Enabling accurate on-wafer device characterization in the mmw/THz range

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Outline

- Introduction
- mmw/THz System Setups
- Probe System Optimization for mmw/THz
- Infinity mmw Probes
- Calibration Implications

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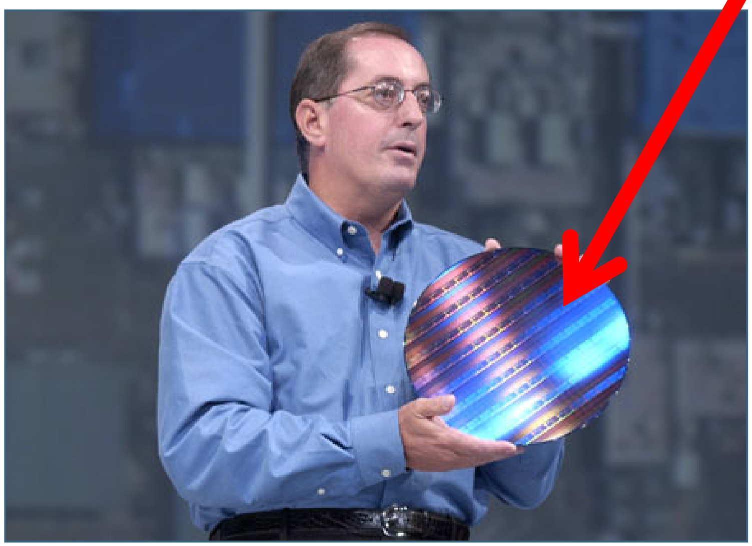
Want Do We Do?

- We enable connecting this to that



Our mission: to make our part of the system invisible for the DUT measurement results

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Wafer-Level Measurement System

- VNA, SMU
- Bias Tees
- Cables
- Probes
- RF positioners
- Probe station
- Controller, Chiller
- Digital imaging system (microscope)
- Calibration substrate (ISS)
- Calibration software (WinCal XE™)

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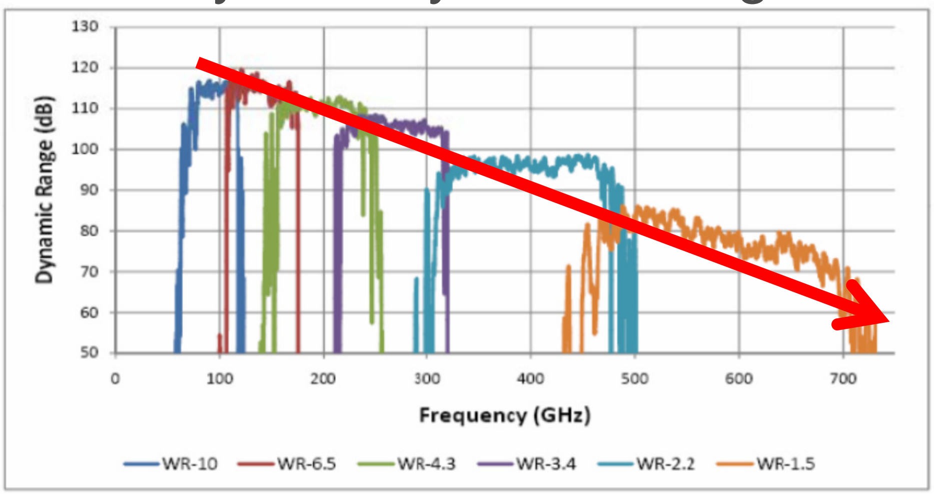
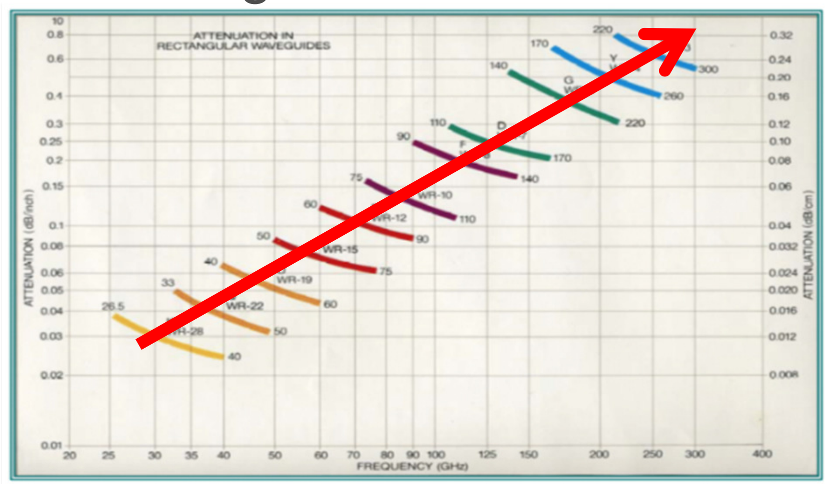
Challenge for Dynamic Range

System Dynamic Range



Waveguide Attenuation



- Available power and VNA dynamic range decreases with the frequency
- Waveguide loss increases

→ Optimized on-wafer systems required (station, probes, calibration)

System Setups and Connection Schemes

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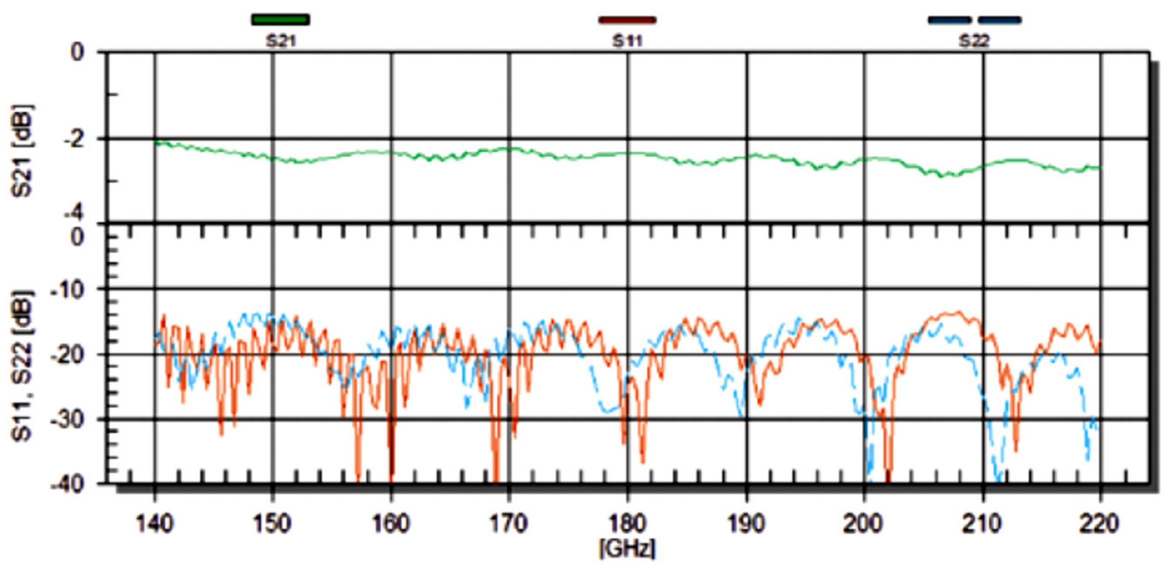
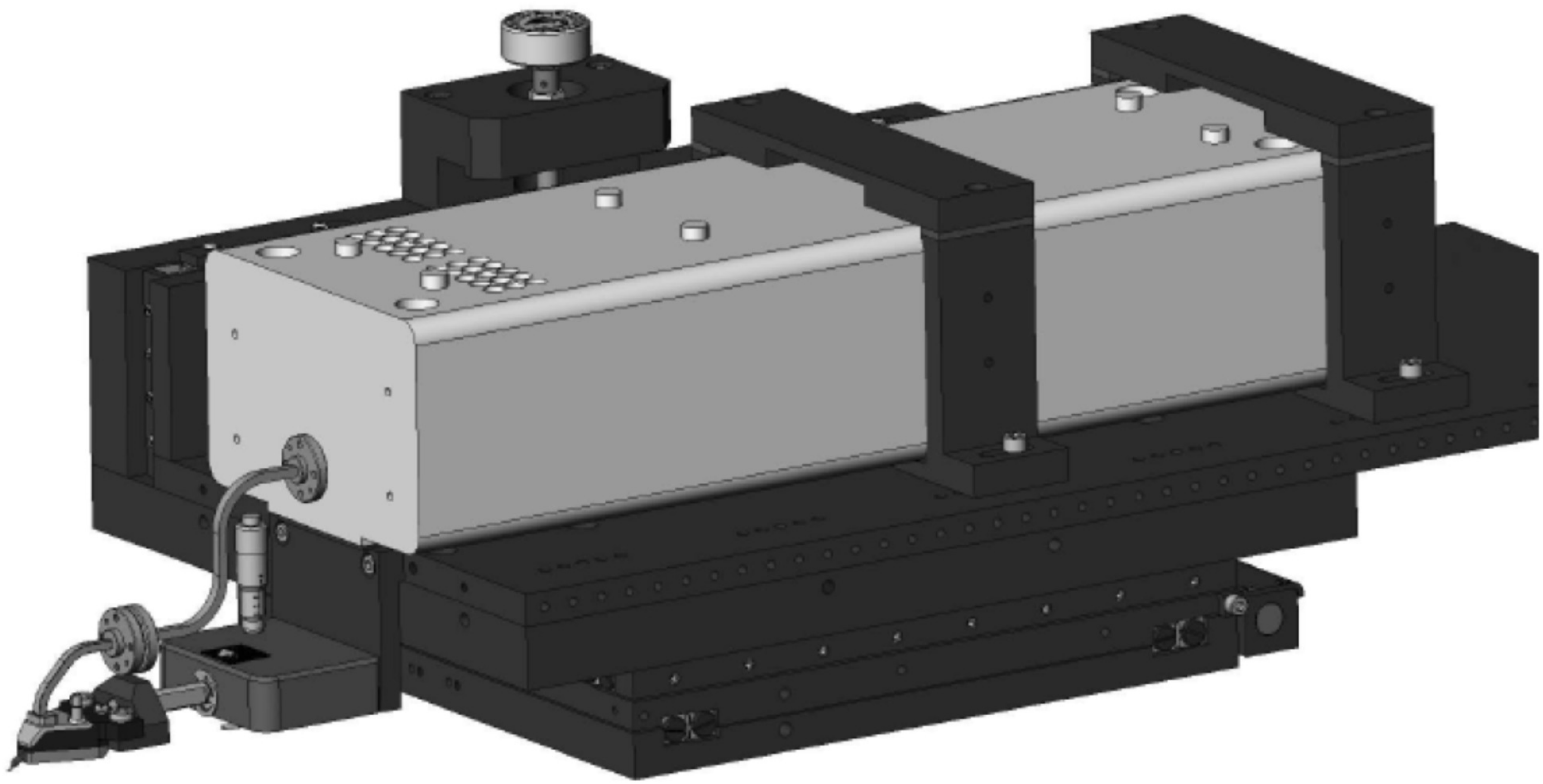
Waveguide Connection Scheme < 220 GHz

220 GHz Probing Performance

- WR-5 waveguide specification:
  0.223 dB/cm @ 140 GHz -> 0.140 dB/cm @ 220 GHz
- For 20 cm waveguide section:
  4.5 dB @ 140 GHz – 2.8 dB @ 220 GHz

