NIST Nonlinear Network Analyzer Interlaboratory Measurement Comparison Round 1

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22 July 2002; Last Revision 9 April 2003

Objectives

- To reveal the level of agreement between different nonlinear rf network measurement systems (NNMS) in characterizing a set of nonlinear verification devices.
- To determine the level of detail that the NNMS measurement community can discriminate.

Method

- Fabricate wafer of diode circuit verification devices.
- Develop modeling methods to capture input-output behavior for each verification device referenced to NIST NNMS measurements.
- Select statistical methods of analyzing the data and summarizing the comparison results.
- Develop protocol for measuring wafer and reporting data, including a set of measurements to assess contact, instrument, and calibration repeatability for each participant.
- Characterize temperature response of IV behavior of each verification device at NIST.
- Measure nominal rf performance of each verification device at NIST.
- Circulate two DIODE2 wafers to each participant, requesting each to follow the same protocol and measurement procedures, and having them measure a dc bias condition for each device to check for changes in junction temperature or behavior.
- Collect data from all participants and construct composite behavioral model of NIST data to cover range over which the labs report their data.
- Measure nominal performance of each verification device at NIST again to check for damage and device changes.
- Use a participant's ***a***-wave data as input into the composite model, and predict the ***b***-waves.
- Compare predictions to measured ***b***-wave data for each device.
- Assign significance to the differences between prediction and measurement based on contact and instrument repeatability, and a check on calibration repeatability.
- Report on comparison results, preserving anonymity of each participant.

Verification Wafer DIODE2

Substrate

- Alumina, as fired, 25.0 mm x 12.5 mm
- Gold metalization, one layer x.x μm thick

Multiline TRL Calibration Standards, CPW

These standards are not used in this Round 1 study.

- Nominally 50 Ω transmission lines
- T 0.500 mm
- SHORT 0.0 mm offset, with 0.250 mm lines
- L2 2.635 mm
- L3 3.2 mm
- L6 7.065 mm
- L19 20.195 mm

Diode Circuits

- Using Agilent HSCH-5300 Beam Lead Schottky Diodes with CPW connections
- DT1 Diode termination at end of 0.250 mm long CPW connections at each port
- DS1 Series diode with 0.250 mm long CPW connections at each port
- DP1 Two parallel diodes with 0.250 mm long CPW connections at each port
- DA1 Two anti-parallel diodes 0.250 mm long CPW connections at each port
- ***DIODE2-01 and -02 have parallel diodes at DA1 & 2***
- DT2 Diode termination at end of 2.000 mm long CPW connections at each port
- DS2 Series diode with 2.000 mm long CPW connections at each port
- DP2 Two parallel diodes with 2.000 mm long CPW connections at each port
- DA2 Two anti-parallel diodes 2.000 mm long CPW connections at each port

Capacitor Circuits

- Using Metleics MIS5010B12 10 pF Beam Lead MIS Capacitors with CPW connections
- CS1&2 Series capacitor with 0.250 mm long CPW connections at each port

Contact Repeatability Circuits

- DS1a Series diode with 0.250 mm long CPW connections at each port
- DS1b Series diode with 0.250 mm long CPW connections at each port
- DS1c Series diode with 0.250 mm long CPW connections at each port
- DS1d Series diode with 0.250 mm long CPW connections at each port
- DS1e Series diode with 0.250 mm long CPW connections at each port

Experiment Protocol and Instructions

Time Duration

Complete all measurements within one day to limit instrument drift.

Equipment List

Provide a detailed list of equipment and connection drawings for reference, including:

- Type of downconverter and digitizer (MTA or parts used in NNMS configuration)
- RF source make, model, and serial number
- Software (Agilent's, with version number, or custom)
- Locations of bias tees and couplers
- Probes make, model number, and serial number.
- Locations of any switches
- Locations of terminations
- Cal kits (aux. and on-wafer) make, model, & serial numbers.

Device and Standards Connections

- Use 150 μm pitch GSG probes.
- Connect leveled probes to each device, skating the probes between alignment marks as shown in Figure 1.

Source Power Reference and Measurement Reference Plane

- For all device measurements, connect source to Port 1 as shown in Figure 2.
- The measurement reference plane will be at the probe tips for both dc and rf signals.
- Source power setting will be referenced to power of $\boldsymbol{a}_{11}$ at probe tips, unless stated otherwise. ($\boldsymbol{a}_{11}$ is $\boldsymbol{a}_1$ at the fundamental frequency).
- The phase of all wave components should be referenced to phase($\boldsymbol{a}_{11}$)=0, if possible.
- dc voltages and currents will be referenced to probe tips.
- ***a***- and ***b***-wave data will be referenced to probe tips.

Source Settling Time

For all device measurements, each lab needs to ensure that their instrument is waiting an appropriate amount of settling time between setting the source to a desired value, and when starting to make measurements. For our source at NIST, we wait 1-2 seconds between changing the output power setting and collecting measurement data. Once we turn the RF Output to ON, we do not turn it off, since we see a 5-10 minute settling period for this control. Rather than turning RF Output = OFF, we set to power to a low value (for example, -40 dBm) while changing our connections. Each lab should ensure proper operation of their own source.

