Keysight Technologies PNA Microwave Network Analyzers

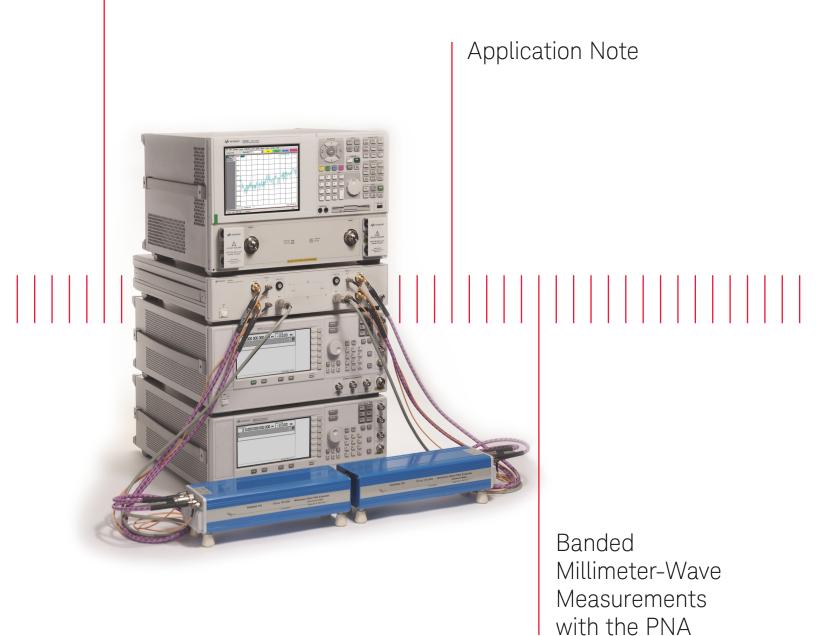




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Introduction

Millimeter-wave is becoming more common as measurement needs are pushed beyond 110 GHz, to 220 GHz, 325 GHz, and even 1 THz! Applications include on-wafer device characterizations as well as various types of materials measurements.

The Keysight Technologies, Inc. PNA series network analyzers can be configured for wide dynamic range reflection and transmission measurements of components at millimeter-wave frequencies. Two types of millimeter-wave solutions are available from Keysight Technologies:

- One solution is the N5250C network analyzer. With 1.0mm coaxial test port connectors, this solution provides single, continuous measurement sweeps from 10 MHz to 110 GHz.
- 2. The other solution is based on banded millimeter-wave test head modules with waveguide (WG) interfaces. System configuration differs depending on frequency range of interest.

The objective of this application note is to provide detailed information on the banded millimeter-wave solutions. This includes system configurations, system operation, system calibration, and some typical measurement examples. This note applies to the following product numbers within the PNA and PNA-X series: E8362B, E8363B, E8364B, E8361A, N5242A, N5244A and N5245A.

Banded Millimeter Wave System Configuration

To configure a banded millimeter wave measurement system, three basic components are required:

- 1. A performance network analyzer
- 2. Millimeter wave test set controller
- 3. A waveguide module based on application need and frequency band
- 4. An optional calibration kit in waveguide unless on-wafer or other media is being used

Performance network analyzer

Product model	Description	Minimum required options
E8362C	20 GHz 2-port performance network analyzer	H11, 080, 081, 014 and UNL
E8363C	40 GHz 2-port performance network analyzer	H11, 080, 081, 014 and UNL
E8364C	50 GHz 2-port performance network analyzer	H11, 080, 081, 014 and UNL
E8361C	67 GHz 2-port performance network analyzer	H11, 080, 081, 014 and UNL
N5242/44/45A Opt. 2xx	2-port PNA-X network analyzer	Option 020
N5242/44/45A Opt. 4xx	4-port PNA-X network analyzer	Option 020

Note: When configuring the N5242/44/45A (Option 200 and 224 required) with a N5262A 4-port millimeter wave test set controller, also include Option 551 for 4-port calibration capability.

Optionally for rear panel connection of the RF source to the N5261A/N5262A test set controller include the switch combiner options to the N5242/44/45A selected above. For N5242/44/45A with Option 2xx, add Option 224 and for the N5242/44/45A with Option 4xx, add Option 423.

For E836x based systems used with modules above 200 GHz, these systems require a pair of external synthesizers (one for RF and the other for LO) to increase the dynamic range, see Figure 9 for improvement. Recommended synthesizers are E8257D with Options 520 and UNX.

Product number	Description	Options
N5260A	2-port test controller for PNA based solution	Includes all cables for connection to PNA as well as two sets of 48 inch RF, LO, DC and IF cables for connection to a pair of T/R millimeter modules.
N5261A	2-port test set controller for PNA-X based configuration	Option 102 – A set of cables for connection to a 2-port PNA-X Option 104 – A set of cables for connection to a 4-port PNA-X Option 50x – A single set of RF, LO, DC and IF cables for connection to a single T/R millimeter module (see Option Descriptions for details).
N5262A	4-port test set controller for PNA-X based configuration	Option 102 – A set of cables for connection to a 2-port PNA-X Option 104 – A set of cables for connection to a 4-port PNA-X Option 50x – A single set of RF, LO, DC and IF cables for connection to a single T/R millimeter module (see Option Descriptions for details).

Millimeter wave test set controllers

When configuring the PNA-X with a N5260A millimeter wave test set controller, please include a 10 dB 3.5 mm pad for connection to the LO and a set of four BNC to SMA adapters.

Millimeter wave modules

Several modules are available and other special options may be configured on request. Select the appropriate quantity of modules required for the measurement set up. To request a specially configured test module contact your local Keysight sales engineer.

The single and dual channel receiver modules are used for antenna applications or for 1-port single path S-parameter measurements.

Transmission reflection modules

Waveguide flange	Frequency GHz	Standard transmission/ reflection modules	Transmission/ reflection Modules with 25 dB mechanical attenuator	Transmission/ reflection Modules with 15 dB LO and RF amplifier1
WR22	33 - 50	N5256AW22 - STD	N5256AW22 - 001	N5256AW22 - 002
WR15	50 - 75	N5256AW15 - STD	N5256AW15 - 001	N5256AW15 - 002
WR12	60 - 90	N5256AW12 - STD	N5256AW12 - 001	N5256AW12 - 002
WR10	75 - 110	N5256AW10 - STD	N5256AW10 - 001	N5256AW10 - 002
WR08	90 - 140	N5256AW08 - STD	N5256AW08 - 001	N5256AW08 - 002
WR06	110 - 170	N5256AW06 - STD	N5256AW06 - 001	N5256AW06 - 002
WR05	140 - 220	N5256AW05 - STD	N5256AW05 - 001	N5256AW05 - 002
WR03	220 - 325	N5256AW03 - STD	N5256AW03 - 001	N5256AW03 - 002
WR02.2	325 - 500	N5256AW02 - STD	Not available	N5256AW02 - 002 ²
Extended WR12	56 - 94	N5256AX12 - STD	N5256AX12 - 001	Available on request

1. Note the modules with the RF/LO amplifiers are for antenna applications that include a cable loss of 15 dBm to the module from the port of the Test set being used. Do not connect these directly to the test set controller port with the standard 48 inch cable, use a 15 dB pad if needed.

These modules require an external DC power supply (e.g. E3615A) when using them with the N5260A.
 For transmission reflection modules with both the 25 dB mechanical attenuator and the 15 dB LO and RF amplifier order N5256AWxx-003. Not available for N5256AW02

Single channel receive modules

Waveguide flange	Frequency GHz	Standard single channel receive modules	Single channel receive modules with 15 dB LO amplifier
WR22	33 - 50	N5257AR22 - STD	N5257AR22 - 001
WR15	50 - 75	N5257AR15 - STD	N5257AR15 - 001
WR12	60 - 90	N5257AR12 - STD	N5257AR12 - 001
WR10	75 - 110	N5257AR10 - STD	N5257AR10 - 001
WR08	90 - 140	N5257AR08 - STD	N5257AR08 - 001
WR06	110 - 170	N5257AR06 - STD	N5257AR06 - 001
WR05	140 - 220	N5257AR05 - STD	N5257AR05 - 001
WR03	220 - 325	N5257AR03 - STD	N5257AR03 - 001
WR02.2	325 - 500	N5257AR02 - STD	Available on request

Dual channel receive modules

Waveguide flange	Frequency GHz	Standard dual channel receive module	Dual channel receive module with 15 dB LO amplifier
WR15	50 - 75	N5258AD15 - STD	N5258AD15 - 001
WR12	60 - 90	N5258AD12 - STD	N5258AD12 - 001
WR10	75 - 110	N5258AD10 - STD	N5258AD10 - 001
WR08	90 - 140	N5258AD08 - STD	N5258AD08 - 001
WR06	110 - 170	N5258AD06 - STD	N5258AD06 - 001
WR05	140 - 220	N5258AD05 - STD	N5258AD05 - 001
WR03	220 - 325	N5258AD03 - STD	N5258AD03 - 001

Millimeter wave calibration kits

Waveguide flange	Frequency GHz	Calibration kit
WR22	33 - 50	Q11644A
WR15	50 - 75	V11644A
WR12	60 - 90	N5260AC12
WR10	75 - 110	W11644A
WR08	90 - 140	N5260AC08
WR06	110 - 170	N5260AC06
WR05	140 - 220	N5260AC05
WR03	220 - 325	N5260AC03
WR02.2	325 - 500	N5260AC02
Extended WR12	56 - 94	N5260AC12

OML VNA2 waveguide test head modules are available in transmission/reflection (T/R) and transmission (T) configurations. Each Keysight part number, N5260AWxx, includes a pair of T/R test head modules and the respective WG calibration kit. Figures 2 and 3 show the simplified block diagrams of an OML VNA2 T/R test head module and a T test head module, respectively. Other combinations of test head modules may be available from Keysight Technologies; as an example, one T/R and one T modules. Please contact your local Keysight Technologies representative for more detail.

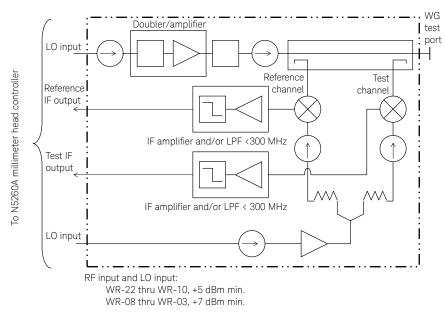


Figure 2. Simplified block diagram of an OML T/R test head module.

