Application Note

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Combining On-Wafer Vector Network Analyzer and Spectrum Analyzer Measurements to 110 GHz

Introduction

Characterizing devices and sub-systems on-wafer presents a unique set of challenges. For devices such as capacitors, inductors, and transistors, the objective might be the creation of accurate models to be used in device simulations. Accurate device modeling requires the ultimate broadband vector network analyzer (VNA) measurements for successful circuit simulation. When designing an amplifier, issues such as power saturation, linearity, IMD, harmonics, gain, and match need to be measured. For sub-systems such as MMICs, a number of compliance tests might be the goal. In either case, achieving accurate measurements is a constant need and at millimeter-wave (mmWave) frequencies a number of factors will contribute to the overall success. Multiple parameters must often be included in the overall analysis. From a test equipment perspective, features such as overall measurement accuracy, the ability to include multiple parameters in a system setup with minimal re-configuration, and the ease of installation on a probe station come into play. This application note describes how some of these goals can be achieved using a combination of the VectorStar™ ME7838x broadband system, the Spectrum Master™ MS2760A ultraportable spectrum analyzer, and the Anritsu MN25110A W1 coaxial precision directional coupler (Figure 1).

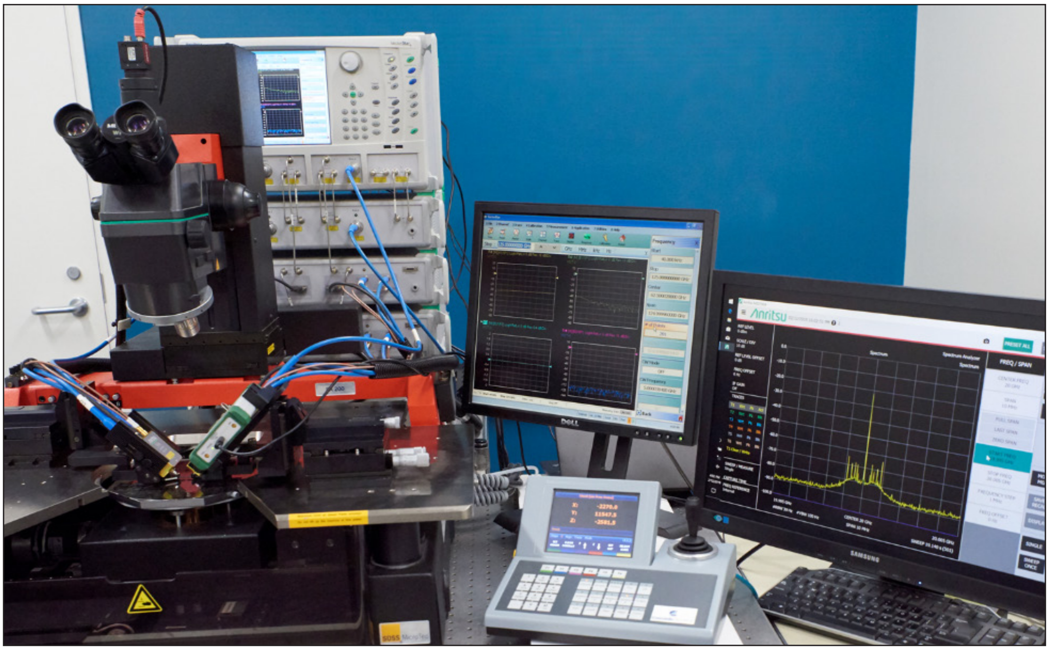

Figure 1. Setup of the VectorStar ME7838x broadband system, MN25110A W1 (110 GHz) coaxial precision directional coupler, and Spectrum Master MS2760A ultraportable spectrum analyzer for on-wafer measurements.

At the heart of the setup is the incorporation of the compact non-linear transmission line (NLTL) 3743x broadband mmWave module and Spectrum Master MS2760A ultraportable spectrum analyzer utilizing the same technology (Figure 2). This unique combination can be used to obtain accurate S-parameter and spectrum analysis measurements on-wafer with a single touchdown. This means that both parameters can be monitored at the same time, thereby greatly improving the overall design success of the device under test (DUT), reducing the time to test, and increasing time to market.

