SW Test Workshop
Semiconductor Wafer Test Workshop
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Production Test RF Calibration for Multi-DUT Probe Cards: How to get the most accurate measurements

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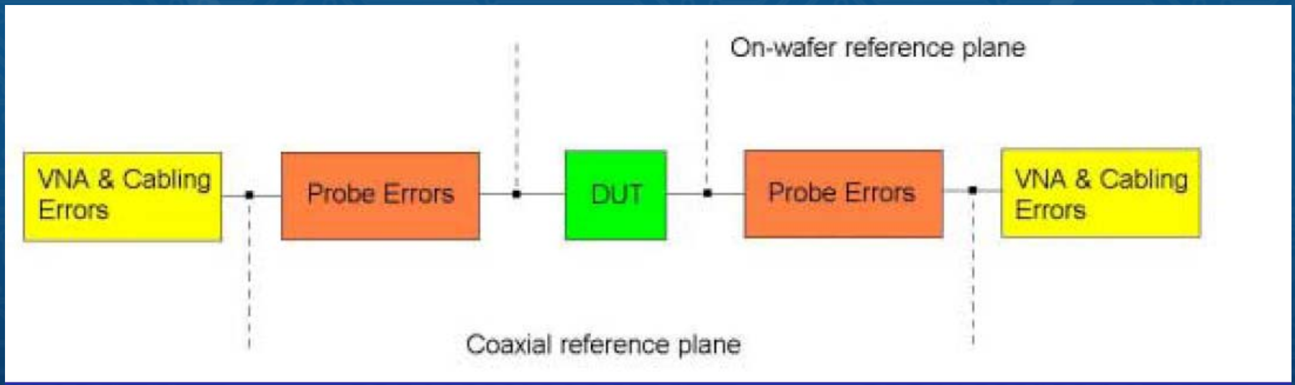
Overview

- What is Calibration?
- What are the differences between single site and multi-site calibration?
- Simulation investigation
- Summary

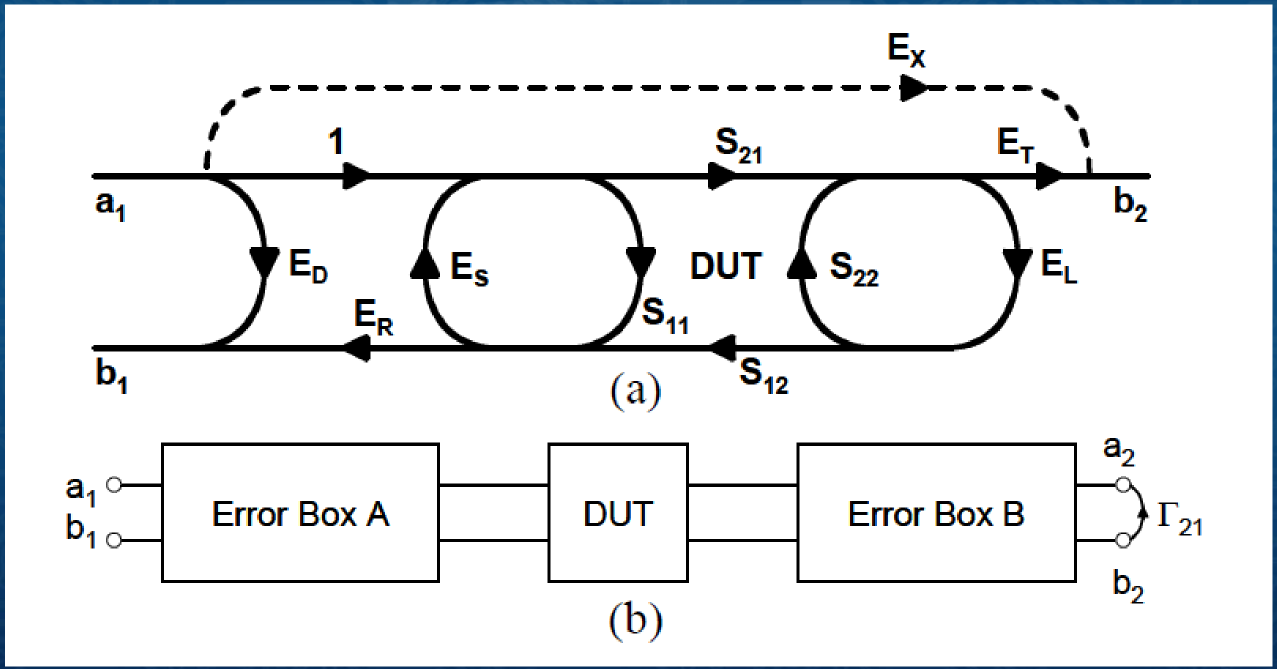
Why do you need Calibration?