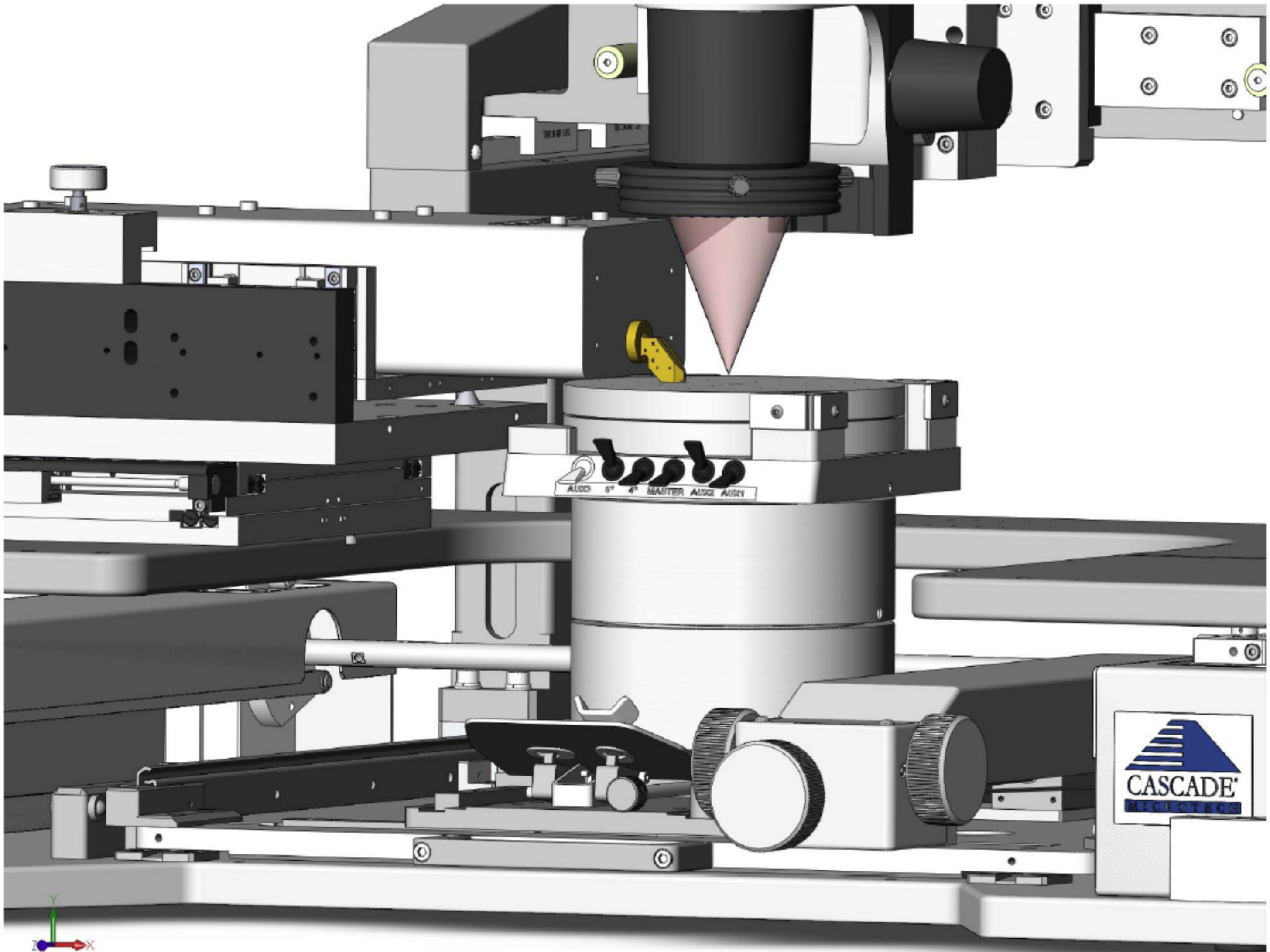


325 GHz Connection Scheme

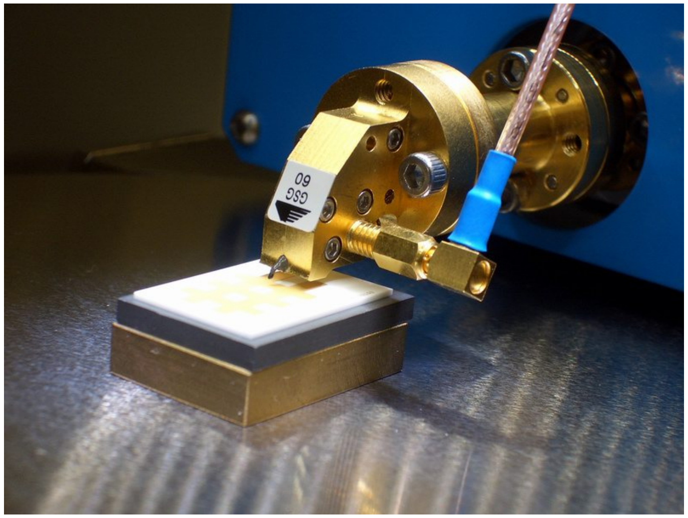


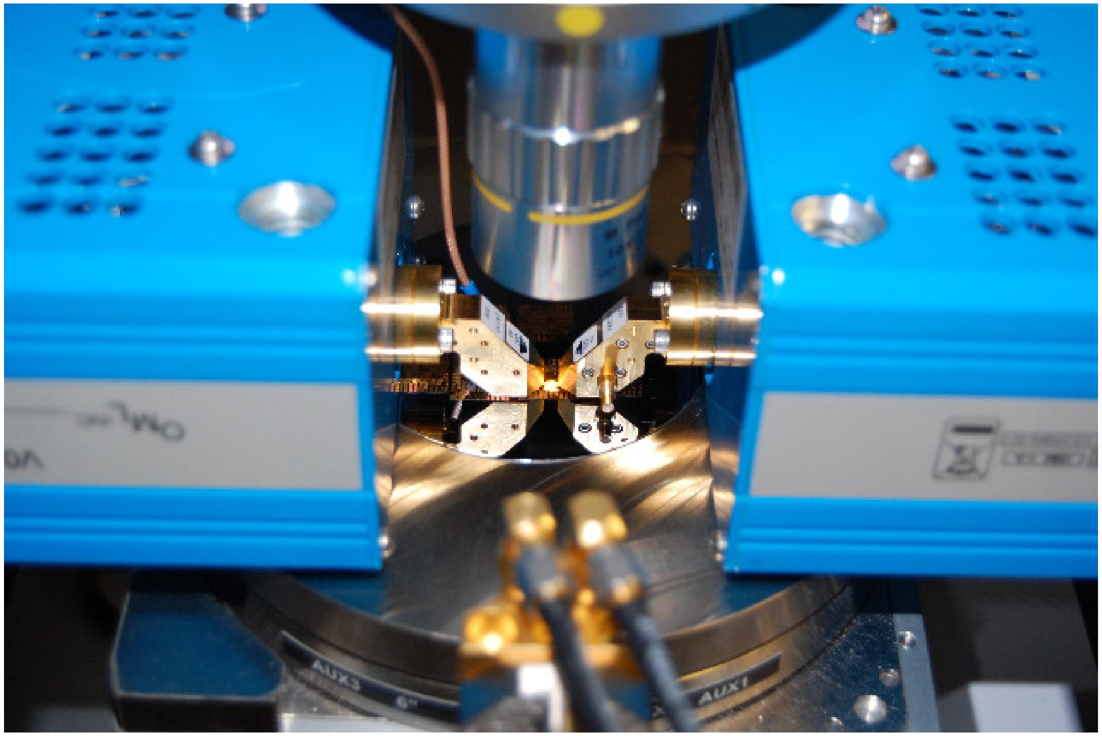
i325-GSG-xx probe and 144-414 S-Bend shown with waveguide head inverted on positioner to minimize loss

