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. PNA-L firmware revision must be 5.22 or higher.

This documentation provides step-by-step instructions needed to set up a calibration kit before a 4-port SOLT (Short-Open-Load-Thru) calibration can be performed. The steps outlined here can be applied toward nearly any kind of non-coaxial applications, of which on-wafer is one of them.

Equipment used:

- PNA-L N5230A with Option 240 or 245 (referred to throughout this document as PNA-L)
  - 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 Standard Substrate)

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

Although a total of six thru paths are present for any 4-port measurement setup, only three thru paths (not six) are required with the PNA-L to yield a full 4-port SOLT calibration. Any three-thru combinations can be chosen for the calibration. (If desired, the user can also choose to apply all six thru paths; but measuring more paths will take more time and will cause more wear-and-tear of the calibration standards.)

The PNA-L performs 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 4-port calibration, only SmartCal is applicable, plus, it is necessary to accommodate thru standards of different lengths because different thru configurations are used during the calibration. Three of the most common configurations are “straight thru,” “loop-back thru,” and “cross thru.”

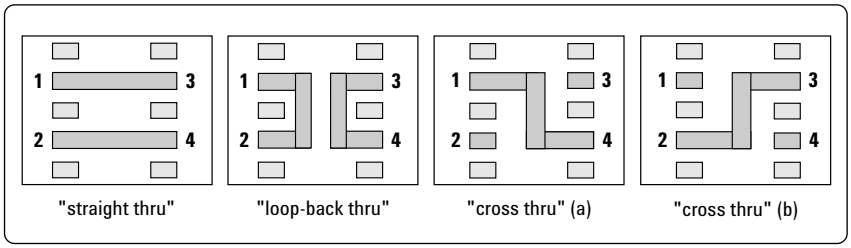

Figure 3. Examples of common thru configurations of a GSGSG probe.

Two major steps are needed to complete a 4-port, on-wafer calibration manually using the PNA-L. The details in these steps describe how to properly define a calibration kit to handle multiple thru lines, and then how to select the correct lines to be applied during the actual calibration.

Step 1. Create an on-wafer calibration kit.

Step 2. Perform the calibration.

Step 1. 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.

To create a calibration kit, simply follow the numbers boxed in each of the figures shown below (Figures 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"

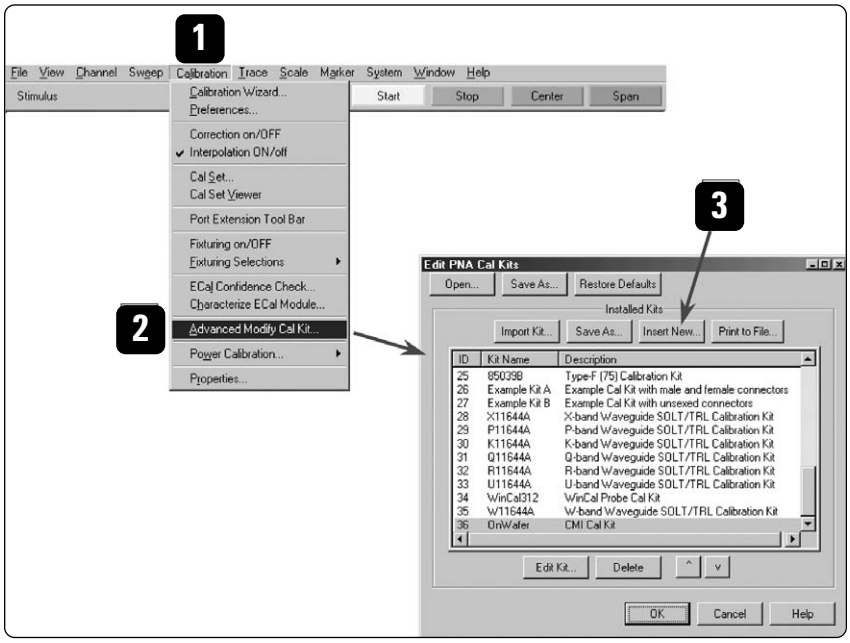

Figure 4. Creating an on-wafer calibration kit.

