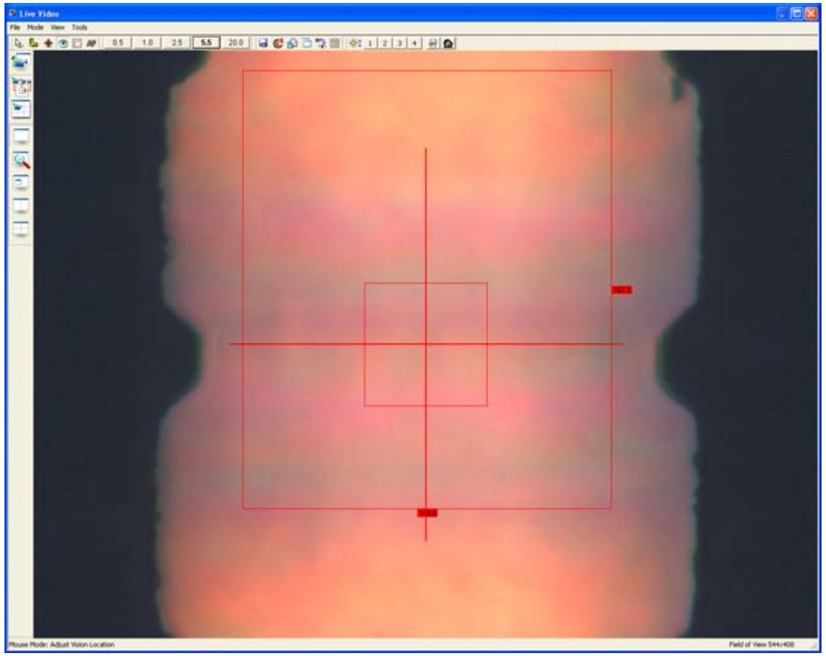
:: Calibration Procedure

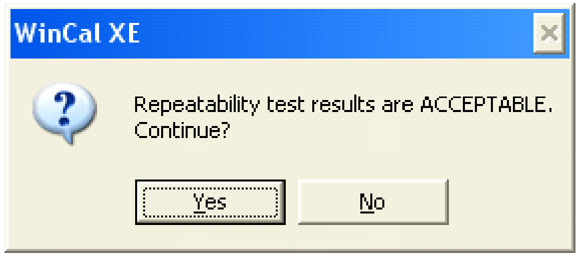
- **Automatic calibration will use the prober to automatically move from standard to standard**
- **On pressing autocal the procedure is as follows**
  - Repeatability check measures raw open multiple times in order to check the system is repeatable (often picks up problems relating to cabling, system 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

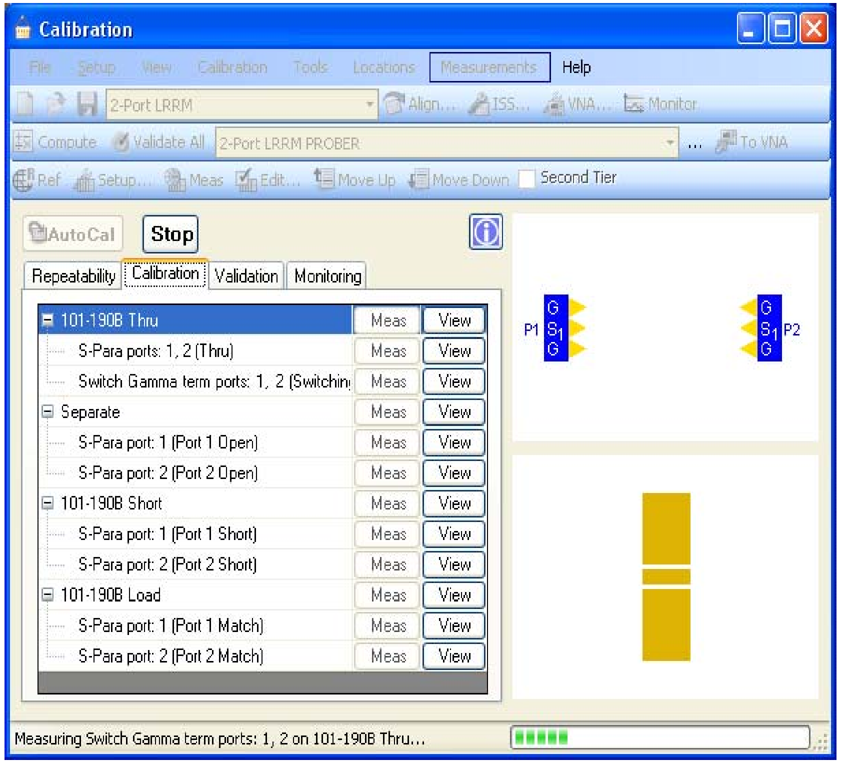






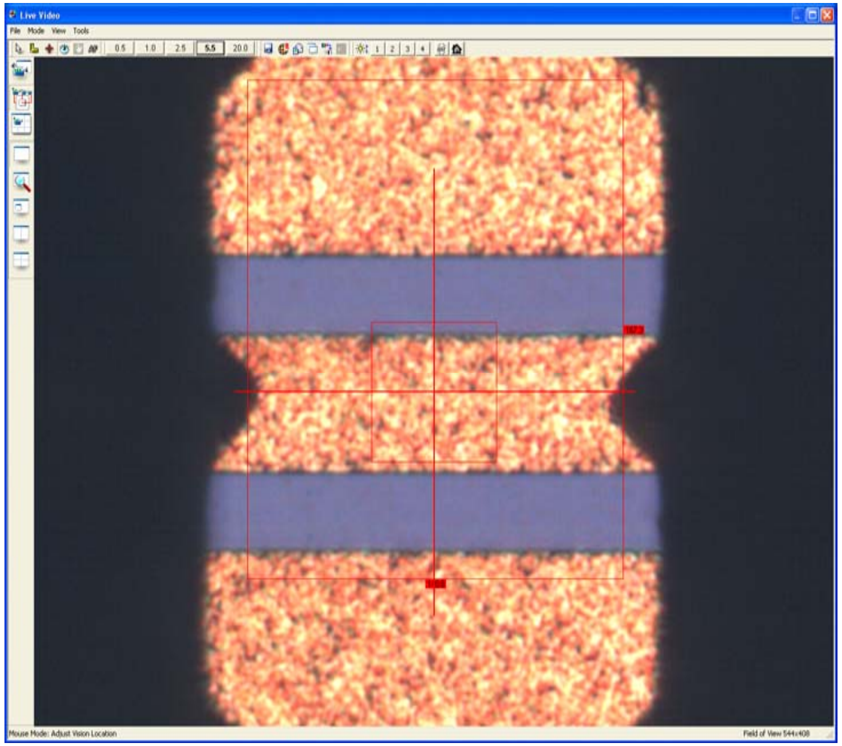
Repeatability test results are ACCEPTABLE.
Continue?

:: Calibration measurements for LRRM - Thru

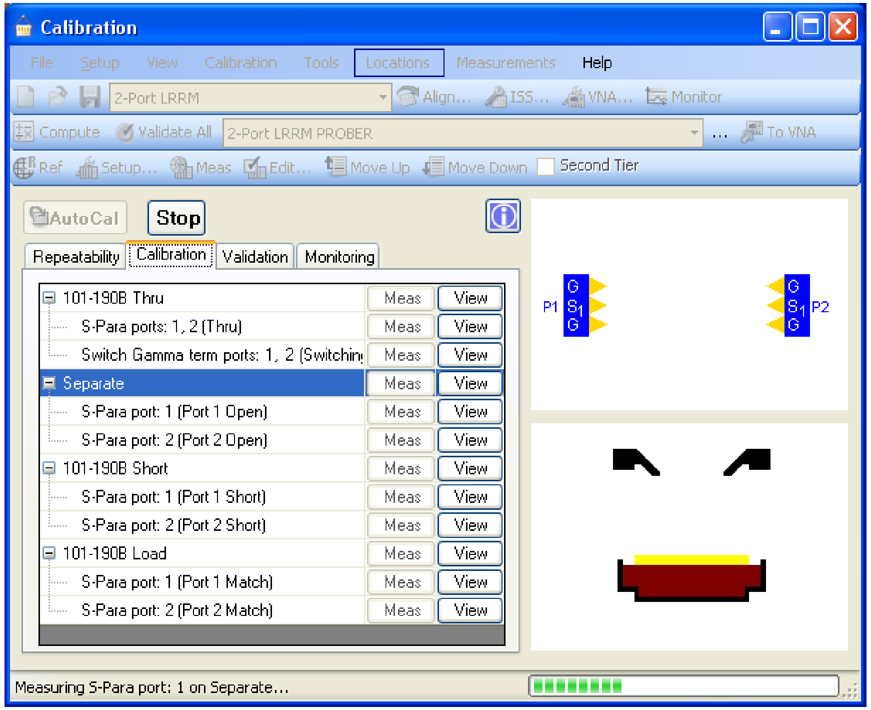


- ⊟ 101-190B Thru — Meas — View
  - S-Para ports: 1, 2 (Thru) — Meas — View
  - Switch Gamma term ports: 1, 2 (Switching — Meas — View
- ⊟ Separate — Meas — View
  - S-Para port: 1 (Port 1 Open) — Meas — View
  - S-Para port: 2 (Port 2 Open) — Meas — View
- ⊟ 101-190B Short — Meas — View
  - S-Para port: 1 (Port 1 Short) — Meas — View
  - S-Para port: 2 (Port 2 Short) — Meas — View
- ⊟ 101-190B 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 101-190B Thru...