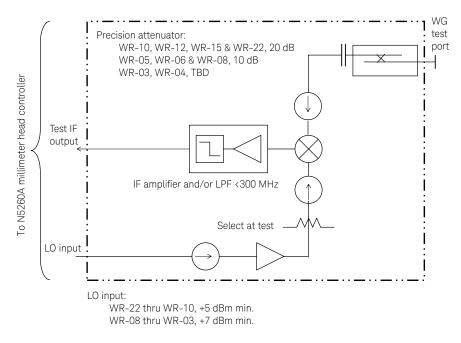


Figure 3. Simplified block diagram of an OML T test head module.

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Different combination of test head modules covering the same frequency range can be used together, but will result in different available parameters. Table 3 shows details of the possible combinations. A full "S-parameter" test set requires two T/R modules. One T/R module and one T module will result in a "T/R" test set where only one transmission measurement and one reflection measurement are possible.

Table 3. Combination of test head modules and available measurements.

	Port 1	Port 2	Available Parameters	Comments
Combination #1 (Figure 4a)	T/R module	T/R module	S11, S21, S12, S22	Both ports 1 and 2 can supply stimulus to DUT
Combination #2 (Figure 4b)	T/R module	T module	S11, S21	Only port 1 can supply stimulus to DUT

If S12 and S22 are needed for combination #2, two approaches are possible:

- 1. Reverse the DUT to measure the reverse parameters.
- 2. Reconfigure the test head modules by placing the T/R module on port 2 and the T module on port 1. This approach requires a calibration before measurements can be made.



(a)



(b)

Figure 4. Two combinations of test head modules: (a) Two T/R modules, and (b) one T/R module (left) and one T module.

System Operation

This section describes how to operate the banded millimeter-wave system. System operation includes creating a configuration for each set of millimeter-wave modules, calibrating the system, and taking measurements.

Figures 5 and 6 illustrate the front and rear panel connections of the system. Rear panel connections are slightly different if external synthesizers are used (Figure 6b). For details on system installation, please refer to the N5250A Network Analyzer Systems Installation Guide, part number N5250-90001.

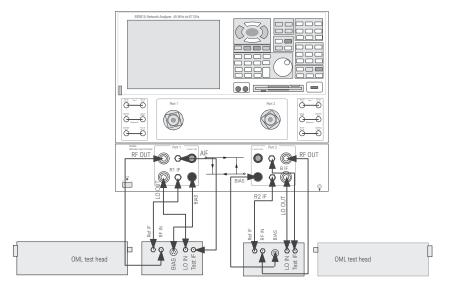


Figure 5. Front panel connections of the N5260A millimeter-wave controller to the waveguide test head modules.

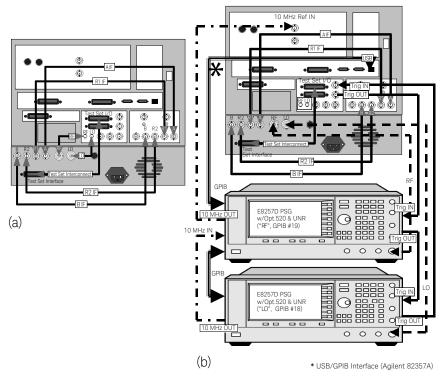


Figure 6. Rear panel connections: (a) without external synthesizers, and (b) with two PSGs as external synthesizers. Connection between the PNA and a PSG must be done via USB/GPIB Interface (Keysight 82357A), and PNA Trig OUT must go to Trig IN of RF synthesizer.

System setup procedure has been greatly simplified due to extensive enhancements made to the PNA firmware. The following steps show how to create a configuration for each set of millimeter-wave modules. For multiple frequency bands, one configuration is needed for each band.

Configuring millimeter-wave modules:

Before proceeding to the front panel of the PNA, please make sure the rear panel connection of the system is completed as illustrated in Figure 6a, and the N5260A millimeter-wave controller has been turned on.

- 1. **System > Configure > Millimeter Module Config...**, this brings up display (a) as shown in Figure 7.
- 2. Click on Module Config, this brings up display (b).
- Click on New, this brings up display (c), and enter the name of configuration. I
 t is best for the name to be descriptive and representative of the frequency band.
 (The example shows "60 to 90 GHz".)
- 4. Click **OK**. This brings up display (d). Enter values of the frequency range and the values of the multipliers, both RF and LO. Multiplier values can be obtained either from the labels on the test head modules, or from Table 4 below. Click **Save** when done.

Table 4. RF and LO harmonic multipliers of each frequency range.

Band	Frequency range of operation (GHz)	RF frequency range (GHz)	RF harmonic multiplier	LO frequency range ± IF offset (GHz)	LO harmonic multiplier
WR-15	50 – 75	12.5 to 18.8	N = 4	10.0 to 15.0	M = 5
WR-12	60 - 90	10.0 to 15.0	N = 6	12.0 to 18.0	M = 5
WR-10	75 – 110	12.5 to 18.4	N = 6	9.3 to 13.8	M = 8
WR-08	90 - 140	7.5 to 11.7	N = 12	11.2 to 17.5	M = 8
WR-06	110 – 170	9.1 to 14.2	N = 12	11.0 to 17.0	M = 10
WR-05	140 - 220	11.6 to 18.4	N = 12	14.7 to 18.1	M = 12
WR-04	170 – 260	8.5 to 13.0	N = 20	12.1 to 18.6	M = 14
WR-03	220 - 325	12.2 to 18.1	N = 18	12.2 to 18.1	M = 18

5. To apply a configuration, highlight the configuration, and then click on **Activate Selected Config**. This brings up display (e), click **OK** and the PNA will exit and restart with the new configuration, as shown in Figure 8. This step may take a minute.

Step One:

Select **System Configure Millimeter Wave** configuration to initiate setup.

Available Configuration	(s): Selec	cted Configuration:	Config0	
Standard PNA Config0 Config1	Selec	Set Properties sted Test Set: sute PNA RF to rear p	anel "SW SRC O	N5262A 💌
New	Max I - RF C	able Test Set RF ALC Power Limit: 11.00 c able Loss (DO NOT i or Offset: 0.00 dB	IBm 🗧	Jse Full Bandwidth At Multiplier RF IN nin) r Sløpe: 0.113 dB/Ghz F
Frequency Settings	Start Frequency	Stop Frequency	Multip	
Multiplier RF IN: Multiplier LO IN:	11.1666666667 GHz 8.3750000000 GHz	18.3333333333 G	10	PNA RF Source
Test Port Frequency:	67.00000000 GH			- Proced Source
Clicking OK will preset				Cancel Help

Step Two:

Provide a Name for the Configuration

Standard PNA	
onfig0	
onfig1	

- Test Set Configuration
 - Select Test Set Controller being used.
 - Uncheck **RF ALC** only if you need to make **Pulse** measurements.
 - Check "Use Full Bandwidth" only for mixer measurements.
 - Leave all other settings to default.

Test Set Properties	
Selected Test Set:	N5262A 💌
Route PNA RF to rear panel "SW S	SRC OUT"
Enable Test Set RF ALC	Use Full Bandwidth
Max Power Limit: 11.00 dBm 💌	At Multiplier RF IN
-RF Cable Loss (DO NOT include tes	t set gain)
Power Offset: 0.00 dB	Power Slope: 0.113 dB/Ghz

Step Four:

Frequency Settings

- Set the **RF** multiplier factor for the frequency extenders.
- Set the **LO** multiplier factor for the frequency extenders.
- Set the **Start** and **Stop Frequency** for the frequency extender.
- Select **PNA RF** or **PNA LO** source if external sources are being used.

	Start Frequency	Stop Frequency	Multiplier	Source
Multiplier RF IN:	11.1666666667 GHz	18.3333333333 GHz	6 +	PNA RF Source
Multiplier LO IN:	8.3750000000 GHz	13.7500000000 GHz	8 +	PNA LO Source
Test Port Frequency:	67.00000000 GHz +	110.00000000 GF 🗧		

Figure 7. Steps necessary to create a millimeter-wave module configuration. The example shows a frequency band of 67 to 110 GHz.

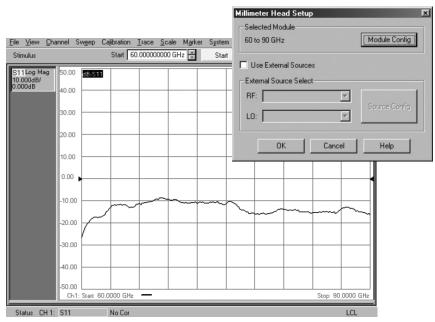


Figure 8. PNA operating in newly created millimeter-wave band configuration.

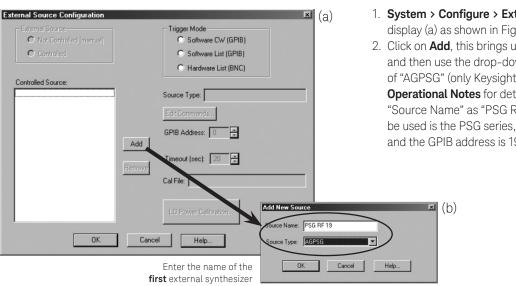
Configuring external synthesizers:

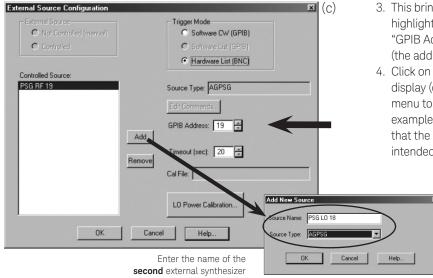
External synthesizers can be added to any banded millimeter-wave configuration at anytime. Before proceeding to the PNA front panel,

- Make sure the rear panel connection of the system is completed as illustrated in Figure 6b
- Turn on the N5260A millimeter-wave controller
- Turn on both external synthesizers and set the GPIB address of each unit via its front panel as illustrated in Figure 9b:
 - Utility > GPIB/RS-232 LAN > GPIB address
 Enter 19 (for the RF unit) and 18 (for the LO unit)
 Press softkey Enter

Proceed to the PNA front panel to configure the external synthesizers.

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- 1. **System > Configure > External Source Config...**, this brings up display (a) as shown in Figure 9.
- Click on Add, this brings up display (b). Enter "Source Name" and then use the drop-down menu to select the "Source Type" of "AGPSG" (only Keysight PSG Series are supported, please see Operational Notes for details). Click OK. (The example shows the "Source Name" as "PSG RF 19" to indicate that the synthesizer to be used is the PSG series, the unit is intended for the RF signal, and the GPIB address is 19.)

