SWTEST
PROBE TODAY, FOR TOMORROW
2025 CONFERENCE

Fine Pitch RF Calibration and Sensitivity to Variation for Pyramid Probe

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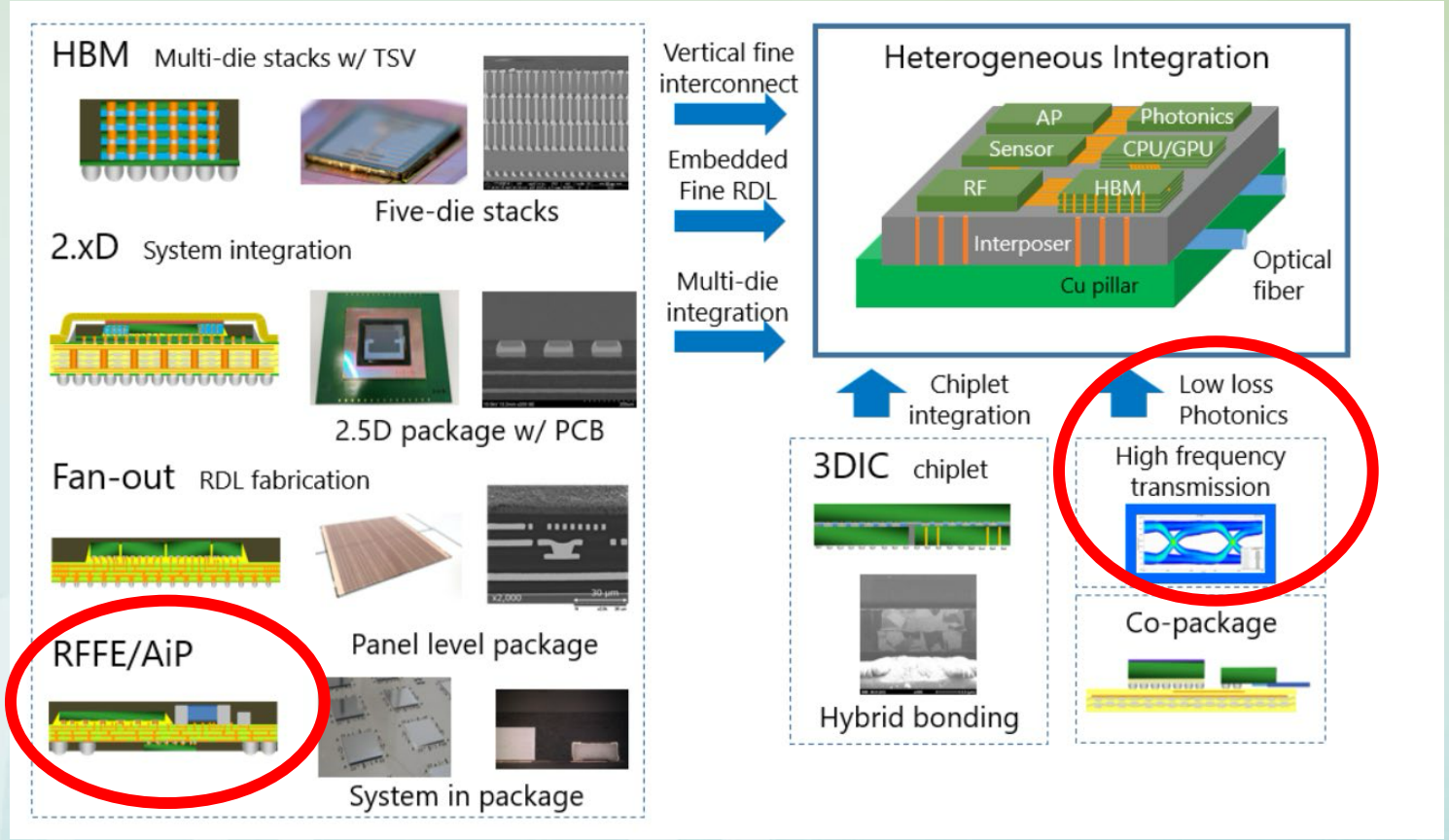
FormFactor

Agenda

- Market Driver: Multi-Chip Modules (MCM)
- DOE study design
- Measurements of Calibration Standards
- Analysis and conclusions on sensitivity to process in fabrication and testing
- Final recommendations

Heterogenous Integration: Device Pitch

- Heterogenous integration of different chips into MCMs is requiring ‘more finely pitched and three-dimensionally integrated’ modules with a larger variation of different functions combined
- The finer pitch affects all pieces in the stack-up, including the RF and High Speed Digital chips:
  - RFFE
  - AiP
  - TIAs and Laser Drivers



Source: https://www.resonac.com/solution/tech/next-gen-semiconductor-packages.html

More (Not Less) Wafer Test

‘The move to multi-die packaging is driving chipmakers to develop more cost-effective ways to ensure only known-good die are integrated into packages, because the price of failure is significantly higher than with a single die.’