Frequency Grid & Number of Data Points

- Set fundamental frequency to 900 MHz.
- Collect data at every harmonic possible up to 22nd order (19.8 GHz).
- Nominal number of points on raw waveforms should be 2048 per fundamental period.
- (default setting for LSNA 2.0 and 2.1 software)

Calibrations

Probe-tip calibrations are to be performed at the beginning and again at the end of all the measurements. The preferred VNA calibrations are listed here by preferred rank: 1) LRRM, 2) LRM, 3) OSLT. Signal magnitude and phase dispersion calibrations should then be performed, also referenced to the probe-tip measurement plane.

Nonlinear Device Power-Bias Sweeps, Partial

For all diode circuits, a power-bias sweep is the basic measurement. The full range of source powers and dc bias conditions forms a 4 x 7 grid. For each of the four power settings (outer loop), the diodes are measured at 7 bias settings (inner loop). For all measurements in this set, the port 2 voltage (or current) bias =0. Vdiode is controlled only by vdc1.

- Power settings , $\boldsymbol{a}_{11}$ at probe tips = {-10, -5, 0, +5} dBm.
- vdc1 settings = {-0.5, -0.2, 0, 0.2, 0.4, 0.5, 0.6} V

Nonlinear Device Power-Bias Sweeps, Partial

In the case the participant is not able to measure all the above condition in a practical amount of time (MTA users), the participant may opt to measure the same set of devices listed below, but for the three power-bias conditions listed here:

device	**condition 1**	**condition 2**	**condition 3**
DT1	-0.4 V; -5 dBm	-0.4 V; 0 dBm	0.2 V; 0 dBm
DS2	-0.6 V; -5 dBm	-0.6 V; 5 dBm	0.2 V; 5 dBm
DP1	-0.6 V; -5 dBm	-0.6 V; 5 dBm	0.2 V; 5 dBm
DA1	-0.6 V; -5 dBm	-0.6 V; 5 dBm	0 V; 5 dBm
DP2	-0.4 V; -5 dBm	-0.6 V; 0 dBm	0.2 V; 0 dBm

Measurement Repeats

Measure each device 26 times, sweep across all settings in a single repetition. That is 26 power-bias sweeps for each diode device and 26 power-bias sweeps for each connection of the contact repeatability measurements; it is 26 frequency sweeps of the linear device.

Data Storage Conventions

- Store and report measurement data in citi files following the attached examples.
- Put all data from one complete run in one folder named *NNMSname_yymmdd*, following this example: *leuven_030408* for 2003 April 08.
- Name the files for each power-bias sweep (or frequency sweep) measurement as DIODE2_nn_ddd_ccc_rrr.citi where nn = wafer number, ddd=device name, ccc=connection number, and rrr=repeat number. Example: DIODE2_01_DS1a_004_021.citi
- In the case of the passive device, generate one file for each sweep of the fundamental.
- In the case of contact repeats, generate one file for each power-bias repeat at each unique connection repeat.
- In the case of the other diode devices, generate one file for each power-bias repeat.
- Report on any deviations to the protocol that were required to acquire the requested data.
- For each dc test (100μA bias) at the end of each device measurement, record the measured (dc-calibrated) vdc1. This is in the Mathematica notebooks for the Agilent LSNA systems, but should be saved in a separate spreadsheet file afterwards: Time stamp, device, v1dc.

Measurement Protocol

Calibration

1. Using calibration standards (ISS wafer), perform a probe-tip VNA calibration of one of the following types. In preferred rank: 1) LRRM, 2) LRM, 3) OSLT. Record which one used.
2. Perform signal magnitude calibration.
3. Perform phase dispersion (alignment) calibration.
4. Save raw standards measurements and correction coefficients.

Linear Device Check

1. Set RF Power ON (and don't turn off for the remainder of all measurements).
2. Set Source Power = -20 dBm (or lower for nominal off condition).
3. Ensure dc bias is OFF.
4. Contact CS1 on wafer DIODE2-01, leaving contacts in place for duration of measurements.
5. Set source frequency = fundamental (900 MHz).
6. Set source power to10 dBm (at source not probe tips for this device).
7. Ensure all settling times have been met before measuring.
8. Measure all waves and save data, setting source to -20 dBm at end (nominal off).
9. Set source frequency = 2x fundamental (1.8 GHz), and repeat steps 6-8, appending data.
10. Set source frequency = 4x fundamental (3.6 GHz), and repeat steps 6-8, appending data.
11. Set source frequency = 9x fundamental (8.1 GHz), and repeat steps 6-8, appending data.
12. Set source frequency = 22x fundamental (19.8 GHz), and repeat steps 6-8, appending data.
13. Now repeat steps 5-12 for a total of 26 times; 26 sweeps and unique files.
14. For example DIODE2_01_CS1_001_026.citi would be last file of the repeat loop. It would contain 5 sets of data for each of the fundamental frequency settings.

