On-Wafer SOLT Calibration Using 4-port PNA-L Network Analyzers (N5230A Options x4x)



Introduction

This application note is intended for on-wafer applications using the 4-port, PNA-L network analyzers with two dual probes to achieve full 4-port on-wafer calibrations manually. 4-port PNA-L network analyzers are available in 13.5 or 20 GHz models. PNA-L firmware revision must be 6.03 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 application, of which on-wafer is one.

Equipment used:

- 4-port PNA-L, N5230A with Option x4x (referred throughout this document as PNA-L)
 - Option 140, 300 kHz to 13.5 GHz, 4-port with standard test set
 - Option 145, 300 kHz to 13.5 GHz, 4-port with configurable test set
 - Option 146, 300 kHz to 13.5 GHz, 4-port with configurable test set and internal second source
 - o Option 240, 300 kHz to 20 GHz, 4-port with standard test set
 - Option 245, 300 kHz to 20 GHz, 4-port with configurable test set
 - o Option 246, 300 kHz to 20 GHz, 4-port with configurable test set and internal second source
- Dual probes and associated ISS (Impedance Standard Substrate)



Figure 1. 4-port PNA-L, 13.5 or 20 GHz. Unit on the left shows a standard test set (Option x40), unit on the right shows a configurable test set (Option x45) or a configurable test set with internal second source (Option x46).



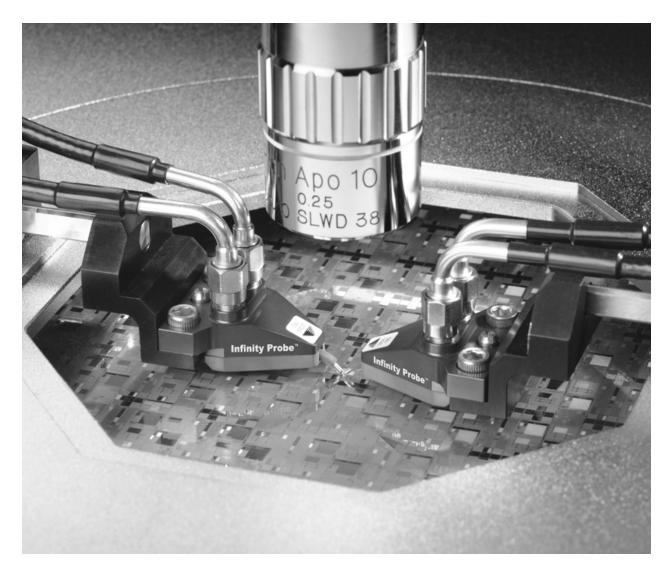


Figure 2. Dual line Infinity probe from Cascade Microtech. Available in GSGSG and GSSG configurations with pitches 100, 125, 150, 200, 225, and 250 um. For more details, please contact Cascade Microtech at www.cmicro.com

Implementation

Although a total of six thru paths are present for any 4-port measurement setup, a minimum of only three thru paths are required with the PNA-L to yield a full 4-port SOLT calibration. (If desired, the user can 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.



Given that most 4-port on-wafer setups tend to have one dual probe on the left and one on the right, we can assume the ports on the left are 1 and 2, and the ones on the right are 3 and 4, see Figure 3. As can be seen from this illustration, performing on-wafer 4-port calibration using dual probes would require the need to measure thru standards of different lengths because more than one thru configuration must be used during the calibration. Three of the most common configurations are "straight thru," "loop-back thru," and "cross thru," as shown in Figure 4.

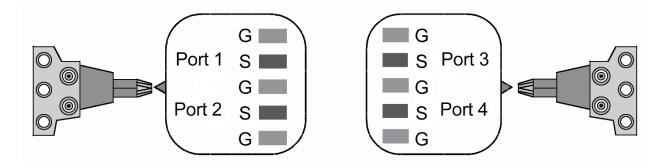


Figure 3. Port assignment used in this application note: ports 1 and 2 on the left, ports 3 and 4 on the right.