Figure 5: Connector definition

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 **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**

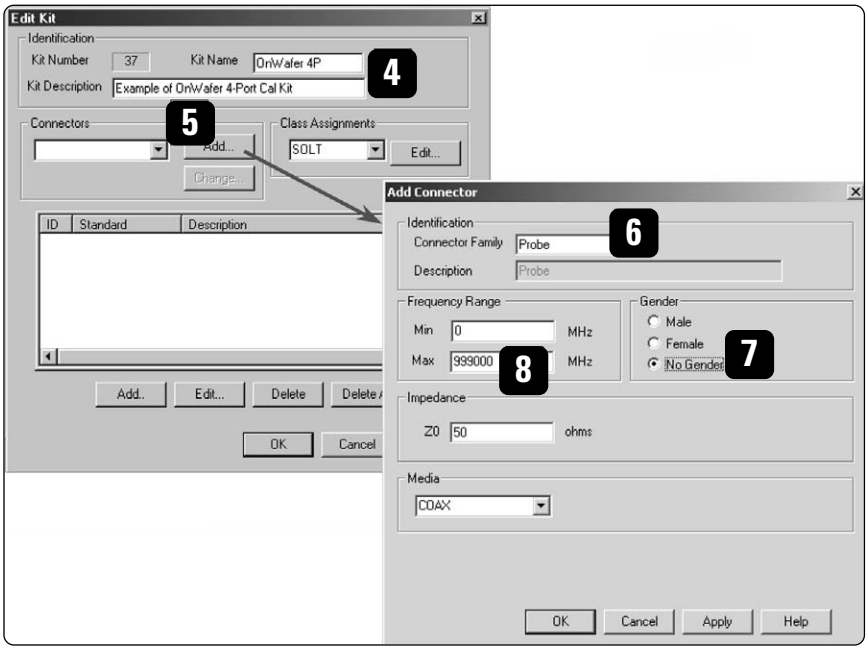

Figure 5. Creating an on-wafer calibration kit: Connector definition.

Figure 6: Defining OPEN

9. Click on **Add** (located near the bottom of the dialog box) – this brings up "Add Standard"
10. Select **OPEN**, then click **OK** – this brings up "Opens"
11. You may wish to modify *Open Description*, otherwise, it can be left as-is
12. 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**.

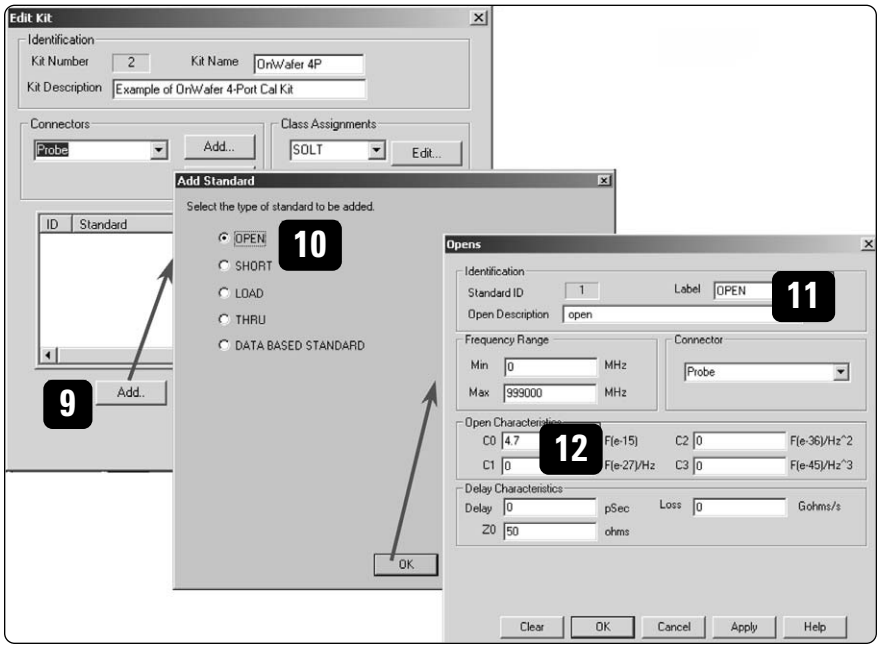

Figure 6. Creating an on-wafer calibration kit: Defining OPEN.

