Comparison of Various RF Calibration Techniques in Production: Which is Right for You?

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Overview

• Introduction
• How does Calibration Work
• Types of Calibrations
• Comparison of Calibration Types
• 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

- In 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

- 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!!!
How to get to the measurement system error terms

• One characterizes the RF parameters of your system by measuring some ‘known’ RF structures
  - Open
  - Short
  - Load
  - Thru

• Calibration can be various combinations of these standards based on your needs
Calibration Substrates

• The choice of the calibration substrate is important based on what you want to do:
  – Edge of pad
  – End of transmission line
  – Type of Calibration
  – Frequency Range
  – Tip Pitch
More about the Reference Plane...

- The reference plane can be placed ALMOST anywhere in the RF signal path
  - Can located at the:
    - Edge of the Pad
    - End of a transmission line to the DUT
Calibration to edge of Pads

• Place standards connected to pads
  – Allows for removal of the full contact area
  – For high frequency, requires accurate Probe-To-Pad-Alignment to be successful
  – Highest accuracy by using standards on wafer, but good accuracy for can be achieved using ISS standards, especially in KGD applications
Calibration to end of Xline

- This will generally require the use of on wafer standards
  - Make a transmission line like that connected to the DUT, and then place your calibration standards
Cal Coefficients

- Cal Coefficients are values that characterize the RF performance of the standards
  - They are never ideal Opens, Short, Loads, and the Thru has a characteristic length
  - These are input into the previous equations as the known terms using the reflection coefficient

\[ \Gamma = \frac{Z_L - Z_S}{Z_L + Z_S} \]
But... Do you need Cal Coeff?

• In some situations, you can actually ignore the Cal Coeff.
  – Depends upon Max Frequency and value of Cal Coeff.
  – Evaluated for 150 µm GSG for the model

• $C_{\text{open}} = 3.5$ fF
• $L_{\text{load}} = -1.7$ pH
• $L_{\text{short}} = 4.8$ pH
Plot of Variation of Open and Short

- The variation is dominated by the Short
  - At less than 20 GHz, it is less than 0.1 dB off from ideal
Calibration Options

- There are several options available on the test floor to calibrate your probe card
- The selection depends upon several factors
  - Accuracy needed
  - Type of Probe Card
TRL

• NIST traceable standard Calibration technique
  – Mulit-line TRL (Thru-Reflect-Line)
  – Uses multiple transmission lines as the standards
  – Measurements referenced to the line impedance
  – Limited frequency range
    • 3 lines for 2-18 GHz
  – Requires multiple probe spacing
  – Not suitable for fixed spacing probes
Thru-Reflect-Reflect-Reflect- Match (LRRM)

• Compares favorably to TRL
• In Cascade’s Wincal
• Does not need well defined standards other than the thru
  – Known length and impedance
SOLT

- Short-Open-Load-Thru
  - Needs well defined standards
  - L-short, C-open, L-load, and Thru length
  - Uses off wafer standards
  - Sensitive to the probe placement
SOLR

• **SOLR is similar to SOLT**
  – Needs well defined Load, Short, and Open
  – The thru does not need to be well defined, just approximate length
  – Convenient for use with probe cards
    • Fixed probe spacing and are usually not inline with each other
2nd Tier Calibration with SOL

- **What is 2nd Tier?**
  1. Calibrate to the end of the cable using standards
  2. Measure SOL to generate 2 port parameters
     - Requires reciprocal probe card (which is true for Pyramid Probes)
  3. The 2-port parameters are then combined with the first calibration
- **Does not require a thru for calibration**
- **Can be compared favorably to SOLR calibration in terms of accuracy**
- **WinCal and most VNAs have this programmed into them**
SO

• Only needs Short-Open
• Can be done with:
  – Probe card in air for open
  – Probe card in contact with a metal wafer

• Assumes that ALL losses are due insertion losses, IE, no RL
  – Works well down to probe cards with -12 dB RL or better
Scalar Analysis

- Loss of DUT
- Loss of Probe Card by Subtraction of DUT performance
- Measured Probe Card and DUT

Frequency (GHz) 0 2 0 4 0 6 0 8 0 1 0 0

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Can be done a few ways:

- Using S-parameters provided, use the loss factors as a correction term at specific frequencies
- Measure golden die that have been characterized using a different method (such as Infinity) that is calibrated to the tips
  - Comparing the two measurements, the loss of the probe card is known
  - Measurements show that the loss is repeatable and does not change much when a new core is placed in the PCB

However, this is the least accurate

- No phase correction
- Is done at only a few frequencies
- Easiest to implement of the calibration options
Comparison of Methods using Thrus - Magnitude

- SOLT, SOLR, and LRRM are all very good
  - Within 0.05 dB of each other using the same calibration files up to 67 GHz
SOL Compared to LRRM

- SOL is reasonable for KGD testing, being within +/- 0.5 dB out to 50 GHz when compared to LRRM.
SO Comparison to SOL

- Short-Open works well as long as the RL is better than -12 dB
  - Because of the assumption that ALL losses are due to insertion loss
Difference in SO and SOL with RL

• Comparing SO and SOL, as long as RL is less than -12 dB, then SO is within 1 dB of SOL.
## Comparison of Calibration Options

<table>
<thead>
<tr>
<th>Calibration Method</th>
<th>Absolute Accuracy</th>
<th>Probe Card Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOLT</td>
<td>Fair</td>
<td>Fair - due to usually not having straight thru</td>
</tr>
<tr>
<td>TRL</td>
<td>Best</td>
<td>Poor - due to inability to have variable length thru</td>
</tr>
<tr>
<td>LRM/LRRM</td>
<td>Good</td>
<td>Fair - due to usually not having straight thru</td>
</tr>
<tr>
<td>SOLR</td>
<td>Good</td>
<td>Best - works best with bends in thru</td>
</tr>
<tr>
<td>SOL</td>
<td>Fair</td>
<td>Fair - works well of KGD test</td>
</tr>
<tr>
<td>SO</td>
<td>Low</td>
<td>Fair to Poor (Depending upon RL) - ease of use due to not needing precise alignment</td>
</tr>
</tbody>
</table>
How to Verify your Calibration?

Trust me.....

• This depends upon the type of calibration, and how accurate

• For more accurate measurements
  – SOLT, SOLR, SOL, SO
    • Use thru
    • Do not use short, open, or load – user defined
  – LRRM, TRL
    • Use open or short
    • Do not use thru – user defined
Now Really Trust Me....

**For lower accuracy applications, you can consider**

- Remeasure your standards (even if using SOLT, SOLR, and SOL)
  - If some measurement was wrong (bad alignment; bad contact), it will appear immediately as excessive loss or gain
  - Compare to previous measurement for system drift
Summary

• Calibration has a lot of different considerations

• The best option depends upon your needs and ease of setup
Questions?