- **You want a guarantee that you are measuring your DUT and NOT your test equipment**
  - The Probes and cabling introduces errors
  - However, Calibration is able to remove those errors



How does Calibration Work

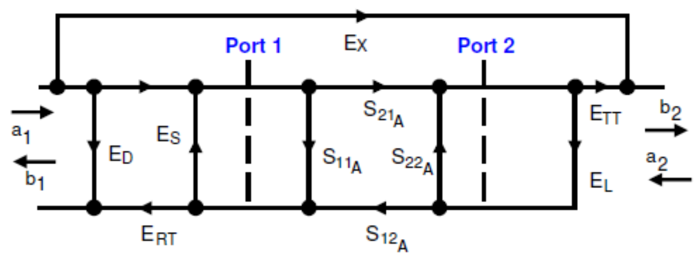
- It characterizes the RF performance parameters of your test hardware
- Then mathematically remove the parameters



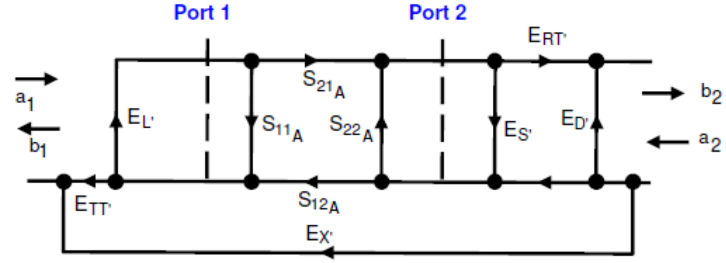
A Little Math….

Two-Port Error Correction

Forward model



Reverse model



E_D	= fwd directivity	E_L	= fwd load match
E_S	= fwd source match	E_{TT}	= fwd transmission tracking
E_{RT}	= fwd reflection tracking	E_X	= fwd isolation
$E_{D'}$	= rev directivity	$E_{L'}$	= rev load match
$E_{S'}$	= rev source match	$E_{TT'}$	= rev transmission tracking
$E_{RT'}$	= rev reflection tracking	$E_{X'}$	= rev isolation

- Each actual S-parameter is a function of all four measured S-parameters
- Analyzer must make forward *and* reverse sweep to update any one S-parameter
- Luckily, you don't need to know these equations to ***use*** network analyzers!!!

$$S_{11a} = \frac{\left(\frac{S_{11m}-E_D}{E_{RT}}\right)\left(1+\frac{S_{22m}-E_D'}{E_{RT}'}E_S'\right)-E_L\left(\frac{S_{21m}-E_X}{E_{TT}}\right)\left(\frac{S_{12m}-E_X'}{E_{TT}'}\right)}{\left(1+\frac{S_{11m}-E_{D'}}{E_{RT}}E_S\right)\left(1+\frac{S_{22m}-E_D'}{E_{RT}'}E_S'\right)-E_L'E_L\left(\frac{S_{21m}-E_X}{E_{TT}}\right)\left(\frac{S_{12m}-E_X'}{E_{TT}'}\right)}$$

$$S_{21a} = \frac{\left(\frac{S_{21m}-E_X}{E_{TT}}\right)\left(1+\frac{S_{22m}-E_D'}{E_{RT}'}(E_S'-E_L)\right)}{\left(1+\frac{S_{11m}-E_D}{E_{RT}}E_S\right)\left(1+\frac{S_{22m}-E_D'}{E_{RT}'}E_S'\right)-E_L'E_L\left(\frac{S_{21m}-E_X}{E_{TT}}\right)\left(\frac{S_{12m}-E_X'}{E_{TT}'}\right)}$$

$$S_{12a} = \frac{\left(\frac{S_{12m}-E_X'}{E_{TT}'}\right)\left(1+\frac{S_{11m}-E_D}{E_{RT}}(E_S-E_L')\right)}{\left(1+\frac{S_{11m}-E_D}{E_{RT}}E_S\right)\left(1+\frac{S_{22m}-E_D'}{E_{RT}'}E_S'\right)-E_L'E_L\left(\frac{S_{21m}-E_X}{E_{TT}}\right)\left(\frac{S_{12m}-E_X'}{E_{TT}'}\right)}$$

$$S_{22a} = \frac{\left(\frac{S_{22m}-E_D'}{E_{RT}'}\right)\left(1+\frac{S_{11m}-E_D}{E_{RT}}E_S\right)-E_L'\left(\frac{S_{21m}-E_X}{E_{TT}}\right)\left(\frac{S_{12m}-E_X'}{E_{TT}'}\right)}{\left(1+\frac{S_{11m}-E_D}{E_{RT}}E_S\right)\left(1+\frac{S_{22m}-E_D'}{E_{RT}'}E_S'\right)-E_L'E_L\left(\frac{S_{21m}-E_X}{E_{TT}}\right)\left(\frac{S_{12m}-E_X'}{E_{TT}'}\right)}$$

