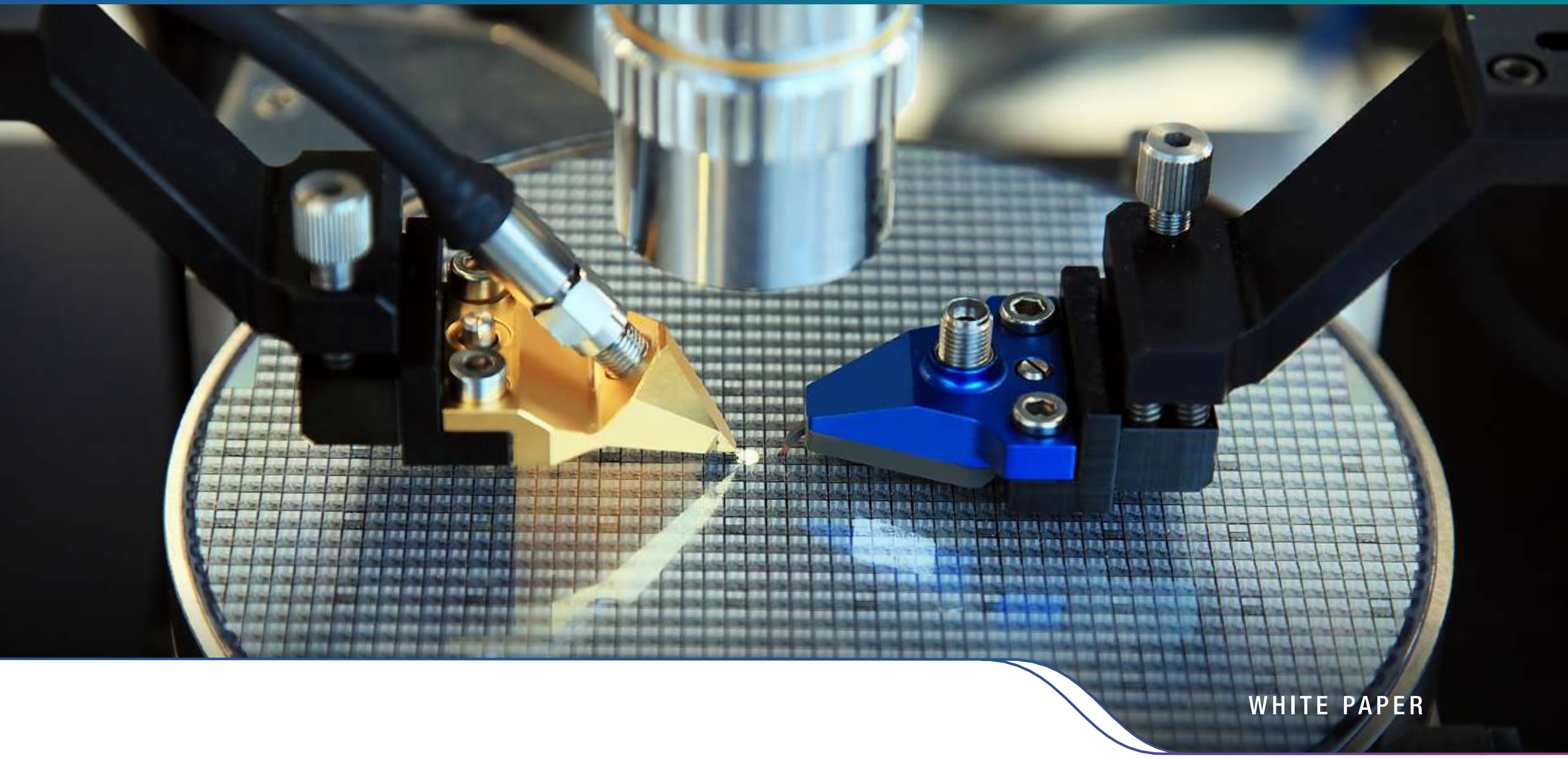


3 Steps to Characterize RF Devices with Stimulus-Response Measurements

In today's wireless systems, frequency spectrum presents a finite resource. Complex modulation schemes improve spectral efficiency, but they cause distortions. Characterizing RF devices requires testing unwanted and nonlinear distortion caused by distortion products that degrade the modulation quality and interfere with other receivers.