500 GHz Connection Scheme

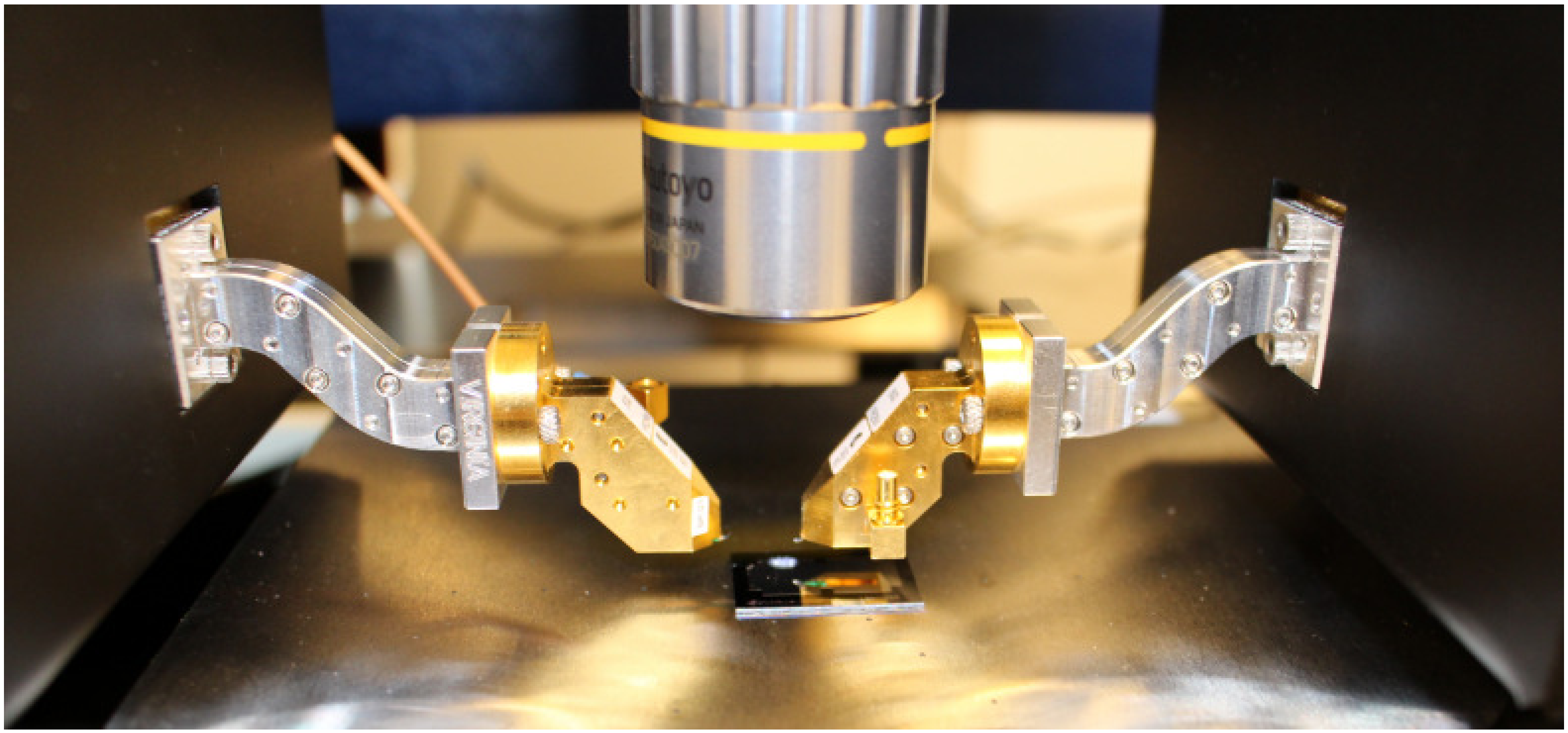


500 GHz Connection Scheme





500 GHz Connection Scheme



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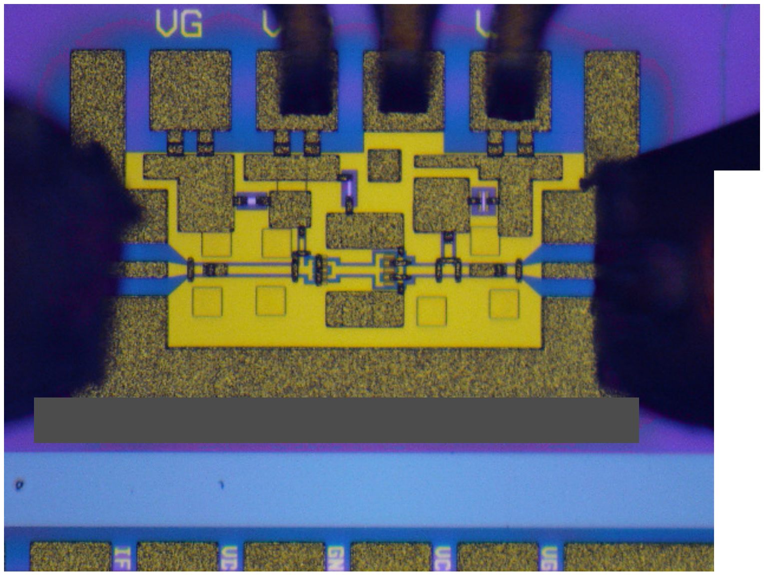
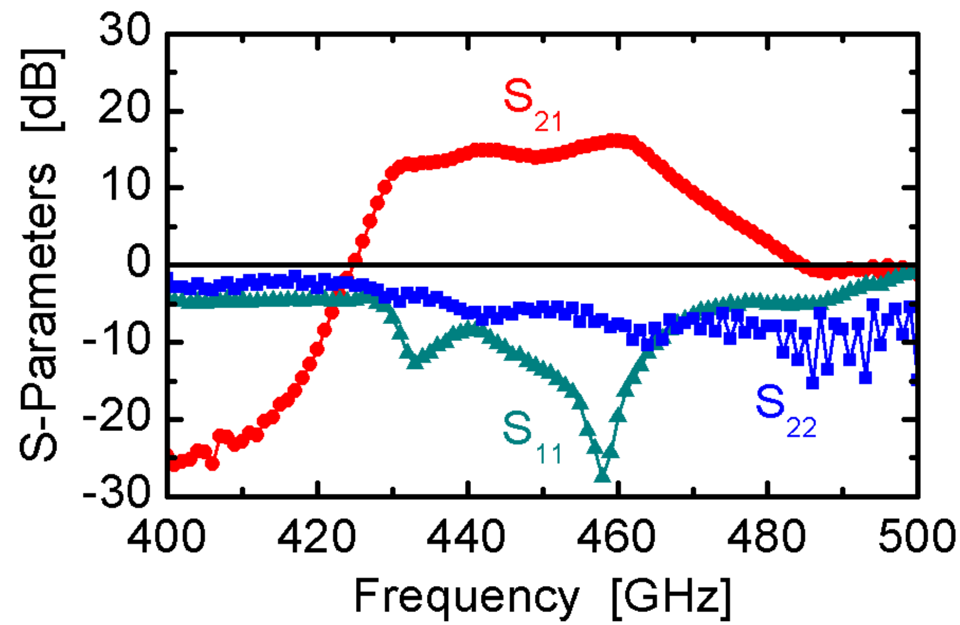
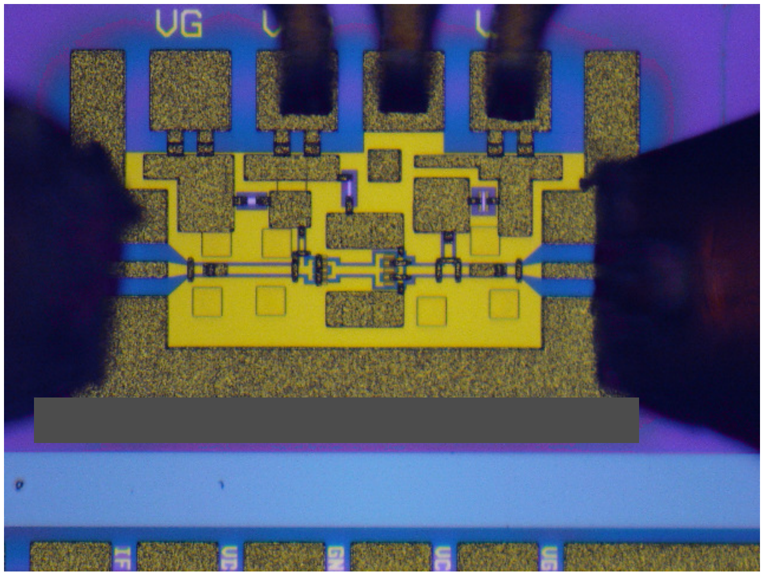
500 GHz Application Example





- Reference: Fraunhofer IAF Freiburg

500 GHz Application Challanges



- Probe pitches decreasing
- Pad/line dimesions

→ High resolution positioners
→ High power microscopy

- Reference: Fraunhofer IAF Freiburg

Manual & semi-auto mmw/THz Probe System Solutions

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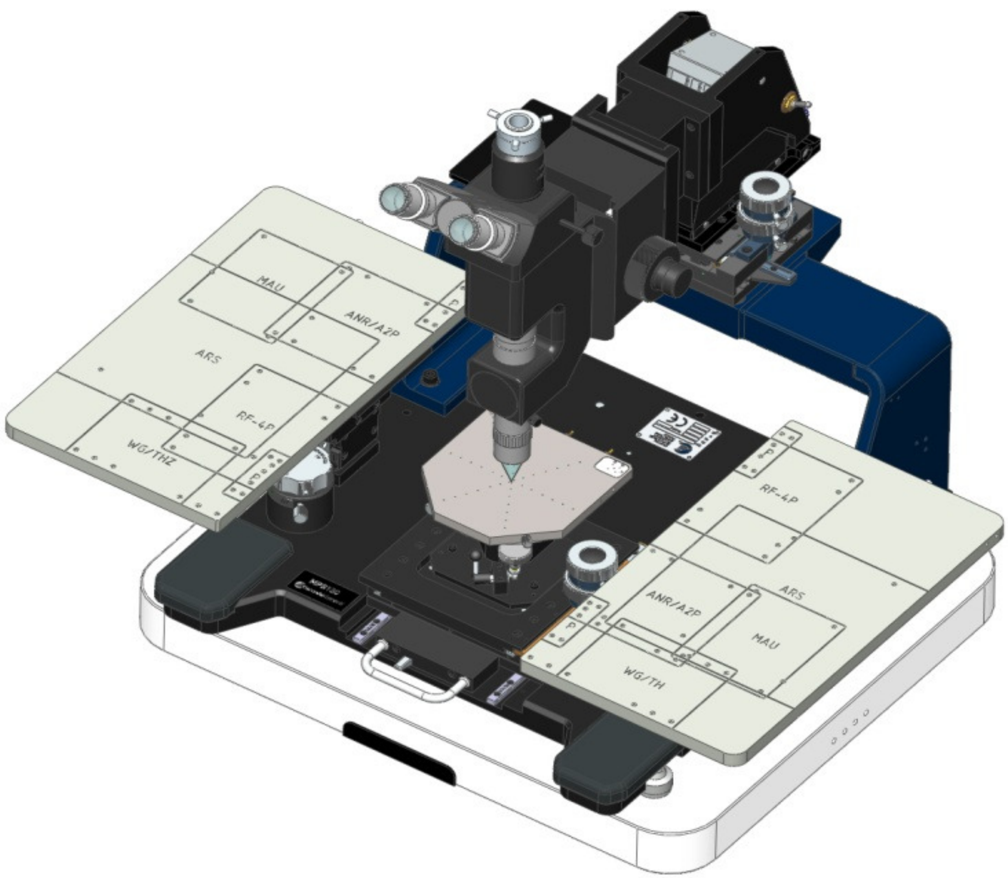
EPS150 Basis



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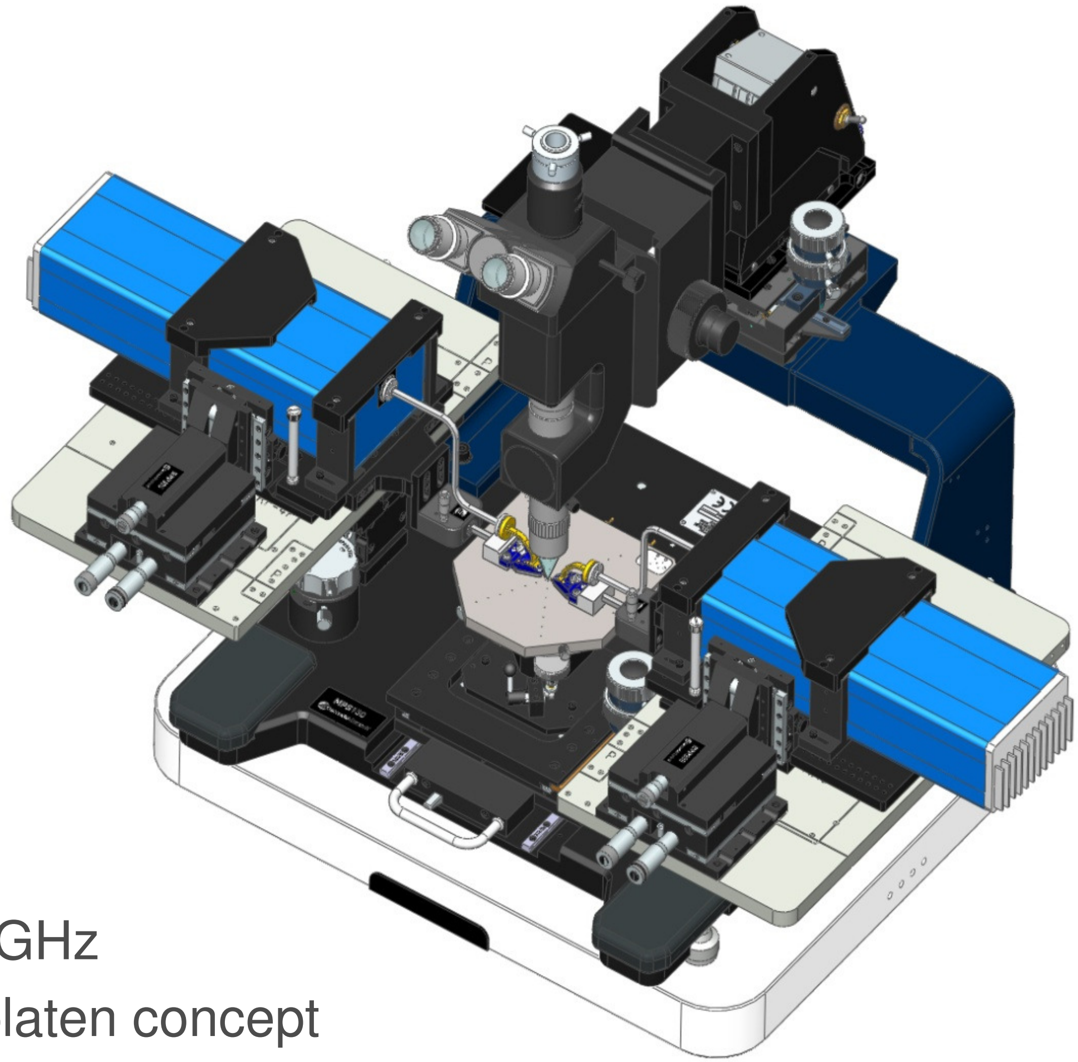
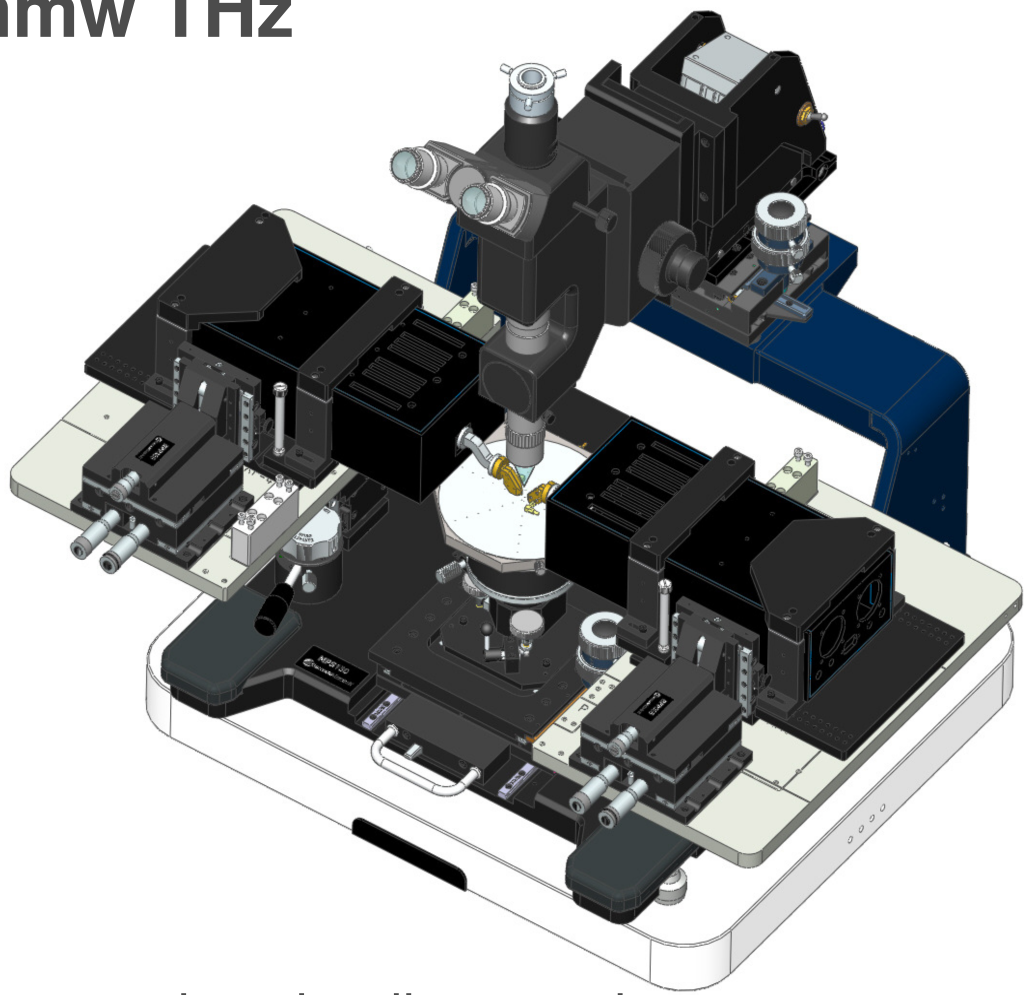
EPS150 mmw waveguide