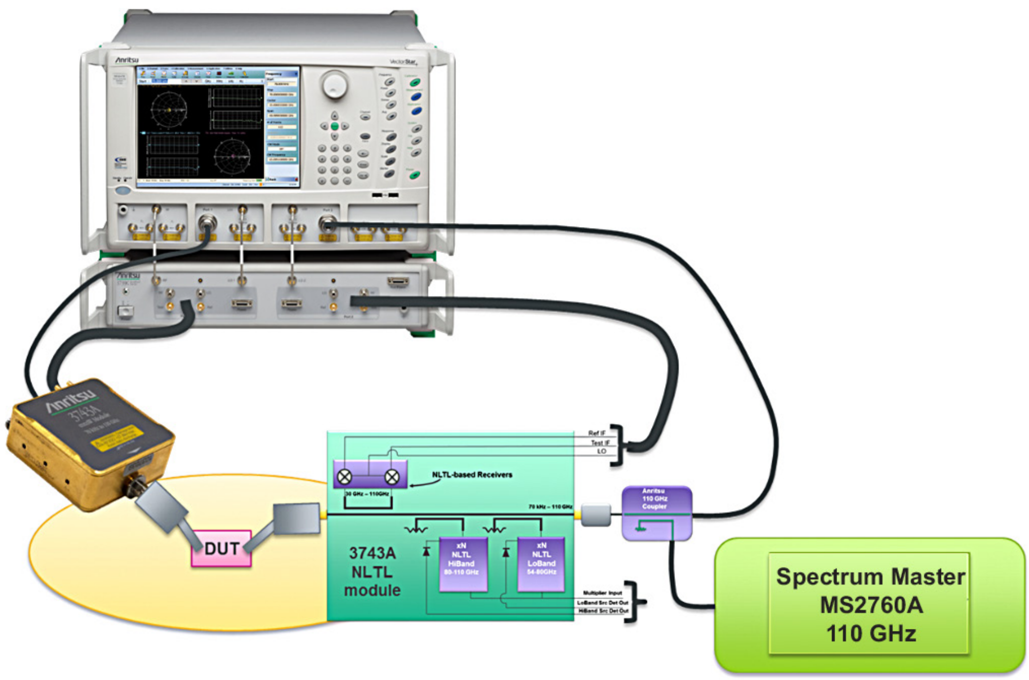

Figure 2. Block diagram of combined VNA and spectrum analyzer setup using the VectorStar ME7838x system, MN25110A W1 coaxial precision directional coupler, and Spectrum Master MS2760A ultraportable spectrum analyzer.

Summary Advantages of Probe Station-Mounted Portable Spectrum Analyzers

The portable spectrum analyzer can be operated independently from the VNA.

Configuring and modifying the spectrum analyzer settings does not require changes or migration from the VNA menus and measurement displays. With the Spectrum Master MS2760A ultraportable spectrum analyzer controlled by a separate laptop or PC, all functions are constantly available for modifications of receiver configurations and display windows.

The portable spectrum analyzer can be mounted on the probe positioner for maximum dynamic range and measurement stability.

With the Spectrum Master MS2760A device mounted close to the mmWave module and coupler, a short 8 cm cable connects the system with minimum loss in power. Short cables also mean less exposure to lab temperature variations, which reduces display drift in the spectrum band. Note that insertion of the coupler does not have an impact on the stability of the S-parameter measurements since additional cables are not needed between the DUT and VNA receivers.

The portable spectrum analyzer can be used elsewhere without the VNA.

The Spectrum Master MS2760A ultraportable spectrum analyzer can be easily and quickly setup in alternative installations with minimal impact on the existing VNA setup. For example, the spectrum analyzer can be removed and used elsewhere while leaving the coupler in place, allowing the VNA to continue with S-parameter measurements with no impact on performance.

A 110 GHz VNA with 110 GHz software is not needed to perform 110 GHZ spectrum analysis.

The DUT S-parameters can be analyzed at 22 GHz with a low-frequency VNA while monitoring the 5th harmonic with the 110 GHz spectrum analyzer.