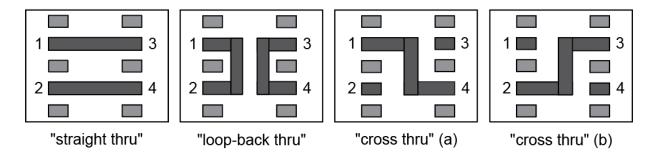


Figure 4. Examples of common thru configurations of a GSGSG probe.

With the PNA-L, the unknown thru calibration method is available and can be applied whenever through standards are not perfect. Since loop-back and cross throughs are in general not perfect, as compared to straight throughs, the unknown thru calibration method provides a much more accurate calibration. This approach is preferred because with the unknown thru method, the through standard does not need to be perfect.

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 and then how to perform the actual calibration.

Step 1. Create a new calibration kit for probing.

Step 2. Perform the SOLT (Short-Open-Load-Thru) calibration.

Step 1. Create a new calibration kit for probing

To create a calibration kit, simply follow the boxed numbers in each of the figures shown below (Figures 5 through 11).

Figure 5:

- 1. Click Calibration
- 2. Select Advanced Modify Cal Kit ... this brings up the Edit PNA Cal Kits dialog box
- 3. Click Insert New... this brings up the Edit Kit dialog box

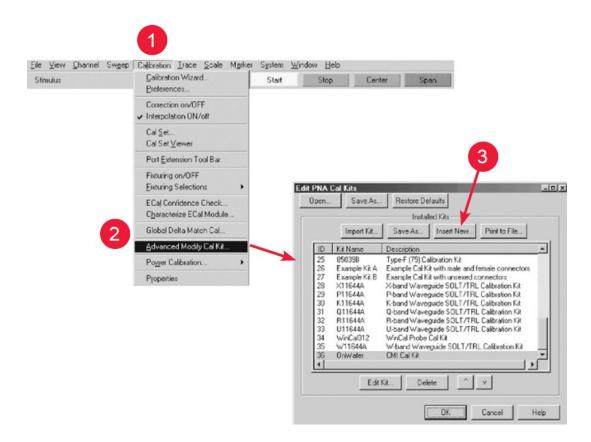


Figure 5. Creating a new calibration kit for probing.

Note:

PNA-L **[front-panel keys]** are shown in brackets, while the **menu items/buttons** are displayed in bold; "page titles" refer to the Windows dialog page names.



Figure 6: Connector definition

- 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

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 such that it offers the PNA-L the easiest way to execute minimum thru. See Figure 6a for test port assignment. The actual calibration sequence will then be determined by the instrument, via the Calibration Wizard.

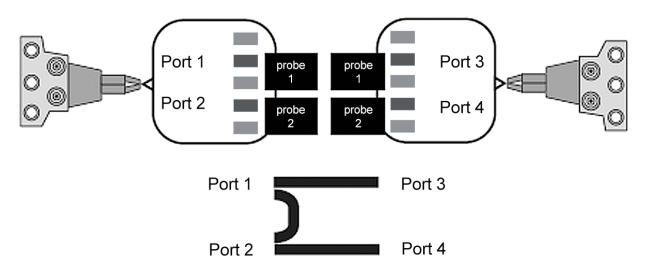


Figure 6a. Assigning test ports as either probe 1 or probe 2 offers the PNA-L the most efficient way of executing minimum thru. This example allows the PNA-L to maximize the number of straight thrus and minimize the number of non-straight ones.