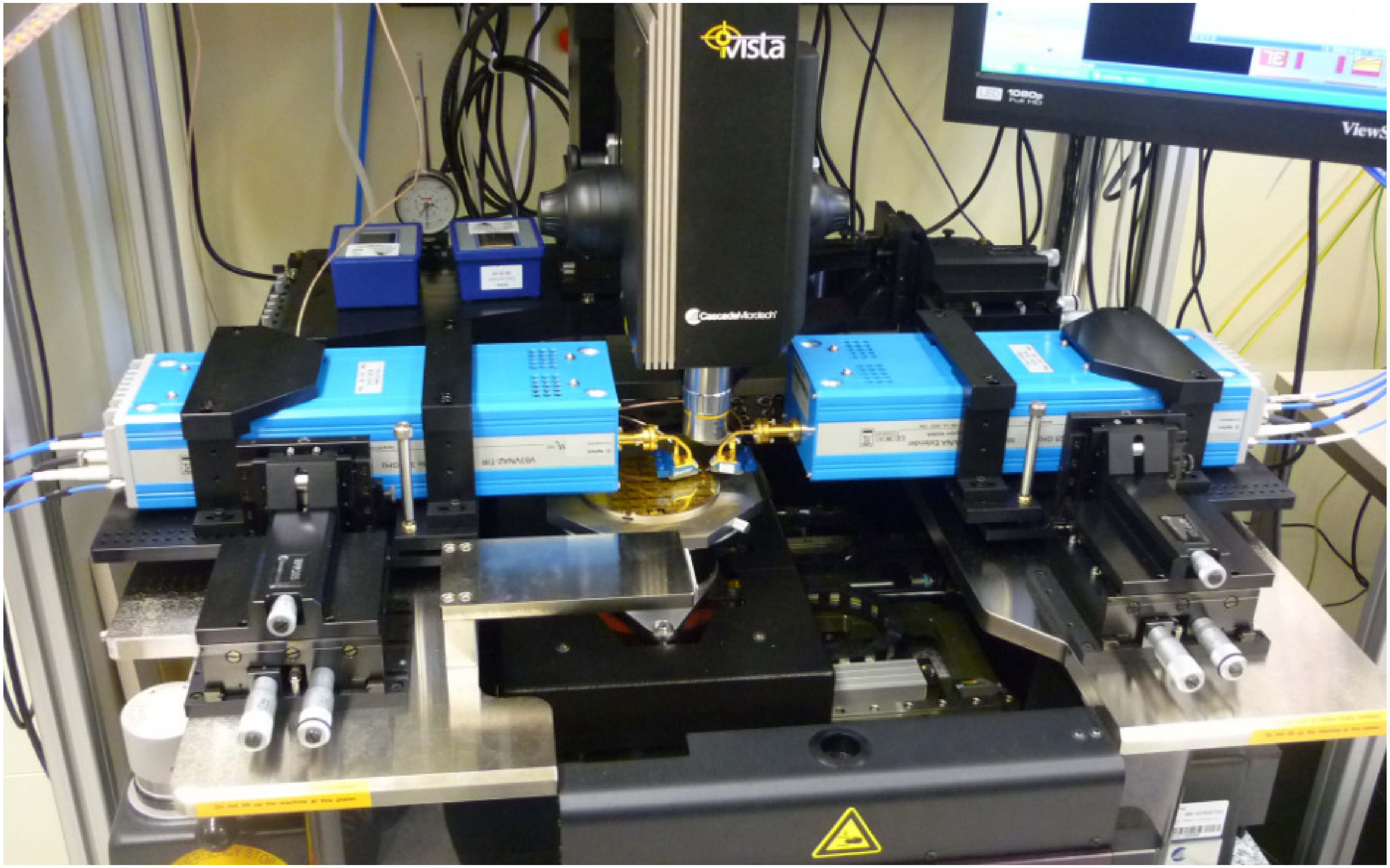
- 65…220(325) GHz
- Chuck below platen concept

EPS150 mmw THz

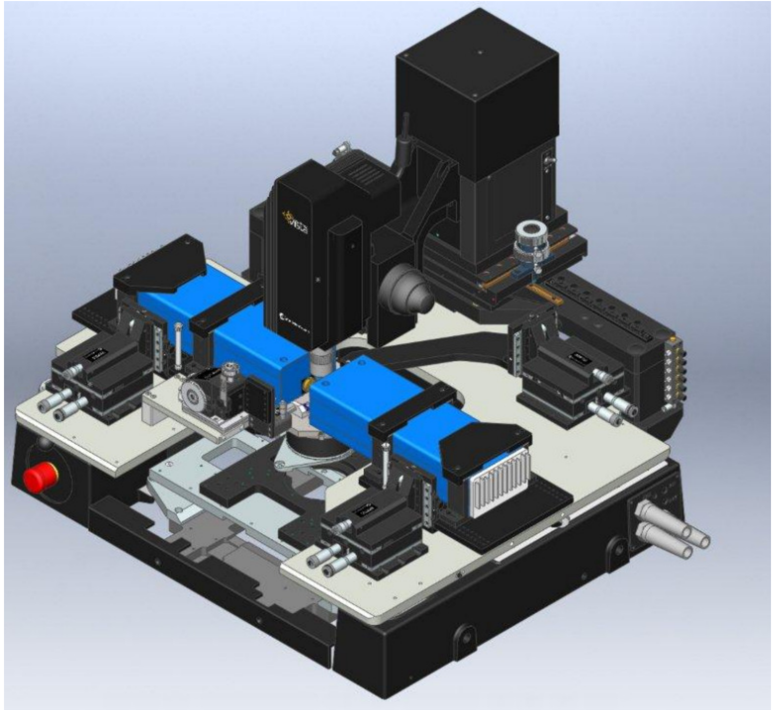


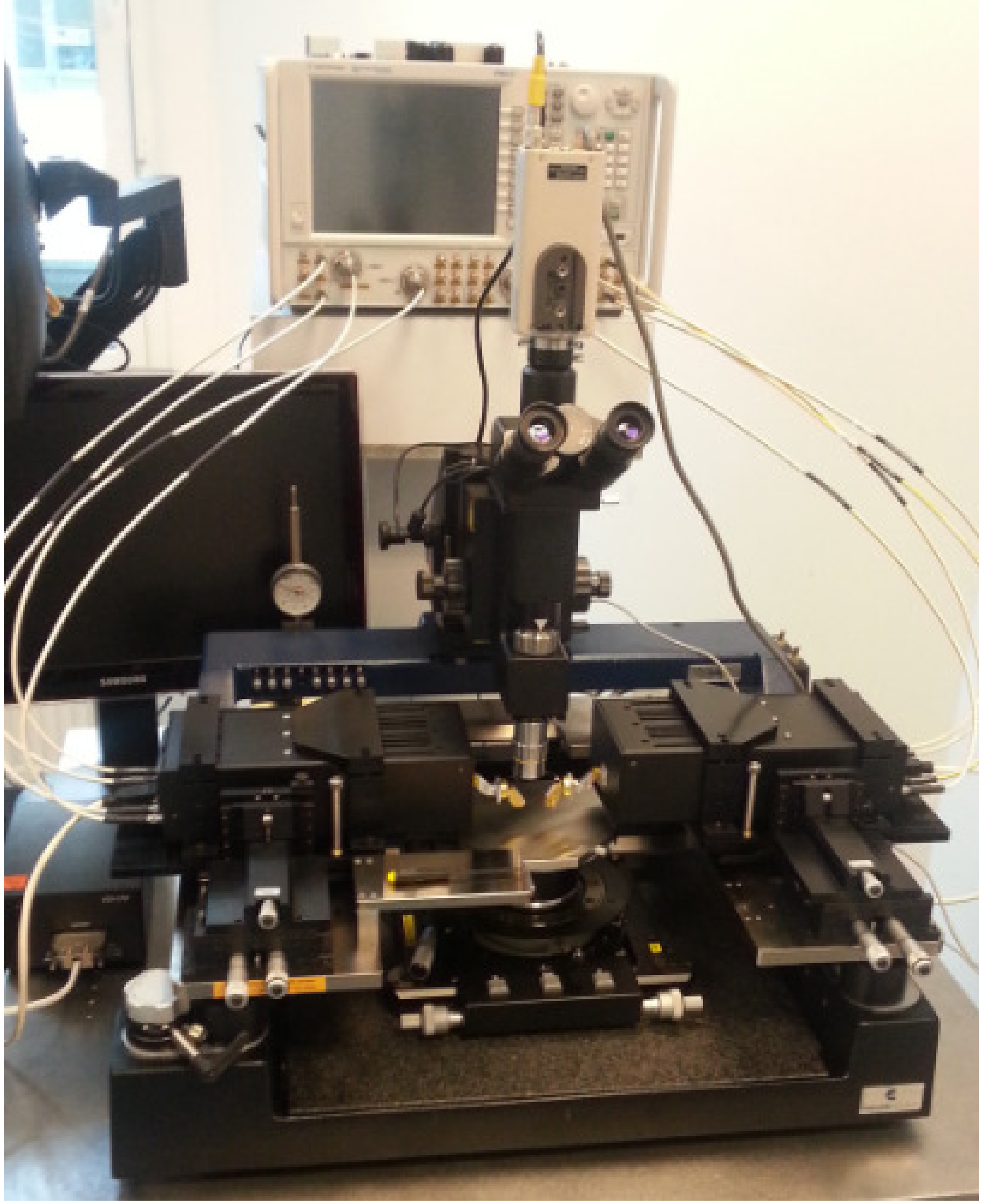
- Chuck raised to mmw heads, direct probe mount
- Requires tilt mechanism for probe planarization
- Limited travel range for chuck