Calibration Substrates

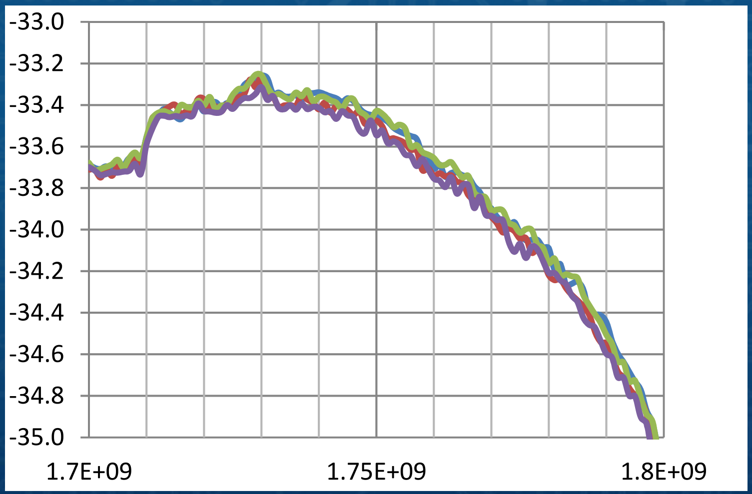
- **A calibration substrate is used in order to characterize the measurement path**
  - Measure some combination of
    - Short
    - Open
    - Load
    - Thru

But what about Multi-DUT?

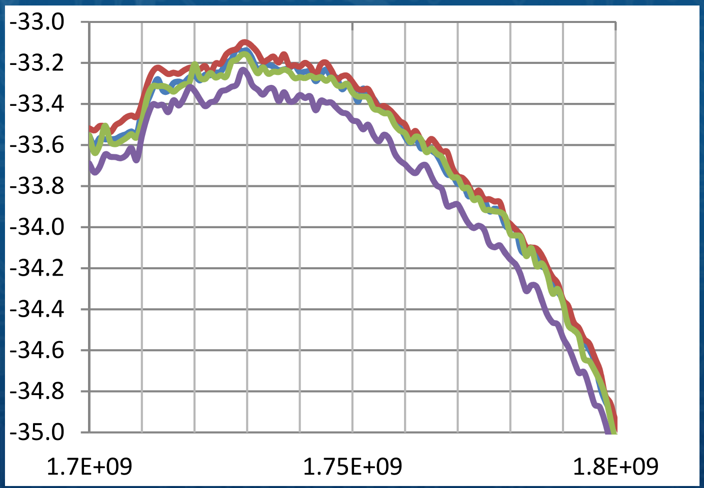
- **In order to improve Cost Of Ownership, many companies are moving to multi-DUT test**
  - Increase number of wafers tested per probe card
  - Increase speed of test with lower number of index steps
- **But now DUT are being tested with different measurement sites, leading to the requirement for site-to-site correlation**

Single Site Cal vs. Multi-site Cal

- Comparing a single site cal and a multi-site cal shows a bifurcation of the S-parameters
- Data indicates that the ISS using a multi-site cal has better correlation between sites on the same probe card measurement



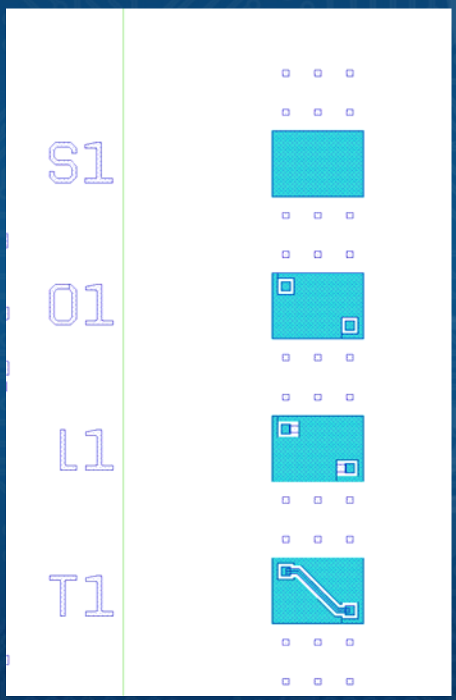
Multi-site Cal



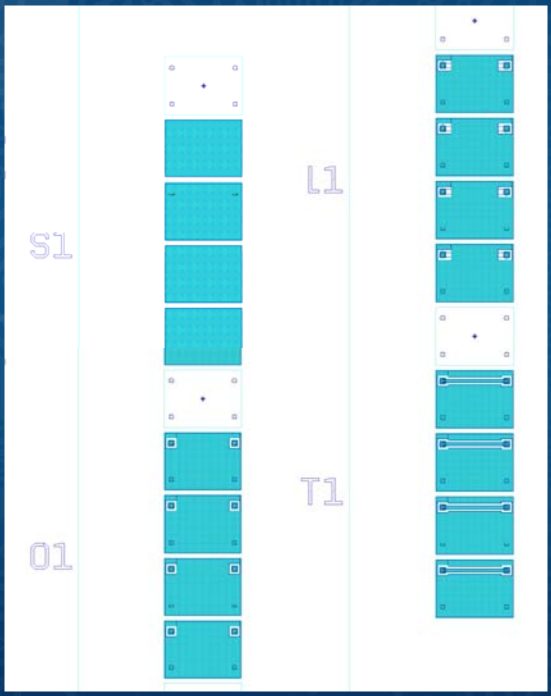
Single Site Cal

What is the difference in a single site layout and multi-site?