-**Need For KGD Drives Singulated Die Screening,** MARCH 31ST, 2025 - BY: **ANNE MEIXNER, SEMICONDUCTOR ENGINEERING**

- **Therefore, excellent signal integrity probe cards, with stable calibration with low variation over time and from test cell to test cell, is needed to keep it cost effective**

RF Wafer Test: Pyramid Probe and ISS

- The Pyramid Probe provides excellent signal integrity for RF wafer test up to 81 GHz
  - Return loss better than 10 dB

- For the best measurements, the custom Impedance Standard Substrates (ISS) are used to do RF calibration to the tip
  - Match device layout to minimize variation

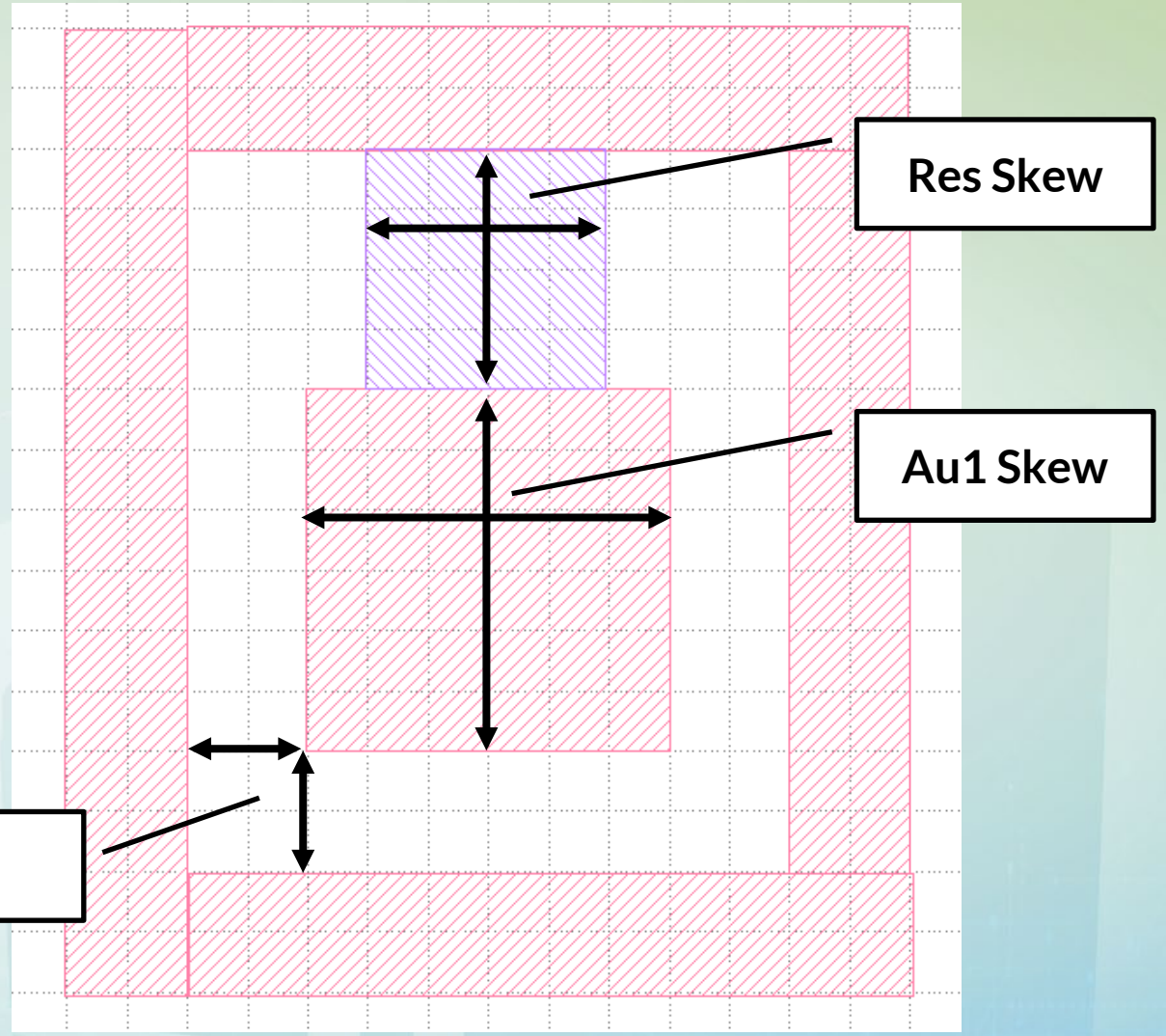
Questions about RF Calibration with Narrow Pitch?

- Some questions that people have asked about moving to narrower pitches and how it affects RF calibration include:
  - How does RF calibration vary from substrate to substrate due to process variation?
  - How does probe-to-pad alignment affect RF measurements at narrow pitch?
  - How does the pad gap affect RF measurements, where a small gap will make routing easier but will increase coupling to ground?

ISS Load DOE Variations

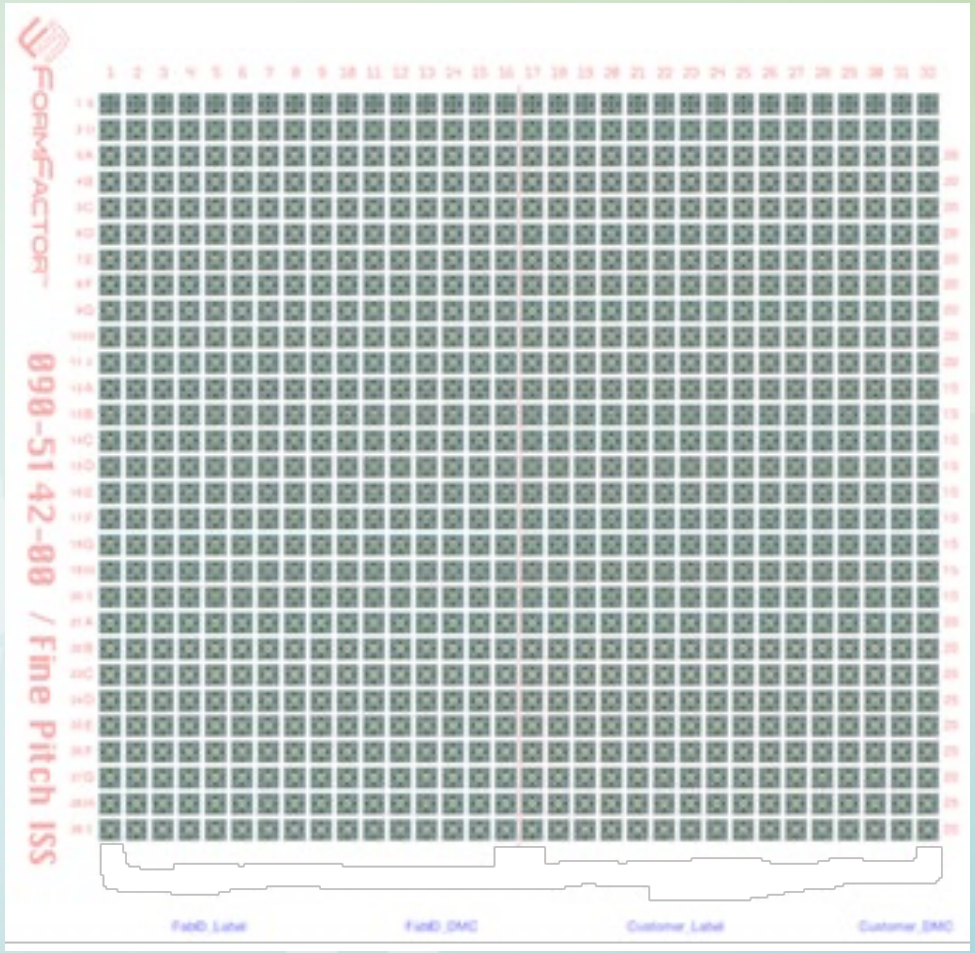
Variable	Target	Variations
Metal Pad (Au1)	60 um	+/- 2 um
Resistor width (Res)	40 um	+/- 1.5 um
Pad-Ground Gap	20 um	+/- 5 um
Probe-to-Pad Alignment*	0 um	5 um, or 10 um in X and/or Y from pad center