semi-auto THz



Demo System





On-Wafer Probes

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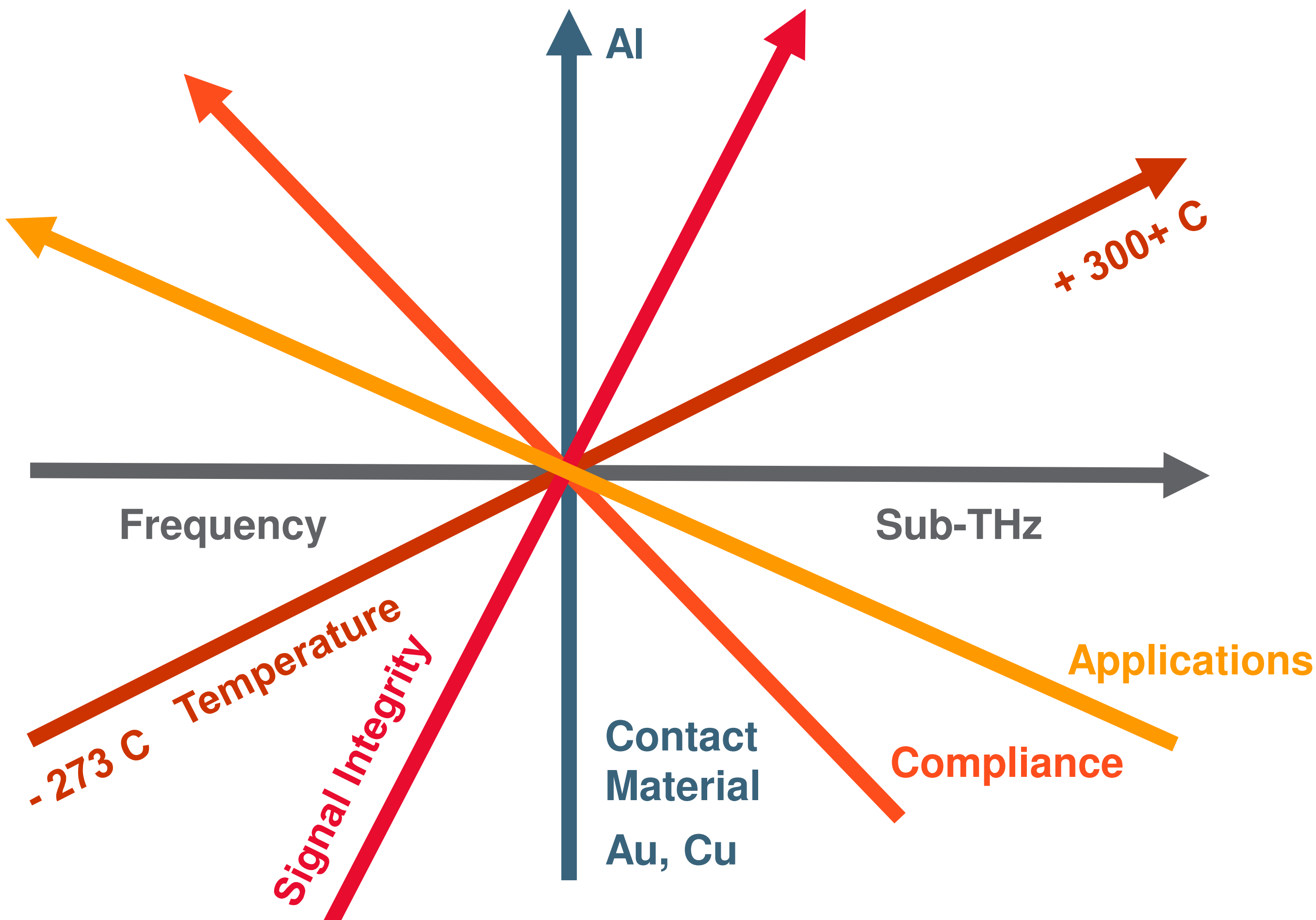
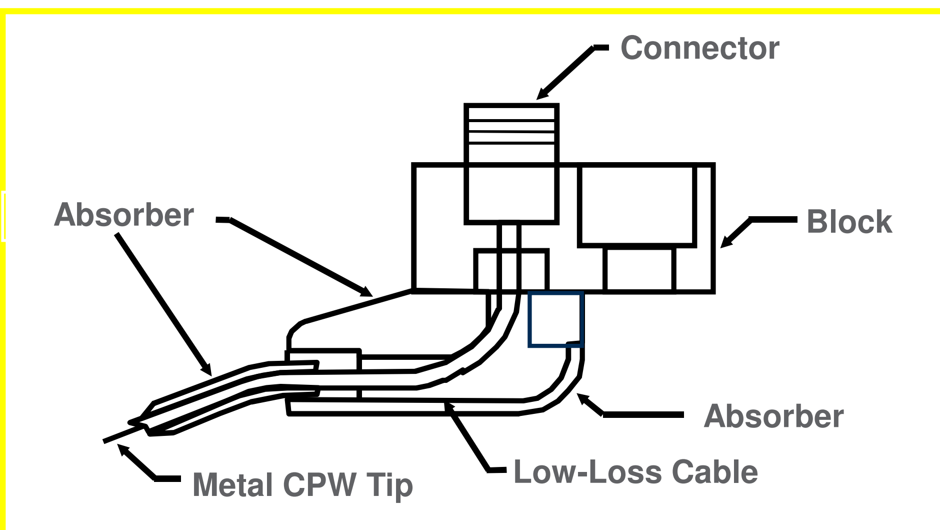
RF Probing

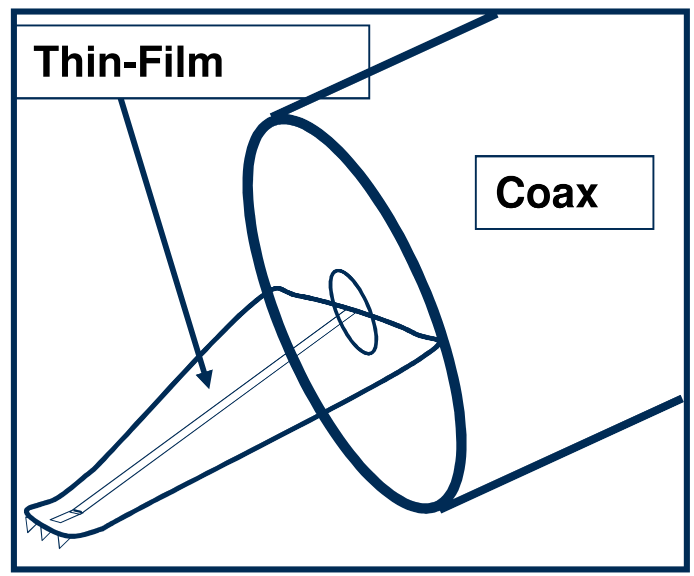


…is a multidimensional challenge!

Infinity Probe Technology

- Infinity Technology is the worlds only engineering probe to use a lithographical defined thin film tip technology





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Infinity Probe Family

2003 – 67 GHz

2004 – 110 GHz

2004 – Dual 67 GHz

2007 – 325GHz
Waveguide

2010 – 500 GHz

2011 - InfinityQuad

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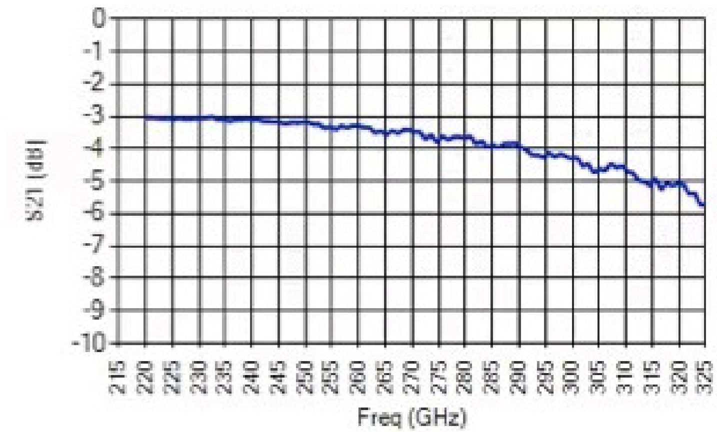
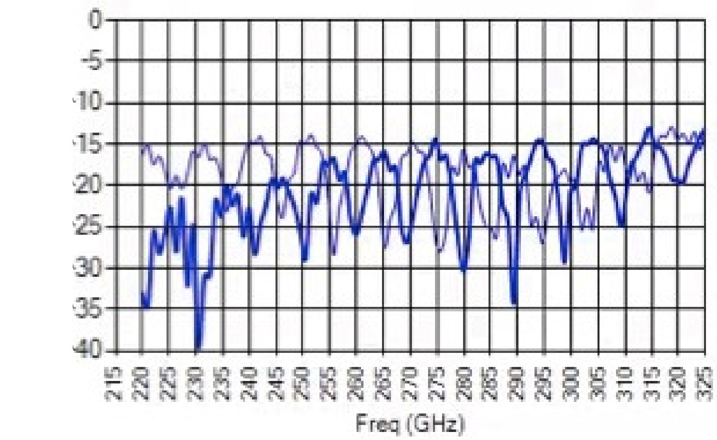
325 GHz infinity Probe

- MicroChamber compatible
- Controlled EM fields at the tips
- Infinity tip design for low and stable contact resistance
- Bias tee option





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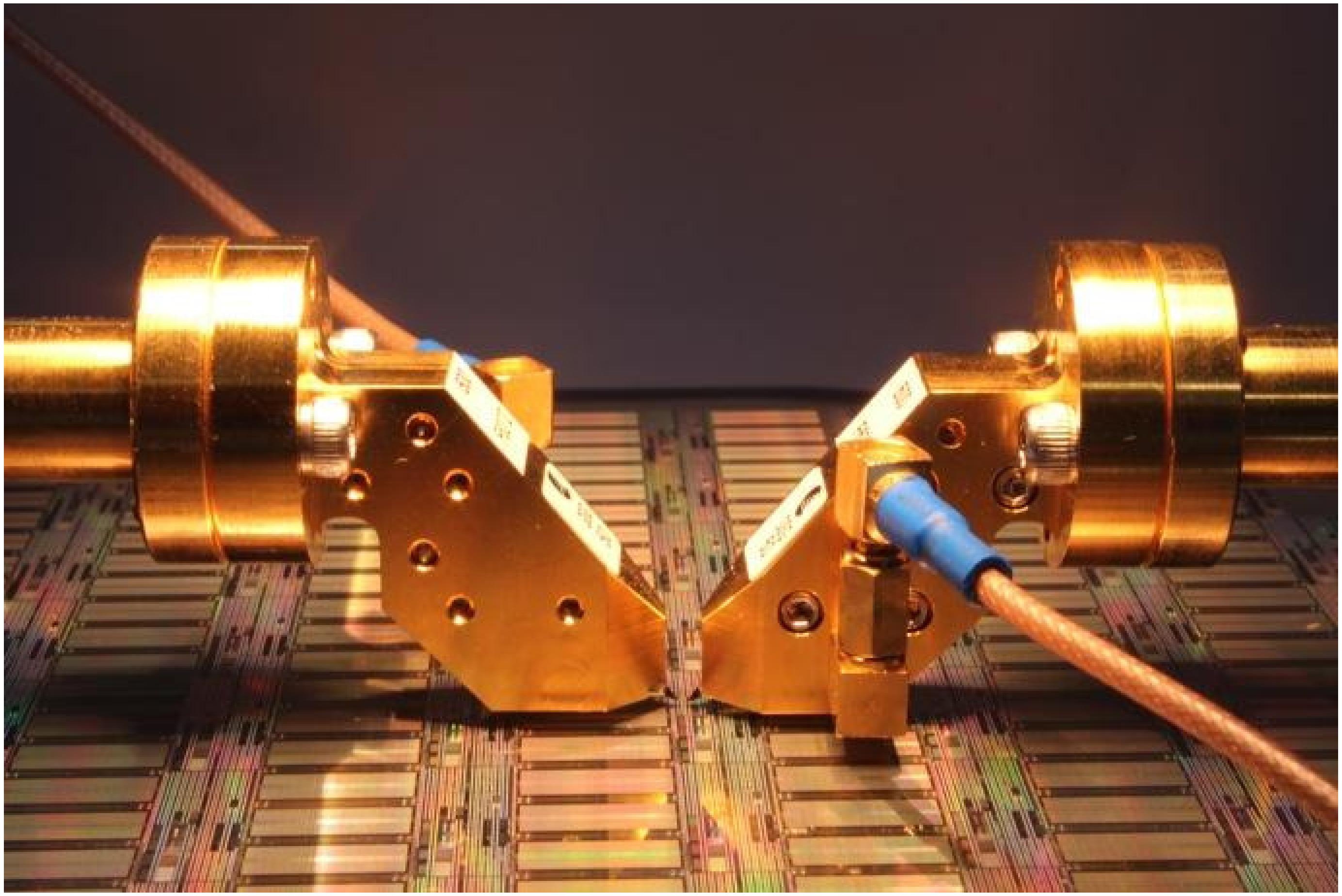
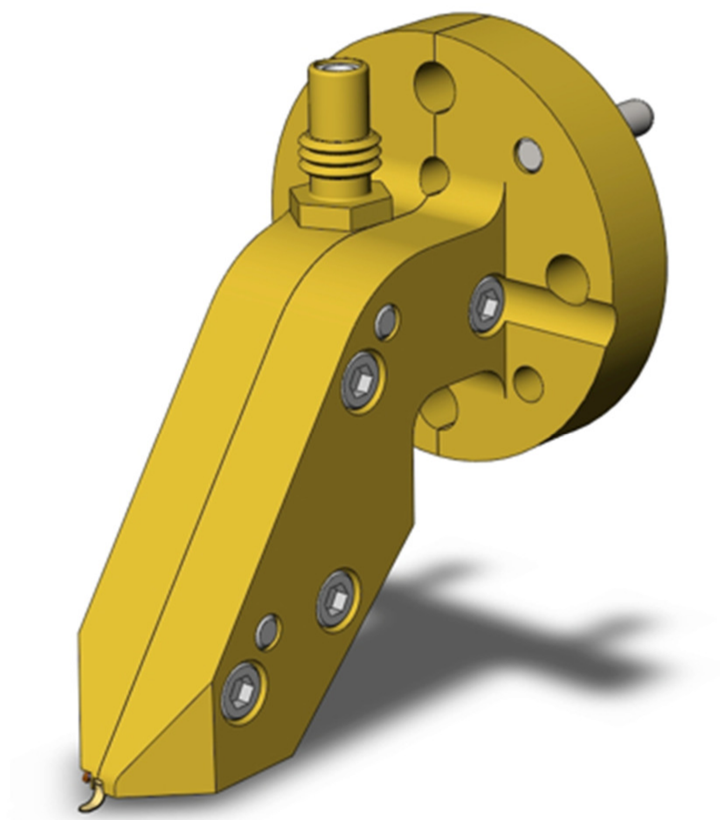
500 GHz Infinity Probe