- 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**



LORINA	
Identification	
Kit Number 37 Kit Name OnWafer 4P	
Kit Description Example of On/Wafer 4-Port Cal Kit	4
Connectors Class Assig	
	Friends
Add or Ed.	
Family:	Edt
Family Charge remity	Add or Edit Connector
	(Identification
ID Standard Description	Connector Family
	6
	Description probe
	Frequency Range Gender
	Min 0 MHz C Male
	C Famila
	Мак 399007 8 MHz © No Gender 7
	Impedance
	Z0 50 ohms
Add Edit Delete Delete All	
Add Edit Delete Delete All	Media
OK Canc	COAX
	OK Cancel Apply Help
	OK Cancel Apply Help

Figure 6b. Creating a new calibration kit for probing: Connector definition.

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 6c, left).

At this point, you should have two probes defined under Connectors, and they are "probe 1" and "probe 2" (Figure 6c, right).

Add or Edit Connector	Edit Kit 2 Identification Kit Number 36 Kit Name OnWater 4P Kit Description Example of OnWater 4-port Cal Kit
Frequency Range Gender Min 0 MHz C Male Max 399000 8 MHz C Remale Max 599000 8 MHz C No Gender	Connectors Description: probe 2 Add or Edk probe 2 Change Family Class Assignments Edk Frobe 2 Change Family
Impedance 20 [50 ohms Media [COAX Y	ID Standard Description
OK Cancel Apply Help	Add Edit Delete Delete All OK Cancel Help

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



Figure 7: 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.

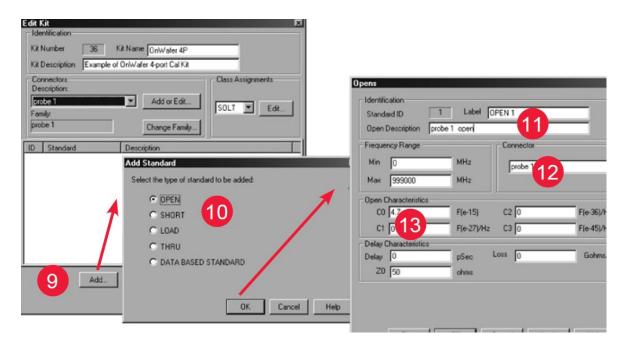


Figure 7a. Creating a new calibration kit for probing: Defining OPEN.



Repeat steps 9 through 13. This time,

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

Freque	ncy Range		Connector	
Min	0	MHz	probe 2	12 🗉
Max	999000	MHz		U -
Open C	Characteristics			
CO	4.7 13	F(e-15)	C2 0	F(e-36)/Hz^2
C1	p V	F(e-27)/Hz	C3 0	F(e-45)/Hz^3
Delay (Characteristics			
Delay	0	pSec	Loss 0	Gohms/s
Z0	50	ohms		

Figure 7b. Changing to "OPEN 2" and "probe 2".



Figure 8: 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

Edit Kit 🔀	
Kit Number 36 Kit Name Onlw/afer 4P	
Kit Description Example of On/Wafer 4-port Cal Kit	
Connectors Class Assignments	Shorts F
Family: Add or Edk SOLT Y Edk	Identification Standard ID 3 Label SHORT 1 16
probe 1 Change Family	Short Description probe 1 short
ID Standard Description	Frequency Range Connector
Add Standard	Min 0 MHz probe 1 17
Select the type of standard to be added:	Max 999000 MHz
	Short Characteristics L0 [51.7] H[e-12] L2 0 H[e-33]/Hz ⁻²
	L1 0 18 H(e-24)/Hz L3 0 H(e-42)/Hz^3
C THRU	Delay Characteristics
C DATA BASED STANDARD	Delay 0 pSec Loss 0 Gohms/s
14 Add.	20 50 ohms
OK Cancel Help	
	Clear OK Cancel Apply Help

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



Repeat steps 14 through 18. This time,

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

Freque	ncy Range		Connector	
Min	0	MHz	probe 2	17 🗉
Max	999000	MHz	I	
	haracteristics		L	
LO	51.7 18	H(e-12)	L2 0	H(e-33)/Hz
L1	0	H(e-24)/Hz	L3 0	H(e-42)/Hz
Delay (Characteristics -			
Delay	0	pSec I	Loss 0	Gohms/s
Z0	50	ohms		

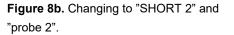


Figure 9: Defining LOAD

- 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.



