IEEE SW Test Workshop

Semiconductor Wafer Test Workshop

Probe to Pad Placement Error Correction for Wafer Level S-Parameter Measurements

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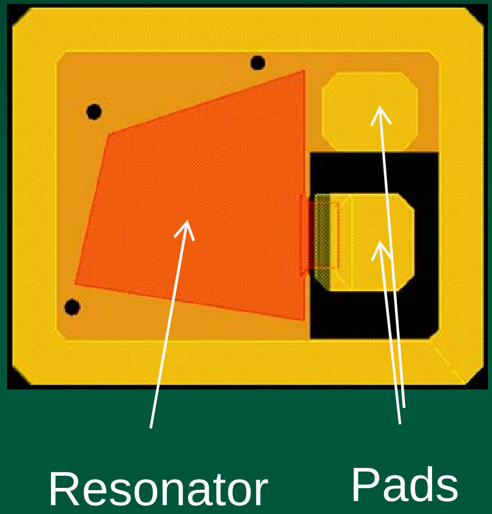
Overview

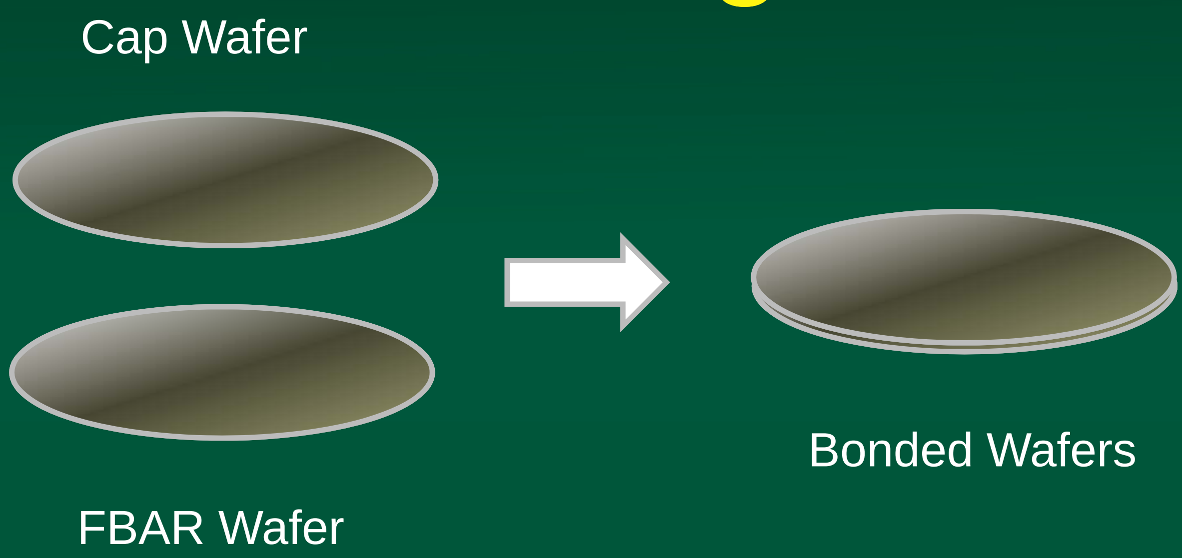
- New product development pushes measurement capabilities
- Review of pad de-embedding technique
- Application of de-embedding in novel way to correct probe to pad placement errors
- Experimental design
- Results

Film Bulk Acoustic Resonator



- New product development geared towards using FBARs in oscillators for timing solutions
- 1.5GHz resonant frequency
- 27,000 um^2 resonator area
- Quality factor over 1000, up to several thousand
- 1 year aging spec less than 25ppm