New 500 GHz Infinity Probe



Calibration Implications

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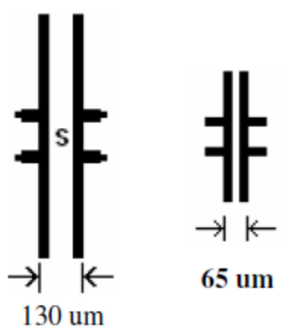
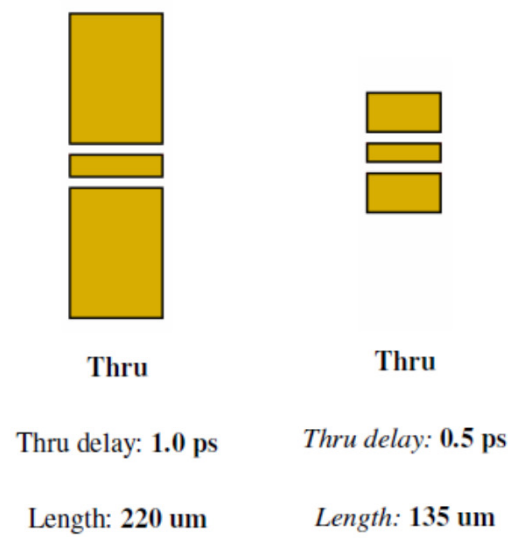
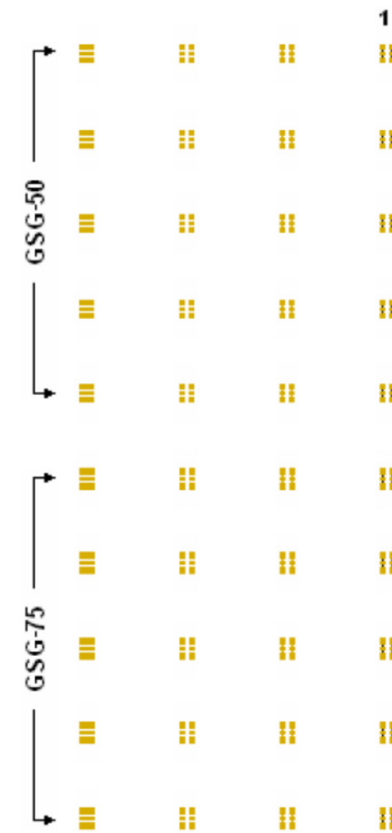
ISS Specifics for W-Band and mmw

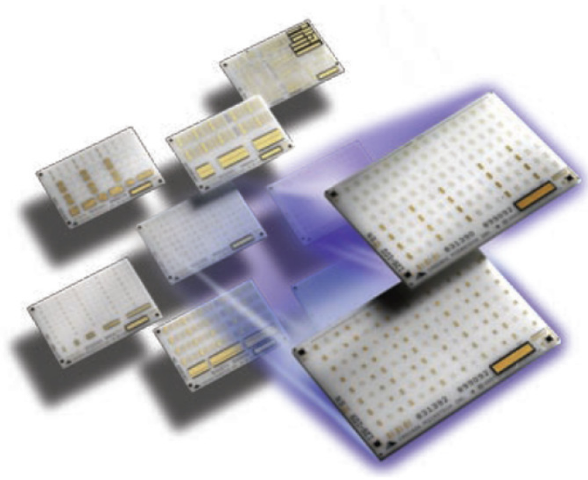
- Different alignment marks for less overtravel 25-50µm instead of 50-75µm for standard Infinity
- Shorter THRUs: 0.5ps instead of 1ps
- OPENs on substrate
- Pitch specific to reduce parasitics
- ISS is thinned to 254µm instead of 635µm

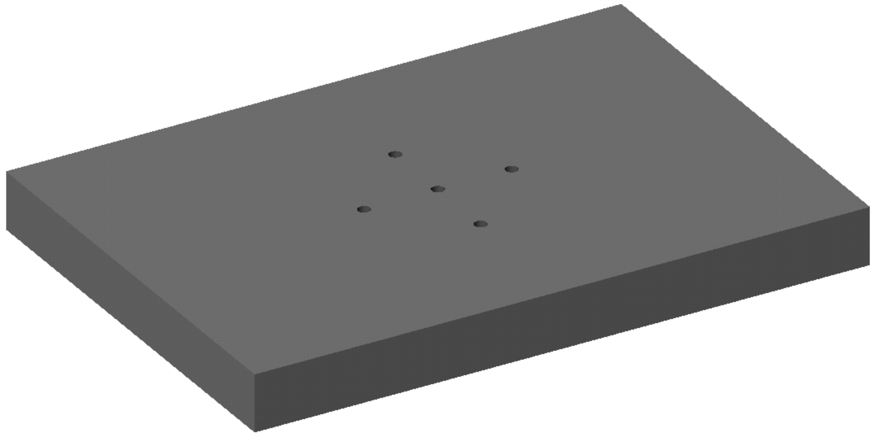




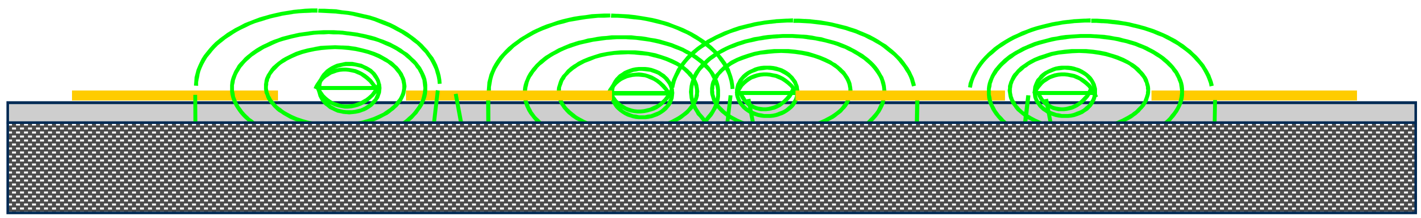


Microwave Absorbing ISS holder to reduce unwanted substrate modes





PN 116-344



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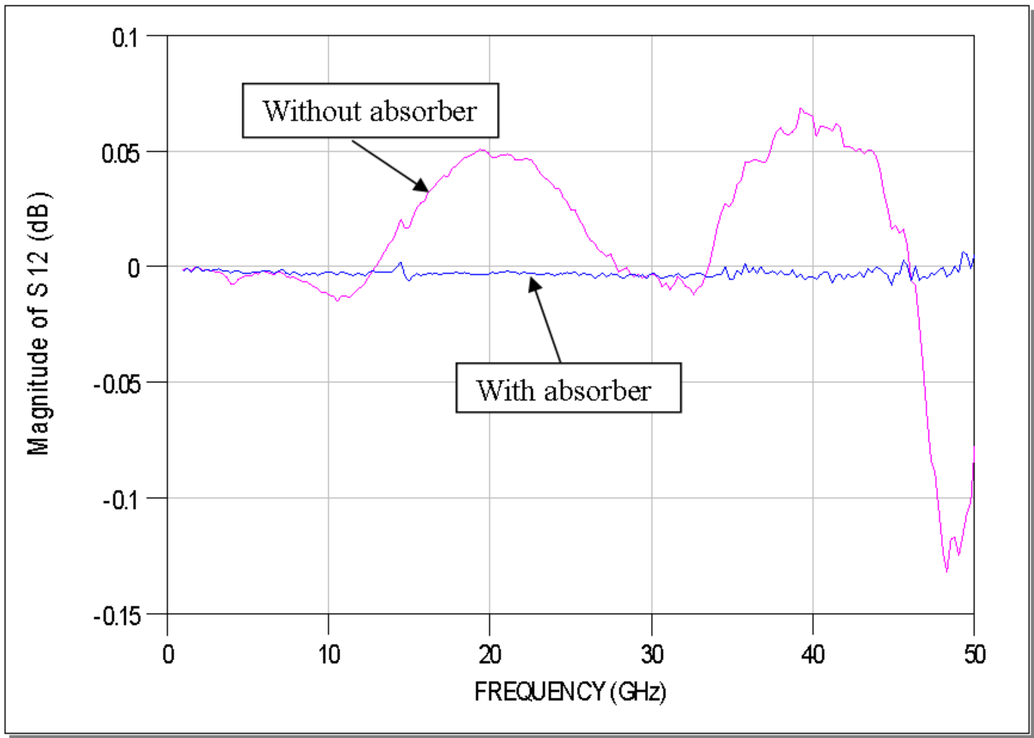
Influence of Auxiliary Chuck Materials

- Same two picosecond CPW line with and without microwave absorber under the substrate