Challenges of On-Wafer Measurements

There are a number of key aspects of on-wafer measurements that can either lead to successful characterization or render the analysis unhelpful due to measurement uncertainties.

- Spectrum analysis is primarily a relative measurement. In some cases, absolute power knowledge is desirable. In these cases, a power reference point can be established with a power meter and subsequent relative readings can be made. Accurate spectrum analysis measurements will therefore rely on receiver linearity of the spectrum analyzer and noise floor. Thus, during touchdown, relative measurements using a spectrum analyzer can typically be made with reasonable confidence.
- VNAs also have very linear receivers and can be calibrated for power at the source and receiver ends for additional analysis (i.e., gain compression, intermodulation, harmonic, and noise figure measurements). The challenge of on-wafer VNA measurements is the quality and maintenance of the calibration, especially at mmWave frequencies where touchdown probe repeatability may be a concern. Calibration of the VNA characterizes and corrects systemic errors in order to obtain acceptable measurement uncertainties. Maintaining calibration status therefore relies on repeatability of the connection (i.e., probe touchdown repeatability) as well as the integrity of system cables, temperature, and other environmental conditions. The compact nature of the Anritsu NLTL modules allow for direct connection to probes, thus eliminating the need for cables at the most critical point in a broadband measurement.
- Additional aspects of calibration and measurement success that come in to play include issues such as the substrate environment, number of layers in the DUT substrate, proximity of structures to other metalized layers, and replication of the calibration standards environment to the DUT environment. These additional concerns are beyond the scope of this application note but are of increasing interest as the frequencies continue to rise.

VNA Calibrations

Accurate S-parameter measurements depend on a well-calibrated VNA. There are different calibration techniques available on a VNA, and the method used will depend on the frequency range and media used. A common approach identifies and extracts the more influential error terms or proxies thereof (directivity, reflection and transmission tracking, source/load match).

SOLT (short, open, load, thru) is a popular calibration method for connectorized VNA systems operating up to 40 and 70 GHz. The SOLT technique uses the load to establish system-effective directivity and thus determine return loss measurement uncertainties. Some VNA calibration kits do not offer terminations with adequate performance above 40 GHz. These require a combination of SOLT and offset shorts (SSST) for acceptable calibrations to cover 70 GHz. VectorStar calibration kits provide high-performance terminations for excellent SOLT calibrations to 70 GHz using V connectors.

For on-wafer measurements, calibration substrates are available with SOLT standards supporting calibrations up to 40 GHz (and in some cases up to 70 GHz). Above 40 GHz, the performance of the terminations and modeling of the opens become more challenging. When measurements go beyond 40 GHz, alternatives to SOLT calibrations should be considered.

TRL and derivatives such as LRL, LRM, and multiline TRL (mTRL) are commonly used for on-wafer measurements above 40/70 GHz and up to 1 THz. A benefit of the TRL family is the use of the thru line for determining characteristic impedance rather than relying on a load. However, establishing repeatable characteristic impedance properties is highly dependent on connection repeatability (i.e., probe touchdowns), so operator expertise can be a contributor when considering measurement uncertainties.

Calibration substrates are readily available for TRL-type calibrations up to and beyond 110 GHz. Typically, the LRM method (using a Line, Reflect, and Match) is implemented since it supports frequencies from DC to mmWave. An advantage of LRM is that it is not band limited as with LRL. With LRL, the delta length of the two lines establish the low-end frequency. Thus, if the VNA's range goes from as low as 70 kHz to as high as 110 GHz and above (like as the VectorStar ME7838x series), then long multiple lines will be required. To support the lowest frequencies, the long lines can take up valuable real estate (especially if the cal standards are located on the DUT substrate, as is the current tendency within the industry). The match in the LRM technique is essentially an infinitely long line and thereby establishes the low frequency calibration. There are also advanced versions of LRM, such as ALRM and LRRM, where multiple reflections and standards coefficients are included for additional improvements when measuring well-matched devices.