Figure 7: Defining SHORT

13. Click on **Add** (located near the bottom of the "Edit Kit" dialog page) - this brings up "Add Standard"
14. Select **SHORT**, then click **OK** - this brings up "Shorts"
15. Enter the **L0** (Lshort) value, then click **OK**.

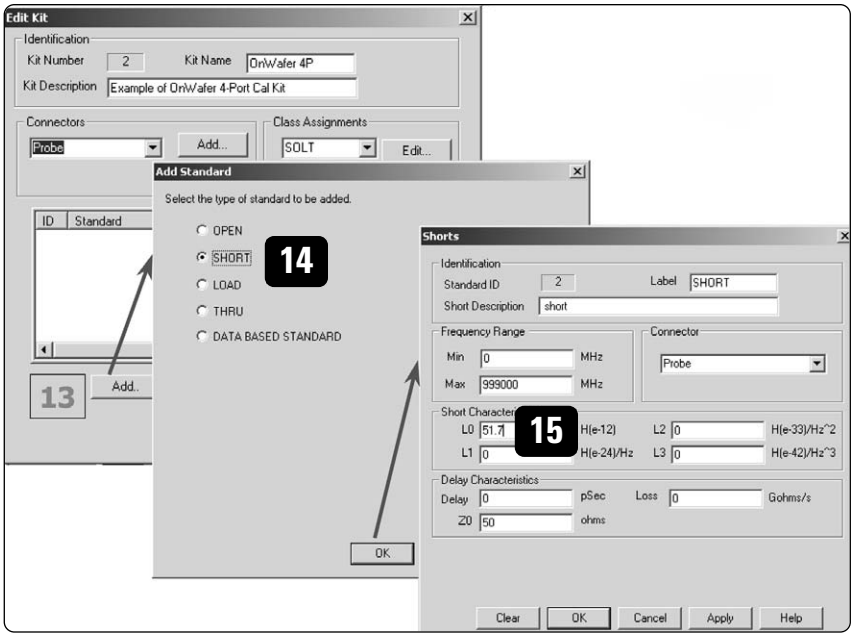

Figure 7. Creating an on-wafer calibration kit: Defining SHORT.

Figure 8: Defining LOAD

16. Click on **Add** (located near the bottom of the "Edit Kit" dialog page) – this brings up "Add Standard"
17. Select **LOAD**, then click **OK** – this brings up "Loads"
18. 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**.

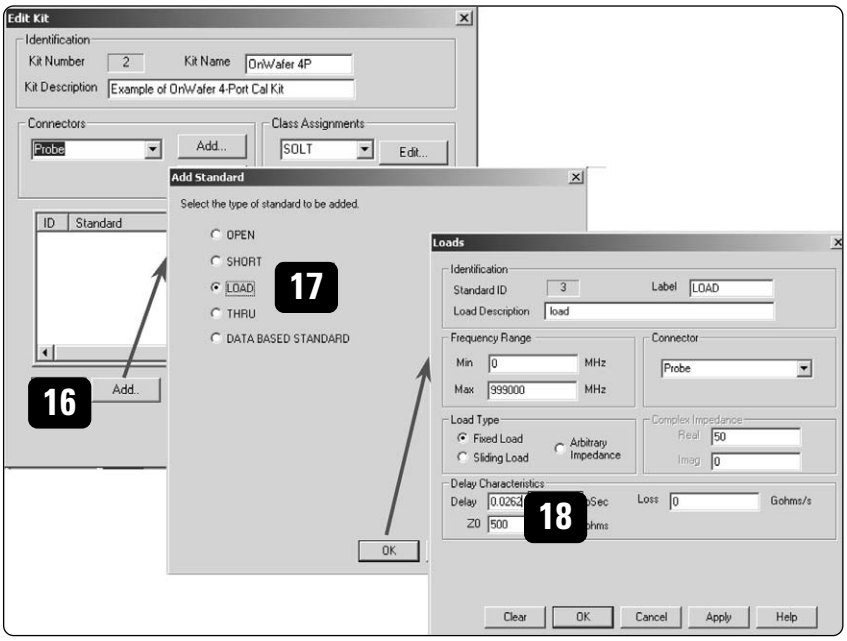

Figure 8. Creating an on-wafer calibration kit: Defining LOAD.