Hermetic Wafer Level Package

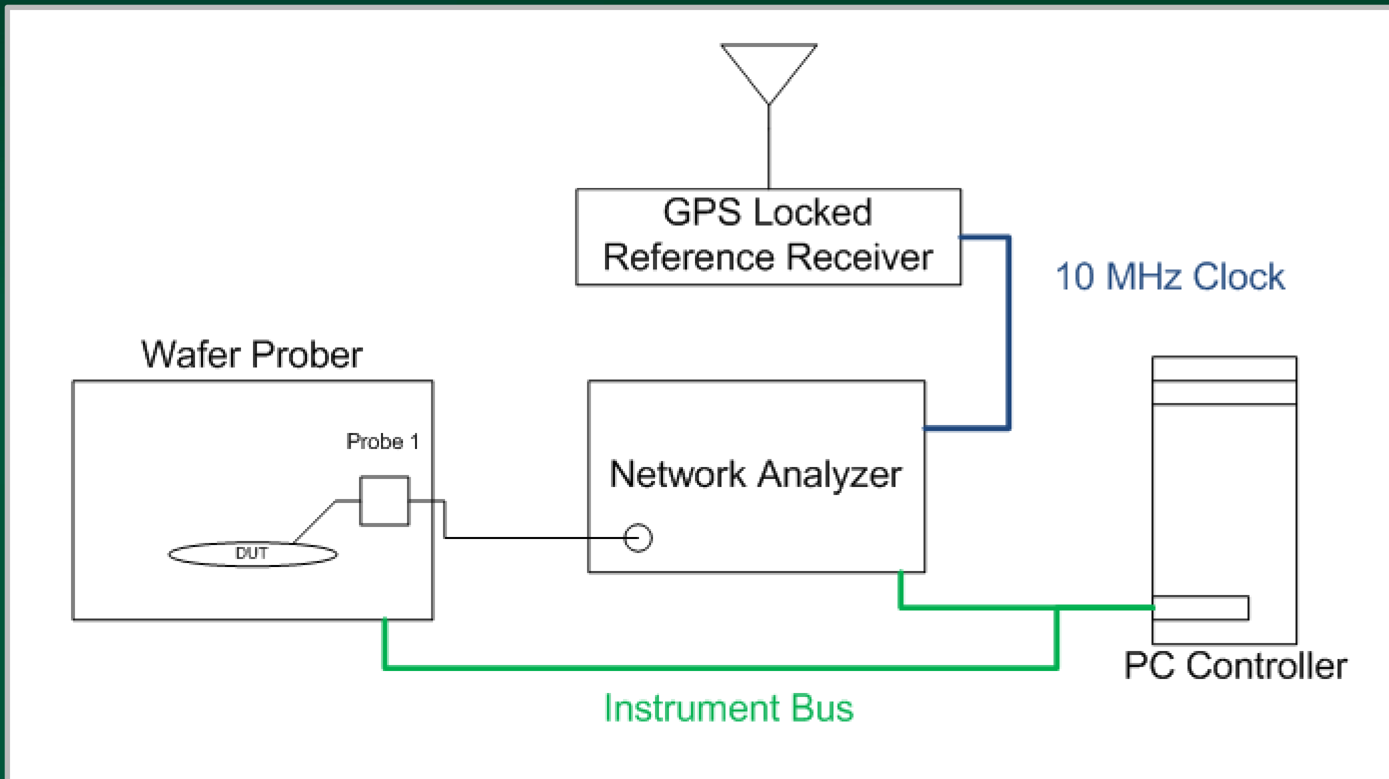


Cap wafer contains pads with vias down to FBAR wafer

Test Requirements

- Most difficult specification to test is 1 year aging of less than 25 ppm
- Probe-stress-probe tests performed at wafer level to get high confidence in low failure rate
- Since resonator must have less than 25 ppm drift, the tester should be at least 10x better ~2.5 ppm = 3.75 kHz at 1.5 GHz

