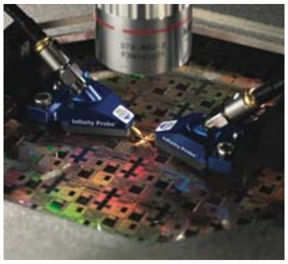
Validation of On-Wafer Vector Network Analyzers



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Purpose

- Investigate a proposed VNA comparison technique to validate on-wafer VNA systems
- Outline a detailed procedure and define terms
- Explore limitations
- Show sample results
- Provide conclusions

Typical Scenario

- Choose an on-wafer calibration technique
  - Review calibration comparison studies
  - LRRM, SOLT, LRM, TRL, etc.
- Perform the on-wafer calibration

How do I know my calibration is good?

- Measure your on-wafer device

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What is Needed

- A convenient calibration validation check
- Preferably automated
  - Quick and easy
  - Generate insightful reports
- WinCal XE Calibration and Measurement Software Calibration Validation Application Tool Kit

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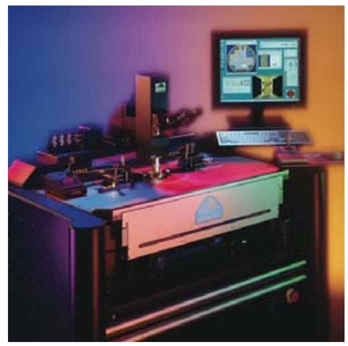
Validation by Comparison

Validate an on-wafer VNA system of unknown accuracy…

by comparing it to an on-wafer VNA system of trusted accuracy



Case Study

Apply comparison technique described in

"A Method for Comparing Vector Network Analyzers"
D. C. DeGroot, R. B. Marks and J. A. Jargon
50th ARFTG Conference Digest, pp. 107-114
Portland, OR, December 1997

to an On-Wafer Environment

Comparison Technique

- **Measure** a family of validation structures on both VNA systems
- **Calculate** the Error Vector Magnitude (EVM) difference between the two systems for each structure
- **Find** maxEVM for entire family of structures
- **Determine** Repeatability bounds for each system
- **Compare** the EVMs and maxEVM to the sum of the Repeatability bounds

Validation

- **Criteria:** Are the measurement differences between the VNAs bounded by the overall repeatability limits?

- **Yes** – the Test system is validated for these devices.

- **No** – the Test system has residual errors unaccounted for during calibration that are significant relative to the Reference system.

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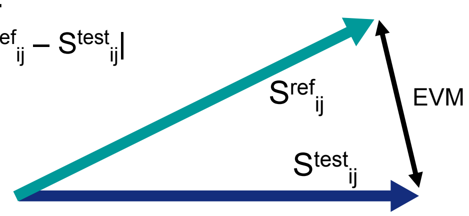
Limitations

- This comparison technique is only valid for the specific set of validation devices used during the experiment.
- Assumes the Reference system has trusted accuracy.
- However, for many users this quick and convenient validation check provides enough important feedback to either gain or lose confidence in their measurement system.

Definitions

- **ERROR VECTOR MAGNITUDE** (EVM) difference between two measurements is defined as:

$EVM_{ij} = |S^{ref}_{ij} - S^{test}_{ij}|$



Where:

- S^{ref}_{ij} are S-Parameter data files from Reference system
- S^{test}_{ij} are S-Parameter data files from Test system

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Definitions

- **ACCURACY** is the level of agreement of a measured or calculated quantity to its actual true value.
- **MEASUREMENT ERROR** is closely related to accuracy and is defined as the difference between a measured value of quantity and its true value.

Definitions

- **MEASUREMENT REPEATABILITY** is the variation in multiple measurement results taken by the same instrument on the same item and under the same conditions.
  - A measurement may be said to be repeatable when this variation is smaller than some agreed limit.
  - Repeatability conditions[1] include:
    - the same measurement procedure
    - the same observer
    - the same measuring instrument, used under the same conditions
    - the same location
    - repetition over a short period of time.

[1]Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results

Definitions

- **MEASUREMENT REPRODUCABILITY** is the variation in multiple measurement results taken by different persons or instruments on the same item and under the same conditions.
  - A measurement may be said to be reproducible when this variation is smaller than or equal to some agreed limit.

Warning

- Repeatability and reproducibility do not necessarily imply accuracy.
- Measurements may be repeatable and reproducible yet inaccurate.
- To use reproducibility as a validation test, the Reference system must be trusted.

