APPLICATION NOTE

9 Best Practices for Optimizing Your Signal Generator – Part 2

Making Better Measurements

In consumer wireless, military communications, or radar, you face an ongoing bandwidth crunch in a spectrum that is filled with interference. Testing your devices via signal simulation is critical. Signal generators provide precise, highly stable test signals for a variety of components and system test applications.

Knowing the capabilities and performance of your signal generators is the first step to make accurate and consistent measurements. In this two-part Application Note, we discuss the best practices to optimize your signal generator.

Part 1:

1. Increase Amplitude Accuracy
2. Optimize Wide Bandwidth Signal Performance

Part 2:

3. Optimize Switching Speed
4. Optimize Signal Generator's Phase Noise Profile

KEYSIGHT TECHNOLOGIES

3. Optimize Switching Speed

As wireless devices increasingly integrate different functions, more tests and setups are required to accommodate diverse conditions. A wireless device includes multiple wireless standards, frequency bands, and antennas. This significantly increases test challenges in verification and production testing. Test engineers are always looking for ways to improve test throughput and reduce cost.

Speed is all-important in manufacturing. The longer you test, the more it will cost you. Therefore, signal generator speed matters in manufacturing. So, what is speed in a signal generator? Speed is defined as how fast you can switch from one frequency/amplitude to another, or how fast you can switch from one waveform to another.

Whenever the signal generator is set to a new frequency, the frequency synthesizer will change its output to the desired frequency. The output amplifier will then adjust the power level so that the output power stays the same at the new frequency. Essentially, frequency switching requires changes to both the frequency synthesizer and output amplifier, which is why frequency switching is often slower than amplitude switching. While switching, command processing takes up the most time.

For digital waveforms, the I/Q waveform data must also be computed and downloaded into the playback memory. The sample rate and digital-to-analog converter (DAC) values must be computed and stored with the file for accurate playback.