Figure 9: Defining THRU

19. Click on **Add** (located near the bottom of the "Edit Kit" dialog page) – this brings up "Add Standard"
20. Select **THRU**, then click **OK** – this brings up "Thru/Line/Adapter"
21. In order to define several thrus each with a different length, it is best to modify the "Thru Description" field to reflect the standard you are adding. The following examples are shown:
    (a) "straight thru"
    (b) "loop-back thru"
    (c) "cross thru"

In each case, enter the value for **Delay** as provided with the ISS, then click **OK**. The delay value is different depending on the thru configuration. Repeat steps 19 through 21 for each thru length/definition.

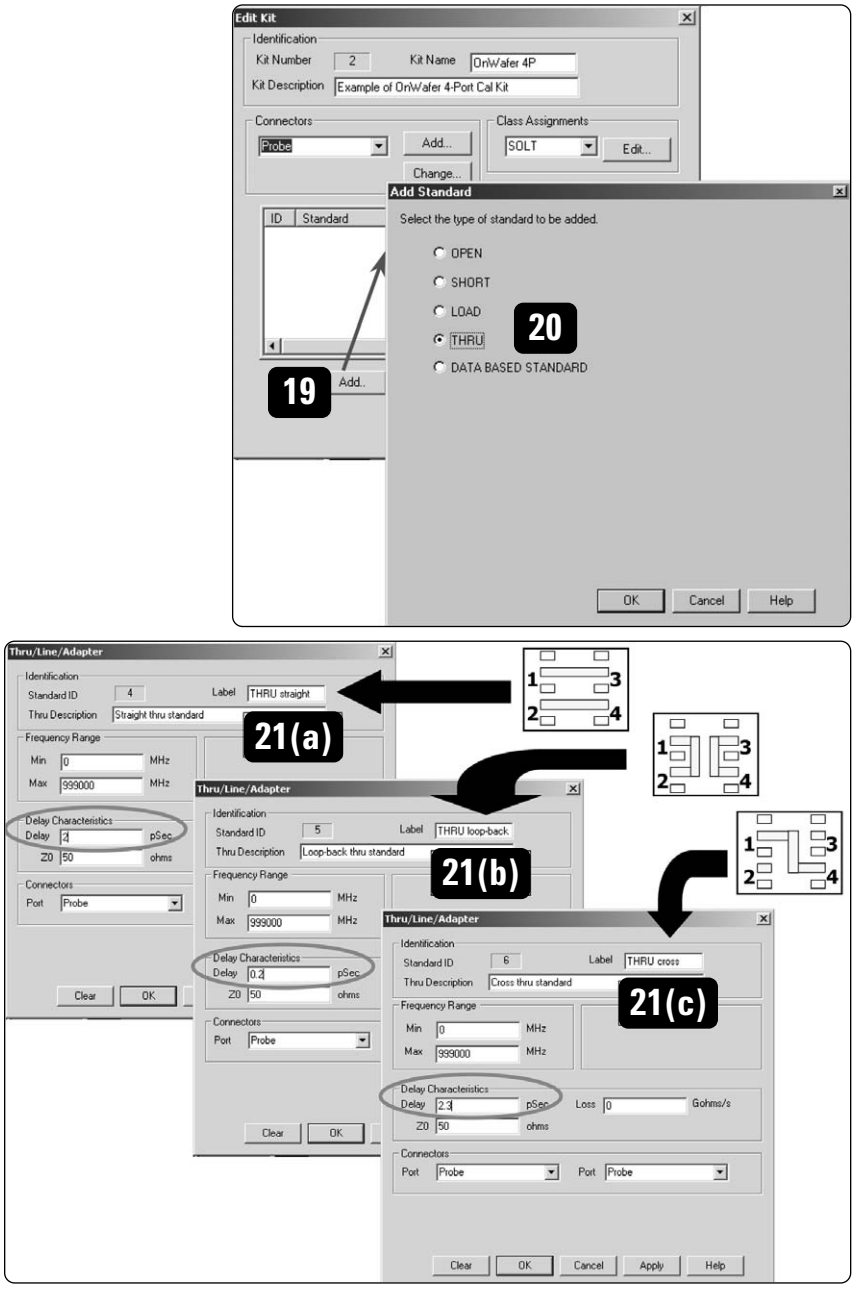

Figure 9. Creating an on-wafer calibration kit: Defining THRU standards.

