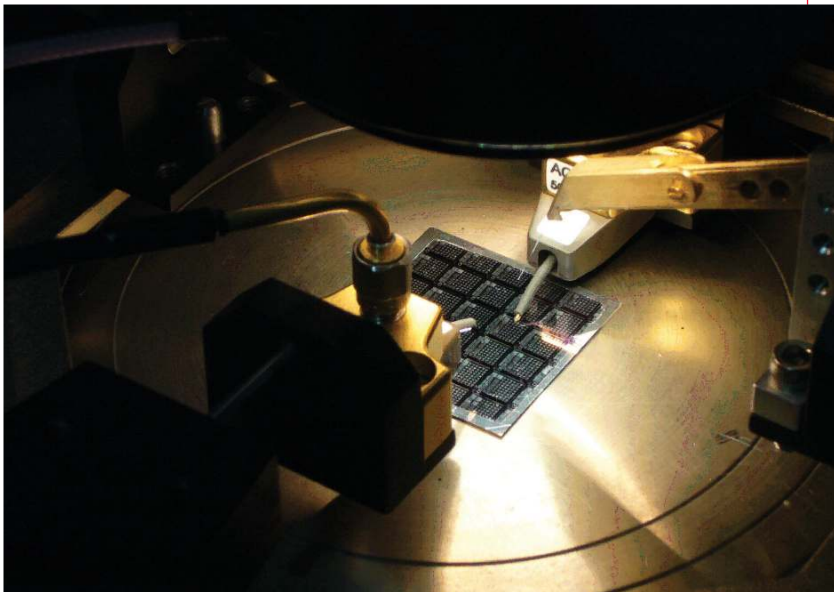
Keysight Technologies

On-Wafer Testing of Opto-Electronic Components Using the Lightwave Component Analyzers

Application Note



KEYSIGHT TECHNOLOGIES

Introduction

When measurements of optoelectronic components are performed on the wafer, e.g. at an early stage in the device processing, or under balanced operation where exact phase information at the DUT electrical interfaces is needed, it is important to precisely extend the electronic and optical calibration reference planes to the DUT interfaces and to fully reference out the device fixture and cables. Use of Electronic Multiport Calibration Kits, on-wafer calibration standards together with characterization utilities allows electrically calibrating the setup with reference to the coaxial interfaces closest to the DUT and extending this calibration plane to the DUT connection plane, e.g. beyond the wafer probe.

This application note is intended to assist on-wafer applications using the N437xB/C Lightwave Component Analyzer with single and dual probes to perform single-ended and balanced opto-electronic component full Sparameter measurements manually.

Lightwave Component Analyzers are available in 4.5 GHz, 20 / 26.5 GHz and 67 GHz models. The principles of Lightwave Component analysis are described in the “Keysight Technologies, Inc. High-speed Lightwave Component Analysis Application Note” (5989-7808EN).

This document describes the principles of on-wafer measurements on opto-electronic components and provides step-by-step instructions needed:

- to set up a calibration kit before an on-wafer SOL(T) (Short-Open-Load-(Thru) calibration can be performed.
- to perform the electronic calibration and deembedding of the wafer probes.

For more detailed instructions on electronic on-wafer measurements for RF components with PNA and ENA network analyzers please refer to the application notes “On-Wafer SOLT Calibration Using 4-port PNA-L NWAs” (5989-2287EN) and “On-Wafer Balanced Component Measurement using the ENA RF Network Analyzer with the Cascade Microtech Probing System” (5988-5886EN)[3].

The setup and example measurements presented throughout this application note have been performed using the N4373B 67 GHz Lightwave Component Analyzer with an N4694A-00F 2 port microwave electronic calibration kit f-f and single ended wafer probes and calibration substrates from Cascade Microtech.

The principles are also applicable to balanced measurements.

Equipment used

- N4373B/C 67 GHz LCA using E8361A/C 67 G PNA (referred to throughout this document as LCA)
- N4375B 20 GHz Single Mode LCA using N5230A/C 20 G PNA-L with Option x2x or Option x4x
- N4375B 20 GHz Single Mode LCA using N5242A 26.5 PNA-X with Option 2xx or Option 4xx
- N4376B 20 GHz Multimode LCA using N5230A/C 20G PNA-L with Option x2x or Option x4x
- N4376B 20 GHz Multimode LCA using N5242A 26.5 PNA-X with Option 2xx or Option 4xx
- N4374B 4.5 GHz Single Mode LCA using E5071C ENA
- N4694A 67 GHz 2 port micro-wave electronic calibration kit
- N4691B 26.5 GHz 2 port microwave electronic calibra-tion kit
- 85092C 2-port RF Electronic Calibration (ECal) Module Type-N 50 ohm
- Single or dual probes and associated ISS (Impedance Standard Substrate)

Implementation

A typical on-wafer measurement of an opto-electronic transmitter component uses an RF wafer probe for the electronic stimulus and optical probe for picking up the optical response. For receive components the device under test is stimulated via the optical probe and the RF response is picked up by the RF wafer probe.

For calibrated opto-electronic S-Parameter measurements on opto-electronic components like lasers, modulators, detectors, receivers, and PIN-TIAs the Light-wave Component Analyzer requires an RF calibration of the measurement setup and test fixture, up to the electrical RF interfaces of the device under test prior to the LCA measurement.

The LCA normally requires an electronic calibration up to the coaxial DUT interface. Mechanical or electronic calibration kits are available for the coaxial interface calibration. The LCA allows for extension of the coaxial calibration plane to the tip of the wafer probe via the “RF path deembedding” feature (see Figure 1). For the RF path deembedding the RF wafer probe is considered as an RF adapter. The adapter characteristics can easily be determined by the adapter characterization macro provided with the NWA firmware.

The steps described in this application note refer mainly to LCAs based on the PNA Series Network Analyzers. However the principles apply for the ENA Series based Network Analyzers as well.