Tester Block Diagram

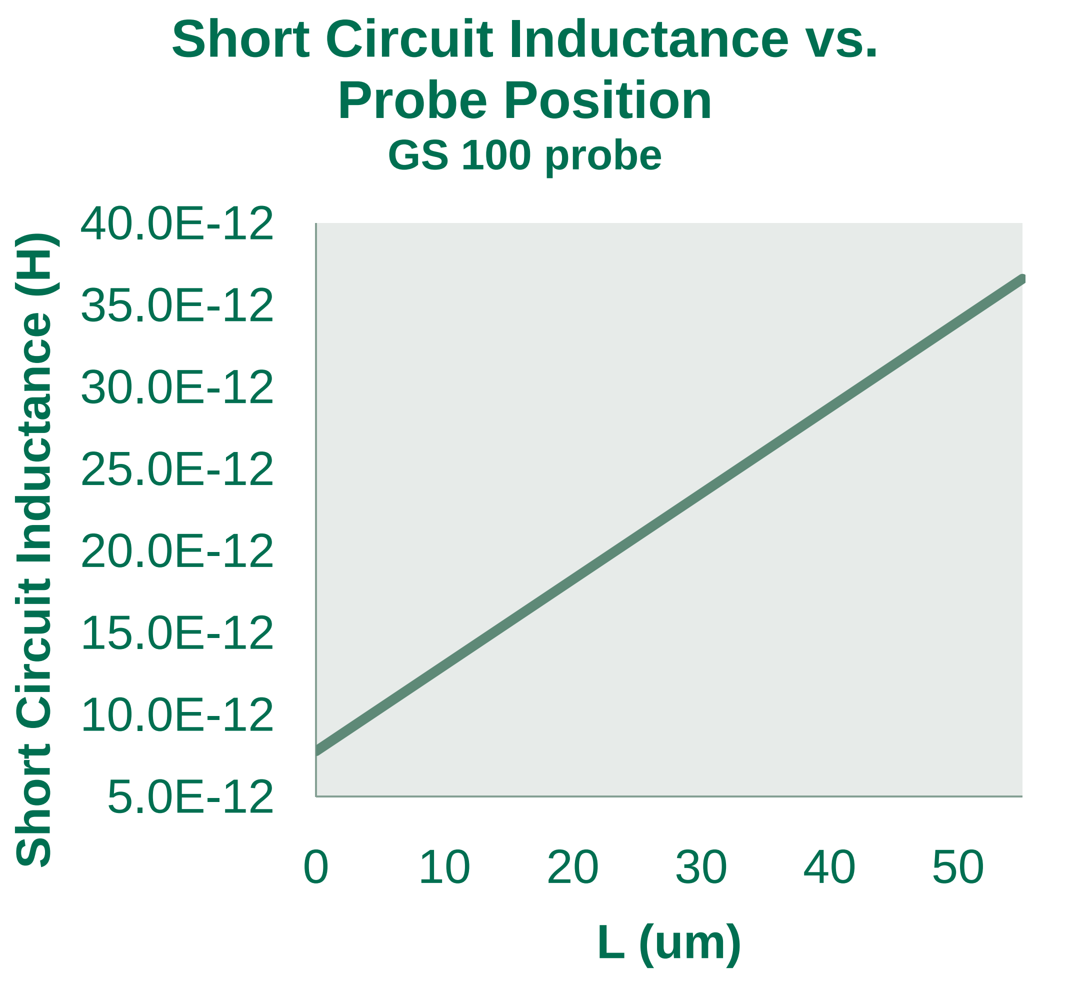


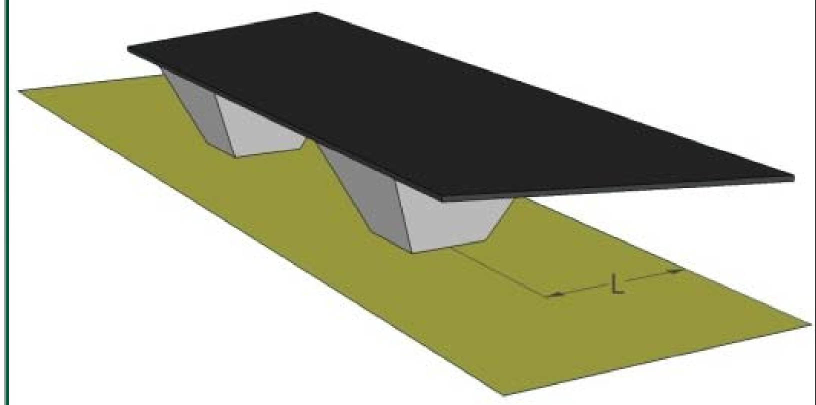
Frequency stability achieved with GPS locked reference receiver

Measurement Practices

- More than frequency control required:
  - Careful calibration
  - Temperature controlled chuck
  - Accurate and precise probe to pad placement
  - Small probe tip contact area
  - Verification wafer

It's not enough to just hit the pads





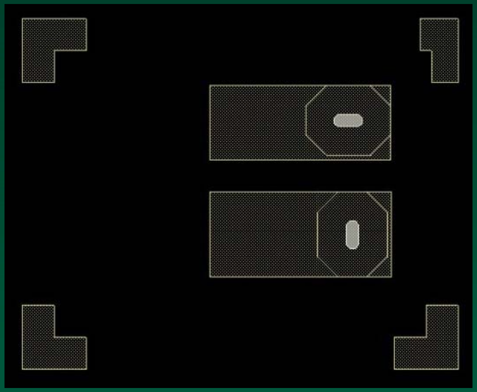
Sensitivity to probe position

- A 1.5 GHz FBAR shows 4um shift in the probe position on the pads causes about a 1PPM shift in the resonant frequency
- Modern probers specify accuracy of about +/- 3 um in X-Y across wafer and +/-3 um in Z stage. With a 2:1 overtravel to skate ratio the Z error plus the X-Y errors combine to +/- 4.5 um
- Infinity probe contact area is 12x12 um – effective contact point is inside this square