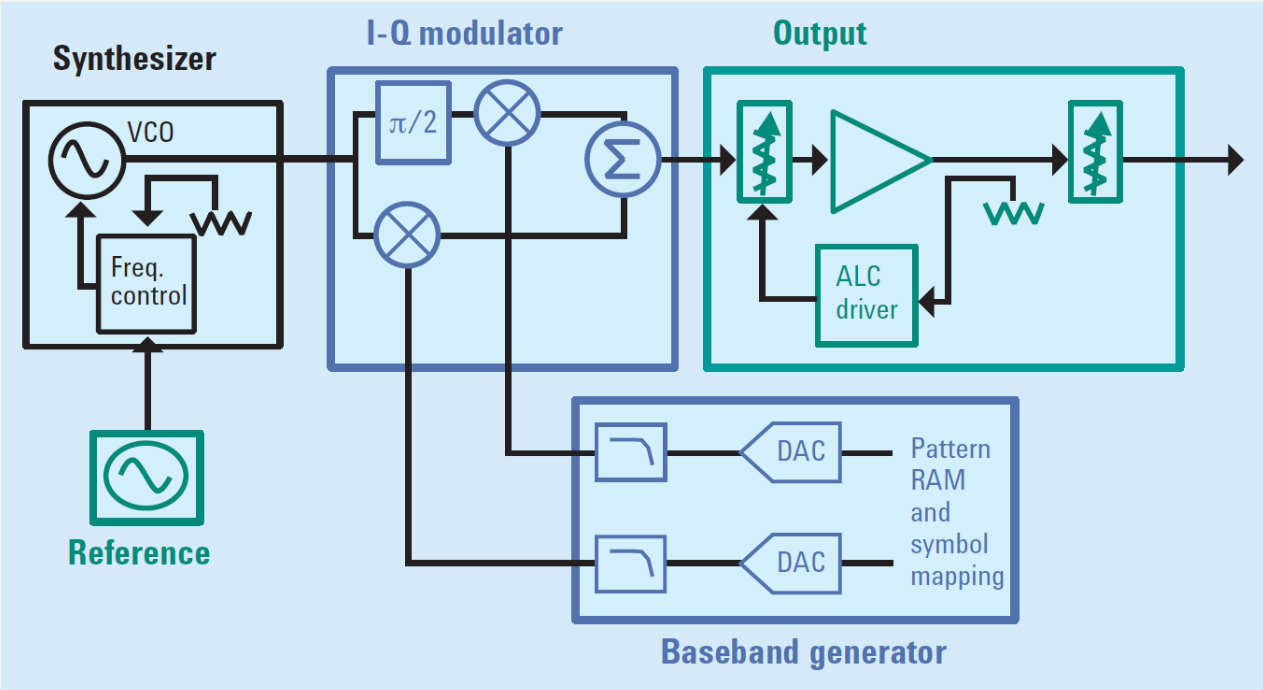


Figure 3.1: A typical vector signal generator block diagram

BEST PRACTICE 5: Use Sweep Mode - STEP and LIST

There are various ways to control the signal generator's output in automatic test systems. It is straightforward to send commands to a signal generator for setting frequency, amplitude, and waveform. This is useful when the frequency, amplitude, and waveform states are not initially known. Due to command sending, parsing, and processing, there is an overhead time when using SCPI commands before the switching can begin.

If the frequency, amplitude, and waveform combination is known in advance, then using STEP or LIST sweep, which can switch multiple parameters simultaneously, is significantly faster.

Step sweep

Step sweep offers a linear or logarithmic progression from one selected frequency and amplitude setting to the next, pausing at linearly or logarithmically spaced points (steps) along the sweep base.

List sweep

List sweep enables you to enter frequencies and amplitudes at unequal intervals, in nonlinear ascending, descending, or random order. In addition to amplitude and frequency, you can also switch baseband I/Q waveform at the same time. You need to provide frequency, amplitude level, waveform, and dwell time at each point. For fastest switching speeds, use list sweep.

Dwell Time: The time that the signal is settled, and you can make a measurement before the sweep moves to the next point.

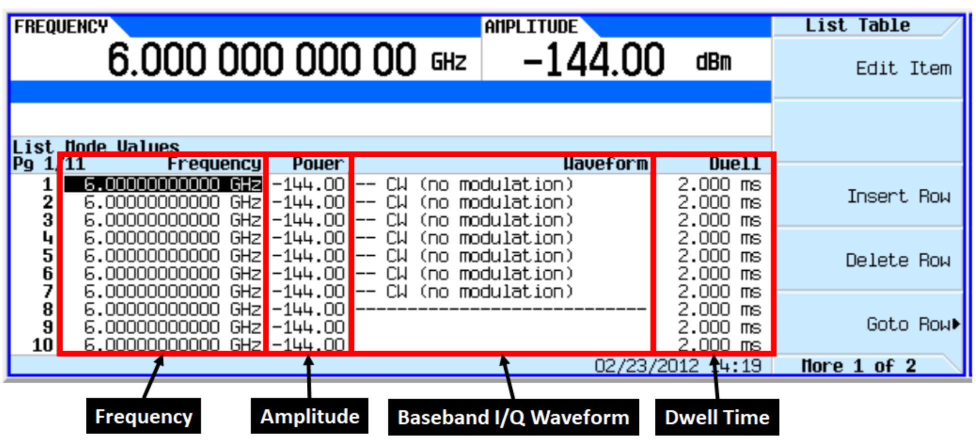


Figure 3.2: MXG N5182B list sweep configuration table.

Before you enable the sweep, you need to configure the sweep trigger or point trigger. The trigger setup could be free run, trigger key (the front panel button), bus (trigger on a remote command), external trigger or internal sync signal.

BEST PRACTICE 6: Digital Baseband Tuning Technique

For most wireless device production test, the speed of the test process is often limited by the device itself. Test response time of the device is typically measured in milliseconds. Traditional analog frequency and amplitude tuning speed are sufficient to support device-level production tests. The ultimate speed challenge occurs at the RF component level of the wireless food chain. For example, RF power amplifiers, transceivers, front-end modules (FEM), system in package (SiP), and system on chip (SOC) require fast test speed in the production line.

