Recent enhancements in RF On-Waver probe tip calibrations

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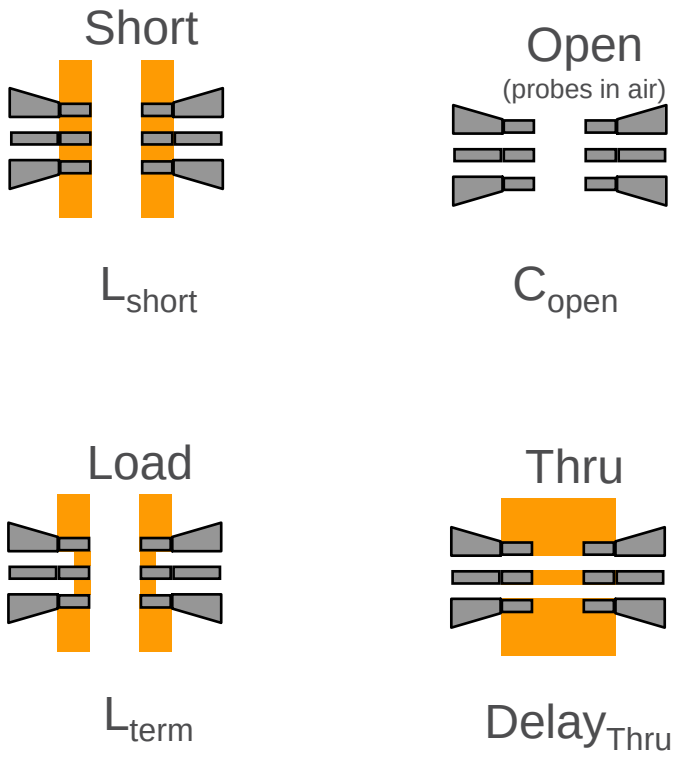
Agenda

- Basic Calibration techniques challenges
- Augmented Probe Align
- New Least Square Calibration Algorythm
- Second Tier calibrations

SOLT Calibration

- Oldest calibration technique
- All standards must be perfectly known
- Cal Kit Definition required
  - Open has capacitance (often negative)
  - Short and load have inductance
  - Mathematically over-determined
- Not easy to validate



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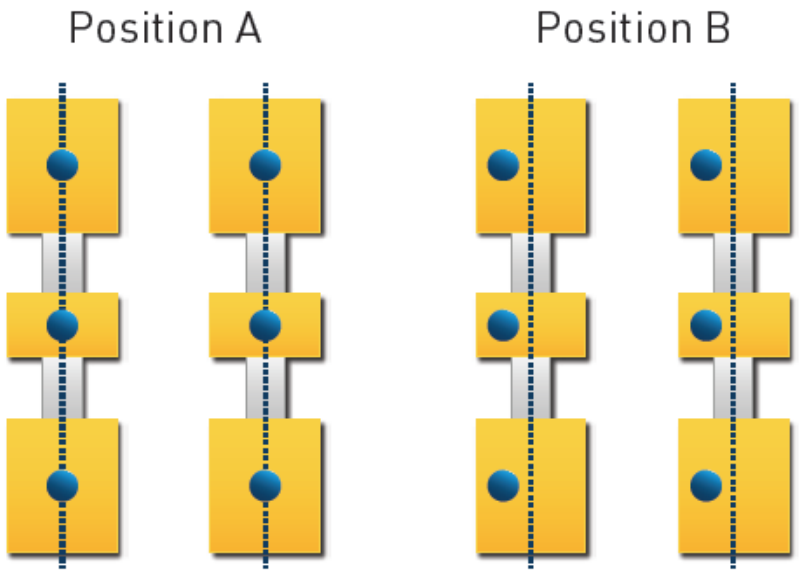
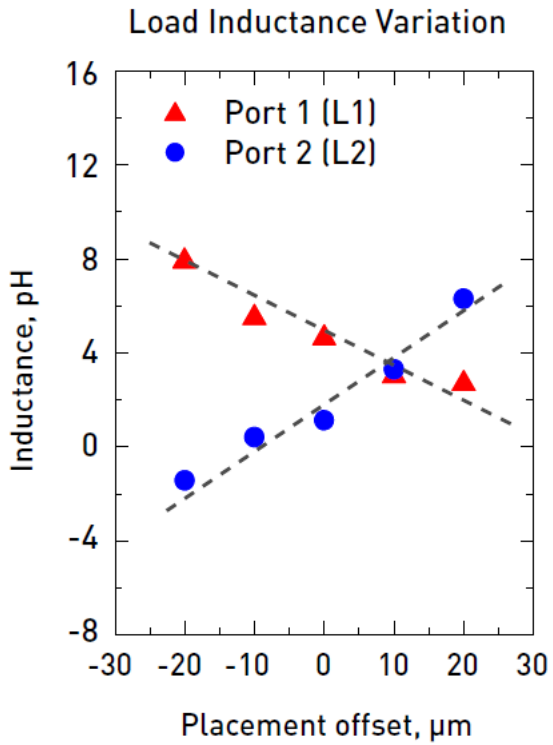
SOLT is sensitive to Probe Placement





	Open C, fF	Short L, pH	Load L, pH Port 1	Load L, pH Port 2
Table value	-7.2	5.0	-3.3	-3.3
Extracted value	-5.5	6.0	0.1	1.0