- 3. This brings up display (c). With the source name "PSG RF 19" highlighted, click on **Hardware List (BNC)** and then update the "GPIB Address" to make sure it is in agreement with the setup (the address is 19).
- 4. Click on Add (this time to add the LO source). This brings up display (d). Enter "Source Name" and then use the drop-down menu to select the "Source Type" of "AGPSG." Click OK. (The example shows the "Source Name" as "PSG LO 18" to indicate that the synthesizer to be used is the PSG series, the unit is intended for the LO signal, and the GPIB address is 18.)

(d)

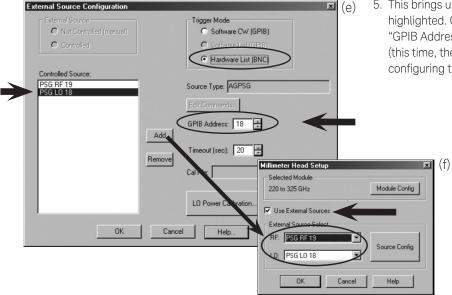


Figure 9. Steps necessary to configure and apply external synthesizers.

5. This brings up display (e). With the source name "PSG LO 18" highlighted. Click on **Hardware List (BNC)** and then update the "GPIB Address" to make sure it is in agreement with the setup (this time, the address is 18). Click **OK**. You have now completed configuring the external synthesizers.

Now apply the external synthesizers to the active configuration:

- System > Configure > Millimeter Module Config..., this brings up display (f) of Figure 9. (This example shows the "Selected Module" as "220 to 325 GHz.")
- Click on Use External Sources, and then use the drop-down menu to select the "RF" and "LO" under "External Source Select." Click OK when done. (As you can see, all sources you have configured will appear under each drop-down menu. This is why it is important to make the "Source Name" descriptive. Otherwise, it maybe difficult to figure out each one.)

Operational Notes

Power control

Power control is not available when operating at banded millimeter-wave frequencies. Although one appears to be able to vary power under **Channel > Power... > Test Port Power**, in reality, it makes no difference at the waveguide interface because (1) the amplifiers inside the test head modules are designed to operate at saturation (see Figure 2), therefore, increasing the RF Test Port Power in the PNA results in no change at the waveguide interface; (2) the RF and LO outputs from the rear panel of the PNA are coupled off before the splitter or any control mechanism, thus, providing no control for power.

Without external synthesizers, the RF and LO signals are provided by the PNA's rear panel (Option H11). These values vary over a wide range; the typical values are shown in Table 5.

Table 5. Typical values of the RF and LO outputs from the rear panel of the PNA.

Rear Panel LO power (typical)	
1.7 GHz to 20 GHz	–16 to –7 dBm
Rear panel RF power for E8362B (typical)	
1.7 GHz to 20 GHz	–16 to –5 dBm (at –5 dBm test port power ¹)
Rear panel RF power for E8363B/E8364B	(typical)
1.7 GHz to 10 GHz	–12 to –2 dBm (at –5 dBm test port power ¹)
10 GHz to 16 GHz	–8 to 0 dBm (at –5 dBm test port power ¹)
16 GHz to 20 GHz	–1 to +5 dBm (at –5 dBm test port power ¹)

With external synthesizers, the PSG sources are remotely controlled by the PNA. The PNA downloads the frequency list to each PSG (E8257D with Option 520) and the output is set to 0 dBm for each frequency point.

How do we know if the heads are driven with sufficient power? The ALC loops inside the N5260A millimeter-wave controller are in place to guarantee sufficient RF power is available at the test heads to drive them (see Figure 10).

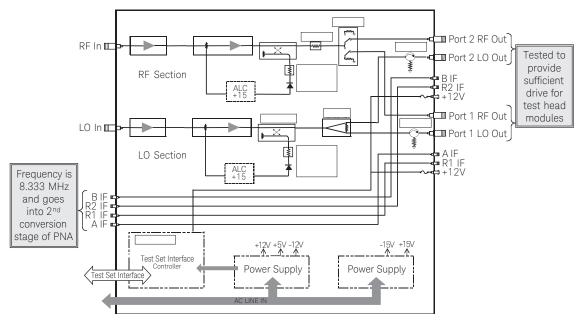


Figure 10. Simplified block diagram of N5260A millimeter-wave controller.

 Test port power has to be at a high enough level such that the "Drop Cal" does not occur. If Drop Cal occurs, then the power out of the rear panel RF connector will drop by about 15 dB.

Power leveling

Power leveling is not available when operating at banded millimeter-wave frequencies. (Please see Power control in this document for more information.)

Expected output power

For each test head module shipped, OML ships along a plot of its output power vs. frequency at the waveguide interface. These values vary depending on the frequency band of interest.

IF BW selection

For optimal performance at millimeter-wave frequencies, it is recommended that the IF BW be no wider than 1 kHz, preferably 10 Hz. Otherwise, traces can be noisy.

Resolution of frequency source

Only Keysight PSG sources are supported. Because frequency up-conversions done in the test heads require high harmonic multipliers (higher multipliers for higher frequency bands, see Table 4 for details), it is necessary for external synthesizers to have precision to sub-Hz resolution level. If 1-Hz resolution sources are used, errors can propagate resulting in sizable frequency errors.

Frequency resolution of the PSG Series (CW) is 0.001 Hz. PNA 1st IF = 8.333333... MHz IF = N*rf +/- M*LO

Example:

RF = 110 GHz (measurement frequency of WR-10) N = 6 (from Table 4) rf = RF / N = 110 GHz / 6 rf = 18.33333333... GHz (frequency of external RF source) M*LO = IF + N*rf M*LO = 8.333333... MHz + 110 GHz = 110008333333.333... Hz M = 8 (from Table 4) LO = 110008333333 Hz / 8 LO = 13751041666.625 Hz (frequency of external LO source)

As you can see, due to the unique value of the PNA 1st IF, the values needed for the external RF and LO synthesizers are most likely never to be whole numbers. Therefore, it is necessary for external synthesizers to have sub-Hz resolution in order to yield an accurate PNA 1st IF.

Multiple channels

Using multiple channels is not supported when operating in external synthesizer configuration. This is primarily because when switching from one channel to the next, the PNA has to download all the necessary information to the PSGs before starting a sweep. Timing differences between channel switching (within the PNA) and signals within the trigger chain (outside the PNA) could result in erroneous data collection for the trace being swept.

System Calibration (error-correction)

Choosing the right calibration technique

Applicable calibration techniques depend on the system (hardware) configuration. Table 6 shows the available calibration techniques for two possible system configurations: one with two T/R modules, and the second with one T/R module and one T module. Depending on the technique chosen, the calibration interface on the PNA may be different.

Table 6. Combination of test head modules and applicable calibration techniques.

	System configurations			Calibration interface		
	T	Configuration #1 ¹ wo T/R modules parameter test set)	Configuration #2 ² One T/R module and one T module (transmission/reflection (T/R) test set)		SmartCal (guided calibration)	Unguided calibration
OPEN Response	√	S11 or S22	√	S11	(3	
SHORT Response	1	S11 or S22		S11	-	
THRU Response		S21 or S12		S21	-	
1-Port Reflection		S11 or S22		S11		
Full SOLT 2-Port		S11, S21, S12, S22				
Full TRL 2-Port		S11, S21, S12, S22			\checkmark	

1. 1. See Figure 4a.

2. 2. See Figure 4b.

Each N5260AWxx includes a pair of T/R test head modules (configuration #1) and the respective WG calibration kit. With this, the setup would allow for measurements of S11, S21, S12 and S22. Plus, full 2-port calibration is possible with SOLT, and TRL.

With configuration #2, although the setup only allows for measurements of S11 and S21, the user can perform either 1-port calibration for S11, or thru response calibration (normalization) for S21, or **append** the latter calibration to the previous thus creating one calset for both traces within one measurement channel¹. Here are the steps to append two calibrations:

- With trace S11 active, perform 1-port calibration using SmartCal, then click **Save As User CalSet** to finish
- With trace S21 active (in the same channel), while the 1-port calibration is selected, perform response calibration (or normalization) using Unguided Cal, then click Save As User CalSet to finish but make sure the selected calset is the same one as the currently active 1-port cal click Save to complete
- As the final step, the Calibration Wizard will then ask if appending this calibration to the existing one is desired, as shown in Figure 11, simply click **OK** to confirm. Once finished, the same calset will cover both calibrations, 1-port for S11 and thru response for S21. This way, when you click on S11, the status bar (located on the bottom of the display) shows **C 1-Port**, and when you click on S21, it shows **C Response**.

Confirm appe	nd calset.		×
You have ch Confirm?	osen to append thi	is calibration to	calset: CalSet_1.
	OK OK	Cancel]

Figure 11. Appending a calibration to an existing CalSet.

Each WG calibration kit from OML comes with the following standards and a floppy disk loaded with the calibration definition file formatted for the PNA:

- Precision Terminations, Fixed Loads, qty 2
- Precision (flush) Shorts, qty 2
- Precision Insert A (line1), Null Shim
- Precision Insert B (line2),
 ¼ Offset Shim
- Adjustable Load
- Precision Section

Note

Setting System Z_0 to $1-\Omega$: When performing **Unguided** calibration with waveguide interface, the user must manually set the System Z_0 to $1-\Omega$ to match the waveguide kit. This is because **Unguided** calibration uses System Z_0 during calibration computation. Whereas, SmartCal uses the Z_0 defined by the connector definition and is applied automatically during calibration.

System > Configure > System Z0

Enter a value of 1 for waveguide, then click **OK**.

1. Enhanced-response calibration is currently not available.

Loading and checking calibration definition file

Each PNA is shipped with calibration definition files from Keysight calibration kits. For non-Keysight calibration kits such as the WG calibration kits from OML, the user must first load the file and then check to make sure all the items are in order. (The user can also choose to create his own WG cal kit file if desired. Refer to Appendix A for details.)

Calibration > Advanced Modify Cal Kit ... > Import Kit ...

Use dropdown menu to select "3½ Floppy (A:)" Highlight the file to be imported, and click **Open**

Once the file is loaded, it will appear on the list of **Installed Kits** as shown in Figure 12. Highlight the file of interest, (The example shows **V05_OML**.) and click **Edit Kit** ... in order to view the kit definition. On this page, you can see all the standards (and combinations) as defined for this particular WG calibration kit.

