Keysight Technologies
Solutions for Reducing Phase Noise at RF and Microwave Frequencies

Application Note

Radar Measurement Series

KEYSIGHT TECHNOLOGIES

Overview

Over the past 20 years, radio frequency (RF) and microwave signal generators have grown in capability and complexity to keep pace with the swift advances of vector-modulated communications and radar systems. In these applications, phase noise is one of the most critical performance parameters for signal generators and the systems under test. For example, Doppler radar applications require excellent close-in phase noise to enable accurate simulation and testing of moving target indicator (MTI) systems.

To address these needs, some off-the-shelf generators offer "low phase noise" options that offer meaningful improvement. Test engineers can extend the benefits of these options by taking advantage of additional capabilities that further improve phase noise performance. Examples include access to the internal reference hardware, voltage-controlled oscillators (VCOs) and phase-locked loops (PLLs) within the synthesizer chain—provided the standard signal generator or its options provide these features.

Before exploring these methods, it will be helpful to review the causes of phase noise and how it is specified. Phase noise is the result of random fluctuations in the phase of a signal. The major contributors are the various components and circuits used within a signal generator. These disperse output power to the surrounding frequencies, and this effect can be modeled as random phase modulation.

Phase noise in referred to as L(f) and its units are dBc/Hz, which indicates the number of decibels below the measured carrier power in a 1-Hz bandwidth at a specific frequency offset from the carrier. Close-in offsets are 1 kHz or less and far-out offsets are 100 kHz and above. The section of the curve between 1 and 100 kHz is sometimes referred to as the pedestal region.

Phase noise is typically plotted on a log-log chart (Figure 1). This makes it easier to examine both the close-in-and far-out phase noise in a single plot.

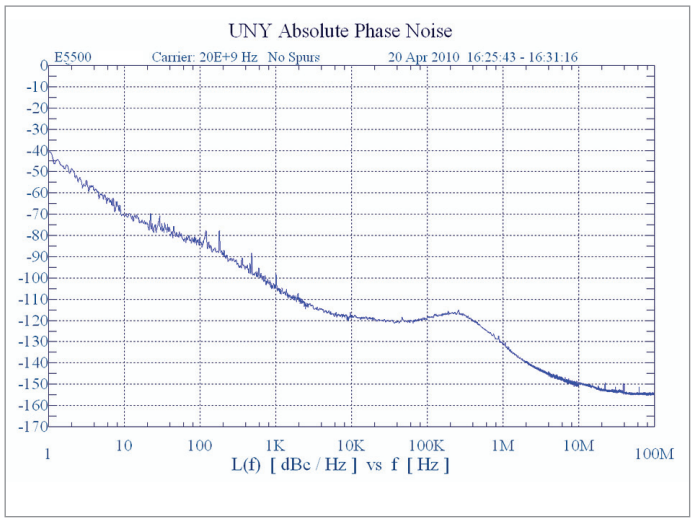

Figure 1. An example of a log-log plot that shows phase noise at a carrier frequency of 20 GHz

Problem

Within a signal generator there are four main contributors to phase noise: the frequency reference, the oscillator, the synthesizer (phase detectors and PLLs) and the output section (broadband noise floor). Figure 2 shows which sections of the block diagram dominate the different portions of the phase-noise characteristics. Reading from left to right, the reference section dominates close-in phase noise (1 kHz and below) while the synthesizer, oscillator and output section—in succession—have the dominant effects on phase noise in the pedestal and far-out regions. Let's take a closer look at each section and how it affects phase noise performance.

Frequency reference

At frequency offsets of less than 1 kHz, stability and phase noise are determined by the reference section and the reference signal. This is usually a 10 MHz frequency reference that can be generated internally or supplied externally.

The reference section multiplies the fall-off initially as 1/f3 and then transitions to a 1/f2 dependence. This represents a slope of 20 dB per decade on a log-log plot (see Figure 2).

Synthesizer

The bandwidth of the PLL determines the point at which the yttrium-iron-garnet (YIG) oscillator contribution to overall phase noise becomes suppressed. For frequency offsets within the PLL bandwidth, the generator's phase noise—overall and especially in the pedestal region—is dependent on contributions from the phase detector and reference oscillator.

Oscillator

Generally, signal generators with low phase noise use a YIG oscillator. These provide better performance than a typical VCO.