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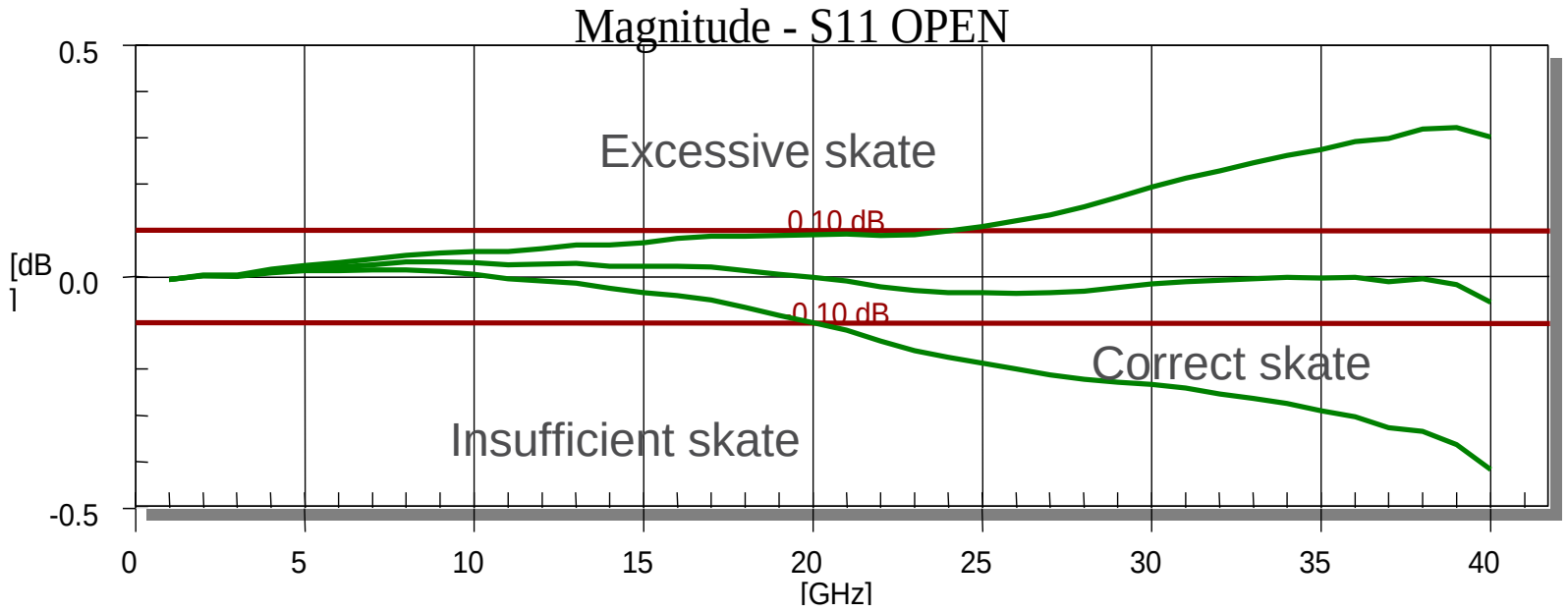
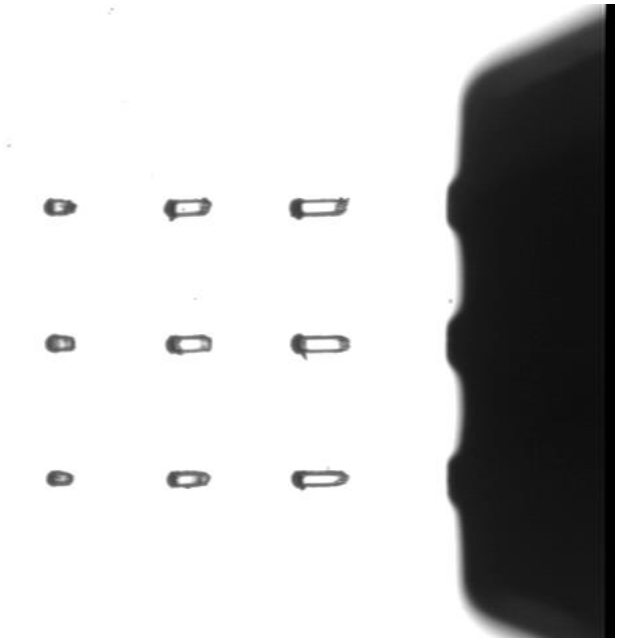
SOLT is sensitive to Overtravel/Skate

- Incorrect skate will have a frequency dependent effect on the reflection measurement





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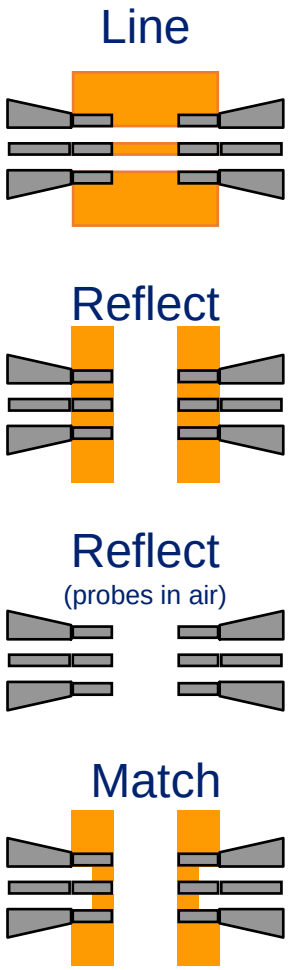
LRRM Calibration



- Line-Reflect-Reflect-Match Calibration
- Uses same Standards as SOLT
- Requires less information about standards
- Thru (line) delay, Match resistance must be known
- Measurements referenced to trimmed resistor

