Agilent
PNA-L Network Analyzers

Application Note

On-Wafer Calibration Using a 4-port, 20 GHz PNA-L Network Analyzer (N5230A Option 240/245)

Agilent Technologies

Introduction

This application note is intended for on-wafer applications using the 4-port, 20 GHz PNA-L network analyzer with two dual probes to achieve full 4-port on-wafer calibrations manually.

This documentation provides step-by-step instructions needed to set up a calibration kit in order to perform a 4-port SOLT (Short-Open-Load-Thru) calibration using only three thrus.

Equipment used (referred to throughout this document as PNA-L):

- PNA-L N5230A with Option 240 or 245
  - Option 240: 4-port, 20 GHz PNA-L with standard test set
  - Option 245: 4-port, 20 GHz PNA-L with configurable test set
- Dual probes and associated ISS (Impedance Substrate Standard)

Figure 1. N5230A with Option 240, standard test set (shown on left) and Option 245, configurable test set (shown on right).

Figure 2. Dual line Infinity probe from Cascade Microtech. Available in GSGSG and GSSG configurations with pitches 100, 125, 150, 200, 225 and 250 um. For more details, please contact Cascade Microtech: www.cmicro.com

Implementation

Three major steps are needed to complete a 4-port, on-wafer calibration manually using the PNA-L:

Step 1. Decide which three thrus to use.

Step 2. Create an on-wafer calibration kit.

Step 3. Perform the calibration.

Step 1. Decide which three thrus to use

Since the PNA-L only requires the measurement of three thru standards (and not six thru standards) to achieve a full 4-port calibration, different three-thru combinations are possible. Depending on the configuration chosen, a slightly different way of labeling each "port" will be required in order to accommodate thru standards of different lengths.

The PNA-L can perform 4-port calibrations using either SmartCal (Guided calibration) or an Electronic Calibration (ECal) module. With Guided calibration, the process chooses the standards to use from the calibration kit based on proper mating of the connectors. This was designed to provide easy "adapter removal" between different families of connectors. For on-wafer calibration, it is necessary to use different lengths of thru standards; but with a little care, the connector labeling will enable the Guided calibration to select the desired thru standard from those defined in the calibration kit. In this case, carefully setting the "gender" of the probe at each port (even though the probes are all the same and are gender-less) will allow us to uniquely define the thru combinations between ports.

Figure 3 shows two possible 3-thru configurations of a GSGSG probe. Configuration #1 shows the third thru as a "loop-back," as such, we label ports 1 and 2 as M (for male), and ports 3 and 4 as F (for female). This configuration allows us to create two thru standards: one with male-female connectors (such as paths 1-3 and 2-4) and the other with male-male connectors (such as paths 1-2 and 3-4). By having two thru standards, we can then define each one with a different length.

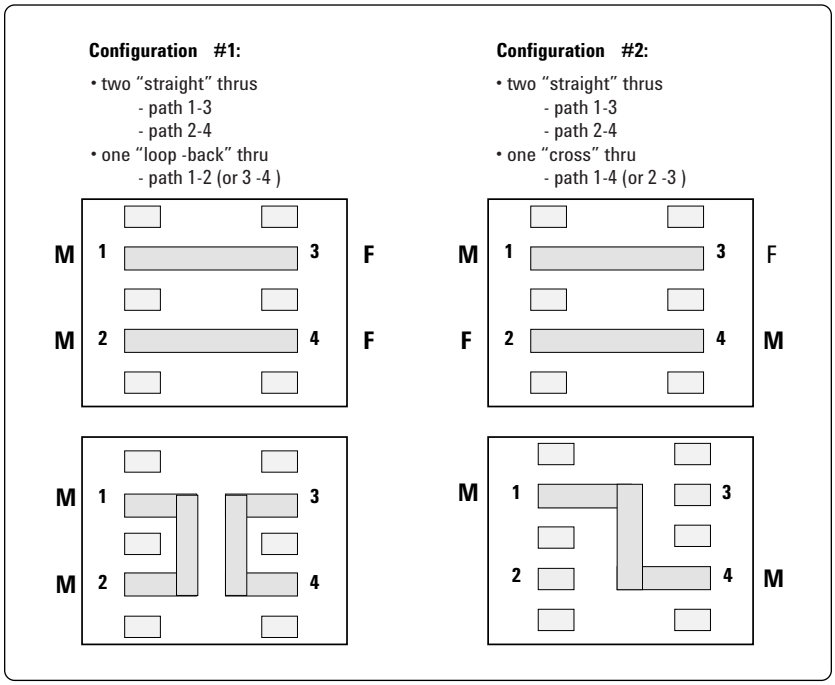

Figure 3. Two possible 3-thru configurations.

