WHITE PAPER

Three Best Practices for

Optimizing EVM Measurements for Wideband Signals

Wireless technologies increase signal bandwidth and use higher-order modulation schemes to achieve faster data rates. However, wider bandwidth and higher-order modulation schemes introduce challenges related to link quality requirements at millimeter-wave (mmWave) frequencies. Engineers need to take extra care to evaluate radio-frequency (RF) components and devices accurately.

Error vector magnitude (EVM) measurements provide powerful insight into the performance of digital communications transmitters and receivers. EVM and related measurement displays are sensitive to any signal flaw that affects the magnitude and phase trajectory of a signal for any digital modulation format.

This white paper discusses three best practices for accurately making and optimizing EVM measurements.

Making EVM Measurements

EVM measurements provide a simple and quantitative figure of merit for a digital modulation signal. The errors may result from the phase noise of local oscillators (LOs), noise from power amplifiers, IQ modulator impairments, and many other sources. Figure 1 shows the modulation analysis used for common modulation formats. The IQ measured waveform data goes into a demodulator for recovering original data bits, then modulates the data bits to get the IQ reference (ideal) waveform. The other path is the IQ measured waveform data processed with signal compensation and a measurement filter. The signal error is the difference between the reference waveform and the compensated measured waveform.

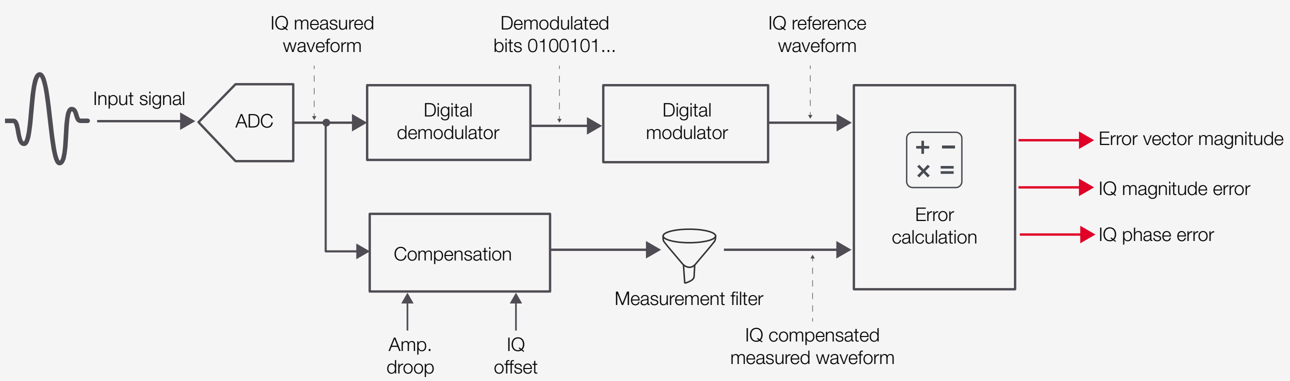

Figure 1. Error vector signal analysis block diagram

Figure 2 illustrates the vector signal error. The error vector (red arrow) goes from the detected point of the IQ reference signal vector (green arrow) to the IQ measured signal vector (black arrow). EVM is the root mean square of the error vectors computed, expressed as a percentage of the EVM normalization reference.