The phase noise of a YIG oscillator falls off more quickly for far-from-carrier offsets above 100 kHz. These oscillators also exhibit a wide tuning range, which means less multiplying of the signal is required to achieve the desired frequency. Less multiplying ensures lower phase noise, especially at higher frequencies.

Output section

The primary source of broadband noise is the thermal noise present within the generator. Most of this is contributed by the amplifier in the output section. Generally, phase noise at offsets greater than 10 MHz are limited by this noise floor.

Far-from-carrier noise has the greatest effect on wideband communication systems, particularly those using orthogonal frequency-division multiplexing (OFDM) techniques. The closely spaced multiple carriers can begin to interfere with one another. This is especially problematic if the phase noise is too high at offsets that approach the carrier spacing.

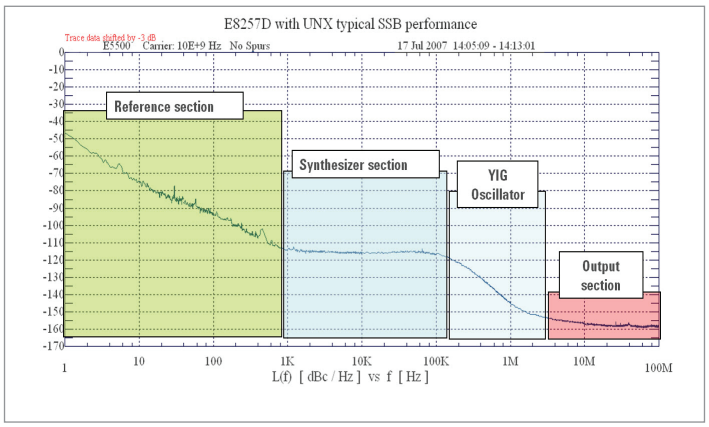

Figure 2. Each section of the instrument block diagram is the dominant contributor to an identifiable portion of phase noise performance

Solutions: Within the Design

To gain—and provide—a competitive advantage, equipment manufacturers are always looking for ways to suppress phase noise in the signal generators they offer. Keysight Technologies, Inc. has three models that provide excellent phase noise performance: the E8257D PSG analog signal generator, the E8267D PSG vector signal generator and the E8663D PSG RF analog signal generator.

In these models, high performance is built on foundation of architectural improvements that address the underlying causes of phase noise. For example, the use of a multi-frequency reference design and a YIG oscillator in the synthesizer section helps minimize the number and size of spurious signals. Another basic change is to install a lower-noise 10 MHz reference oscillator. A good example is an oven-controlled crystal oscillator (OCXO), which is stabilized with respect to temperature.