  →Less sensitive to probe placement errors

Alignment marks on calibration substrates

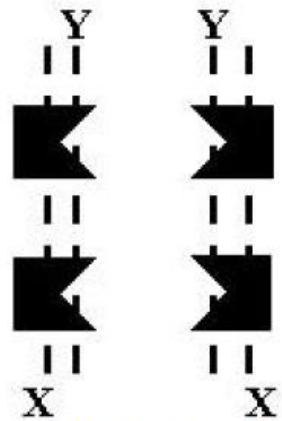


Figure 1: Alignment marks

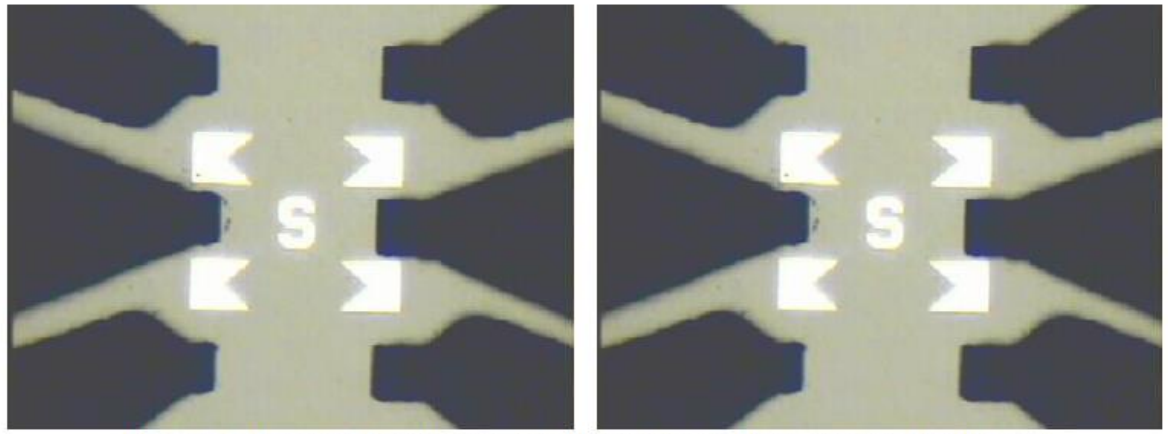


Figure 2: Images showing correct alignment and placement of probe tips

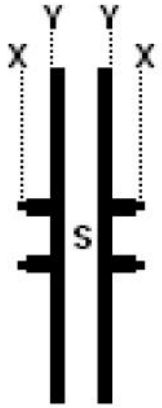


Figure 1: Alignment marks

Initial contact **Final contact**

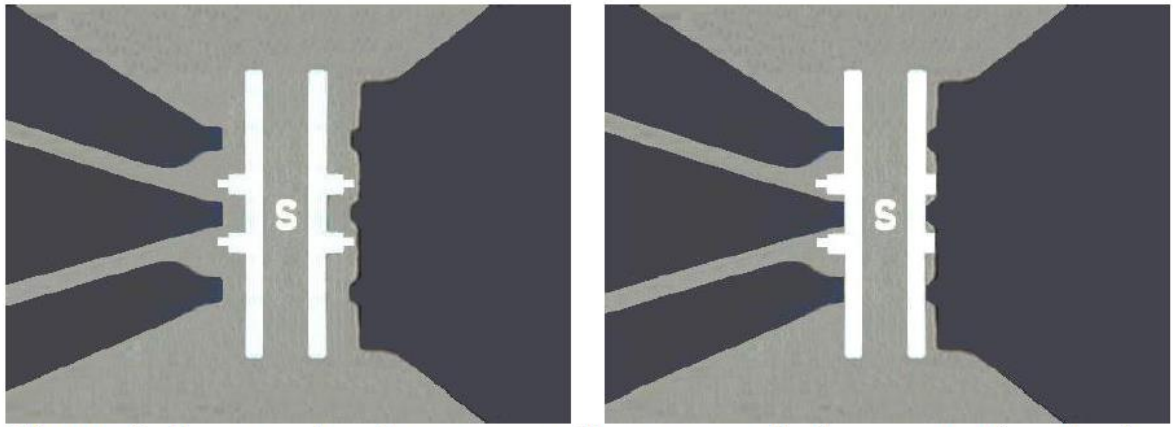


Figure 2: Images showing correct alignment and placement of probe tips of both ACP and Infinity style probes.

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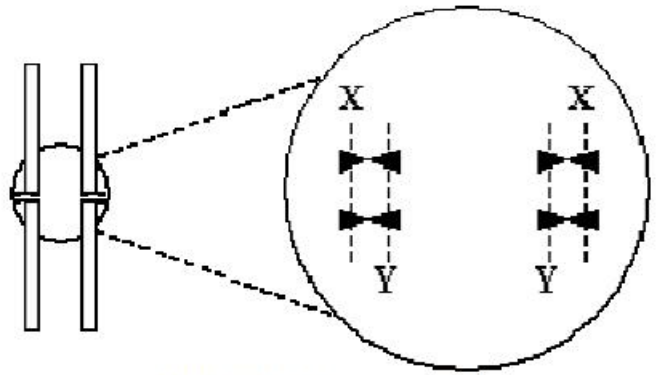
Alignment marks on calibration substrates



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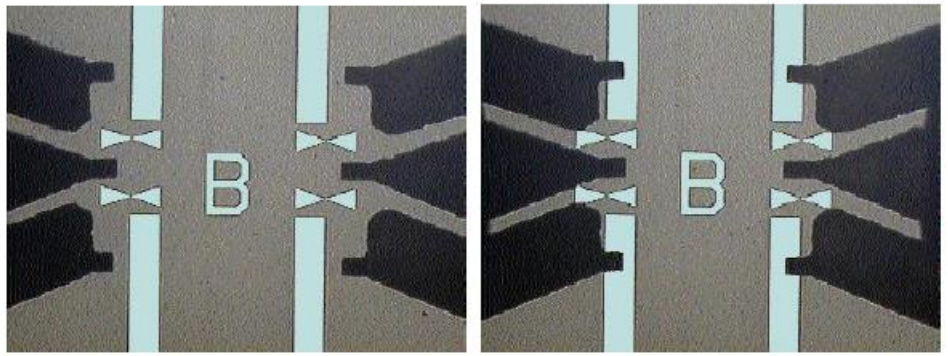
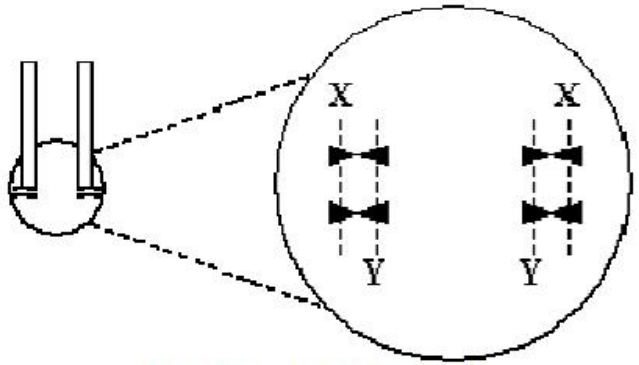


