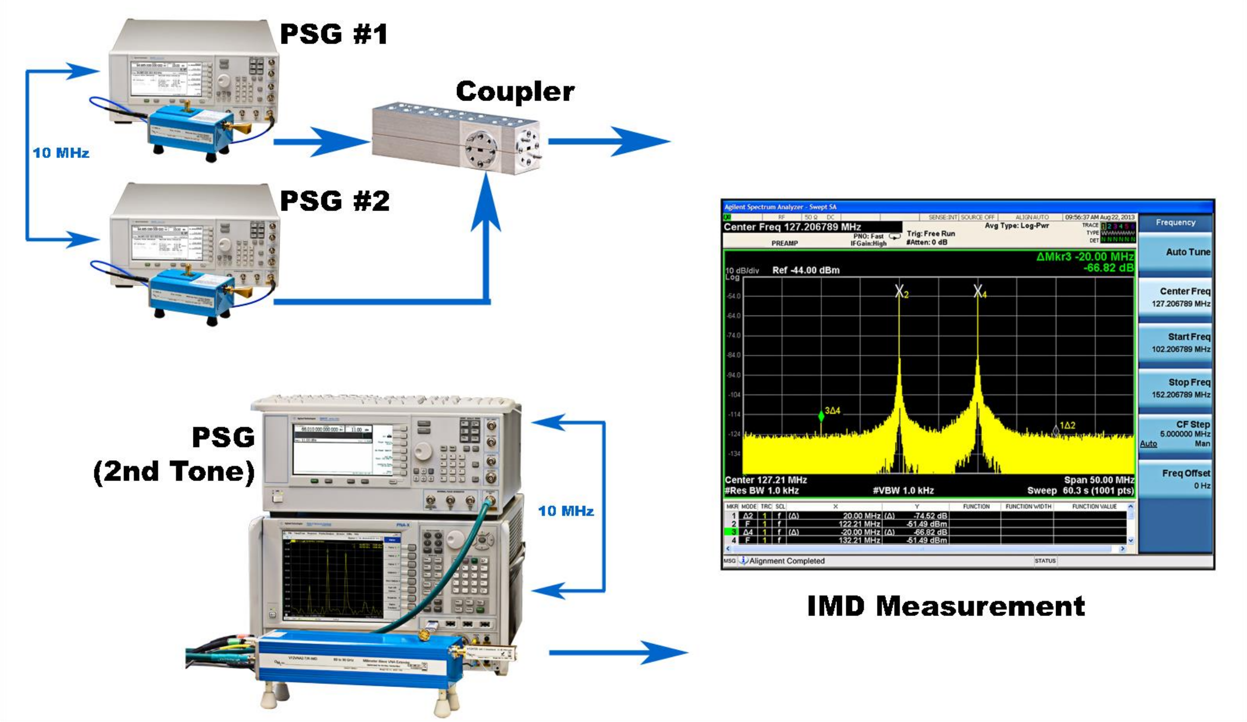
Application Note

How to Use the T/R-IMD Module from OML

Introduction

Intermodulation distortion (IMD) is a powerful measurement tool for characterizing the linearity of emerging devices; unfortunately, the setup complexity for millimeter wave (mm-wave) prevents many engineers from currently using this tool.

As shown in the following setup, a straightforward IMD approach consists of using two synthesizers, two source modules and a combining network. The resulting mm-wave two-tones connect to the DUT and eventually outputs to a spectrum analyzer for measurement.

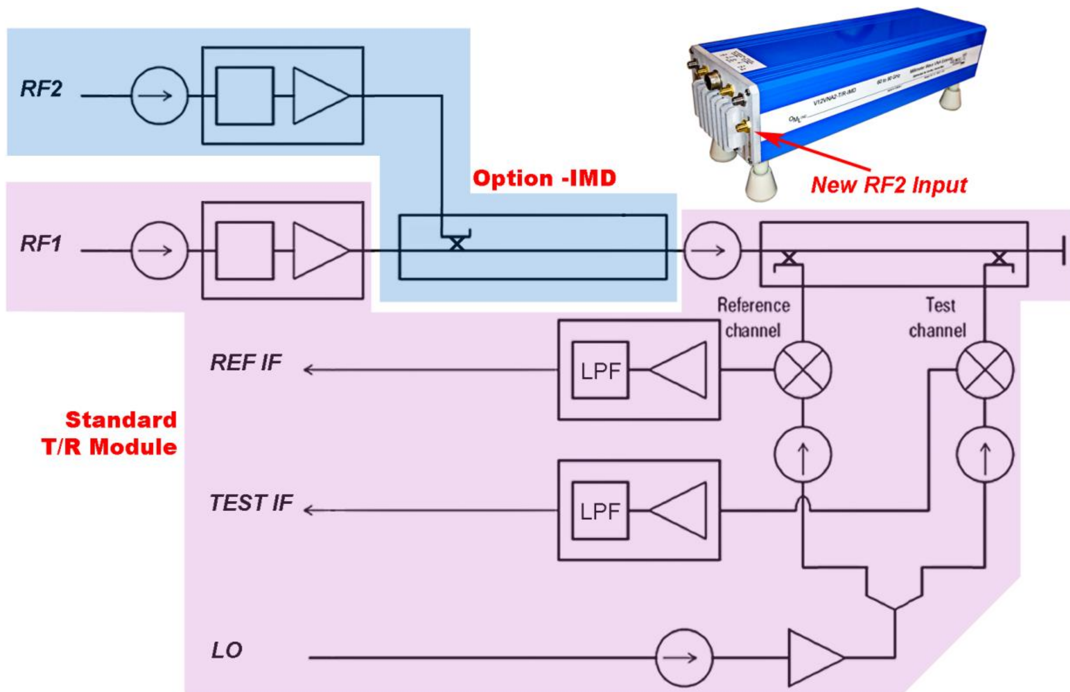


In many cases, the DUT also requires gain compression, harmonics and S-parameter measurements for thorough characterization. Ideally, a single instrument using a single connection offers potential improvements in efficiency, throughput, precision and capital equipment expenditures. For that reason, the purpose of this application note is to describe how to conduct IMD measurements using the T/R-IMD module from OML.