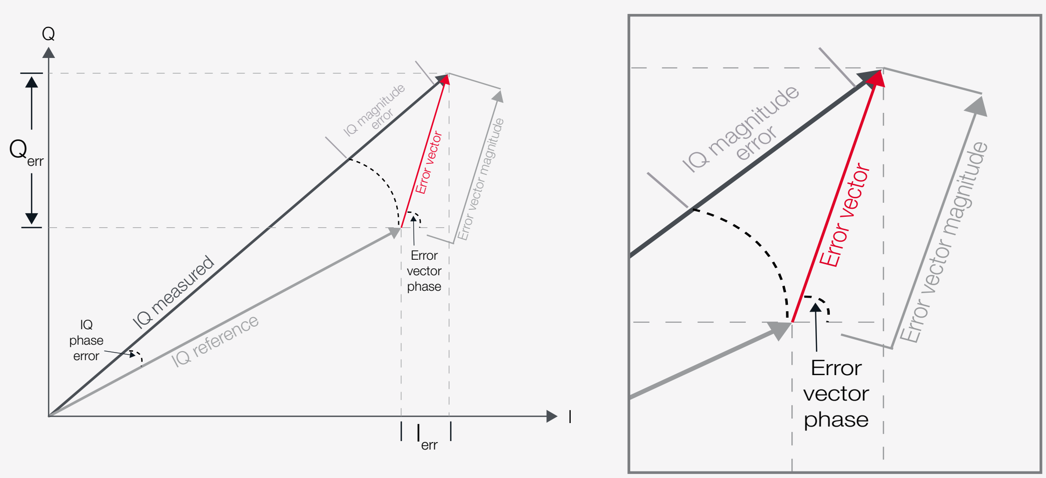

Figure 2. Illustration of EVM calculation

Some wireless standards, such as Wi-Fi and LTE, use decibels (dB) for EVM results. The conversion equation appears below. For example, 1% EVM is equal to -40 dB EVM.

EVM (dB) = 20 log10 (EVM (%))

A signal analyzer for EVM measurements also contributes to a certain amount of error. The residual EVM floor of a signal analyzer should be 5 to 10 dB lower than a device's performance or test specification. For example, the 802.11ax transmitter EVM specification requirement for 1024QAM is -35 dB. Chipset research and development engineers prefer a residual EVM floor of signal analyzers lower than -45 dB. For production test, EVM performance should be less than -40 dB as a 5 dB test margin.

Learn more

To learn more about basic EVM measurements and troubleshooting skills, download the product note Using Error Vector Magnitude Measurements to Analyze and Troubleshoot Vector-Modulated Signals.

Optimizing EVM Measurements

Figure 3 is a simplified block diagram of a vector signal analyzer. When making EVM measurements, you need to set optimum levels for the signal analyzer's input mixer, the phase noise configuration of the LO, and the digitizer to achieve the best EVM measurement results. Each of these components has its constraints and use cases. Let's start with the input mixer.

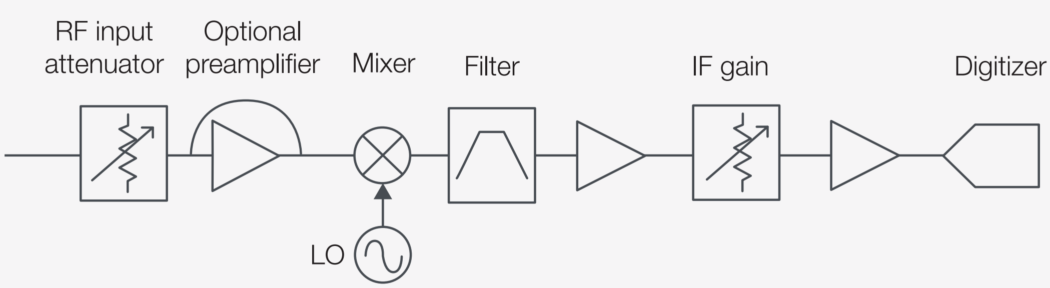

Figure 3. A block diagram of a signal analyzer

Practice 1. Optimize mixer level

All wireless standards specify EVM measurements using the maximum output power. You can control the power level at the first mixer of a signal analyzer to ensure that the high-power input signal does not distort the signal analyzer. However, there is no rule about the best mixer-level setting. The best mixer-level setting depends on the measurement hardware, characteristics of the input signal, and specification test requirements.

Nonlinear components in a signal analyzer, such as a mixer and an amplifier, may generate distortion under certain conditions. When you input a high-power signal to a signal analyzer, the signal causes distortion in the input mixer. The distortion products may be in-channel or out-of-channel unwanted spectral signals, as shown in Figure 4.