Calibration Stability

After calibration, most VNA systems are reasonably accurate. Depending on the quality of the calibration substrate, corrected performance of 30-40 dB directivity and source/load match are common. However, the effects that environmental factors can have on calibration are a concern. If the system is highly sensitive to environmental factors such as temperature variations and cable flex, then the system will require constant re-calibration and result in reduced measurement efficiency.

Raw directivity is perhaps the single most influential aspect of calibration stability. Although calibration corrects raw directivity, the quality of raw directivity will have an effect on measurement stability after calibration. For example, unlike the VectorStar system, architectural constraints in alternative broadband systems result in negative raw directivity in certain bands. This means the directivity error signal is larger than the measurement signal. Consequently, environmental changes and test cable movement after calibration using systems with negative raw directivity will have significant effects on the calibration, resulting in the need for frequent recalibrations.

Combining S-parameter and Spectrum Analysis Measurements

VNAs provide accurate, calibrated, ratioed S-parameter measurements. They also provide a variety of non-ratioed measurements such as quasi-linear/non-linear measurements of gain compression, intermodulation distortion, and harmonics. These additional capabilities are available because of their ability to perform power calibrations of the source and receivers, as well as program the receiver frequency independently of the source. Figure 3 is an example of a VectorStar system setup for measuring the IMD performance of an amplifier. The VectorStar system is equipped with a dual-source option with internal switches and combiners plus the IMD software for complete integration of two-tone measurements. Note that tone separation and tone power can be controlled in real time while monitoring the effects on the display. Since the VectorStar system knows the frequency setup of the tones, the intermodulation components can be calculated and the receiver automatically setup to sweep and display the intermodulation products.

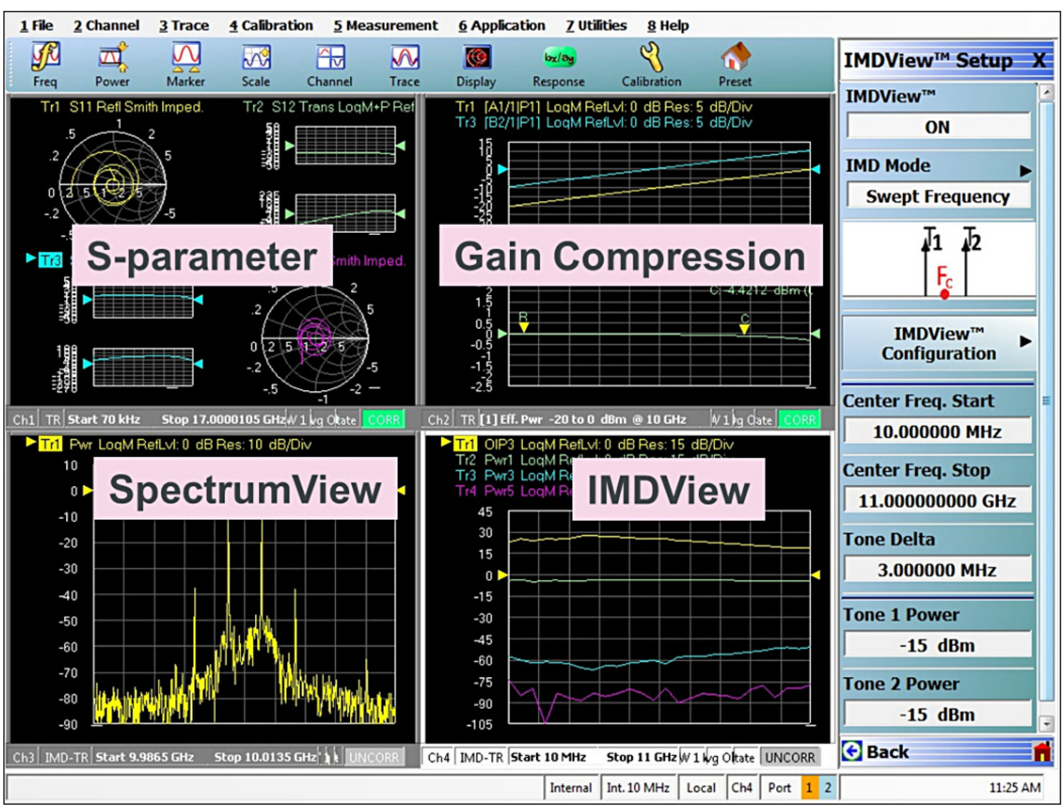

Figure 3. VectorStar system combined with the IMDView application software provides a display of S-parameters, gain compression, spectrum, and intermodulation products when configured for two-tone IMD measurements.