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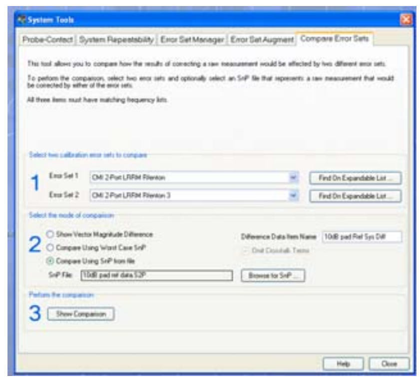
Repeatability Bounds

WinCal XE calculates the estimated repeatability bounds for VNAs using the method described in

“Calibration Comparison Method for Vector Network Analyzers”
R. B. Marks, J. A. Jargon, and J. R. Juroshek
48th ARFTG Conference Digest, pp. 38-45
Clearwater, FL, December 1996



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Repeatability Bounds

- Two types of repeatability bounds:
  - **Device Dependent Bounds:** Apply the error terms to the S-Parameter measurement data for each particular device
  - **Worst Case Bounds:** Apply the error terms to an S-Parameter data set with all terms equal to one

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Repeatability Bounds

- The overall repeatability bound was determined by adding Reference system bound (Δ^{ref}_R) and Test system bound (Δ^{test}_R) using device dependent and worst case methods.

$$\Delta^{ref}_R + \Delta^{test}_R = \text{Overall Repeatability Bound}$$

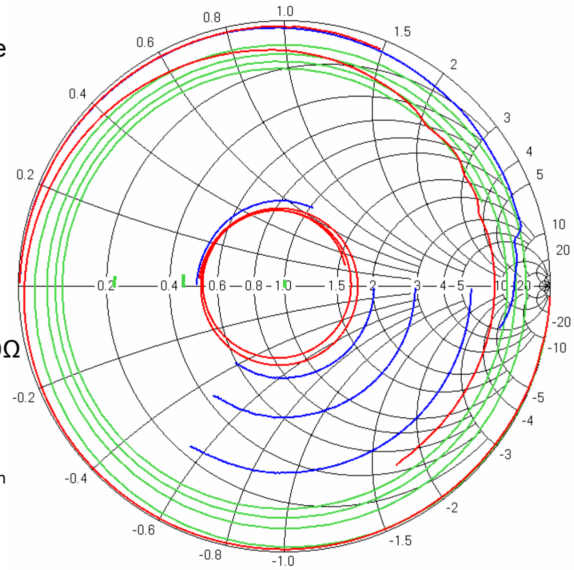
Systems to Compare

Reference System	Test System
S300 probe station **Agilent E8361A PNA**	**Summit 12K probe station** **Agilent E8364A PNA**
Infinity Probe (50GHz, GSG, 150µm pitch) Impedance Standard Substrate (101-190) 50GHz Gore RF test cables WinCal XE calibration software	Infinity Probe (50GHz, GSG, 150µm pitch) Impedance Standard Substrate (101-190) 50GHz Gore RF test cables WinCal XE calibration software

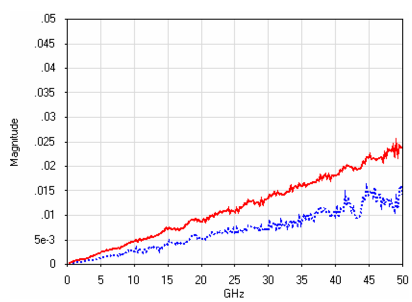
Validation Structures

- 40ps Transmission Line
- 40ps Open Stub
- Attenuators:
  10dB, 20dB
- Resistors:
  12.5Ω, 25Ω, 50Ω
- Offset Short
- Inductor
- Capacitor
- Offset Resistors:
  25Ω, 100Ω, 150Ω, 300Ω
- Long Offset 25Ω Resistor

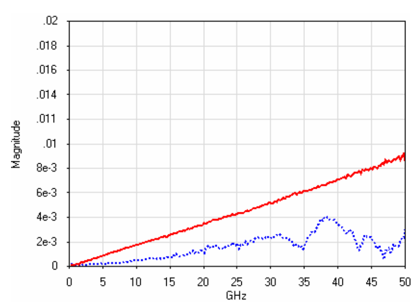
The majority of these structures are available on the Cascade Microtech 101-190 and 005-016 Impedance Standard Substrates