For modulated signals (the right plot), the in-channel distortion products (burgundy) degrade modulation measurements, and the out-of-channel distortion products (red) impact adjacent channel power and spurious measurements. Adjustable input attenuation prevents the input mixer from distorting high-power input signals.

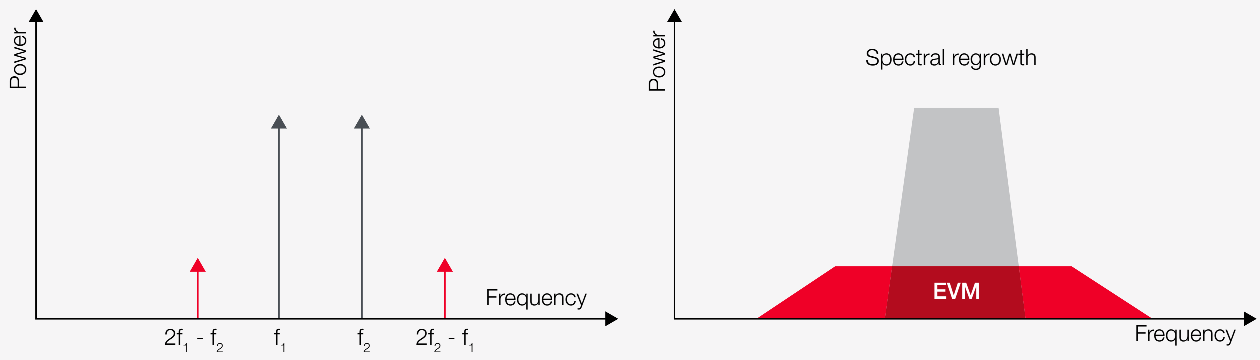

Figure 4. Nonlinear distortion: two-tone intermodulation and modulated signal with spectrum regrowth

Adjust input attenuation

The input attenuator of an analyzer reduces a signal passing into the input mixer. However, the input mixer-level setting is a trade-off between distortion performance and noise sensitivity. You can achieve a better signal-to-noise ratio (SNR) with a higher input mixer level or better distortion performance with a lower input mixer level.

The signal analyzer offers a mechanical attenuator in a 5 dB or 2 dB step and an electronic (optional) attenuator in a 1 dB step. The electronic attenuator offers finer steps than the mechanical attenuator and gives better resolution for optimizing the input mixer level.

Enable a built-in preamplifier

In scenarios such as over-the-air (OTA) tests and test systems with huge insertion loss, the input signal level can be lower than the optimum mixer level. A built-in preamplifier provides a better noise figure but a poorer intermodulation-distortion-to-noise-floor dynamic range. You can enable this setting for low-input-level test scenarios.

Practice 2. Optimize SNR for an IF digitizer

Exponential growth in demand for faster data rate applications has triggered the need for technologies capable of wide signal bandwidth at higher frequencies. Unfortunately, wider bandwidths also gather more noise. Wideband noise and excess path loss at millimeter frequencies between instruments and devices under test (DUTs) result in a lower SNR for the digitizer.

Optimize the attenuation setting

Keysight signal analyzers allow you to adjust attenuation for minimum clipping to protect against input signal overloads. This function accelerates setting the input attenuation but does not necessarily optimize measurement dynamic range. A user needs to adjust the attenuation manually to achieve the best measurement results.

The low SNR causes the transmitter measurements to have a poor EVM and adjacent channel power ratio performance, which does not represent the performance of the DUT, as shown in Figure 5. The noise power includes anything that causes the symbol to deviate from the ideal state position, including noise from the DUT and the signal analyzer.