Stimulus-response measurements provide a straightforward method for evaluating the performance of RF devices. They require a stimulus input test signal and acquisition of the output signal for further analysis. You can then assess and troubleshoot the differences between the input and output signals to determine the origination of the variances. In this paper, we will discuss common stimulus-response measurements and how they can help you characterize and troubleshoot your RF designs.

KEYSIGHT TECHNOLOGIES

Step 1. Characterize Digitally Modulated Signals

Increasingly complex modulated signals cause both a higher peak-to-average power ratio and nonlinear distortion. To extract useful power-related information from complex signals, you need statistical analysis of the power levels.

Power Complementary Cumulative Distribution Function (CCDF) curves characterize the higher-level power of a signal and provide critical information such as the peak-to-average power ratio (PAPR). You can use PAPR for evaluating nonlinearities in power amplifiers (PA) and transmitters.

Evaluate waveform designs

When you simulate a digital modulation signal with a signal generator, you need to make sure the output signal is not saturated by the signal generator. You can use the CCDF plot capability of a signal generator to identify the power distribution curve of a signal waveform. Figure 1 below shows a 64-QAM modulation signal at 10 MHz symbol rate.

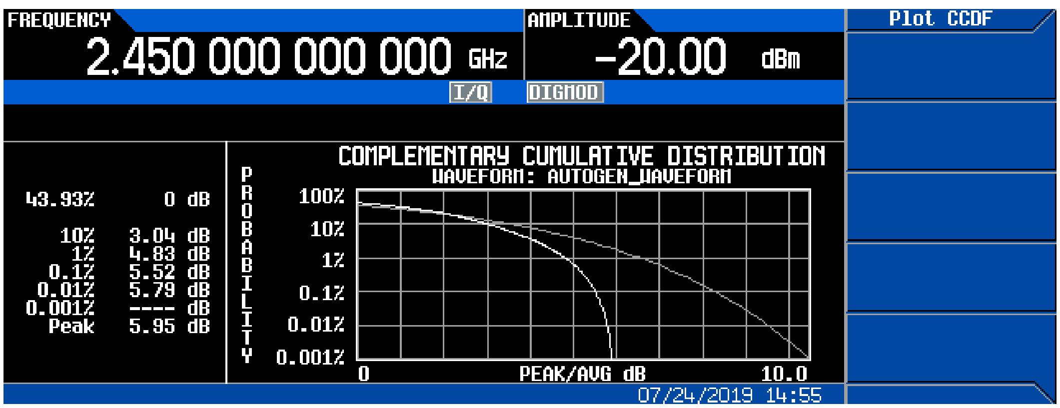


Figure 1. CCDF plot from waveform utility of Keysight CXG vector signal generator

If the output power of the signal generator is saturated, it impacts not only the output power level accuracy, but also the modulation quality due to AM-to-AM compression. The amplitude level setting on a signal generator cannot be greater than the maximum output power of the signal generator minus the PAPR value of the simulated signal.

Making CCDF measurements

When you input a digitally modulated signal to a DUT, you compare the input and output power CCDF plot with a signal analyzer to see if there is any clipping to the original design. Figure 2 shows a power CCDF plot of an RF PA. The pink trace is the power CCDF plot of the input signal, and the yellow trace is the power CCDF plot of the PA's output signal. You can find the output power CCDF plot does not align with the input signal. You need to either reduce the input power level or redesign the PA to minimize the PA's distortion at the higher output level.