VectorStar IMDView application software provides the ability to display the spectrum associated with the IMD setup while tracking the IMD products (note SpectrumView window in Figure 3). When greater instrument control for spectrum display is needed (i.e., increasing the swept range, quick adjustment of resolution bandwidth, configuring search markers, etc.), having a separate, independent spectrum analyzer can be desirable to simultaneously monitor the entire spectrum or a portion of it while performing VNA measurements. Incorporating the Spectrum Master MS2760A device into the measurement is an ideal solution that provides a fully independent spectrum display while allowing for independent VNA and spectrum analyzer control for optimized measurements.

An important aspect of the measurement setup, especially at the mmWave frequencies up to 110 GHz, is the minimization or elimination of test cables. Combining the VectorStar ME7838x broadband system with the Spectrum Master MS2760A spectrum analyzer offers the opportunity to combine two key elements of the measurement close to the DUT for best measurement performance, all while maintaining optimum dynamic range and reducing long cables for best stability. The compact size of the Spectrum Master MS2760A device allows installation next to the VectorStar 3743x mmWave module using the Anritsu MN25110A 110 GHz W1 coaxial precision directional coupler. The through path of the NLTL mmWave module and coupler provides a DC path from the DUT to the VectorStar system for the low band measurements (70 kHz to 30 GHz), while the coupled port of the coupler provides a 20 to 110 GHz path for the Spectrum Master MS2760A spectrum analyzer. Signals above 30 GHz are down-converted in the mmWave module to the IF frequencies and delivered to the VNA for analysis. The result is simultaneous VNA and spectrum analyzer measurements to 110 GHz.

System Configuration

The setup is comprised of the following items:

VectorStar MS7838x Broadband System

- This concept can be used with any of the VectorStar broadband systems including the ME7838A 110 GHz through the ME7838D 145 GHz systems.

MN25110A 110 GHz W1 Precision Directional Coupler

- The new Anritsu 1.0 mm 110 GHz coupler has a nominal 10 dB coupling factor and can be used well below 20 GHz depending on acceptable coupling loss.

Spectrum Master MS2760A Ultraportable Spectrum Analyzer

- This light and compact analyzer is ideal for mounting on the probe station positioner for minimal cable length as well as maximum dynamic range and stability.

SC8537 Bracket Assembly

- Although not a requirement, this kit provides the mounting bracket, cable, and coupler for easy installation of the 3743A NLTL module and Spectrum Master MS2760A spectrum analyzer on an existing positioner. Contact Anritsu for recommended positioners and probe station configurations.

Figure 4 illustrates how the portable Spectrum Master MS2760A ultraportable spectrum analyzer can be mounted close to the mmWave module and DUT, thereby eliminating long test port cables. Due to their compact size, the Anritsu NLTL mmWave modules are connected directly to the probes with no cables for maximum dynamic range as well as best calibration and measurement stability.