Identification	
Kit Number 2 Kit Nome Tretutater did	Loads
Kit Description Example of Onwales 4-port Cal kit	
Connectors Class Assignments Description	Identification Standard ID 2 Label LOAD 1
Probe 1 Add or Edk SOLT T Edk	
rang,	Load Description Probe 1 load
Probe 1 Change Family	Frequency Range Connector
ID Standard Description	Min 0 MHz
1 LOAD 2 Add Standard	Max 999000 MHz Probe 1 22
Select the type of standard to be added:	Complex Impedance
C OPEN	Fixed Load Impedance Real S0
C SHORT 20	C Siding Load C Offset Load Imag 0
C SHORT	- Delay Characteristics
(LOAD	Delay 0.0262 23 Sec Loss 0 Gohms/s
	20 500 ohms
C DATA BASED STANDARD	Offset Load Definition First Offset Standard
	Second Offset Standard
	Load Standard LDAD 2
OK Cancel	Help
	Clear OK Cancel Apply Help

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

Repeat steps 19 through 23. This time,

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

		Label De 2 load	Connector
Min	0	MHz	
Мак	9999000	MHz	Probe 2 22 •
C SI	iding Load	Offset Load	0 geml
	Dharacteristics	pSec	Loss 0 Gohms/s
Delay Delay Z0	Characteristics 0.0262 500 23	pSec	
Delay Delay Z0	Dharacteristics	pSec ohms	
Delay I Delay 20 Difset I	Characteristics 0.0262 500 23 Load Definition	pSec ohms	

Figure 9b. Changing to "LOAD 2" and "Probe 2".



Figure 10: Defining THRU

- 24. Click **Add** (located near the bottom of the *Edit Kit* dialog page) this brings up the *Add Standard* dialog box
- 25. Select THRU, then click OK this brings up the Thru/Line/Adapter dialog box

The kit, as defined, allows one of the simplest 4-port on-wafer calibrations possible. Although the ISS has several thru lines ("straight thru", "loop-back thru", and "cross thru"), only two thru standards need to be defined. Using the configuration shown in Figure 6a, the two thru standards are best "straight thrus". For this document, one thru will have two "probe 1" as *Connectors* and the other will have two "probe 2" as *Connectors*.

- 26. Modify Label to read "THRU 1"
- 27. Under Connectors, select "probe 1" for both ports
- 28. Enter the value for Delay as provided with the ISS, then click OK.

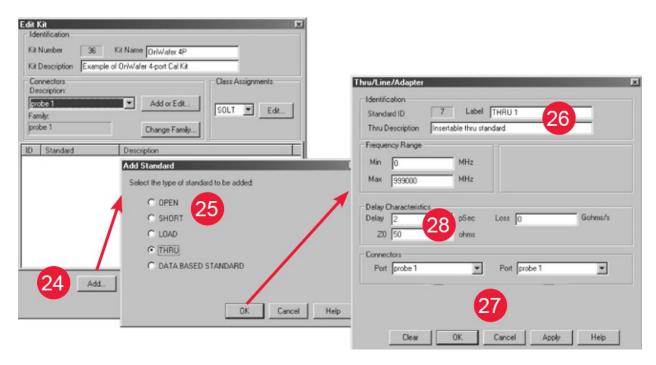


Figure 10a. Creating a new calibration kit for probing: Defining THRU standards.

Repeat steps 24 through 28. This time,

- enter "THRU 2" for *Label* (step 26)
- select "probe 2" under *Connectors* for both ports (step 27)

Thru D	escription In	sertable thru sta	ndard	-26	
reque	ncy Range				
Min	0	MHz			
Max	999000	MHz			
Connec	50				
Port	probe 2	٣	Port prob	e 2	٣

Figure 10b. Changing to "THRU 2" and "probe 2".