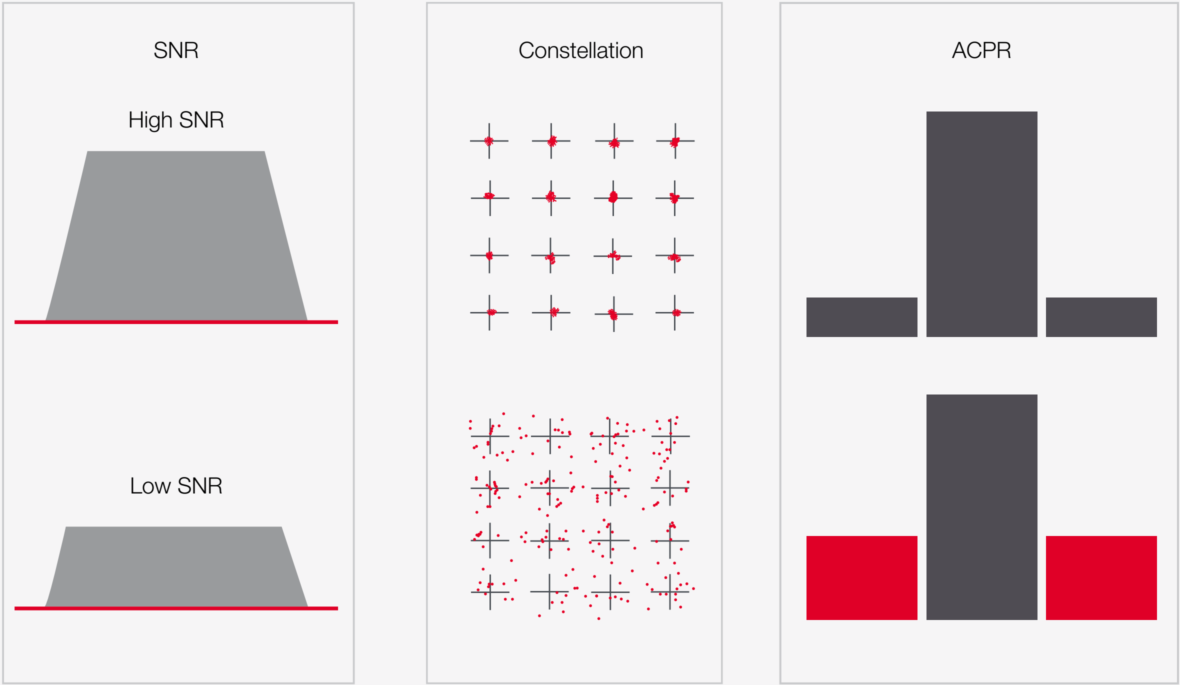

Figure 5. SNR impacts on transmitter measurements

At mmWave frequencies, excess cable loss makes RF power limited and costly. You need to measure performance metrics using OTA test methods at mmWave frequencies, making it more difficult to achieve accurate and repeatable results.

The system intermediate frequency (IF) noise of a signal analyzer must be low enough to get the best EVM measurement results. On the other hand, the input signal to the digitizer must be high enough without overloading the digitizer. This requires a combination setup of RF attenuators, preamplifier, and IF gain value based on the measured signal peak level. New signal analyzers let you press a single key to optimize these hardware settings, improving SNR and avoiding digitizer overload, as shown in Figure 6. The optimization processing requires measuring the signal peak level and setting up the analyzer. However, the measured period may not represent the complete power characteristics of the input signal. A user can manually tweak the settings, such as IF gain and RF attenuators, to achieve the best measurement results.