- Figure showing the state of the adjacent DIE location



Single Site Standards



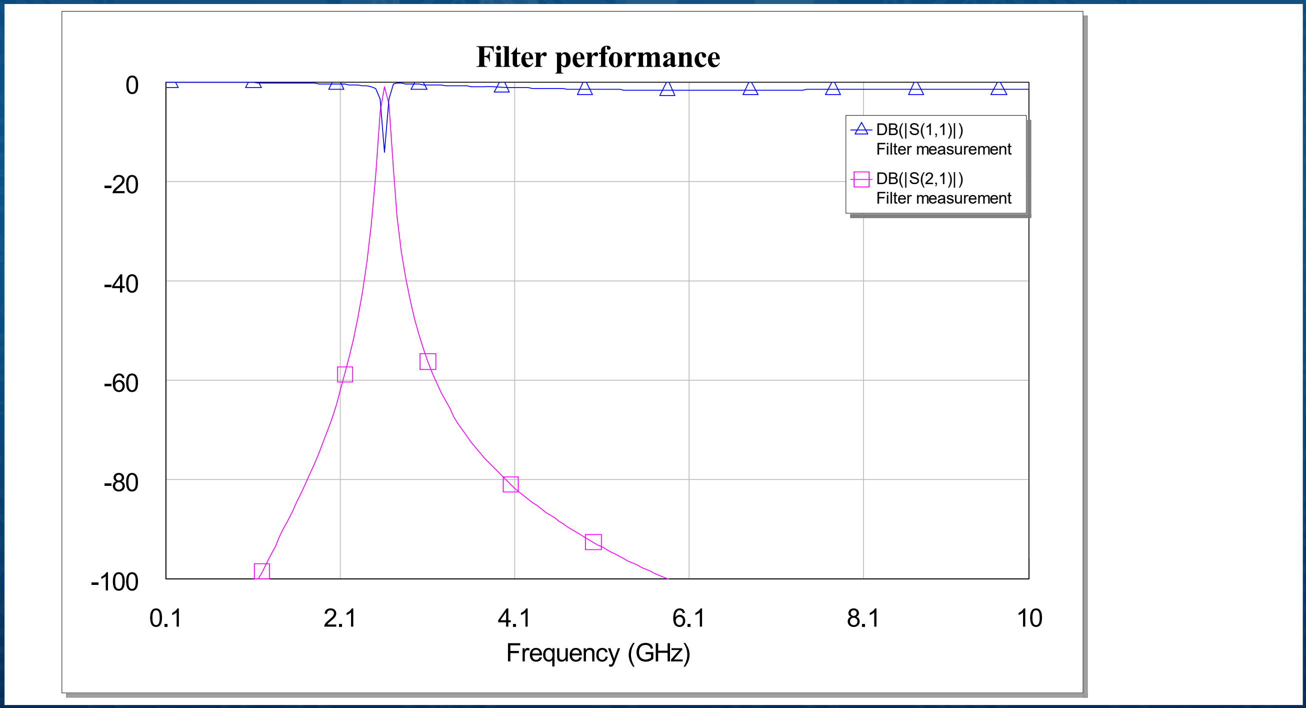
4-site Standards

Simulation Evaluation

- **In order to investigate further, we used simulation to control all other factors**
- **Simulate two die with same ground return**
  - Comparison between two different scenarios
    - Look at error terms when both ports are controlled (multi-site cal)
    - Look at the error terms when only one port is controlled, but the other can be a random state (single site cal) which includes short, open, load

Filter measurement data

- The filter is a simple bandpass, with a center frequency of 2.6 GHz, with a 3 dB width of 100 MHz