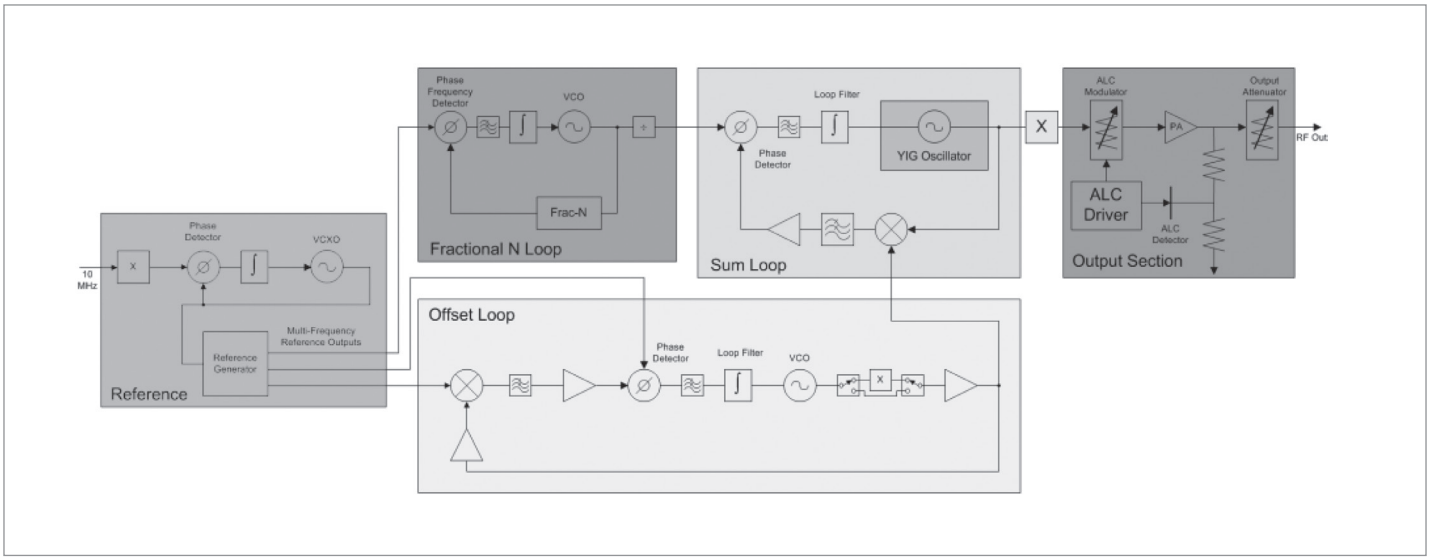

Figure 3. Keysight's triple-loop architecture enables tremendous improvements in phase noise performance

Changing the architecture

A deeper change is the use of a multiple-loop design, which provides enhanced stability. Keysight PSG signal generators use the triple-loop architecture shown in Figure 3. This design improves phase noise by as much as 12 dB in the pedestal region at offsets of 1 kHz to 200 kHz. One contributor is a higher signal-to-noise ratio that is achieved by allowing more of the YIG signal to drive the loop. The other is greater rejection of VCO noise due to the wide loop bandwidth.

This design provides improved close-in phase noise through the use of a high performance voltage-controlled crystal oscillator (VCXO) in the reference section. The improvement is typically 5 dB at a 1 Hz offset.

The PSG signal generators include three more enhancements that further improve phase noise performance. One is direct access to the reference path, which allows insertion of a higher-frequency reference signal (e.g., 1 GHz). Next is built-in functionality that enables adjustments to the reference-oscillator bandwidth (also called loop bandwidth).

The third improvement is the use of dividers rather than heterodyne mixing at carrier frequencies below 250 MHz. Mixing produces the same phase noise as the higher intermediate frequency before downconversion, just at a lower frequency. In contrast, dividing a signal provides lower phase noise—at all offsets—by a factor of 20*log (n) where n is the integer divisor. In equation form this is expressed as $L(f)_{out} = L(f)_{in} - 20*\log(n)$ and, as an example, dividing by 2 produces a 6 dB improvement in the phase noise of the output signal.

Providing optional enhancements

Option UNY, enhanced ultra-low phase noise performance, is available for the E8257D, E8267D and E8663D. This option provides an enhanced multi-loop synthesizer along with a high-performance internal frequency reference. The high-performance reference improves close-in phase noise while the new advanced synthesizer design provides superior pedestal phase noise performance.

The option also adds a 1 GHz output that can be used to drive other PSGs. This provides enhanced phase stability for applications such as phased-array radars and multiple-input/multiple-output (MIMO) communications devices that require multiple synchronized stimulus signals.

Solutions and Results: User-Applied Methods

You can use the signal generator options and enhancements described above to dial in phase noise performance to fit your specific application. The most beneficial tweaks fit into two categories: references and adjustments.

Applying external references

The PSG series provides inputs for 10 MHz and 1 GHz external references. When applied to the reference section, a 10 MHz signal that is cleaner and more precise than the stabilized internal reference will provide further improvements in close-to-carrier phase noise. Even so, close-in phase noise will remain far above the residual levels produced by the other sections of the block diagram (Figure 4).

PSG Option H1S provides an input for an external 1 GHz reference, and this has the potential to drive phase noise even lower than the specified absolute levels. Because PSG signal generators provide excellent phase noise specifications, improving on the standard level of performance requires an astonishingly good 1 GHz signal. Such high quality signals can be generated by MASER-class oscillators, which typically are quite costly.[1]

Using built-in adjustments

PSG signal generators provide two user-controlled adjustments; the reference oscillator PLL bandwidth, and the YIG oscillator loop bandwidth. The PLL bandwidth adjustment capability is included as part of Options UNR, UNX and UNY; the YIG oscillator loop bandwidth adjustment capability is included with Option UNY. In the E8257D and E8663D PSG analog models, Options UNX and UNY also provide user-controlled activation of internal frequency dividers.