*This was controlled not in the design, but programmed offset with the prober



Narrow Pitch Test: ISS Design

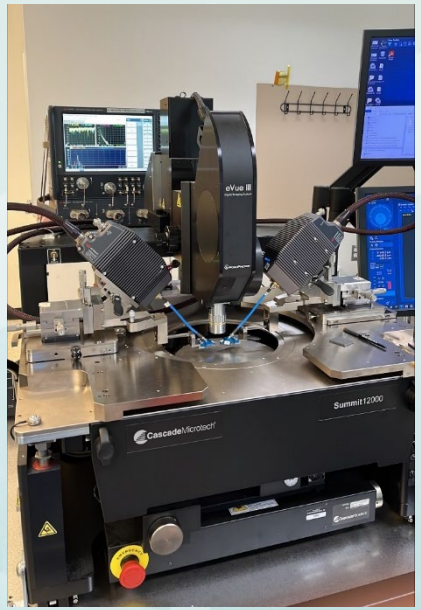
- To evaluate RF calibration variation, an ISS with smaller pads and loads to support narrower pitches was designed and manufactured
  - 100 um -> 80 um in GSG line
- ISS includes:
  - Loads in row 3-29
    - The rows tested all combinations of the design parameters
    - Each ISS has 864 loads
    - Loads are 50 +/- 0.5 Ohm
    - Yield of the loads was > 99%
  - Shorts in row 1 and opens in row 2 for SOL 1-port calibration to the tip



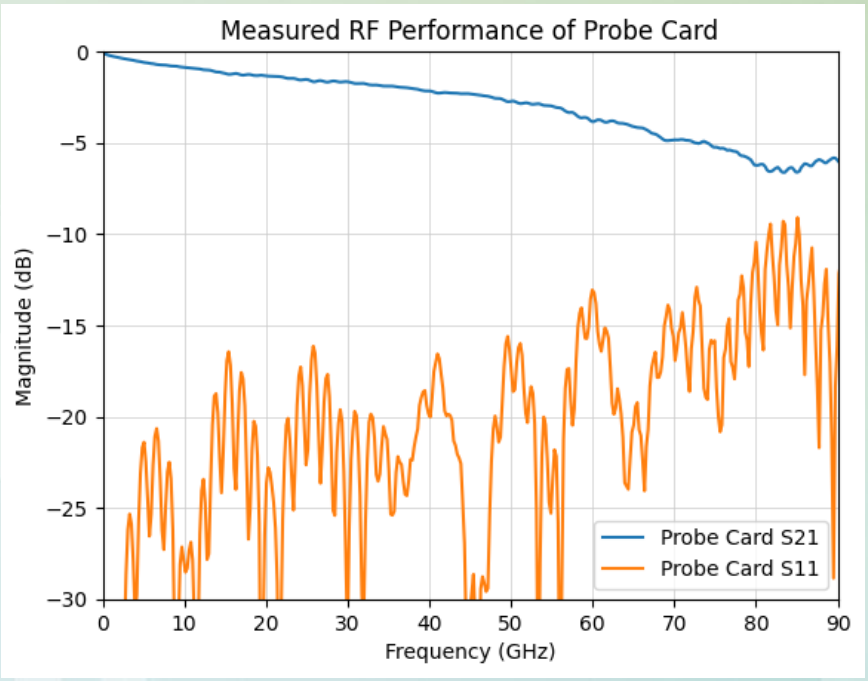
ISS Variation Test Setup

- Pyramid Probe Card
  - RFC Pyramid Probe with 1 mm connectors on the PCB
- Test System:
  - Keysight PNA-X with mmW test setup up to 110 GHz
  - FormFactor 12000 station
- RF Measurements were calibration to the tip
  - Calibration standards were:
    - The load at row 3, column 1
    - The short and open in column 1

Experimental Pyramid Probe in Test Environment



12000 Station with PNA-X mmW Test Set



Measured S-parameter Performance of the RFC Probe Card

RF Analysis Methods

- The performance of the ISS was evaluated using two methods
  - Calculated average load inductance over frequency

