



Comparing Spectral Purity in Microwave Signal Generators

Written by: Leonard Dickstein

Giga-tronics Incorporated

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Introduction

An ideal signal has no phase noise, harmonics nor spurious frequency components associated with it. Unfortunately the ideal signal does not exist in the real world, and these factors degrade the spectral purity of all real world signals to some degree. High-performance microwave signal generators are designed to maximize spectral purity, with very low levels of phase noise, harmonics and spurs, while maintaining general purpose flexibility. The levels of spectral purity performance are one of the key differences between high-performance, mid-range and low-end or entry-level signal generators. This paper discusses the factors that make up spectral purity specifications to help you make more informed comparisons of microwave signal generator performance for test and measurement applications.

Phase Noise

Phase noise refers to short-term, random fluctuations in the phase of the signal, and is usually expressed as value normalized to a 1 Hz bandwidth and at some offset frequency away from the signal frequency and relative to the amplitude of the signal. It can be expressed as a number (such as -100 dBc/Hz at 10 GHz and 10 kHz offset), but is also shown as a graph of phase noise versus offset frequency for one or more signal frequencies. While the actual spectral density is double sided around the signal or carrier frequency, as you would observe on a Spectrum Analyzer display, the phase noise of microwave signal generators is typically shown as a graph of only one side, called single side band (SSB) phase noise. See Figure 1.

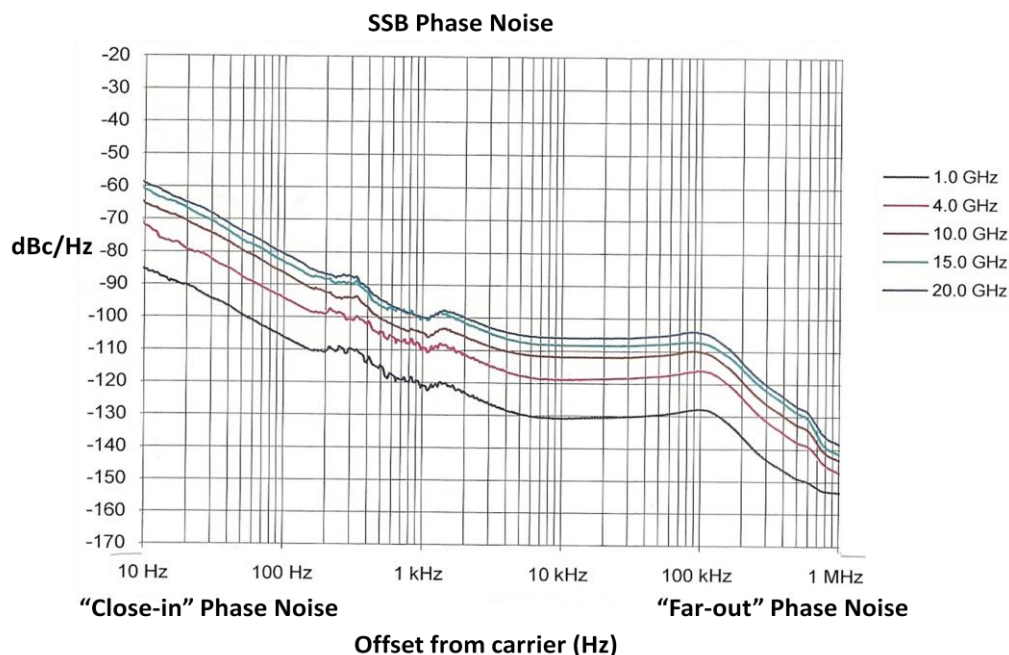


Figure 1.

The vertical axis is the phase noise to carrier ratio in dBc/Hz where a smaller value is better. The horizontal axis is the offset from the carrier frequency in Hz where offsets from 1 Hz to 100 Hz away

from the carrier are referred to as “close-in” and offsets from 100 kHz to 10 MHz away from the carrier are referred to as “far out”. Phase noise close in to the carrier presents a problem in applications where the signal is used as a local oscillator and could limit the receiver’s sensitivity or when the signal is used as a clock and could limit the bit error rate (BER) performance. Phase noise far out from the carrier presents a problem in wideband communications systems raising the noise floor and limiting the systems ability to recover weak signals. Close-in phase noise is often critical for Aerospace and Defense applications such as high-resolution radar, while the far-out phase noise is often critical for broadband digital wireless communications.