Figure 2: Images showing correct alignment and placement of probe tips



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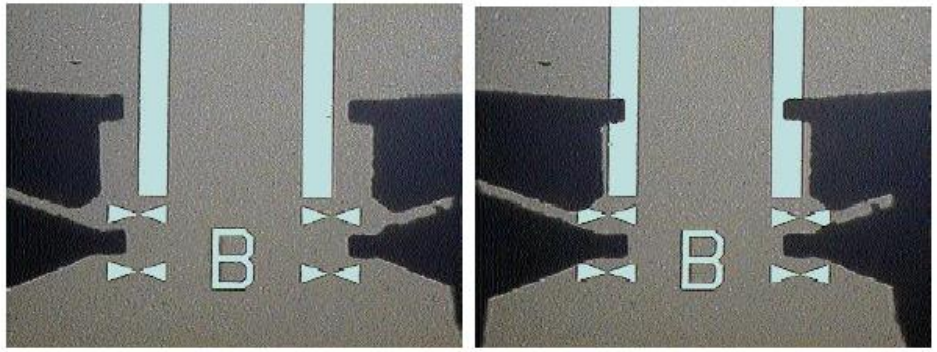

Figure 2: Images showing correct alignment and placement of probe tips

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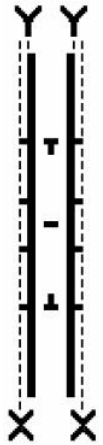
Alignment marks on calibration substrates



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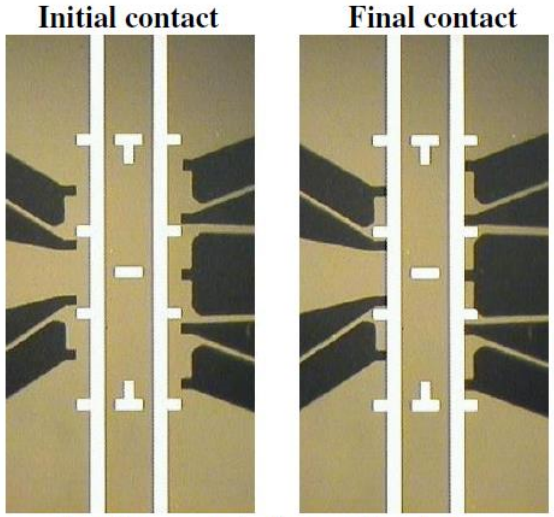
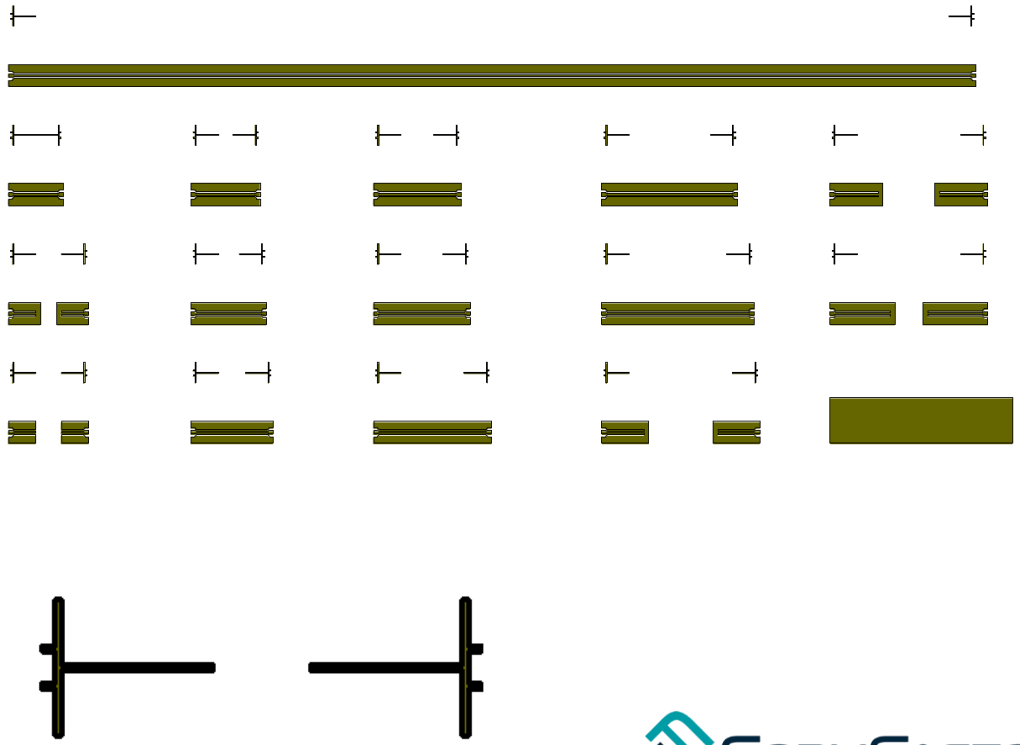


Figure 2: Images showing correct alignment and placement of probe tips of both GSSG and GSGSG ACP style probes.



