IEEE SW Test Workshop

Semiconductor Wafer Test Workshop

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Design Considerations for Parametric-RF Probing in Production Test Environments

June 3-6, 2007

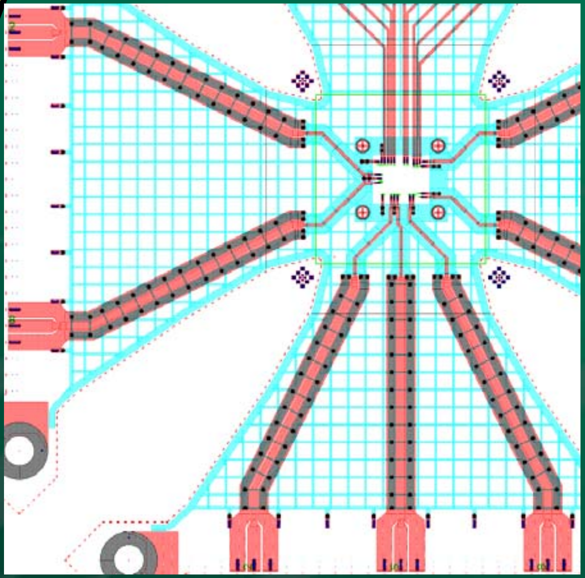
San Diego, CA USA

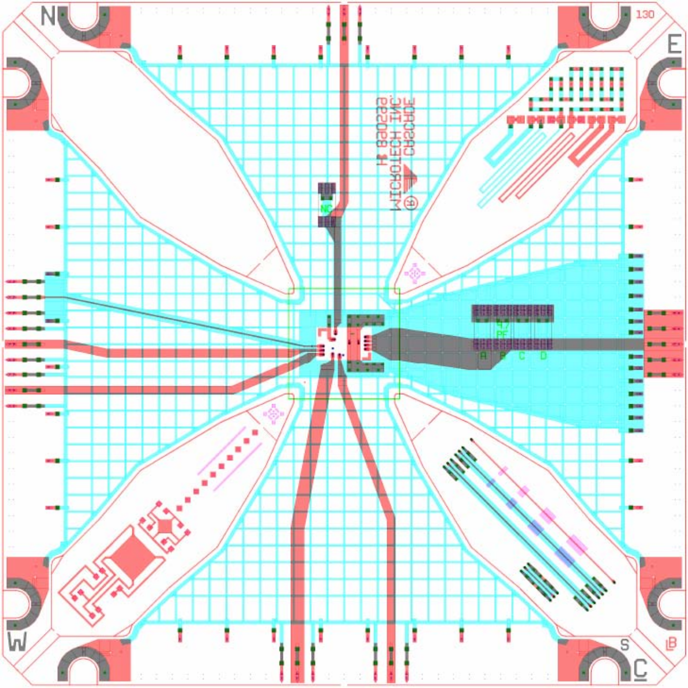
Outline

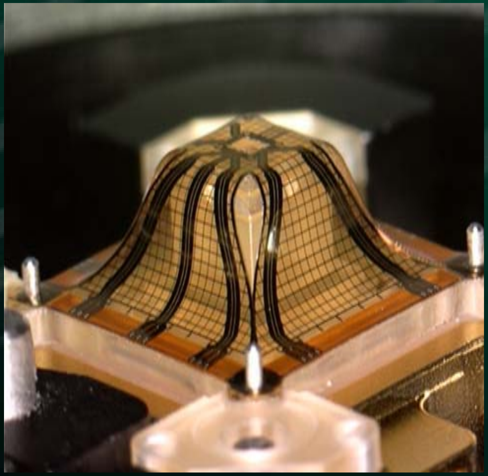
- Pyramid Probe Technology
- Parametric Measurements
- RF Parametric
- Design Considerations
  - Contact Resistance
  - Calibration
  - Probe Card Validation

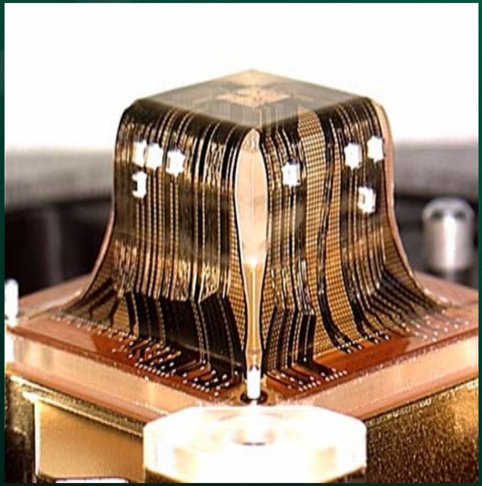
Pyramid Probe Technology

- Full-custom to match die layout
- Thin film high-tech flex-circuit
- Controlled impedance transmission lines



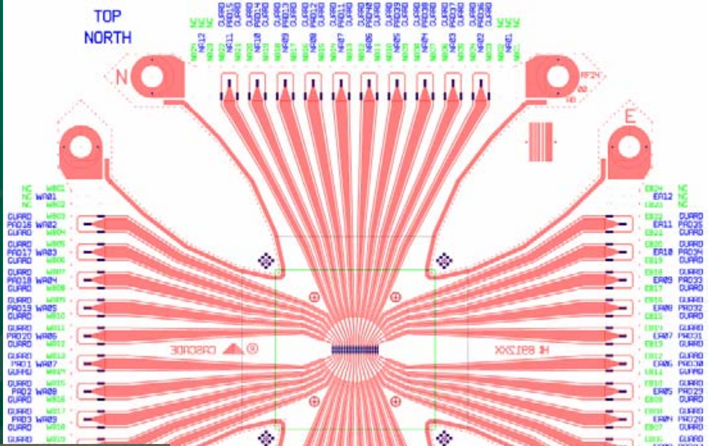




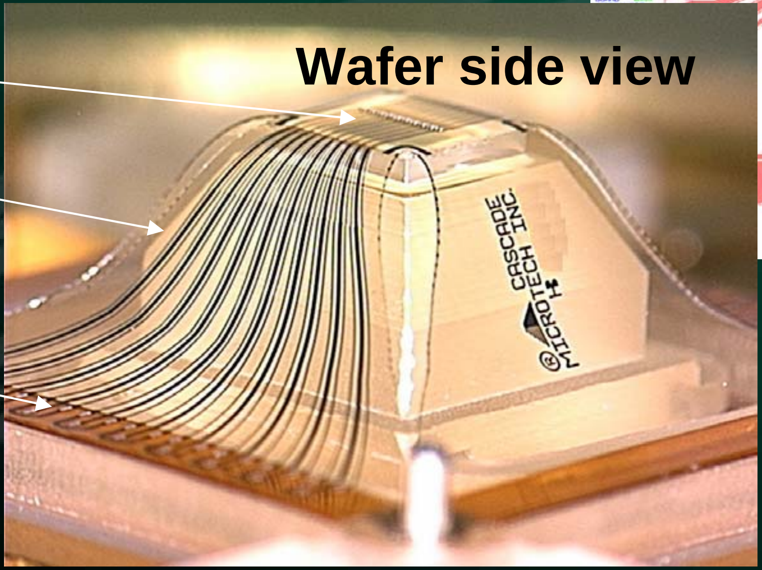


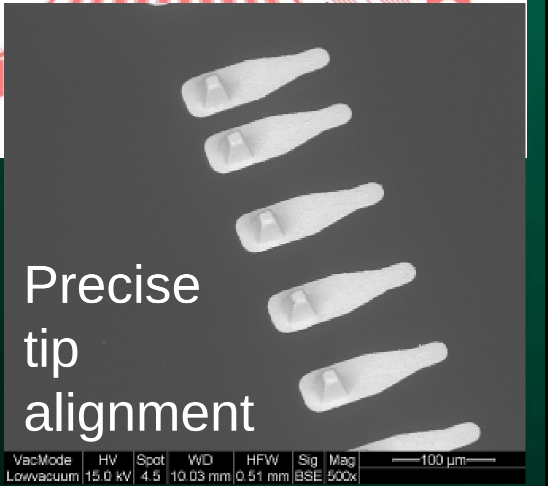
Pyramid Probe for Parametric Test

- Inter-die structures for parametric test
- Probe must provide low loss, low noise & low leakage paths to probe tips
- Signal traces are DC-guarded during measurement



- Probe tips
- Guarded signal traces to probe tips
- Guarded circuit board interface





Precise tip alignment

Parametric Test

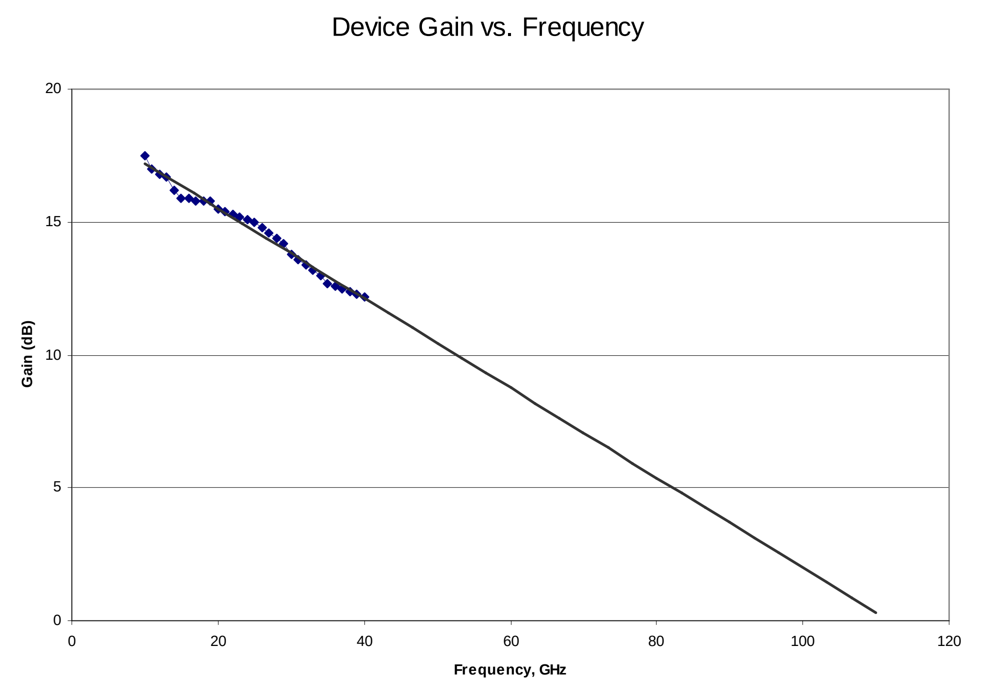
- DC / AC Measurements
  - Resistance
  - Leakage current
  - Source impedance
  - Capacitance, inductance
- Techniques
  - C-V
  - I-V
  - HF C-V (to 100-300 MHz)

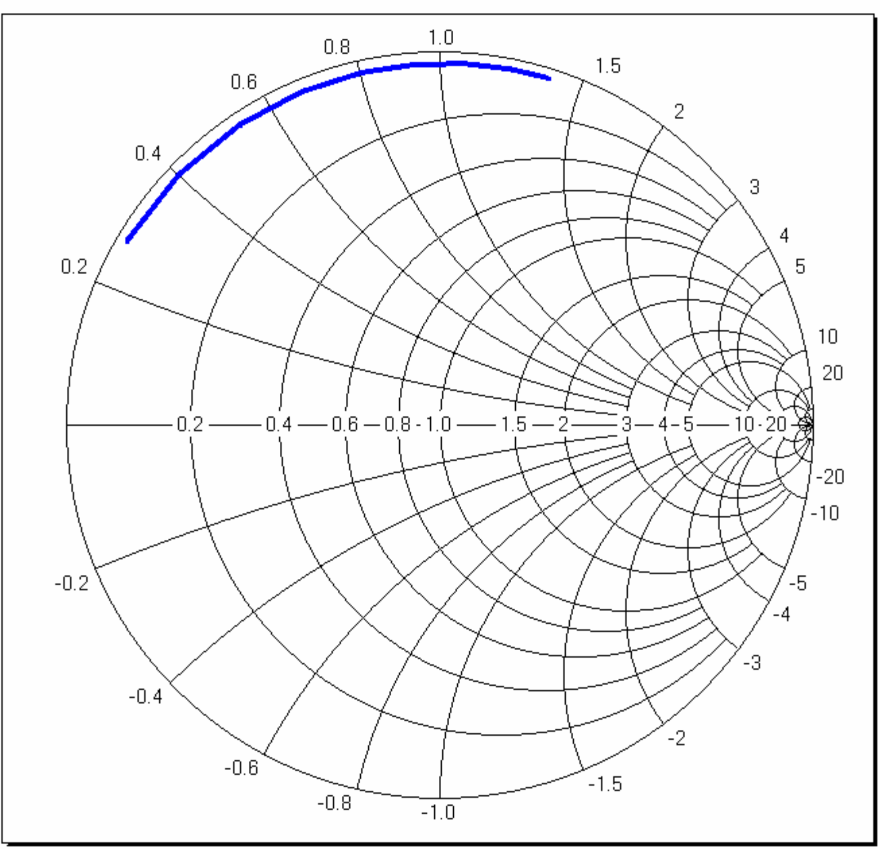
- RF Measurements (1-40+ GHz)
  - Active:
    - $F_{t,}$ F_{max}
  - Passive:
    - Inductors, Capacitors
    - Q
- Techniques
  - RF C-V, I-V
  - Network Analysis
    - (S-Parameters)

RF Measurements

- F_t – Active device frequency of unity gain
- F_{max} – Maximum oscillation frequency

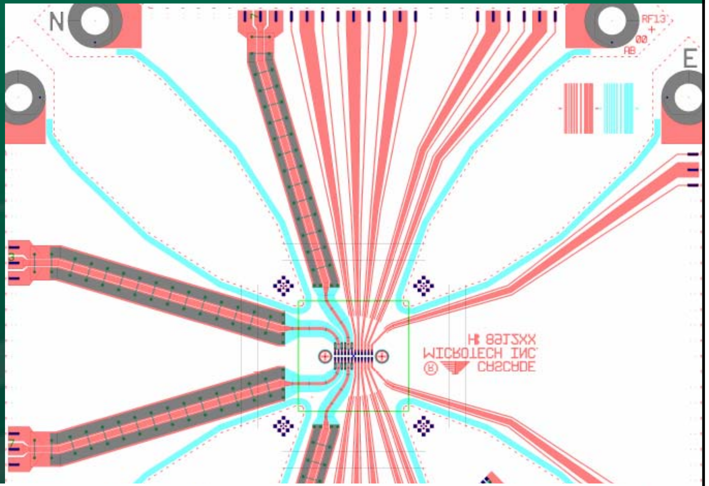
- Q – Reactance vs. passive losses

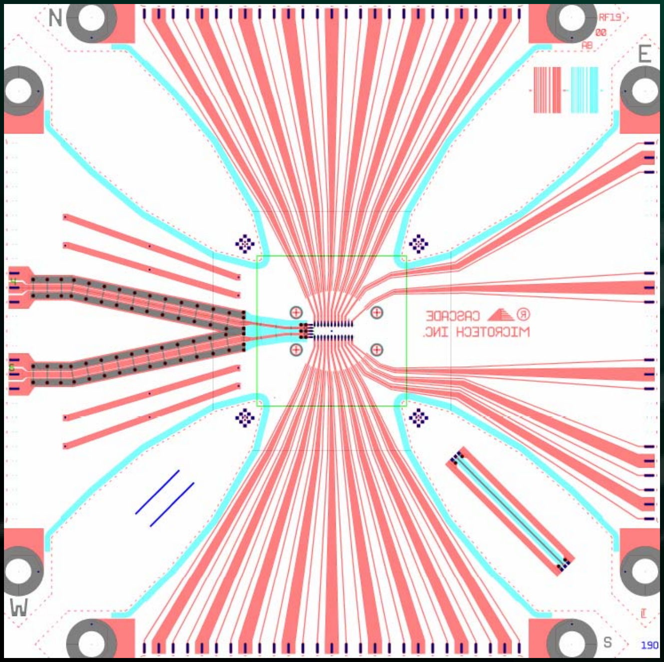


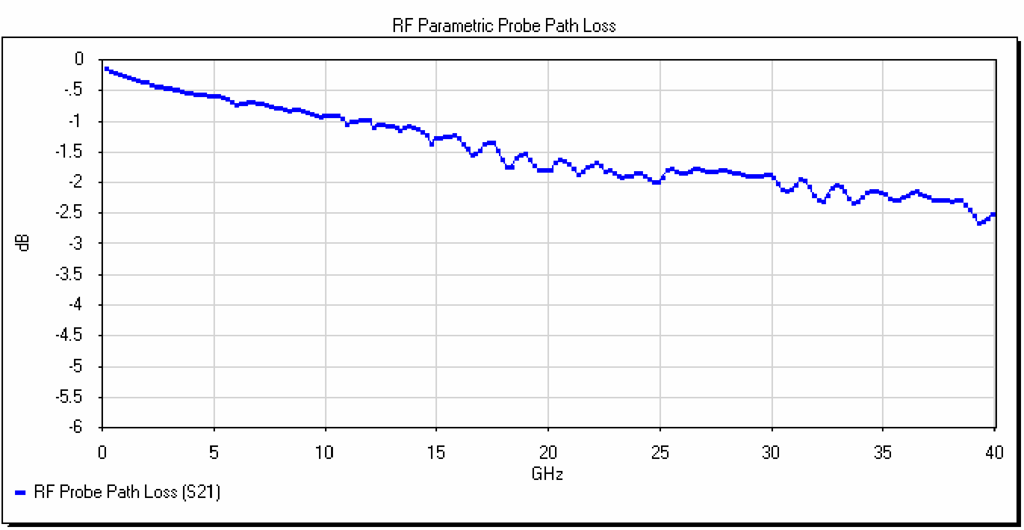


Combining Parametric & RF Measurements

- ATE systems include parametric + RF capabilities
- Membrane card supports both:
  - Low loss, low leakage, DC parametric
  - RF: Controlled impedance, low loss
- Probe card layout matches on-wafer test structures

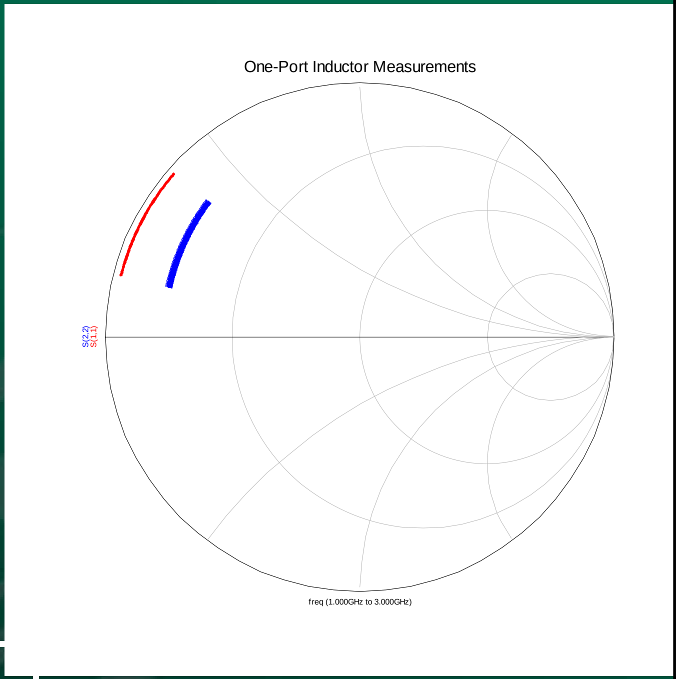






Probe Contact Resistance

- Low contact resistance is important:
  - Stable resistance can be calibrated out;
  - *Variations* in contact resistance cannot be removed.
- Variations in contact resistance affect:
  - Resistance measurements
  - Device Q calculations
- Example: Inductor Q


One-Port Inductor Measurements

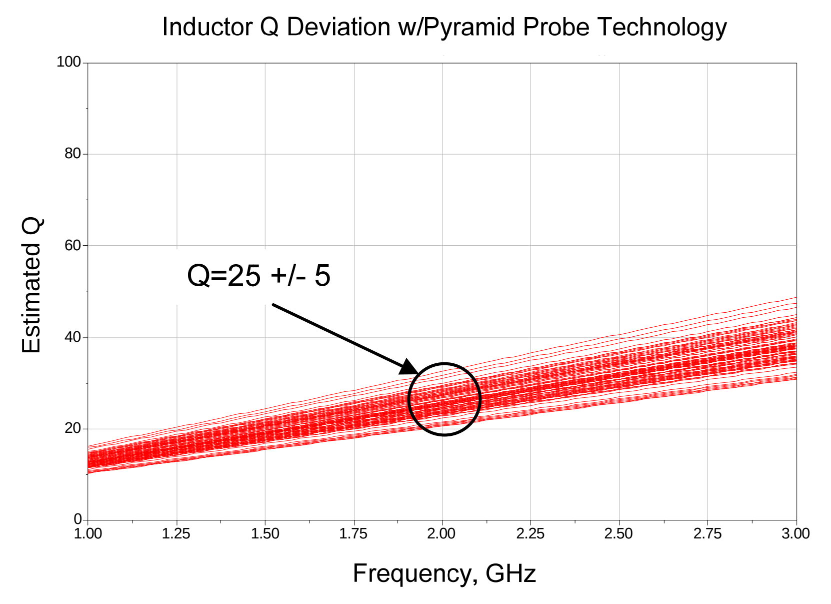
Inductance	Frequency	X_L	Resistance	Q
10nH	150 MHz	9.4 Ohm	1 Ohm	9
2.2nH	1 GHz	13.8 Ohm	0.8 Ohm	17
400pH	3.5 GHz	8.8 Ohm	0.3 Ohm	30

$$X_L = 2\pi f L$$

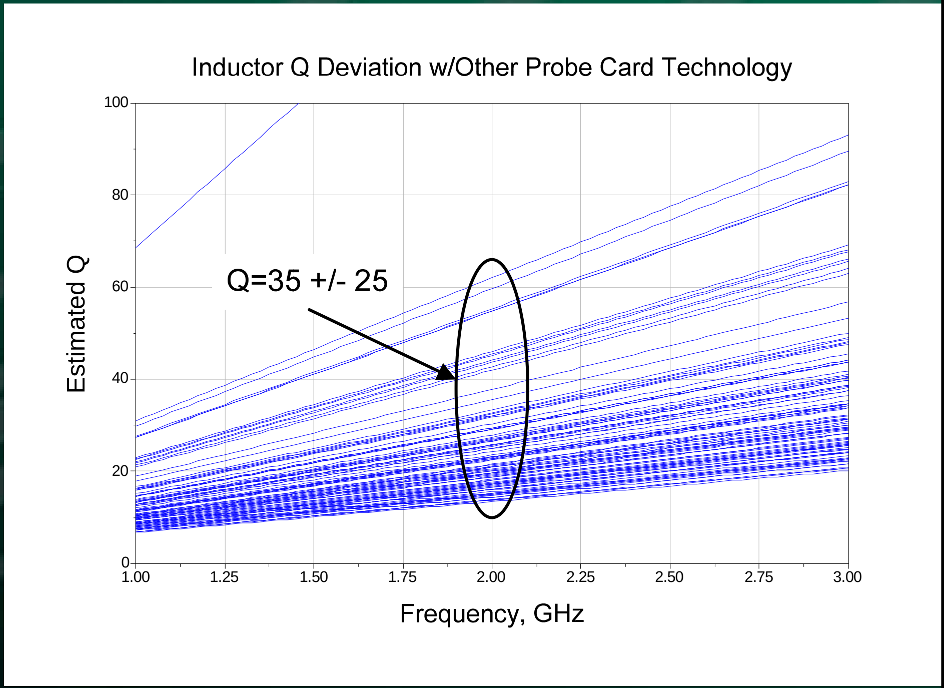
$$Q = \frac{X_L}{R}$$

Probe Contact Resistance

- Example: Inductor Q
  - One-port (S_{11}) calibrated
  - False-positive Q possible due to low $R_{contact}$ during calibration.

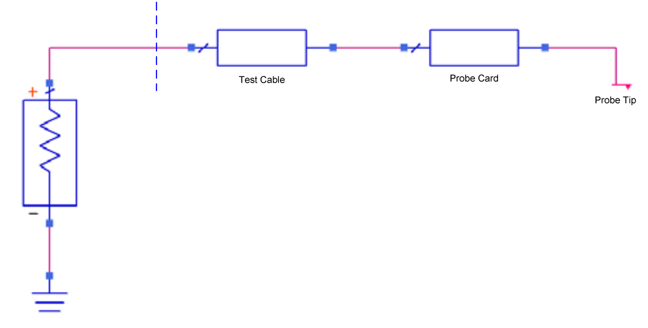

Inductor Q Deviation w/Pyramid Probe Technology

Q=25 +/- 5


Inductor Q Deviation w/Other Probe Card Technology

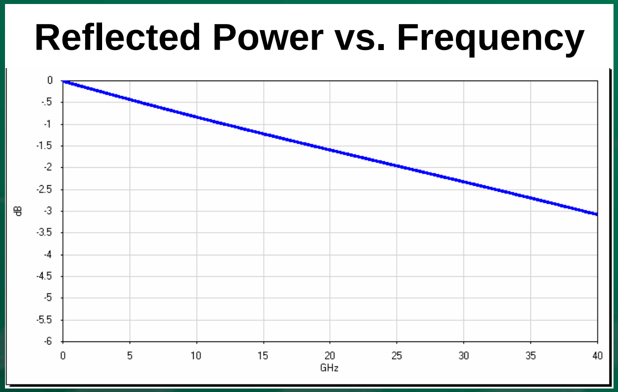
Q=35 +/- 25

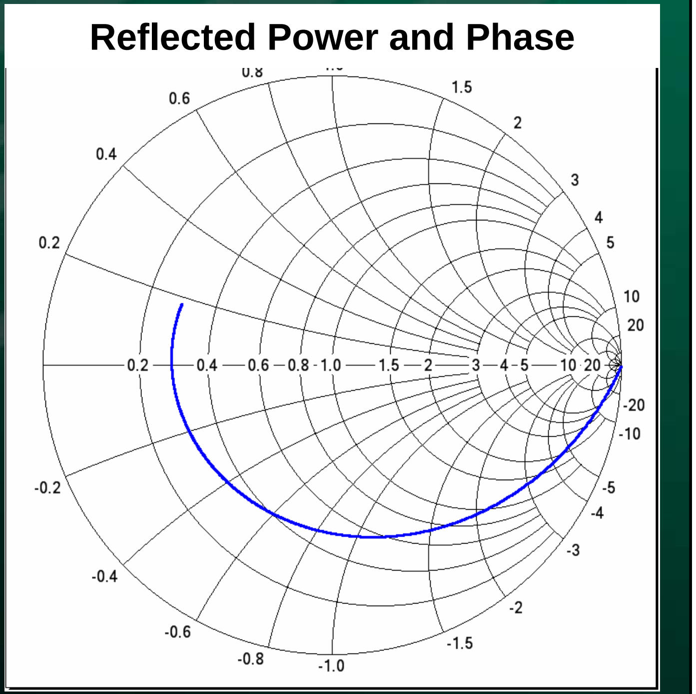
RF Calibration



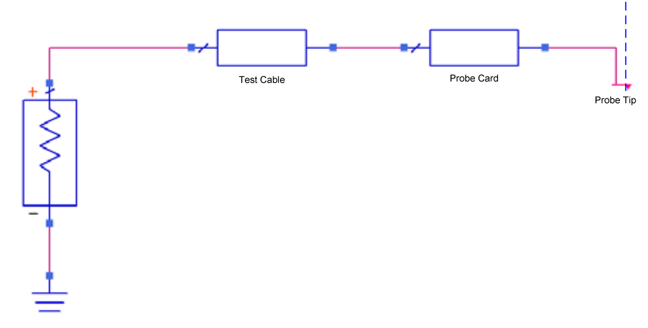
- Removing the anomalies from the measurement system
  - Eliminate electrical delay
  - Eliminate path loss
- Account for temperature, humidity, aging.
- Routine re-calibration required.
- *Measure only the device, not the probe card.*

- VNA: Vector Network Analyzer. Measures Reflected Power and Phase.
- *Calibration must be performed whenever anything between the VNA and the probe tip has been altered.*


Reflected Power vs. Frequency


Reflected Power and Phase

RF Calibration



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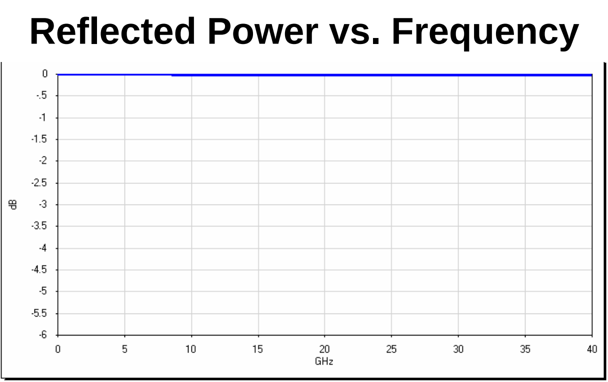
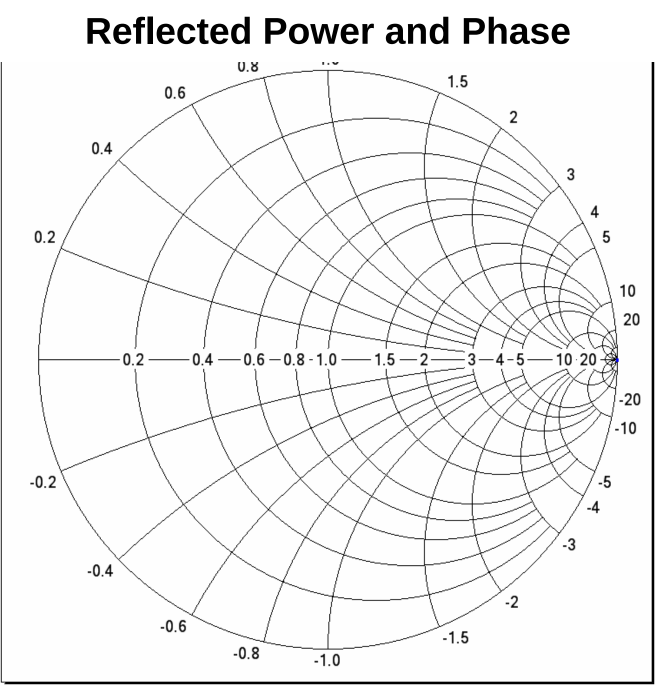


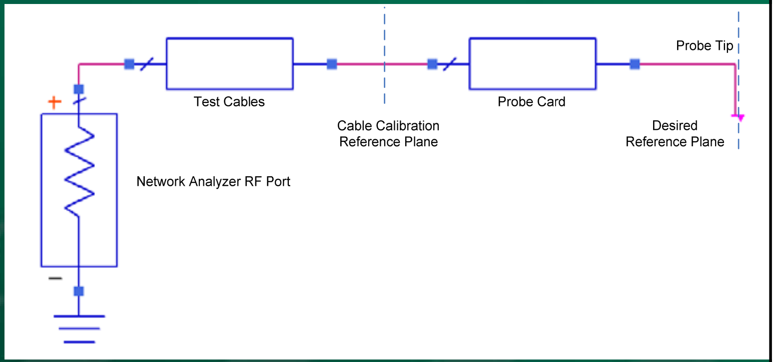
Reflected Power vs. Frequency

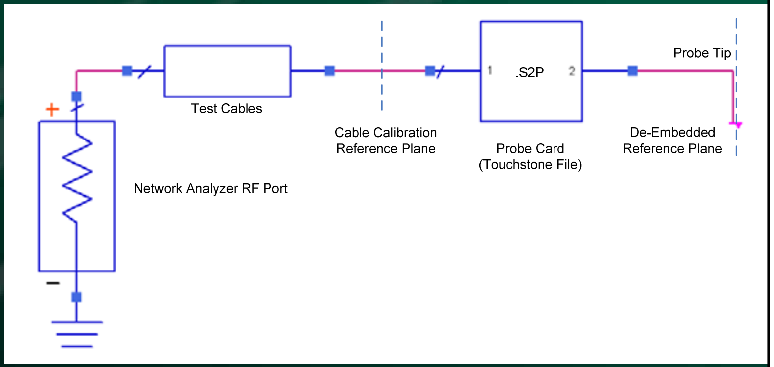


Reflected Power and Phase

Calibration Techniques

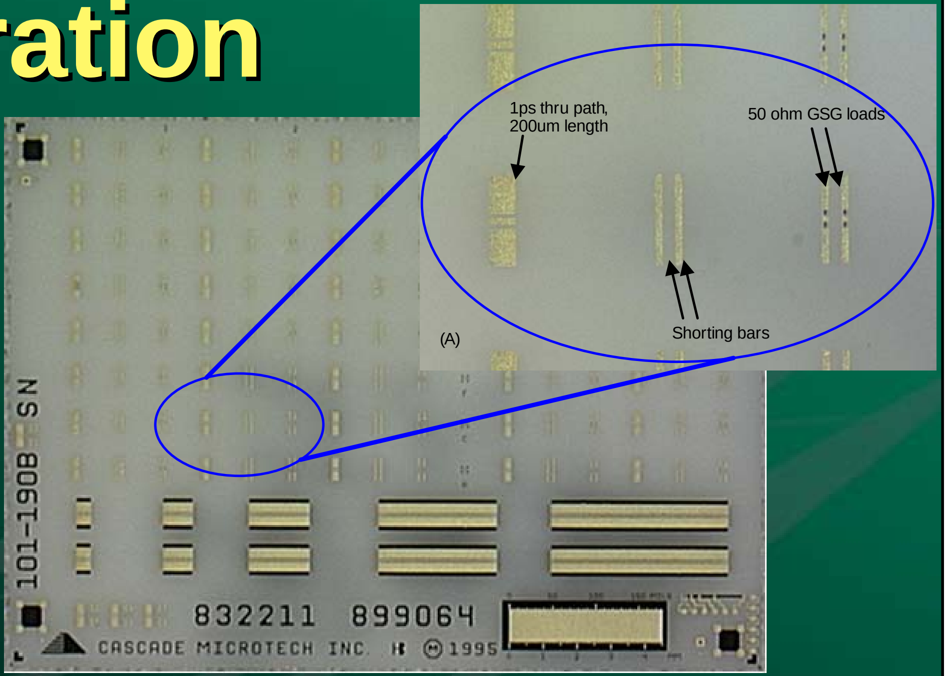
- Cable Calibration:
  - Mechanical Standards:
    - Short, Open, Load, Thru…., ECal, etc.
- Port Extensions:
  - Extend reference plane to the probe
  - Subtract estimated (linear) path loss
- Fixture De-embedding:
  - Characterize path loss for each port
  - VNA augments error-set with this data
- Tip Calibration:
  - Probe onto standards:
    - Short, Open, Load, Thru….
  - Advanced algorithms characterize the errors. Correction factors are stored in the VNA.
- *Parametric RF test requires high accuracy, repeatable measurements.*

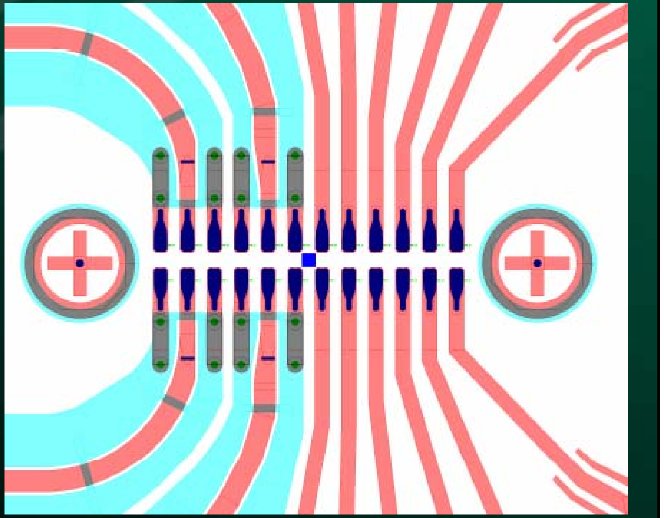




Impedance Standards for RF Calibration

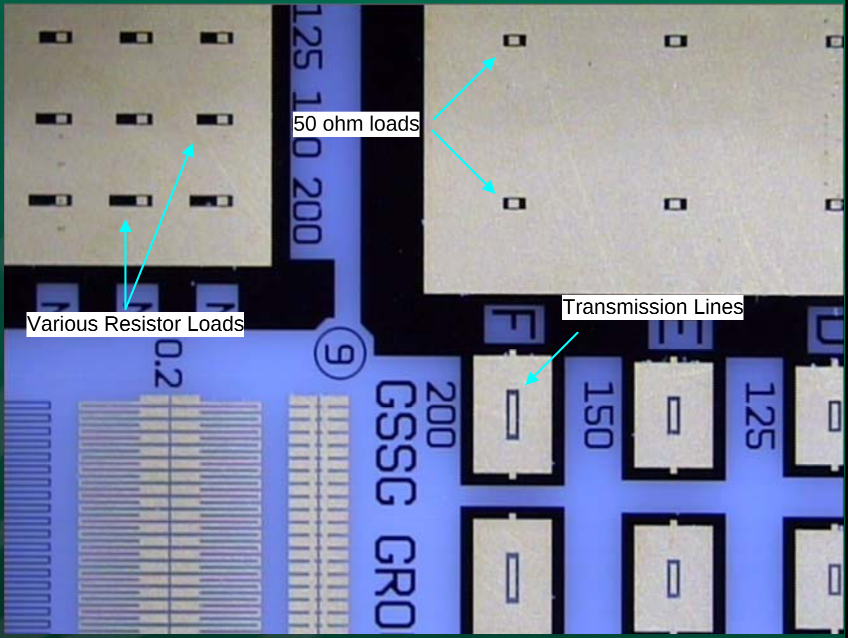
- Useful for tip calibration, probe card validation
- GSG 100um Standards:
  - Shorts, thru paths, 50 ohm loads, etc.
- Other structures to match popular probe configurations:
  - Varying pitch
  - Varying topology (GSGSG, etc.)
- *Use GSG probe configuration*
- *Match pad layout to standards, whenever possible.*





Establishing a Plan for Calibration

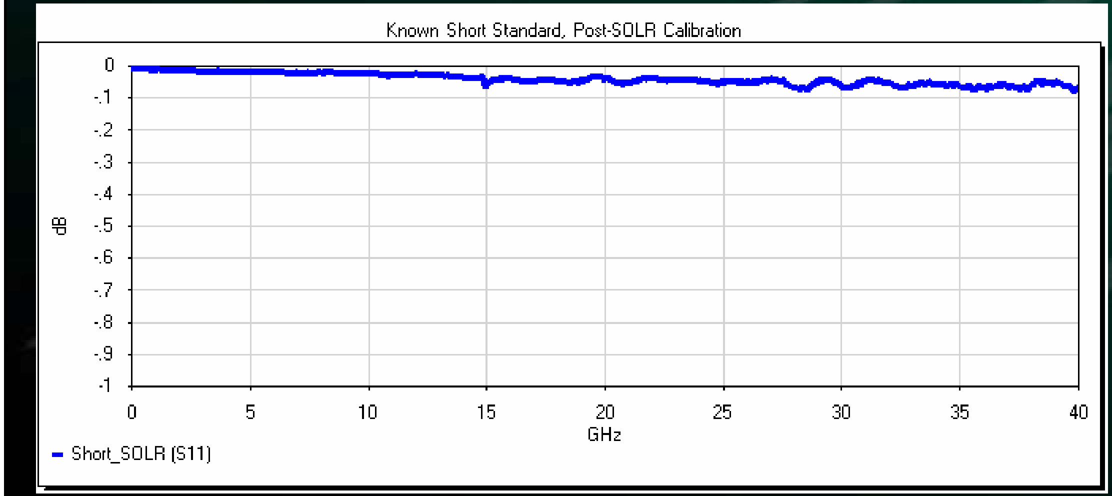
- Choose your calibration algorithm:
  - SOLT, SOLR, LRM, LRRM, etc.
- Have appropriate standards available:
  - ISS mounted on tester
  - ISS on wafer
  - Standards fabricated on wafer
- Establish a calibration schedule
- Determine where the calibration will be implemented:
  - VNA, embedded, PC, etc.
- Validate calibration & probe card assembly:
  - Probe onto known standards
  - Sample structures
- *Test the entire procedure with known standards.*

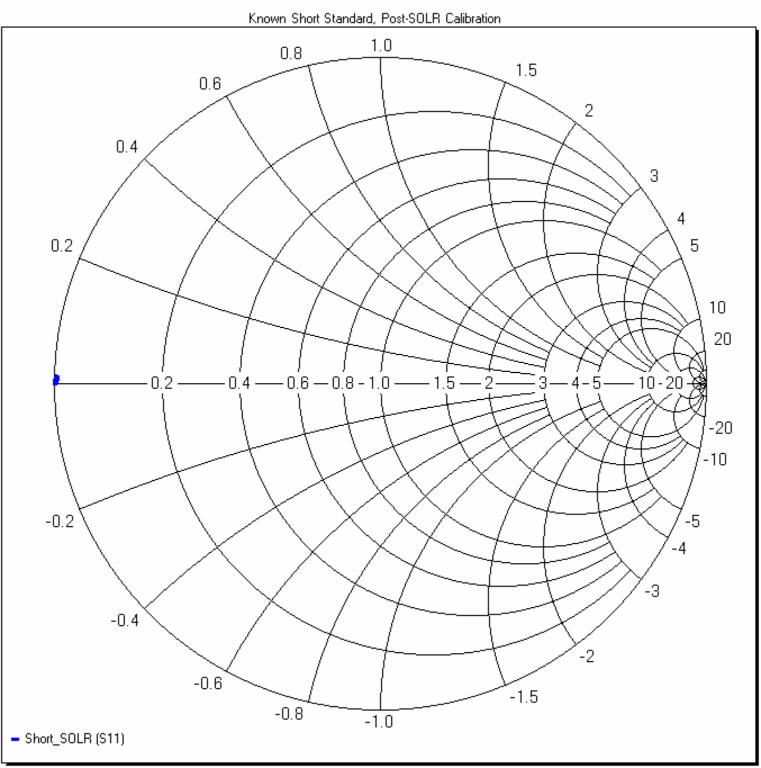


- General purpose ISS:
  - Sea of gold, 50 ohm loads.
  - Miscellaneous resistive loads

Probe Card Validation

- Calibrate to the probe tips:
  - SOLR allows for a general purpose thru.
  - LRRM:
    - Highly repeatable measurements.
    - Requires a perfect thru-path.
- Validation:
  - Verify calibration by landing onto known standards.
  - Example: Perfect Short, after an SOLR calibration.

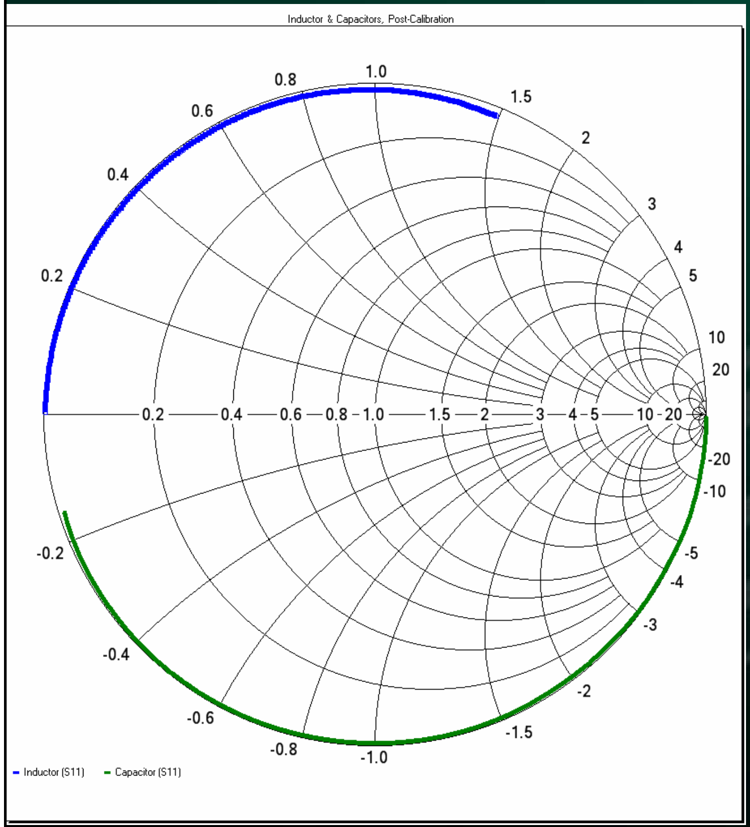

Known Short Standard, Post-SOLR Calibration

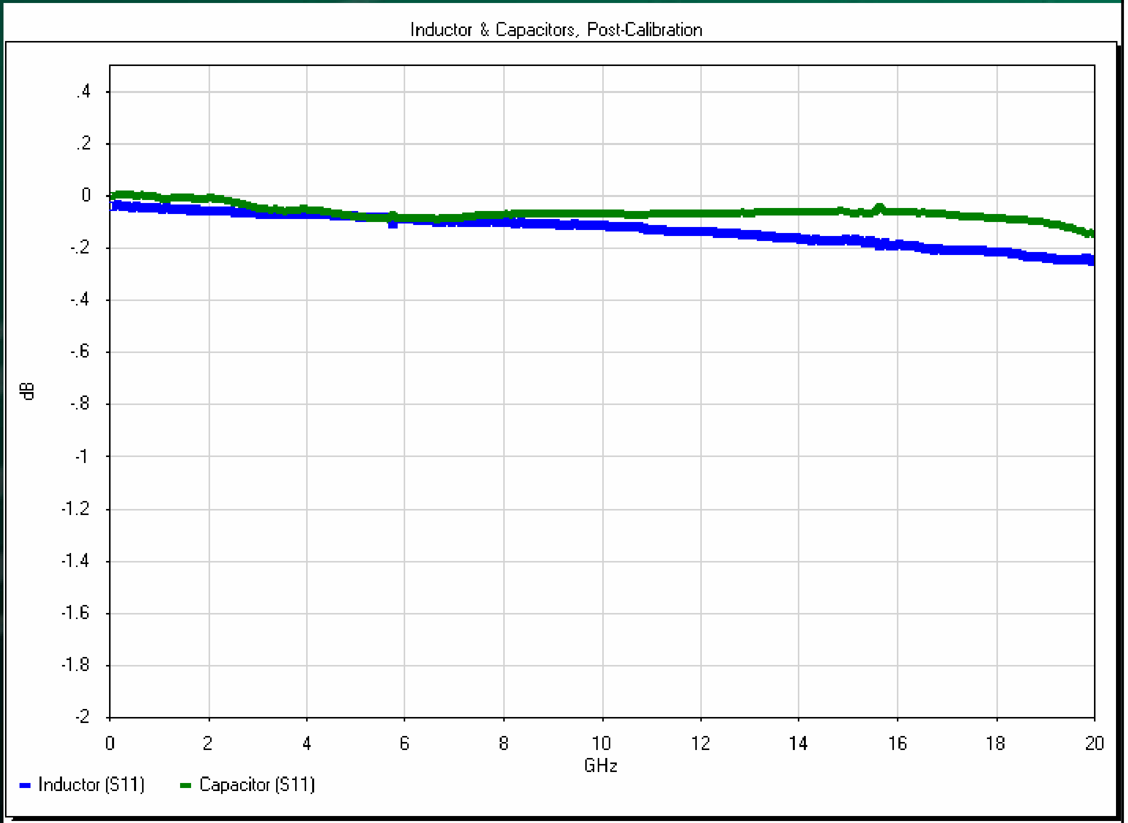

Known Short Standard, Post-SOLR Calibration

- Smith chart reveals one dot.
- Magnitude Power (dB) plot reveals all energy is reflected. (The loss variation is minimal).

Probe Card Validation

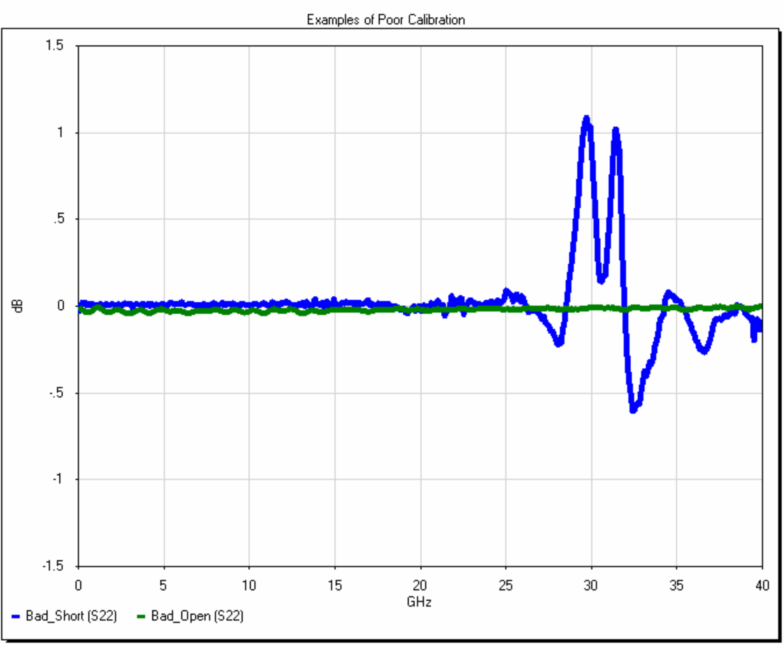
- Inductor & Capacitor:
  - Inductor appears as a short at DC.
  - Capacitor appears as an open at DC.

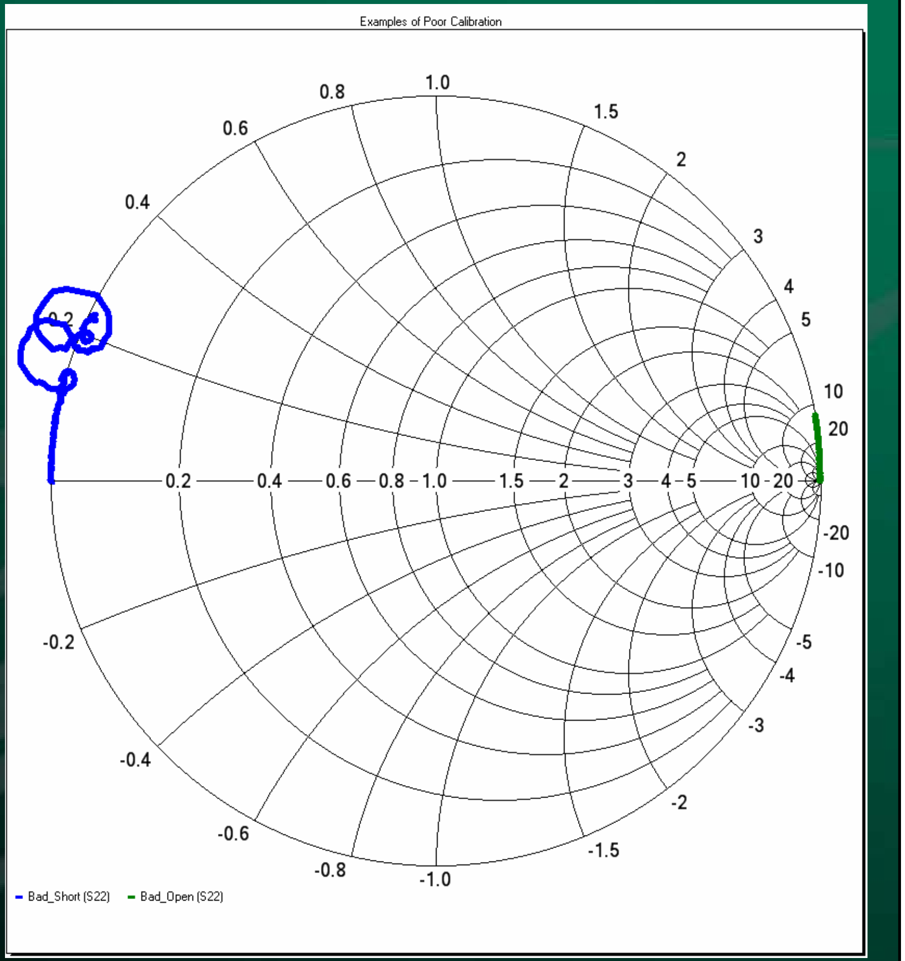




Incorrect Standards

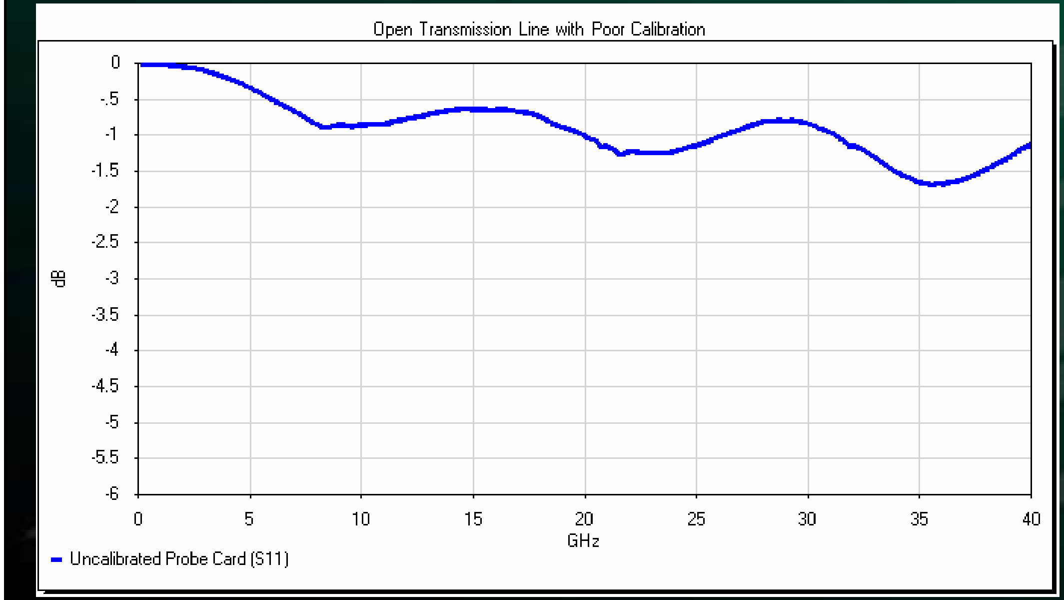
- Poor calibration:
  - When a short is not a short:
    - (left side of Smith chart)
  - When an open is not an open:
    - (right side)
  - Calibration should never reveal “gain”

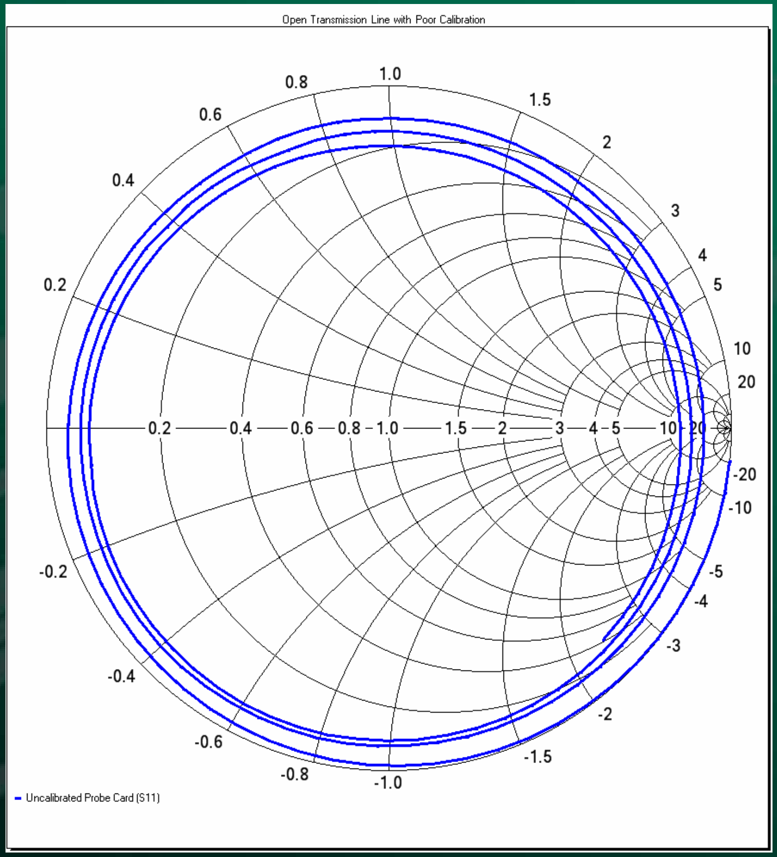




Incorrect Calibration

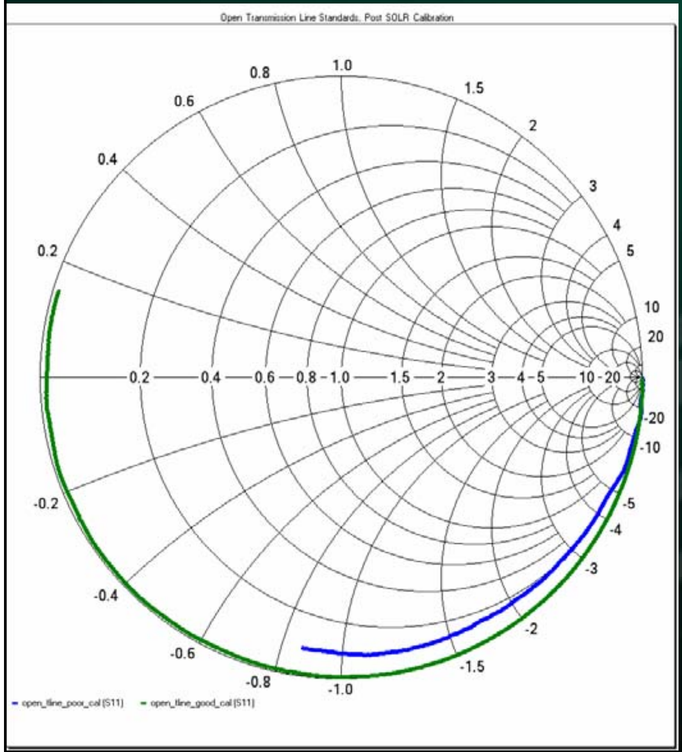
- Example: Long, open transmission line.
  - General pattern matches expectations.
  - Calibration is poor.
- Verify expectations on the Smith chart.
  - Magnitude power may not reveal enough information.

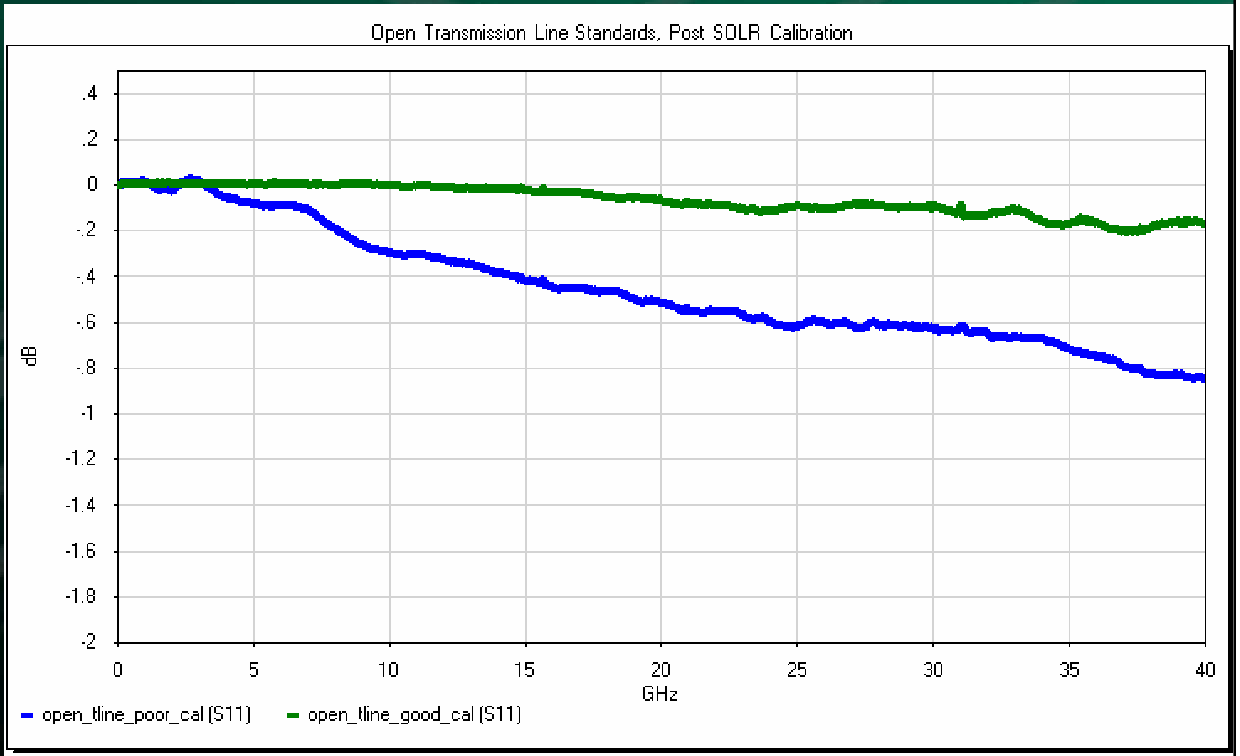




Probe Card Validation

- Open Transmission Line stub:
  - Two calibration examples:
    - Good cal reveals little or no loss through 40 GHz.
    - Other calibration reveals ~1dB loss at 40 GHz.





Conclusion

- Parametric RF Test establishes improved methods for process monitoring:
  - Device characterization.
  - At-frequency component validation.
- Establish a plan for calibration.
  - Establish a location for calibration standards within the ATE.
  - Know and understand the limitations of your measurements.
- Validate your probe card with something other than your DUT.
  - Develop experience with the system to assure that calibration functions as expected.