Similarly, by labeling configuration #2 with port 1 as M, port 2 as F, port 3 as F, and port 4 as M, we are also able to create two thru standards. One thru standard with male-female connectors (such as paths 1-3 and 2-4), and the other thru standard with male-male connectors (such as paths 1-4, and 2-3). Again, by having two thru standards, we are able to define each one with a different length.

Step 2. Create an on-wafer calibration kit

Note
PNA-L **[front-panel keys]** are shown in brackets, while the **softkeys** are displayed in bold; "menu item" refers to the Windows® drop down menus.

Regardless of which configuration is chosen from Figure 3, the same steps are used in creating a calibration kit. Extra attention must be paid when setting up the thru standards so that the correct value is entered for the correct path. To create a calibration kit, simply follow the numbers boxed in each of the figures shown below (Figure 4 through 10).

Figure 4:

1. Click on **Calibration**
2. Select **Advanced Modify Cal Kit...** – this brings up "Edit PNA Cal Kits"
3. Click on **Insert New...** – this brings up "Edit Kit"

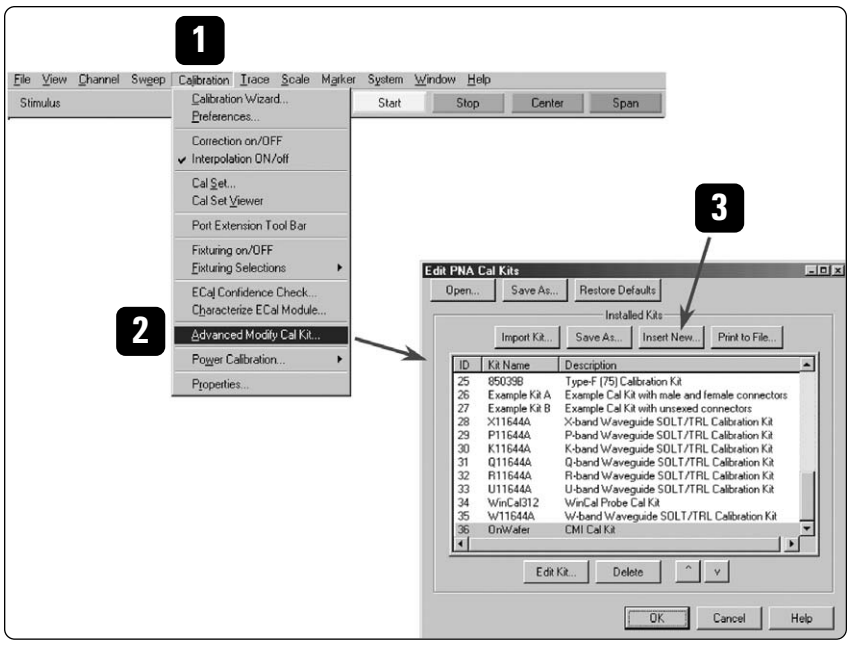

Figure 4. Creating an on-wafer calibration kit: steps 1 through 3.

Figure 5:

4. Enter *Kit Name* and *Kit Description*
5. Click on **Add** (located near the middle of the dialog box) to add connectors to this calibration kit – this brings up "Add Connector"
6. Enter *Connector Family* – "probe" was typed in here
7. Select **Male** 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**

Repeat Steps 5 through 8, but this time select **Female** for connector *Gender*.