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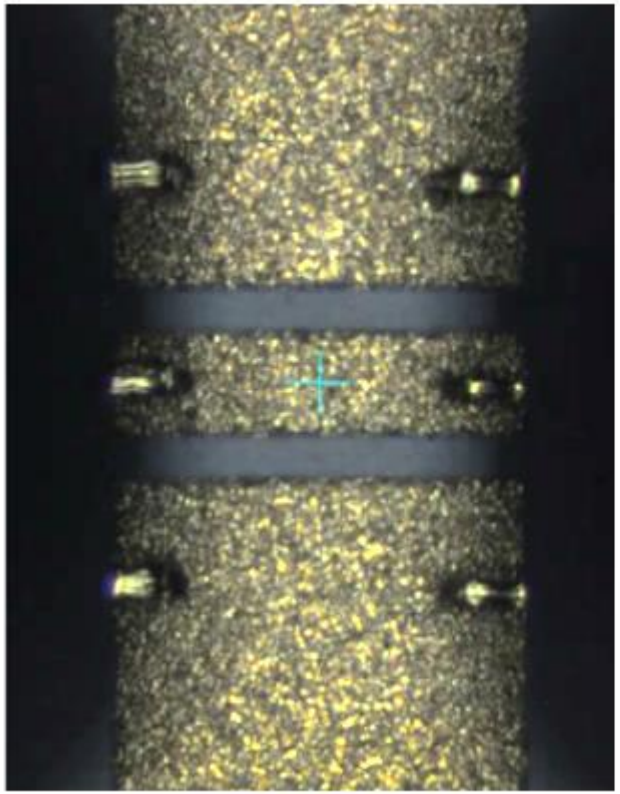
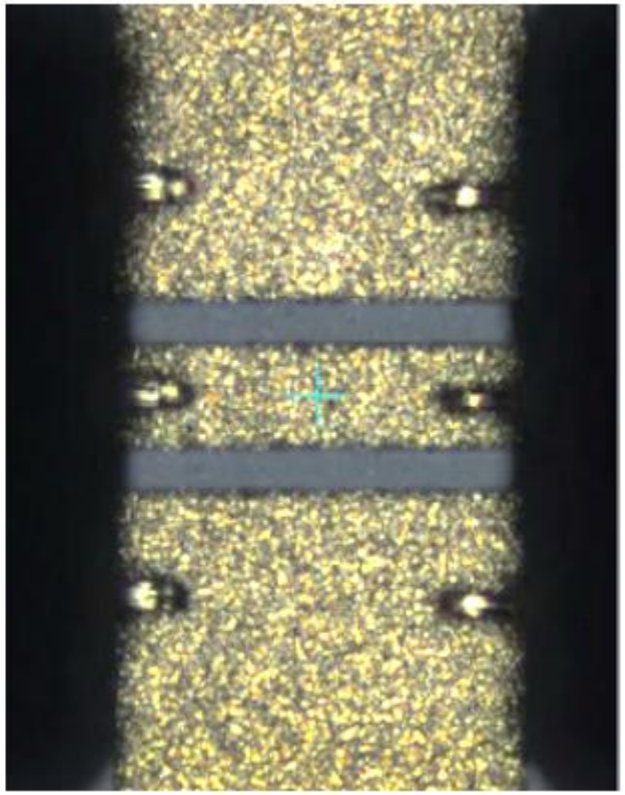
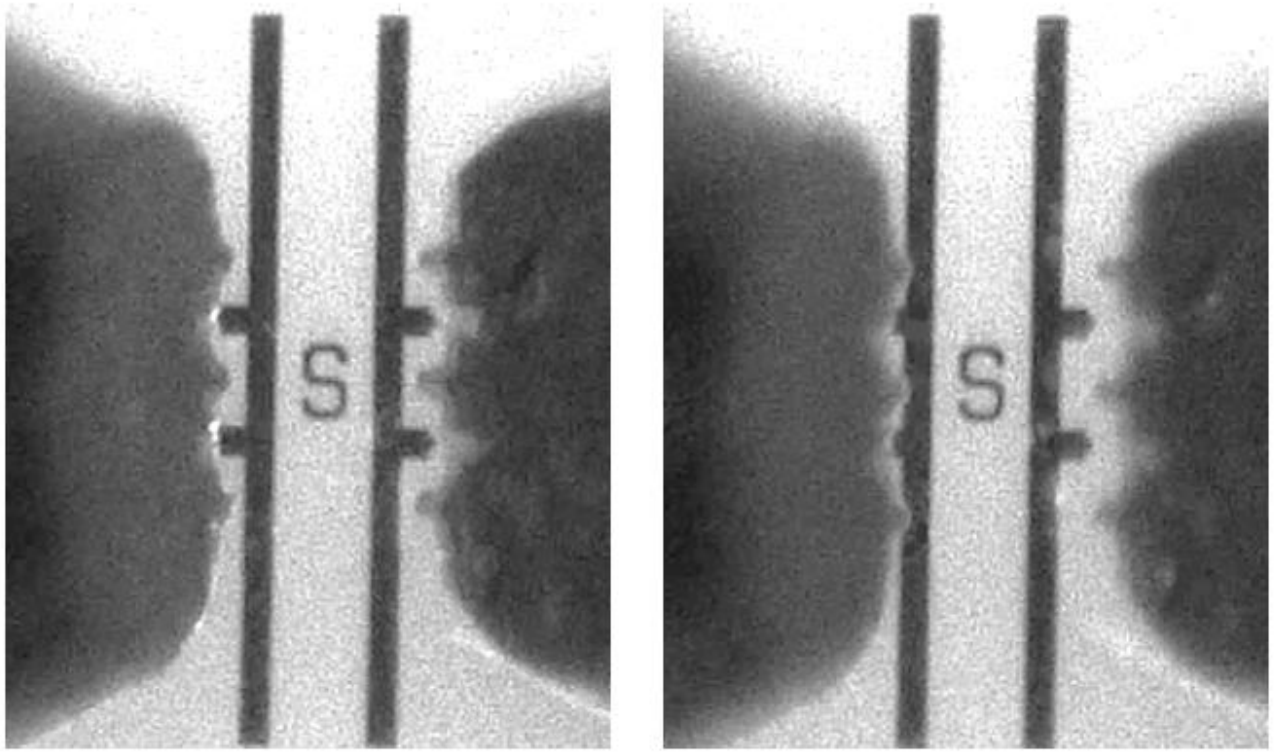
Microscopy impacts