Edit PNA Cal Kits Open Save As Installed Kits Example Kit A Example Cal Kit Int unseed connectors Installed Kits Calibration Kit Installed Kits <th colspa<="" th=""><th>Edit Kit Identification Identification 37 Kit Name VISE 01ML Kit Description OML WR-05 (G Band) Universal Calibration Kit Connectors Description: WR-05 Waveguide Add or Edit. SOLT WR-05 Waveguide Change Fam. SOLT Edit Image: Standard Description Solt Solt Image: Standard Description Solt Solt Image: Standard G-Band Flash Stript (IS-05) Solt Solt Image: Standard G-Band Flash Stript (IS-05) Solt Solt Image: Standard Stript (IS-05) Solt Solt<!--</th--></th></th>	<th>Edit Kit Identification Identification 37 Kit Name VISE 01ML Kit Description OML WR-05 (G Band) Universal Calibration Kit Connectors Description: WR-05 Waveguide Add or Edit. SOLT WR-05 Waveguide Change Fam. SOLT Edit Image: Standard Description Solt Solt Image: Standard Description Solt Solt Image: Standard G-Band Flash Stript (IS-05) Solt Solt Image: Standard G-Band Flash Stript (IS-05) Solt Solt Image: Standard Stript (IS-05) Solt Solt<!--</th--></th>	Edit Kit Identification Identification 37 Kit Name VISE 01ML Kit Description OML WR-05 (G Band) Universal Calibration Kit Connectors Description: WR-05 Waveguide Add or Edit. SOLT WR-05 Waveguide Change Fam. SOLT Edit Image: Standard Description Solt Solt Image: Standard Description Solt Solt Image: Standard G-Band Flash Stript (IS-05) Solt Solt Image: Standard G-Band Flash Stript (IS-05) Solt Solt Image: Standard Stript (IS-05) Solt Solt </th
OK Cancel	Help Media WAVEGUIDE Cutoff Frequency 115636 MHz Height/Width Ratio 0.5	
	OK Cancel Apply Help	

Figure 12. Loading the calibration definition file and checking on the connector definition.

The examples in Figure 14 show the standards and class assignments for both TRL and SOLT. These are defined as shown in Table 7. Figure 15 shows examples of the details of each standard definition.

	Class Assignments	Class Label	Selected Standards
TRL	TRL THRU	THRU	Thru + Null Shim
	TRL REFLECT	REFLECT	Flush Short
	TRL LINE/MATCH	LINE	Thru + ¼ Offset Shim
SOLT	S11A, S22A	OPENS	Short + Null Shim
	S11B, S22B	SHORTS	Short + ¼ Offset Shim
	S11C, S22C	LOADS	Flush Fixed Load
	FWD TRANS	THRU	Thru

Table 7. Standards and class assignments of TRL and SOLT calibrations.

Thru-reflect-line (TRL) calibration:

Setting test port reference plane

Two selections are available for setting the test port reference plane; **Thru Standard** or **Reflect Standard** (see Figure 13). If a flush short is used for the reflect standard, then select the "Reflect Standard" for the "Test port Reference Plane." A flush short provides a much more accurate phase reference than a thru standard.

Short-open-load-thru (SOLT) calibration:

Adjustable load

Although an adjustable load is shipped in each WG calibration kit from OML, this standard is not ideal for millimeter-wave frequencies because mechanical tolerances make obtaining repeatable results difficult. Plus, adjustable loads are best if step sizes can be varied from large to small as one tries to trace out circles on a smith chart. Given the frequency ranges of these calibration kits, it would be very challenging to produce repeatable results. Therefore, fixed loads are used for the load standards for SOLT.

Offset load

Offset load is available in the PNA with firmware 6.0. Using offset load can result in a more accurate calibration than with broadband load, but it does require extra connections. A typical offset load requires two known offsets along with a load element. As such, one connection is made using the **first offset with the load**, and the other one is made using the **second offset with the load**. Figure 13 shows a definition of an offset load.

Loads
Identification Standard ID 3 Label Offset Load Load Description WR-03 Waveguide load
Frequency Range Connector Min 173580 MHz Max 347159 MHz Load Type Arbitrary Complex Impedance C Fixed Load Impedance Real Sliding Load O Iffset Load Imag
Delay Characteristics Delay Department Decore Cost Cost Cost Cost Cost Cost Cost Cost
First Offset Standard Thru+Null Shim Second Otfset Standard Thru+1/4 Offset Shim Load Standard Load
Clear OK Cancel Apply Help

Figure 13. Example of an offset load definition.

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	K Name V05_0ML (G Band) Universal Calibration Kit Class Assignments
WR-05 Waveguide Family: WR-05 Waveguide	Add or Edit SOLT Edt Solt TRL
ID Standard 1 Short 2 Short+V/40 [Shim 4 Short+V/40 [Shim 5 Load 6 Load+Null Shim 8 Load+Null Shim 9 Load Skiding+Null Shim 10 Load Skiding+Null Shim 11 Thru-Null Shim 16 Thru-1/4 Offset Shim 16 Thru-1/4 Offset Shim	Description ▲ G-Band Fluids Short [5:05] G-Band Short [5:05] G-Band Short [5:05 - 05:05] Short + 0.100" NJ, S., G-Band Short [5:05 - 05:05] Short + 0.100" NJ, S., G-Band Short [5:05 - 05:05] Short + 0.100" NJ, S., G-Band Short Fixed Load [7:05 + 05:05] Load + 0.100" G-Band Short [5:05 + 05:05] Load + 0.100" G-Band Short [5:05 + 05:05] Load + 0.100" G-Band Short [5:06] Alu 05 + 05:05] Short + 0.51/4:05] Load + G-Band Thru [105:06] Null Shim G-Band Thru [105:05] Null Shim G-Band Thru [05:05] Null Shim G-Band 1/4 Offset Thru [05:1/4:05] 1/4 wave Offs ▼
Add	Edit Delete Delete All OK Cancel Help

OML: Modify SOLT Calibration Class	Assignments		_	_
alibration Kit Class				DK
S11A C S22A C FWD TRA				UK
	CH O REV			Cano
C S11C C S22C C ISOLATIO	N			
Link FWD TRANS, FWD MATCH, REV TR	ANS, and REV_			Help
panded Calibration (applies to reflection clas	ses)-	- Calibration Class Labe		-
Measure all mateable standards in class		S11A OF	PEN	
Use expanded math when possible				\sim
nselected Standards		Selected Standards		
D Label Description	-	ID Label	Descrip	tion
Short G-Band Flush Sho		2 Short+Null Shi		Short [S-0
Short+1/4 Offs G-Band 1/4 Offse				
i Load G-Band Flush Fixe Load+Null Shim G-Band Fixed Loa				
Load+1/4 Offset G-Band 1/4 Offse				
Load Sliding G Band Sliding Lo		4		
0 Load Sliding+N G-Band Sliding Lo	2	Mountin	M	nue Doure
Load Sliding+N G-Band Sliding Lo Load Sliding+N G-Band Sliding Lo Particle Standards is used to lid at a given frequency. Standards listed first	determine which t have priority.			ove Down
Load Skidng+N G-Band Skiding Lo Deards Skidng+N G-Band Skiding Lo Part of the selected standards is used to idid at a given frequency. Standards listed first /05_OML: Modify TRL Calibration Cl Calibration Kit Class	determine which thave priority. ass Assignme Calibration F	h standard is used when ents Reference Z0 —		lards are
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Load Siding-N. G Band Siding Le order of the selected standards is used to id at a given frequency. Standards listed firs Collocation KR Case TRL THRU TRL THRU TRL FRLECT	determine which thave priority.	h standard is used when ints feference Z0 4 Z0		lards are
Load Siding NL. G-Band Siding Le erder of the selected standards is used to the selected standards is used to the selected standards is defined the selected standards the	determine which thave priority.	h standard is used when ints feference Z0 4 Z0		lards are
Load Siding-N. G Band Siding Le order of the selected standards is used to id at a given frequency. Standards listed firs Collocation KR Case TRL THRU TRL THRU TRL FRLECT	determine which thave priority.	nts Reference 20 ference Plane		lards are
Load Siding-N. G Band Siding Le order of the selected standards is used to id at a given frequency. Standards listed firs Collocation KR Case TRL THRU TRL THRU TRL FRLECT	determine which thave priority.	In standard is used when ints Teference Z0 4 Z0 ference Plane — TANDARD		lards are
Load Siding-NL. G Band Siding L control (He releated landards is used to id a given frequency. Standards isted first (05_OML: Modily TRL Catibration CP Calibration KR Class O TRL THRU CISOLATION O TRL REFLECT (TRL BEFLECT (TRL DISCHARTCH	determine which thave priority.	In standard is used when ints Teference Z0 4 Z0 ference Plane — TANDARD		lards are
10 Load Skidng-N	determine which thave priority.	Ints Ints Interence Z0 Interence Plane TANDARD T STANDARD		lards are
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0 Load Siding-NG.Band Siding L.B. e order of the selected standards is used to ikid at a given frequency. Standards listed first of the selected standards is used to its of the selected standards is used to its of the selected standards. 05 OML: Modify TRL Collibration CI Calibration KI Class 05 FIR. TRHU 07 TRL HAU C ISOLATION 07 TRL HAU C ISOLATION 07 TRL LINE / MATCH 10 Label GBand Short 13 Short-Null Shim G-Band Short 14 Short-Null G-G-Band Float 15 Label G-Band Short 16 Label G-Band Short 17 Short-Null Shim G-Band Short G-Band Float	determine which thave priority.	h standard is used when Inference Z0 – 420 ference Plane – TANDARD T STANDARD Selected Standards ID Label	multiple stanc	lards are
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0 Load Siding-NL. G Band Siding L B a conder of the selected standards is used to idid at a given frequency. Standards listed first CBDMLE Modify TRL Calibration CL Calibration RT Calibration CL Calibration RT Calibration CL Calibration CL CTRL REPLECT C TRL LINE-MATCH Vinstected Standards Description ID Lobel Description 1 Short G Bard Flush 1 2 Short Null Shim G Bard Flush 1 3 Short 1 AD III. G Bard 1/4 00 Short AD III. G Bard Flush 1 4 Short Null Shim G Bard Flush 1 5 Load AVNUll Shim G Bard Flush 1	determine which thave priority.	h standard is used when Ints Interence 20 420 Iterence Plane - T STANDARD Selected Standards 10 Label 14 Thru-Nud St	multiple stanc	lards are

Figure 14. Examples of TRL and SOLT class assignments.