Figure 2. Power CCDF measurements of Keysight CXA signal analyzer

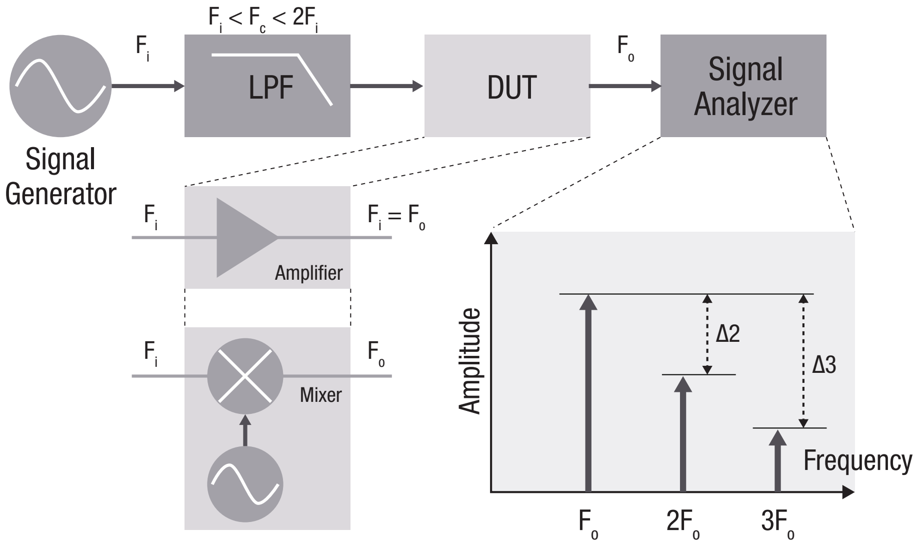
Step 2. Make Distortion Measurements

In today's wireless communications systems, frequency channel spacing is close to achieving excellent spectral efficiency. Narrow frequency channel spacing and wide bandwidth communication systems require critical tests for unwanted and nonlinear spectral distortion. The distortion products might be unwanted in-channel, in-band, and out-of-band spectral signals. Distortion not only degrades transmitter performance but also interferes with other receivers. There are two major types of nonlinear distortion measurements — harmonic and intermodulation distortion.

Harmonic distortion

The amplitude transfer characteristics of a circuit or device cannot precisely track the input signal. The amplitude shifts generate higher frequency components at integer multiples of the input signal.

Using a continuous wave (CW) tone as an input signal and measuring the output signal with a signal analyzer is the most straightforward method for measuring harmonic distortion; see Figure 3. A device DUT might be an RF amplifier or mixer.



Tip: Use a signal generator with low harmonic distortion and include a low pass filter (LPF) between the signal generator and the DUT to ensure measured harmonics come from the DUT, and not from the signal generator.

Figure 3. Harmonic distortion measurement setup

The signal analyzer sets to zero-span, which enables a time-domain power measurement to measure the power level at the fundamental and harmonic frequencies as shown to the right of Figure 4. For a higher-order harmonics measurement, you can choose a higher dynamic range signal analyzer.

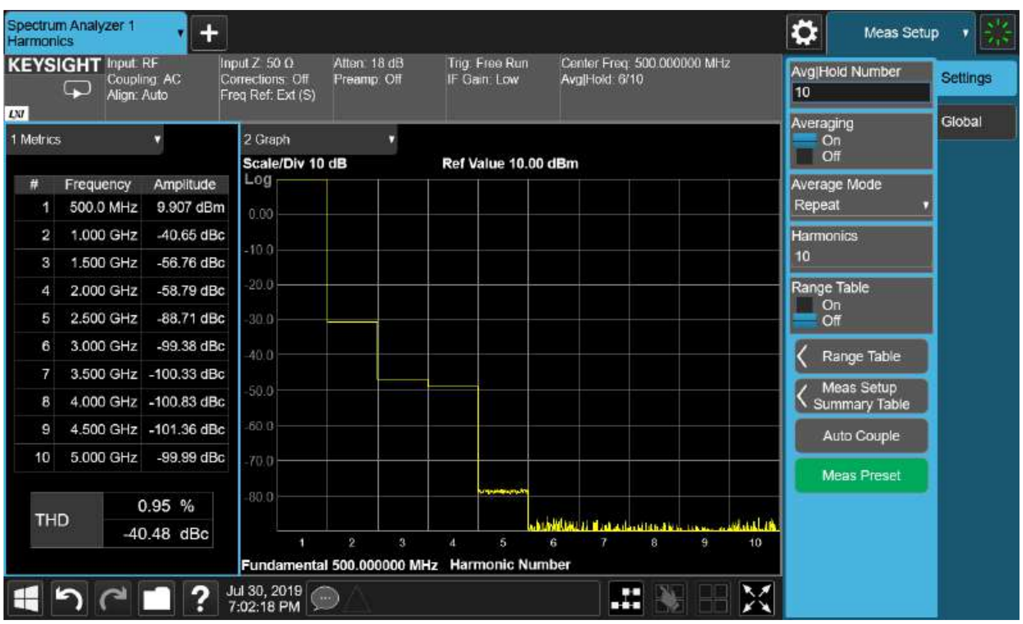


Figure 4. Harmonics measurement with Keysight CXA signal analyzer

Third-order intermodulation distortion

Two-tone, third-order intermodulation (TOI) distortion is a common test for RF distortion measurements. When two or more signals are present in a non-linear system, they can interact and create additional components at the sum and difference frequencies of the original frequencies and at sums and differences of multiples of those frequencies. Figure 5 below shows the two-tone third-order Intermodulation measurement setup. The device under test could be an amplifier or a mixer.