In this approach, the –IMD option adds a second source module and coupler into the existing T/R module. Afterwards, the T/R-IMD module can satisfy popular single connection multiple measurement scenarios for emerging active devices. This new integrated approach is the simplest solution for overcoming mm-wave IMD testing complexities.

T/R-IMD Module from OML

As shown in the following block diagram, the T/R-IMD leverages the inherent precision, repeatability, reliability, and stability of the standard T/R module. The careful positioning of the combining coupler minimizes impacts to S-parameter measurements while offering insertion of the second tone with maximum preservation of mm-wave power. The coupler selection ensures adequate isolation between the two tones. The "source module" integration completes the path so the new module now accepts two microwave signals as input. By integrating the source module and coupler into the T/R-IMD module simplifies the IMD setup while enabling further single connection multiple measurement scenarios.



OML T/R-IMD Block Diagram

IMD Measurement Overview

As an overview, the IMD measurement is a popular task consisting of the following two main steps:

1. Set the desired IMD separation & power levels
2. Optimize "receiver" to measure IMD

In practice, the workflow happens in reverse: first setup the receiver and then set IMD separation and power levels. This application note will follow this logical workflow.

Optimize “receiver” to measure IMD

Whether using a network analyzer or spectrum analyzer, the “receiver” is essential for visualizing and independently verifying attributes of the IMD setup. Getting started involves configuring the receiver for center frequency and span. As a practical tip, the span is usually set for five times the IMD tone separation. Similarly, the center frequency is set for the first tone plus half the separation.

For example, a 75 GHz IMD measurement with 10 MHz offset consists of the first tone at 75 GHz (f_1) and the second tone at 75.01 GHz (f_2). According to IMD equations, the third order products will appear at 74.99 GHz ($2f_1$- f_2, lower) and 75.02 GHz (f_1-$2f_2$, upper). Applying the practical tip yields an optimal span as 50 MHz (5 x 10 MHz offset). Additionally, an optimal center frequency for hands-free measurements is 75.005 GHz (75 GHz + 10 MHz / 2). Given these optimal settings, the receiver is ready to setup and measure IMD.

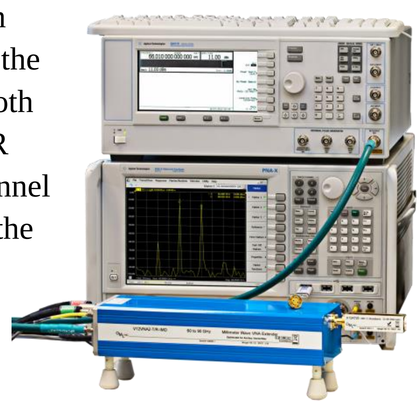
Set the desired IMD separation & power levels

A through connection between the two tone combining network and the receiver offers a convenient mechanism for configuring IMD measurements. In this configuration, the IMD separation and power levels are set according to prerequisites. This configuration also reveals the residual IMD products that may represent a limitation in the overall setup.

For example, we want two IMD measurements using the previously described setup at 75 GHz. The two power levels are -2 dBm and -10 dBm. The preparation involves setting the first and next the second tone to the desired power level, which is now easy using the previously configured receiver settings as feedback.

General receiver comment

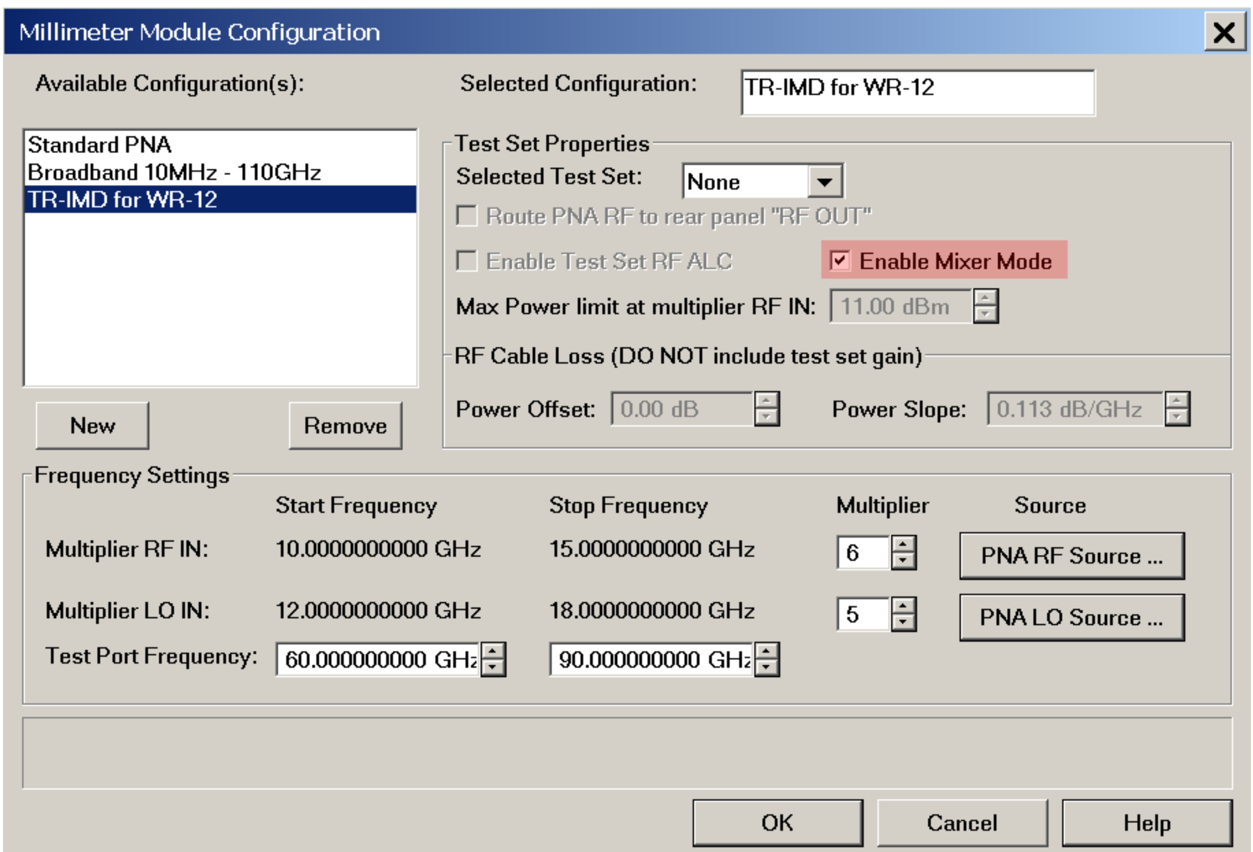
The T/R-IMD module is compatible with using both spectrum analyzer and network analyzer as a receiver. For that reason, the following measurement examples will display results using both receivers. To duplicate these results will require a second T/R module in a through connection scenario, where the Test Channel (B1) is split (e.g., Mini-Circuits, ZFSC-2-1-S+): one path to the spectrum analyzer and the other path to the network analyzer. The side-by-side results will demonstrate comparable results for confidence building purposes.



