Improving Probe-Tip S-parameters Measurements with Power Calibrations

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Agenda

- Market Trends
- Quick Recap of S-parameters Measurements
- Current Practices for Wafer-level RF Measurements & Challenges
- Proposed Probe-tip S-parameter + Power calibration
- Summary
Market Trends

- **5G will dominate RF device growth**
  - Not just for mobile comms but for
    - IoT, eHealth, Transportation, Industrial Machine Control & more
  - Higher Operating Frequencies
    - 28 to 73 GHz
    - ↑ New 110 GHz Systems around the world
  - Important & Urgent to address Challenges in testing RF devices at these frequencies.

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**5G 2020**

- Very High Data rate
- Very High Capacity
- Reliable & Secure
- Huge no. of Devices
- Long Battery Life
- Very Low latency

... Everything Everywhere Connected
Quick Recap of S-parameters Measurements

- **Forward**
  - Port 1 - Stimulus
  - Port 2 - Load
  - \( S_{11} = \frac{\text{Reflected}}{\text{Incident}} = \frac{b_1}{a_1} \quad | \quad a_2 = 0 \)
  - \( S_{21} = \frac{\text{Transmitted}}{\text{Incident}} = \frac{b_2}{a_1} \quad | \quad a_2 = 0 \)

- **Reverse**
  - Port 1 - Load
  - Port 2 - Stimulus
  - \( S_{22} = \frac{\text{Reflected}}{\text{Incident}} = \frac{b_2}{a_2} \quad | \quad a_1 = 0 \)
  - \( S_{12} = \frac{\text{Transmitted}}{\text{Incident}} = \frac{b_1}{a_2} \quad | \quad a_1 = 0 \)

- **S-parameters are relative and not absolute measurements!**
Current Practices for Wafer-level RF Measurements & Challenges

- Only Adopts S-parameter calibration
  - Since S-parameters are relative measurements, Probe-tip power calibration is redundant – or so we thought?

- Uncalibrated RF Source Power – Affects Accuracy
  - Large RF power, Stable Cal but Active Device’s DC bias condition would be incorrect
  - Small RF power, Difficult to get a stable calibration
  \[\Rightarrow\] Need to Optimize RF power & make it Constant w.r.t. Frequency

- Post-Calibration Stability – How long a calibration state can lasts?
  - Affects Accuracy & Measurement Throughput
  - Environment & Cable lengths are often assumed to be primary root cause
    - Control Lab temperature/Humidity
    - Use Shortest cable possible
  - Optimizing VNA instrument settings eg Low IFBW of 5 Hz
Typical Single Sweep 110 GHz Probe System Setup
Implications of Inaccurate RF Source Power

- With device scaling, $L_G \downarrow$, $V_T \downarrow$  
  $\Rightarrow$ Optimal RF power $\downarrow$
Uncalibrated Probe Tip RF Source Power

Source Power @ Tips

- Source Power = -20 dBm setting
- Power should be constant w.r.t freq.

Measured Power @ P2 Receiver

- P1 & P2 connected by low-loss thru'
- P2 should detect -20 dBm
Post-Calibration Stability (No Tip Power Cal)

- Probes in Air as OPEN, Source power = -20dBm, IFBW = 10 Hz, LRRM cal.

- ±0.1dB as criteria, Cal. only last 10 mins

- Test engineers need to recalibrate every 10 mins
  - Passive devices take 1 min
  - RFCMOS device requires about 30 mins to measure
**Probe-Tip Power+S-parameter Cal.**

- **Create Power Table (one time pain)**
  - Characterize losses to the cables
  - Extend losses to the RF probe tips
  - Table is reusable unless setup modifications

- **Wafer-Level Power+S-parameter Calibration**
  - Perform Power cal. with power table
  - Perform standard S-parameters cal.

- **No removal/installation of RF cables/probes during calibration**

- **Simple & Convenient**

- **Takes about 10% more time to complete Cal.**
Creating Power Table for Power Calibration
Creating Power Table for Power Calibration

Measuring Actual Power at the 1mm cable
RF Power @ Probe Tips after Power Calibration

- **Consistent Source Power**
  - RF Source power Consistent

- **P2 detects -20 dBm regardless of freq.**

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Dr Sia Choon Beng, 2019
Probes in Air - Calibration Drift over 20 Hours

- Cal. Valid for only 10 mins
- Cal. Valid for 4 hours!
Probes in Air - Calibration Drift over 20 Hours

- S-parameters Calibration
  - Cal. Valid for only 10 mins

- S-parameters+Power Calibration
  - Cal. Valid for 4 hours!
Summary

- Power Calibration is Critical even though S-parameters is a relative and not absolute measurement!

- Adopting Power+S-parameters Probe Tip Calibration takes 10% more time but will...
  - Ensure Accurate RF source power is applied to Active Devices
  - Improve Calibration Stability to more than 4 Hours
  - Maximize Test Throughput