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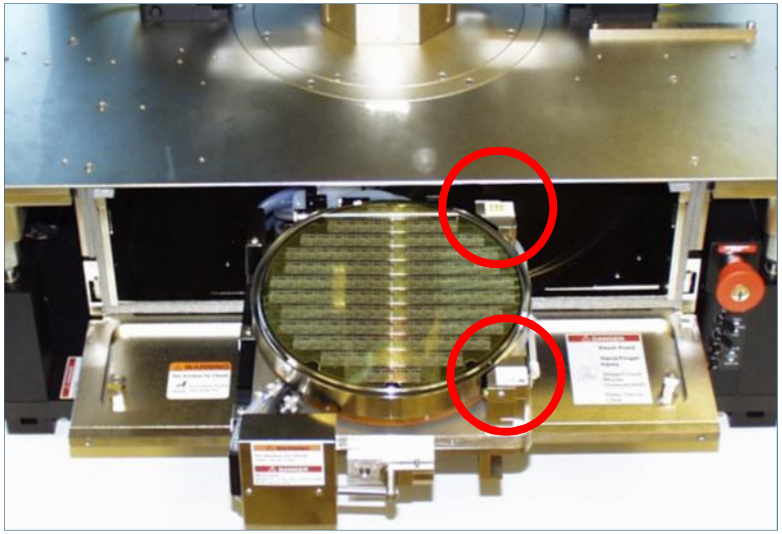
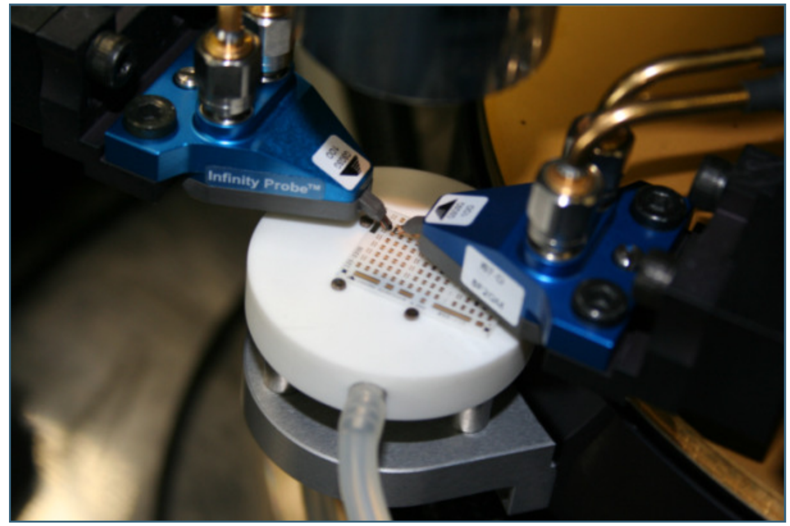
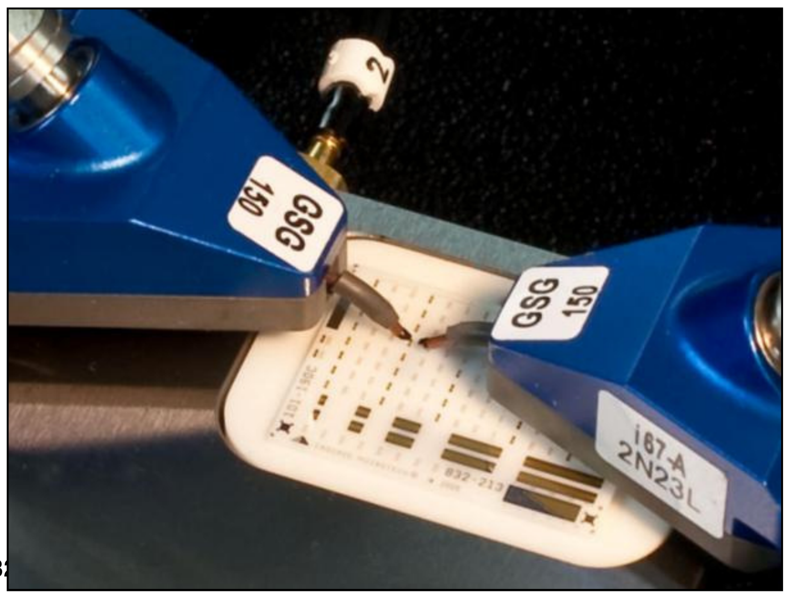
Maintaining Calibration Substrates



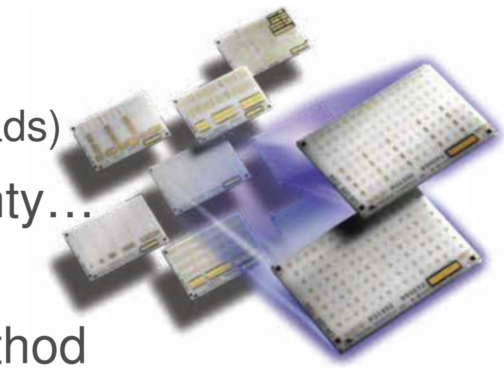




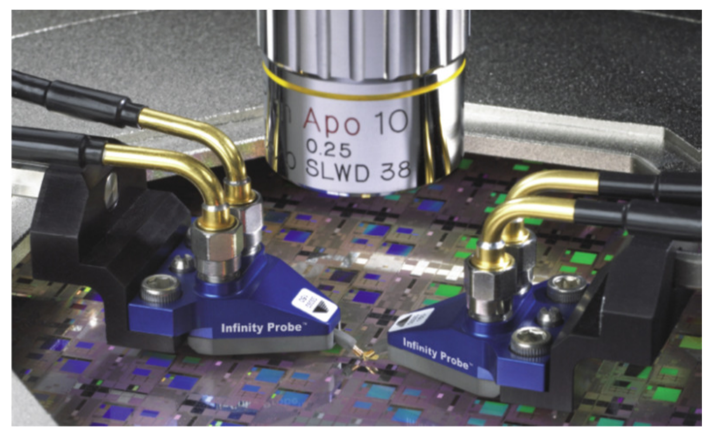
- 2 AUX chucks support ceramic calibration substrates
- Satellite for thermal systems
- Embedded for room temp

Off-Wafer vs On-Wafer Calibration

- **Off-wafer calibration**
  - Commercial impedance standard substrate
    - Process supporting precision standards (e.g., trimmed loads)
  - Launch differences absorbed as additional uncertainty…
    - Pad layout and/or substrate dielectric differences
  - …or corrected by intrinsic device de-embedding method
    - Limited at high freq or when precision phase is needed (T-lines) ->



- **Custom standards ON the wafer**
  - Identical launch for DUT and Standards
  - Need simple standards and cal requiring minimal knowns
    - E.g., known loads usually hard, transmission lines often easy



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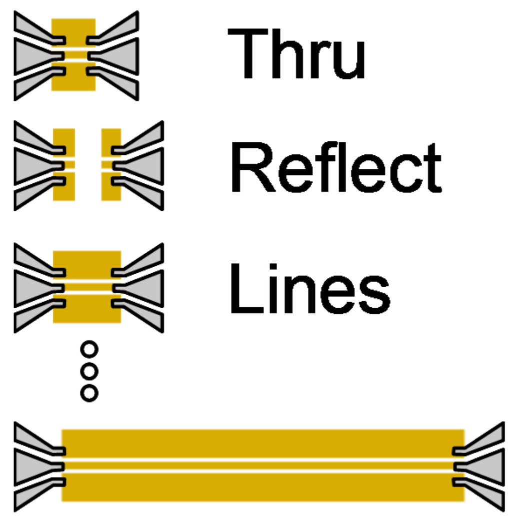
TRL Calibration

- With TRL the standards are:
  - Thru (short transmission line)
  - Reflect (unknown but equal reflect on both ports, sign known)
  - Line (transmission line with electrical length ~20-160 degrees)
- Lines cannot be 0 or 180 degrees long (or near there) since the electrical behavior is not distinguishable from the Thru
- Multiple lines are required, each covers a subset frequency range
  - Data discontinuities occur at band edges
- Resulting S-parameter measurements are referenced to the unknown (and sometimes complex) characteristic impedance of the lines



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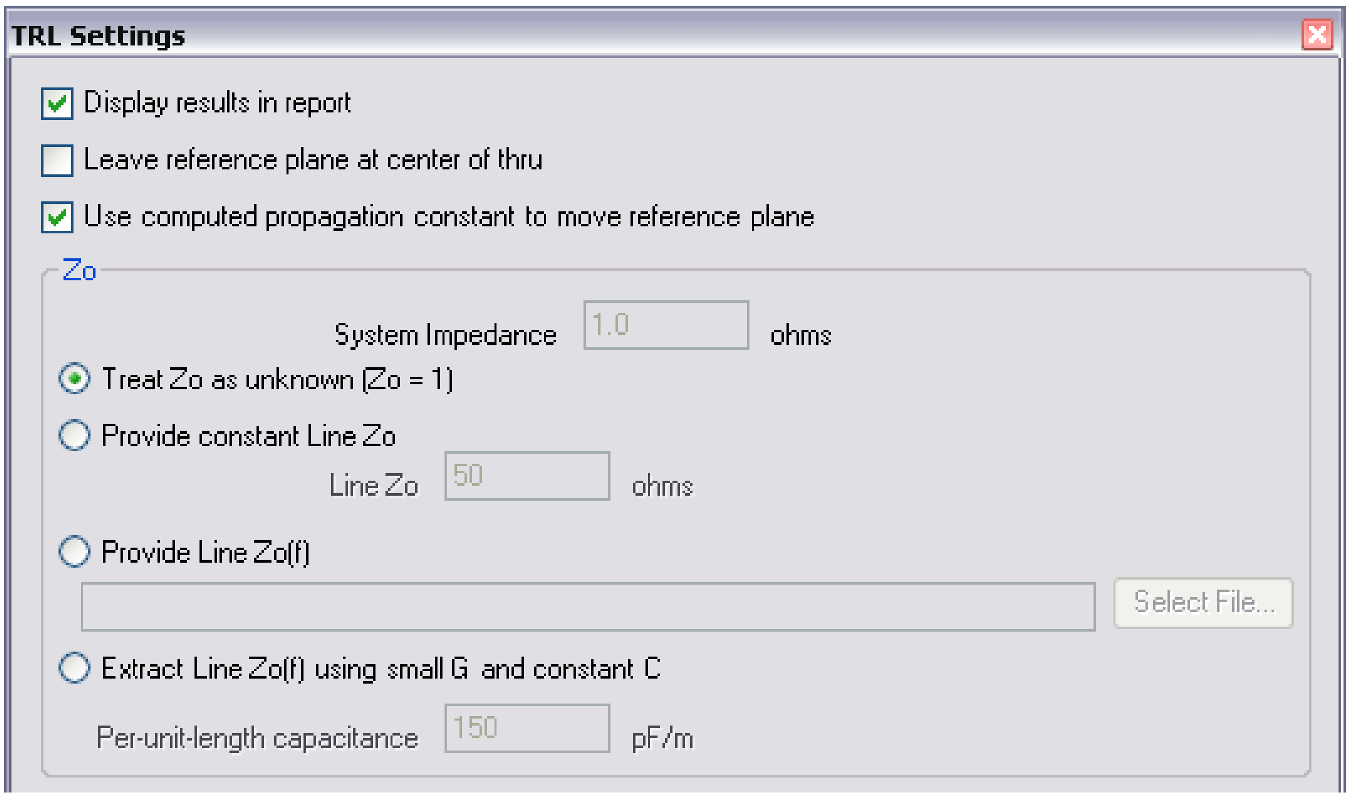
Characteristic Impedance Correction

- With known Zo, the S-parameters may be renormalized to 50 ohms

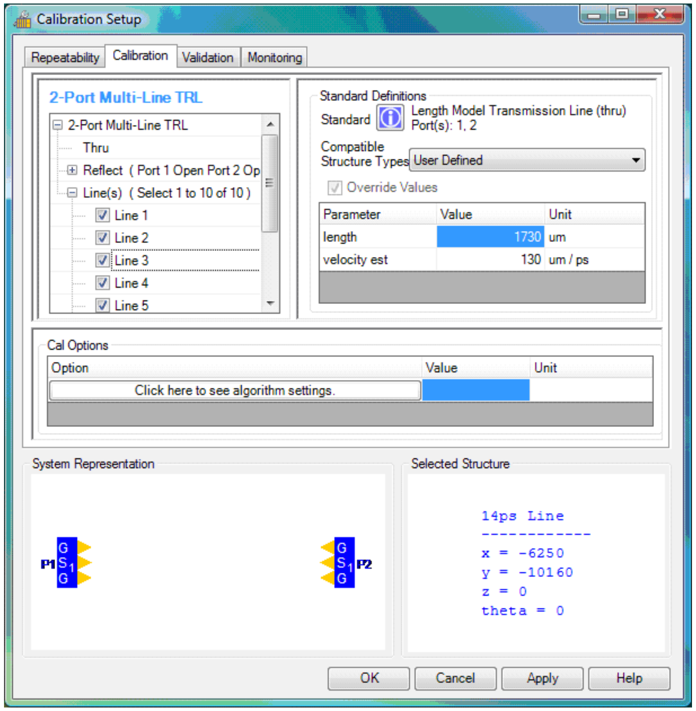


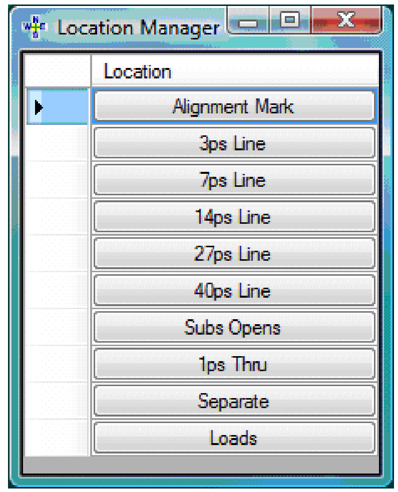
Characteristic Impedance Correction

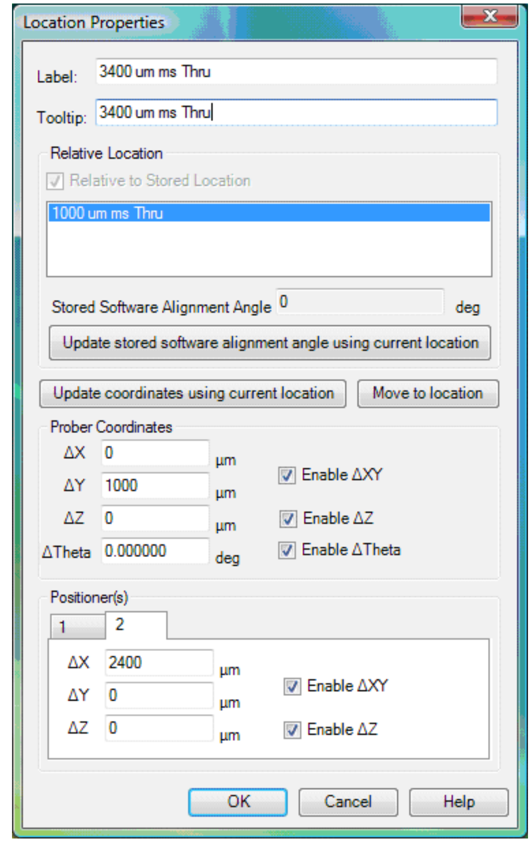
The WinCal XE implementation of TRL includes a number of options for handling the reference transmission line impedance.