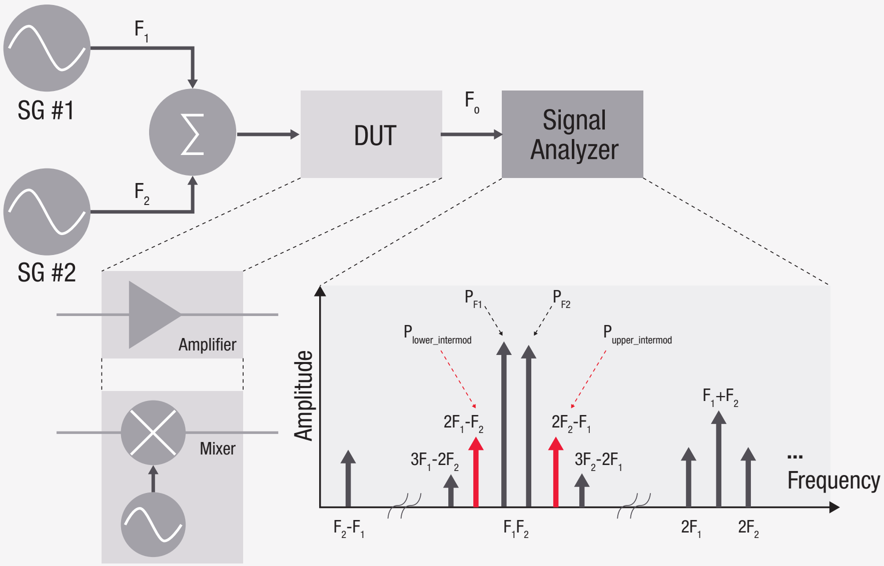


Figure 5. Two-tone intermodulation distortion measurement setup

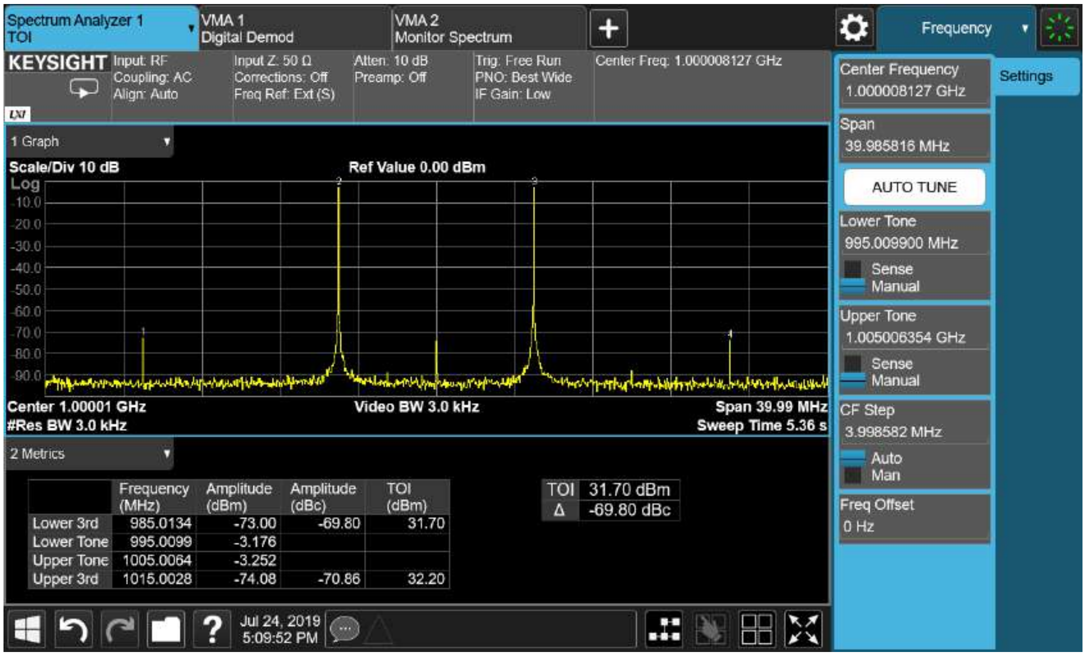
F_1 (lower tone) and F_2 (upper tone) are frequencies of the two test tones from two signal generators. The two tones injected into the system must be free from any third-order products. The third-order distortion products occur at frequencies $2F_1$-F_2 and $2F_2$-F_1 (red notations), which are the closest distortion products to the original two test tones. Removing the closest distortion products with filtering is difficult. In a communication system, the distortion products can be interfering signals to the adjacent channels.