When the probes are lifted up and out of focal plane, it can be difficult to anticipate their landing point.

Microscopy impacts



→ Augmented (Reality) Alignment!

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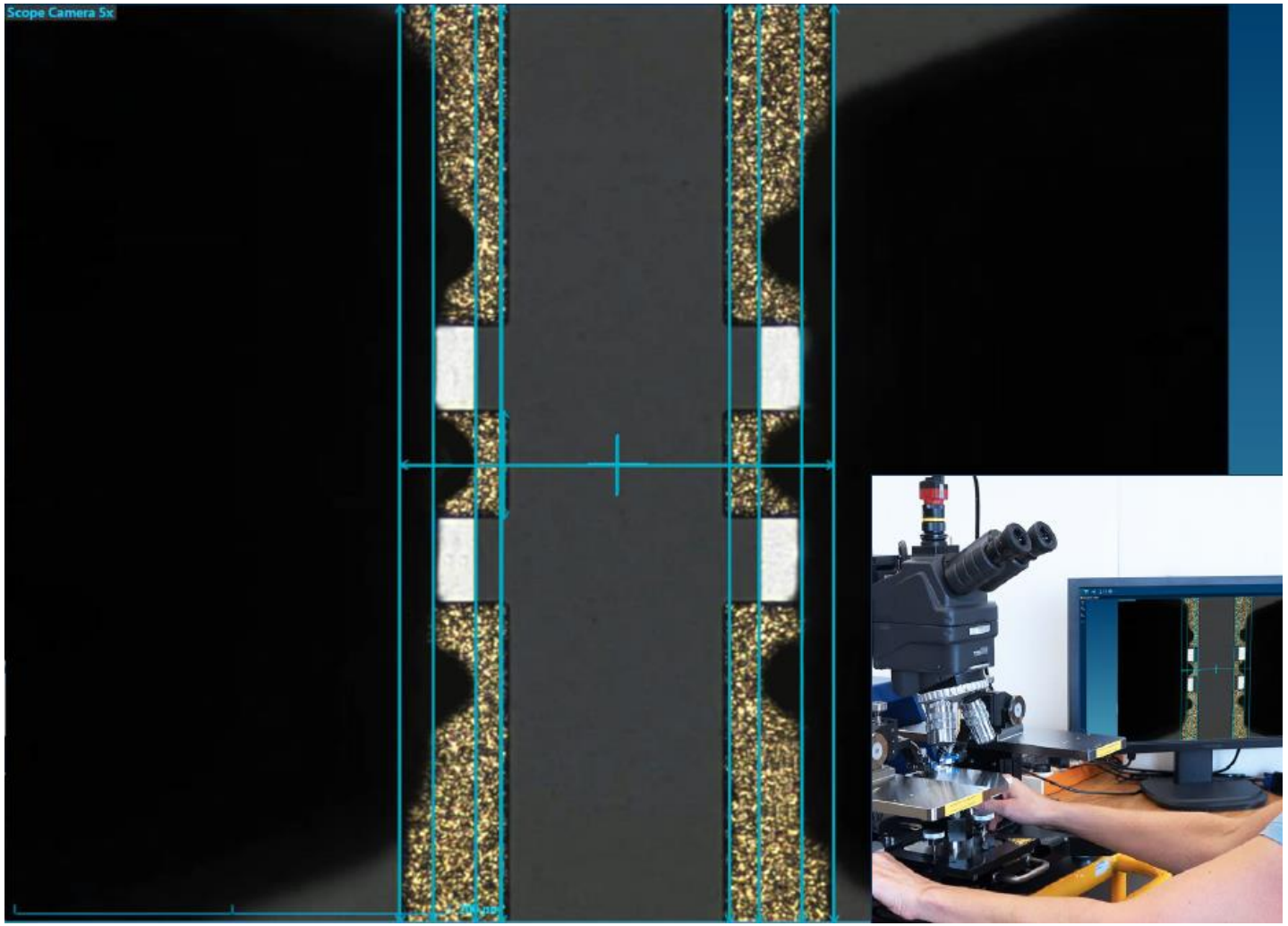
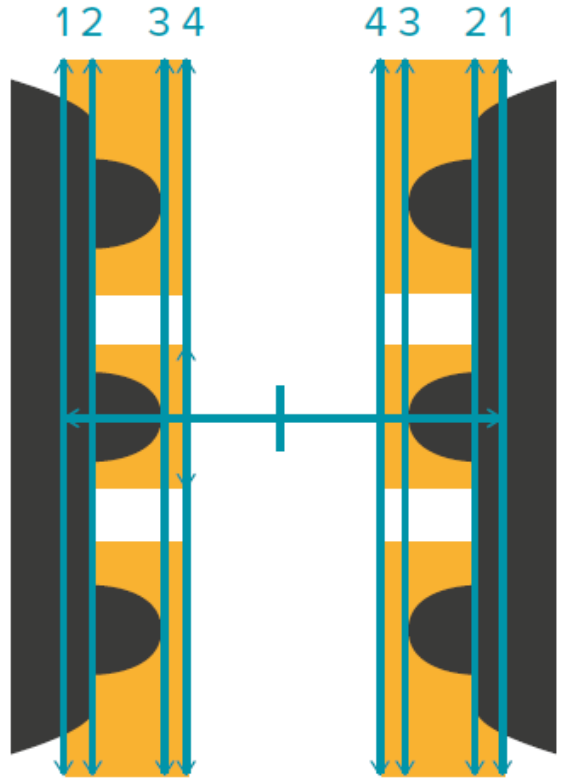
Augmented Alignment