Digital baseband tuning techniques offer the ability to digitally shift both the frequency and amplitude levels of the signal within the VSG's available modulation bandwidth without the need to retune the synthesizer. The baseband tuning is enabled by a proprietary application-specific integrated circuit (ASIC), as shown in Figure 3.3. The ASIC includes three signal processing functions:

1. Real-time multiplier for amplitude offset.
2. Real-time numerical controller oscillator for the frequency offset.
3. Real-time channel correction to flatten amplitude and phase response.

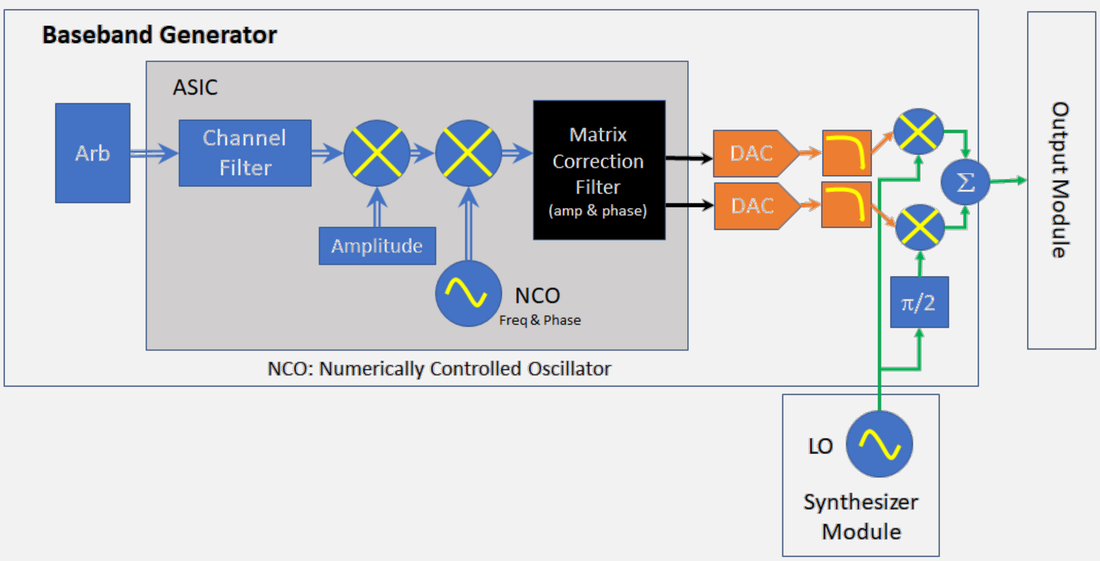


Figure 3.3: Signal processing block diagram for digital baseband tuning

As new VSGs offer wider modulation bandwidths, the digital baseband allows wider frequency shifts. The maximum frequency shift is dependent on the modulation bandwidth of the VSG. For example, the RF bandwidth of Keysight PXI VSG M9381A is 160 MHz. The waveform can be shifted arbitrarily within the 160 MHz bandwidth. The amplitude shift is within about 20 dB. The frequency shift speed can be down to 10 μs. The same speed also applies to any level change within a 20-dB range.

Although the signal bandwidth is smaller than the maximum bandwidth of the VSG, a real-time channel correction is required when the tuning ranges extend to 160 MHz. The real-time channel correction can flatten the amplitude and phase response across the entire tuning band as shown in Figure 3.4.