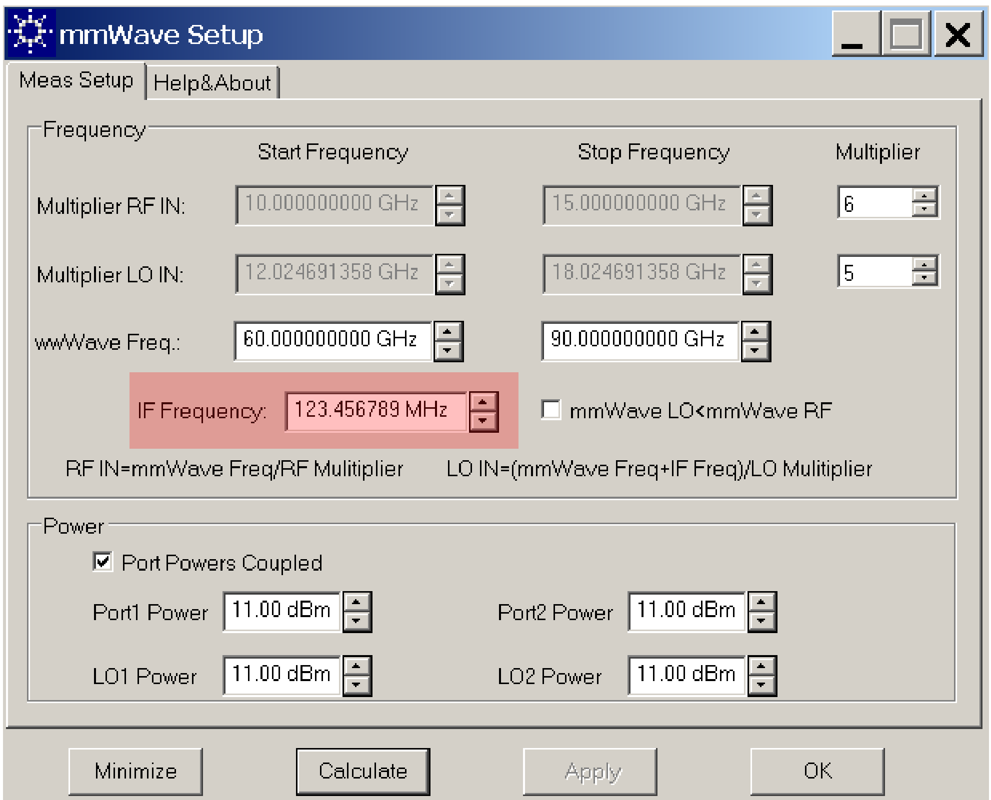
Measurement examples using Keysight's PNA-X (direct connect)

The purpose of the following example is to describe the process towards conducting an IMD measurement using a network analyzer and external synthesizer that are 10 MHz synchronized. The following procedure highlights the workflow for the mm-wave equipped Keysight PNA-X (e.g., N5247A with firmware A.09.90.02) and generic Keysight PSG (e.g., E8257D). The WR-12 setup also consists of the V12VNA2-T/R-IMD and V12VNA2-T/R modules. Results are from the test channel (B1) and generic Keysight EXA (e.g., N9010A).

Getting started begins with configuring the network analyzer for mm-wave measurements. This usually involves first specifying the modules, including the frequency range and multipliers for RF & LO. It's important that the network analyzer offer flexible configurations for mixer measurements, which for the PNA involves enabling the mixer mode. An example from the millimeter wave configuration menu is shown in the following screen capture.



Next, the network analyzer for the direct connect scenario requires the selection of an IF frequency, where the OML modules support an IF between 5 and 300 MHz. In addition, the IF establishes the location of images in subsequent network analyzer displays when configured for spectrum analyzer measurements such as IMD. As an advanced tip, the display may benefit by optimizing this IF selection for image avoidance with IMD measurement results. The following screen capture illustrates how the Keysight mm-wave macro prompts for an IF selection. In this case, the measurement examples will use an IF of 123.456789 MHz.



Once the network analyzer is mm-wave ready for measurements, we can proceed with the specific steps toward implementing an IMD measurement.

IMD Settings

In this measurement scenario, a 75 GHz IMD measurement with 10 MHz offset consists of the first tone at 75 GHz (f_1) and the second tone at 75.01 GHz (f_2). According to IMD equations, the third order products will appear at 74.99 GHz ($2f_1$- f_2, lower) and 75.02 GHz (f_1-$2f_2$, upper).