The PNA performs 2- and 4-port calibrations using either SmartCal (Guided calibration) or an Electronic Calibration (ECal) module. With Guided calibration, the process chooses the standards to apply from the calibration kit based on how they were defined. For on-wafer calibration, only SmartCal is applicable.

The on-wafer LCA measurement requires the following preparatory steps:

Step 1. Create a new calibration kit for probing.
Step 2. Perform an electronic calibration of the coaxial RF interfaces of the LCA
Step 3. Connect RF cable to wafer probe
Step 4. Characterization of the wafer probe
Step 4a. Perform a 1-port SOL (Short-Open-Load) calibration of the wafer probe
Step 4b. Run adapter characterization macro on PNA to determine adapter file for wafer probe
Step 5. Start and configure LCA including specifying wafer probe adapter file

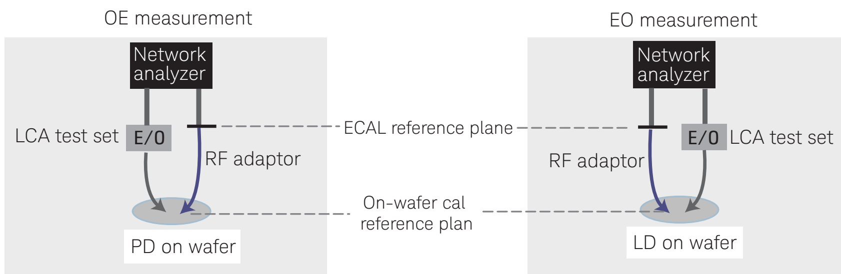


Figure 1. LCA configurations for On-Wafer measurements

Step 1. Create a new calibration kit for probing

To create a calibration kit on the PNA network analyzers, simply follow the boxed numbers in each of the figures shown below (Figure 2 through Figure 10). For creating a calibration kit on the ENA network analyzers, please follow the steps as described in the application note "On-wafer Balanced Component Measurement using the ENA RF Network Analyzer with the Cascade Microtech Probing System"[3].

