RF S-Parameter Wafer Probing – A Production Solution

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Agenda

- The Need for Fully Automated, On-Wafer S-Parameter Measurement
- Test System Requirements
- System Calibration / Diagnostics
- Device Layout Considerations / De-Embedding
- Considerations for Probe Selection
- Probe Cleaning
- Data Extraction Techniques
The Need for Fully Automated S-Parameter Measurement

- Statistical Model Generation
- Manufacturing SPC of high frequency device characteristic
- Yield Analysis

Baseband Filter
Digital Control
FSK Demodulator
Mixers
Rx LNA
Tx PA

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A GREATER MEASURE OF CONFIDENCE
Need – Statistical Process Control

Process Correction

RF SPC Data

RF Product Performance Improves

DC is Necessary but not Sufficient.
Overlay of DC and RF Wafer Maps Makes Systematic Defects Visible.
Three Main Aspect of Requirements

- Vector Network Analyzer (VNA), Cable and Connector calibration
- Probe Card Stability
- Wafer Test Structures and De-embedding
Parametric tester with DC and RF interconnect To an automatic prober
Probe Card And Prober

System interconnect showing cables, bias tees, probe card interconnect, and probe card adapter mounted in an automatic prober.
RF Test GUI

- RF Test Setup
- RF Data Display
- Global Data Entry
Global Data Entry

- Control Wafer Loading
- Optimize Probe Contact
- Verify Contact Resistance
- Minimize Probe Wear
- Set Control limits by technology
- Log all events and associate with data
- Enable Tester SPC

### Global Data Entry Interface

<table>
<thead>
<tr>
<th>Data Name</th>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ManualWaferLoad</td>
<td>int</td>
<td>1</td>
</tr>
<tr>
<td>rf_cal_verify_logging</td>
<td>int</td>
<td>1</td>
</tr>
<tr>
<td>ktxe_min_SS_touch</td>
<td>int</td>
<td>0</td>
</tr>
<tr>
<td>enable_chuck_control</td>
<td>int</td>
<td>1</td>
</tr>
</tbody>
</table>
RF SETUP - VNA

File  About
VNA  Signals  Calibration  Auto-Z  Limits  SOLT  LRM

Measurement
512 Number of points to average
1e3 IF Band, Hz

Frequency
Frequency Set Label freqName

Start, Hz  Stop, Hz  Number of Freq
Start, Hz  Stop, Hz  Number of Freq

Subset 1 1e8 1e9 2e9 3e9 4e9 5e9 6e9 7e9 8e9
Subset 2 10e9 15e9 20e9
Subset 3

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### RF SETUP - Signals

#### Number of Signal Levels

<table>
<thead>
<tr>
<th>Label</th>
<th>Port1 Attn</th>
<th>Port1 Power</th>
<th>Port2 Attn</th>
<th>Port2 Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>s1:</td>
<td>20</td>
<td>-1</td>
<td>30</td>
<td>-7</td>
</tr>
<tr>
<td>s2:</td>
<td>10</td>
<td>-10</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>
### RF SETUP - Calibration

#### File
- Log File in $KILOG
- Probe Card Label

#### Calibration
- Use Manual Prober
- Use Cal Kit

#### Pin Pair 1
- Port1 DC pin
- Port2 DC Pin

####.pathname
- `/opt/kiS600/dat/rfcal/rf_cal_file.rfi`
**RF SETUP— Auto-Z**

<table>
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<th>File</th>
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<td>VNA</td>
<td>Signals</td>
</tr>
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- **Enable Auto-Z**
  - 1: Pin pair used for AUTO-Z test
  - 16.0: Contact trigger value, Ohms
  - auto_z: Subsite Name from WDU

- **Subsite Index**
  - 2: Subsite Index
  - 5.0: Increment step for a contact
  - 25.0: Additional Overdrive
  - RFCALSUP: KULT Library
  - rfcalsup_t: KULT Function
  - 190.0: Maximum Travel. PLEASE USE CAUTION WHEN SETTING!
RF SETUP—Limits

Contact Test Limits:
- 1e-6 Leakage on OPEN, Amp
- 60 Resistance on MATCH, Ohms
- 8.0 Resistance on SHORT, Ohms
- 16 Resistance on THRU, Ohms

S-Parameter Verify Limits:

<table>
<thead>
<tr>
<th>OPEN</th>
<th>SHORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1e-1</td>
<td>0.01</td>
</tr>
<tr>
<td>1e-1</td>
<td>0.01</td>
</tr>
<tr>
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</table>
RF SETUP – SOLT

RF SETUP ---- /opt/kiS600/dat/rfcal/rf_cal_file.rfi

File  About

VNA  Signals  Calibration  Auto-Z  Limits  SOLT  LRM

OPEN
6.5e-15  C0, F
0.4525e-3  Length, m

LOAD
0  Inductance, H
50  Impedance, Ohm

THRU
0  Length, m
50  Impedance, Ohm

SHORT
-4e-12  L0, H
0.053e-3  Length, m

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Requirements - VNA Calibration

- Calibration is required to correct for systematic errors in the VNA and cabling.
- The fixed probe spacing of a production probe card limits the choice error correction methods to SOLT (two port, 12 term error corrected).
- Automatic calibration is performed by inserting a calibration standard onto a silicon wafer.