De-embedding Review

- Typically used for transistor measurements above 10 GHz where pad effects are deemed significant
- Yields a measurement of device without pad parasitics

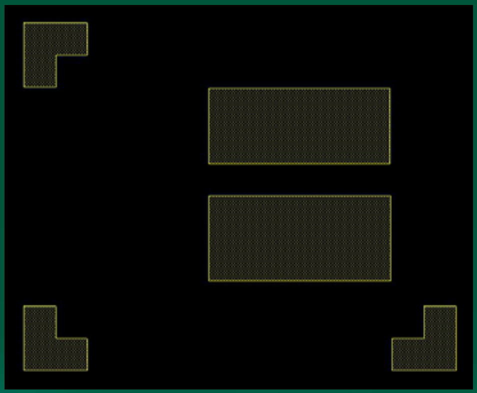
De-embedding Structure Layout



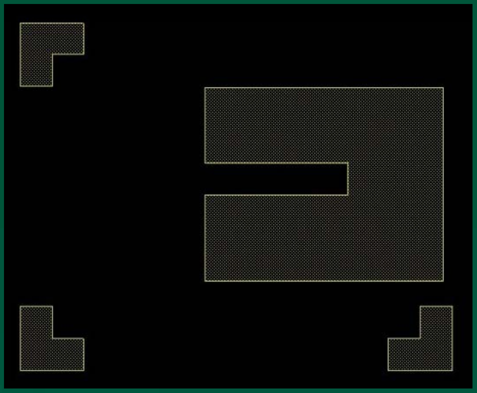
Device pads

Start with Device Under Test (DUT), then reproduce pads replacing device with Open and Short at device plane

Open and Short structure repeated 80 times equally spaced on wafer



Open structure

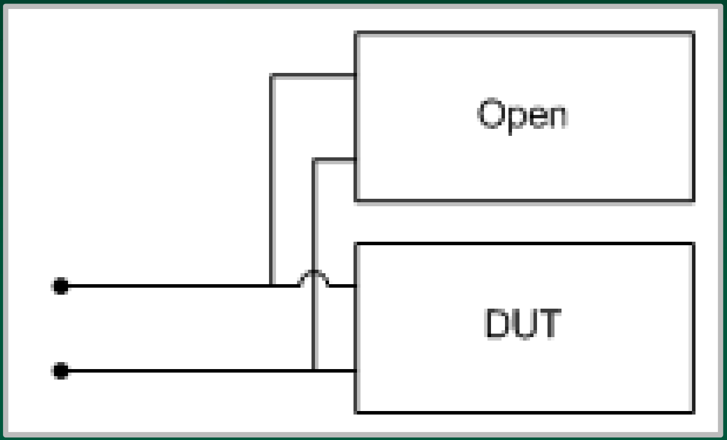


Short structure

Measurement

- Vector Network Analyzer calibrated down to probe tips
- Scattering parameters of Short, Open, and Device collected
- Complex S matrices converted to Z and Y parameters for de-embedding
- De-embedding moves reference plane down to device inside of pads