N5242A PNA-X, N5230C PNA-L and E836xC PNA Models

1. Click **Response**
2. Select **Cal -> More -> Cal Kit** .... – this brings up the *Edit PNA Cal Kits* dialog box

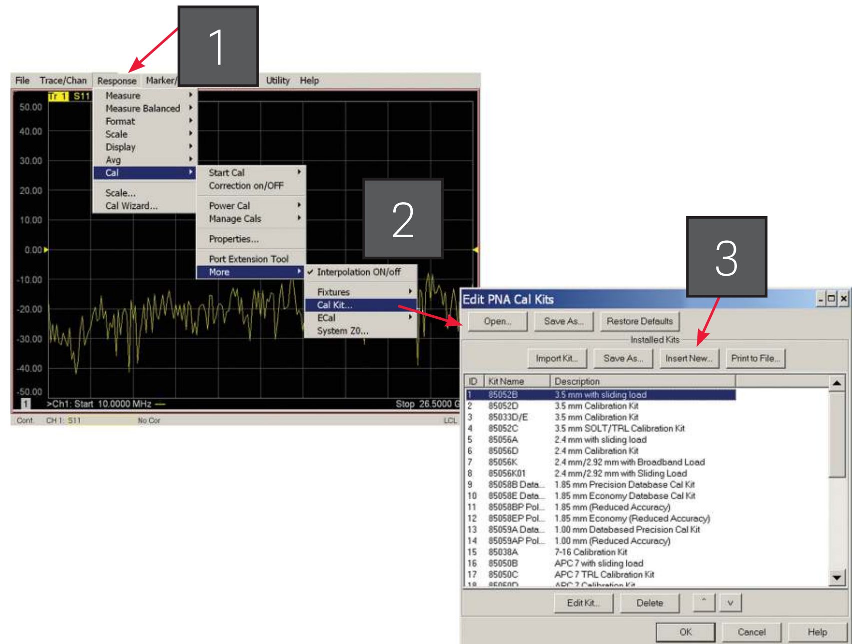


Figure 2. Creating a new calibration kit for probing

N5230A PNA-L and E836xB PNA Models

1. Click **Calibration**
2. Select **Advanced Modify Cal Kit**... – this brings up the *Edit PNA Cal Kits* dialog box

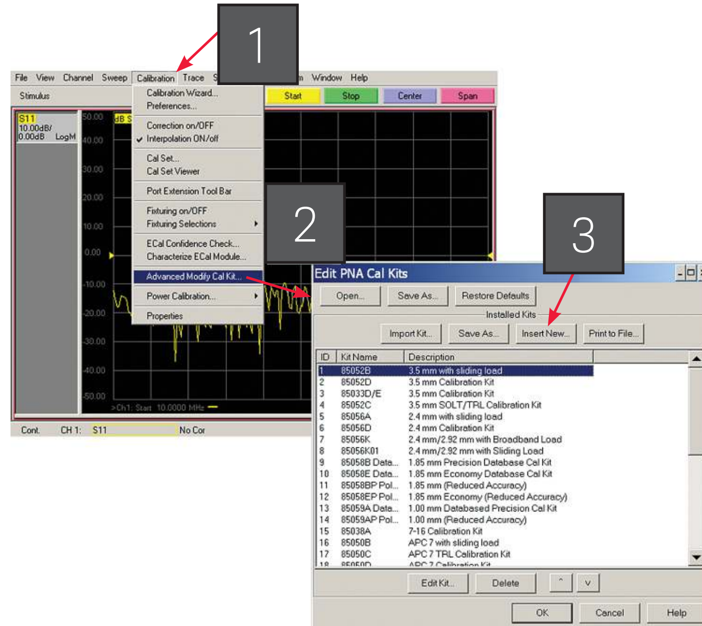


Figure 3. Creating a new calibration kit for probing

3. Click **Insert New**... – this brings up the *Edit Kit* dialog box

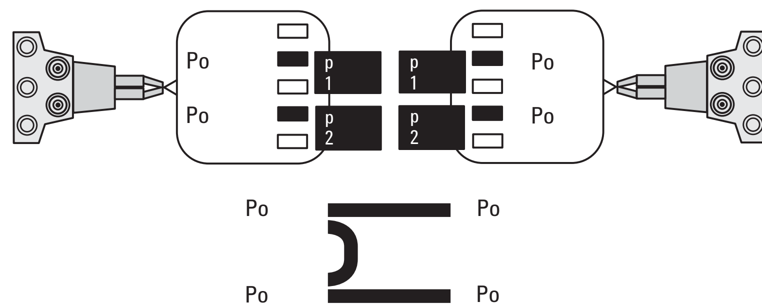


Figure 4. Assigning test ports as either probe 1 or probe 2

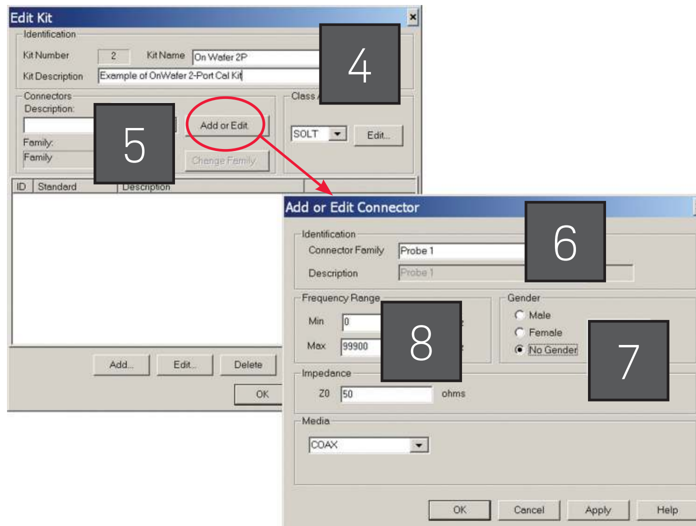


Figure 5. Creating a new calibration kit for probing: Connector definition

Adding or editing a kit

4. Enter *Kit Name and Kit Description*
5. Click **Add** or **Edit** (located near the middle of the dialog box) to add connectors to this calibration kit – this brings up the *Add or Edit Connector* dialog box

If you are using balanced probes or if you make full electrical on-wafer measurements in order to maximize the benefits of the minimum thru approach (only three thrus, not six, are needed to achieve a full 4-port calibration), it is best to set up a calibration kit with two probes (for example, “probe 1” and “probe 2”, or “male” and “female”), and then assign the ports so that it offers the PNA the easiest way to execute minimum thru. See Figure 4 for test port assignment. The actual calibration sequence will then be determined by the instrument, via the Calibration Wizard.

6. Enter *Connector Family* – “probe 1” was typed in here
7. Select **No Gender** for connector Gender
8. Double check to make sure *Max Frequency Range* is above maximum frequency range of the instrument, for example, 999000 MHz, then click OK

Each standard (open, short, load (and thru)) will be defined with two probes, described here under Connector Family. They are identified as “probe 1” and “probe 2”. As such, repeat steps 5 through 8, this time, enter “probe 2” for Connector Family (Figure 6, left). At this point, you should have two probes defined under Connectors, and they are “probe 1” and “probe 2” (Figure 6).

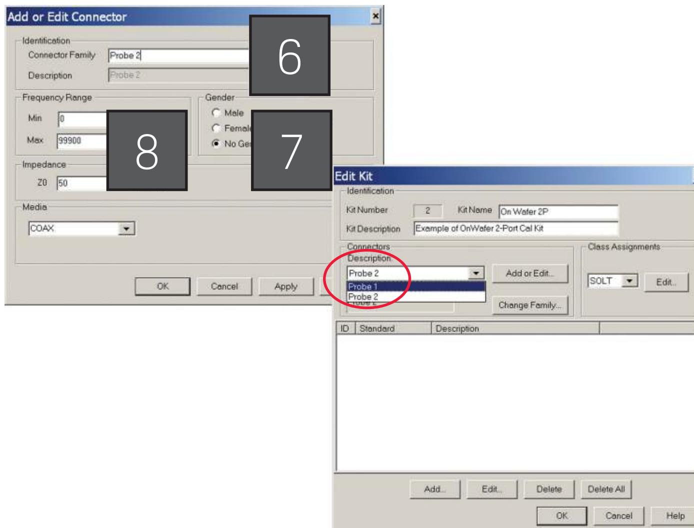


Figure 6. Repeating steps 5 through 8 with "probe 2"

Defining OPEN

9. Click **Add** (located near the bottom of the dialog box) – this brings up the Add Standard dialog box
10. Select **OPEN**, then click **OK** – this brings up the Opens dialog box
11. Modify *Label* to read "OPEN 1"
12. Under *Connector*, select "probe 1"
13. Enter the **C0** value, then click **OK** – each ISS (Impedance Standard Substrate) often comes with its own Calibration Coefficients. These values may differ depending on the configuration and pitch of the probes. Typical parameters that come with each ISS include
    – Copen (the capacitance term for the Open standard)
    – Lshort (the inductance term for the Short standard)
    – Lterm (the inductance term for the Load standard)

For more details regarding ISS and its coefficients, please contact Cascade Microtech at **www.cmicro.com**.