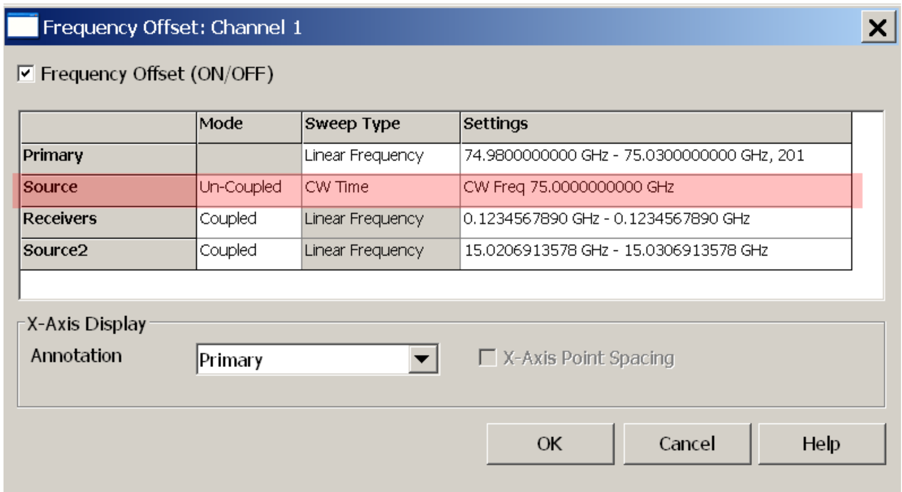
This IMD measurement will use a center frequency of 75.005 GHz and a span of 50 MHz. Furthermore, the measurement consists of two amplitude scenarios: -2 dBm and -10 dBm.

PNA-X: Optimize "receiver" to measure IMD

With the PNA-X ready for mm-wave S-parameter measurements, the following framework establishes how to conduct an IMD measurement. Keywords indicate available menu selection items on the PNA-X. Depending on preferences, further refinements are possible to optimize results.

1. Set trace 1 to measure R1 and set IF Bandwidth to 1 kHz.
2. Stimulus, power, power & attenuators…
    a. Uncheck 'port powers coupled'
    b. Set Port 1 power to 0 dBm
3. Set desired center frequency and span: 75.005 GHz, span 50 MHz
4. Best practice to ensure external PSG is set to RF OFF during calibration
5. Calibrate Source Power: response, cal, power cal, source power cal…
    a. Set accuracy tolerance to 0.25 dBm
    b. Options (cal power = 0 dBm)
        i. Use a receiver, R1
        ii. Power table: load power table for V10VNA2-T/R-IMD (RF1)
        iii. Check calibrate the source at multiple power levels
        iv. Specify power levels…
            1. -5 dBm to -12 dBm in 0.5 dB steps
        v. OK returns to source power calibration menu
    c. Take Cal Sweep (PNA-X builds power in/out table in approximately 5 minutes)
6. Calibrate Receiver (effectively transfer source calibration to test channel receiver)
    a. Through connection
    b. Set trace 1 to measure B1
    c. Response, cal, power cal, receiver power cal…
        i. Receiver power (0 dBm), next, take receiver cal sweep
        ii. PNA builds receiver cal

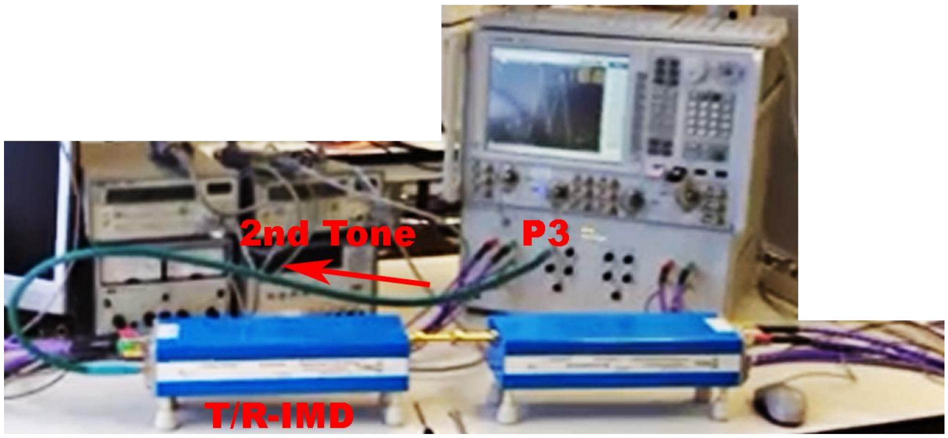
7. Change sweep from swept frequency to CW
    a. Stimulus, freq, frequency offset…
        i. As shown in following capture, change source to uncoupled, CW, 75 GHz