Figure 11:

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

Edit Kit	x			
Identification				
Kit Number 36 Kit Name OnWater 4P				
Kit Description Example of OnWater 4-port Cal Kit				
Connectors Class Assignm Description:				
probe 1 Add or Edt SOLT		A Cal Kits		-0×
Family.	Edit Oper	n Save As	Restore Defaults	
probe 1 Change Family			Installed Kits	
ID Standard Description		Import Kit	Save As Insert New Print to File	
1 OPEN 1 probe 1 open	ID K	it Name	Description	-
2 OPEN 2 probe 2 open	20 8	5032F	TypeN (50) Calibration Kit	
3 SHORT 1 probe 1 short 29			TypeN (50) Calibration Kit	
			TypeN (50) with sliding load	
5 L0AD 1 probe 1 load 6 L0AD 2 probe 2 load			TypeN (50) Calibration Kit TypeN (75) Calibration Kit	
7 THRU 1 Insertable thru standard			Type-F (75) Calibration Kit	
8 THRU 2 Insertable thru standard			Example Cal Kit with male and female connectors	
	27 E		Example Cal Kit with unsexed connectors	-
			X-band Waveguide SOLT/TRL Calibration Kit	
			P-band Waveguide SDLT/TRL Calibration Kit	
			K-band Waveguide SDLT/TRL Calibration Kit	
			Q-band Waveguide SOLT/TRL Calibration Kit R-band Waveguide SOLT/TRL Calibration Kit	
Add Edit Delete Delete All			U-band Waveguide SOLT/TRL Calibration Kit	
			V-band Waveguide SOLT/TRL Calibration Kit	
OK Cancel			W-band Waveguide SOLT/TRL Calibration Kit	
	36 0	Iniwater 4P	Example of OnWater 4-port Cal Kit	-
	6	Edit	GtDelete	
	C C		OK Cancel	Help

Figure 11. Creating a new calibration kit for probing: Complete.

Step 2. Perform the SOLT (Short-Open-Load-Thru) 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.

For 4-port calibrations, performing SOLT with Unknown Thru yields the best accuracy with the least complexity. Using the port assignment of Figure 6a, the minimum three thru paths to be measured can be the following:

Thru #1	ports 1 – 2	Unknown Thru
Thru #2	ports 1 – 3	Defined Thru
Thru #3	ports 2 – 4	Defined Thru

This way, the two Defined Thru paths measured are each a "straight thru," and we use Unknown Thru to characterize the non-straight thru which in turn can yield better calibrated results.

To perform a full 4-port calibration, simply follow the boxed numbers in each of the figures shown below (Figures 12 through 16).



Figure 12:

- 1. Click Calibration
- 2. Select Calibration 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 "4 Port Cal" is selected
- 6. Click **Next** > this brings up the *Guided Calibration: Select DUT Connectors and Cal Kits* dialog box

			1										
Elle ⊻ie	w <u>C</u> hannel	Swgep		Irace Scal		System Y	(indow <u>H</u> elp)					
Stimulus			Calibratio Preference		2	Start	Stop	Ce	niter	Span			
			Correctio	n on/OFF ion DN/off									
			Cal <u>S</u> et CalSet⊻				-						
		Calibratio	n Wizard: Be	gin Calibratio	on							×	
		G Sma	tCal (GUIDED	Calibration): Use	e Mechanica	Standards	3						
		C UNG	UIDED Calibra	tion (Response,	1-port, 2-po	rt): Use Mecha	nical Standard	Select	calibration p	references.			
		C Use	Electronic Calib	ration (ECal)					e aboul pre nce is avail	ferences? able in the on	ine		
							☐ Save	Preference	1 show	this page ag	ain.		
							< <u>B</u> ack	<u>N</u> ext>	Can	el	Help	1	
				Select Guide							- senite in		X
				Cal Type Sel	lection		4 Port Cal Confi Select 1 st Por	and the second s	-				
				3 Port Cal 2 Port Cal			Select 2nd Fo		-				
				1 Port Cal	5	- 11	Select 3rd Por		2				
						- 11	Select 4th Por		-				
				J			Delect 4in Po	c la	<u> </u>				
											6		
								_ <	Back	Next >	Ca	ncel	Help

Figure 12. Begin calibration.



Figure 13:

- Under *Connectors*, using the dropdown menu, select "probe 1" for ports 1 and 3, and select "probe 2" for ports 2 and 4 (as shown in Figure 6a).
- 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 1** and **Probe 2**, **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 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 the *Modify Cal* dialog box
- 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); and they were chosen primarily for convenience. (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 "Defined Thru," "Unknown Thru," and "Adapter Removal." Default shows Defined Thru. Choose **Defined Thru** for the "straight thru" paths; these include paths 1-3 and 2-4. For the "loop-back thru," choose **Unknown Thru**; this includes path 1-2.
 - "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, ± ¼ λ); otherwise, phase could be 180 degrees out.
 - "Unknown Thru" ideal for non-straight or non-insertable thru, this must be a passive device where its forward and reverse characteristics are the same; as such, it is also referred to as "reciprocal thru." The calibration process will measure the unknown passive device, determine its delay value, and then apply it in order to complete the calibration.
 - "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. Click Next >



Guided Calibra	ation: Select DUT Conne	ectors and Cal Kits		×	
	Connectors	Cal Kits			
DUT Port 1	APC 3.5 male	850528	Cal Method: 4-Port		
DUT Port 2	1.85 mm femal 7	850528			
DUT Port 3	1 85 mm male	85056A *			
DUT Port 4	1.00 mm female	85056A			
Modify Cal	7-16 male 7-16 female				
OPTIONAL. Se	APC 7	e Cal Method and/or standards used for the s	مخالعه استنبات		
UPHONAL SE	Type N (50) male Type N (50) female	e cal method and/or standards used for the s	relected call kes.		
	Type N (75) male	a Bash a Maria			
	Type N (75) female Type F (75) male	< <u>B</u> ack <u>N</u> ext	> Cancel	Help	
	Type F (75) female				
	Type A (50) male Type A (50) female	Guided Calibration: Select D	UT Connectors and Cal I	Kits	×
	Type B	Connect	ors	Cal Kits	Culturback (Deal
	X-band waveguide P-band waveguide	DUT Port 1 probe 1	Or/Water 4P		Cal Method: 4-Port
	K-band waveguide	DUT Port 2 probe 2	OrWaler 4P	9 🗉	
	Q-band waveguide R-band waveguide	DUT Port 3 probe 1	OnWater 4P		
	U-band waveguide	DUT Port 4 probe 2	Or/Water 4P	*	
	V-band waveguide W-band waveguide	Modify Cal			
	probe 1	OPTIONAL. Select [Modify Cal] t	o change the Cal Method and	for standards used for 1	d cal kits.
	probe 2 WRD180				
	WRD750	10		< Back Next>	Cancel Help
	WRD650			Kack Tiews	
		Modify Cal			×
		Thru Calibration Options (Cal T)			
			u Cal Method:		
		Thru #1 1-2 Unkno	and the second se	Thru #4	
		Thru #2 1-3 💌 Defined	Thru 13 lod Stds	Thru #5	
		Thru #3 24 V Defined	Thru Mod Stds	Thru #6	
				Choose delta match	
			2	< Back Next >	Cancel Help

Figure 13. Select Connectors, Cal Kits, and Thru paths.

At this point, you should see the dialog box showing "Guided Calibration Step 1 of 15," which is the beginning of the calibration.