The definition of TOI level:

$$TOI_{lower}\ (dBm) = P_{F2}/2 + P_{F1} - P_{lower\_intermod}/2$$

$$TOI_{upper}\ (dBm) = P_{F1}/2 + P_{F2} - P_{upper\_intermod}/2$$

Figure 6 illustrates TOI measurements with a signal analyzer. The two test tones are at frequencies 995 MHz and 1005 MHz. The third order intermodulation products occur at frequencies 985 MHz and 1015 MHz and the TOI measurement results are 31.7 dBm (lower) and 32.2 dBm (upper).



	Frequency (MHz)	Amplitude (dBm)	Amplitude (dBc)	TOI (dBm)
Lower 3rd	985.0134	-73.00	-69.80	31.70
Lower Tone	995.0099	-3.176		
Upper Tone	1005.0064	-3.252		
Upper 3rd	1015.0028	-74.08	-70.86	32.20

Figure 6. TOI measurement with a Keysight CXA signal analyzer

For production testing, a vector signal generator alone can be used to generate two test tones using the internal baseband generator to save costs. Keysight offers an advanced correction routine which can suppress distortion products generated by the signal generator itself or an external pre-amplifier. To learn about how to configure distortion-free two-tone and multitone test signals, download the technical overview "N7621B Signal Studio for Multitone Distortion."

Adjacent channel power (ACP) measurements

Wider bandwidths and multi-carrier techniques are used broadly to increase data throughput for the latest wireless standards. Two-tone third-order intermodulation technique does not completely characterize the behavior of wide-bandwidth components. Digital modulation, which uses both amplitude and phase shifts, generates distortion, also known as spectral regrowth. Figure 7 shows the spectral regrowth (red curve) of a digital modulation signal.

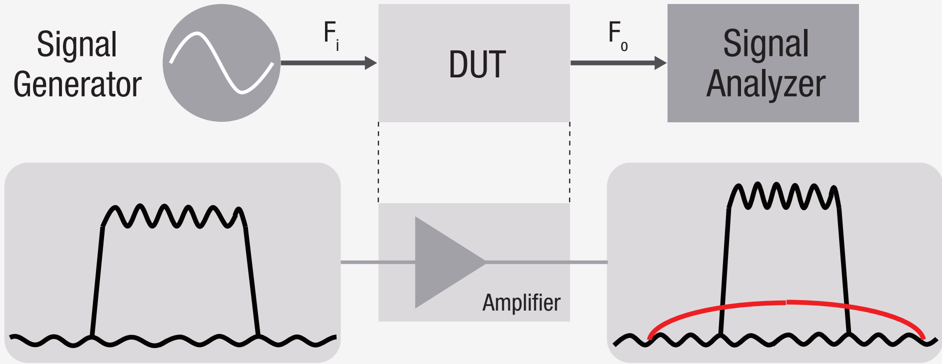


Figure 7. Spectrum regrowth due to intermodulation

Like TOI, the spectrum regrowth also interferes with the adjacent channels and spreads energy outside the main channel. ACP measurement describes the ratio of power in a modulated signal versus power emitted into an upper or lower adjacent channel. ACP measurements provide useful information for spectrum regrowth and emissions to characterize the transmitter design, including baseband filter and non-linear distortion. Figure 8 shows the ACP measurement results of a W-CDMA signal with a 3.84 MHz channel bandwidth.

Figure 8. ACP measurement with Keysight CXA signal analyzer

Step 3. Analyze and Troubleshoot Modulation Quality

An ideal transmitter outputs a digitally modulated signal which has constellation points at the ideal locations. However, various imperfections such as phase noise, system noise, distortion, and modulator impairments move the constellation points out of the ideal locations, resulting in a weak communication link.