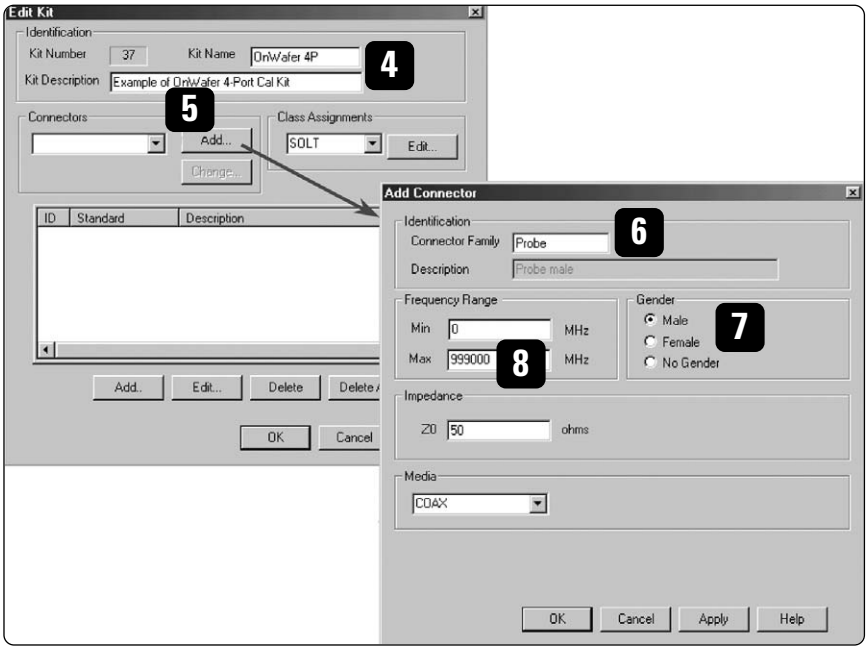

Figure 5. Creating an on-wafer calibration kit: steps 4 through 8.

Figure 6:

9. Double check to ensure you have both connector *Genders* ("Probe male" and "Probe female") by clicking on the dropdown menu. Leave the *Connectors* selection as "Probe male."
10. Click on **Add** (located near the bottom of the dialog box) – this brings up "Add Standard"
11. Select **OPEN**, then click **OK** – this brings up "Opens"
12. You may wish to modify *Open Description*, otherwise, it can be left as is
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**.

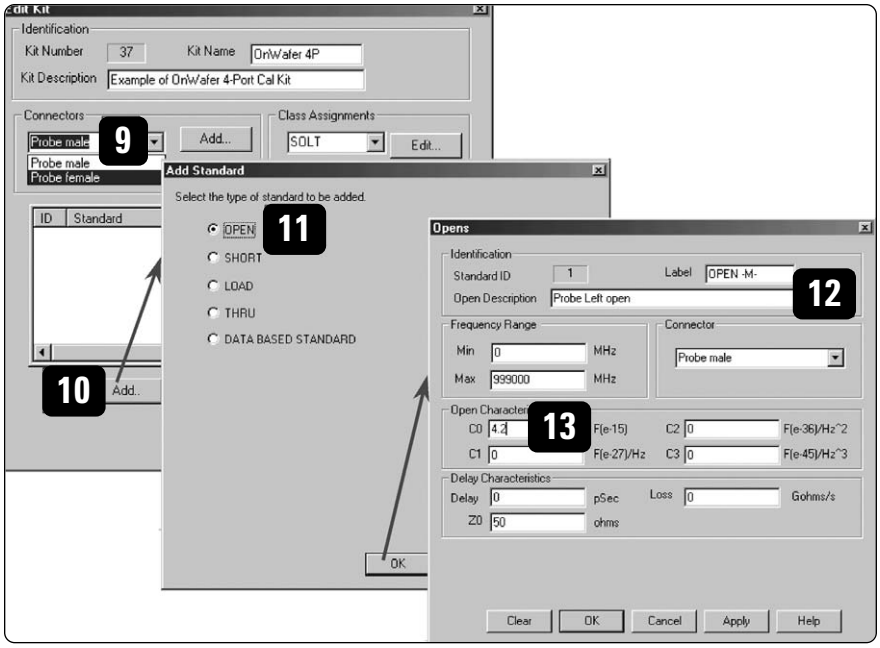

Figure 6. Creating an on-wafer calibration kit: steps 9 through 13.

Figure 7:

14. Repeat steps 9 through 13, leaving the *Connectors* at "Probe male" (step 9), select **SHORT** (step 11), and enter a value for **L0** (step 13).
15. Repeat steps 9 through 13, leaving the *Connectors* at "Probe male" (step 9), select **LOAD** (step 11), and enter a value for Lterm (step 13). Since the Loads dialog page does not have an entry for the Lterm, here is the workaround:
    - 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.