Figure 10:

22. With the Thru standards added, the calibration kit is now complete. Click **OK**.
23. The calibration kit is now ready for use, as shown here in the Cal Kit list.

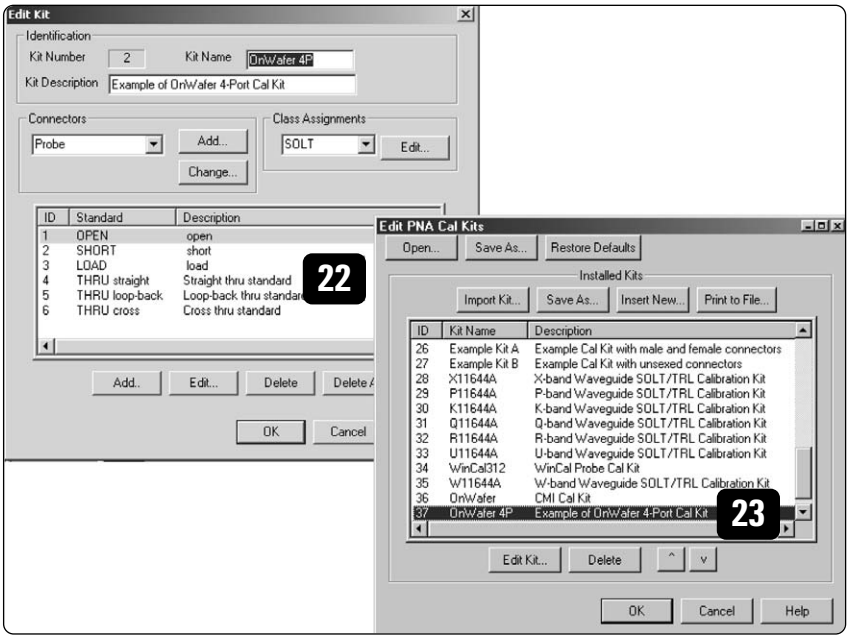

Figure 10. Creating an on-wafer calibration kit: Complete.

Step 2. Perform the calibration

The PNA-L can perform 4-port calibrations 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 (Figures 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"

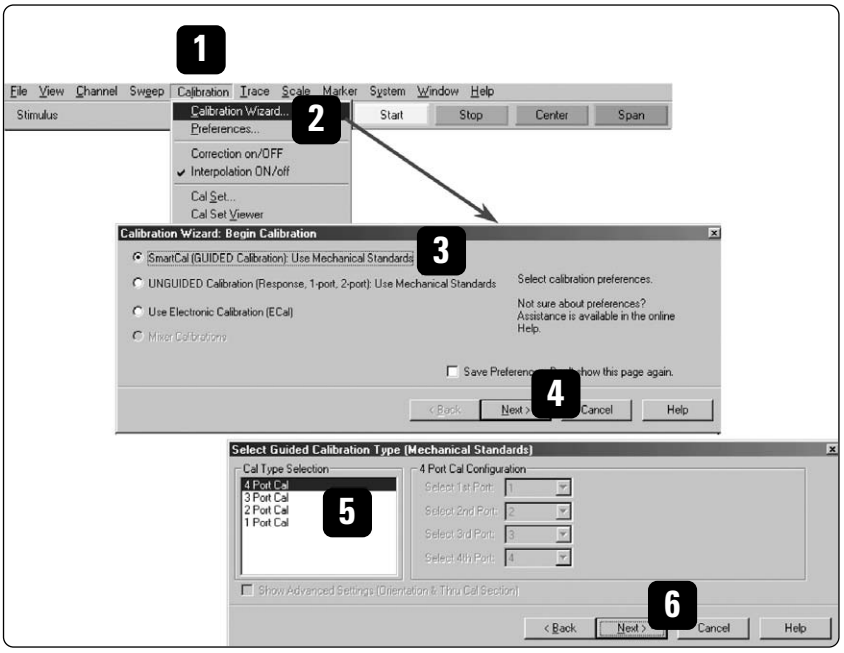

Figure 11. Begin calibration.