When comparing microwave signal generator phase noise performance, it is important to realize that datasheet specifications can be misleading when you are just comparing the phase noise numbers. For example, Figure 2 shows a comparison of measured data for three competing high-performance microwave signal generators, taken at the same carrier frequency:

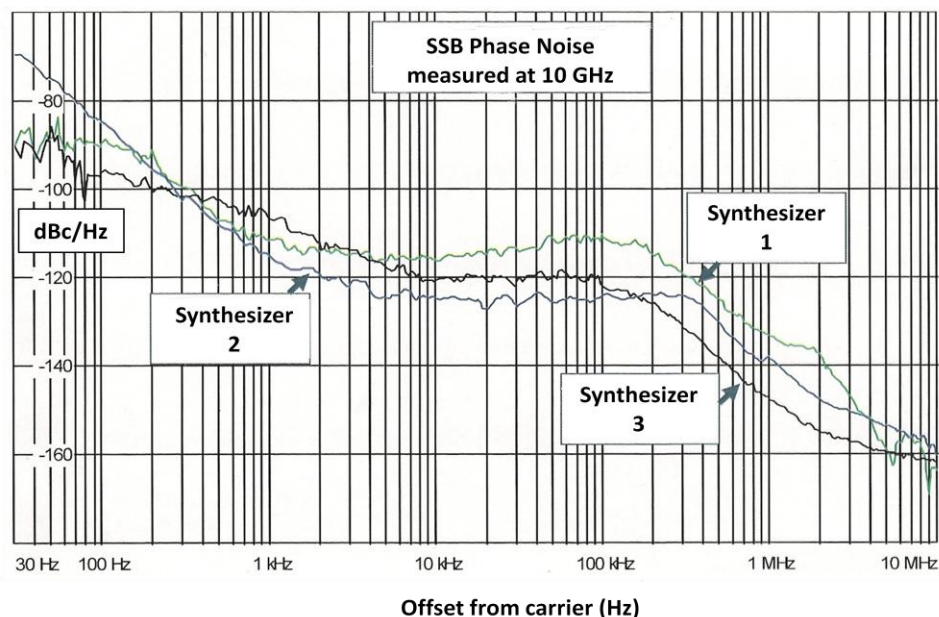


Figure 2.

Notice that the performance of the three different synthesizers overlap and that no one is significantly better everywhere. All three products show very good phase noise performance. It is important to note that while the 10 kHz offset from carrier is typically used for comparison, it may not be a critical difference for many applications, where either the close-in or far-out phase noise dominates. A signal generator manufacturer may optimize their phase noise performance for an impressive specification at 10 kHz offset, while compromising the performance in both the close-in and far-out regions, as with “Synthesizer 2” in the example. Although all three companies in the example can claim the lowest phase noise at some point, what is most meaningful is to take into consideration the entire range and how it applies to your specific test scenarios.



Some times you may see a vendor advertise frequency synthesizer phase noise at 100 kHz offset rather than 10 kHz offset just to make their phase noise performance appear better or they present phase noise without specifying the carrier frequency or the offset which is ambiguous and of dubious value.

As indicated in Figure 1 with the five traces for the five different carrier frequencies, the phase noise in most microwave signal generators increases as the carrier frequency increases. This is attributed to the fact that almost all modern microwave signal generators use frequency multiplication to generate the higher frequency ranges, and the phase noise increases as $20 \log N$ where N is the multiplication factor. What this means is that one signal generator that multiplies less than another to provide the same final frequency will probably have lower phase noise at the higher frequency. It is important to note that while 10 GHz (and 10 kHz offset) is typically used for comparison for microwave signal generators, better performance at 10 GHz does not necessarily mean better performance at 40 GHz or 50 GHz, because of possible differences in multiplication factors.

The majority of microwave signal generators used for test and measurement applications are designed around YIG-based microwave oscillators, rather than VCO based. There are several reasons for this fact and phase noise performance is one of the key reasons. First, YIG oscillators have a very wide tuning range. This means that the multiplication factors can be smaller, resulting in lower phase noise at the higher frequencies. And second, the phase noise of YIG-based oscillators drops off more rapidly far out from carrier than it does in VCOs, so the total integrated phase noise with YIG-based oscillators tends to be lower.

Phase noise is a function of the internal oscillator and any external frequency reference used. Different microwave signal generators use different loop bandwidths when locking to an external frequency reference. A narrow bandwidth on the external frequency reference input can help minimize the effects of phase noise resulting from a noisy external frequency reference signal. A few companies use a wider bandwidth to allow more stable phase tracking of multiple signal generators, but that makes them more susceptible to phase noise from the external frequency reference. Other companies overcome this trade-off limitation by providing the capability to phase track using an internal 100 MHz oscillator with wide loop bandwidth while keeping a narrow bandwidth on the 10 MHz external frequency reference input.

Occasionally, in a microwave signal generator datasheet, you will find that phase noise plots are provided for the absolute phase noise (the phase noise performance of the signal generator) and residual phase noise (the phase noise performance with the contribution from the internal frequency reference removed). This residual phase noise information is only useful when an external frequency reference is used, and is added to the phase noise of the external frequency reference. The residual phase noise information is needed because of that specific synthesizer's sensitivity to the phase noise of the external frequency reference, and the fact that its phase noise performance is potentially degraded by using a noisy external frequency reference signal. Typically the differences between absolute and residual show up only in the close-in phase noise region.

Harmonics and Spurious

When comparing harmonics and spurious performance note that all frequency synthesizers create harmonic and spurious signals. Depending on your application, these harmonics and spurious signals may or may not be a problem. It is important to note that different applications may be sensitive to spurious at different amplitudes and frequencies, and while one synthesizer may have a problematic spur in one specific application and another synthesizer does not, the opposite will be true in a different application or in even the same application at different frequencies. It is incorrect to generalize that any of the top performing microwave signal generators are consistently better or worse than any other, when it comes to harmonic and spurious performance.