Adjustment of the PLL bandwidth works with internal or external 10 MHz reference signals and is allowed in fixed steps: 25, 55, 125, 300 and 650 Hz. This adjustment affects the bandwidth of the PLL integrator (Figure 5), and this in turn reduces close-in phase noise (offsets below 1 kHz).

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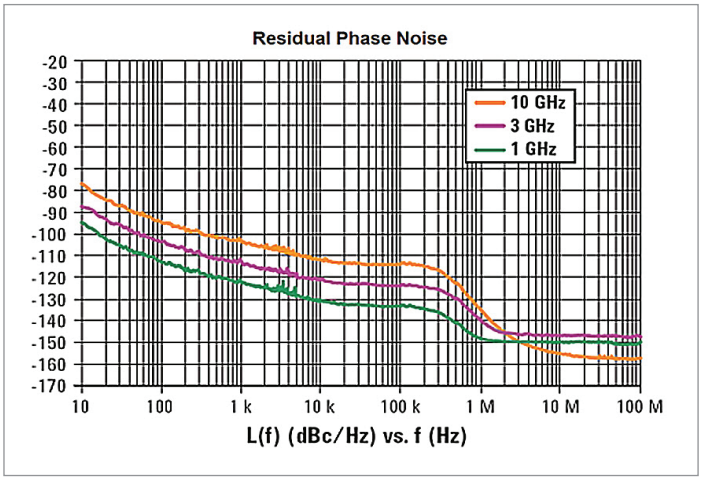

Figure 4. Residual phase noise represents the phase noise of the signal generator, excluding the reference section. This is in contrast to absolute phase noise, which represents the generator's total phase noise.

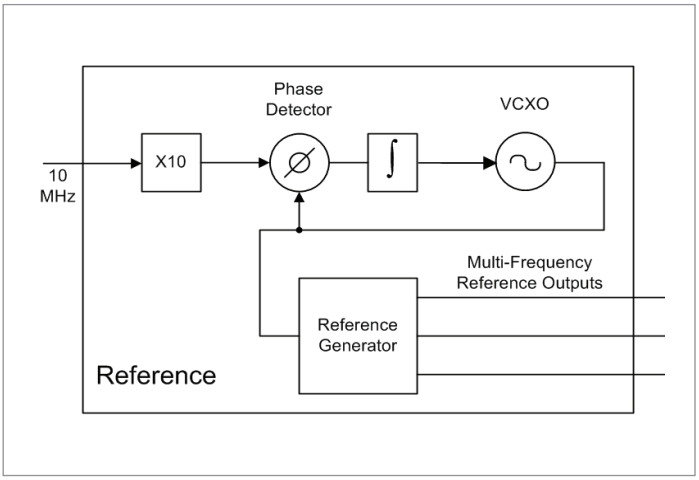

Figure 5. Adjusting the bandwidth of the integrator reduces close-in phase noise

1. MASER or maser: microwave amplification by stimulated emission of radiation

Applying external references *(continued)*

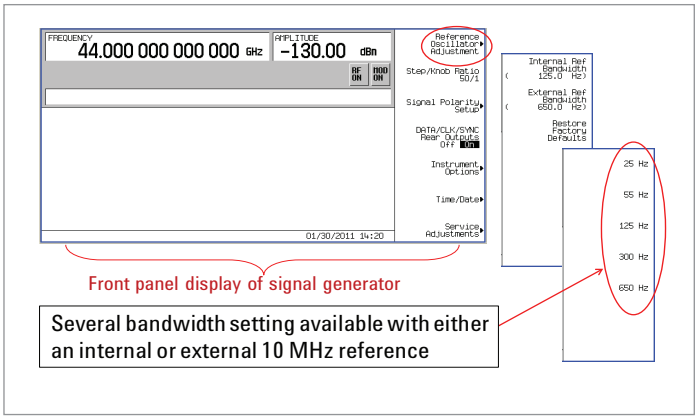

Figure 6. Bandwidth adjustments are accessed through front-panel soft menus in the PSG