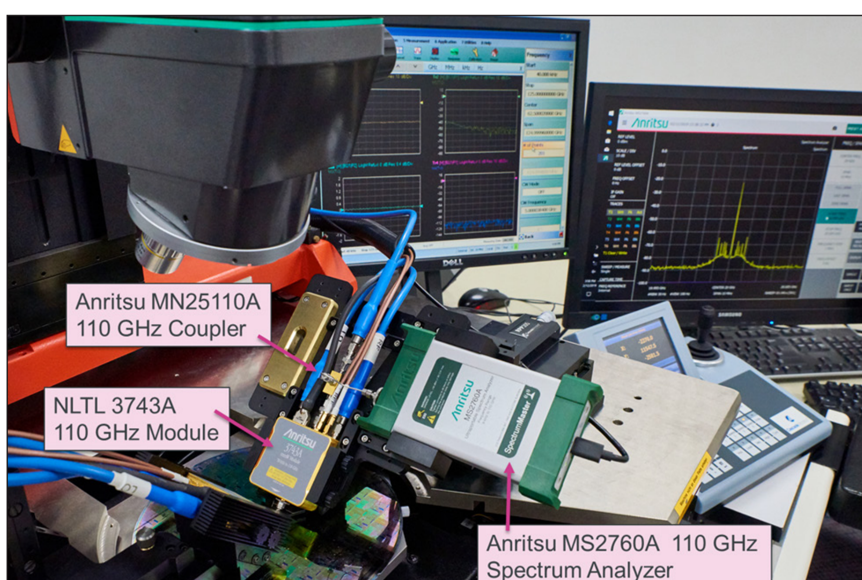

Figure 4. Incorporation of the VectorStar ME7838x broadband system, the MN25110A 110 GHz W1 directional coupler, and the Spectrum Master MS2760A ultraportable spectrum analyzer with minimal cabling.

Example: Set up a two-tone IMD measurement centered at 20 GHz while simultaneously monitoring to the 5th harmonic.

The VectorStar IMDView (Option 44) offers a wide range of configuration settings for IMD analysis. The two tones can be set for a specific separation (in this case 3 MHz) and for CW measurements while monitoring in SpectrumView or while sweeping the tones over a frequency range. Figure 5 illustrates how the tones can be programmed to display various parameters (such as tone power, IM products up to the 9th order, tone gain, etc.). Note that with the VectorStar Internal Combiner (Option 32) installed, the internal combiner and switch can be utilized for automatic switching between the linear, gain compression, spectrum monitoring, and swept IMD display (Figure 3) without the need for re-connections.

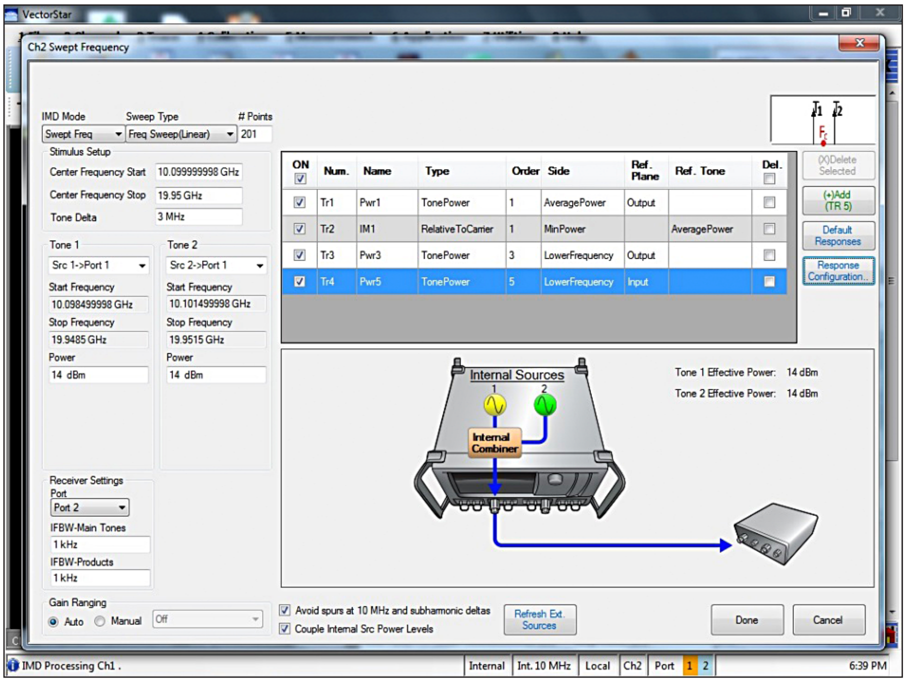

Figure 5. IMDView Configuration Panel. Used to set up source path for internal or external combination, sweep frequency range, tone separation, and selection of trace display.

The IMDView configuration panel is used to configure the trace display, IMD configuration, and other system parameters. Additional trace configurations are available using the Response Configuration panel (Figure 6). The Response Configuration panel provides individual customization of each trace for display of IM tone power, intercept point, tone gain, and even tone asymmetry.