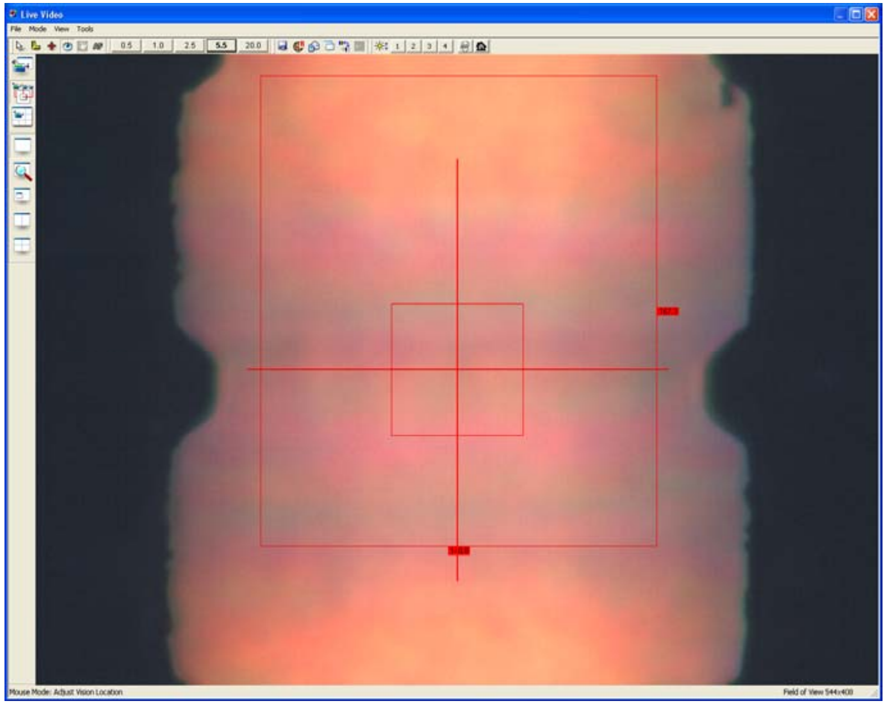


:: Calibration measurements for LRRM – Open



- 101-190B Thru
  - S-Para ports: 1, 2 (Thru)
  - Switch Gamma term ports: 1, 2 (Switchin
- Separate
  - S-Para port: 1 (Port 1 Open)
  - S-Para port: 2 (Port 2 Open)
- 101-190B Short
  - S-Para port: 1 (Port 1 Short)
  - S-Para port: 2 (Port 2 Short)
- 101-190B Load
  - S-Para port: 1 (Port 1 Match)
  - S-Para port: 2 (Port 2 Match)

Measuring S-Para port: 1 on Separate...

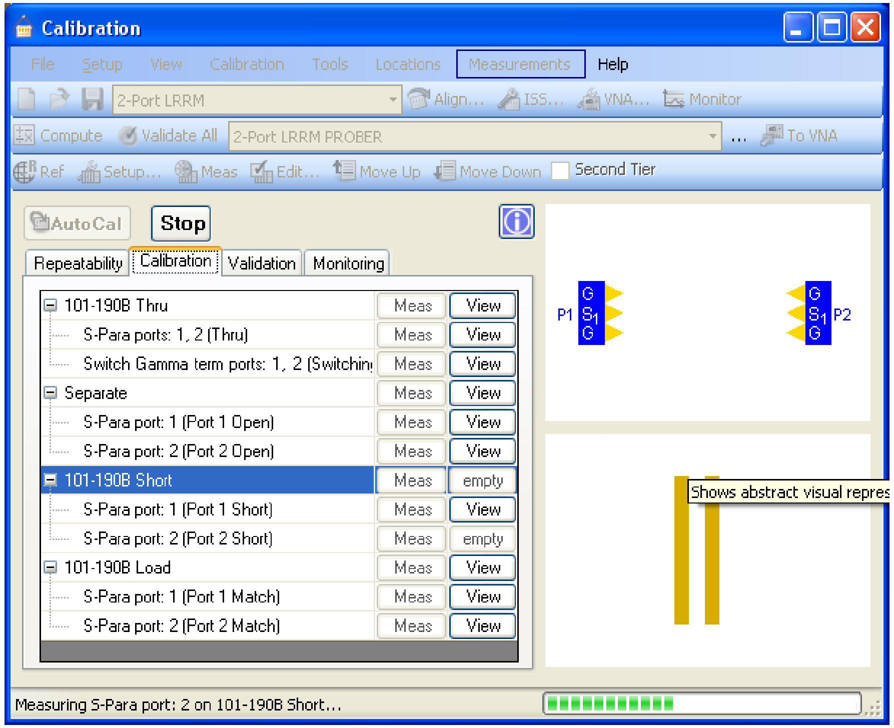


Mouse Mode: Adjust Vision Location

Field of View 544x408

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

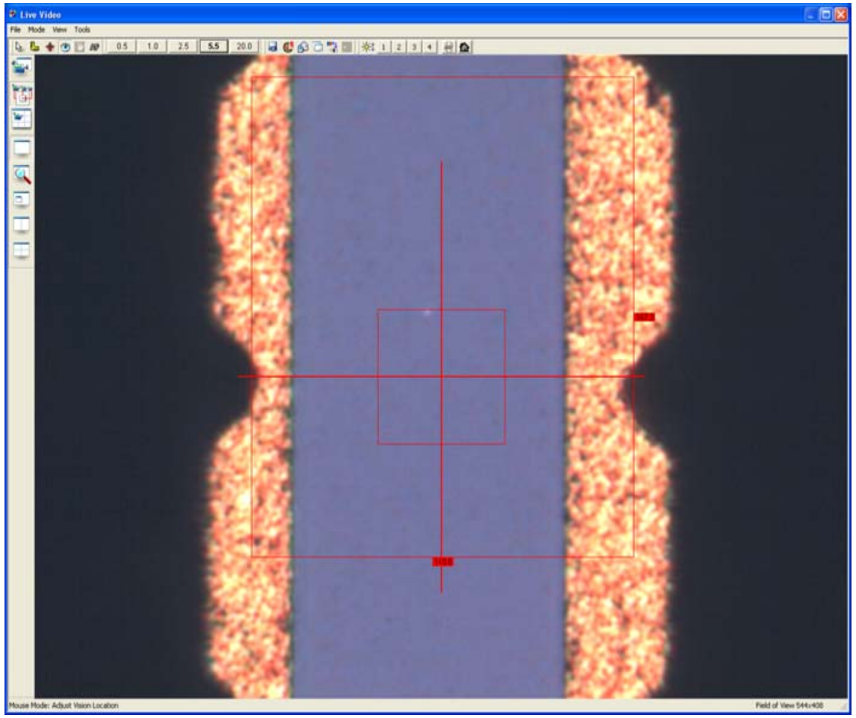
:: Calibration Measurements for LRRM - Short



⊟ 101-190B Thru	Meas	View
S-Para ports: 1, 2 (Thru)	Meas	View
Switch Gamma term ports: 1, 2 (Switchin	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	empty
S-Para port: 1 (Port 1 Short)	Meas	View
S-Para port: 2 (Port 2 Short)	Meas	empty
⊟ 101-190B Load	Meas	View
S-Para port: 1 (Port 1 Match)	Meas	View
S-Para port: 2 (Port 2 Match)	Meas	View

Shows abstract visual repres

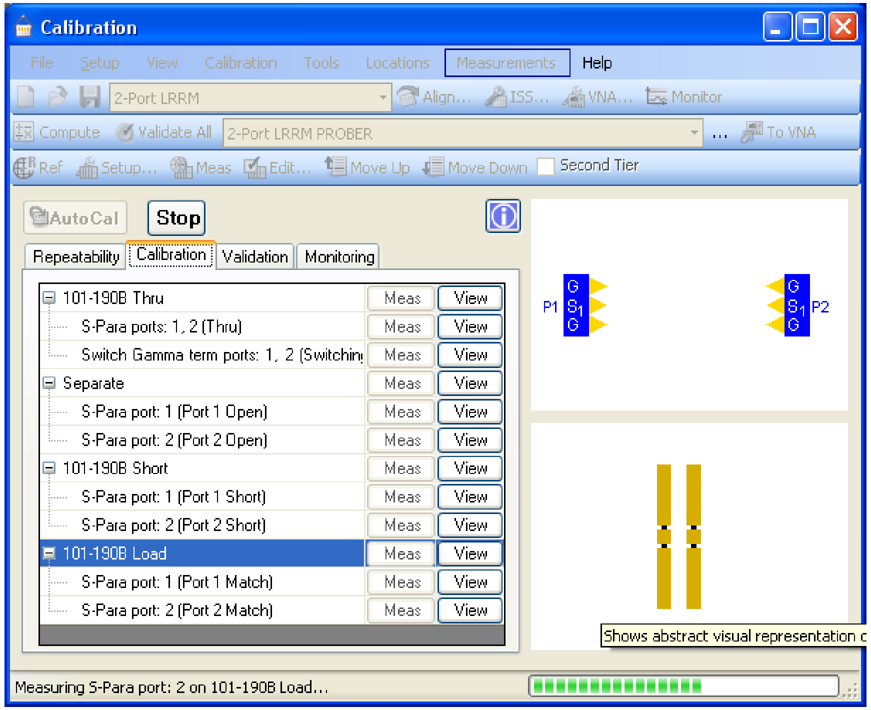
Measuring S-Para port: 2 on 101-190B Short…



Mouse Mode: Adjust Vision Location

Field of View 544x408

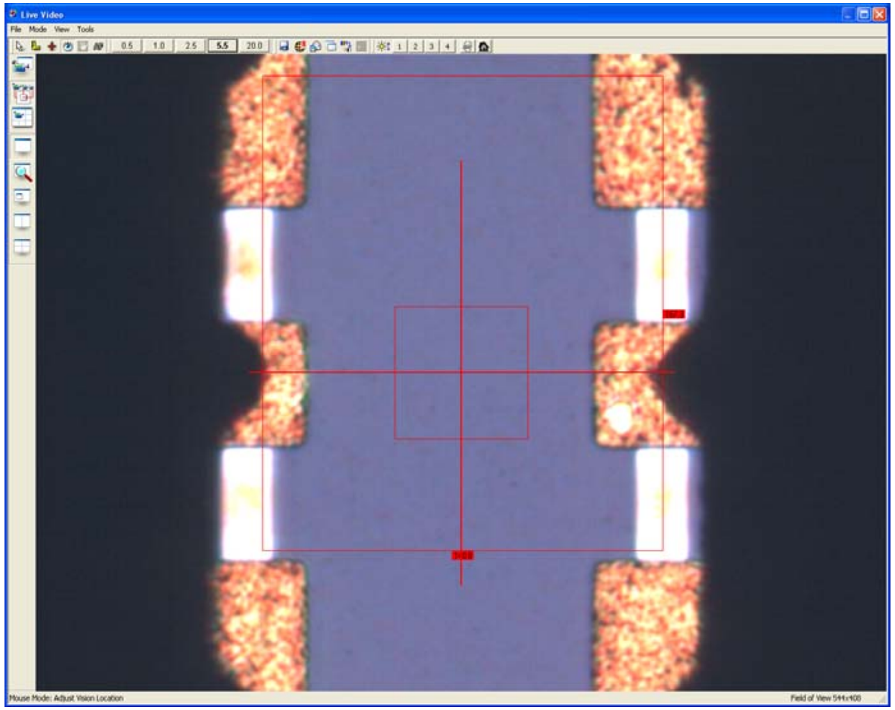
:: Calibration Measurements - Load



⊟ 101-190B Thru	Meas	View
S-Para ports: 1, 2 (Thru)	Meas	View
Switch Gamma term ports: 1, 2 (Switching	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
⊟ 101-190B Load	Meas	View
S-Para port: 1 (Port 1 Match)	Meas	View
S-Para port: 2 (Port 2 Match)	Meas	View