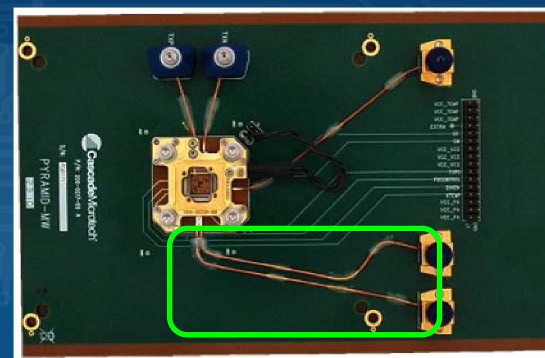


Cal Coefficients

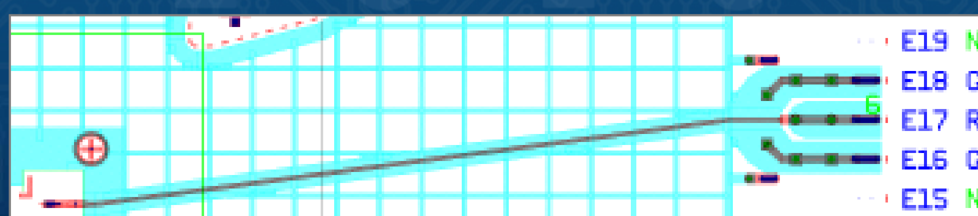
- **In order to properly do SOLT calibration, we need to have cal coeff**
- **They were extracted using LRRM to calculate the values**
  - L-load = 215 pH
  - L-short = 208 pH
  - C-open = 19 fF
  - Thru length = 4.8 ps

Probe Card

- **The simulated probe card is modeled after a Pyramid Probe**
  - 50 mm 0.031” semi-rigid coax

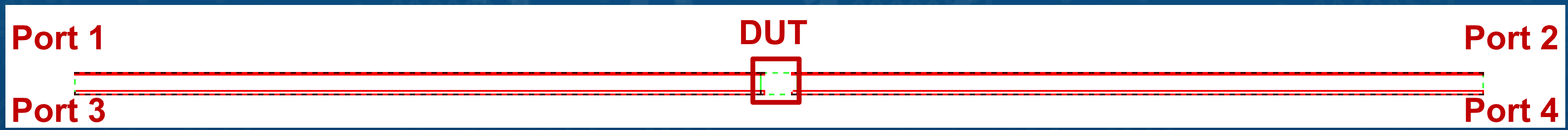


  - 10 mm microstrip transmission line on the Pyramid Probe



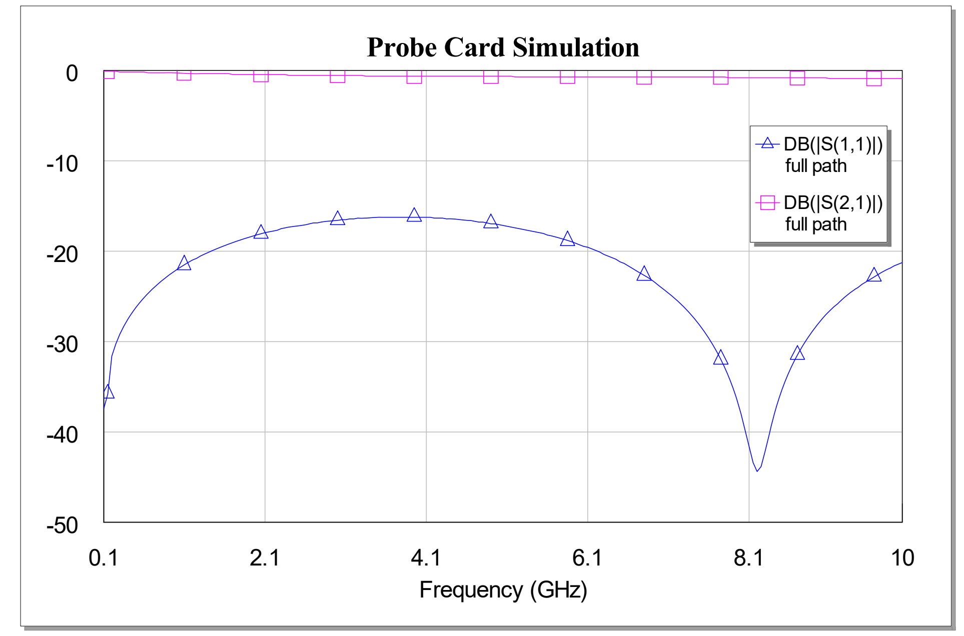
Membrane Layout

- **The design has a two filter layout**
  - Each filter has a single input/output pair
    - DUT 1 is port 1, 2
    - DUT 2 is port 3, 4
  - Shared ground return