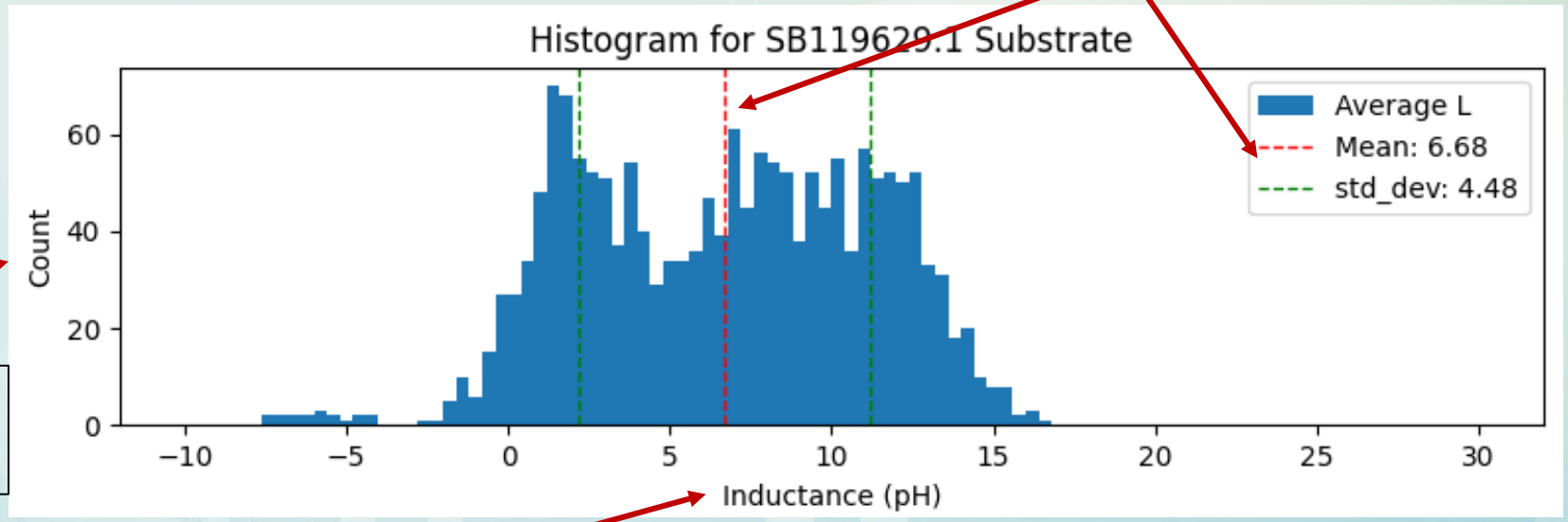
$$L_{ave} = \frac{1}{n}\sum_{i=0}^{n}\frac{Z_{im}}{2\pi f}$$

    - Inductance was picked to evaluate variation because inductance directly relates to how the load is operating at RF frequencies
  - Evaluated the S-parameters, comparing the mean and standard deviation of the S-parameters over the measurements

Inductance Histograms: Quick Summary

- Once the Inductance was calculated, we then plotted the histogram of the extracted inductance