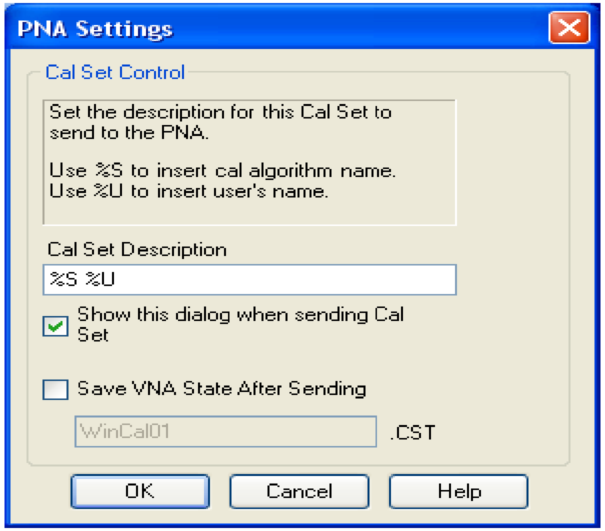
Shows abstract visual representation c

Measuring S-Para port: 2 on 101-190B Load...



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

:: Calibration – Computation and sending of error coefficients



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

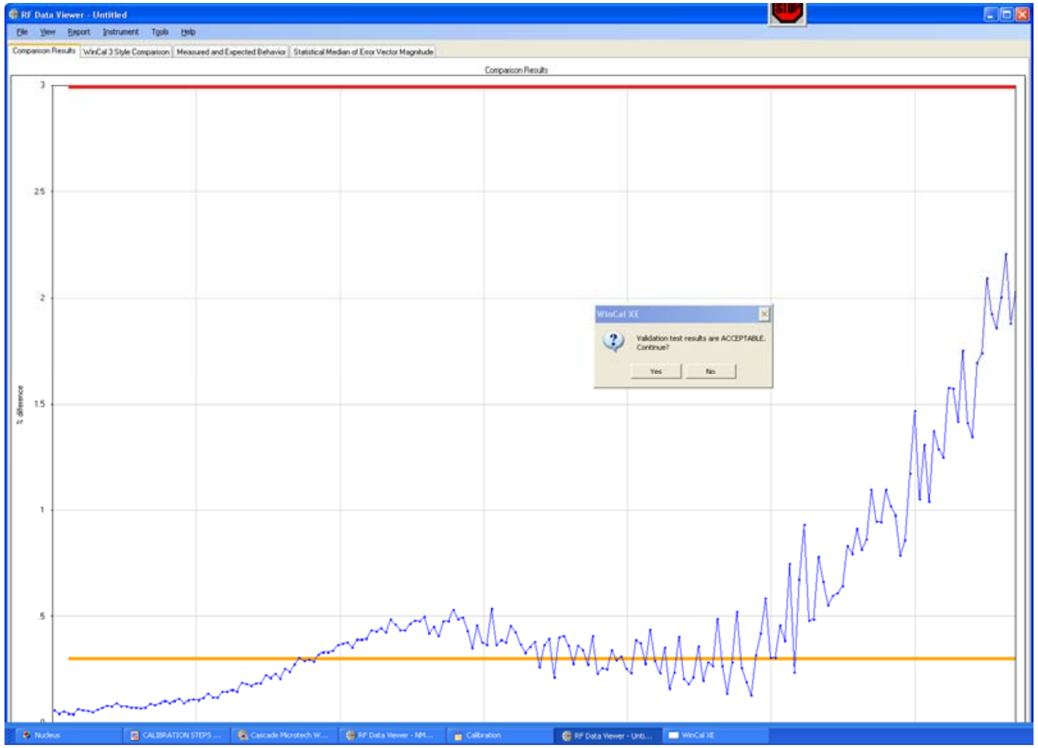
☑ Show this dialog when sending Cal Set

☐ Save VNA State After Sending

WinCal01 .CST

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

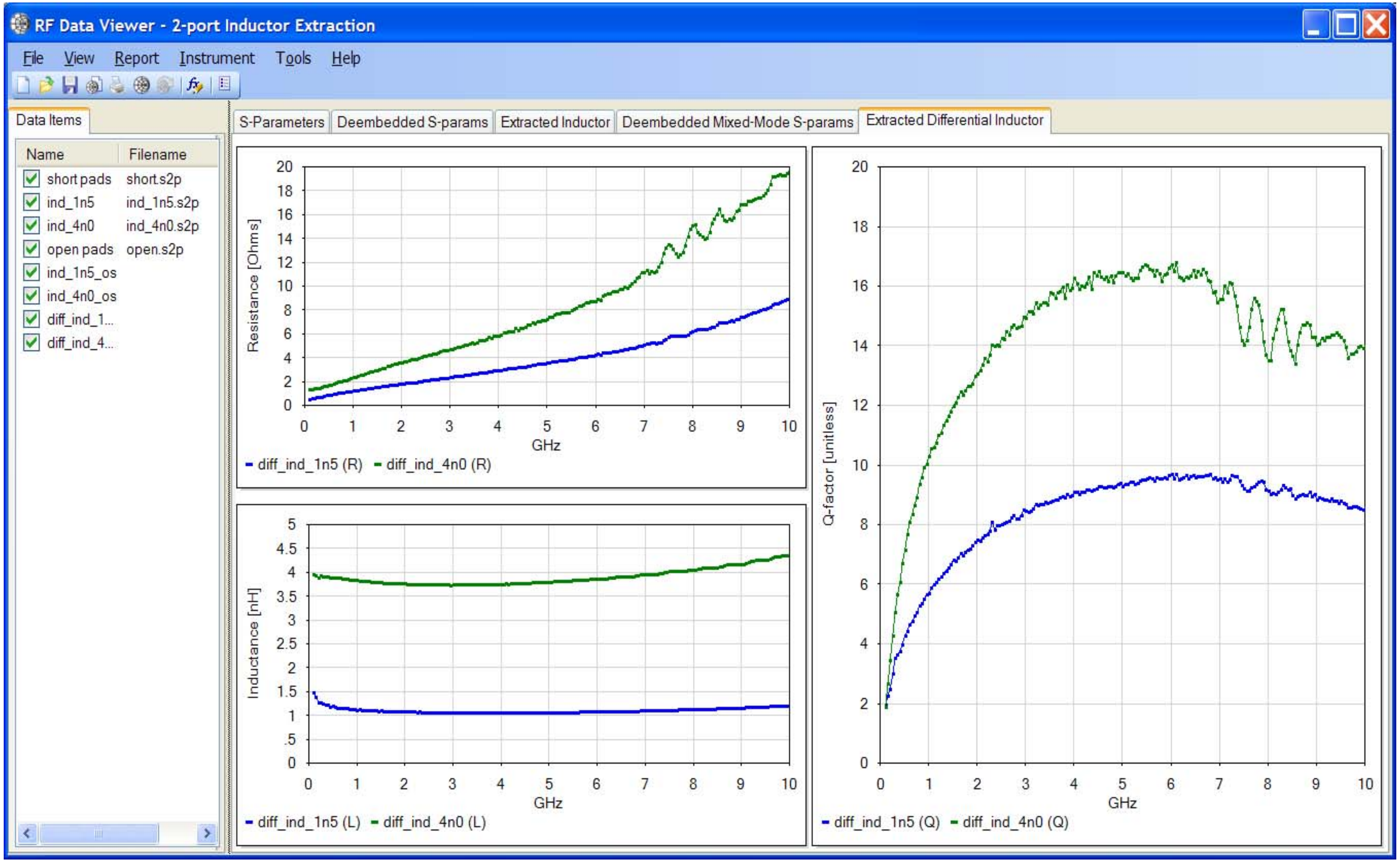
:: Calibration - Validation



Validation test results are ACCEPTABLE.
Continue?