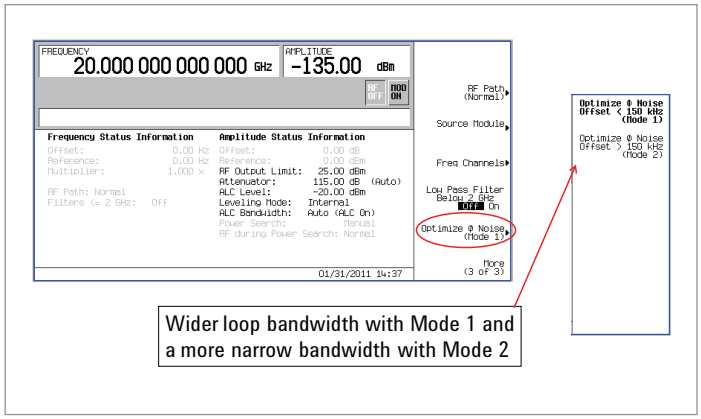

Figure 8. The "Optimize Φ Noise" function provides two modes that affect YIG oscillator loop bandwidth

Figure 6 shows the associated front-panel display and soft menus from a PSG signal generator. Typical results are shown in Figure 7.

The effect of the bandwidth adjustments can be observed as a change in the slope of the signal generator's phase noise curve. To optimize the overall phase noise performance of the signal generator for your application, make this adjustment depending on your confidence in the stability and phase noise of the external or internal reference versus the synthesizer hardware at relevant frequency offsets from the carrier.

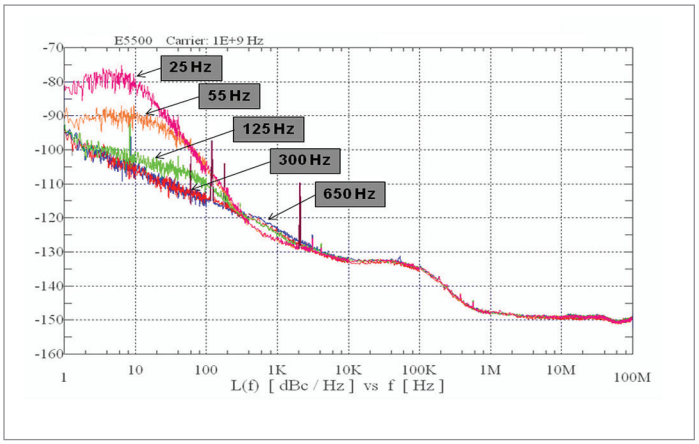

Figure 7. Each bandwidth setting provides visible changes in PSG phase noise

There are two settings for the YIG oscillator loop bandwidth: wide and narrow. The wide bandwidth mode ("Mode 1") optimizes phase noise for offsets greater than 150 kHz. The narrow mode ("Mode 2") optimizes phase noise in the pedestal region, which includes offsets ranging from 1 kHz to 100 kHz.

Figure 8 shows the associated front-panel display and soft menus from a PSG signal generator. Typical results are shown in Figure 9. The effect of the bandwidth adjustments can be observed as a change in the slope of the signal generator's phase noise curve.

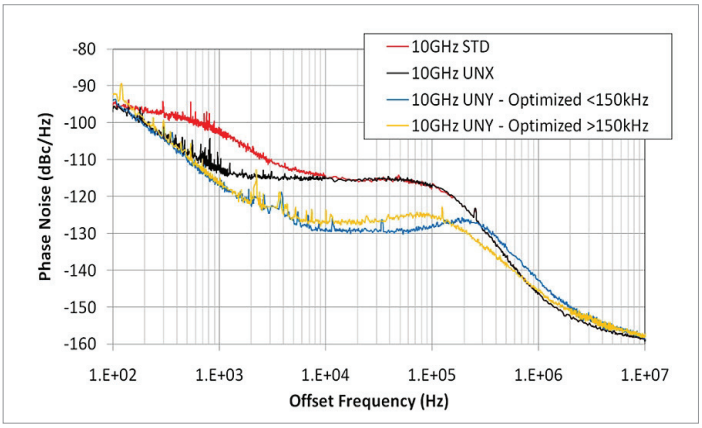

Figure 9. Modes 1 and 2 provide improved phase noise performance in the pedestal region (1 kHz to 100 kHz)

Using frequency dividers

As noted above, Options UNX and UNY enable internal frequency dividers in the E8257D and E8663D PSG analog signal generators. Figure 10 shows the associated front-panel display and soft menu from a PSG signal generator. This capability is applied to carrier frequencies of up to 250 MHz and provides improved phase noise performance at all offsets from those carrier frequencies (Figure 11).