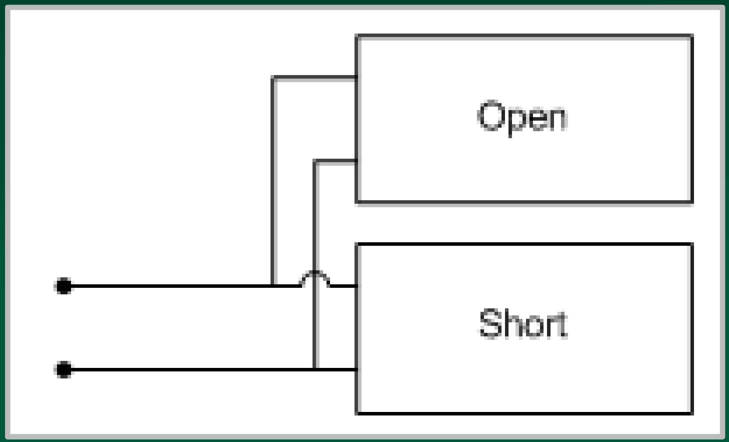
De-embedding Method 1 of 3



1. De-embed Open from Device
   - Since Open is in parallel with DUT, use admittance

$$Y_{DUT} = Y_{DUT\_MEAS} - Y_{OPEN}$$

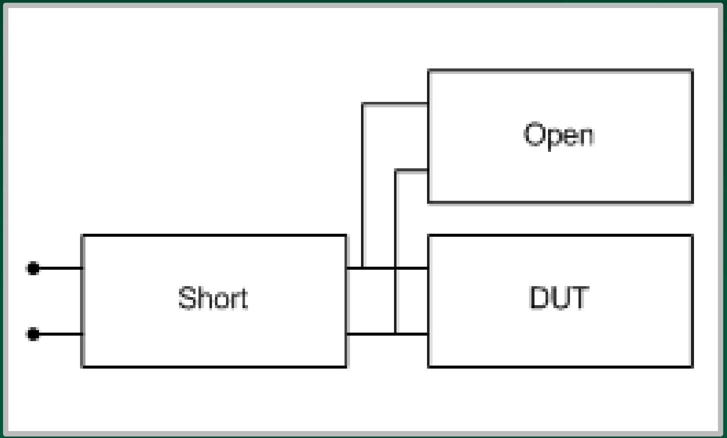
De-embedding Method 2 of 3



2. Short is made as an Open plus a shorting strap, so de-embed Open from Short

$$Y_{SHORT} = Y_{SHORT\_MEAS} - Y_{OPEN}$$

De-embedding Method 3 of 3



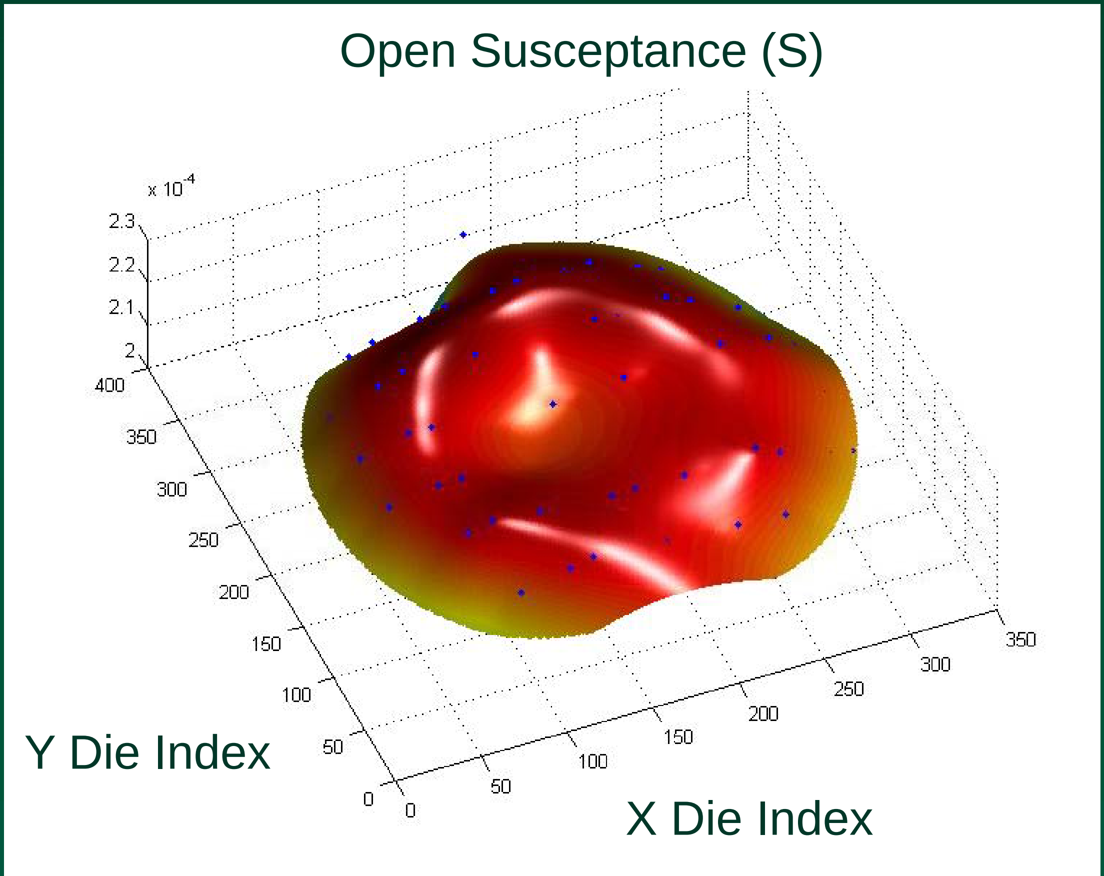
3. De-embed Open and Short from DUT

$$Z_{DUT} = \frac{1}{Y_{DUT\_MEAS} - Y_{OPEN}} - \frac{1}{Y_{SHORT\_MEAS} - Y_{OPEN}}$$