	Shorts 🗵
1	Identification
	Standard ID 1 Label Short
Edit Kit	Short Description G-Band Flush Short [S-05]
Kit Number 37 Kit Name V05 OML	Frequency Range Connector
Kit Description OML WR-05 (G Band) Universal Calibraton Kit	Min 115696 MHz WR-05 Waveguide
Connectors Description: Class Assignments	Max 231392 MHz
WR-05 Waveguide I dd or Edit	Short Characteristics L0 0 H(e-12) L2 0 H(e-33)/Hz^2
WR-05 Waveguide Change Family	L1 0 H(e-24)/Hz L3 0 H(e-42)/Hz^3
ID Standard Description	Delay Characteristics
1 Short G-Band Flush Short [S-05] 2 Short+Null Shim G-Band Short [S-05 + 0S-05] Short + 0.100" Null S	Delay 0 Does 0 Gohms/s
4 Short+1/4 Offset Snim Peod 1/4 Offset Short [S-05+ DS1/4-05] Short+	20 1 ohne
5 Load G-Band Flush	
8 Load+1/4 Offset G-Band 1/4 Offset Load [T-05 + 051/4-05] Load +	Shorts X
9 Load Sliding G Band Sliding Load [AL-05] 10 Load Sliding+Null Shim G-Band Sliding Load [AL-05 + OS-05] Sliding Load +	I della supervisione
12 Load Sliding+1/4 Off G-Band 1/4 Offset Sliding Load [AL-05 + OS1/4-05]	Standard ID Label Shot+Null Shim
14 Thru+Null Shim G-Band Thru (OS-05) Null Shim	Short Description G-Band Short [S-05 +0S-05] Short + 0.100" Null Si
16 Thru+1/4 Offset Shim G-Band 1/4 Offset Thru [OS1/4-05] 1/4 wave Offs	Frequency Range Connector
Add Edit Delete Delete All	Min 115696 MHz WR-05 Waveguide 💌
OK Cancel Help	Max 231392 MHz
	Short Characteristics
	L0 0 H(e-12) L2 0 H(e-33)/H2^2
	L1 0 H(e-24)/Hz L3 0 H(e-42)/Hz^3
	Delau Characteristics
	Oelay [8,475] pSec Loss [0] Gohms/s Z0 1 ohms
	Clear OK Cancel Apply Help

Figure 15. Examples of standards definitions. Key parameters to check included Min and Max of Frequency Range, as well as Delay and ZO.

Configuration #1: Two T/R Modules (S-parameter test set)

With a full 2-port calibration, this configuration allows one to measure all four S-parameters (S11, S21, S12, S22). Full 2-port calibrations are available in either TRL or SOLT. These calibrations are available under **SmartCal** (guided) or **Unguided** calibrations on the PNA under **Calibration Wizard**.

Example #1:	WR-12, 60 to 90 GHz
Equipment:	E8364B with Options 014, UNL, 080, 081, H11
	N5260A test set controller
	WR-12 (60 to 90 GHz) T/R test heads modules
Setup:	IF BW: 100 Hz
	Number of Points: 201
Calibration:	Channel 1: SmartCal, 2-port, Flush Thru, TRL

For 2-port calibrations in waveguide, SmartCal defaults to TRL with Flush Thru. Figure 16 shows that the system dynamic range is better than 90 dB and trace noise is better than ± 0.10 dB.

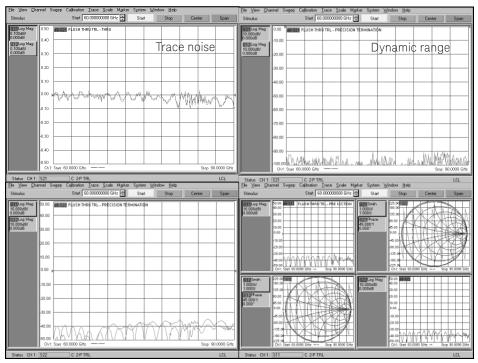


Figure 16. WR-12, 60 to 90 GHz, Flush Thru TRL calibration results.

Note

TRL calibration

TRL only requires four steps. It requires one reflect standard for each test port, one thru and one line (a section with a defined length).

- The reference must be established by the SHORT (reflect) standard.
- The impedance selected must be LINE Z0.

These are the default settings when using **SmartCal**. When using **Unguided** calibration, the user must check to confirm these settings, as well as setting system Z0 to 1-Ω **(System > Configure > System Z0)**.

SOLT calibration

SOLT requires seven steps, three more steps than TRL! It requires three standards for each test port, and one thru.

Unknown Thru is available, but only with SOLT. Since SOLT takes more steps and is less accurate than TRL, the only time you should consider performing SOLT calibration is to benefit from an Unknown Thru. One such situation may be where the test heads are restricted from movement (such as bolted down to avoid cable movements); in such a case, an Unknown Thru would be very useful as it would eliminate the need to move them. Another example is when the test port cables are at 90 degrees, preventing a straight thru from being connected. When SOLT is needed, using offset load (instead of fixed load) will result in a more accurate calibration. This may require you to modify a cal kit definition as well as performing more connections during the actual calibration.

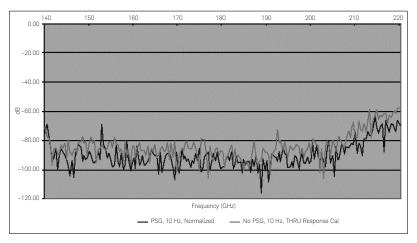
Configuration #2: One T/R module and one T module (T/R test set)

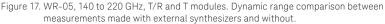
This configuration allows you to measure only two S-parameters (S11 and S21). For simultaneous corrected measurements of both parameters, one can perform a 1-port calibration for trace S11 and then append the thru response calibration (or normalization) performed for trace S21; thus, resulting in one calset for both traces.

1-port calibrations are available under SmartCal (guided) or unguided calibrations, while Thru Response calibrations (or normalization) are only available under unguided calibrations (see Table 6).

Example #2:	WR-05, 140 to 220 GHz	
Equipment:	E8364B with Options 014, UNL, 080, 081, H11 N5260A test set controller	
	WR-05 (140 to 220 GHz) T/R and T test head modules	
	E8257D with Options 520 and UNR (Qty of 2)	
Setup:	IF BW: 10 Hz	
	Number of Points: 201	

For the frequency range of 140 to 220 GHz, Figure 17 compares dynamic range and Figure 18 compares trace noise (for S21). In both cases, using Keysight PSG Series as external synthesizers to improve performance. For dynamic range, the improvement was up to 10 dB on average; for trace noise, it went from less than 0.05 dB around 220 GHz to practically non-existence!





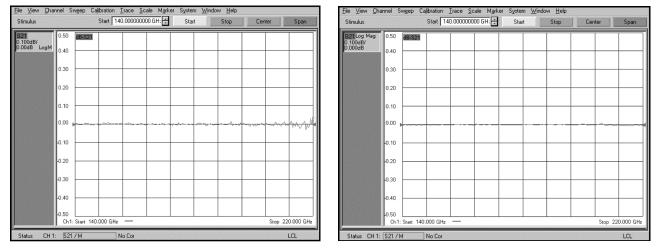


Figure 18. WR-05, 140 to 220 GHz, trace noise comparison between measurements made with external synthesizers (right) and without (left). Both plots have the same scale, 0.10 dB per division.

Example #3:	WR-03, 220 to 325 GHz
Equipment:	E8364B with Options 014, UNL, 080, 081, H11 N5260A test set controller
Satur	WR-03 (220 to 325 GHz) T/R and T test head modules E8257D with Options 520 and UNR (Qty of 2) IF BW: 10 Hz
Setup:	Number of Points: 201

For the frequency range of 220 to 325 GHz, Figure 19 compares dynamic range and Figure 20 compares trace noise (for S21). Similar to the previous example (WR-05), using Keysight PSG Series as external synthesizers do improve performance in both cases. However, the improvement for this higher frequency range is much more significant. For dynamic range, the improvement was up to 20 dB on average; for trace noise, it went from less than 0.20 dB around 300 GHz to less than 0.02 dB – that's an improvement of at least ten times!

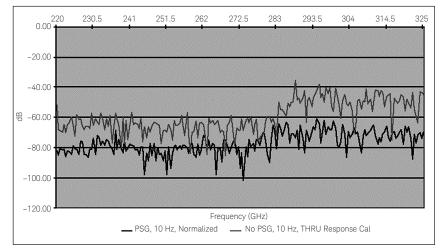


Figure 19. WR-03, 220 to 325 GHz, T/R and T modules. Dynamic range comparison between measurements made with external synthesizers and without.

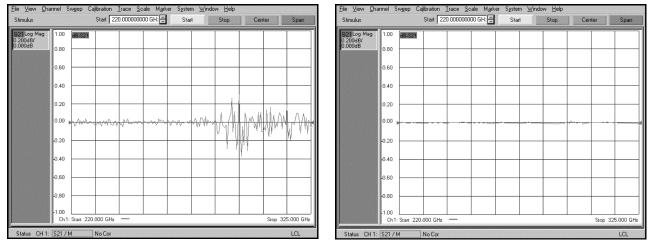


Figure 20. WR-03, 220 to 325 GHz, trace noise comparison between measurements made with external synthesizers (right) and without (left). Both plots have the same scale, 0.20 dB per division.

Application Examples

Example #1: Antenna measurements

Below are two examples of antenna configurations. For more details, please refer to the *Keysight Antenna Test – Selection Guide*, literature number 5968-6759E or visit our web site at **www.keysight.com/find/antenna**.

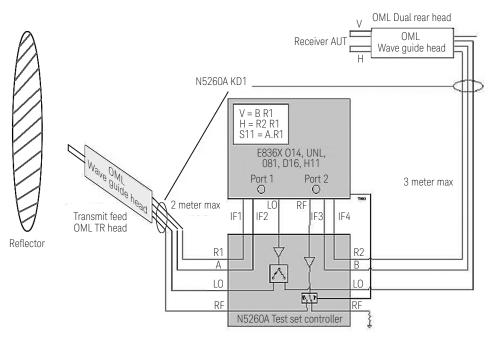


Figure 21. PNA banded millimeter-wave solution applied to **indoor** antenna measurements. The transmit side (left) uses an OML T/R module, and the receive side (right) uses the OML Dual T module. Dual T modules are ideal for measuring both vertical and horizontal polarities of the antenna.

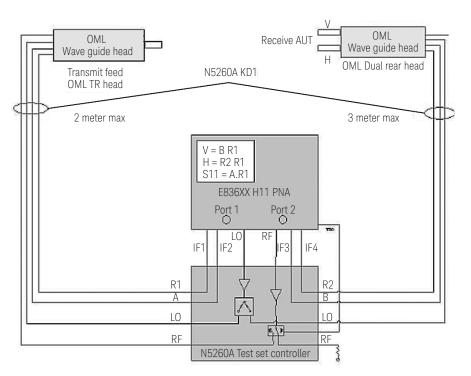


Figure 22. PNA banded millimeter-wave solution applied to **outdoor** antenna measurements. The transmit side (left) uses an OML T/R module, and the receive side (right) uses the OML Dual T module. Dual T modules are ideal for measuring both vertical and horizontal polarities of the antenna.