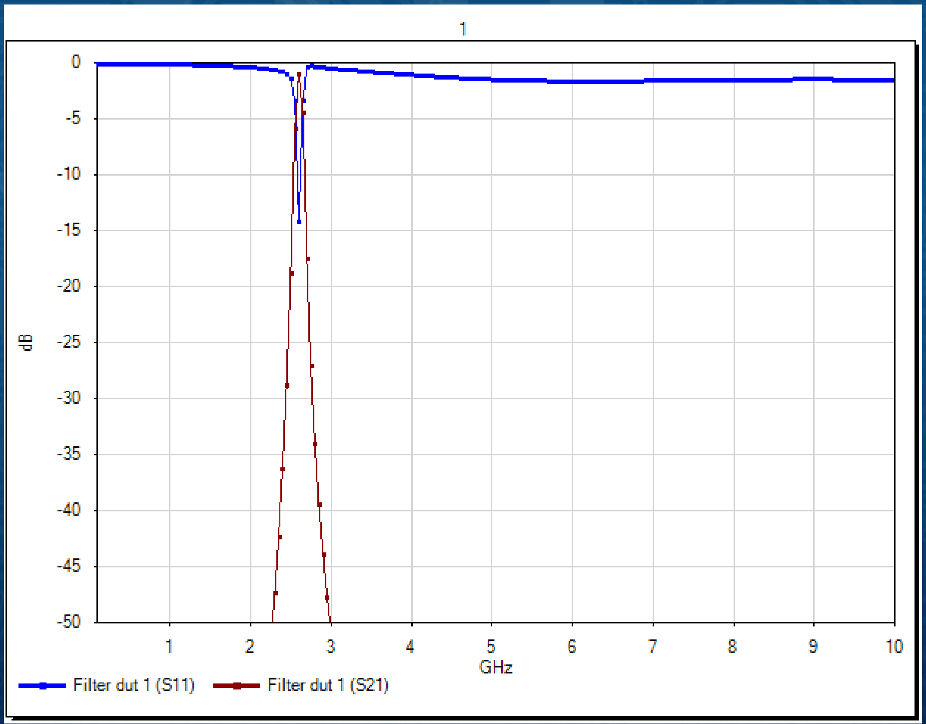
Simulated performance of a single Channel

- **The simulated probe card meets the standard specification of a Pyramid Probe:**
  - < 3 dB insertion loss
  - > 10 dB return loss
  - Cross talk is better than 55 dB at 2.5 GHz



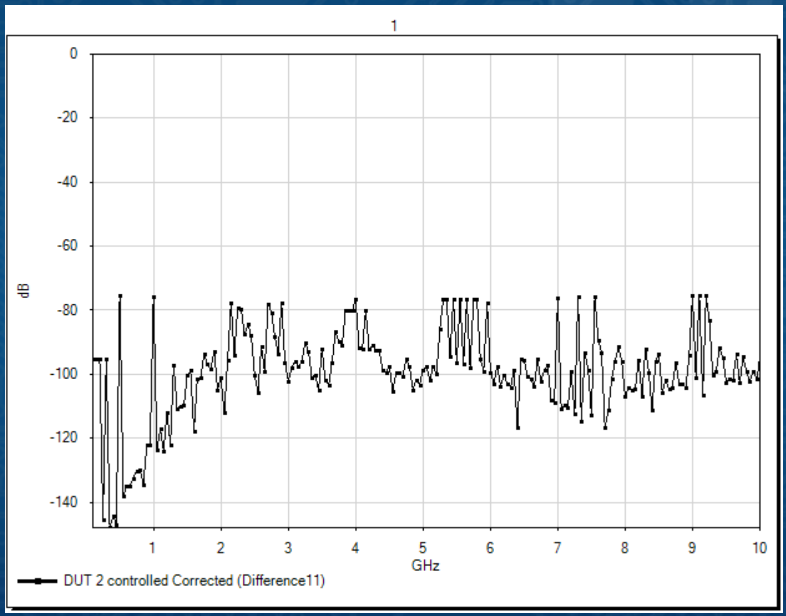
Measurements before Calibration

- **The measurements prior to calibration are identical in each DUT**
  - This is ideal scenario

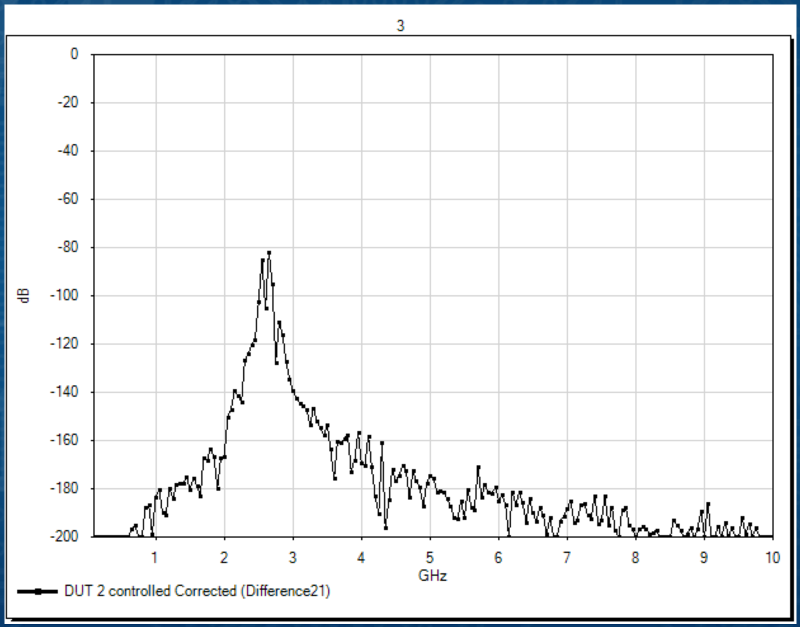


After Calibration Controlled

- **Looking at the different between DUT 1 and DUT 2, the variation is in the noise**