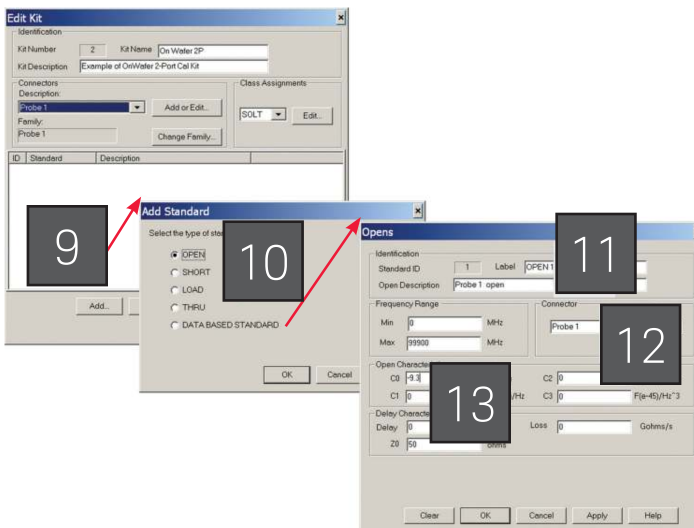


Figure 7. Creating a new calibration kit for probing: Defining OPEN

If you are setting up the probe for balanced measurements repeat steps 9 through 13. This time,

- enter “OPEN 2” for Label (step 11)
- select “probe 2” under *Connector* (step 12)

Defining SHORT

14. Click **Add** (located near the bottom of the *Edit Kit* dialog page) – this brings up the *Add Standard* dialog box
15. Select **SHORT**, then click **OK** - this brings up the Shorts dialog box
16. Modify *Label* to read “SHORT 1”
17. Under *Connector*, select “probe 1”
18. Enter the L0 (Lshort) value, then click OK

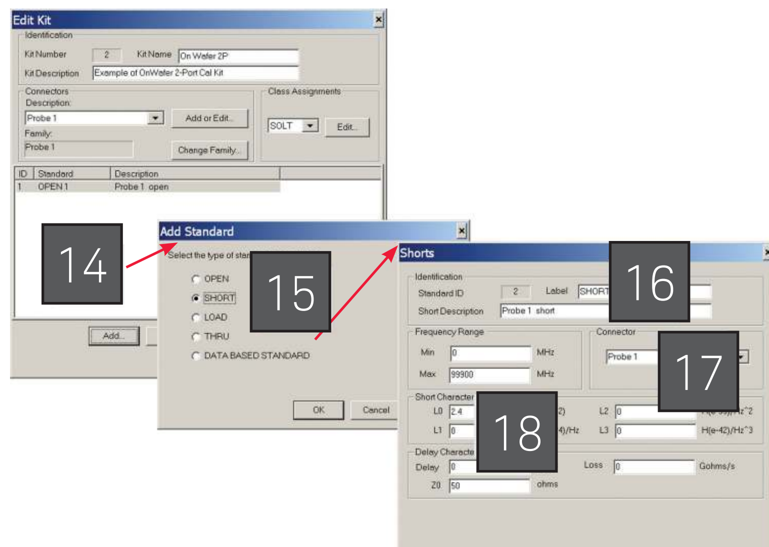


Figure 8. Creating a new calibration kit for probing: Defining SHORT.

If you are setting up the probe for balanced measurement repeat steps 14 through 18. This time,

- enter “SHORT 2” for Label (step 16)
- select “probe 2” under *Connector* (step 17)

Defining LOAD

19. Click **Add** (located near the bottom of the *Edit Kit* dialog page) – this brings up the *Add Standard* dialog box
20. Select **LOAD**, then click **OK** – this brings up the *Loads* dialog box
21. Modify *Label* to read "LOAD 1"
22. Under *Connector*, select "probe 1"
23. Enter the following values (because the Loads dialog page does not have an entry for the Lterm):

- specify a high impedance for **Z0**, enter a value of 500 ohms enter a value for **Delay** that is derived from L/500, where L is the value
- of Lterm as provided with the ISS.

Then click **OK**

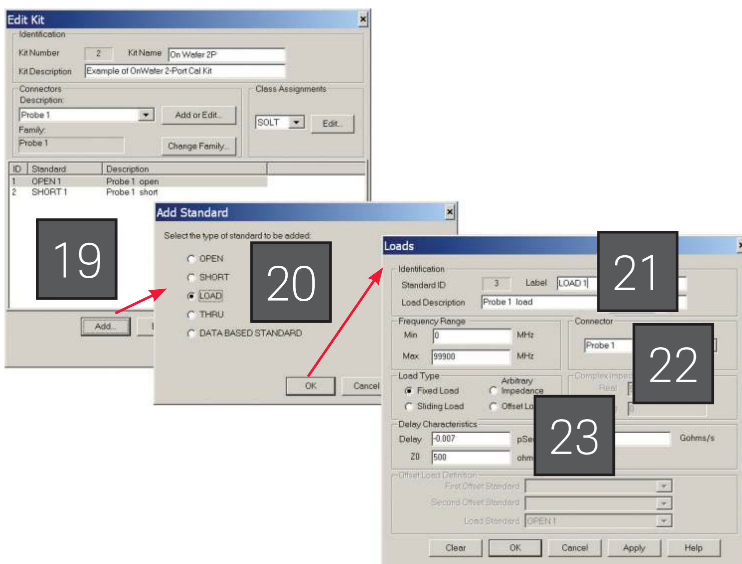


Figure 9. Creating a new calibration kit for probing: Defining LOAD.

If you are setting up a the probe for balanced measurement repeat steps 19 through 23. This time,

- enter "LOAD 2" for *Label* (step 21)
- select "probe 2" under *Connector* (step 22)

If you set up the calibration kit for full electrical on-wafer measurements it is also required set up standards for "THRU". Please continue to follow the instructions as described in the application note "On-Wafer SOLT Calibration Using 4-port PNA-L NWAs" 2

Completion

24. For pure LCA measurements with the LOAD standards added, the calibration kit is now complete.
    Click **OK**.
25. The calibration kit is now ready for use, as shown here in the Cal Kit list.

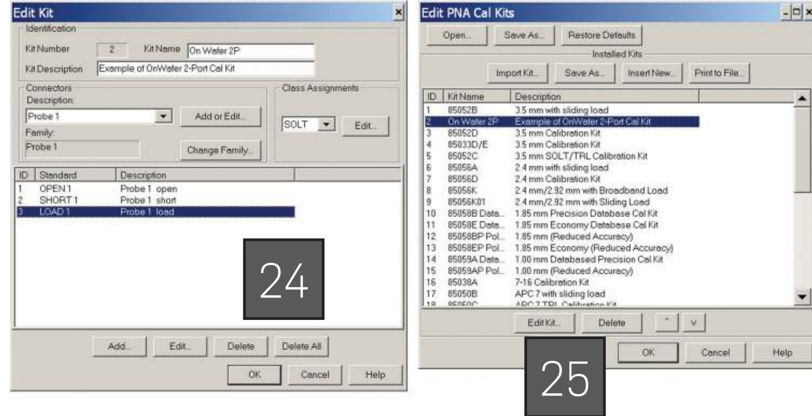


Figure 10: Creating a new calibration kit for probing: Complete.