Example #2: Pulsed measurements

In a banded millimeter-wave configuration, the pulse modulator can be applied to the RF signal coming from either the front of the N5260A millimeter-wave controller or the rear of the PNA. In either case, a dual output pulse generator (Keysight 81110A) will be needed to provide a pulse drive to the modulator as well as the B gate of the PNA. Measurements of point-in-pulse and pulse profiling have been performed for V-band (50 to 75 GHz) and W-band (75 to 110 GHz).

Figure 23 shows the pulse modulator (Keysight Z5623AH81) being placed between the front of the N5260A millimeter-wave controller and the test head module. Since this pulse modulator is unidirectional, this is connected to the port 1 path only. In this configuration, the modulator takes the CW signal coming out of the front of the N5260A and provides a pulsed-RF signal going into the test head module of port 1 and it will in turn deliver a pulsed-RF stimulus to the device-under-test (DUT).

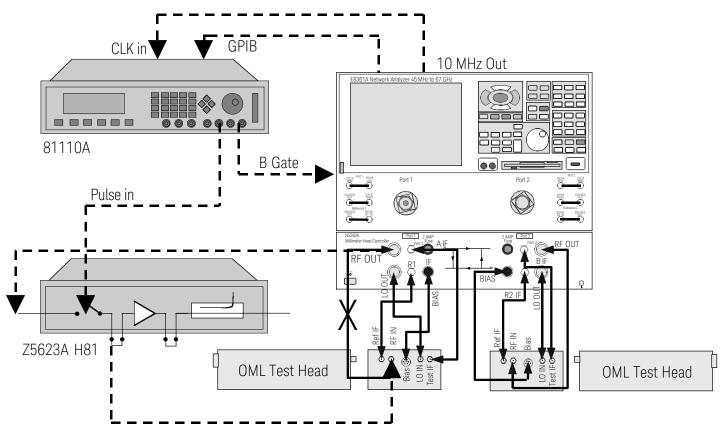


Figure 23. Pulsed the RF signal coming from the front of the N5260A millimeter-wave controller.

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Figure 24 shows the pulse modulator being placed between the PNA and the N5260A millimeter-wave controller. In this configuration, the modulator takes the CW signal coming out of the rear panel of the PNA and provides a pulsed-RF signal going into the N5260A millimeter-wave controller. Although the pulse modulator is unidirectional, this configuration will provide a pulsed-RF signal to both ports 1 and 2 because any input into the millimeter-wave controller. Figure 25 compares measurement results of pulse profiling at 100 GHz, and there is no difference whether the signal is pulsed in the front or the rear.

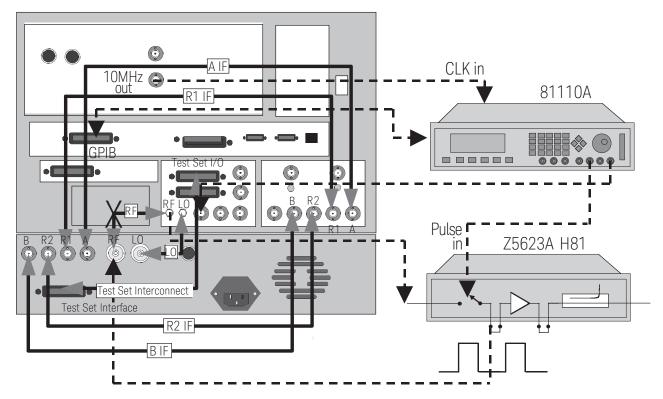


Figure 24. Pulsed the RF signal coming from the rear of the PNA.

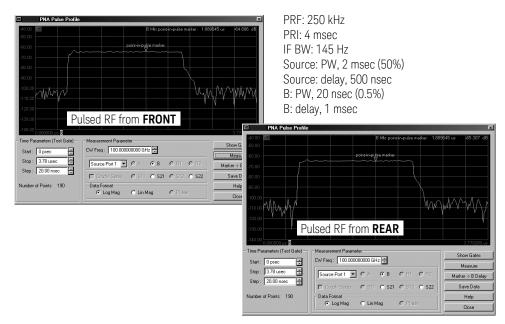


Figure 25. Results of pulse profiling measurements at 100 GHz by pulsing the RF signal from the front of the N5260A as well as from the rear of the PNA.

Example #3: Materials measurements

Figure 26 shows one example configuration of materials measurement in W-band, 75 to 110 GHz. This application requires two W-band waveguide horns and alignment of the test heads in order to transmit and receive test signals. In addition, using the measurement software shown requires two T/R test heads (an S-parameter setup). For more details, please visit our web site at **www.keysight.com/find/materials**.

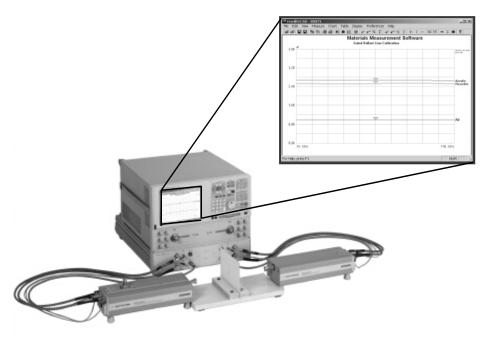


Figure 26. Using materials measurement software and Free Space Calibration technique to perform materials measurements in millimeter-wave. Insert shows measurement software interface.

Appendix A: Creating Your Own Waveguide (WG) Calibration Kit Definition

1. Calibration > Advanced Modify Cal Kit > Insert New

2. Enter "Kit Name" and "Kit Description" and then click on "Add or Edit" to enter connector information (Figure 27)

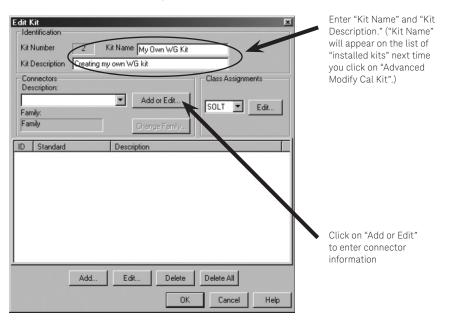
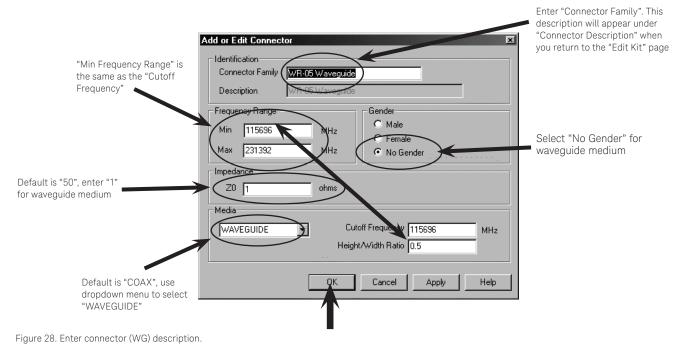


Figure 27. Enter calibration kit name.

 Enter "Connector Family," "Frequency Range" (Min. frequency = Cutoff frequency), 1 for "Z0;" select "No Gender," and "WAVEGUIDE" (Figure 28)



4. Click **OK**. This returns to the "Edit Kit" page (name of the page is shown on the upper-left corner of the dialog box). Click "Add" to start adding standards (Figure 29).

	Edit Kit	×
	Identification	
	Kit Number 3 Kit Name My Dwn WG Kit	
	Kit Description Creating my own WG cal kit	
Clicking OK (on the "Add or Edit Connector" page) returns to the "Edit Kit" page and the connector information appears.	Connectors Description: WG X-band Family: Change Family Class Assignments Edit Class Assignments Edit	
	ID Standard Description	-1
		1
Click "Add" to start	Add Edit Delete Delete All	
Click "Add" to start adding standards	OK Cancel Help	

Figure 29. Completed connector description, and start adding standards.

5. For waveguide, the best calibration technique may be thru-reflect-line (TRL). There is almost no reason to use SOLT since TRL is more accurate and SOLT requires more steps. Thus, for TRL or its variation such as line-reflect-line (LRL), you may want to add the following standards:

TRL	THRU REFLECT LINE	Thru (O delay) Flush Short (O delay) Thru with offset (a known delay)
LRL	LINE 1 REFLECT LINE 2	Thru with offset 1 (a known delay) Flush Short (0 delay) Thru with offset 2 (a different known delay)

However, if SOLT is needed, offset load can be used in place of fixed load. Using offset load will result in a more accurate calibration than with broadband load, and below are the standards needed:

SOLT	Short	Flush Short
	Open	Flush Short and Offset
	Offset Load	Load with Offset 1 (a known delay)
		Load with Offset 2 (a different known delay)
	Thru	Thru (0 delay)

Select a standard by clicking on it, the example shows SHORT (Figure 30, left). This brings up the "Shorts" page. The key parameters to note are the frequency range, the delay value if applicable, and the value of Z0 (Figure 30, right). Click OK when done, and this returns to the "Add Standard" page. Repeat this step until all standards have been added. Figure 31 shows adding a THRU standard.

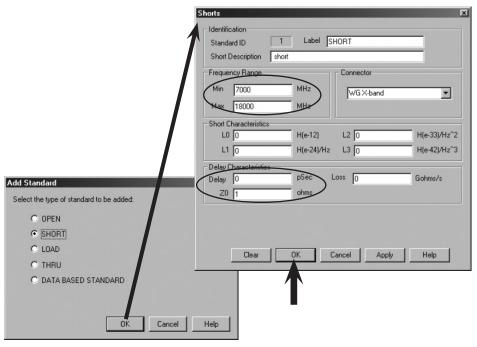


Figure 30. Add a SHORT standard.

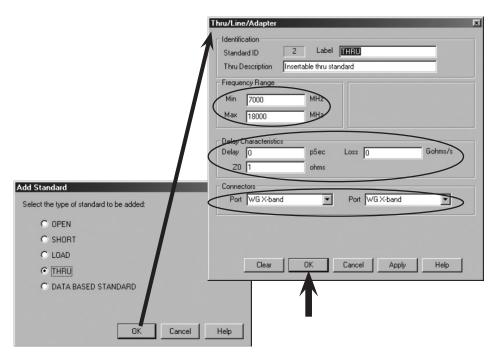


Figure 31. Adding a THRU standard.

Once you have added at least one fixed load and two offsets of different length, you can then define an offset load. Figure 32 shows the "Loads" page, and the default of this page is "Fixed Load." When "Offset Load" is selected, the "Offset Load Definition" area becomes active and you must use the dropdown menu to select each standard element. The "Delay Characteristics" area then becomes inactive because this is applicable for "Fixed Load."