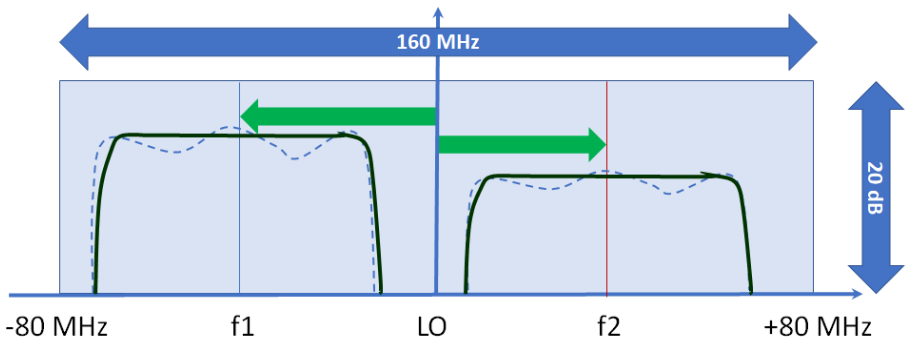


Figure 3.4: Baseband tuning across 160 MHz bandwidth and 20-dB amplitude range

Digital baseband tuning introduces a new VSG architecture that is dramatically faster than traditional RF tuning techniques. Table 3.1 shows the measurement speed comparison between RF and baseband tuning.

Keysight PXI VSG	RF Tuning	Baseband Tuning
Descriptions	Changes to the RF Carrier Frequency and Output Attenuation using the “RF” interface of the IVI driver	Changes to the frequency offset and Amplitude Offset in the signal processing ASIC using the “Modulation” interface of the IVI Driver • Frequency Range: Modulation BW of the VSG • Amplitude Range 0 to -20 dB
Programmed Command Tuning Speeds	• CW: 500 μSec to 1.4 mSec • Modulation: 3.4 mSec to 3.5 mSec	x2~x14 Speed improved compare with RF tuning • Frequency and Amplitude: 250 μSec • Amplitude Only: 250 μSec
List Mode Tuning Speed	Frequency and Amplitude (ALC Off/On): 220 μSec	x12~x22 Speed improved compare with RF tuning • Frequency and Amplitude (ALC Off): 10 μSec

Table 3.1: Measurement speed comparison between RF tuning and baseband tuning

Production test engineers must take linearity into account. Figure 3.5 shows the output power linearity. The baseband tuning (green line) offers a very small degradation in linearity because all the adjustments are done digitally. The RF tuning has fewer errors on average but is jagged due to the ALC circuit.

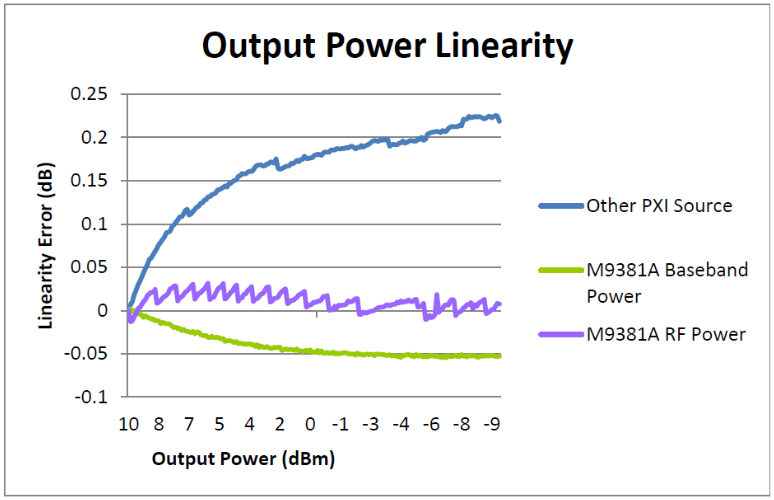


Figure 3.5: Output power linearity error within ±0.05 dB range with baseband tuning

4. Optimize Signal Generator's Phase Noise

The phase noise performance of a signal generator is a key factor in obtaining accurate measurements. It can be a limiting factor for many applications, such as radar testing, ADC testing, and OFDM communication systems. These applications require signal generators with ultra-low phase noise at different frequency offsets. You need to understand where you care most first. Even with some improvements in phase noise, it makes big difference in measurement results.

Signal generators provide several ways to optimize phase noise for your applications. Let's start with the signal generator's phase noise profile and why the profile impacts your measurements. Then you will learn how to optimize a signal generator's phase noise profile for your applications.