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1-port Least Square Calibration Algorythm

- Allows calibration of 1 port THz setups using a series of reflects
- This method is an extension of a standard SOL One-port calibration algorithm.
- Instead of generating 3 equations to solve with 3 standards for 3 unknown VNA error terms, the method generates N (> 3) equations to solve for 3 unknown errors.
- Still requires ideal knowledge of the standards

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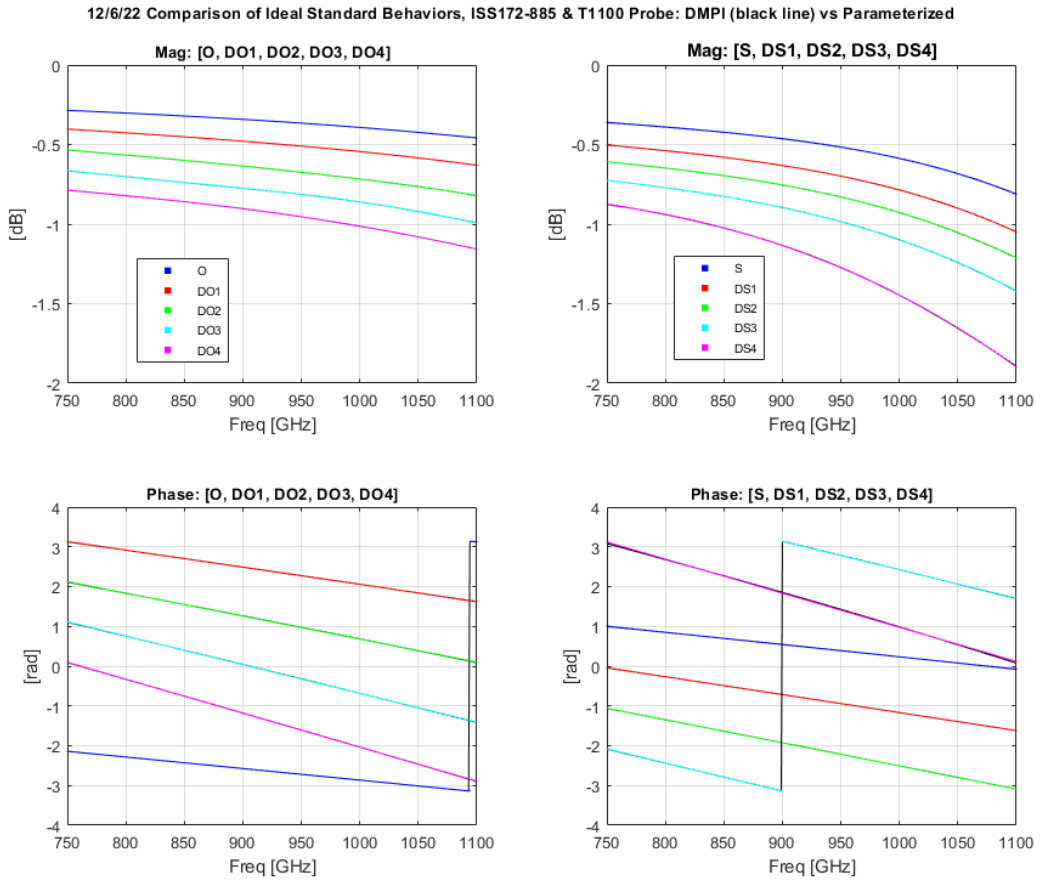
1-port Least Square Calibration Algorythm

Standard	a0	a1	a2	a3	p0	p1
OPEN	1.00944319E+00	-1.15756346E-13	1.34286786E-25	-7.21562295E-38	4.32761411E-02	-2.90863975E-12
DO1	1.04570896E+00	-2.65159231E-13	2.91071551E-25	-1.32362676E-37	6.36302306E+00	-4.30602966E-12
DO2	1.04901269E+00	-2.98233890E-13	3.07983872E-25	-1.37981504E-37	6.46146020E+00	-5.78103774E-12
DO3	1.28557296E+00	-1.15025909E-12	1.27017304E-24	-4.99908996E-37	6.52145556E+00	-7.20564132E-12
DO4	9.70059866E-01	-1.54825828E-13	1.98079888E-25	-1.23394033E-37	6.50497371E+00	-8.54224103E-12
SHORT	1.38501280E+00	-1.50735718E-12	1.84183366E-24	-7.84879380E-37	3.32051378E+00	-3.08610129E-12
DS1	1.33137639E+00	-1.37756702E-12	1.71216357E-24	-7.52486425E-37	3.34310419E+00	-4.51002353E-12
DS2	1.24652214E+00	-1.12899918E-12	1.44393520E-24	-6.62785123E-37	3.29575144E+00	-5.80282772E-12
DS3	1.20186538E+00	-1.01966090E-12	1.33606950E-24	-6.37041925E-37	3.26877676E+00	-7.12921784E-12
DS4	8.12522097E-01	2.32770428E-13	4.01969157E-27	-2.02691180E-37	9.55173334E+00	-8.57446045E-12