Contact Repeatability Using DS1x

1. Set source to fundamental (900 MHz).
2. Set Source Power = -20 dBm (or lower).
3. Ensure dc bias is off.
4. Contact specified DS1x circuit. (DS1b, for the second lab, for example).
5. Set bias mode = voltage, voltage (port 1, port 2)
6. Perform power-bias sweep measurement over available states.
7. Save one citi file of data for the power-bias sweep following attached example.
8. Repeat steps 6-7 for a total of 26 times.
9. Set source power = -20 dBm (or lower).
10. Set bias mode = current, voltage.

11. Set idc1 = 100 μA, vdc2 = 0.
12. Measure and record all idc and vdc at probe tips for a temperature measurement.
13. (Just save bias data in Mathematica notebook, not citi file.)
14. Turn dc bias off.
15. Lift probes and reposition (individually)
16. Repeat steps 5-14 for a total of 10 times.

Power-Bias Sweeps of Diode Circuits

1. Set Source Power = -20 dBm (or lower).
2. Ensure dc bias is off.
3. Contact **DIODE2-01 DT1** at port 1 only.
4. Set bias mode = voltage, voltage.
5. Perform power-bias sweep over specified states.
6. Save all data in one citi file following example.
7. Repeat power-bias sweeps for a total of 26 times without lifting probes.
8. Set source power = -20 dBm (or lower).
9. Set bias mode = current, voltage.
10. Set idc1 = 100 μA, vdc2 = 0 (no port 2 connection).
11. Measure and record vdc1 and idc1 at probe tips for a temperature measurement. (Just save bias data in Mathematica notebook, not citi file.)
12. Turn dc bias off.

13. Contact **DIODE2-01 DS2**.
14. Set bias mode = voltage, voltage.
15. Perform power-bias sweep over specified states.
16. Save all data in one citi file following example.
17. Repeat power-bias sweeps for a total of 26 times without lifting probes.
18. Set source power = -20 dBm (or lower).
19. Set bias mode = current, voltage.
20. Set idc1 = 100 μA, vdc2 = 0.
21. Measure and record all idc and vdc at probe tips for a temperature measurement. (Just save bias data in Mathematica notebook, not citi file.)
22. Turn dc bias off.

23. Contact **DIODE2-01 DP1**.
24. Set bias mode = voltage, current.
25. Perform power-bias sweep over specified states.
26. Save all data in one citi file following example.
27. Repeat power-bias sweeps for a total of 26 times without lifting probes.

28. Set source power = -20 dBm (or lower).
29. Set bias mode = current, voltage.
30. Set idc1 = 100 μA, vdc2 = 0.
31. Measure and record all idc and vdc at probe tips for a temperature measurement. (Just save bias data in Mathematica notebook, not citi file.)
32. Turn dc bias off.

33. Contact **DIODE2-01 DP2**.
34. Set bias mode = voltage, current.
35. Perform power-bias sweep over specified states.
36. Save all data in one citi file following example.
37. Repeat power-bias sweeps for a total of 26 times without lifting probes.
38. Set source power = -20 dBm (or lower).
39. Set bias mode = current, voltage.
40. Set idc1 = 100 μA, vdc2 = 0.
41. Measure and record all idc and vdc at probe tips for a temperature measurement. (Just save bias data in Mathematica notebook, not citi file.)
42. Turn dc bias off.

43. Contact **DIODE2-01 DA1**.
44. Set bias mode = voltage, current.
45. Perform power-bias sweep over specified states.
46. Save all data in one citi file following example.
47. Repeat power-bias sweeps for a total of 26 times without lifting probes.
48. Set source power = -20 dBm (or lower).
49. Set bias mode = current, voltage.
50. Set idc1 = 100 μA, vdc2 = 0.
51. Measure and record all idc and vdc at probe tips for a temperature measurement. (Just save bias data in Mathematica notebook, not citi file.)
52. Turn dc bias off.

53. Repeat steps 1-52 for same diode devices on wafer DIODE2-02.

Calibration Check

1. Perform a complete calibration of the type performed at the start of the measurements.
2. Save raw standards measurements and correction coefficients for comparison to first.

The End

Measurement Check Sheet

Date:______________

User:____

Measurement System Name & Location:_____________________________

Version of Measurement System Software:___________________________

Data Directory Name:____

Starting Time:____

- ❑ Starting Calibration
  Cal substrate:

Wafer 1

- ❑ DIODE2-01, CS1 Fundamental Frequency Sweep
- ❑ DIODE2-01, DS1c Contact Repeatability
- ❑ DIODE2-01, DT1 Power-Bias Sweep
- ❑ DIODE2-01, DS2 Power-Bias Sweep
- ❑ DIODE2-01, DP1 Power-Bias Sweep
- ❑ DIODE2-01, DP2 Power-Bias Sweep
- ❑ DIODE2-01, DA1 Power-Bias Sweep

Wafer 2

- ❑ DIODE2-02, DT1 Power-Bias Sweep
- ❑ DIODE2-02, DS2 Power-Bias Sweep
- ❑ DIODE2-02, DP1 Power-Bias Sweep
- ❑ DIODE2-02, DP2 Power-Bias Sweep
- ❑ DIODE2-02, DA1 Power-Bias Sweep

- ❑ Ending Calibration