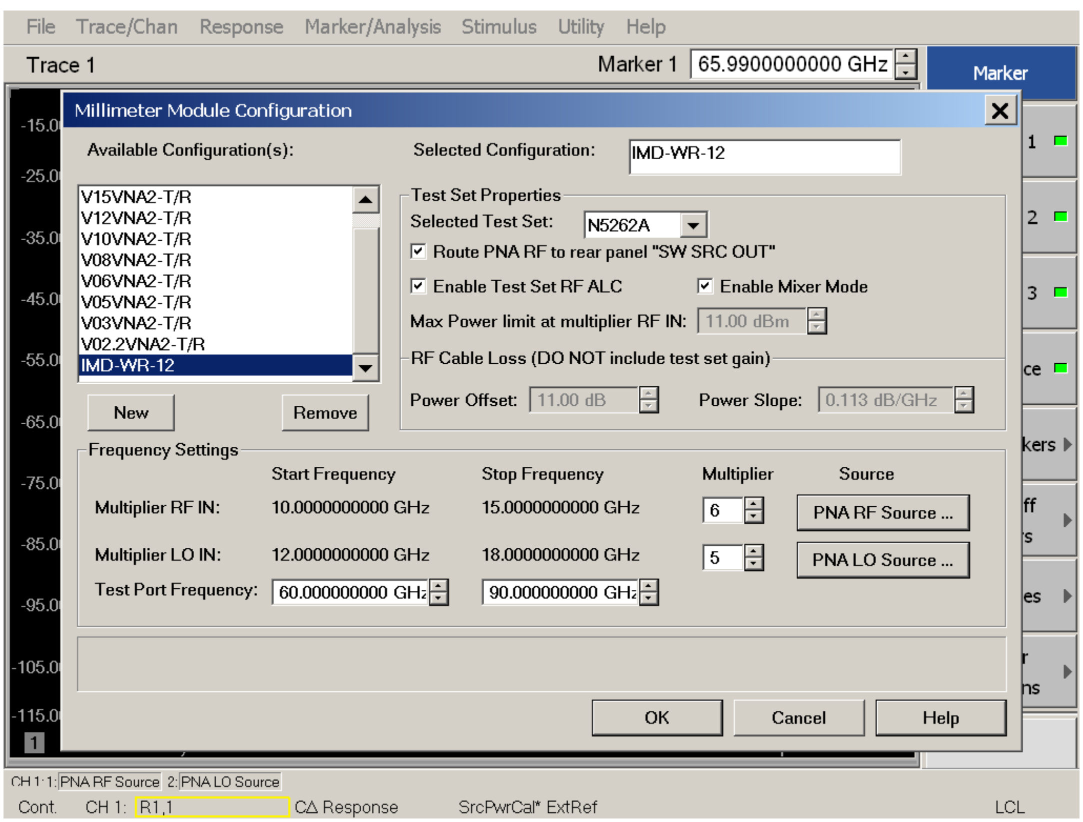
8. Best practice to ensure external PSG is synchronized to PNA (10 MHz)
9. On PNA-X, the display shows the first CW tone at 75 GHz
10. On PSG, set frequency for IMD separation of 10 MHz
    a. Configure PSG for OEM source module: WR-12
    b. Set frequency to 75.01 GHz
    c. Set amplitude to 10 dBm (default for maximum output power)
    d. PSG is set to RF ON
11. On PNA-X, the display shows both tones at 75 GHz and 75.01 GHz, including products
12. Using B1 display, adjust PNA-X power to -2 dBm
    e. Stimulus, power, power…
        i. Set Port 1 power to -2 dBm
        ii. Adjust power as necessary for amplitude precision
13. On PSG, adjust amplitude for -2 dBm output power (using B1 display)
    f. Lower amplitude produces lower RF: target 0 to – 15 dBm
        i. This Pin/Pout technique is how to adjust mm-wave output power
    g. Adjust amplitude as necessary for amplitude precision
14. Once the two tones are equal in amplitude, the IMD measurement is ready for interpretation

Advanced Overview: PNA / N5262A Configuration

The IMD procedure is similar whether you use the direct connect or N5262A configuration. The setup simplifies when using the N5262A because the IF is predetermined. An overview of this system configuration is shown in the following photo. Note that there is a Port 3 connection to the SRC 2 RF IN of the N5262A.



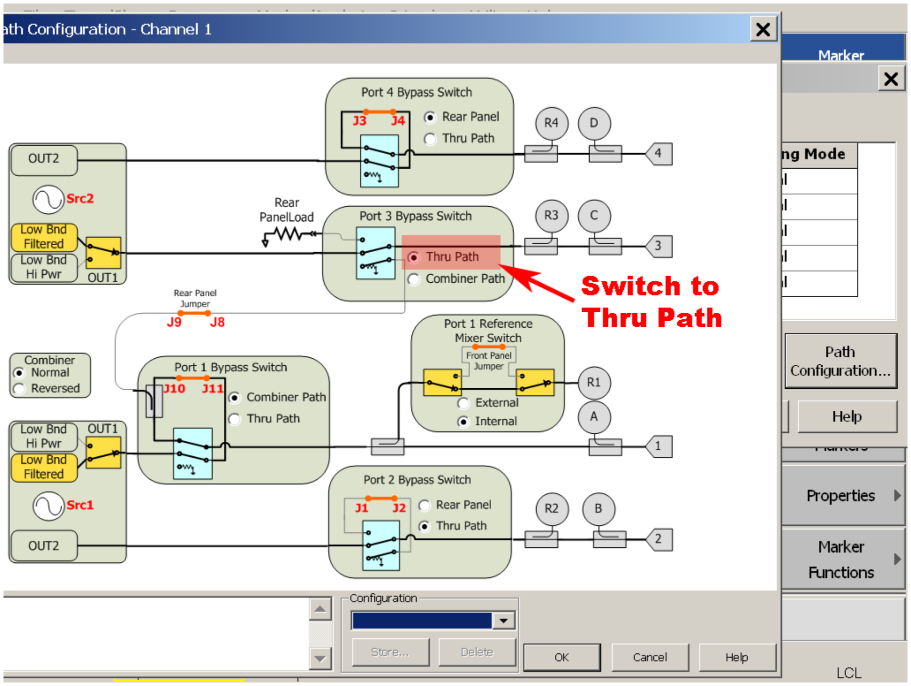
The firmware setup steps follow a similar sequence. In the following screen capture, the mm-wave module configuration requires the 'Enable Mixer Mode' selection. Using the N5262A test set controller imposes a predetermined IF setting on the test system of 7.8 MHz.