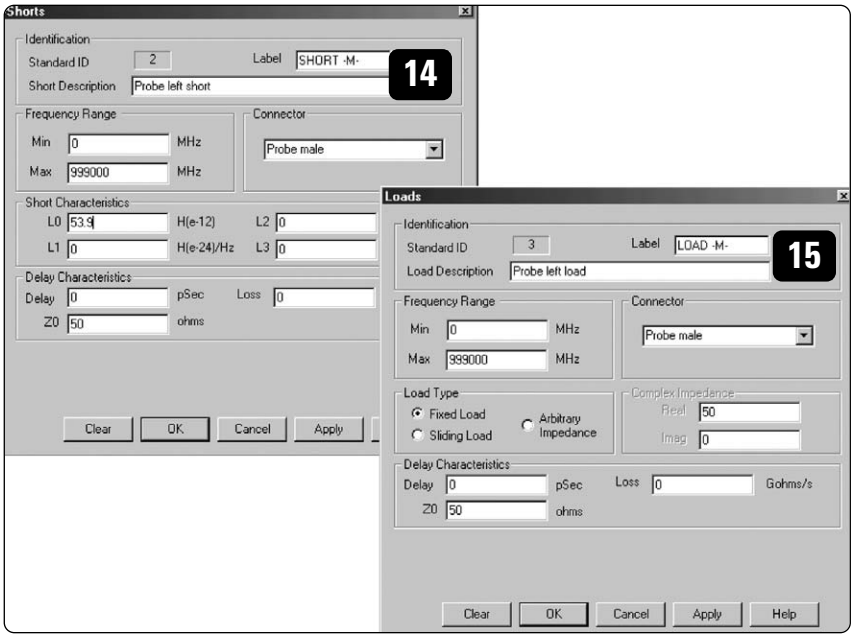

Figure 7. Creating an on-wafer calibration kit: steps 14 through 15.

Figure 8:

16. This is the result you can expect to see after following figures 6 and 7. As shown here, we have designated the probes on the left with male connectors. This is the case because we are following Configuration #1 as outlined in Figure 3. As such, we will designate the probes on the right with female connectors.
17. Repeat steps 9 through 15. This time, select *Connectors* as "Probe female" (step 9).
18. This is the result you can expect to see after following step 17. At this point, you have completed creating the standards for the left probes (male connector) and the right probes (female connector). The next step is to create two thru standards, each one can have a different length. Click on **Add** – this brings up "Add Standard"
19. Select **THRU**, then click **OK** – this brings up "Thru/Line/Adapter"

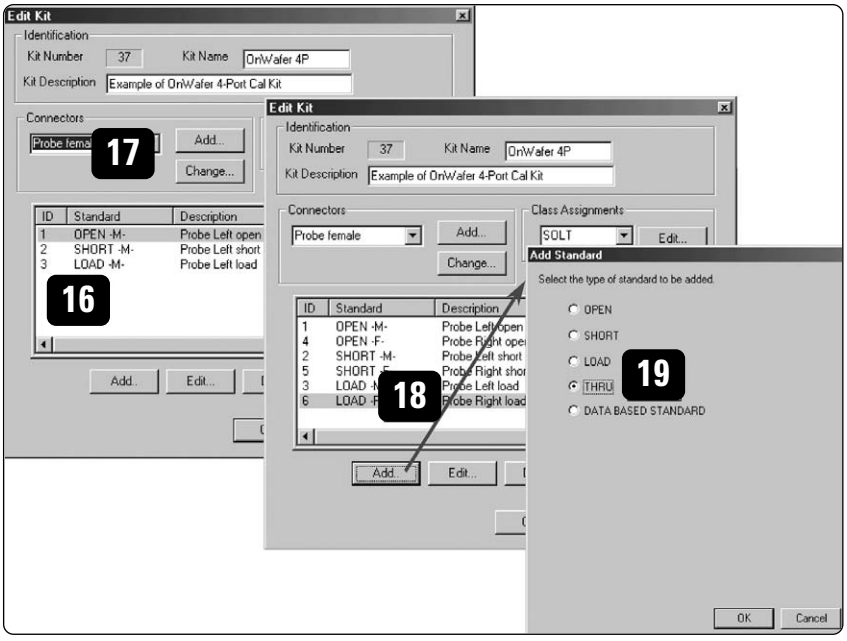

Figure 8. Creating an on-wafer calibration kit: steps 16 through 19.

Figure 9:

20. Here, you may wish to modify *Thru Description*, otherwise, leave as-is. For convenience, we are labeling this as "Thru Male Female" so that we can distinguish this from the next thru.
21. Select the *Connectors* to make sure one is "Probe male" and the other one is "Probe female," then click **OK**.
22. Click on **Add** (step 18), then **THRU** (step 19), and here, for convenience, change the *Thru Description* to "Thru Male Male."
23. Select the *Connectors* to make sure both are "Probe male," then click **OK**.