One note: The use of dividers will reduce the maximum possible deviation when using the frequency or phase modulation (FM or PM) capabilities of the signal generator. At low carrier frequencies the modulation deviation can become too small to be useful. For that reason, the use of dividers is user-controllable in Options UNX and UNY. Disabling the dividers reactivates heterodyning and provides wider deviation bandwidth in FM and PM.

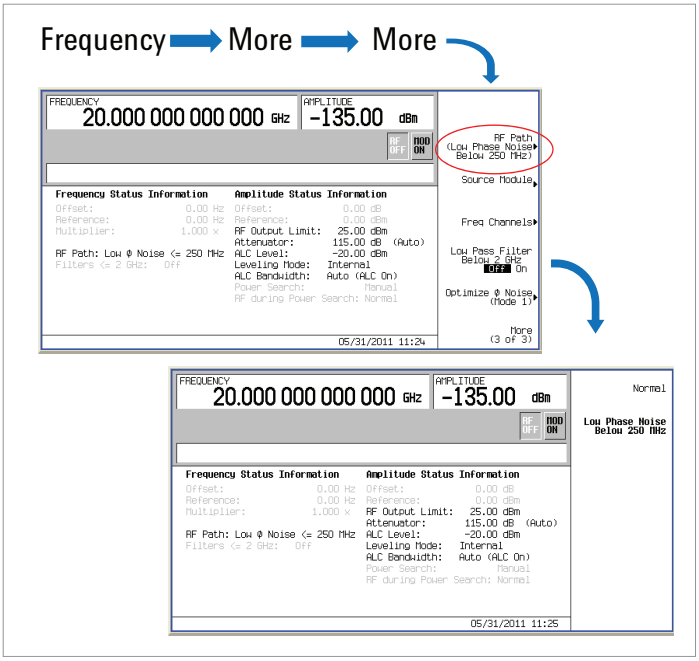

Figure 10. The "RF Path (Low Phase Noise Below 250 MHz)" function activates the divider mode

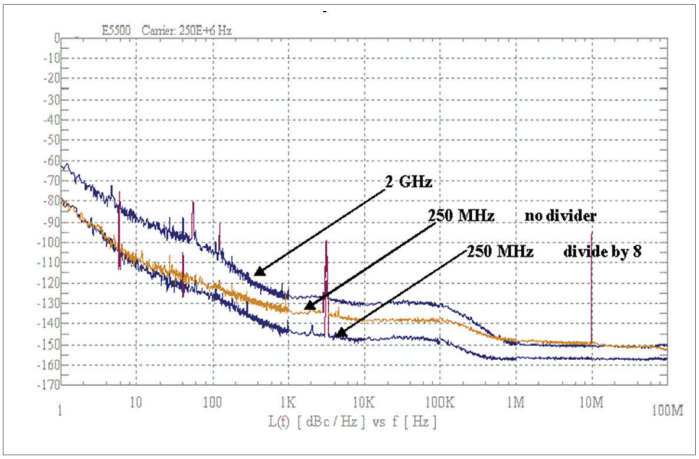

Figure 11. Comparison of 250 MHz signals produced via heterodyning (no divider) or dividing by 8

Conclusion

With the technological and architectural innovations described above, Keysight PSG signal generators provide excellent phase noise performance. That performance can be tuned to meet the needs of specific applications through capabilities such as inputs for external reference signals and user-controlled adjustments of loop bandwidth and oscillator bandwidth.

Discerning use of the methods described in this note make it possible to handle demanding applications such as the testing of Doppler-based radar systems. As an example, the simulation of moving targets requires extremely low phase noise at a 30 kHz offset, which equates to a single target moving at Mach 1.5, and at a 60 kHz offset, which equates to a pair of aircraft closing on each other at Mach 3.0.

Related information

- Product Brochure: *PSG Signal Generators*, literature number 5989-1324EN
- Data Sheet: *E8257D PSG Microwave Analog Signal Generator*, literature number 5989-0698EN
- Data Sheet: *E8267D PSG Vector Signal Generator*, literature number 5989-0697EN
- Data Sheet: *E8663D PSG RF Analog Signal Generator*, literature number 5990-4136EN
- Selection Guide: *Keysight's Phase Noise Measurement Solutions*, literature number 5990-5729EN

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