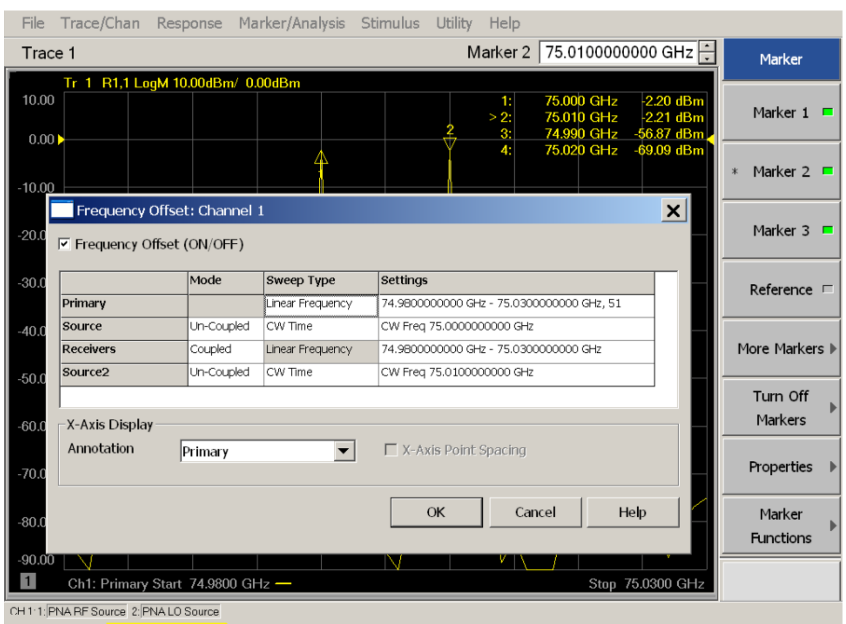
The IMD setup continues on a similar path as the direct-connect sequence:

1. Set trace 1 to measure R1 and set IF Bandwidth to 1 kHz.
2. Stimulus, power, power & attenuators…
    a. Uncheck 'port powers coupled'
    b. Set Port 1 power to 0 dBm
3. Set desired center frequency and span: 75.005 GHz, span 50 MHz
4. Best practice to ensure 2nd Source (P3) is set to RF OFF during calibration
5. Calibrate Source Power: response, cal, power cal, source power cal…
    a. Set accuracy tolerance to 0.25 dBm
    b. Options (cal power = 0 dBm)
        i. Use a receiver, R1
        ii. Power table: load power table for V10VNA2-T/R-IMD (RF1)
        iii. Check calibrate the source at multiple power levels
        iv. Specify power levels…
            1. -5 dBm to -12 dBm in 0.5 dB steps (direct connect)
            2. A different Pin versus Pout range may apply when using N5262A
        v. OK returns to source power calibration menu
    c. Take Cal Sweep (PNA-X builds power in/out table in approximately 5 minutes)
6. Calibrate Receiver (effectively transfer source calibration to test channel receiver)
    a. Through connection
    b. Set trace 1 to measure B1
    c. Response, cal, power cal, receiver power cal…
        i. Receiver power (0 dBm), next, take receiver cal sweep
        ii. PNA builds receiver cal
7. Change sweep from swept frequency to CW
    a. Stimulus, freq, frequency offset…
        i. Change source to uncoupled, CW, 75 GHz

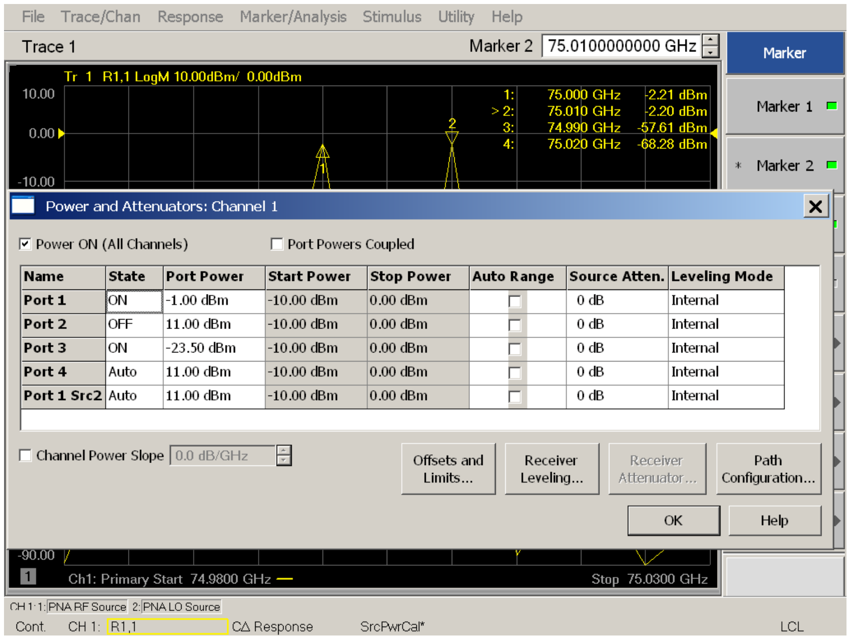
This is when we optimize the procedure for the N5262A configuration. First, we need to adjust the path configuration to route the second source to Port 3 as shown in the following screen capture. This selection is found with the following front panel keystrokes: Trace/Chan / Channel / Hardware Setup / Path Config. The adjustment involves ensuring the Port 3 Bypass Switch is in the Thru Path position.



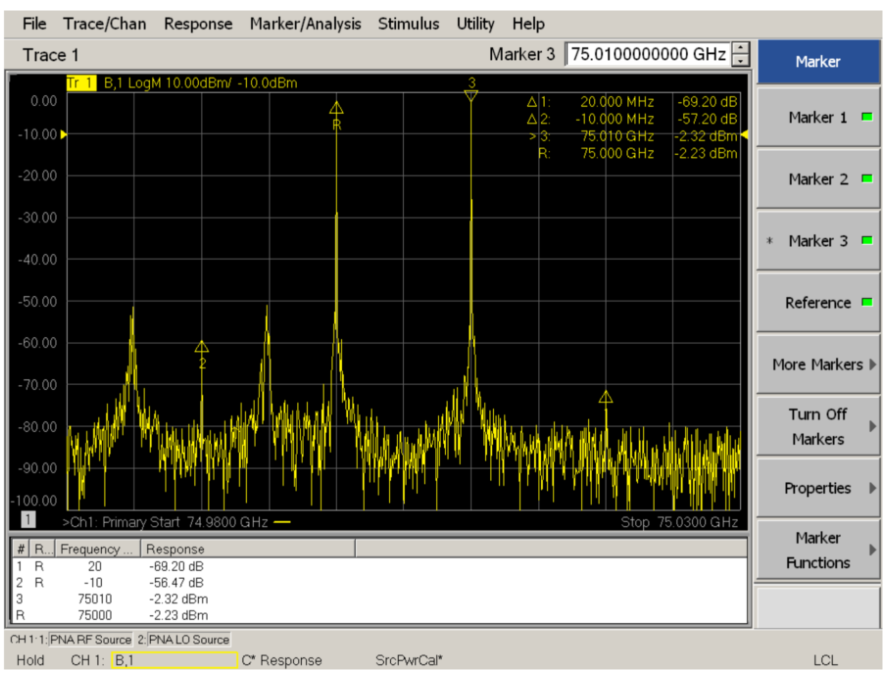
Next, the frequency setting for the second source is controlled via the frequency offset menu as shown in the following screen capture. Note that Source2 becomes the second source set with 10 MHz offset.