Added in lines for mean and 1 standard deviation to plot, with value in legend

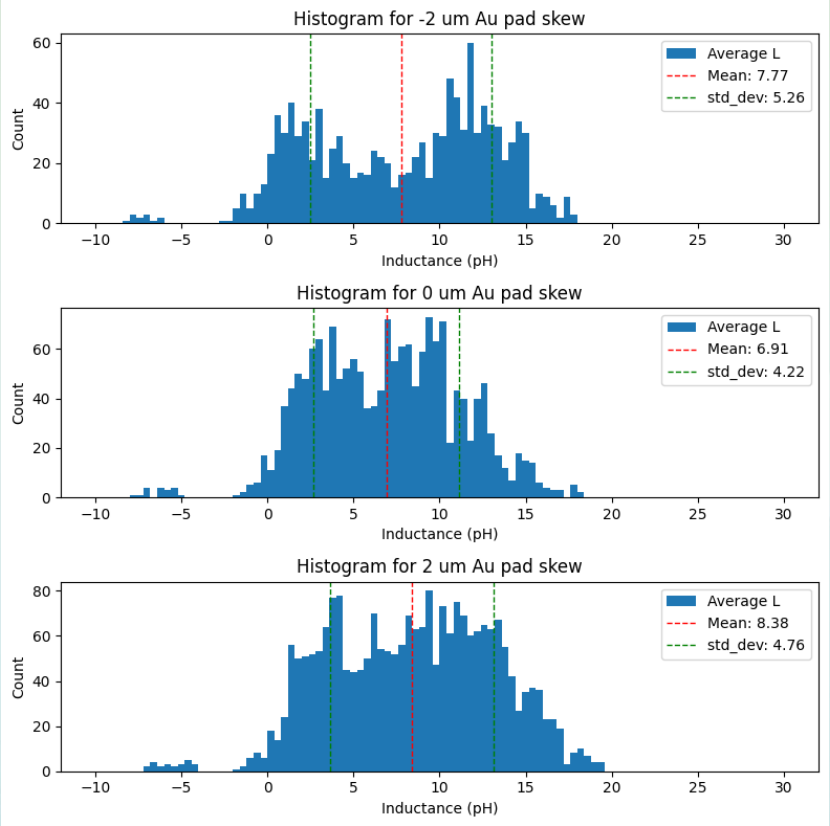


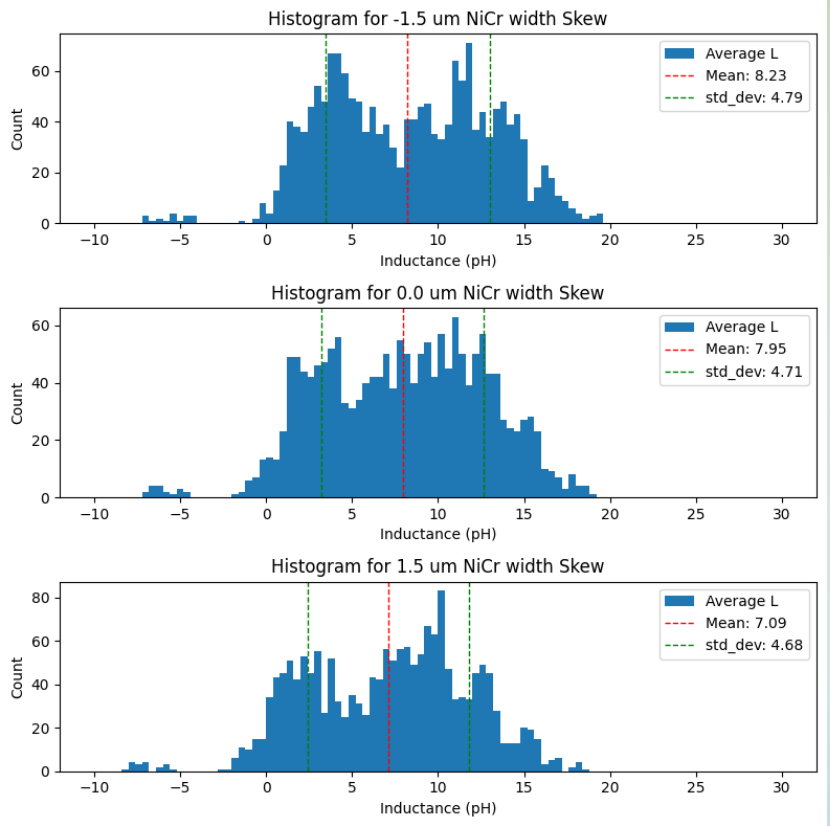
Y-axis is number (count) of loads with a given inductance

X-axis is calculated Inductance (pH)

Variation of Load: Res and Au Skew

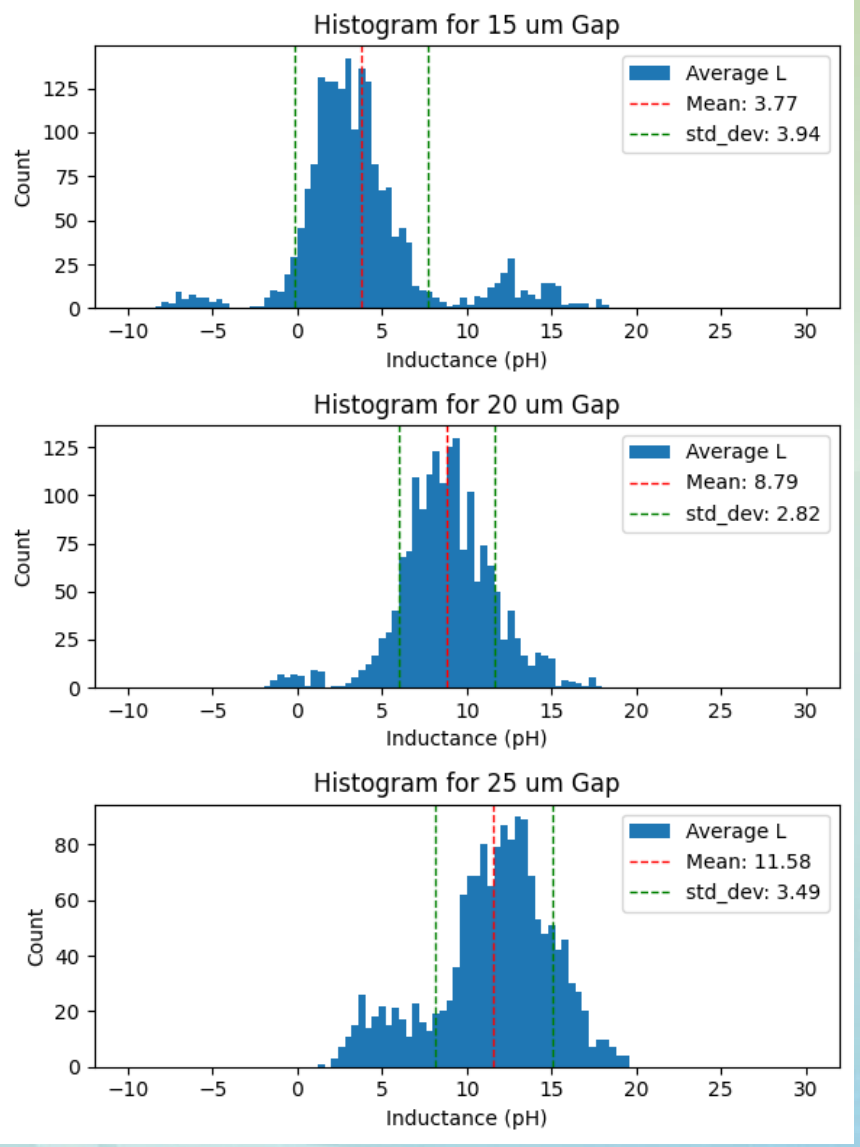
- The variation when looked at vs Au1 and Res, there was not a strong effect with the calculated inductance