Example shown if for T1100 probes and 172-885 iss

1-port Least Square Calibration Algorythm

- $(\Gamma_{L1}, \Gamma_{L2}, \Gamma_{L3}, \ldots, \Gamma_{Ln})$: one-port electrical behavior definition of n standards.
- $(\Gamma_{m1}, \Gamma_{L2}, \Gamma_{m3}, \ldots, \Gamma_{mn})$: the corresponding one-port measurements of n standards.

$$\begin{bmatrix} 1 & \Gamma_{m1}\Gamma_{L1} & -\Gamma_{L1} \\ 1 & \Gamma_{m2}\Gamma_{L2} & -\Gamma_{L2} \\ 1 & \Gamma_{m3}\Gamma_{L3} & -\Gamma_{L3} \\ \vdots & \vdots & \vdots \\ 1 & \Gamma_{mn}\Gamma_{Ln} & -\Gamma_{Ln} \end{bmatrix} \begin{bmatrix} e_d \\ e_s \\ \Delta S \end{bmatrix} = \begin{bmatrix} \Gamma_{m1} \\ \Gamma_{m2} \\ \Gamma_{m3} \\ \vdots \\ \Gamma_{m4} \end{bmatrix} \quad (1)$$

$$Where\ \Delta S = (e_d)(e_s) - (e_r) = S_{11}\,S_{22} - S_{12}\,S_{21}$$

$$e_r = S_{11}\,S_{22} - \Delta S \quad (2)$$

Equation (1) can be rewritten as:

$$A \cdot x = b \quad (3)$$

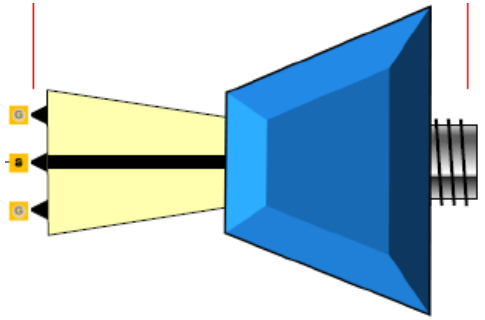
An optional solution is given as:

$$x = [A^H \cdot A]^{-1} \cdot A^H \cdot b \quad (4)$$

Where A^H is Hermitian Matrix of A, of which every entry is the conjugate of the corresponding entry of A.

2 Tier Calibrations

- Two Tier Calibration of a Vector Network Analyzer is a technique that allows two calibration error sets to be combined into one resulting error set for the VNA error correction.
- This technique solves VNA calibration problems that are not easily solved by one calibration error set alone.
- Examples:
  - Mixed port connections (probe + coax)
  - Probes with different pitches
  - Non-matching tip configurations (GSSG + GSG)



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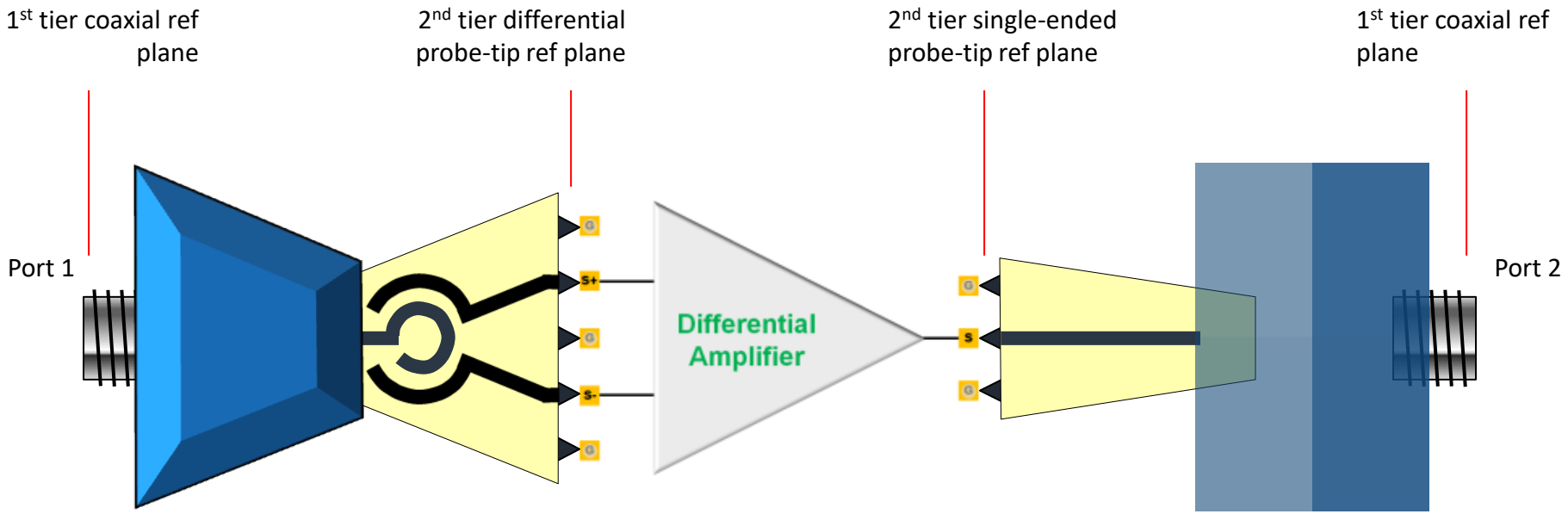
Case Study: Differential Amplifier



- No possible Thru, so how do we calibrate to the probe tips?
- Answer:
  - 1st tier 2-port coaxial calibration
  - 2nd tier differential probe-tip 1-port cal (port 1)
  - 2nd tier single-ended 1-port cal (port 2)

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Summary

- On wafer calibrations have several challanges
- Advanced algorythms optimized for on-wafer situations
- Lines are always involved, accurate positioning required
- Additional software often required for specialized cases:
  - Least square calibration (1-port THz)
  - Second Tier (missing/impossible Thru connections)