Finally, we set the Port 3 source to the desired ON/OFF state using the following menu. During calibration, the Port 3 state is in the OFF position. During measurements, the Port 3 state is in the ON position.



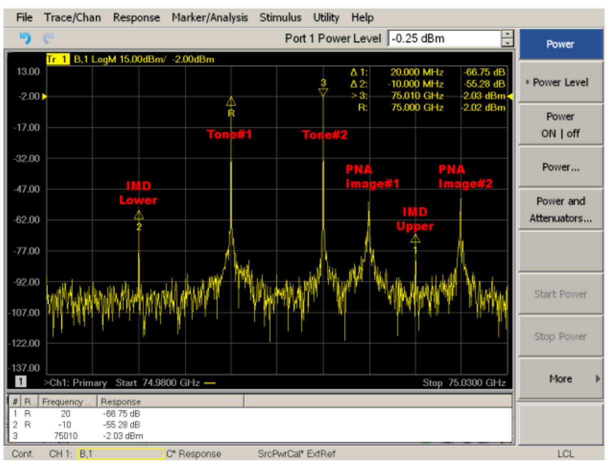
Using these advanced settings, the IMD measurements are ready for interpretation. An example is shown in the following screen capture using 801 data points. Notice the images are also present at the IF = 7.8 MHz offset.

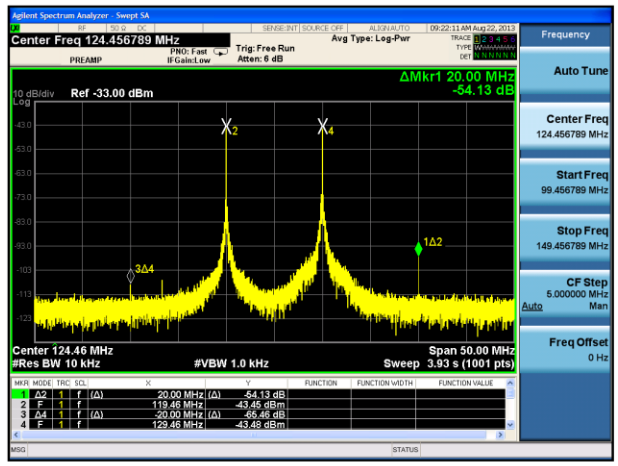


IMD Measurement Results & Comparison

The following IMD measurement uses -2 dBm input power for each tone. The side-by-side captures are from network analyzer and spectrum analyzer, respectively. Note the network analyzer capture includes two additional signals unrelated to the IMD measurement. These two signals are images from the PNA-X related to the IF of 7.6 MHz. This image phenomenon explains why 15 MHz offsets (i.e., 7.6 MHz * 2) are also visible. As a reminder, the two captures are from a power splitter to verify these unrelated signals as images instead of real signals.

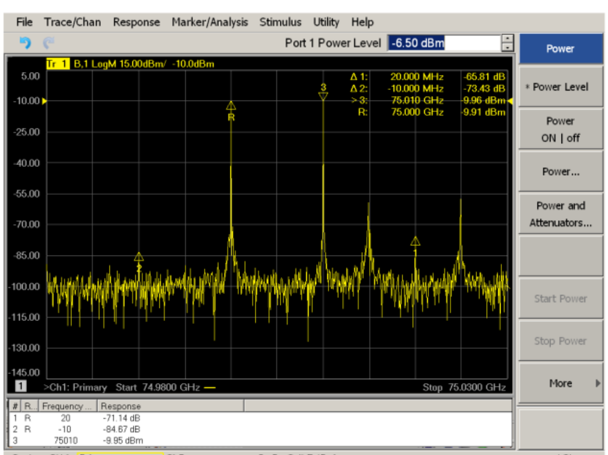
With these IMD results, TOI calculations reveal +25 to +26 dBm at 75 GHz using two tones at -2 dBm with 10 MHz separation.

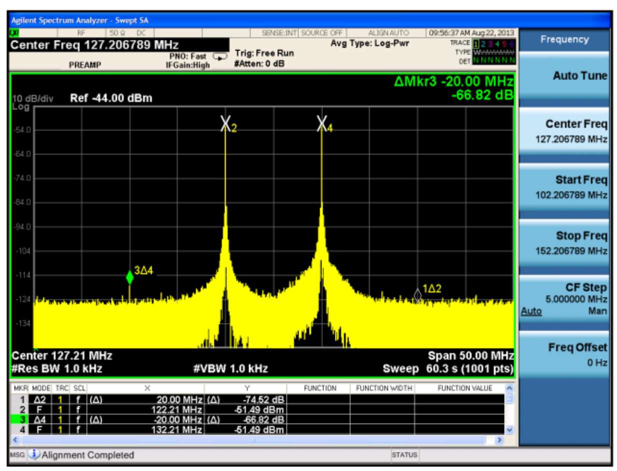




Network Analyzer (801 pts) **Spectrum Analyzer (1001 pts)**

With the following IMD results using -10 dBm (instead of -2 dBm), TOI calculations reveal +22.5 to +23.5 dBm at 75 GHz with 10 MHz separation.