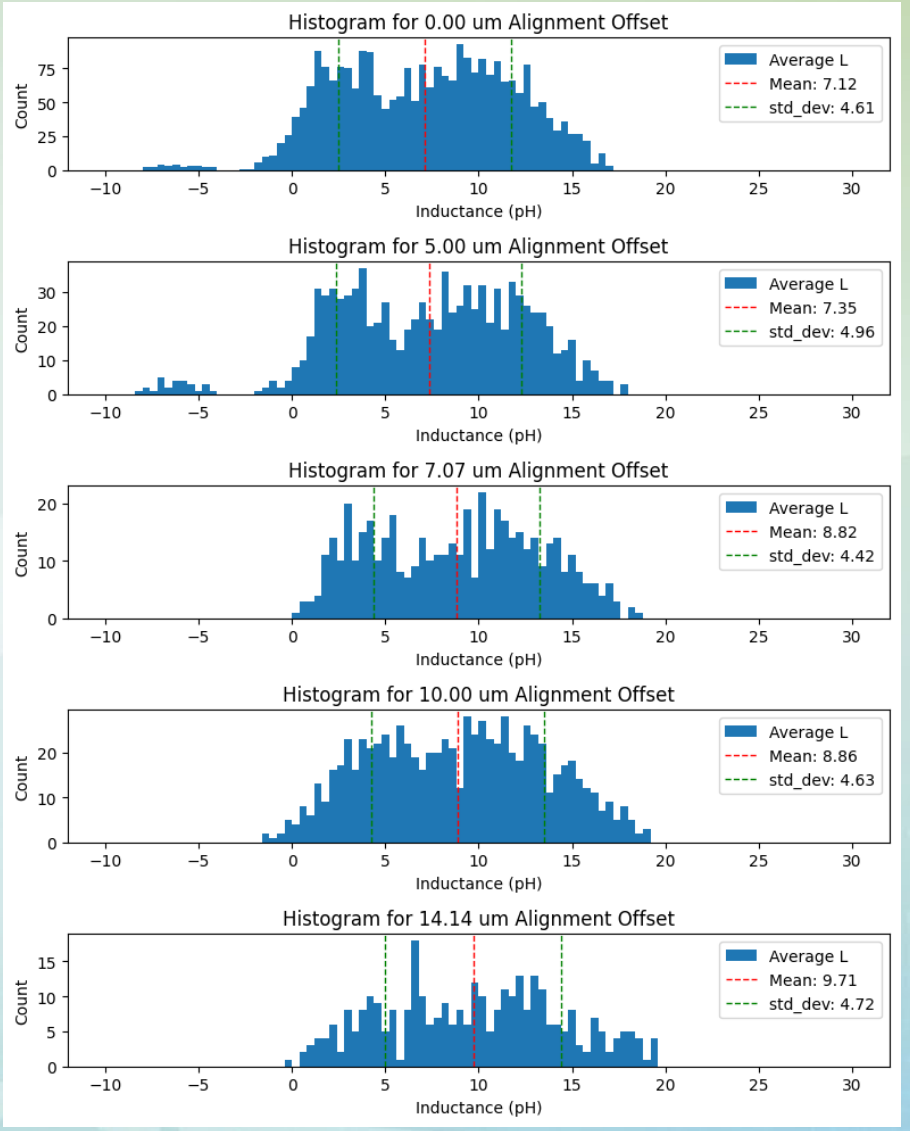
Variation of Load Inductance due to Gap

- There is a strong effect due to the gap
  - As the gap is increased from the nominal, the extracted load inductance increases
  - Or if the gap is decreased from the nominal, inductance is reduced
  - This was expected due to the amount of change: 15, 20, and 25 um gap



Variation of Load: Probe Contact Offset

- The variation in the extracted load inductance based on probe to pad alignment was not large
  - There is a small amount of increase in inductance as the offset distance was increased