Signal Generators' Architecture and Phase Noise

Most signal generators' architecture includes reference oscillator, synthesizer, voltage-controlled or yttrium iron garnet (YIG) oscillator, and output amplifier. Each component has different effects on the phase noise characteristics, as shown in Figure 4.1. For offsets below 1 kHz, the noise is dominated by the performance of the reference oscillator, which is multiplied up to the carrier frequency. From offsets 1 kHz to roughly 100 kHz, synthesizer influences most. The VCO or YIG oscillator is from 100 kHz to 2 MHz, and the output amplifier is at offsets above 2 MHz.

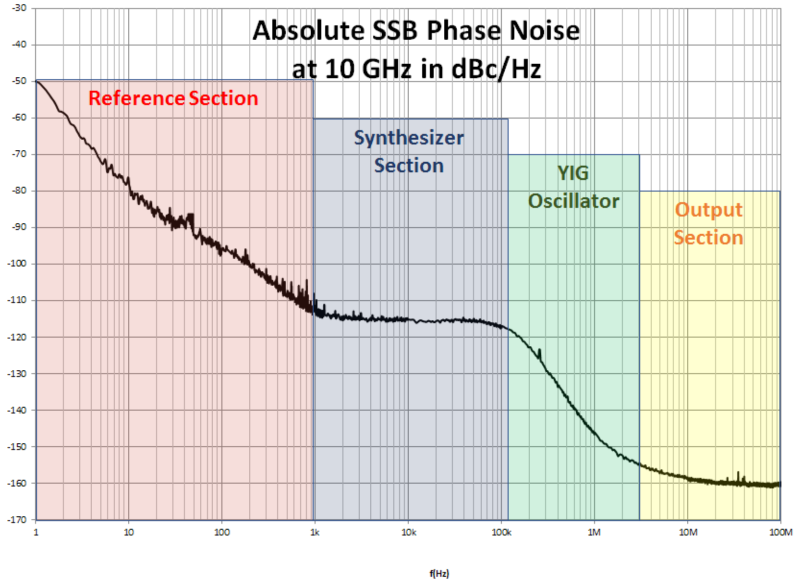


Figure 4.1: Contributions to the phase noise performance

When the Phase Noise Matters

Phase noise performance is often the key factor in the selection of a signal generator for demanding applications, such as radar systems and orthogonal frequency-division multiplexing modulation schemes.

Orthogonal Frequency-Division Multiplexing (OFDM)

OFDM is a popular modulation scheme for wideband digital communications. OFDM uses many closely spaced orthogonal sub-carrier signals to transmit data in parallel. When frequency conversion occurs with a poor phase noise local oscillator (LO), the sub-carrier with phase noise spreads into other sub-carriers as an interference. The phase noise degrades the modulation quality of the OFDM signal. Table 4.1 is sub-carrier spacing of modern wireless standards with OFDM modulation scheme.

Sub-carrier spacing	
IEEE 802.11ac	312.5 kHz
IEEE 802.11ax	78.125 kHz
LTE/LTE-A	7.5, 15 kHz
5G new radio (NR)	15, 30, 60, 120, 240, 480 kHz

Table 4.1: Sub-carrier spacing of OFDM signals

In the table above, the sub-carrier spacings appear in a signal generator's synthesizer or oscillator session. In order to get a modulation quality performance, you need to reduce the carrier's phase noise specific frequency offset as low as possible.

Doppler RADAR

In radar systems, good phase noise is critical for stable local oscillators (STALOs) and coherent oscillators (COHOs) because these signals are at the heart of the radar. For example, a radar receiver cannot identify the moving object if the downconverted signal of interest is masked by the phase noise as shown in Figure 4.2 below.