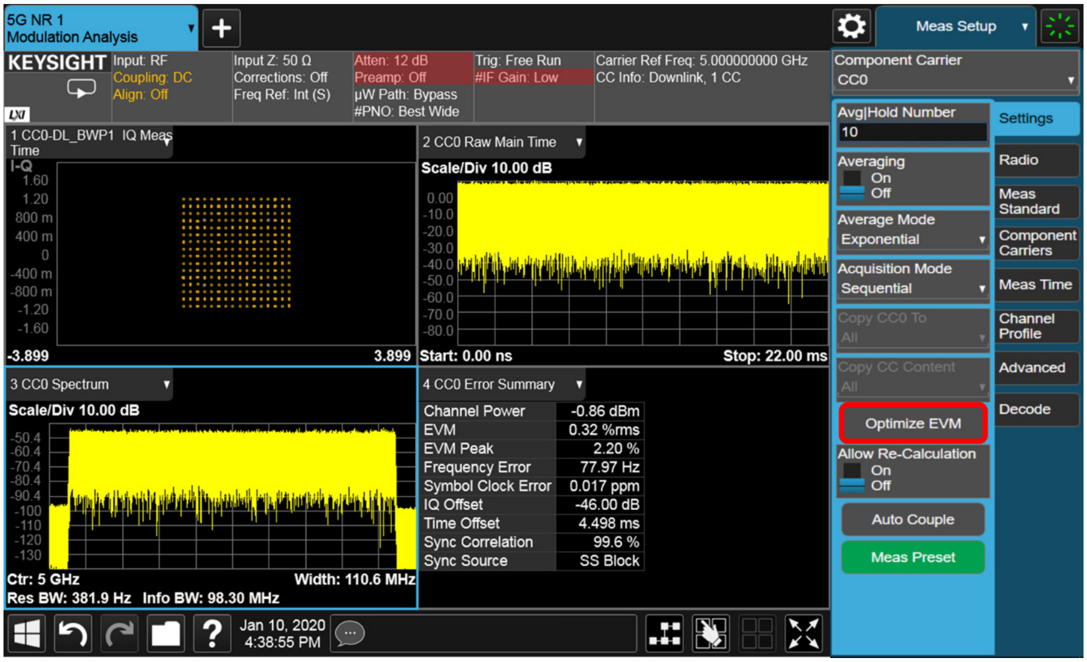

Figure 6. Optimizing EVM measurements for 5G NR modulation analysis

Signal analyzers provide several RF signal paths — such as default path, microwave preselector bypass, low-noise path, and full-bypass path — to lower noise, improve sensitivity, and reduce signal path loss for a better SNR. To learn more about improving wideband signal analysis, download the application note Full Bypass Path for X-Series Signal Analyzers.

Practice 3. Optimize phase noise for wideband applications

Phase noise describes the frequency stability of an oscillator. It is the noise spectrum around the oscillator's signal in the frequency domain. Phase noise can cause errors in the phase component of an error vector. The phase noise performance of a signal analyzer contributes error to EVM measurements.

Digital modulation

The phase noise of the signal analyzer's LO signal is translated into the input of the signal analyzer's mixer. The direct effect of phase noise on the IQ constellation diagram is the radial smearing of the symbols, as shown in Figure 7. For a higher-order modulation scheme (for example, 256QAM), the symbols are closer and the requirement of EVM performance is higher. Ensure that the signal analyzer's phase noise performance will not impact the EVM measurement results.

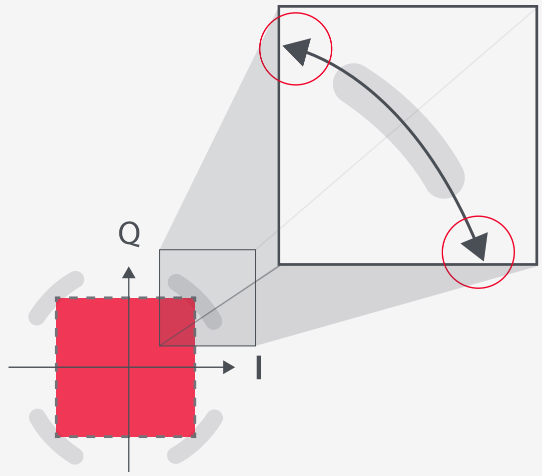

Figure 7. LO phase noise impairs the QPSK modulated signal

Orthogonal frequency-division multiplexing (OFDM)

OFDM is a common modulation scheme for wideband digital communication. It uses many closely spaced orthogonal subcarrier signals, each with its own modulation scheme, to transmit data in parallel. During frequency conversion with a poor phase noise LO, the subcarrier with phase noise spreads into other subcarriers as interference, as shown in Figure 8. The phase noise degrades the modulation quality of the OFDM signal.