Figure 9. Creating an on-wafer calibration kit: steps 20 through 23.

Figure 10:

24. With the Thru standards added, the calibration kit is now complete.
25. The calibration kit is now ready for use, as shown here in the Cal Kit list.

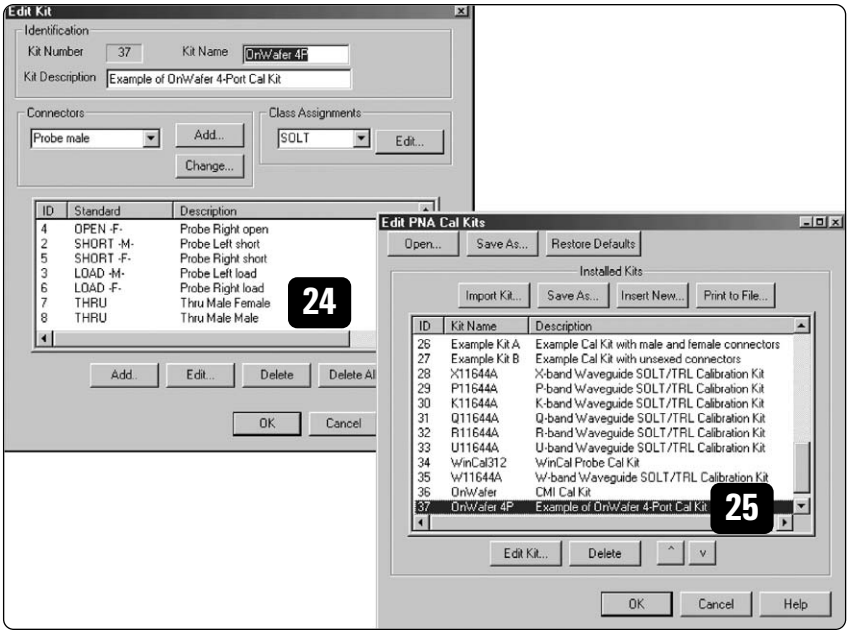

Figure 10. Creating an on-wafer calibration kit: steps 24 and 25.

Step 3. Perform the calibration

The network analyzer can perform 4-port calibration with either SmartCal (Guided calibration) or an Electronic Calibration (ECal) module; but 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.

To perform a full 4-port calibration, simply follow the numbers boxed in each of the figures shown below (Figure 11 through 15).

Figure 11:

1. Click on **Calibration**
2. Select **Calibration Wizard...** – this brings up "Calibration Wizard Begin Calibration"
3. Select "**SmartCal (GUIDED Calibration): Use Mechanical Standards**"
4. Click **Next >** – this brings up "Select Guided Calibration Type (Mechanical Standards)"
5. Under *Cal Type Selection*, make sure "**4 Port Cal**" is selected
6. Click **Next >** – this brings up "Guided Calibration: Select DUT Connectors and Cal Kits"

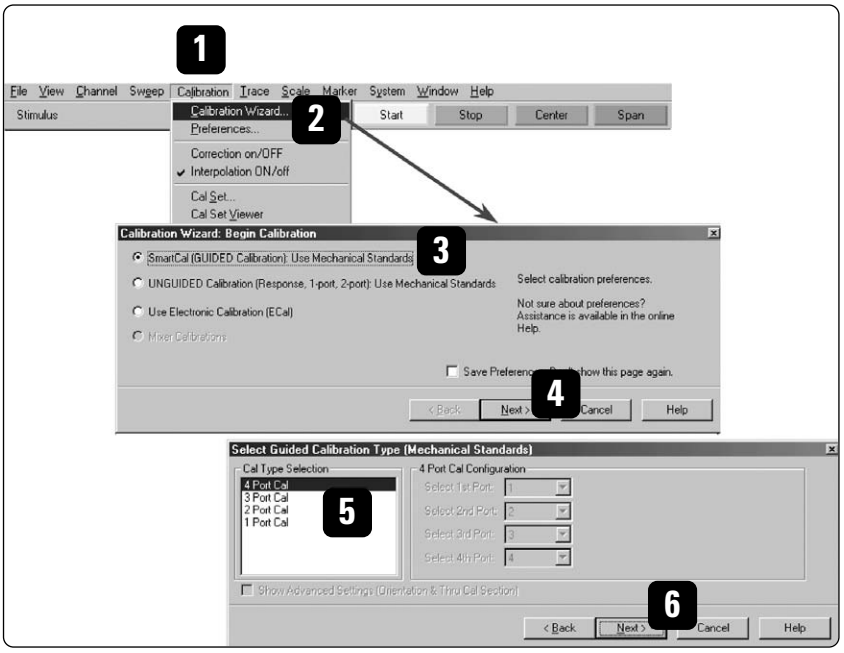

Figure 11. Begin calibration: steps 1 through 6.