Figure 12:

7. Under *Connectors*, using the dropdown menu, select **Probe** (as defined in the previous section)
8. This is the view one can expect after repeating step 7 for all four DUT Ports.
9. Once the connector has been chosen (steps 7 & 8), the associated *Cal Kits* will appear. Since there is only one calibration kit defined with *Connectors* of **Probe**, **OnWafer 4P** will automatically appear under *Cal Kits*. If you have more than one calibration kit defined with the same connector, then you would need to select the desired cal kit for this calibration via the dropdown menu.
10. Select **"Modify Thru Method of Cal"** by clicking on the box. You must select this in order to be able to choose the Thru standard of your choice for each path.
11. Click Next > – this brings up "Modify Thru Method of Cal"
12. A minimum of three Thru paths are needed to achieve a full 4-port SOLT calibration. This example shows the Thru paths of **1-2**, **1-3**, and **2-4** (column on the left). (A total of all six Thru paths can also be selected, but it is not necessary for the full 4-port SOLT calibration. Additional Thru paths can be enabled on the right side.)
13. Under *Thru Cal Method*, one must use the dropdown menu to select the method of choice. Available choices include "Flush Thru," "Defined Thru," and "Adapter Removal." Default shows Flush Thru. Please choose **Defined Thru** (because we have defined Thru standards with different delay values).
    - "Flush Thru" – applicable with insertable calibration of ECal. This selection will require the user to disconnect the ECal module and connect the test port cables together for the thru measurement. The default thru measurement of ECal is to use the thru inside the module.
    - "Defined Thru" – applicable when used with a pre-defined adapter because the calibration process will apply the adapter information supplied in the definition. Delay value of the adapter must be reasonably close to the actual value (±90 degrees, ±_ λ); otherwise, phase could be 180 degrees out.
    - "Adapter Removal" – applicable when used with an unknown adapter because the calibration process will attempt to characterize the adapter before its effects are removed.
14. Because we have defined several Thru standards in the calibration kit, click on the **Mod Stds** button of each Thru path to start selecting the correct standard for that particular Thru path – this brings up "Modify Cal"

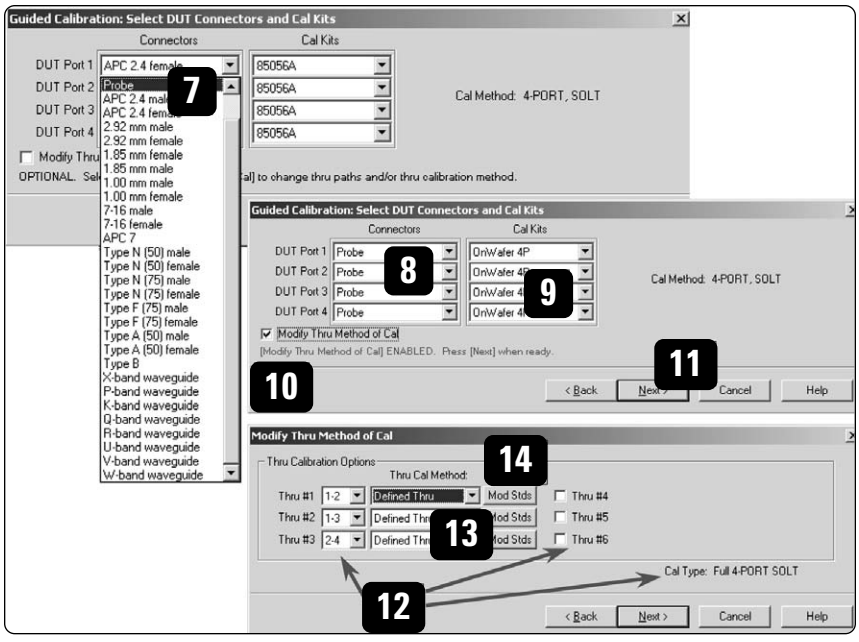

Figure 12. Select Connectors, Cal Kits, and Thru paths.