1. Treat the Zo of the reference line as unknown, leaving the DUT S-parameter normalizing impedance that of the line. In this case the Zo and system impedance are set to 1 indicating the normalization. This is how VNA front panel TRL calibrations normally work. The resultant S-parameters can have a complex reference impedance (particularly at low frequencies).
2. Treat the line as having a constant, real Zo that is known and entered. The line impedance may differ from the target system impedance (often 50 ohms). This is most useful when the data is for frequencies where the line behavior is dominated by the distributed inductive reactance and capacitive susceptance resulting in a real Zo. This is a good choice for a narrow band or measurements only at higher frequencies.
3. Treat the line as having a known, frequency-dependent complex Zo. The Zo is provided in the form of a reflection coefficient (in an S1P file) with a real (typically 50 ohm) normalizing impedance. This approach is very general compatible with even the most complex means of determining the line Zo (even simulation).
4. The line Zo is determined using the small G and constant C assumption and an entered value of C (per-unit-length). This method is suited for low-loss dielectrics such as Alumina, GaAs, etc. If a known DC resistance load is available one can start with an estimated C value and observe the impact when applying the correction to the load. If the load R is incorrect the C estimate is adjusted until the correct load resistance is found.

WinCal TRL Implementation







- TRL calibration standards are defined by physical dimensions
- The Location Manager tool provides a way to conveniently record a set of device locations including moves with probe position changes

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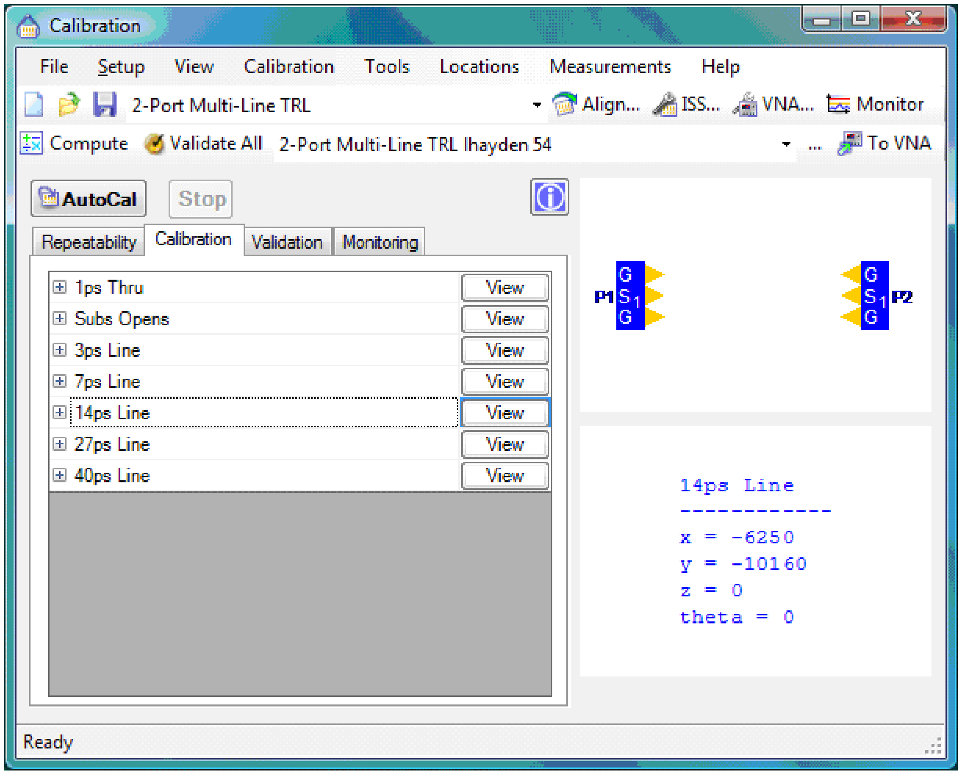
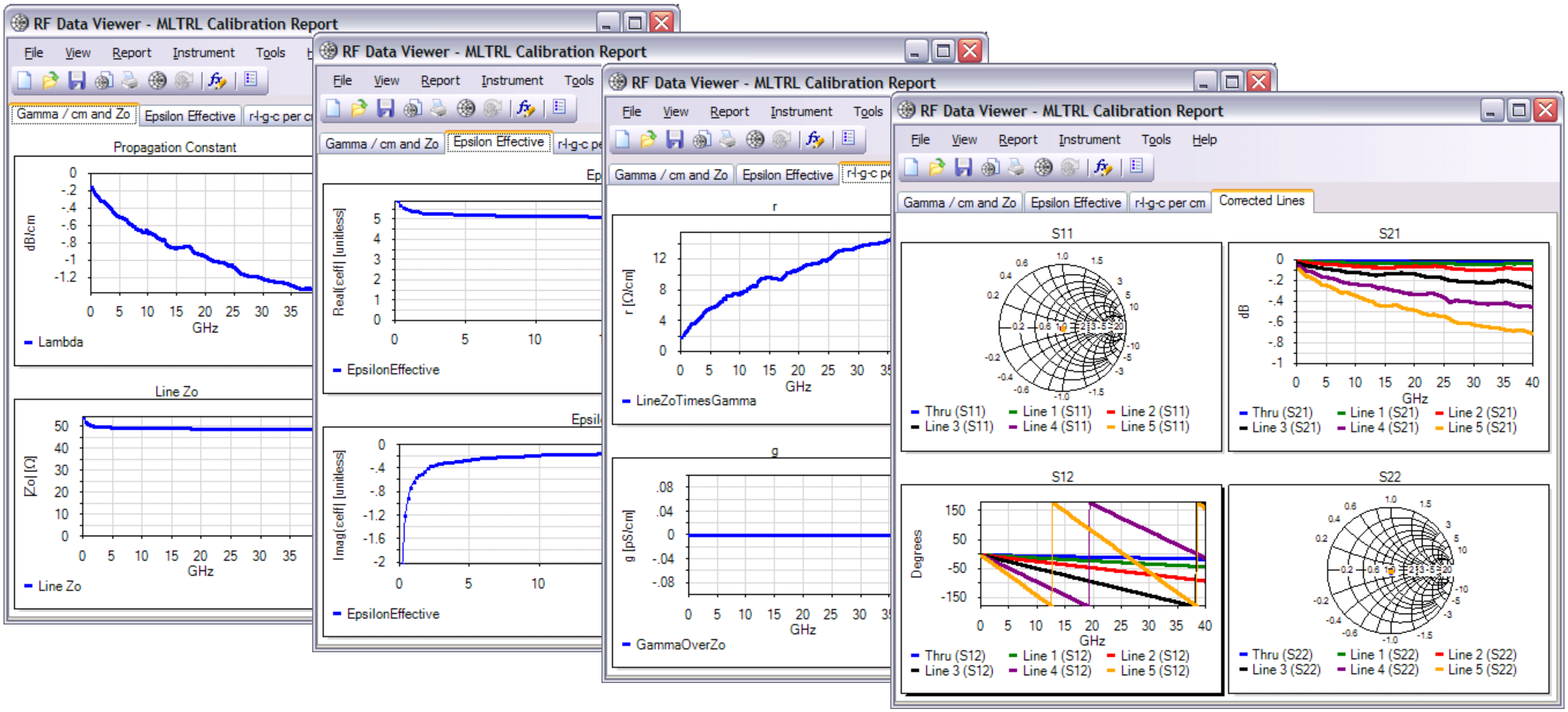
37

WinCal Calibration Measurement Plan



- Moves to any location manager recorded location
- Measure in an automated sequence or one-at-a-time
- Additional measurement for:
  - Pre-cal repeatability test
  - Post-cal validation measurement comparison
  - Post-cal monitoring reference

Default TRL Calibration Report



- Calibration report format is defined by customizable template

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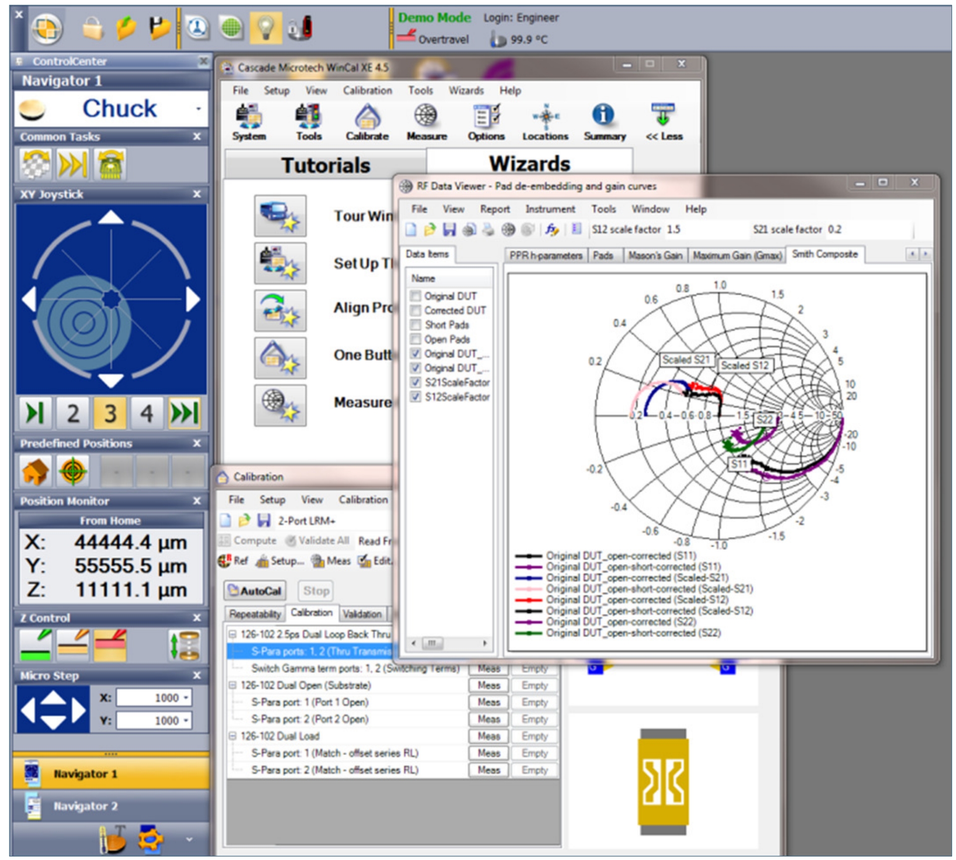
WinCal XE™

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



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Thank you! - Questions?

If you have any questions or comments, please contact me:

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