A Calibration Substrate has gold test structures on alumina substrate.
VNA Calibration SOLT

**Measurement**

**Structure**

- **Short**
- **Open**

**Response**

Ideal: Unity Reflection (0dB), 180 Phase Shift

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>mag (dB)</th>
<th>phase (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
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Ideal: Unity Reflection (0dB), 0 Phase Shift

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<td>10</td>
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<td>0</td>
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</table>
VNA Calibration SOLT (cont.)

measurement Structure

Load

Thru

Response

Ideal: 0 Reflection, 0 Transmission port 1 to port 2

Ideal: Unity Transmission port 1 to port 2
Calibration Considerations

Calibration Frequency
- With each probe card change (when test head docks)
- Periodic by time, DUT type or number of sites probed
- As part of needle cleaning and contact verification

Calibration Pass/Fail Criteria
- Dependent on user requirements (device size, frequency etc)
- Calibration Repeatability Expectations
- Critical factors are probe card docking and probe cleanliness

Frequency Response

Statistics at 7.6 GHz

S11 and S22 Open

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Calibration Pass/Fail Criteria

S12 and S21 Thru

**Frequency Response**

- **Statistics at 7.6 GHz**

Typical Pass/Fail Criteria for MOSFET S Parameter Testing

<table>
<thead>
<tr>
<th></th>
<th>OPEN</th>
<th>THRU</th>
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<tbody>
<tr>
<td>S11</td>
<td>0 ± 0.15 dB</td>
<td>&lt; -50 dB</td>
</tr>
<tr>
<td>S12</td>
<td>&lt; -50 dB</td>
<td>0 ± 0.10 dB</td>
</tr>
<tr>
<td>S21</td>
<td>&lt; -50 dB</td>
<td>0 ± 0.10 dB</td>
</tr>
<tr>
<td>S22</td>
<td>0 ± 0.15 dB</td>
<td>&lt; -50 dB</td>
</tr>
</tbody>
</table>
Requirements – Test Structures and De-Embedding

What Type of De-Embedding?

How Frequently?

Technology Considerations?

DUT Considerations?
Device Layout Considerations - DUT

Device Under Test (DUT)

GSG Configuration

- Fixed Pitch
  - typically 100-200um S to G
  - 100-300um S to S
- Shared Ground for Improved Area Utilization
- Pad size - typically 55x55 to 100x100 um
- Top layer metal only is best
Layout for De-Embedding

DUT

Generic OPEN

SHORT

Ideal OPEN
RF Probe Card
Considerations for Probe Selection

- 50 Ohm impedance match G-S-G construction
- Mechanical Design for Fine Pitch Probing (fine point and steep pitch)
- Metallurgical match to probe pad requirements
- Balance Contact Force and Co-Planarity match to DC probes for mixed DC/RF probe card
- Durability and low cost
Available Probe Technologies

Picoprobe®
by GGB Industries Inc.

Cascade Microtech

Keithley
A Greater Measure of Confidence
Requirements – Probe Card Stability

Two types of contamination are most often observed

Small particulates which systematically build up over many hundreds or thousands touchdowns.

Large particulates which are generated on a random basis

S11 OPEN cal before and after 5000 touchdowns

S11 OPEN cal before and after particle contamination
• S11 measured during prober indexing
• Deviation from 0dB plotted
• Probe pattern:
Contamination Monitor Results

SPC of Probes Up S11 and S22 During a Test with 5000 Devices Measured On Two Sequential Wafer Lots
Real-Time Probe Cleaning, Re-Cal

- Measured Data or Probes Up Sxx Fails Limits.
- Probe Clean and Re-Test at Current or Adjacent Site.

- Probe Clean and Re-Test at Current or Adjacent Site Fails.
- Re-Clean and Re-Test Previously Good Site.

- Re-Clean and Re-Test Previously Good Site Fails.
- Stop Testing, Re-Load Calibration Wafer and Re-Cal.
RF Data Display
Data Browser - FMAX
Data Browser - Capacitance

Data showing 3 measured capacitors
Data Browser – DC; IC vs. VBE
Conclusions

• The need for large amounts of s-parameter data for statistical modeling and process control is becoming increasingly significant.
• The considerations for a solution and the effectiveness of that solution have been demonstrated.
• Using this approach enables automated yield optimization tools to support products with DC to Broadband performance parameters.
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