Figure 13:

15. This is to confirm on the chosen *Thru Cal Method*. Otherwise, use the dropdown menu to make another selection.
16. Click on **View/Modify** – this brings up "Preview and Modify Calibration Selections"
17. Under *Calibration Kit Class*, click on **FWD TRANS**. This brings forth the available Thru standards in the calibration kit. The first defined Thru standard will appear under *Selected Standards* (right bottom half); while all other defined Thru standards will appear under *Unselected Standards* (left bottom half).
18. If the desired Thru standard for the particular path does not appear under *Selected Standards*, then simply highlight the standard of choice on the left (under *Unselected Standards*), and then click on the ">>" arrow to move the highlighted item to the right. Similarly, highlight the unwanted item on the right, and then click on the "<<" arrow to move it to the left.
19. After the standards have been placed in their proper locations, then click on **Link FWD TRANS, FWD MATCH, REV TRANS, and REV_MATCH** (located toward middle-left of dialog box).
20. Click **OK**.
21. Click **Done**.
22. Repeat steps 14 through 21 to select the correct Thru standard for each path. Then, click **Next** > to start calibration.

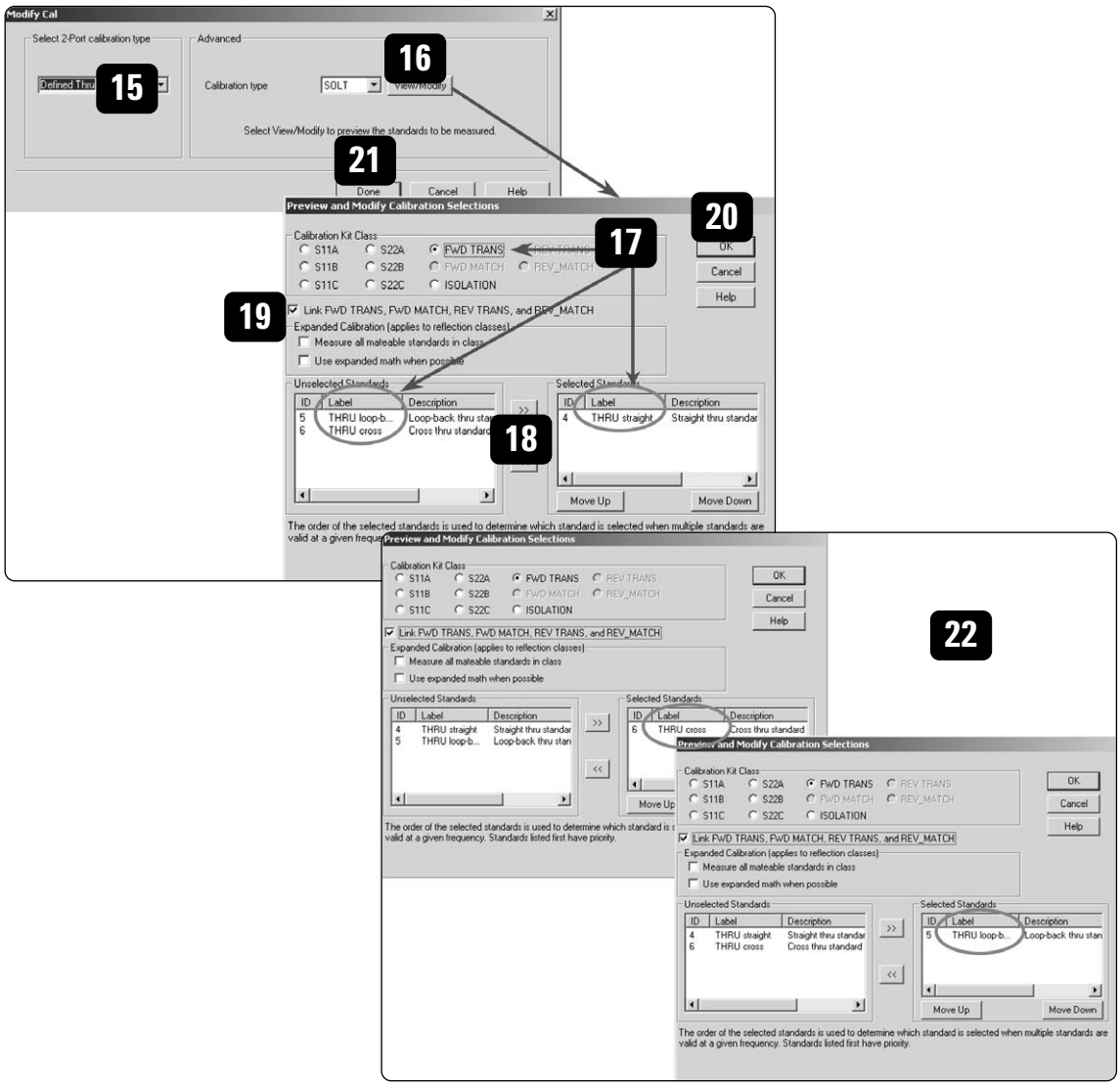

Figure 13. Select the correct Thru standard for each Thru path.

At this point, you should see the dialog box showing "Guided Calibration: step 1 of 15," similar to the three steps shown in Figure 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 14, 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. 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.

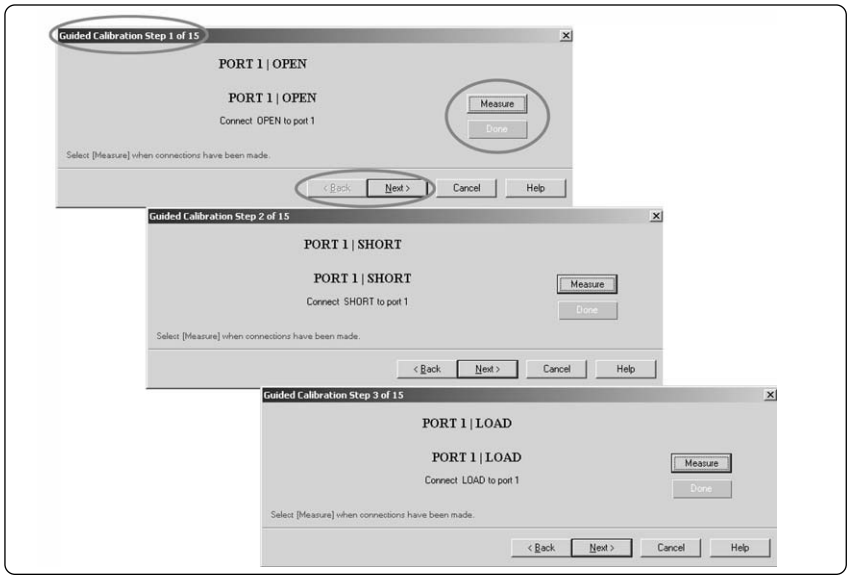

Figure 14. Samples of screens throughout the calibration process. Examples show steps 1 through 3, with descriptions identical to those shown on the first three lines of Table 1

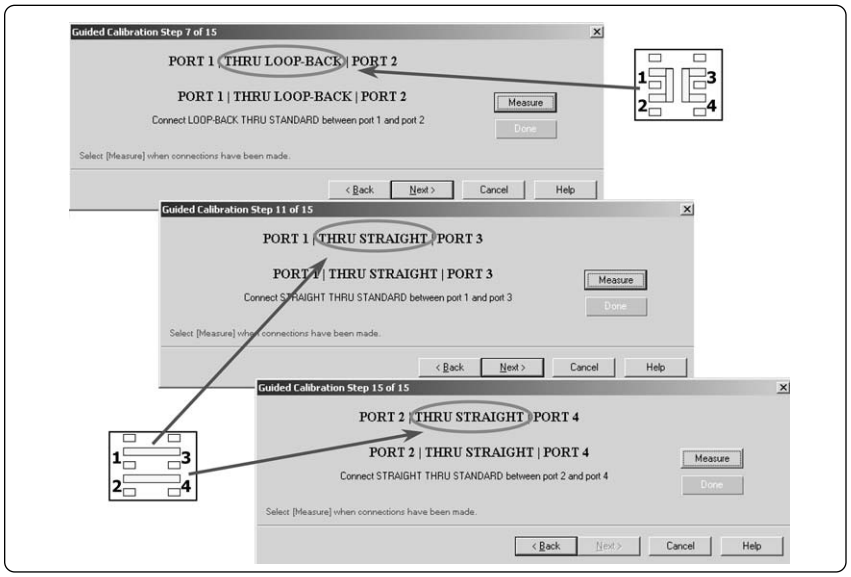

Figure 15. Examples here show the importance of having descriptive labels for different thru standards. Plus, the steps outlined in Figure 13 make sure the user has selected the correct thru standard for the correct path. Otherwise, only the thru standard that appears first on the list will be used, others will be ignored.

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, or any non-coaxial 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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Printed in USA, May 19, 2005
5989-2287EN

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