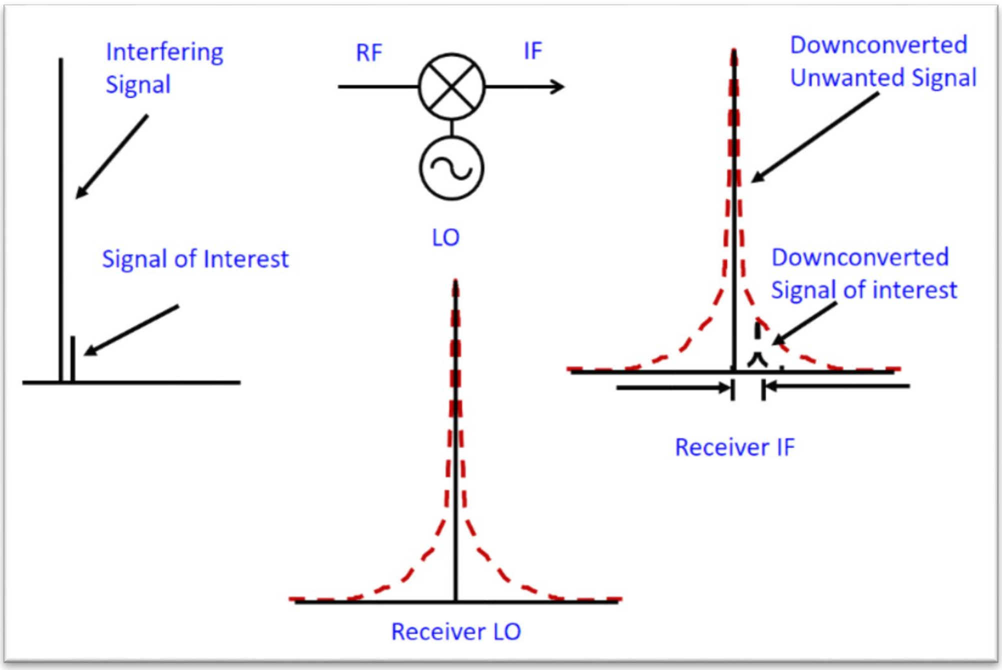


Figure 4.2: Poor LO phase noise affects receiver sensitivity

The Doppler shift is proportional to the radar frequency multiplied by the radial velocity, divided by the propagation velocity. The frequency shift could be from hundreds of Hz to hundreds of kHz. The range is across reference and synthesizer session of a signal generator as shown in figure 4.1.

BEST PRACTICE 7: Adjust Reference Oscillator Bandwidth - Close to Carrier Phase Noise

At frequency offsets below approximately 1 kHz, the stability and phase noise are determined by the internal or external frequency reference. It is straightforward to have a stable and extremely low phase noise reference oscillator that improves the carrier's phase noise in the offset frequency range below 1 kHz. Keysight PSG signal generator provides an option to improve close-in phase noise. The reference oscillator bandwidth (sometimes referred to as loop bandwidth) in the signal generator, is adjustable in fixed steps for either an internal or external 10 MHz frequency reference. You can optimize the phase noise performance of the signal generator for your applications.

The PSG with Option UNR/UNX/UNY can be adjusted in fixed steps for either an internal or external 10 MHz frequency