Figure 12:

7. Select *Connectors* to match those as outlined in Configuration #1 of Figure 3:
8. DUT Port 1, select **Probe male**
   DUT Port 2, select **Probe male**
   DUT Port 3, select **Probe female**
   DUT Port 4, select **Probe female**
9. Since there is only one Cal Kit defined with *Connectors* of **Probe male** and **Probe female**, **OnWafer 4P** will automatically appear under *Cal Kits*. If you have more than one cal kit defined with such connectors, then you would need to select the desired cal kit for this calibration.
10. Select "**Modify Thru Method of Cal**" by clicking on the check box.
11. Click **Next >** – this brings up "Modify Thru Method of Cal"
12. Select the three thru paths for a full 4-port calibration. Using Configuration #1 of Figure 3, let's use paths **1-2**, **1-3**, and **2-4**.
13. Click on the dropdown menu for each box under *Thru Cal method*, and select **Characterized Thru**.
14. Click **Next >** – this brings up "Guided Calibration Step 1 of 15"

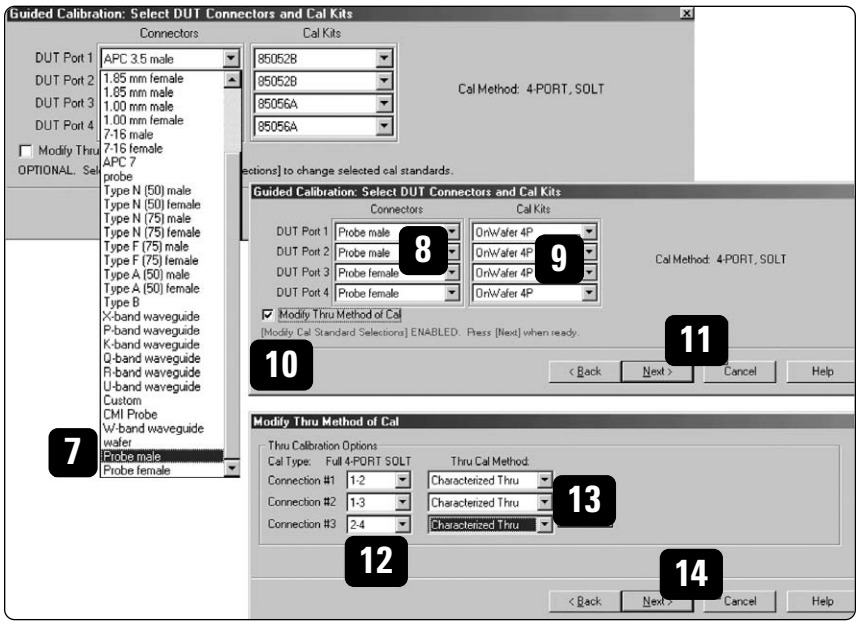

Figure 12. Begin calibration: steps 7 through 14.

Using Guided calibration, the network analyzer will step the user through 15 steps (as shown on the left column of Table 1), allowing the user to calibrate one port at a time. For each port, the instrument normally steps the user through three standards (Open, Short, and Load) before advancing to the next port. This approach was optimized for coaxial calibration, but is not optimum for on-wafer. To be efficient in performing on-wafer calibration, a better approach is to measure one standard at a time (for each touchdown, for all possible ports). This would only require seven touchdowns in order to perform a full 4-port calibration, instead of 13 touchdowns. To measure the standards in a different order than suggested by the Guided calibration process, click on the **Next >** softkeys to skip past standards (for example, to measure all the Opens at one time), and the **< Back** to get back to port 1 to measure other standards (for example, the Shorts and the Loads), until you have completed all the necessary steps for the full 4-port calibration. (These steps are indicated in Table 1 as arrows.)