Using Guided Calibration, the network analyzer will step the user through 15 steps (as shown in part (a) of Table 1), allowing the user to calibrate one port at a time. For each test port, the instrument steps the user through three standards (Open, Short, and Load) before advancing to the next test port. This approach is optimized for coaxial calibration, but not for probing. To be efficient in probing, a better approach would be to minimize the number of touchdowns, while maximizing the number of measurements possible for each touchdown. Such a scenario would only require seven touchdowns instead of 13 in order to complete a full 4-port SOLT calibration. To measure the standards in a different order than suggested by the Guided Calibration process, click the **Next** > softkey to skip standards (for example, to measure all the Opens at one time, as shown in part (b) of Table 1), and then click the **Sack** softkey to return to standards that have been skipped previously (for example, the Shorts and the Loads). Continue to move back and forth until all the necessary steps have been measured.



Table 1. Steps as Guided by the PNA-L (a) and sequence to be measured to minimize the number of probe touchdowns (b).

(a) Steps as guided by the PNA-L:

```
Step 1 of 15
                 Port 1 | OPEN 1
Step 2 of 15
                 Port 1 | SHORT 1
Step 3 of 15
                 Port 1 | LOAD 1
Step 4 of 15
                 Port 2 | OPEN 2
Step 5 of 15
                 Port 2 | SHORT 2
Step 6 of 15
                 Port 2 | LOAD 2
Step 7 of 15
                 Port 1 | ADAPTER | Port 2 ← this is the Unknown Thru
Step 8 of 15
                 Port 3 | OPEN 1
Step 9 of 15
                 Port 3 | SHORT 1
Step 10 of 15
                 Port 3 | LOAD 1
Step 11 of 15
                 Port 1 | THRU 1 | Port 3
Step 12 of 15
                 Port 4 | OPEN 2
Step 13 of 15
                 Port 4 | SHORT 2
Step 14 of 15
                 Port 4 | LOAD 2
Step 15 of 15
                 Port 2 | THRU 2 | Port 4
```

(b) An example of sequence to be measured to minimize the number of touchdowns:

Port 1 | OPEN 1 Port 2 | OPEN 2 Port 3 | OPEN 1 Port 4 | OPEN 2 Port 4 | SHORT 2 Port 3 | SHORT 1 Port 2 | SHORT 2 Port 1 | SHORT 1 Port 1 | LOAD 1 Port 2 | LOAD 2 Port 3 | LOAD 1 Port 4 | LOAD 2 Port 2 | THRU 2 | Port 4 Port 1 | THRU 1 | Port 3 Port 1 | ADAPTER | Port 2 \leftarrow this is the Unknown Thru



Throughout the calibration process, one sees the "Guided Calibration Step" shown on the upper left corner of the dialog box (Figure 14), 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.

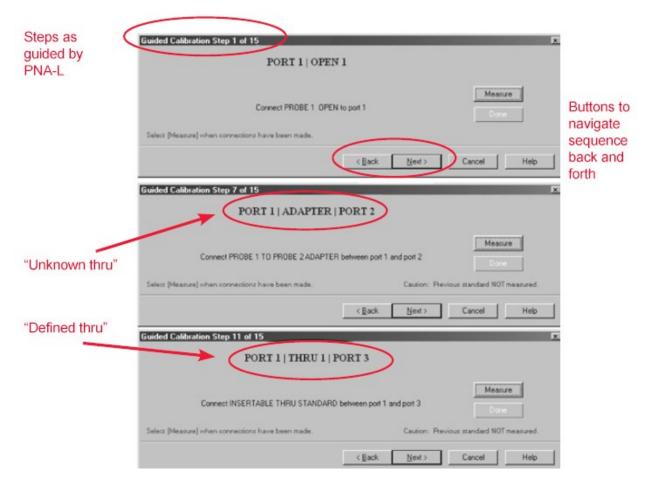


Figure 14. Samples of screens throughout the calibration process.

Conclusion

The 4-port PNA-L (N5230A Opt.x4x) 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).

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