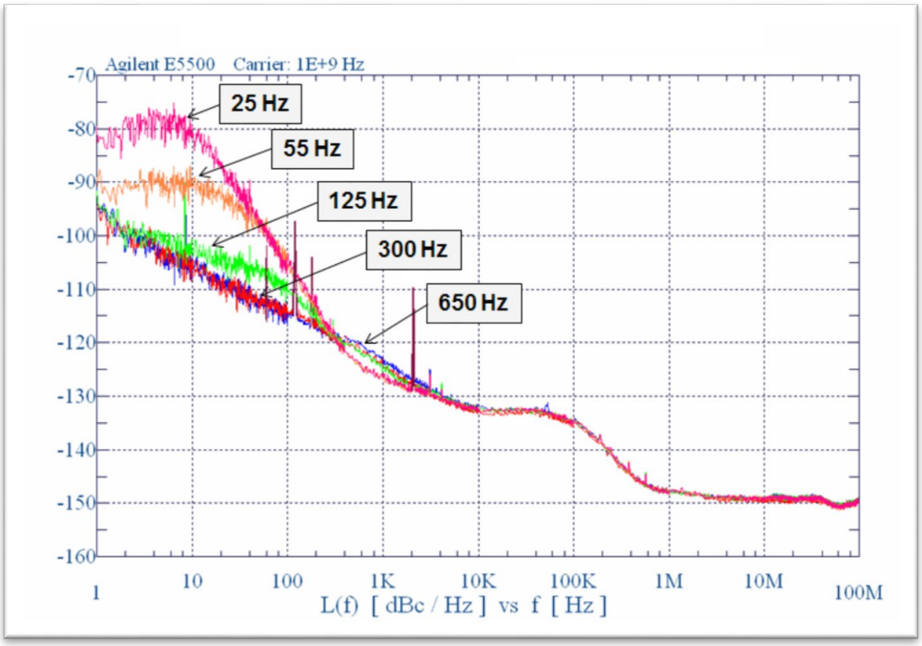


Figure 4.3: Reference oscillator's PLL bandwidth adjustments

BEST PRACTICE 8: Phase-Lock Loop Bandwidth - Synthesizer Session

In the synthesizer session, you can set the phase-lock loop bandwidth to optimize phase noise above or below 150 kHz on Keysight PSG signal generators, as shown in Figure 4.4. The light blue curve is optimized for < 150 kHz frequency offset and the yellow curve is optimized for > 150 kHz. Evaluate your application to choose the appropriate phase noise setting for wider offset frequencies.

This capability is supported on all PSG models with Option UNY.