For the electronic calibration of the LCA for single ended or balanced measurements please follow the steps as described in chapter “Calibrating the Network Analyzer before Measurements” of your LCA user guide. This calibration defines the ECAL reference plane as indicated in Figure 1.

Step 2. Perform an electronic calibration of the coaxial RF interfaces of the LCA

For the electronic calibration of the LCA for single ended or balanced measurements please follow the steps as described in chapter “Calibrating the Network Analyzer before Measurements” of your LCA user guide. This calibration defines the ECAL reference plane as indicated in Figure 1.

Starting electronic calibration

N5242A PNA-X, N5230C PNA-L and E836xC PNA Models

1. Click **Response**

N5230A PNA-L and E836xB PNA Models

1. Click **Calibration**
2. Select **Cal Wizard**... – this brings up the *Calibration Wizard: Begin Calibration* dialog box
3. Select “**Use Electronic Calibration (ECal)**”
4. Click **Next** > – this brings up the *Select Calibration Ports and ECal Module* dialog box
5. Under Cal Type Selection, select “**2 Port Cal**” for single ended measurement or “**3 Port Cal**” for balanced measurement

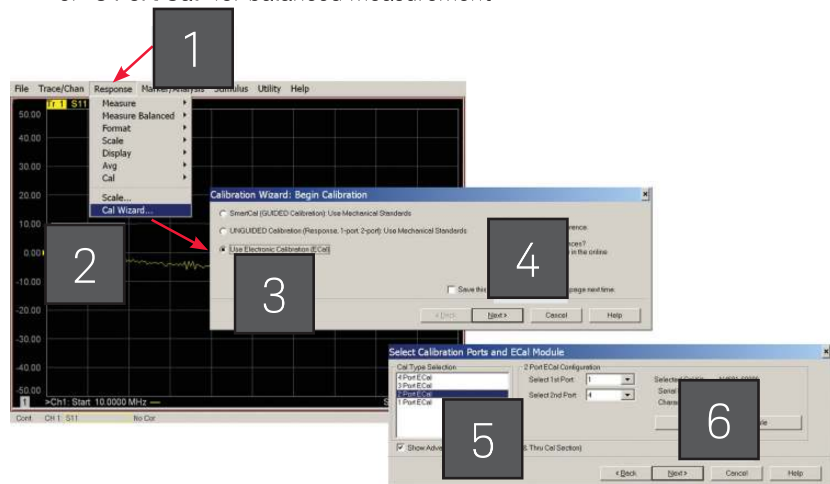


Figure 11: Electronic Calibration Start

6. Enter NWA ports used. Click Next > – this brings up the Electronic Calibration Step 1 of 1

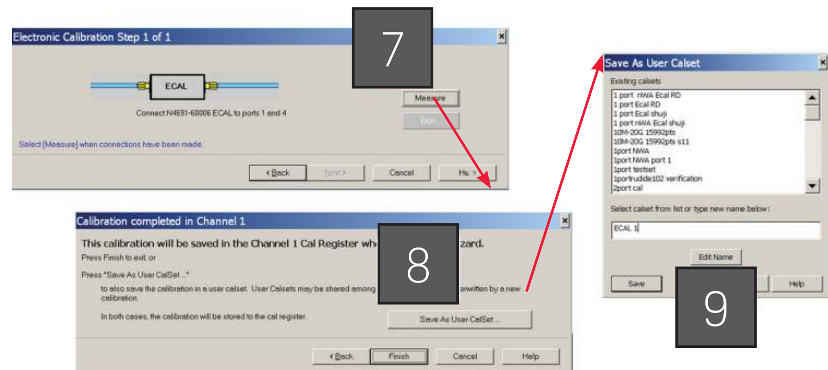


Figure 12: Electronic Calibration and User Calset Save

Starting ECAL

7. Connect the RF cable to the ECAL module according to the description in chapter "Calibrating the Network Analyzer before Measurements" of your LCA user guide for single ended or balanced measurements.
   Click **Measure** > – this starts the ECAL.

For balanced measurements repeat this step for the other RF cable.

8. Click **Save As User CalSet** > – this brings up the final dialog *Save* As User Calset
9. Enter User Calset name e.g. "ECAL 1" and click **Save**.
10. Disconnect ECAL kit from RF cable(s) and or LCA Test set.

Step 3. Connect RF cable to wafer probe

For single ended measurements connect the RF cable to the wafer probe connecting to the DUT. For balanced measurements connect both RF cables to the wafer probes connecting to the balanced DUT.

For the N4373B/C and N4374B connect the remaining RF cable to the LCA test set (for EO measurements connect to Port B, for OE measurements connector for Port A)

Step 4. Characterization of the wafer probe

Steps 4a and 4b describe the steps on the PNA series NWA to characterize the wafer probe as an RF adapter and to create an adapter file for use with LCA.

On the ENA series NWA the wafer probe can be directly characterized using the Adapter Characterization VBA program[4].

Step 4a. Perform a 1-port SOL (Short-Open-Load) calibration of the wafer probe

The PNA can perform 1-port to 4-port calibrations with either SmartCal (Guided calibration) or an Electronic Calibration (ECal) module; but this is not available with Unguided calibration. Since ECal modules are not applicable for on-wafer, we will use SmartCal, a calibration process in which the steps are guided by the instrument. For the deembedding of the wafer probe for LCA on-wafer measurements, only one or two 1-port calibrations are needed for single ended wafer probes or dual-ended wafer probes, respectively.