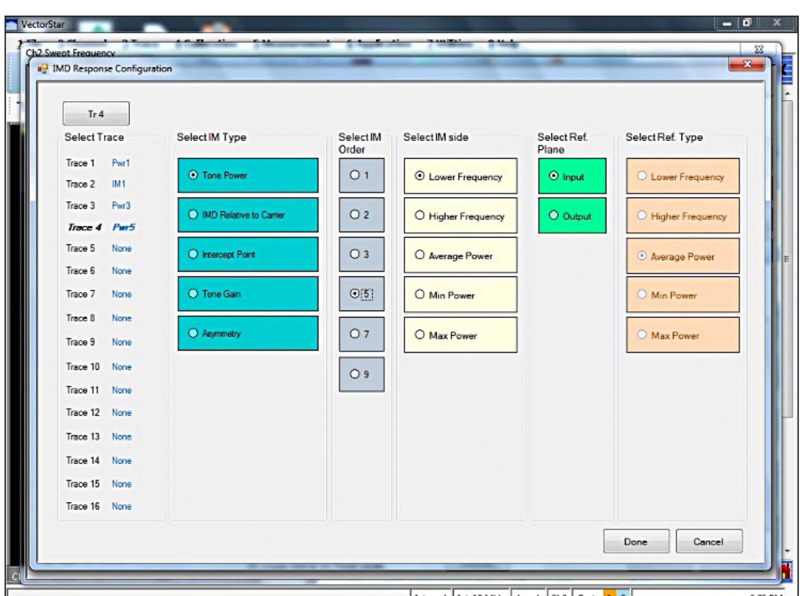

Figure 6. IMD Response Configuration Panel.

Once the IMD measurement is configured, the multi-channel VectorStar system can be set to display the different measurement modes within each channel. Figure 7 demonstrates how one channel can be set to display the spectrum of the two-tone signal while a second channel displays the swept intermodulation tones over the band of interest. Additional channels can be set to display additional parameters such as S-parameters, power sweeps for gain compression analysis, harmonic measurements, etc.

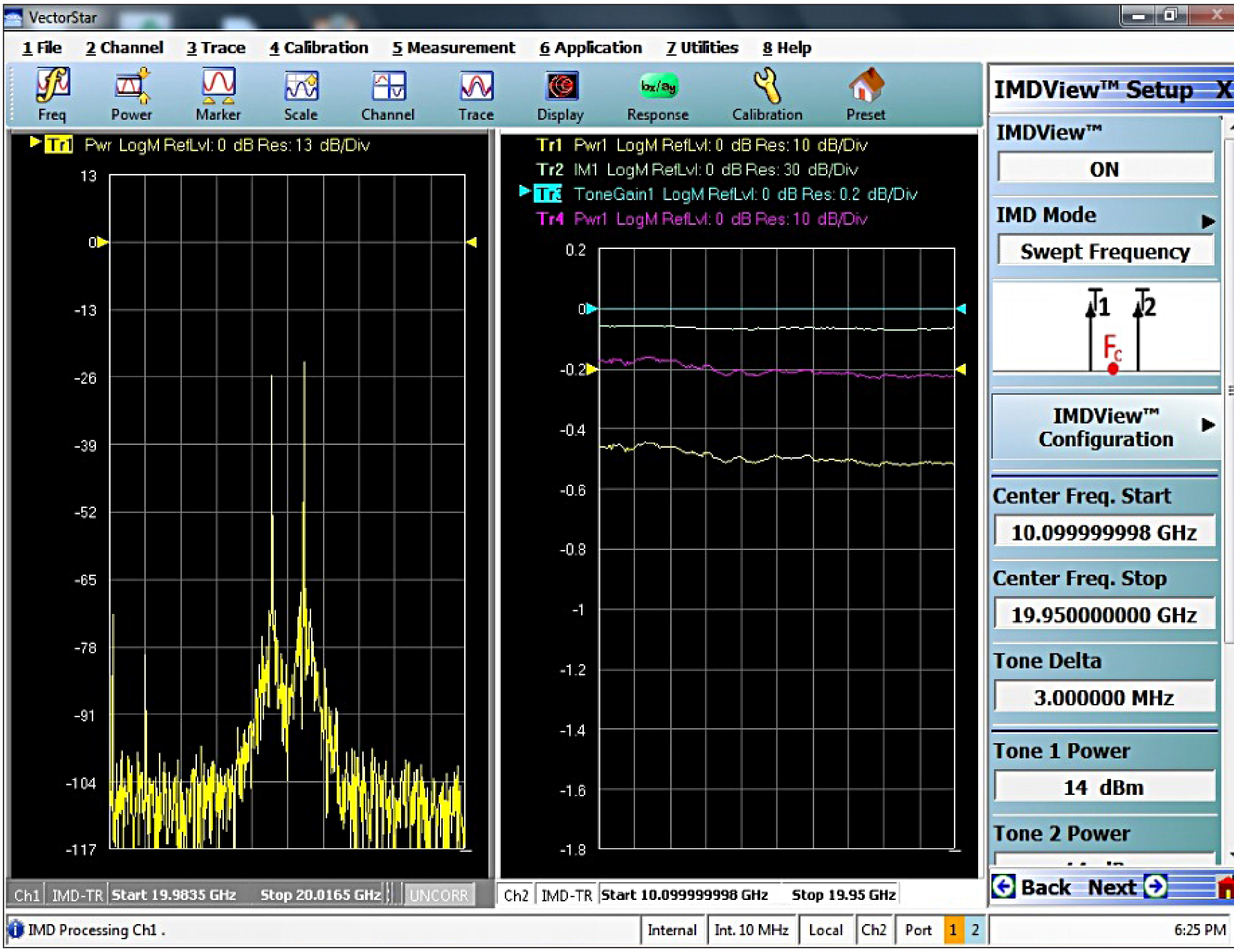

Figure 7. Configuration of VectorStar channels for display of SpectrumView of the two-tone signal plus swept frequency display of the intermodulation products.

In addition to the multi-channel display capabilities of the VectorStar system, it can be useful to monitor the full spectrum response. For example, there are times when the DUT being measured might have low frequency resonances under various operating conditions. One advantage of the 70 kHz low-end frequency capabilities of the VectorStar system is the ability to check for resonances of the device in the DC regions. While these resonances can show up during a low-frequency, ratioed S-parameter sweep, it may also be helpful to monitor the low-end frequency with a spectrum analyzer for quick scanning at the low-end frequencies. If the spectrum analyzer is broadband, it can be used to simultaneously monitor the harmonic performance as well. When using a broadband coupler for simultaneous analysis, the roll-off of the coupled port will determine the low-end frequency. Figure 8 demonstrates how the Spectrum Master MS2760A ultraportable spectrum analyzer with the MN25110A W1 directional coupler can be used to scan the DUT spectrum from 300 MHz to 110 GHz, thereby monitoring low-end resonances and harmonic performance while the VectorStar system displays the non-linear response of the device.

Figure 8. The Spectrum Master MS2760A spectrum analyzer display offers the opportunity to monitor low frequency resonances while tracking up to the 5th harmonic of a 20 GHz two-tone IMD measurement.

Summary

Performing on-wafer measurements presents a unique set of challenges. Achieving accurate on-wafer measurements requires careful planning of installation, calibration, and measurement configuration. Often, multiple parameters must be included in the overall analysis. This application note describes how S-parameters and spectrum analysis can be monitored simultaneously from 70 kHz to 110 GHz using a combination of the VectorStar ME7838A broadband system, the Spectrum Master MS2760A ultraportable spectrum analyzer, and the Anritsu MN25110A W1 coaxial precision directional coupler. At the heart of the setup is the incorporation of the compact Anritsu non-linear transmission line (NLTL) mmWave modules and the Spectrum Master MS2760A ultraportable spectrum analyzer utilizing the same NLTL technology. This unique combination can be used to obtain accurate S-parameter and spectrum analysis measurements on-wafer with a single touchdown. Achieving these measurements on a single touchdown results in a significant reduction in test time without sacrifice in measurement performance, thereby greatly improving the potential for first turn design success and time to market.

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Specifications are subject to change without notice.

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