Table 1. Steps as Guided by the PNA-L and sequence to be measured to minimize the number of probe touchdowns. Down arrows indicate pressing the next key (one time for each skipped standard)and the up arrow indicates pressing the back key.

		Opens	**Shorts**	**Loads**	**Thrus**	**Thru**
Steps as Guided		Probes in air	Probes on Shorts	Probes on Loads	Path 1-3, Path 2-4	Path 1-2
			Touchdown on left and on right	Touchdown on left and on right	Touchdown on left and on right	Touchdown on left
Step 1 of 15	Port 1, Open	Measure 1				
Step 2 of 15	Port 1, Short	↓	Measure 8			
Step 3 of 15	Port 1, Load	↓	↑	Measure 9		
Step 4 of 15	Port 2, Open	Measure 2	↑	↓		
Step 5 of 15	Port 2, Short	↓	Measure 7	↓		
Step 6 of 15	Port 2, Load	↓	↑	Measure 10		
Step 7 of 15	Port 1 thru Port 2	↓	↑	↓		Measure 15
Step 8 of 15	Port 3, Open	Measure 3	↑	↓		
Step 9 of 15	Port 3, Short	↓	Measure 6	↓		
Step 10 of 15	Port 3, Load	↓	↑	Measure 11		
Step 11 of 15	Port 1 thru Port 3	↓	↑	↓	Measure 14	
Step 12 of 15	Port 4, Open	Measure 4	↑	↓	↑	
Step 13 of 15	Port 4, Short		Measure 5	↓	↑	
Step 14 of 15	Port 4, Load			Measure 12	↑	
Step 15 of 15	Port 2 thru Port 4				Measure 13	

As shown on the top screen of Figure 13, throughout the calibration process, one sees the "**Guided Calibration Step**" shown on the upper left corner, 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 (as shown on the bottom screen of Figure 13). Once 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 on **Done**, or choose to remeasure another standard as needed.

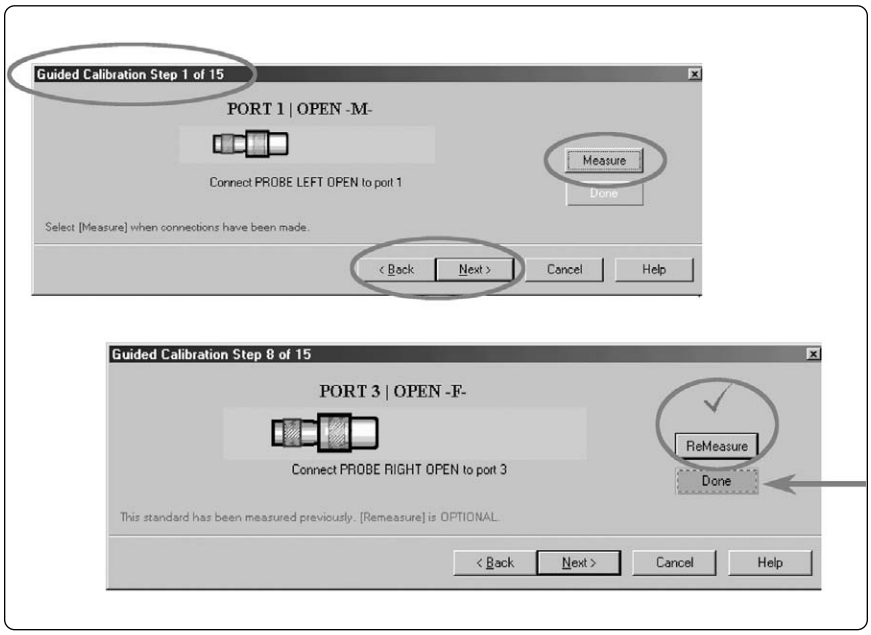

Figure 13. Samples of screens throughout the calibration process.

Once **Done** has been selected, the calibration is finished and it is then turned on with **C 4-P** appear on the status bar (located at the bottom of the display) to indicate that the 4-port correction is now active.

Conclusion

The 4-port, 20 GHz PNA-L (N5230A Opt.240/245) network analyzer can be used for manual calibration of on-wafer applications. In fact, the steps outlined here can be used for any calibration process where the user needs to create their own calibration kit and follow their own sequence in order to minimize the number of connections or touchdowns (in the case of wafer probing).

Web Resources

For additional product information and application literature, visit our Web sites:

PNA Network Analyzers:
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