For the 1-port calibration, performing an SOL calibration is sufficient.

N5242A PNA-X, N5230C PNA-L and E836xC PNA Models

1. Click **Response**

N5230A PNA-L and E836xB PNA Models

1. Click **Calibration**

2. Select **Cal Wizard**... – this brings up the Calibration Wizard: Begin Calibration dialog box
3. Select "**SmartCal (GUIDED Calibration): Use Mechanical Standards**"
4. Click **Next** > – this brings up the Select Guided Calibration Type (Mechanical Standards) dialog box
5. Under Cal Type Selection, make sure "**1 Port Cal**" is selected
6. Select the NWA port to which the wafer probe is connected for 1-port calibration.
7. Click **Next** > – this brings up the Guided Calibration: Select DUT Connectors and Cal Kits dialog box

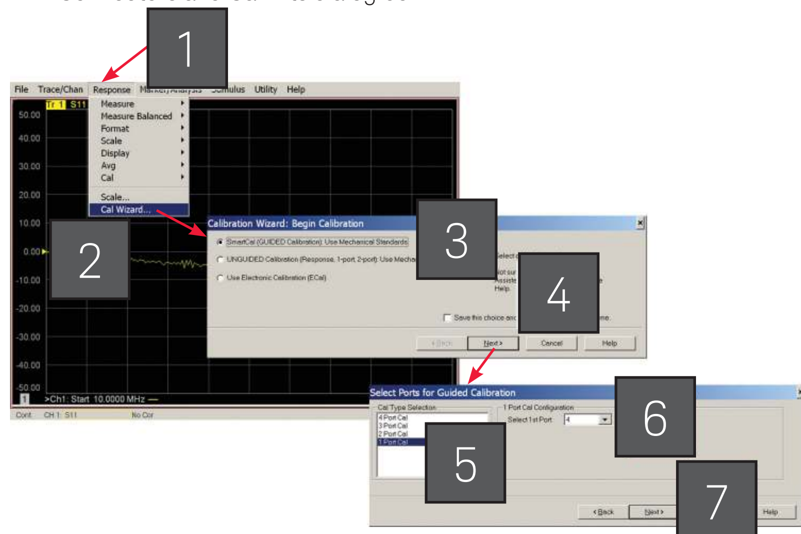


Figure 13. Smart Cal Wizard

Selecting the probe

8. Under Connectors, using the dropdown menu, select “**probe 1**”.

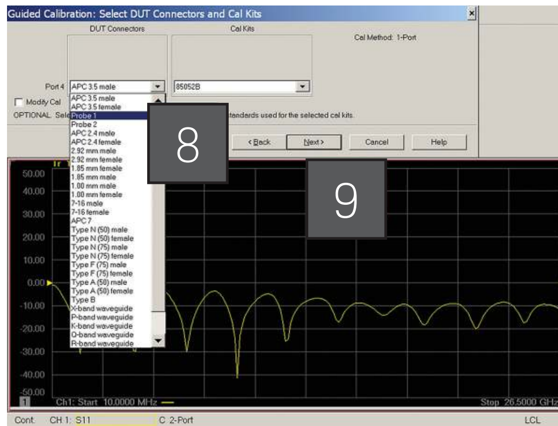


Figure 14. Selection of calibration kit associated to probe 1

9. Click **Next** > –

Guided calibration steps

At this point, you should see the dialog box showing “Guided Calibration Step 1 of 3”, which is the beginning of the calibration. For the test port, the instrument steps the user through three standards (Open, Short, and Load).

As requested use the corresponding calibration substrates provided with your wafer probe.

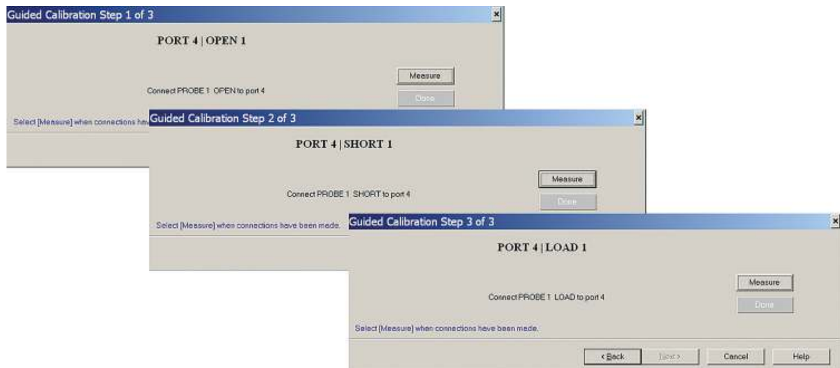


Figure 15. Guided Calibration Steps for “Short, Open, Load”

Throughout the calibration process, one sees the "**Guided Calibration Step**" shown on the upper left corner of the dialog box (Figure 15), the **Measure** button is on the right, and the < **Back** and **Next** > buttons are toward the bottom. Once a standard has been measured, a green "*check*" symbol appears above the **ReMeasure** button which is located at the exact spot where the **Measure** button used to be. After all the standards have been measured, a green Done button will appear below the **ReMeasure** button. You can always go back to re-measure any standard before pressing the **Done** key. At this point, one can finish the calibration by simply clicking **Done**, or choose to re-measure another standard as needed.

Saving CalSet

10. Click **Save As User CalSet** > – this brings up the final dialog *Save As User Calset*
11. Enter User Calset name e.g. "Probe 1-Port" and
12. Click **Save**.