Sample Results – 10dB Pad

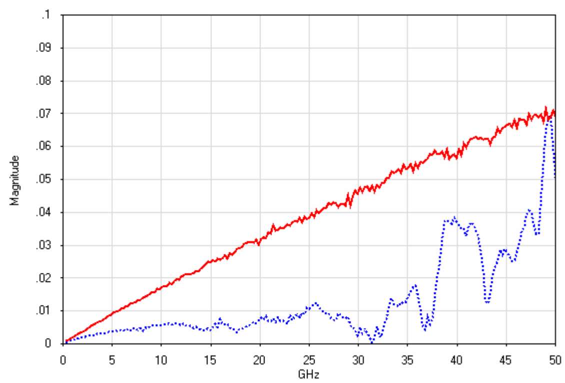


10dB attenuator S11 EVM vs.10dB attenuator device-dependent sum of repeatability bounds



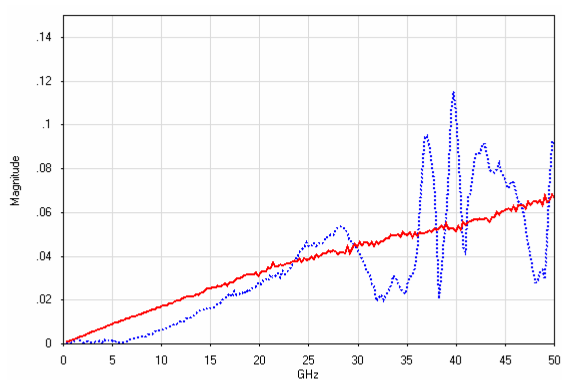
10dB attenuator S21 EVM vs. 10dB attenuator device-dependent sum of repeatability bounds

Sample Results – Inductor



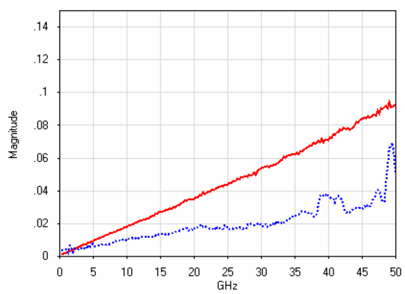
Inductor S11 EVM
vs. inductor
device-dependent sum of repeatability bounds

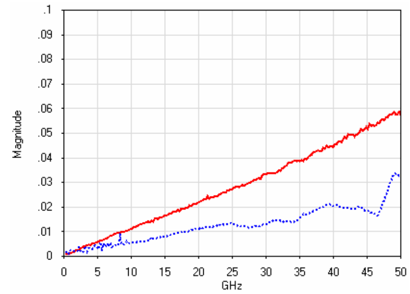
Sample Results – Capacitor



Capacitor S11 EVM
vs. capacitor
device-dependent sum of repeatability bounds

MaxEVM vs. Worst Case Bounds





Maximum S11 EVM
vs. worst case
sum of S11 repeatability bounds

Maximum S21 EVM
vs. worst case
sum of S21 repeatability bounds

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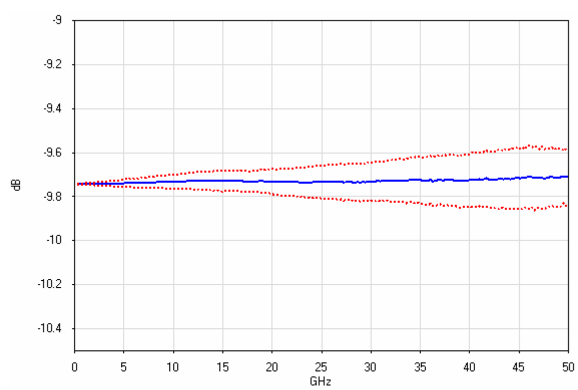
Sample Data with Bounds



10dB Reference system data
with 10dB Reference system
device-dependent repeatability bounds

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Results

- Test system reproduced Reference system results within repeatability bounds
- Test system can be trusted for measurements of these types
- VNA comparison technique proved to be useful and insightful as a validation and troubleshooting check

Cautions

- Validation technique only valid for devices measured
- Worst case repeatability bounds much more conservative compared to device-dependent repeatability bounds
- VNA residual errors are device dependent

Recommendations

- If possible, choose validation structures that resemble your device under test
  - Choose validation structures that cover different regions of the Smith chart
  - Choose validation structures with varying levels of attenuation
- Automate using WinCal XE to make the procedure quick and insightful

Looking Forward

- This technique would also be useful for on-wafer round-robin inter-laboratory measurement system comparisons
- Future work will include comparing on-wafer VNAs employing different calibration algorithms

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Original Summary

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Original Summary

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- This technique would also be useful for on-wafer round-robin inter-laboratory measurement system comparisons
- Future work will include comparing on-wafer VNAs employing different calibration algorithms