New Application

- Periodic Short and Open structures are measured and fit to a set of surfaces
- Systematic probe to pad placement errors are then compensated at every location on the wafer by de-embedding the fitted Open and Short parameters
- Technique corrects systematic errors in X, Y, Z, and rotation of wafer relative to probe tips

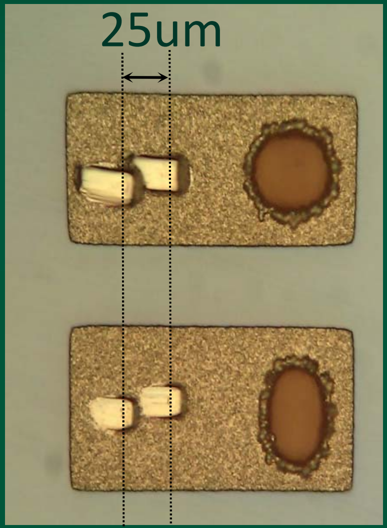
Surface Fit Map Example



Open and Short surface maps generated for conductance and susceptance (two maps each)

Experimental Design

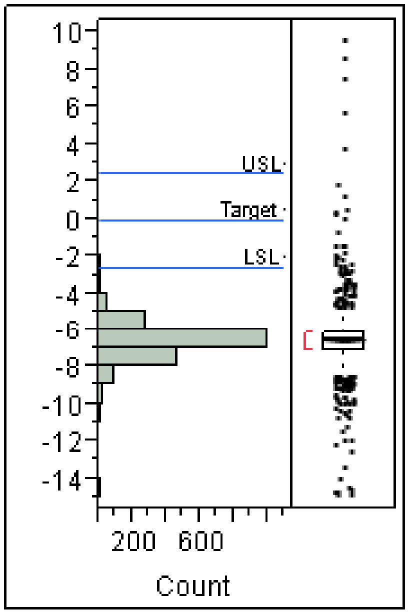
1. Measure Open and Short structures across one wafer
2. Measure 2000 product dice
3. Move probes 25 um in x-direction
4. Re-measure Opens and Shorts
5. Re-measure 2000 product dice
6. Compare results with and without de-embedding Open and Short surface maps



Results 1 of 2

- Moving probes 25um on pads and repeating measurements causes -6.6 ppm frequency shift (9.9 kHz at 1.5 GHz)
- Yield inside +/- 2.5 ppm window is less than 1%

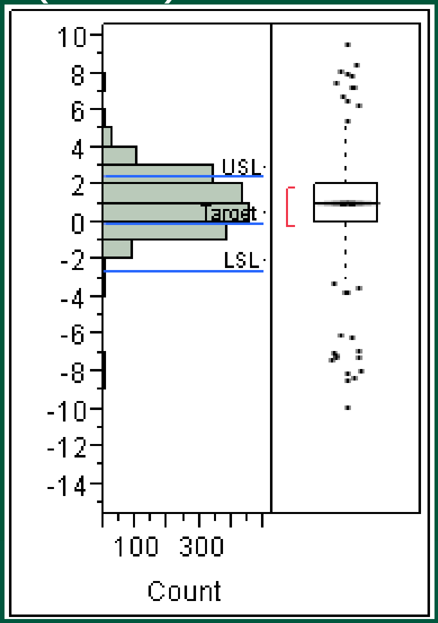
Histogram of Frequency Shift (PPM)



Results 2 of 2

- De-embedding based on surface fit data before and after moving probes makes measurements insensitive to probe to pad placement. Mean shift less than 1 ppm
- Now yield inside +/- 2.5 ppm window improves from less than 1% to over 83%

Histogram of Frequency Shift (PPM)



Future Work

- Calibration repeatability
  - Network Analyzer calibration suffers from same probe to pad placement effects as DUT. How can we improve the repeatability of the calibration?

Conclusion

- Pad de-embedding demonstrated to be useful to correcting systematic probe to pad placement errors on wafer prober
- Pad de-embedding at relatively low frequency necessary for highly repeatable results
- Technique extensible to arbitrary number of ports