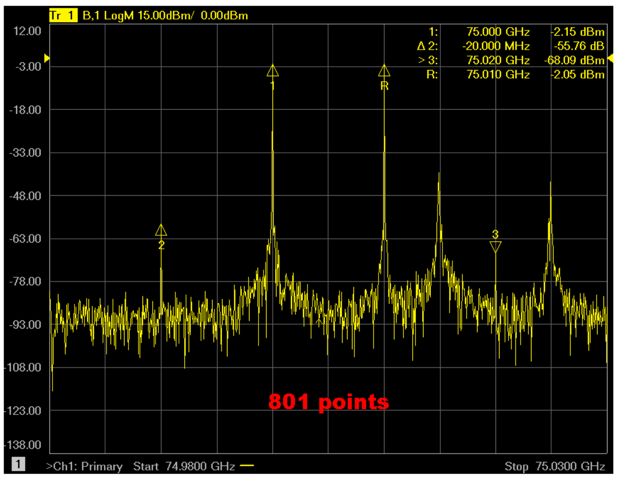


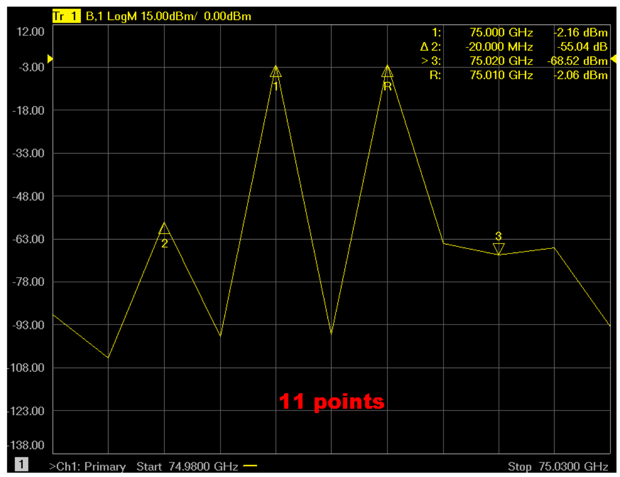
Network Analyzer (801 pts) **Spectrum Analyzer (1001 pts)**

Optimize Network Analyzer Display Discussion

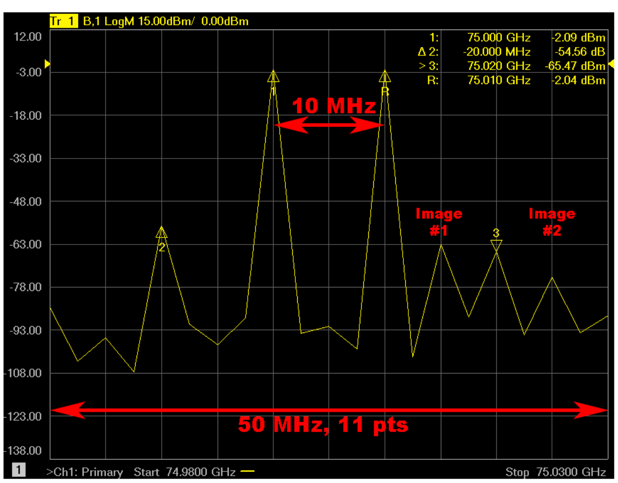
The strategic selection of span, number of points and offset can eliminate the undesirable images from the IMD measurement results. Selecting fewer points can also dramatically increase throughput by eliminating the measurements of unnecessary points except for the tones and IMD products.

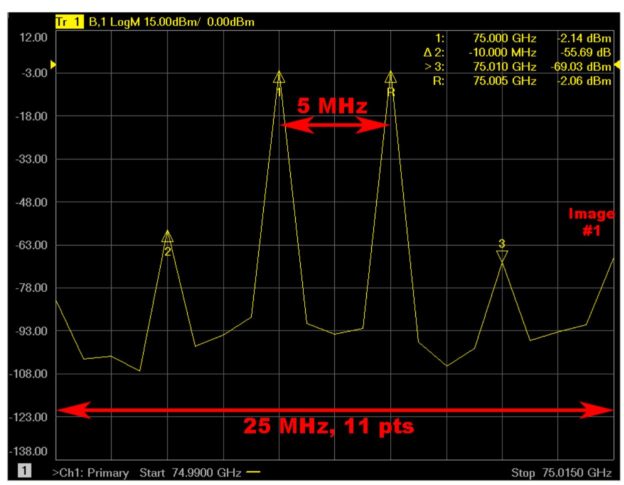
The following network analyzer captures show the difference between 801 and 11 points. Note that the marker readouts remain constant so the measurements are essentially comparable. In terms of measurement speed, the 11 points measure 72 times faster than 801 points (801 / 11). Also, note the images are less noticeable.





In the following comparison, the effects of offset change from 10 MHz to 5 MHz are shown. Note the image is less noticeable now that it is nearly out of the measurement span.





Summary

A simple and quick IMD measurement using the Keysight PNA-X in a direct connect scenario demonstrates the convenience of this single connection approach for characterizing mm-wave active devices. These examples demonstrate how to conduct IMD measurements, including image avoidance by dithering IF frequency selection, tone spacing, span and number of points. In addition, the results correlate to those results from a simultaneous spectrum analyzer measurement. For more sophisticated characterization, couple the T/R-IMD module to the PNA-X with the N5262A test set controller to further conduct swept power variants of these IMD measurements.

The VNA modules from OML are universally compatible with modern vector network analyzers from Rohde & Schwarz, Anritsu and Keysight. Upgrades are available to T/R-IMD from existing VxxVNA2-T/R modules. In this way, mechanical compatibility is possible for on-wafer measurement scenarios using probe stations.

As a premium solution, OML offers IMD architectures with electronic attenuation for enhanced power sweeps. Contact OML for more details at info@omlinc.com.