Use error vector magnitude (EVM) measurement to quantify the performance of digitally modulated signals — a measure of how far the constellation points from the ideal points.

Definition of EVM

EVM is the root mean square (RMS) of the error vectors computed and expressed as a percentage of the EVM normalization reference. The error vector (red arrow) originates from the detected point of the I/Q reference signal vector (green arrow) to the I/Q measured signal vector (black arrow) appearing in Figure 9.

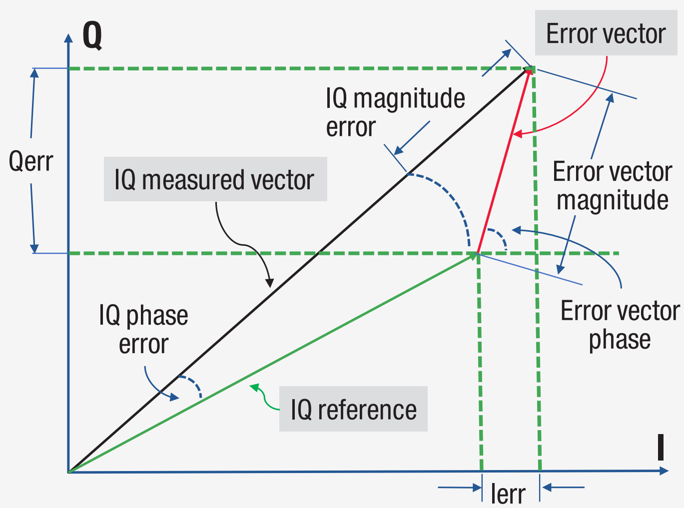


Figure 9. Error vector graphic

Troubleshoot transmitter designs

Successful designs require the ability to evaluate a signal and deduce the source of a problem. Through vector signal analysis, you can demodulate digitally modulated signals and examine error metrics such as EVM, I/Q offset, phase error, and frequency error. You can further analyze and verify the root causes for the source point of the errors. Look into the sub-systems or components with stimulus/response test to troubleshoot the designs. To learn about the common impairments of a transmitter and how to troubleshoot them, download the application note – "Testing and Troubleshooting Digital RF Communications Transmitter Designs."

For illustration, use the RF power amplifier test in the CCDF measurement (Figure 2). The output signal (yellow trace) distorts at the higher peak-to-average ratio. You can perform vector signal analysis and demodulate the input and output signals separately. Figures 10 and 11 show a demodulation analysis of the input signal the output signal. The EVM value increases from 0.48% (input signal) to 1.07% (output signal). Observe the constellation diagram (upper-left), and you can find the outer constellation points are compressed (slightly moved toward the center) in Figure 11. The outer points have higher output power levels, and the compression is because of the saturated output power in the RF power amplifier.