- 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)

:: Wincal – Advanced reporting

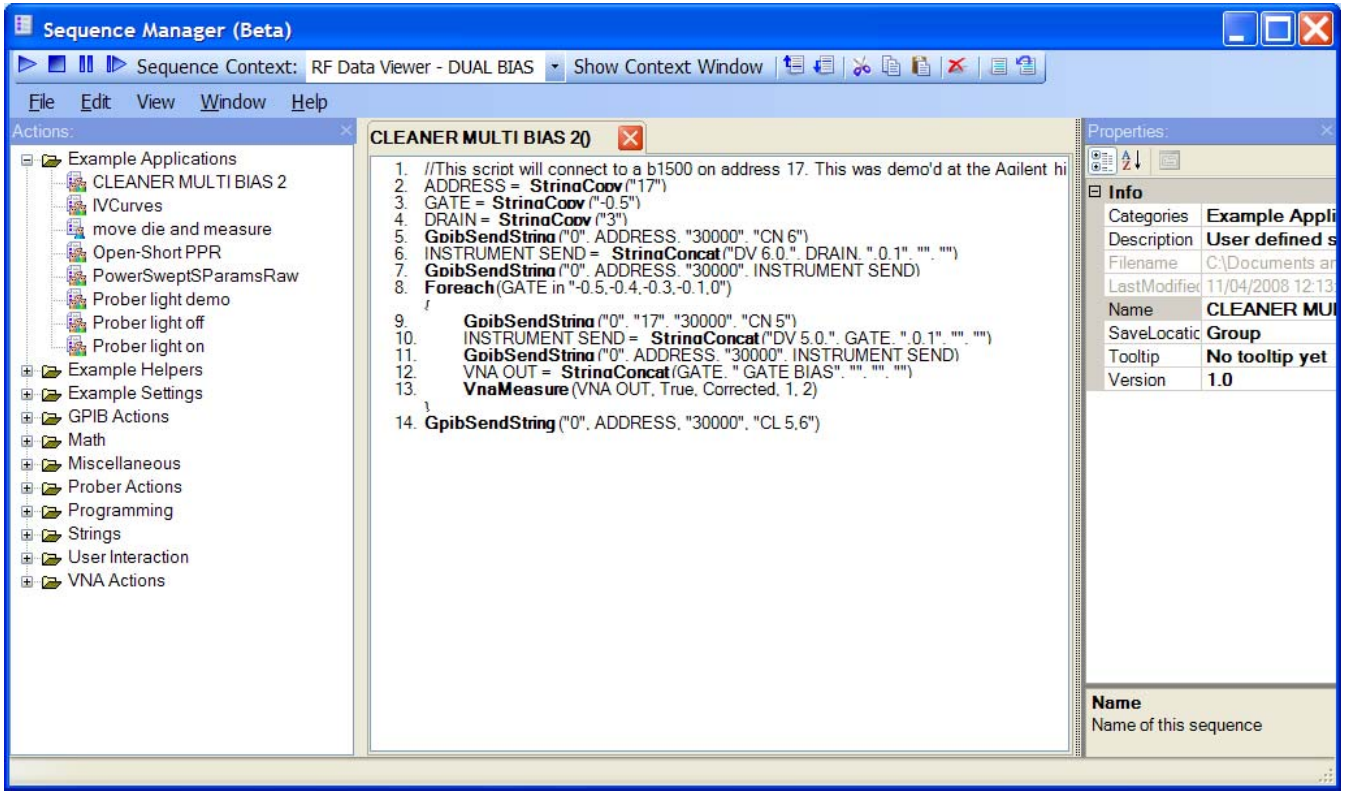


Name	Filename
☑ short pads	short.s2p
☑ ind_1n5	ind_1n5.s2p
☑ ind_4n0	ind_4n0.s2p
☑ open pads	open.s2p
☑ ind_1n5_os	
☑ ind_4n0_os	
☑ diff_ind_1...	
☑ diff_ind_4...	

:: Wincal – Advanced reporting

- Wincal can carry out advanced reporting to carry out post process mathmatics “on the fly” such as parasitic de-embedding, parameter conversion and subtaction, Masons gain etc.
- Multiple page views can be created for truly versatile reporting

:: Wincal - Sequencing



- Example Applications
  - CLEANER MULTI BIAS 2
  - IVCurves
  - move die and measure
  - Open-Short PPR
  - PowerSweptSParamsRaw
  - Prober light demo
  - Prober light off
  - Prober light on
- Example Helpers
- Example Settings
- GPIB Actions
- Math
- Miscellaneous
- Prober Actions
- Programming
- Strings
- User Interaction
- VNA Actions

```
//This script will connect to a b1500 on address 17. This was demo'd at the Agilent hi
ADDRESS = StringCopy ("17")
GATE = StringCopy ("-0.5")
DRAIN = StringCopy ("3")
GpibSendString ("0", ADDRESS, "30000", "CN 6")
INSTRUMENT SEND = StringConcat ("DV 6.0,", DRAIN, ",0.1", "", "")
GpibSendString ("0", ADDRESS, "30000", INSTRUMENT SEND)
Foreach (GATE in "-0.5,-0.4,-0.3,-0.1,0")
{
      GpibSendString ("0", "17", "30000", "CN 5")
      INSTRUMENT SEND = StringConcat ("DV 5.0,", GATE, ",0.1", "", "")
      GpibSendString ("0", ADDRESS, "30000", INSTRUMENT SEND)
      VNA OUT = StringConcat (GATE, " GATE BIAS", "", "", "")
      VnaMeasure (VNA OUT, True, Corrected, 1, 2)
}
GpibSendString ("0", ADDRESS, "30000", "CL 5,6")
```

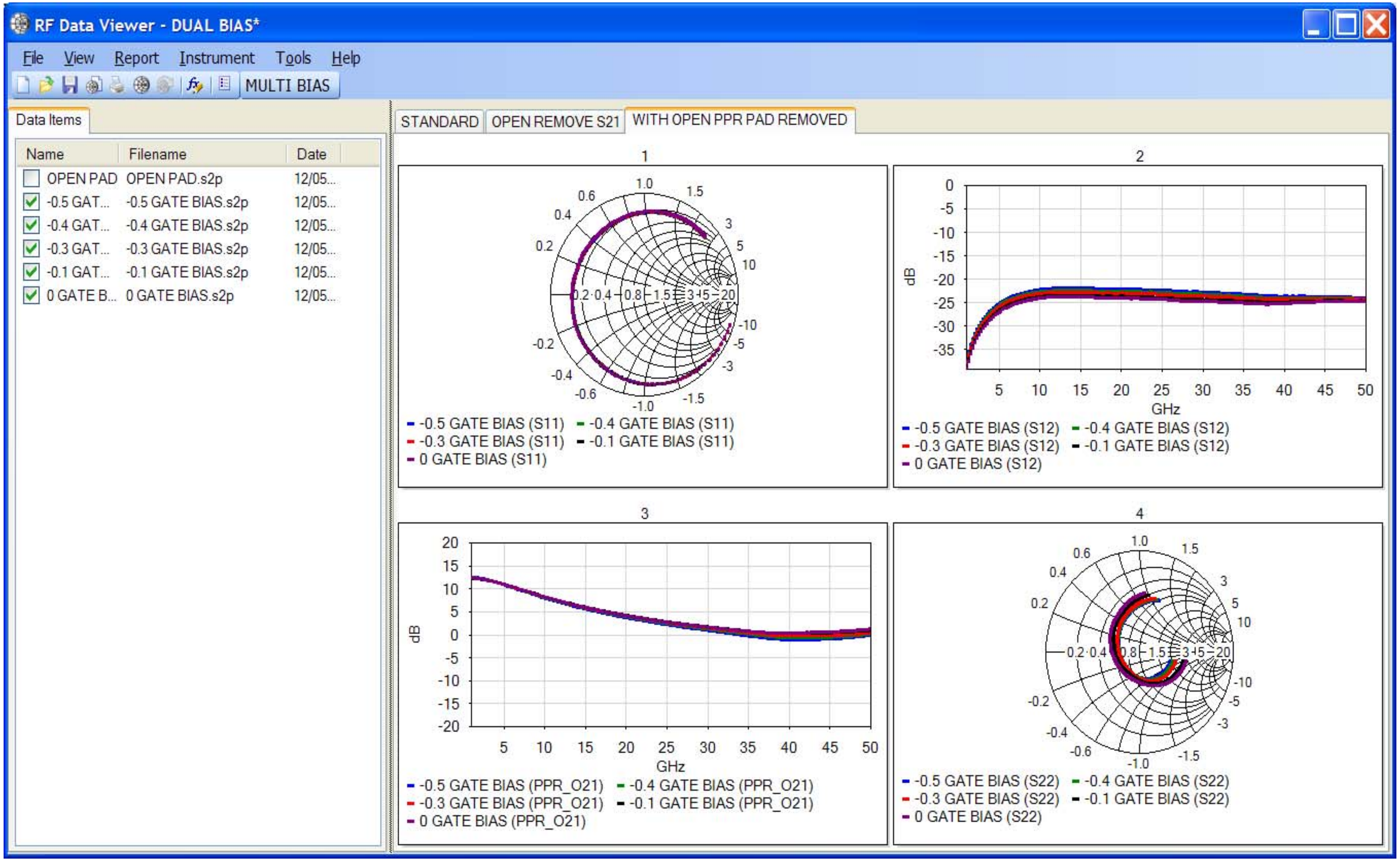
Info

Categories	**Example Appli**
Description	**User defined s**
Filename	C:\Documents ar
LastModifiec	11/04/2008 12:13
Name	**CLEANER MUI**
SaveLocatic	**Group**
Tooltip	**No tooltip yet**
Version	**1.0**

Name
Name of this sequence

- Sequences allow the prober and external instrumentation to be controlled by Wincal for simple automated testing

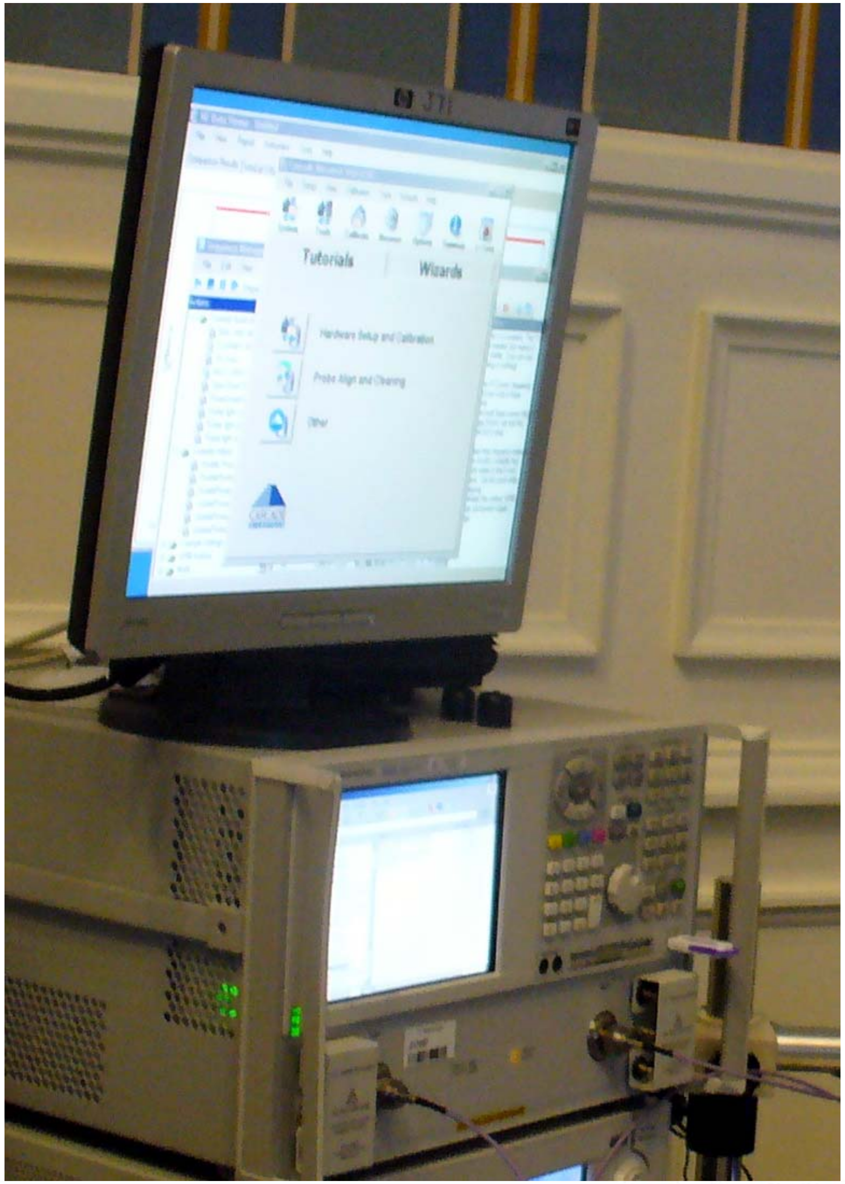
:: Wincal - Sequencing



Name	Filename	Date
☐ OPEN PAD	OPEN PAD.s2p	12/05...
☑ -0.5 GAT...	-0.5 GATE BIAS.s2p	12/05...
☑ -0.4 GAT...	-0.4 GATE BIAS.s2p	12/05...
☑ -0.3 GAT...	-0.3 GATE BIAS.s2p	12/05...
☑ -0.1 GAT...	-0.1 GATE BIAS.s2p	12/05...
☑ 0 GATE B...	0 GATE BIAS.s2p	12/05...

:: Wincal runs native on pna

- No need for external laptop and gpib adaptor
- PNA Can be used to control external instrumentation with Sequencing
- Only 1 external monitor is required



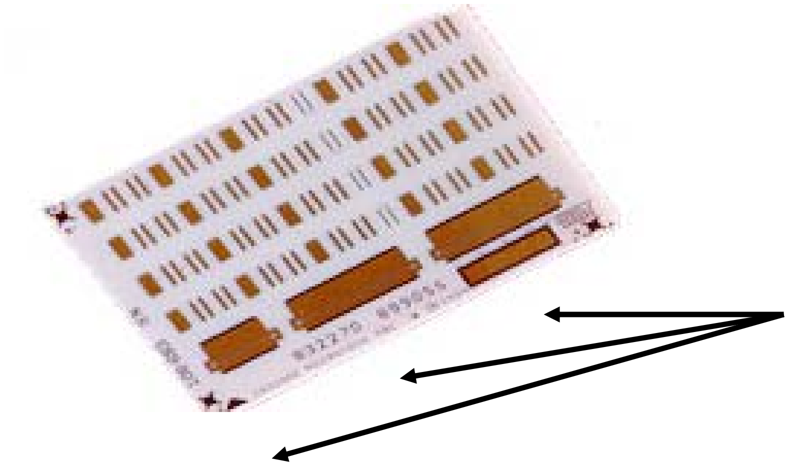
:: Calibration Verification

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

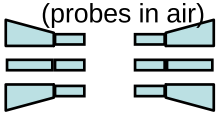


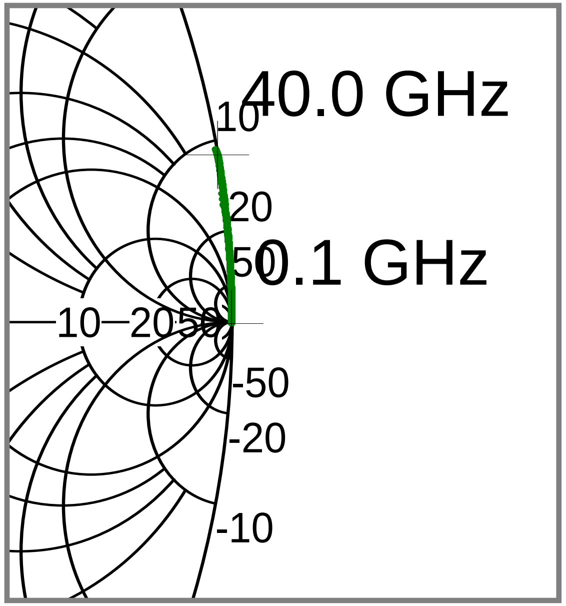
Various lengths of transmission lines

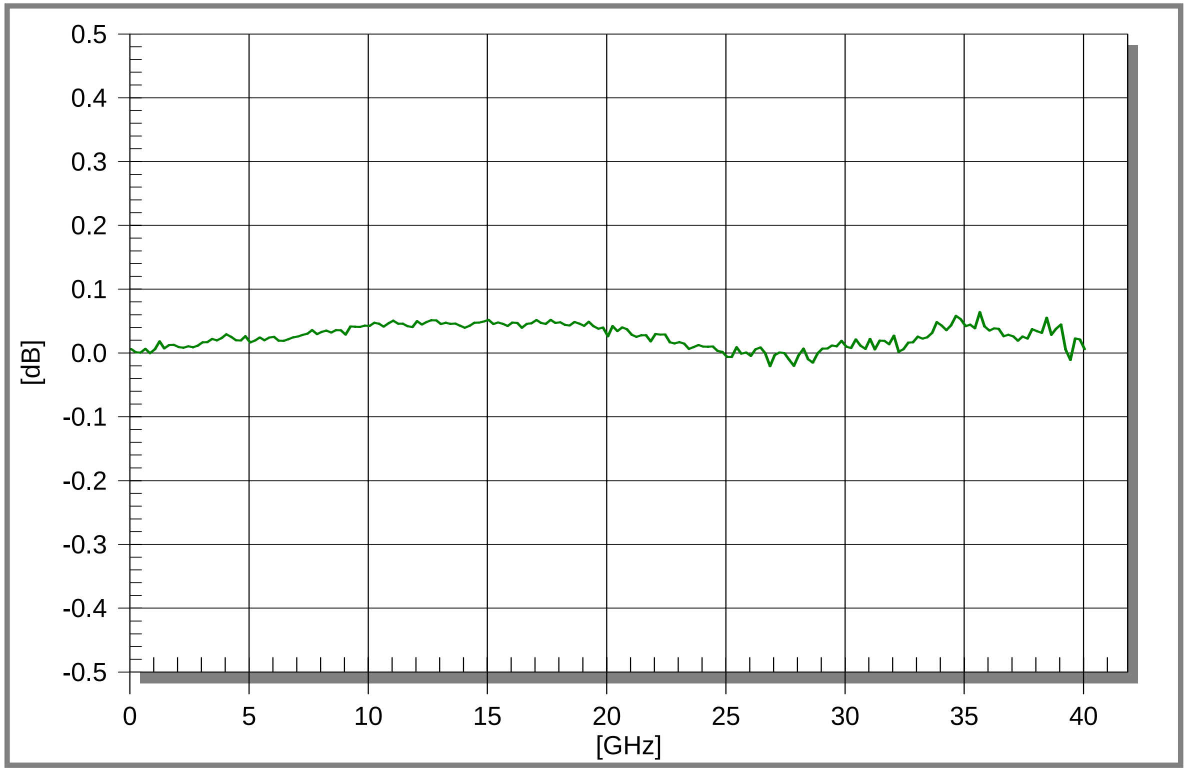
Calibration Verification Standards

Reflect

(probes in air)



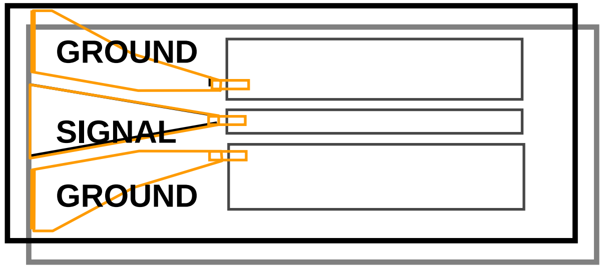


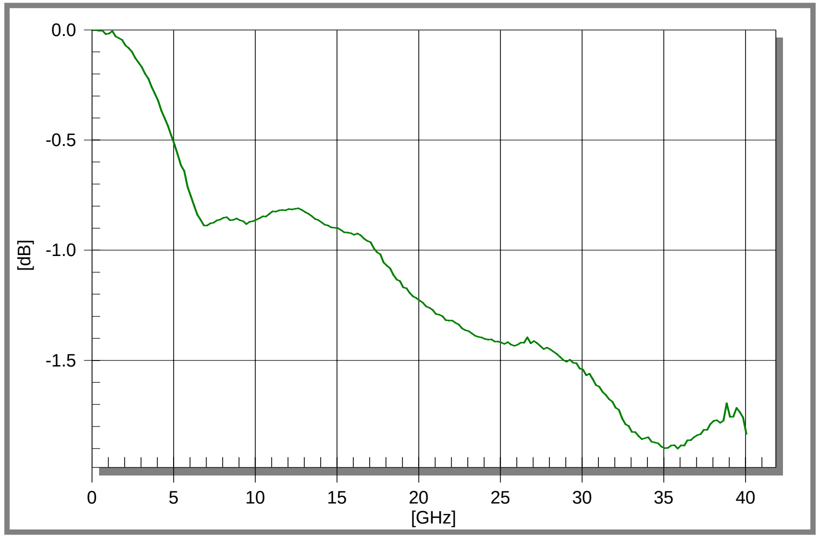


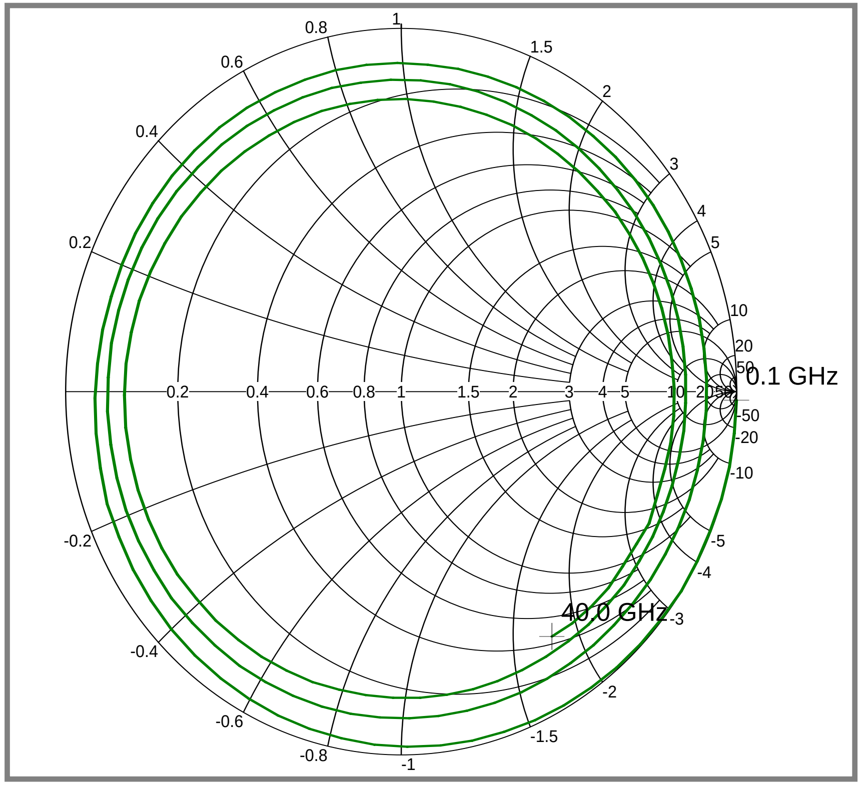
- Unity Gain
- Negative Capacitance
  - Due to wave propagation being faster in air than on the Alumna substrate

Independent Verification Standards

Open
stub



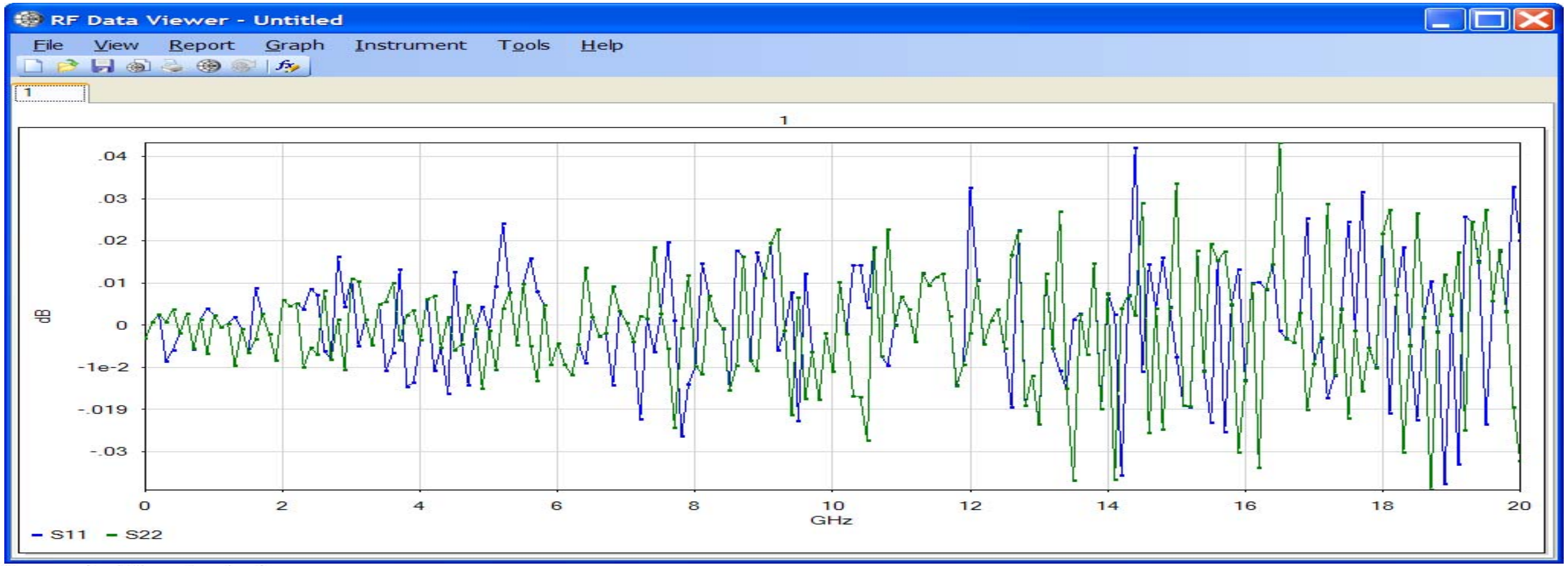




- Linear Phase Lag
- 50ohm to stub Z miss-match
- Fringing C at stub open end

:: Calibration Drift

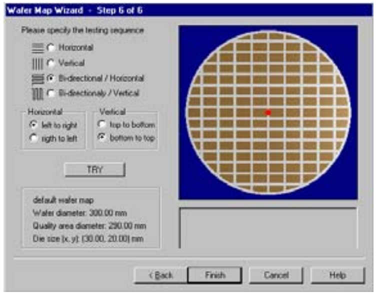
- WinCal XE Calibration software has a feature called monitoring
- Monitoring allows the user to capture calibrated reference data immediately after a calibration has been performed. At a later time, you can re-measure the previously-acquired references (by selecting Calibration>Monitor in the Calibration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



Design for testability

:: 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?



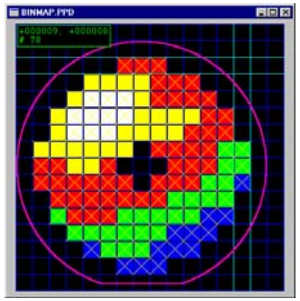
Please specify the testing sequence

○ Horizontal
○ Vertical
● Bi-directional / Horizontal
○ Bi-directionaly / Vertical

Horizontal
● left to right
○ rigth to left

Vertical
○ top to bottom
● bottom to top

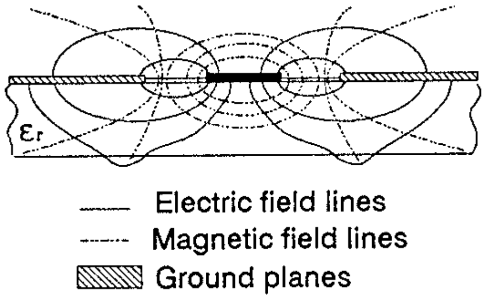
default wafer map
Wafer diameter: 300.00 mm
Quality area diameter: 290.00 mm
Die size (x, y): (30.00, 20.00) mm

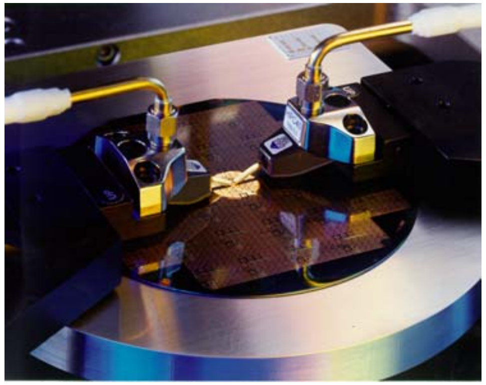


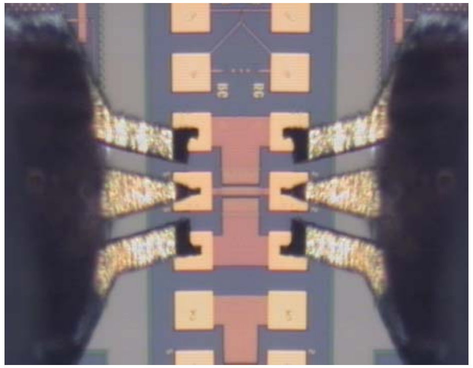
+000009, +000008
78

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

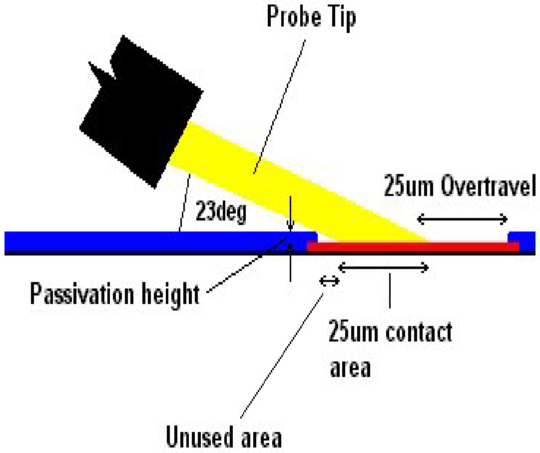


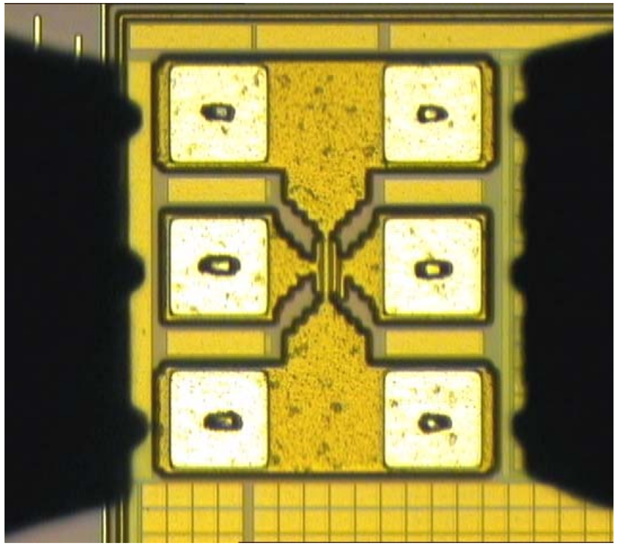




:: Pad Sizes

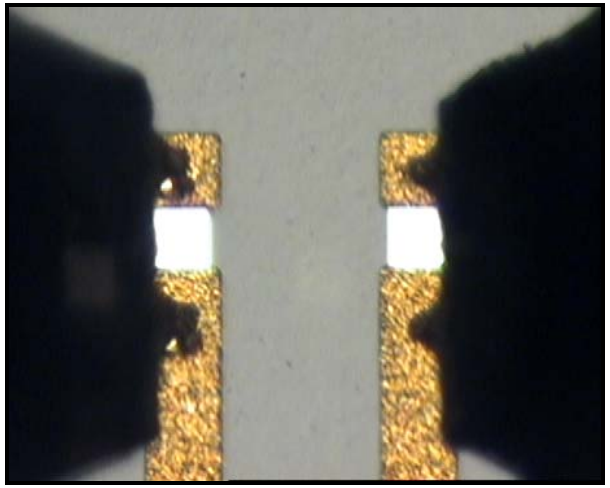
- **Recommended minimum pad is 80um x 80um for ACP Probes**
- Infinity Probe Allows 50um x 50um probing
- **Passivation height must be considered**
- **Pad height variation must not exceed 25um for ACP or 0.5um for Infinity**