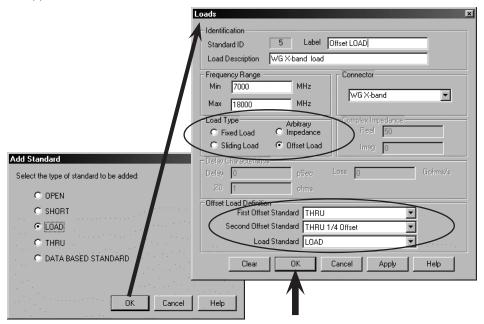
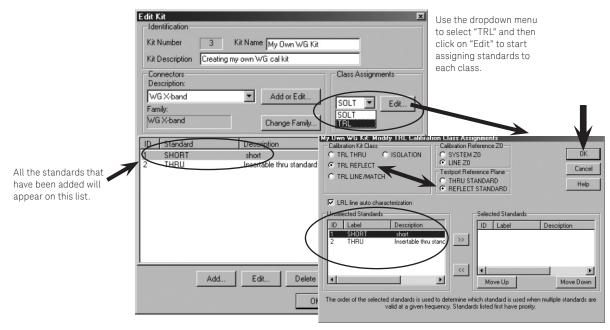


Figure 32. Adding an Offset Load standard.

6. After all standards have been added, click **OK** on the "Add Standard" page to return to the "Edit Kit" page. All the standards that have been added should appear in the table (Figure 33, left). Now, under "Class Assignments", use the drop down menu to select "TRL" (or "SOLT") and then click on **Edit**. This brings up the "Class Assignments" page, Figure 33 (right) shows "Class Assignments" for TRL. For each "Class" selected, highlight the standard on the left, and then click on the ">>" button in the middle, to move the standard to the right under "Selected Standards."



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Description: WG X-band Image: Add or Edit Family: Structure	Assignments DLT V Edit My Own WG Kit: Modify SOLT Calibration Class Assignments
ID Standard Description 1 SHORT WG X-band short 3 LOAD WG X-band load 5 Offset LOAD WG X-band load 2 THRU Insertable thru standard 4 THRU 1/4 Offset Insertable thru standard	Calibration Kit Class C S11A C S22A C FWD TRANS C REV TRANS C S11B C S22B C FWD MATCH C REV MATCH S S11C C S22C C ISOLATION C Link FWD TRANS, FWD MATCH, REV TRANS, and REV_MATCH Expanded Calibration (applies to reflection classes) Measure all mateable standards in class Use expanded math when possible S11C LOAD
Add Edit Delete De	Unselected Standards ID Label Description 1 SHORT VG X-band short 2 THRU Insertable thru standar 4 THRU 1/4 Offset Insertable thru standar Image: Selected Standards Image: Sel

Figure 34. Assigning standards to class SOLT (with Offset Load).

7. Click **OK** when done to return to the "Edit Kit" page, and then click **OK** again to return to the "Edit PNA Cal Kits" page. At this point, you should be able to see the kit that you just created under the list of "Installed Kits" (Figure 35).

Edit	PNA Cal Kits	
0	Ipen Save As.	Restore Defaults
		Installed Kits
	Import Kit	Save As Insert New Print to File
ID	Kit Name	Description
1	85052B	3.5 mm with sliding load
2	85052D	3.5 mm Calibration Kit
3 4 5 6 7	My Own WG Kit	Creating my own WG cal kit
4	85033D/E	3.5 mm Calibration Kit
5	85052C	3.5 mm SOLT/TRL Calibration Kit
6	85056A	2.4 mm with sliding load
8	85056D	2.4 mm Calibration Kit 2.4 mm/2.92 mm with Broadband Load
9	85056K 85056K.01	2.4 mm/2.92 mm with Broadband Load 2.4 mm/2.92 mm with Sliding Load
10	85058B Databa	1.85 mm Precision Database Cal Kit
11	85058E Databa	1.85 mm Economy Database Cal Kit
12	85058BP Polyno	1.85 mm (Reduced Accuracy)
13	85058EP Polyno	1.85 mm Economy (Reduced Accuracy)
14	85059A Data-ba	1.00 mm Data-based Precision Cal Kit
15	85059AP Polyno	1.00 mm (Reduced Accuracy)
16	85038A	7-16 Calibration Kit
17	85050B	APC 7 with sliding load
	Edi	t Kit Delete ^ v
		OK Cancel Help

Figure 35. Calibration kit file created, done!

8. Congratulations! You are now ready to calibrate in waveguide.

Appendix B: Performing Calibrations

I. SmartCal, 2-port calibration

- 1. Calibration > Calibration Wizard ...
- 2. Select SmartCal (GUIDED Calibration), then click Next> (Figure 36, top)
- 3. Select Cal Type, click Next> (Figure 36, middle)
- 4. Use dropdown menu and then the scroll bar to select the DUT connectors (Figure 36, bottom). Also, use dropdown menu to select the available calibration kit based on the selected DUT connectors. Notice, the default **Cal Method** is **2-Port**, **Defined Thru**, TRL. Plus, if "Modify Cal" is not selected, then steps shown in Figure 37 will be skipped. Click **Next>**

	X
Calibration Wizard: Begin Calibration	
SmartCal (GUIDED Calibration): Use Mechanical Sta	
C UNGUIDED Calibration (Response, 1-port, 2-port): U	se Mechanical Standards Select Calibration preferences?
O Use Electronic Calibration (ECal)	Assistance is available in the online Help.
	in the second
	Save Preferences. Don't show this page again.
	< <u>Back</u> . <u>N</u> ext > Cancel Help
Select Guided	Calibration Type (Mechanical Standards)
Cal Type Select	
1 Port Cal	Select 1st Port
	Select 2nd Port: 2
	< <u>₿</u> ack <u>N</u> ext> Cancel Help
Use dropdown menu to	Guided Calibration: Select DUT Connectors and Cal Kits Connectors Cal Kits
select DUT connectors.	Connectors Cal Kits DUT Port 1 WR-03 Waveguide V03 AL_03 Cal Method: 2-Port, Defined Thru, T
select DOT connectors.	DUT Pol 2 WR-03 Waveguide V V03_AL_03 V
Selecting "Modify (
8 ,	(Wodity Cal.)
show steps in Figur	e 30. Optimular Select [Modify Cal] to change the Cal Method and/or standards used for the selected oal kits.
	<back next=""> Cancel He</back>

×

Figure 36. Select SmartCal and DUT connectors.

 Having selected "Modify Cal" allows you to change the Cal Type. Figure 37 (top) shows Cal Type: TRL, you can click Mod Stds, and then use the dropdown menu on the right to select a different cal type. Figure 37 (middle) shows the selection of SOLT. Clicking OK returns you to the previous screen, and this time it shows the Cal Type: SOLT (Figure 37, bottom).

dify Cal			×	
Thru Calibration Options (Cal Type: 1 Thru Cal				
Thru #1 1-2 🔽 Defined Thru Defined Thru				
Flush Thru Unknown Th Adapter Rem	ru	· · · · · · · · · · · · · · · · · · ·		
	< Back	Next > Cancel Help	1	
i	View/Modify Properties of Cal for Port	ts 1 and 2	- X	
		Advanced		
	Defined Thru	Celibration type TRL TRL SOLT Select View/Modify to preview the	View/Modify	
	Constant and a second of	Select view/modily to preview the	standaids to be measured.	
		OK	Cancel Help	
		dify Cal Thru Calibration Options (Cal Type: SOLT) Thru Cal Method Thru #1 12 V Defined Thru V		×
			< Back	Cancel Help

Figure 37. Changing Cal Type.

6. The calibration has now begun. As shown on the upper-left corner of each screenshot (Figure 38), the 2-port, Flush Thru, TRL calibration includes four steps. The example shown here is based on using an OML cal kit.

Step 1 of 4: Port 1, Short Step 2 of 4: Port 2, Short Step 3 of 4: Port 1, THRU + NULL Shim, Port 2 Step 4 of 4: Port 1, THRU + ¼ Offset Shim, Port 2 33 | Keysight | PNA Microwave Network Analyzers – Application Note

Guided Calibration Step 1 of 4	x i
PORT 1 SHORT Connect G-BAND FLUSH SHORT [S-05] to port	Done
Select [Measure] when connections have been made.	
< Back	Next> Cancel Help
Guided Calibration Step 2 of 4	
PORT	2 SHORT
	H SHORT [S-05] to port 2
Select [Measure] when connections have been mad	e.
	< <u>Back</u> Next> Cancel Help
Connect	ap 3 of 4 Year and the second secon
	Guided Calibration Step 4 of 4 PORT 1 PORT 2 I PORT 1 THRU+1/4 OFFSET SHIM PORT 2 Connect G-BAND 1/4 OFFSET THRU [051/4:05] 1/4 WAVE OFFSET NULL SHIM Delevere on 1 and not 2
	between port 1 and port 2 Done Select [Measure] when connections have been made.
	< Back

Figure 38. Steps of the 2-port, Flush Thru, TRL calibration (using an OML cal kit).

7. Congratulations! You have just completed a 2-port, Flush Thru, TRL calibration.

Alternatives:

Using an OML calibration kit, performing an SOLT calibration with Offset Load would require 9 steps:

Step 1 of 9: Port 1, Short + NULL Shim Step 2 of 9: Port 1, Short + 1/4 Offset Shim Step 3 of 9: Port 1, THRU + NULL Shim, Load Step 4 of 9: Port 1, THRU + 1/4 Offset Shim, Load Step 5 of 9: Port 2, Short + NULL Shim Step 6 of 9: Port 2, Short + 1/4 Offset Shim Step 7 of 9: Port 2, THRU + NULL Shim, Load Step 8 of 9: Port 2, THRU + 1/4 Offset Shim, Load Step 9 of 9: Port 1, Port 2 Using an OML calibration kit, performing an SOLT calibration with fixed Load would require 7 steps: Step 1 of 7: Port 1, Short + NULL Shim Step 2 of 7: Port 1, Short + 1/4 Offset Shim Step 3 of 7: Port 1, Load Step 4 of 7: Port 2, Short + NULL Shim Step 5 of 7: Port 2, Short + 1/4 Offset Shim Step 6 of 7: Port 2, Load Step 7 of 7: Port 1, Port 2

II. SmartCal, 1-port calibration

- 1. Calibration > Calibration Wizard ...
- 2. Select SmartCal (GUIDED Calibration), then click Next> (Figure 39, top)
- 3. Select **Cal Type**. Notice on the right that you can choose either Port 1 or Port 2 as the test port for the 1-port calibration. Then, click **Next>** (Figure 39, middle)
- 4. Use dropdown menu and then the scroll bar to select the DUT connectors (Figure 39, bottom). Also, use dropdown menu to select the available calibration kit based on the selected DUT connectors. Notice, the Cal Method here is simply 1-Port. Plus, if "Modify Cal" is not selected, then steps shown in Figure 40 will be skipped. Click Next>

Calibration Wizard: Begin Calibration	×
 SmartCal (GUIDED Calibration): Use Mechanical Standards 	
C UNGUIDED Calibration (Response, 1-port, 2-port): Use Mechanical Standa	rds Select calibration preferences.
C Use Electronic Calibration (ECal)	Not sure about preferences? Assistance is available in the online Help. e Preferences. Don't show this page again.
< <u>B</u> ack	Next> Cancel Help
Select Guided Calibration Type (M Cal Type Selection Port Cal Port Cal	(cchanical Standards) Image: Select 1st Port. Select 1st Port. Image: Select 1st Port.
	Cancel Help
Use dropdown menu to select DUT connectors. Selecting "Modify Cal" will show steps in Figure 39."	Guided Calibration: Select DUT Connectors and Cal Kits Connectors Cal Kits DUT Port 1 WR-03 Waveguide W03_AL_03 Cal Method: 1-Port Image: Select During Calibration W03_AL_03 Image: Select During Calibration Cal Method: 1-Port Image: Select During Calibration Cal Method: 1-Port
	< <u>B</u> ack <u>N</u> ext> Cancel Help

Figure 39. Select SmartCal and DUT connectors.