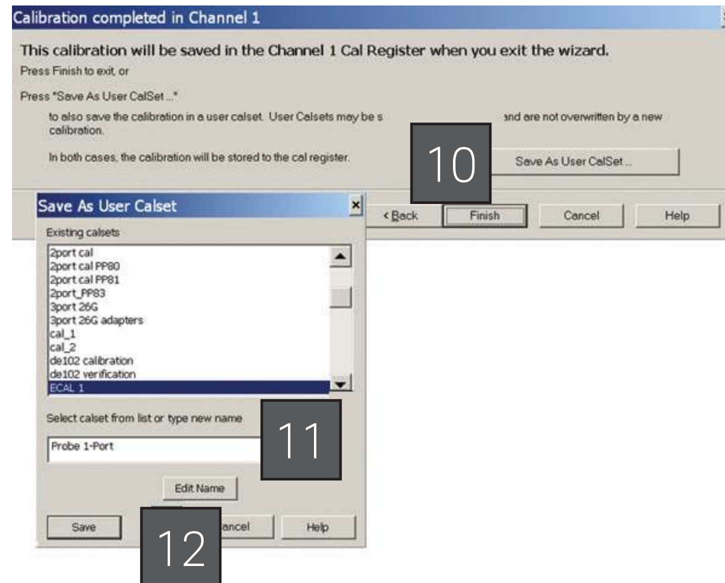


Figure 16. User Calset Save for Probe

13. Remove the calibration substrates.

Step 4b. Run adapter characterization macro on PNA to determine adapter file for wafer probe

Adapter characterization macro

Activate the macro soft keys by pressing the MACRO button at the PNA front panel. Start the Adapter Characterization Macro.

Figure 17. Adapter Characterization Macro Softkeys on PNA and PNA-X User interface

Selecting the port

1. a) Select Calset from the calibration of the coaxial / RF cable interface (e.g. ECAL 1)
   b) Define PNA port where RF cable is connected to (e.g. Port 4)
2. a) Select Calset from the calibration of the wafer probe (e.g. Probe 1-Port)
   b) Define PNA port where the wafer probe has been connected to (via the RF cable) (e.g. Port 4)

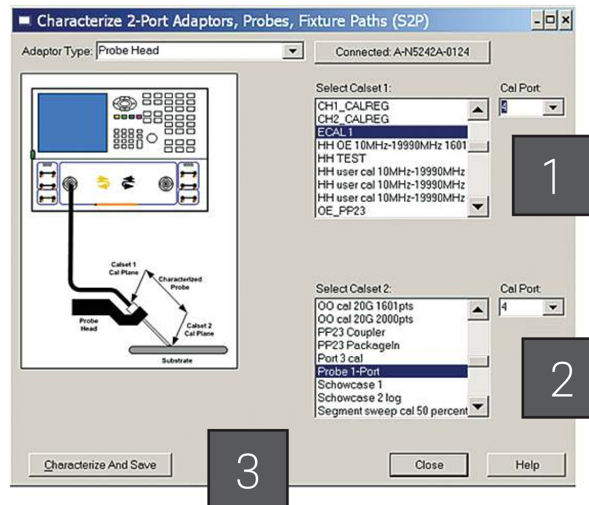


Figure 18. Defining Calsets for Adapter Characterization

3. Click Characterize and Save

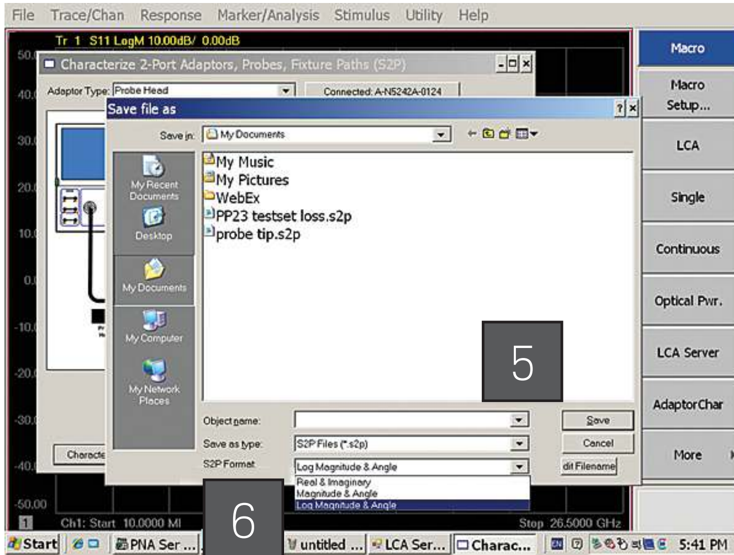


Figure 19. Saving Adapter S2P File

Storing data files

4. Select Data format “Log Magnitude & Angle”
5. Select File Directory, Enter file name and click **Save**

In the case of balanced probes create two separate adapter S2P files using the adapter characterization macro with the ECAL on the coaxial ports (e.g. NWA port 2 and NWA port 3) and the 1-Port calibrations for probes 1 and 2. Store the adapter S2P files under separate names.

Step 5. Start and configure LCA including specifying wafer probe adapter file

LCA measurement setup

1. Start the LCA macro by pressing the “LCA” Softkey.
2. Choose the measurement type (e.g. “OE measurement” or “EO measurement”) and configure the measurement parameters as described in the LCA user manual.
3. Enable RF Path Deembedding by clicking the Enable field (see Figure 20)
4. Select and enter the adapter file name for the wafer probe(s) corresponding to measurement type:
    a. For Single-Ended measurements,
       Src 1 corresponds to the path to Port A, and
       Rcv 1 corresponds to the path to Port B.
    b. For Differential measurements,
       Src 1 corresponds to the path to Port 2 (on the PNA), Src 2 corresponds to the path to Port 3 (on the PNA),
       Rcv 1 corresponds to the path to Port 2 (on the PNA), Rcv 2 corresponds to the path to Port 3 (on the PNA)