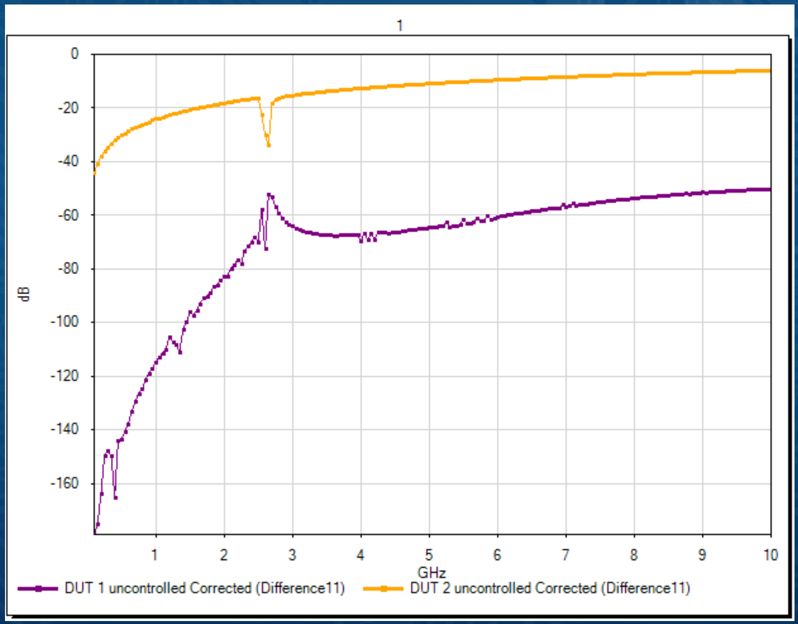
Δ Return Loss (S11)



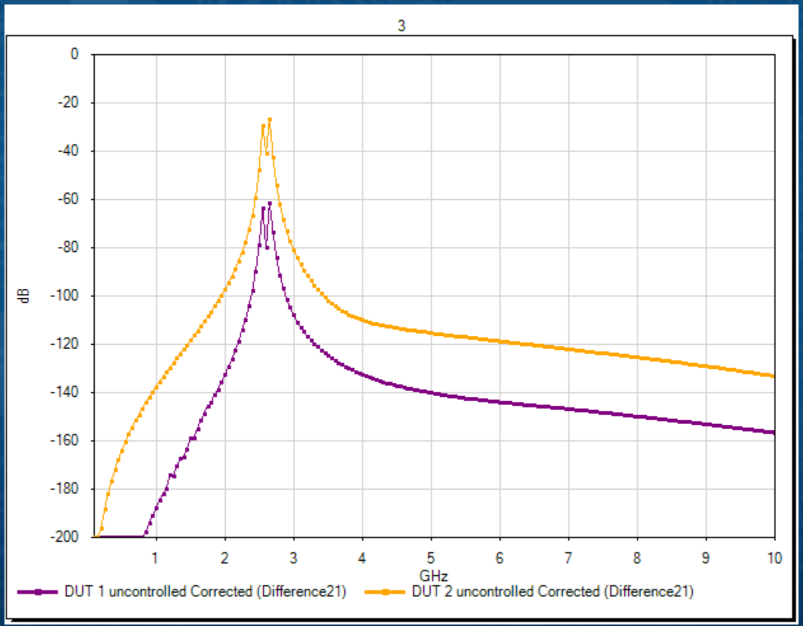
Δ Insertion Loss (S21)

After Calibration Uncontrolled

- **In the uncontrolled state for the unmeasured lines, it affects both sites, as well as making a bi-modal distribution**
  - Compared to DUT 1 from the controlled state