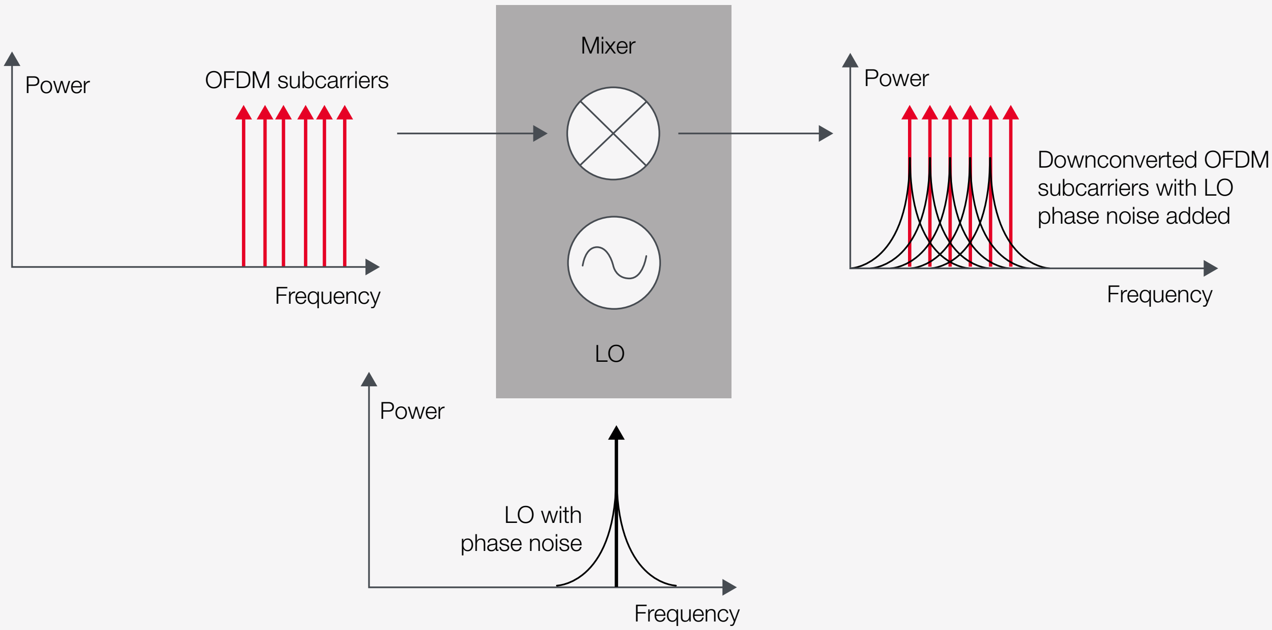

Figure 8. The impact on OFDM subcarriers from poor phase noise LO of a signal analyzer

Signal analyzers offer a choice for phase noise optimization. For example, the new Keysight N9021B MXA signal analyzer offers these operating conditions: best close-in phase noise, best wide-offset phase noise, and fast tuning. The optimization provides a different phase noise profile for various test applications:

1. **"Best Close-In"** phase noise optimizes phase noise for small frequency offsets from the carrier at the expense of phase noise far away.
2. **"Best Wide-Offset"** phase noise optimizes phase noise for wide frequency offsets from the carrier.
3. **"Fast Tuning"** switches from a two-loop local oscillator to a single loop for fast tuning measurements.

To obtain the optimum phase noise performance of a signal analyzer for modulation analysis, consider not only the phase noise profile (close in and wide offset) of the signal analyzer but also the operation frequency, bandwidth, and subcarrier spacing (OFDM signal) of the input signal. Figure 9 shows the MXA phase noise setting for 5G New Radio modulation analysis. The measurement application defaults to wide offset for better modulation analysis.