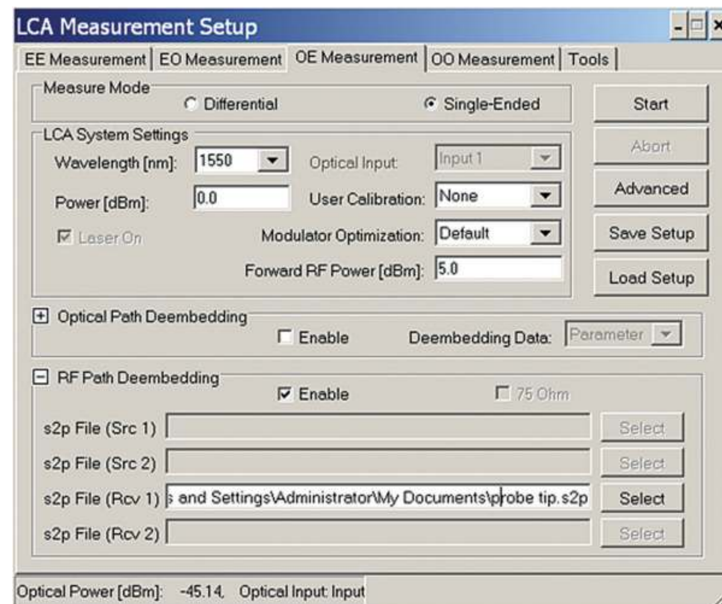


Figure 20. LCA Measurement Setup window

5. Click **Start**

Measurement Example

The following measurements performed on wafer e.g. at an early stage in the device processing, demonstrate the importance of precisely expanding the electronic and optical calibration reference planes to the DUT interfaces, and to fully reference out the device fixture and cables. By applying the steps and procedures described before using electronic calibration kits and the on-wafer calibration standards, the setup has been electronically calibrated with reference to the coaxial interfaces closest to the DUT and this calibration plane has been extend to the DUT connection plane e.g. beyond the wafer probe.

Figure 21 and Figure 22 compare the on-wafer S-Parameter and Group Delay measurements of an unmatched broadband detector with and without proper deembedding of the wafer probe. Both GD curves are offset by the delay of the probe. The “erroneous” group delay ripple, which is an important parameter impacting system performance of the DUT, is effectively removed by the proper deembedding of the ripple contributing wafer probe.

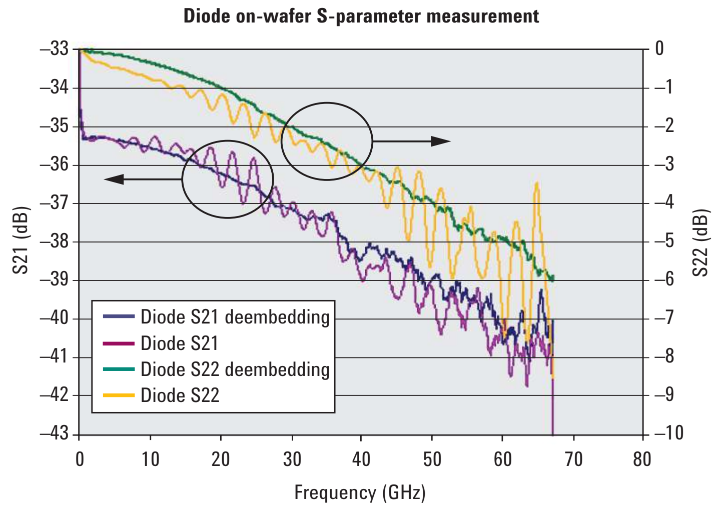


Figure 21. On-wafer OE S-Parameters of Detector

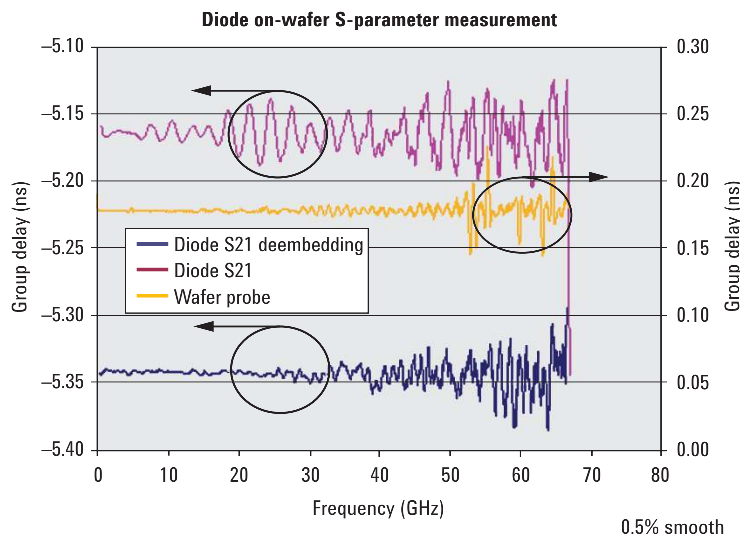


Figure 22. On-wafer Group Delay of Detector

Summary

In this application note, we discussed the calibration procedure and measurement performance of on-wafer optoelectronic component evaluation by using the N437xB Lightwave Component Analyzers based on the PNA and ENA Series Network Analyzers. Usually the Lightwave Component Analyzers used in high speed component analysis typically employ coaxial interfaces, this makes on-wafer characterizing high-frequency opto-electronic devices a challenge. The Keysight PNA and ENA network analyzers with the Cascade Microtech single and dual-tip ACP and high precision calibration standards, provides both an accurate and convenient method for characterization of on-wafer single ended and balanced OE-devices. By understanding how to set up calkits for wafer probes, characterizing the wafer probes as an adapter for use in the LCA user interface and to perform and verify the on-wafer calibration, you will be able to achieve accurate on-wafer opto-electronic device measurements and have absolute confidence in your results.

References

1 *Keysight Highspeed Lightwave Component Analysis Application Note*, Application Note, Document Number 5989- 7808EN
2 *On-Wafer SOLT Calibration Using 4-port PNA-L NWAs*, Application Note, Document Number 5989-2287EN
3 *On-wafer Balanced Component Measurement using the ENA RF Network Analyzer with the Cascade Microtech Probing System*, Application Note, Document Number 5988-5886EN
4 [VBA sample program] Adapter Characterization, see: http://www.home.keysight.com/keysight/redirector.jspx?action=ref&cname=KEYSIGHT_EDITORIAL&ckey= 85082&lc=eng&cc=US&nfr=-11143.0.00

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