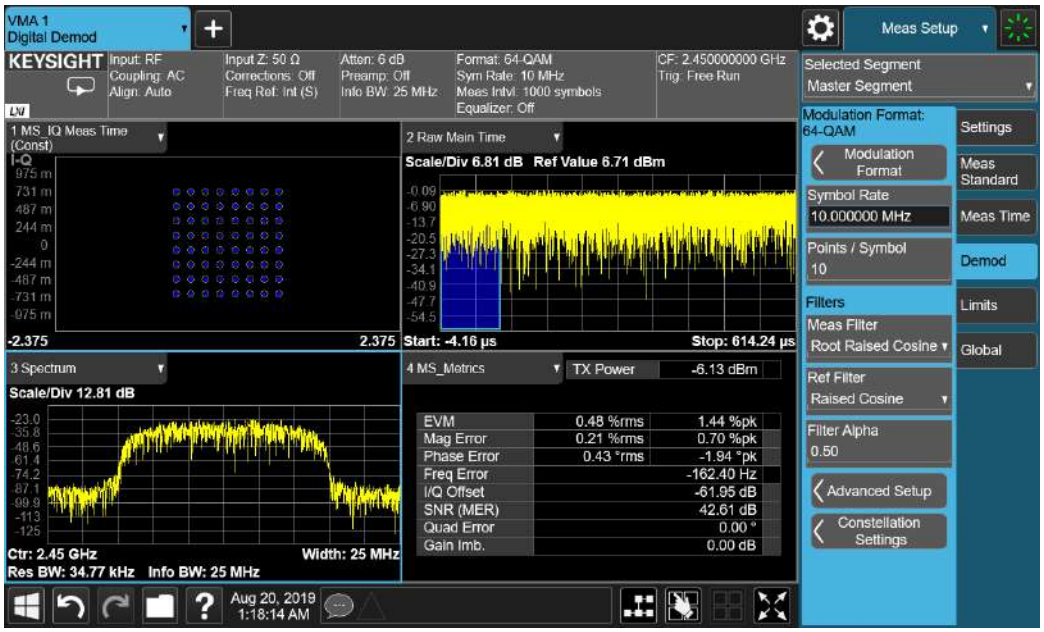


Figure 10. Demodulate the power amplifier's input signal

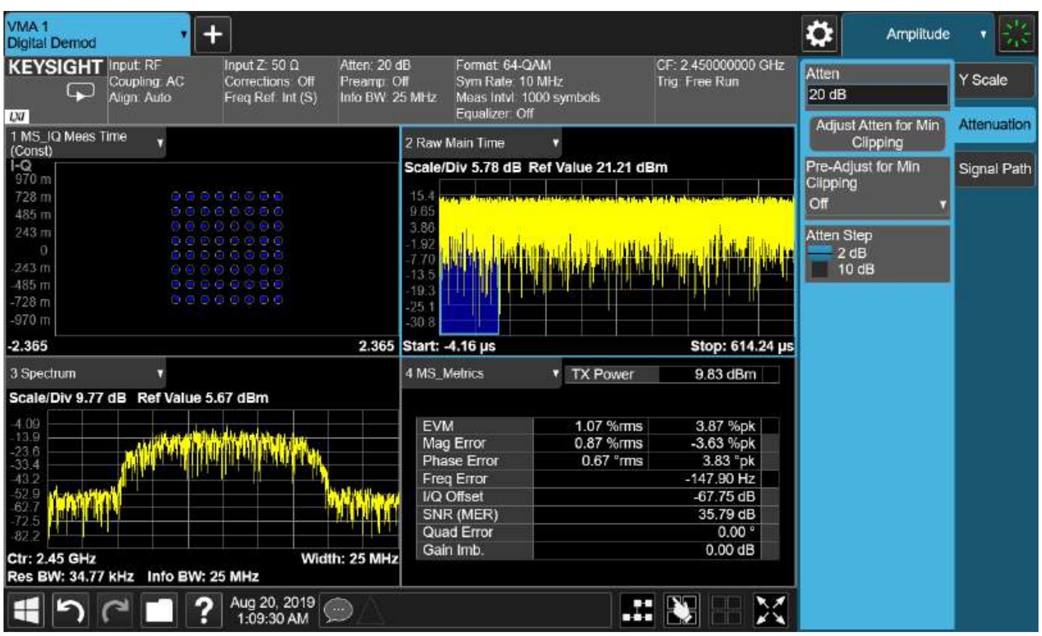


Figure 11. Demodulate the power amplifier's output signal

3 Steps to Characterize and Troubleshoot Your Designs

To better understand the performance of your device under test, you can follow these three steps to characterize and troubleshoot your designs.

1. **Characterize digitally modulated signals.** You need to know the power characteristic of the simulated waveform so that you can apply the right amplitude level to your signal generator. You can now measure and compare CCDF curves of input and output signals to see any compression to the DUT's output.

2. **Make distortion measurements.** Examine the distortion's impacts on the frequency spectrum with harmonic distortion, TOI distortion, and ACPR measurements.

3. **Demodulate and troubleshoot modulated signals.** You can perform demodulation analysis and troubleshoot your designs.

To fully characterize your RF components, you need to know the power characteristic of the simulated input signal and the measured output signal. Perform stimulus-response tests, such as CCDF, harmonics, TOI, ACP, and EVM to understand the performance of the RF components under different conditions to determine the best trade-offs in your design. Performing these three steps will ensure that you make solid design choices and create a great product.

Reference

1. Application note "Optimizing Dynamic Range for Distortion Measurements Distortion Measurements"

2. White paper "Tactics for Improving Distortion Measurements"

3. Application note "Testing and Troubleshooting Digital RF Communications Transmitter Designs"

Learn more at: www.keysight.com

For more information on Keysight Technologies' products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus