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

Daniel Bock, Ph.D.
Cascade Microtech

June 5-8, 2016
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*

- $E_D =$ fwd directivity
- $E_S =$ fwd source match
- $E_{RT} =$ fwd reflection tracking
- $E_{D'} =$ rev directivity
- $E_{S'} =$ rev source match
- $E_{RT'} =$ rev reflection tracking

*Reverse model*

- $E_L =$ fwd load match
- $E_{TT} =$ fwd transmission tracking
- $E_X =$ fwd isolation
- $E_{L'} =$ rev load match
- $E_{TT'} =$ rev transmission 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!!!
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
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.
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)

SW Test Workshop - June 5-8, 2016
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

\[ \Delta \text{Return Loss (S11)} \]
\[ \Delta \text{Insertion Loss (S21)} \]
Which Error Terms are Most Affected?

Daniel Bock
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