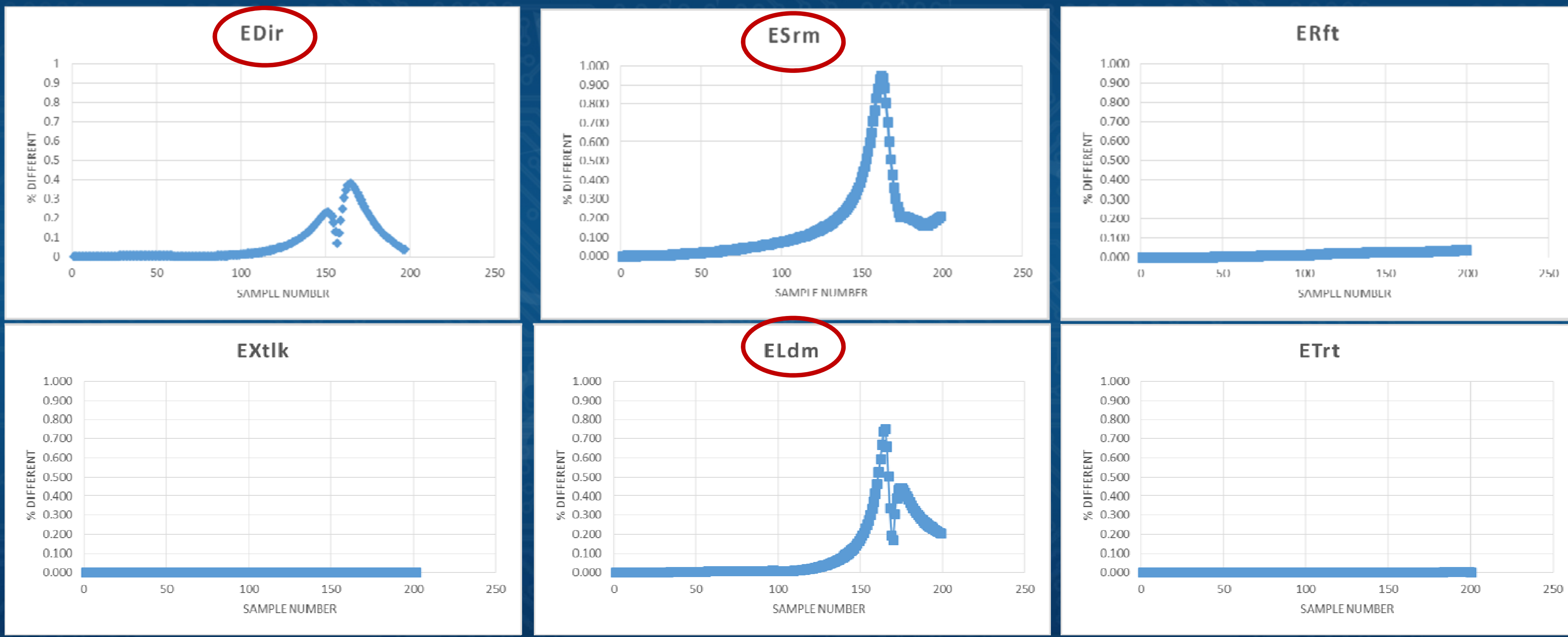


Δ Return Loss (S11)

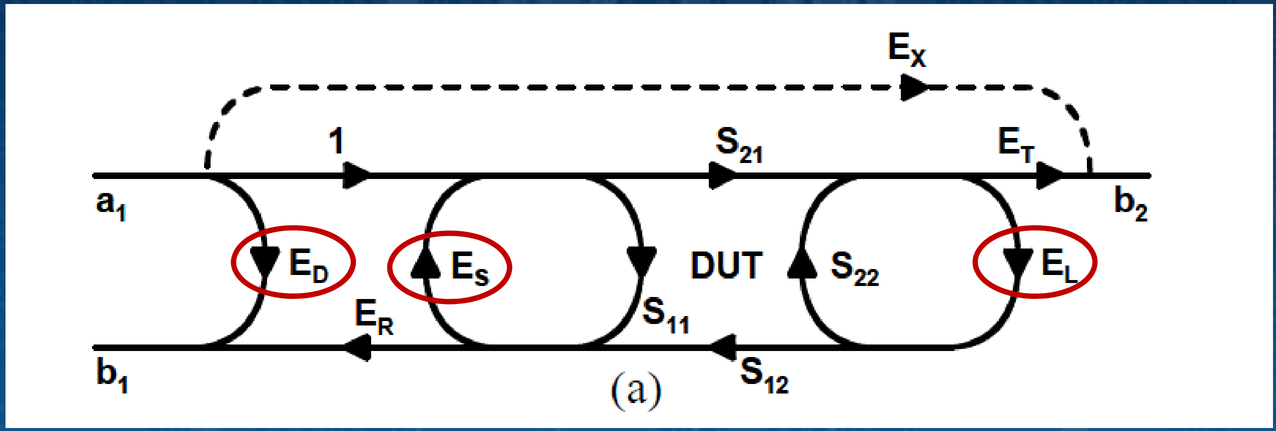


Δ Insertion Loss (S21)

Which Error Terms are Most Affected?



Which Error Terms are Most Affected?



- ES is most affected (Source match)
- EL is next most (Load match)
- ED is third most (Directivity)
- The rest of the terms are affected less than 5%

Summary

- **The most accurate measurement in a multi-site application is to make a calibration substrate that mirrors the multi-site layout**
  - Controls all of the RF traces for the highest correlation between sites