5. Having selected "Modify Cal" allows you to look at the screens shown in Figure 40. However, in the case of 1-port calibrations, you are limited to SOL calibration only. Thus, clicking on "Modify Cal" does not offer you additional selection. Your Cal Type remains as One Port.

Modify Cal	×
Thru Calibrative Uptions (Cal Type: 1- Thru Cal M Port 1 2 One Port	
	<back cancel="" help<="" th=""></back>
	View/Modify Selections of Cal Standards for this Cal
	Select 1-Port calibration type Advanced One Port Calibration type Select View/Modify to preview the standards to be measured.
	OK Cancel Help

Figure 40. Viewing **Modify Cal** displays.

6. The calibration has now begun. As shown on the upper-left corner of each screenshot (Figure 41), the 1-port calibration includes three steps. The example shown here is based on using a OML cal kit.

Step 1 of 3: Port 1, Short + Null Shim Step 2 of 3: Port 1, Short + ¼ Offset Shim Step 3 of 3: Port 1, Load

aided Calibration Step 1 of 3 PORT 1 PORT 2 ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓
PORT 1 SHORT+NULL SHIM Measure Connect G-BAND SHORT [S-05 + 05-05] SHORT + 0.100" NULL SHIM to port 1 Done
ielect [Measure] when connections have been made.
<beck. next=""> Cancel Help</beck.>
Guided Calibration Step 2 of 3 PORT 1 PORT 1 PORT 1 SHORT+1/4 OFFSET SHIM Measure Connect G-BAND 1/4 OFFSET SHORT (5-05+ 051/4-05) SHORT+ 1/4 WAVE NULL One Select [Measure] when connections have been made.
<u> </u>
Guided Calibration Step 3 of 3
PORT 1 LOAD Measure Connect G-BAND FLUSH FD/SED L0AD [T-05] to port 1 Done
Select [Measure] when connections have been made.
Cancel Help

Figure 41. Steps of the 1-port calibration.

7. Congratulations! You have just completed a 1-port calibration.

Alternative:

Using an OML calibration kit to perform a 1-port SOL calibration with Offset Load would require 4 steps:

Step 1 of 4: Port 1, Short + NULL Shim Step 2 of 4: Port 1, Short + ¼ Offset Shim Step 3 of 4: Port 1, THRU + NULL Shim, Load Step 4 of 4: Port 1, THRU + ¼ Offset Shim, Load

III. Unguided Calibration, Thru Response

1. Calibration > Calibration Wizard ...

- 2. Select UNGUIDED Calibration, then click Next> (Figure 42, top)
- 3. For Unguided calibration, the user must select the calibration kit because the default (or the kit last used) is often not what you want. Click on View/Select Cal Kit (Figure 42, middle) and then use the scroll bar to select the calibration kit of choice (Figure 42, bottom). Click **OK**.

Calibration Wizard: Begin Calibration
C SmartCal (GUIDED Calibration): Use Mechanical Standards
C UNGUIDED Calibration (Response, 1-port, 2-port): Use Mechanical Standards Select calibration preferences.
C Use Electronic Calibration (ECal) Not sure about preferences? Assistance is available in the online Help.
Save Preferences. Don't show this page again.
<pre><bpdk next=""> Cancel Hep</bpdk></pre>
Select Calibration Type for Mechanical Standards X Cal Type Selection Perform 2 Port Solt 1 1 Port Solt Flat TPL TypeN(75) Calibration Kit Response View/Select Cal Kit
<pre>< Back Next > Cancel Help</pre>
Select Cal Kit ID Kit Name Description Choose class type 32 Q11644A Q-band Waveguide SOLTIFIC Calibration C SOLT classes 7 R11644A Q-band Waveguide SOLTIFIC Calibration O TRL classes 30 U11644A Q-band Waveguide SOLTIFIC Calibration 31 V11644A Q-band Waveguide SOLTIFIC Calibration 32 W11644A Q-band Waveguide SOLTIFIC Calibration 33 V10_AL_10_R6 Orth, WR-10 Cal Kit, S/N V10-AL-10 34 W03_AL_03 Orth, WR-10 Cal Kit, S/N V10-AL-10 XV03_AL_03 Orth, WR-10 Cal Kit, S/N V10-AL-10 CK Cancel

Figure 42. Select Unguided calibration, and calibration kit of choice.

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4. This returns to the previous page, and the Cal Kit information has been updated (Figure 43, top). Make sure Response is highlighted on the left. (If not, click on it once.) Click Next> to start the Response calibration.

Your Response calibration selection will be different depending on your active trace. If the active trace is S11, then you will see the standard selection for Reflection Response, as those shown in Figure 43 middle. If the active trace is S21, then the standard selection are those for Transmission Response, as those shown in Figure 43 bottom.

Select Calibration Type for Mecha Cal Type Selection 2 Port Solt 1 Port Solt TRL Response	Response Configuration Selected Cal Kit: V03,AL_03 OML WR-03 (J Band) Universal Calibration Characterization: < type> View/Select Cal Kit	
	< Back Next> Cancel Help Measure Mechanical Standards X Port 1 (511) Shout Shout Shout Offset Cal Kit 34, V03, AL, 03, 0ML, WP-03 (J, Band) Universal Reflection Response: Select a standard < Back Best> Cancel Help	
	Measure Mechanical Standards Port 2 · Port 1 (S21) Thru Isolation Thru Isolation [optional] [optional] Cal-Ka-34: V03_AL_03 OME WF-034L Band Universal Transmission Response: Select a standard Transmission Response: Select a standard <a>(Back (Lext>)	Show Prompts Normalize Cancel Help

Figure 43. Response calibration and associated standard selection for Reflection Response and Transmission Response.

5. Congratulations! You have just completed a Response calibration.

Appendix C: Caring For Waveguide (WG) Interfaces

A clean surface at millimeter-wave is much more important than at lower frequencies because any debris on its surface can potentially be added to the measurement distorting the measurement results.

Caring for WG interfaces is not difficult. Dirt and dust can be removed using the following items:

- Isopropyl Alcohol 99.5%
- Lint-free cloth
- Pressurized air for dust removal

To remove dirt on the surface, simply put a few drops of the Isopropyl Alcohol on the Lint-free cloth and then gently wipe the surface.

To remove dust, simply spray the pressurized air on the surface.

Appendix D: Supplemental Data

As can be seen in Figures 17 through 20, using external synthesizers for higher frequency ranges, such as 140 to 220 GHz (WR-05) and 220 to 325 GHz (WR-03), can improve dynamic range up to 10 dB and 20 dB, respectively, as well as improving trace noise. Below, figures 44 through 46 show that the PSG series used as external synthesizers do not make any difference with or without Option UNX, ultra-low (close-in) phase noise. We chose to focus our comparison in the frequency range of 220 to 325 GHz only because if there is any noticeable difference, it would easily appear at this frequency range than at a lower one. In the comparison, either both PSG units have Option UNX, or they both do not.

In the case of trace noise, both transmission (S21) and reflection (S11) have remained very low regardless of Option UNX. They are less than ± 0.0300 dB in the worst case; above 290 GHz in the case of S21, and above 305 GHz in the case of S11.

Based on these measurement results, we are no longer including Option UNX on the PSG configurations when used as external synthesizers.

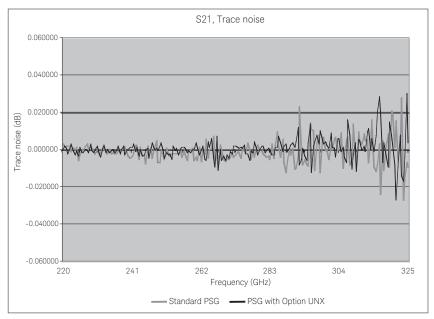


Figure 44. S21 trace noise comparison between measurements made with external synthesizers with and without Option UNX, ultra-low (close-in) phase noise.

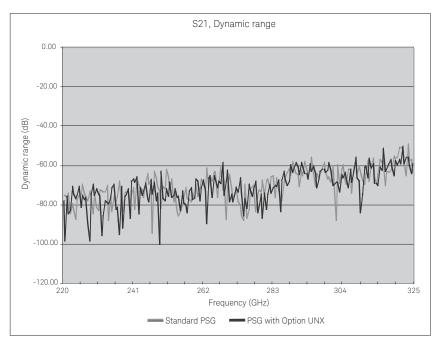


Figure 45. S21 dynamic range comparison between measurements made with external synthesizers with and without Option UNX, ultra-low (close-in) phase noise.

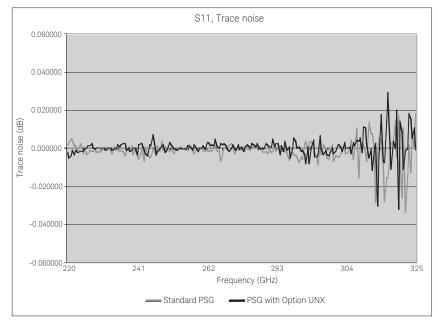


Figure 46. S11 trace noise comparison between measurements made with external synthesizers with and without Option UNX, ultra-low (close-in) phase noise.

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