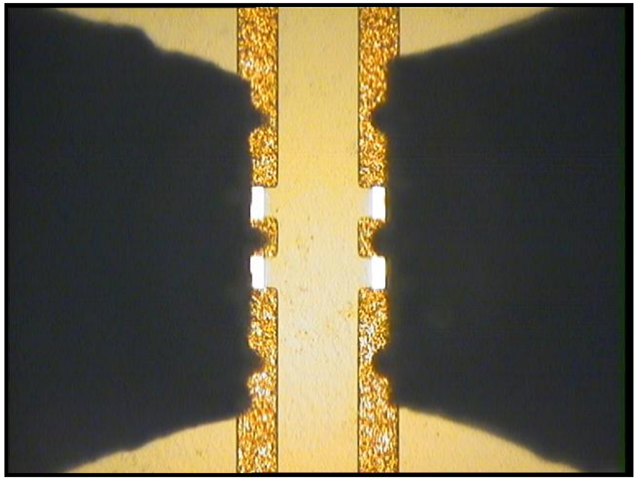




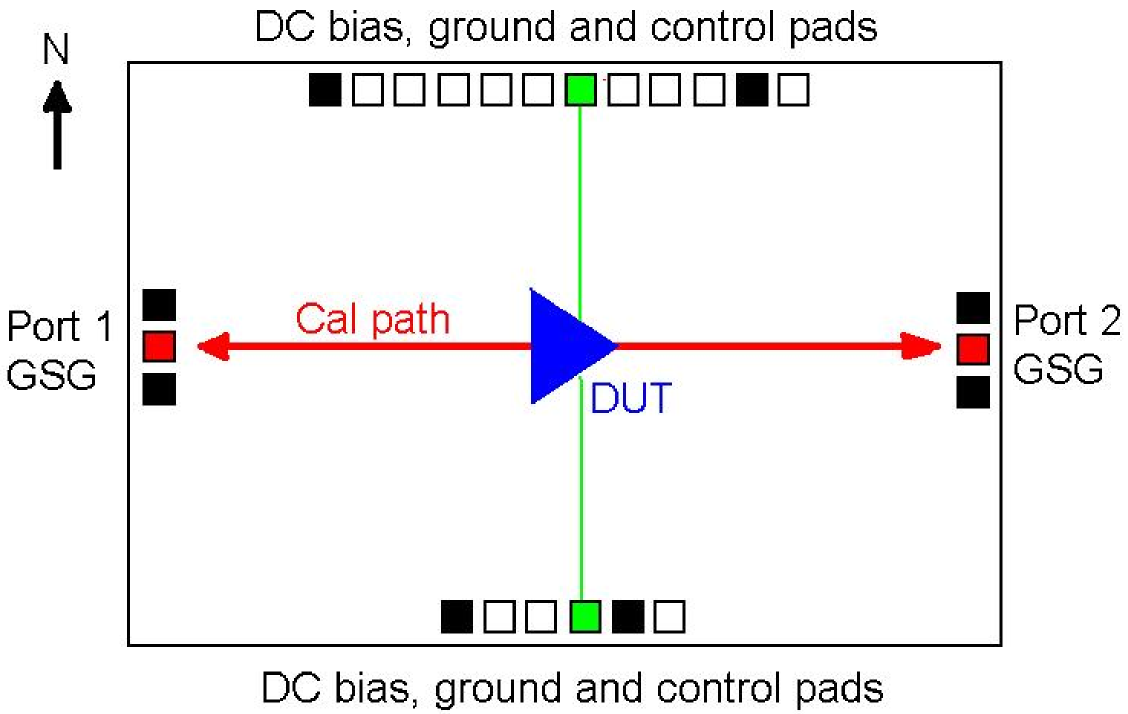
Probe Configuration

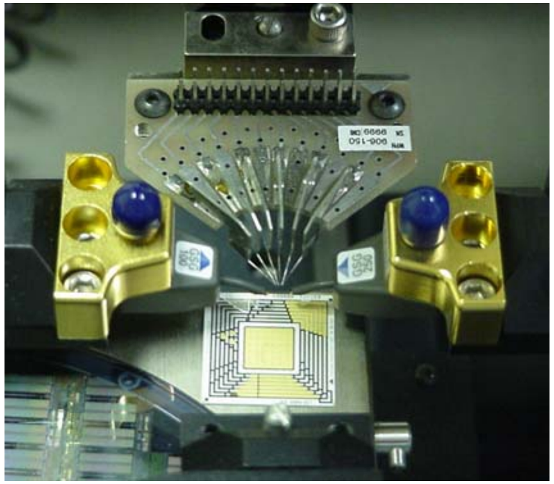
- **Whenever possible use GSG**
  - Use GSG above 10GHz
- **Probe pitch affects S-parameters**
  - Use smallest practical pitch
    - 1/50th λ of highest frequency for GS
    - 1/20th λ of highest frequency for GSG