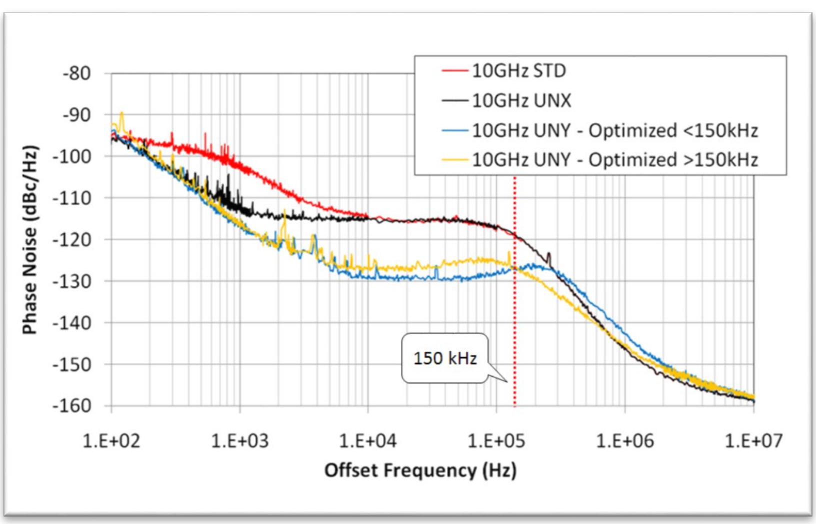


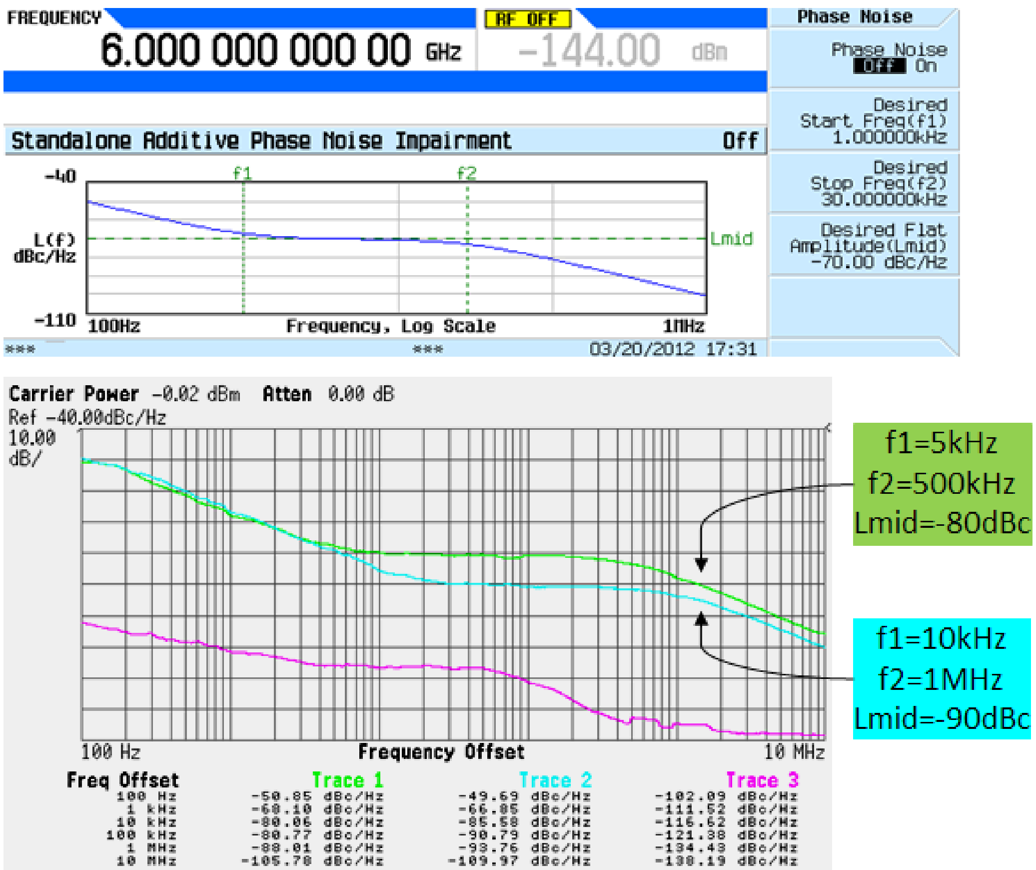
Figure 4.4: Optimize pedestal phase noise at synthesizer session

BEST PRACTICE 9: Real-Time Phase Noise Impairments

Optimizing phase noise performance is not always necessary or even desirable. Some applications and tests require a specific amount of phase noise for accurate signal substitution or tolerance testing of phase noise.

> This feature is available only in Keysight X-Series vector signal generators.

Keysight RF signal generator N5182B/N5172B allows users to adjust phase noise impairment on the synthesizer section. This feature lets you degrade the phase noise performance of the signal generator by controlling two frequency points and amplitude values, as shown in Figure 4.5. This customized phase noise is produced by internal algorithms of the signal generator, operating on a real-time baseband ASIC and processor accelerator. This allows you to simulate a more realistic signal and is helpful in evaluating and troubleshooting your device under test.



Freq Offset	Trace 1	Trace 2	Trace 3
100 Hz	-50.85 dBc/Hz	-49.69 dBc/Hz	-102.09 dBc/Hz
1 kHz	-60.10 dBc/Hz	-66.85 dBc/Hz	-111.52 dBc/Hz
10 kHz	-80.06 dBc/Hz	-85.58 dBc/Hz	-116.62 dBc/Hz
100 kHz	-80.77 dBc/Hz	-90.79 dBc/Hz	-121.38 dBc/Hz
1 MHz	-88.01 dBc/Hz	-93.76 dBc/Hz	-134.43 dBc/Hz
10 MHz	-105.78 dBc/Hz	-109.97 dBc/Hz	-138.19 dBc/Hz

Figure 4.5: Phase noise impairment setting and measurement

Phase noise is an important performance characteristic of a signal generator and obtaining accurate measurements. It is a trade-off for cost, switching speed optimization for far-out or close-in offsets. Some signal generators offer two or more levels of phase noise performance and allow optimization for wide or narrow offsets. On the other hand, you may inject a certain amount of phase noise to simulate a more realistic signal to characterize your device's performance.

Conclusion

Signal generators provide precise, highly stable test signals for a variety of component and system test applications. Different applications require different performance requirements. Keysight's signal generators offer flexibility and diverse capabilities to optimize performance and measurement speed. The best solutions will come from your experience, insight, and creativity, combined with signal generators and measurement software that enable you to generate the signals required to effectively test your DUT.

For more best practices on making better measurements, visit the **RF Test blog**. For more information about Keysight signal generators, visit **www.keysight.com/find/sg**.