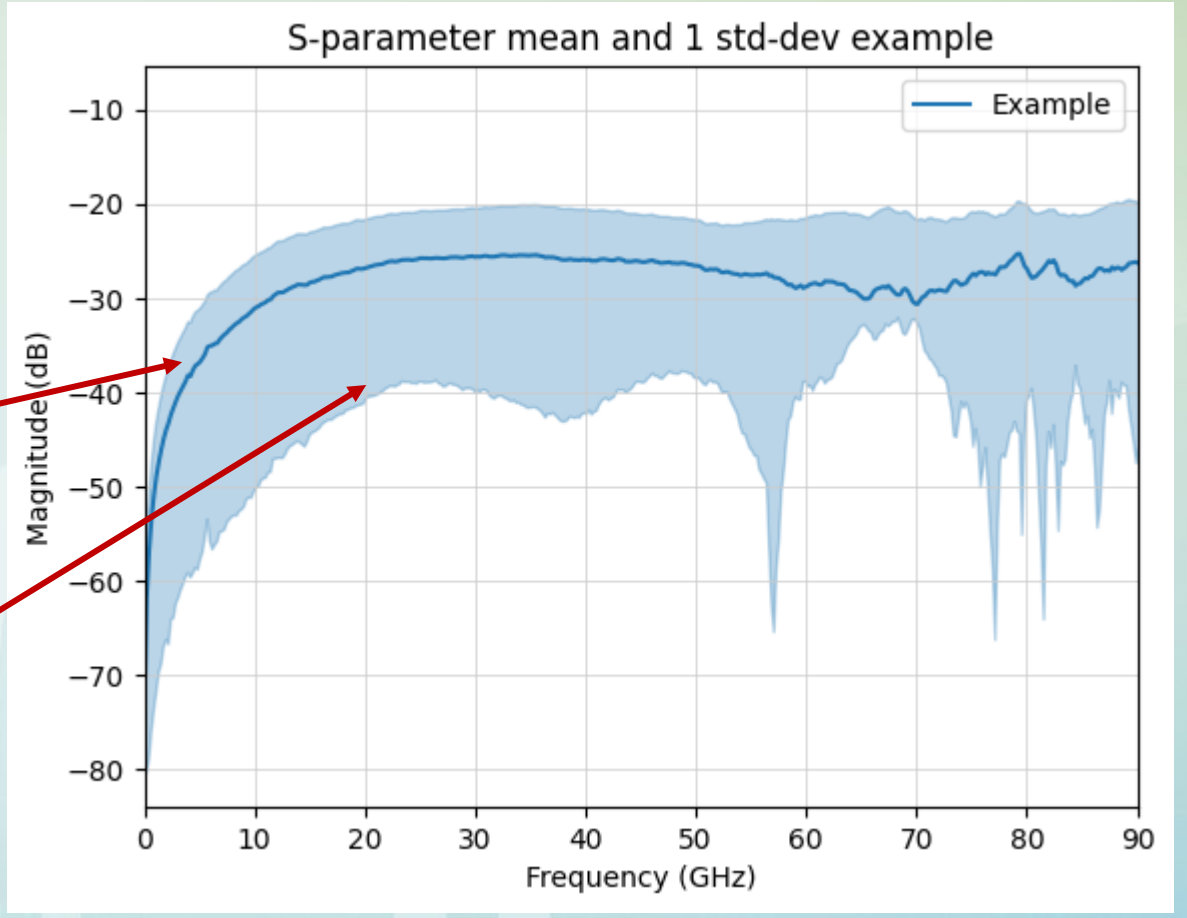
Pearson's Correlation

- Looking at the extracted inductance and correlating with the various DOE factors, the gap has the largest effect
  - The probe to pad alignment (offset) has a small effect

	Average L	Gap	Total offset	NiCr Skew	Au1 skew
Average L	1.000000				
Gap	0.675762	1.000000			
Total offset	0.171474	-0.000197	1.000000		
NiCr Skew	-0.097591	-0.000712	-0.001189	1.000000	
Au1 skew	0.073046	0.026617	0.000387	0.001005	1.000000

How to read the S-parameter Variation Plots

- This S-parameter uncertainty plot allows one to see the variation across frequency for a large set of data for the load measurements