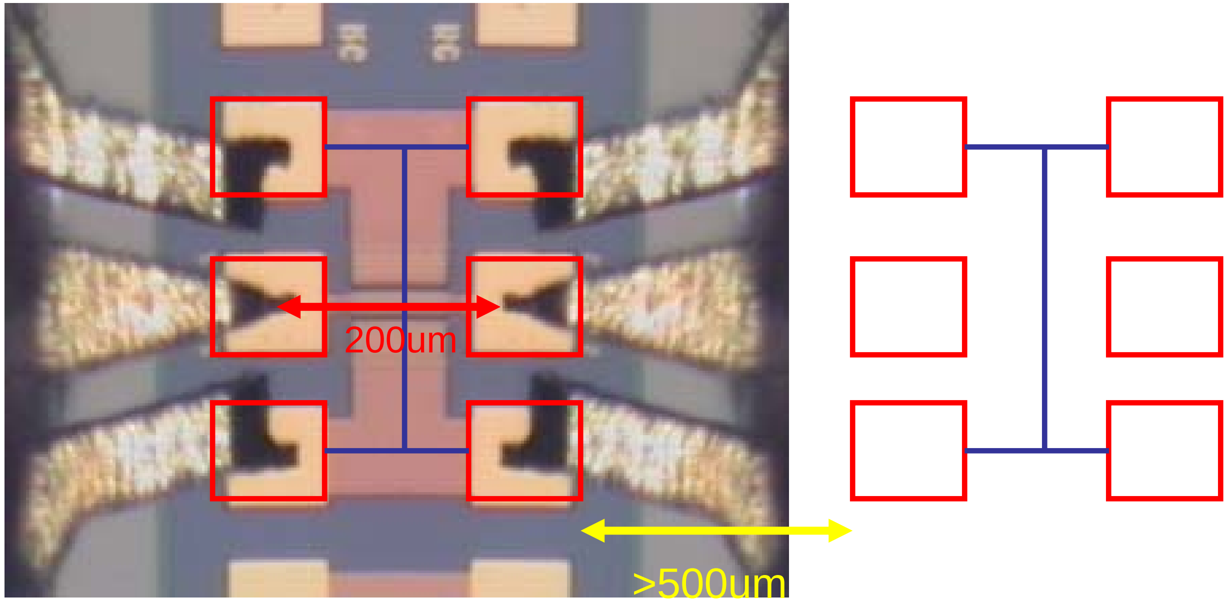


:: Device Pad Layout





:: Probe Pad Positioning

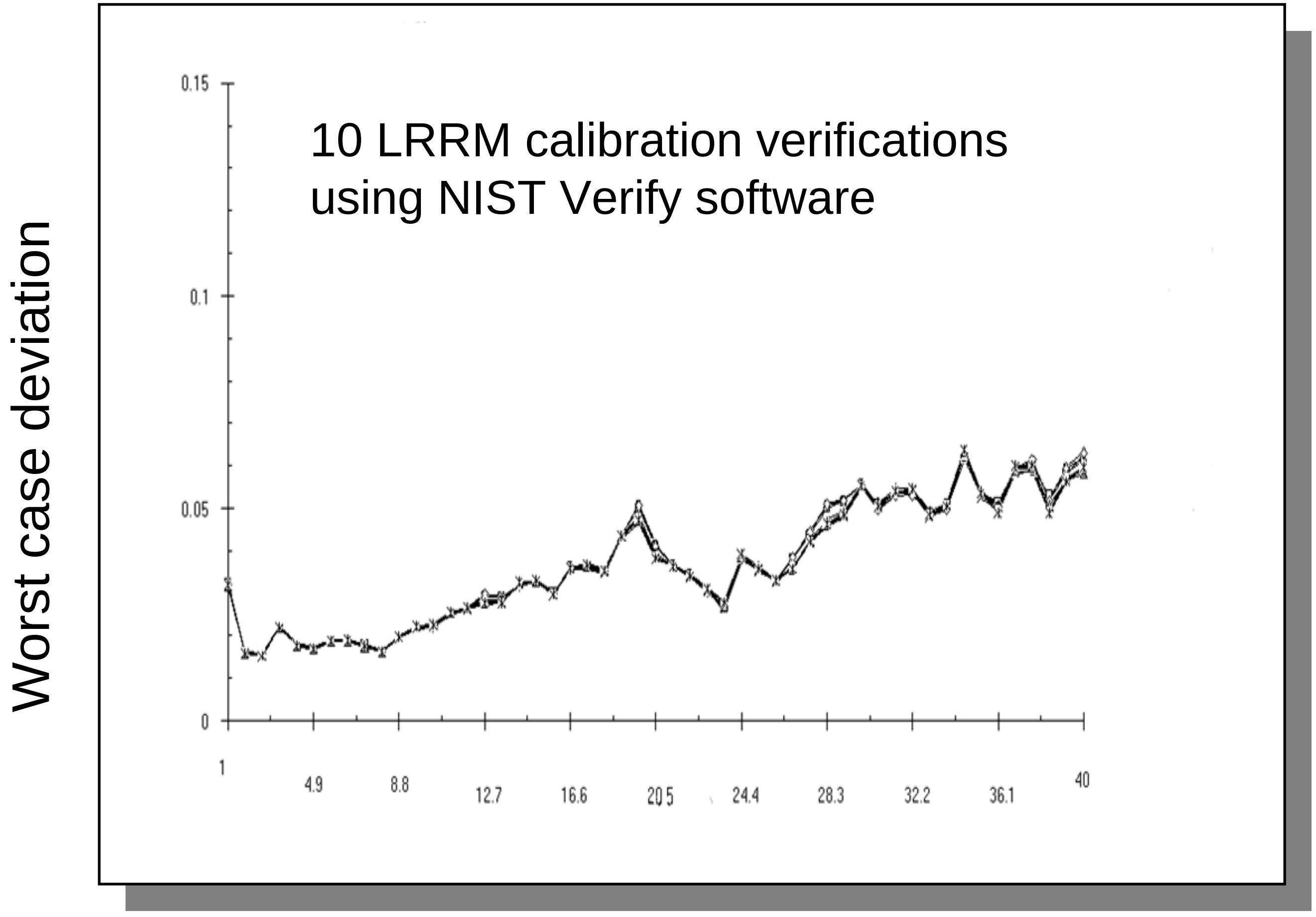


- RF probes should have more than 200um separation to avoid cross-talk
- All pads must be on top surface
- All grounds should be connected together
- Adjacent devices should be >500um away for mm-wave measurements (>250um for Infinity)

:: 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



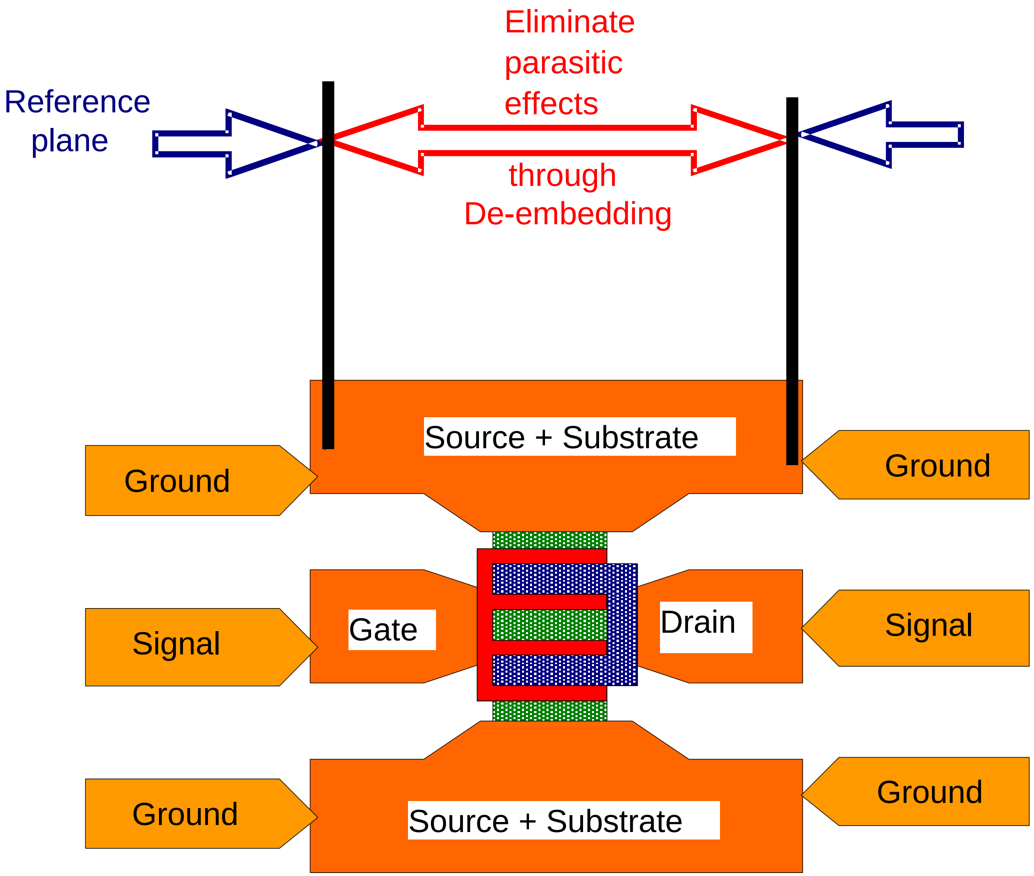
10 LRRM calibration verifications using NIST Verify software

- 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

Measurement and De-embedding

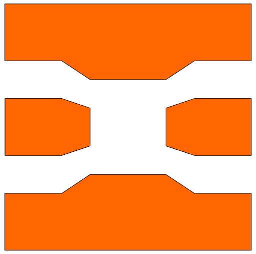


After calibration, the measurement reference plane is at the probe tip

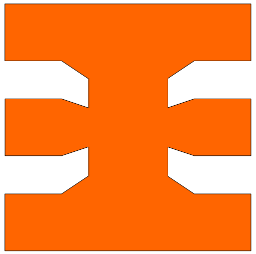
What is measured is the response of the device and the parasitics associated with the pads

De-embedding and Verification Test Structures

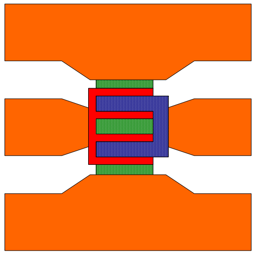
OPEN



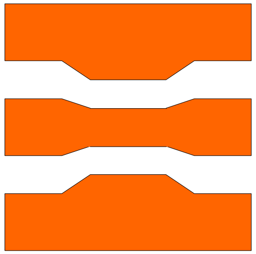
SHORT



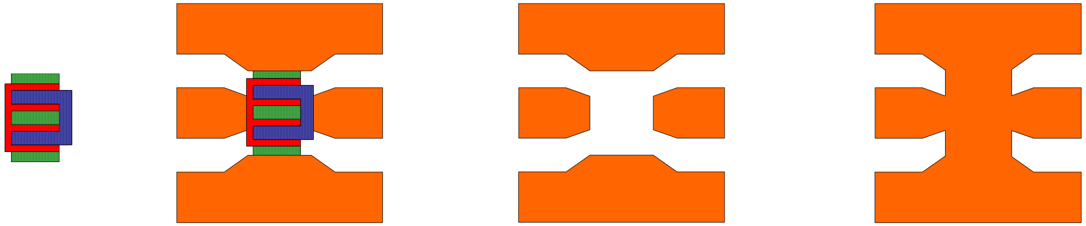
DUT



THRU



:: De-embedding dummy devices



De-embedding from OPEN and SHORT

The parasitics of the OPEN consists only of parallel elements to the DUT

- More importance for high impedance devices

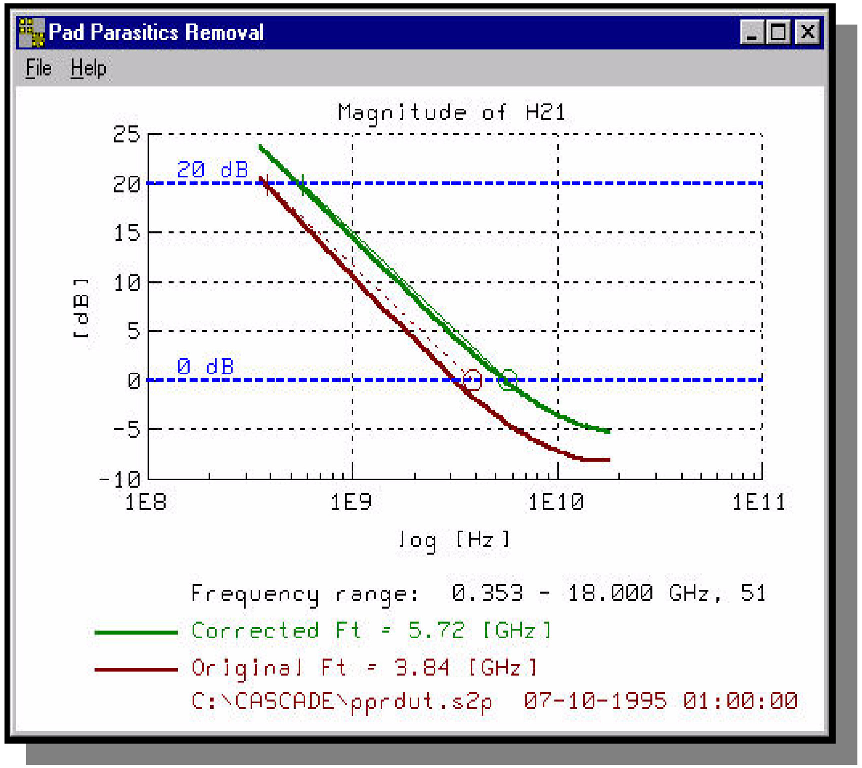
The parasitics of the SHORT consists only of series elements to the DUT

- More importance for high impedance devices

Use of Z and Y correction also helps eliminate residual cal errors

:: 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



Frequency range: 0.353 - 18.000 GHz, 51

Corrected Ft = 5.72 [GHz]

Original Ft = 3.84 [GHz]

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- Thankyou for listening
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