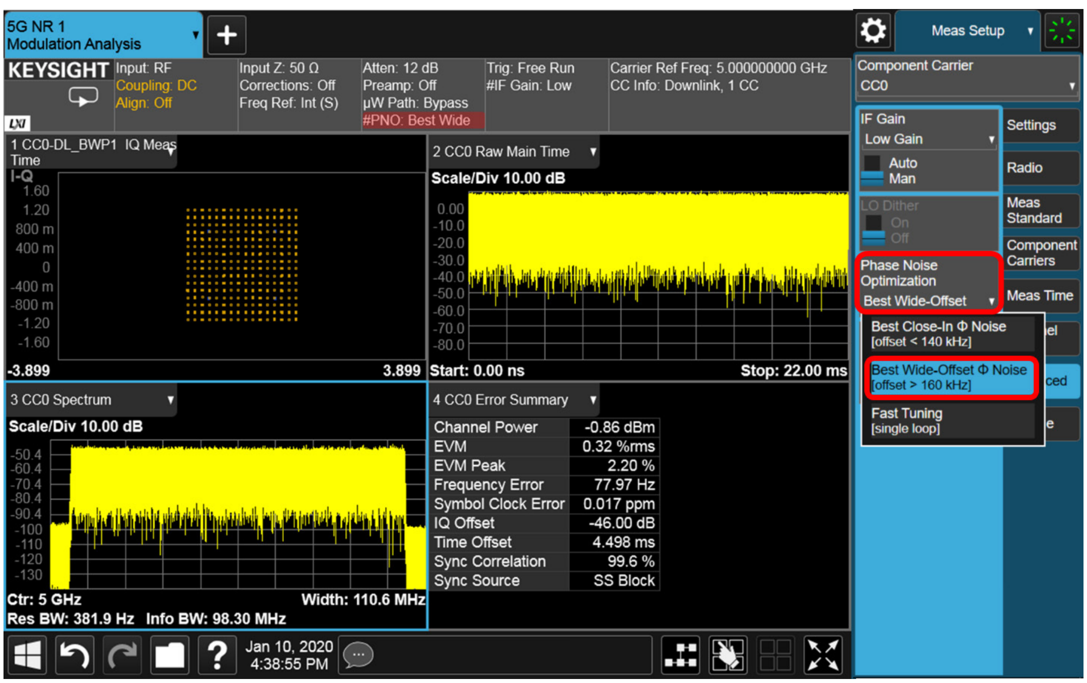

Figure 9. Select the LO phase noise profiles for various operating conditions

Phase noise optimization

Optimization provides various phase noise behaviors for different operating conditions. Actual behavior varies somewhat, depending on the model number and option.

Deliver Your Next Breakthrough

Knowing the capabilities and performance of your signal analyzers is the first step toward making accurate and repeatable measurements. Keysight's signal analyzers offer flexible and optimized settings to accurately evaluate RF components and devices and to achieve the best EVM measurement results.

To see your device's true behavior, use superior phase noise performance signal analyzers for modulation analysis. Do not let the phase noise of the signal analyzer bottleneck your EVM measurements.

Table 1. Keysight signal analyzers and signal generators

	Signal Analyzer						Signal Generator		
	UXA			PXA		MXA	PSG-D	VXG	
	N9042B	N9041B	N9040B	N9032B	N9030B	N9021B	E8267D	M9384B	M9383B[4]
Max. frequency	110 GHz	110 GHz	50 GHz	26.5 GHz	50 GHz	50 GHz	44 GHz	44 GHz	44 GHz
Max. bandwidth	4 GHz	1 GHz (9.6 GHz[1])	1 GHz (1.2 GHz[1])	2 GHz	510 MHz (0.9 GHz[1])	510 MHz (0.9 GHz[1])	80 MHz (2 GHz[2])	2 GHz[3] (4 GHz[2])	2 GHz (4 GHz[2])
Phase noise at 10 GHz, 10 kHz offset	-126 dBc/Hz	-126 dBc/Hz	-126 dBc/Hz	-126 dBc/Hz	-124 dBc/Hz	-121 dBc/Hz	-129 dBc/Hz	-127 dBc/Hz	-127 dBc/Hz

1. Support maximum analysis bandwidth with wide IF output option and an external digitizer.
2. Get up to 4 GHz of RF bandwidth with wideband external differential I/Q inputs.
3. Get up to 4 GHz of RF bandwidth with dual-channel bonding.
4. Modular form factor

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