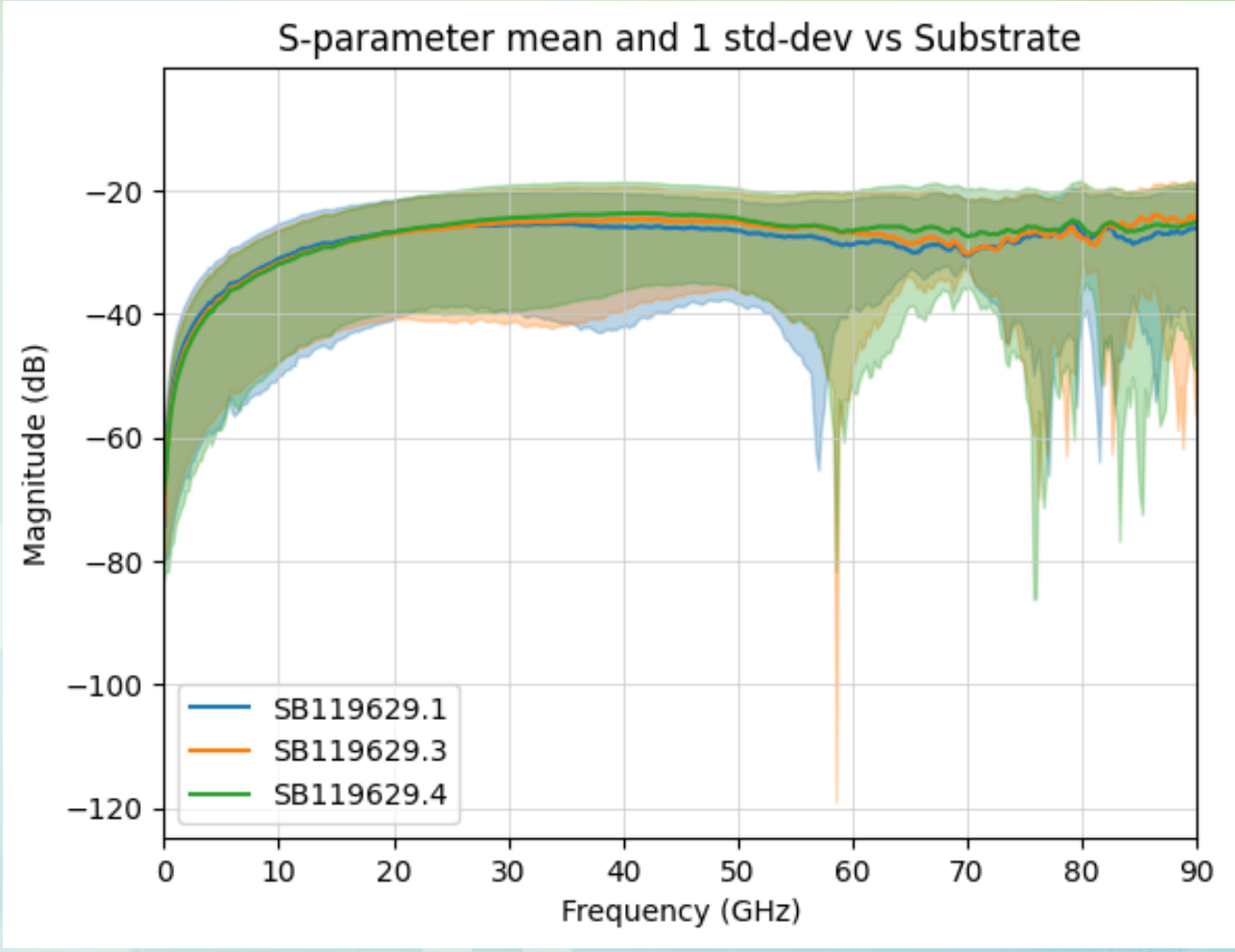


Dark line is the mean

Light shading shows 1 standard deviation of variation in the data

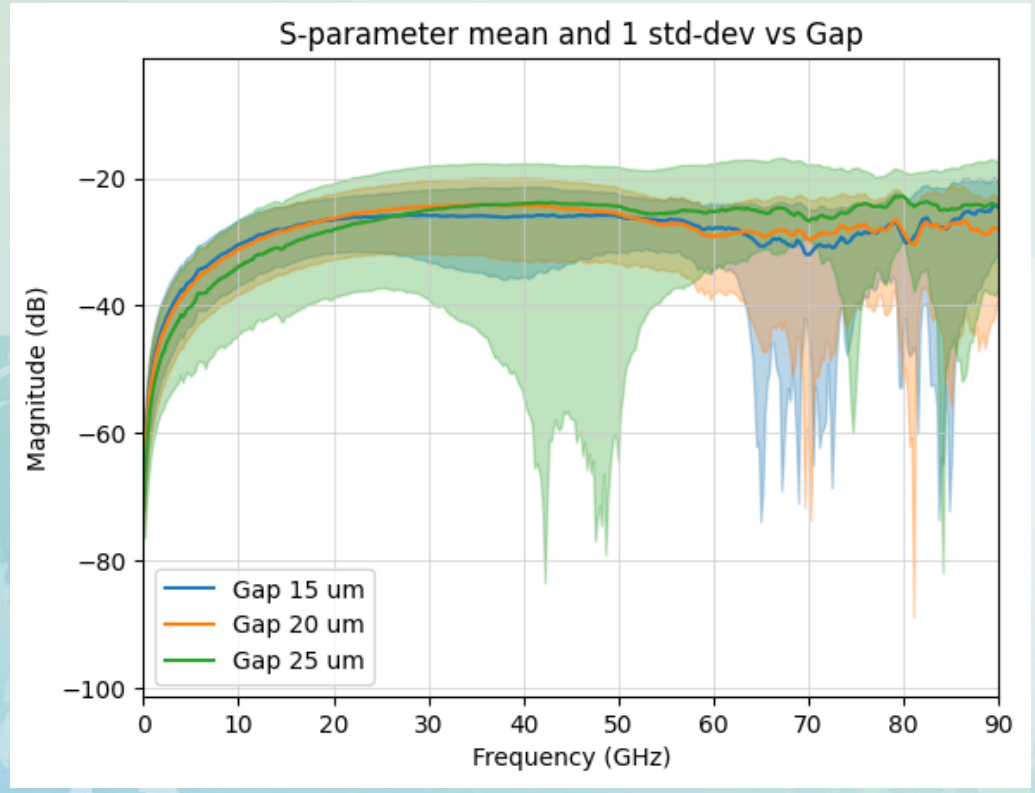
S-parameter Variation

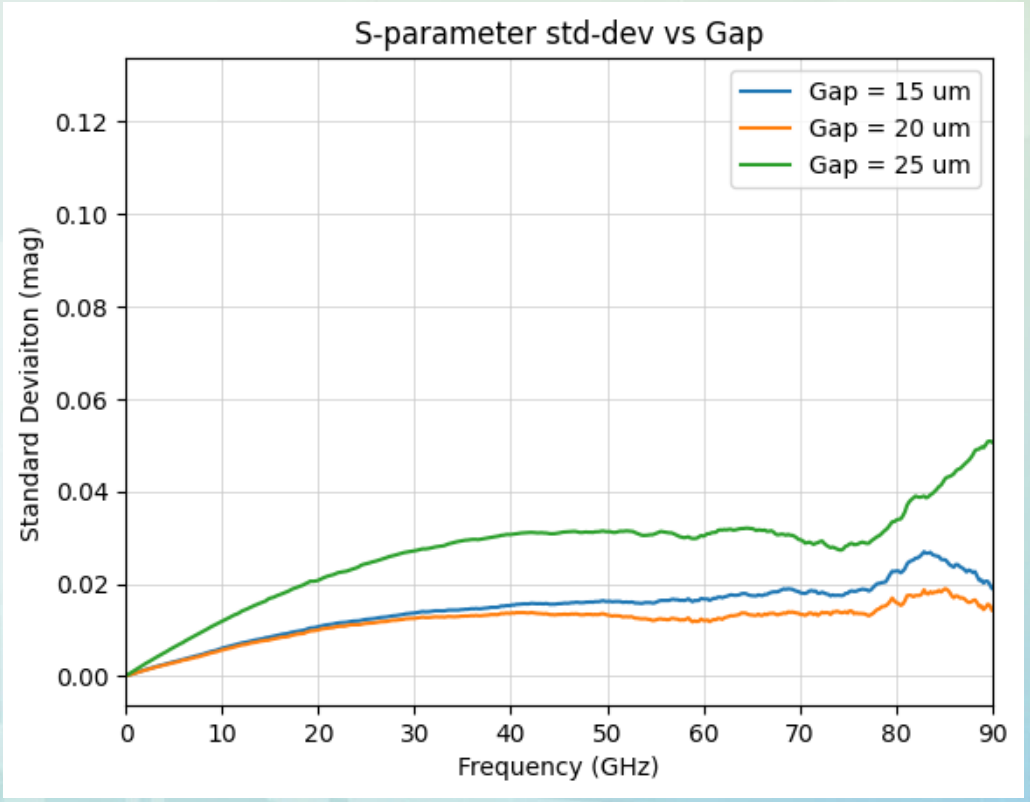
- The S-parameter variation plots show now real different vs:
  - Au1 pad skew
  - Res skew
  - Probe-to-Pad Alignment
  - Substrate



S-parameter Variation: Pad-to-Gnd Gap Effect

- The gap had the largest effect on the extracted inductance, and also had the largest effect in S-parameters
  - The standard deviation from 25 um gap was much larger than 20 and 15 um gaps





Conclusion

- Process variation in the Custom ISS will not have a large effect on the final S-parameters and extracted inductance of test structures
- The largest variation was due to the pad-to-gnd gap in both S-parameters and inductance calculation
  - A gap of 25 um increased variation in the S-parameter measurements when compared to 20 and 15 um
  - Recommendation is to only allow for 20 and 15 um gaps due to the increased variation in measurements with 25 um

Questions