A microwave signal generator can meet and exceed its spurious specification and still exhibit a problematic spur if it just happens to fall in a sensitive region in any specific application. But with that caveat, it is true that the better the spurious specs, the less likely that you will encounter this issue. Microwave signal generators with poor spurious specifications are probably unusable for some applications, such as testing radar and ECM receivers and EW systems where the high level of spurious will appear as ghost (false) signals or threats. In wireless communications systems, high levels of spurious can be a problem when they fall inside the channel.

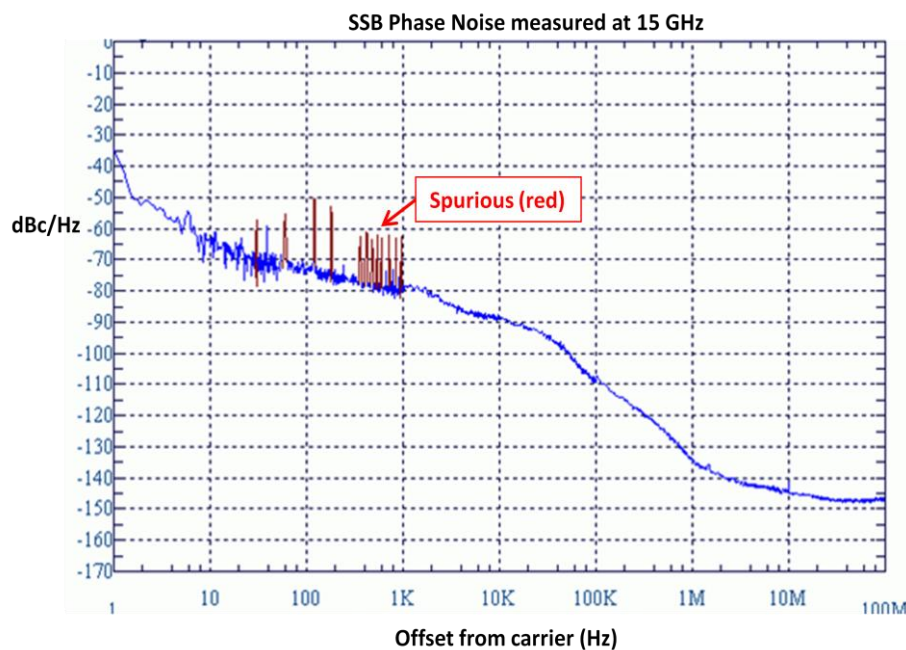


Figure 3.

It's often difficult to understand spurious performance, because the spurious content is usually removed from the graphs of phase noise shown in most datasheets. This is not done to be devious, but rather to separate and distinguish the different phenomena. Figures 1 and 2 show phase noise with the spurs removed and for phase noise comparison purposes, that is useful.

If you visualize Figure 3 as if it were displayed on a spectrum analyzer, then you would recognize the spurs as sidebands around the carrier. In Figure 3, the phase noise is shown in blue, while the spurious signals are shown in red. If the spurious performance specification was -50 dBc or better, then that instrument at that frequency would be meeting its specification. The highest spur appears to be occurring at 120 Hz off the carrier, probably an artifact from the power supply. But the next largest spur appears to be 200 Hz off the carrier, and it may be very difficult or impossible to determine its origin.

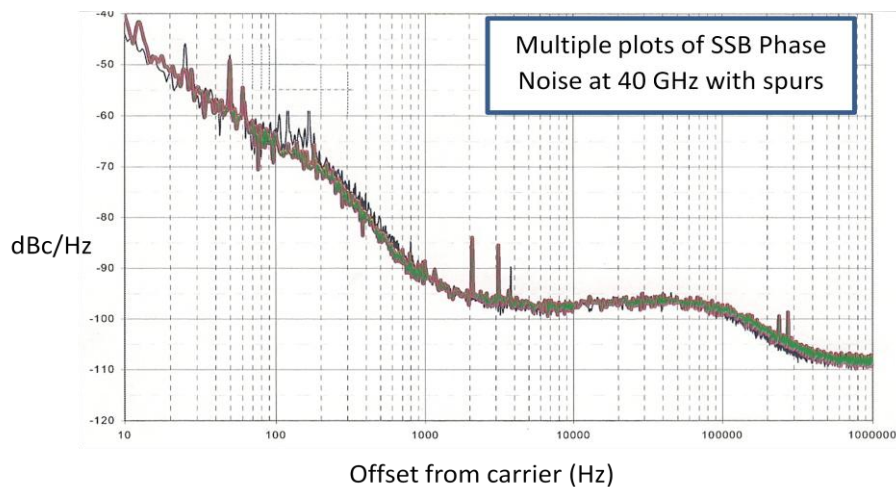


Figure 4.

Figure 4 shows a set of phase noise measurements at 40 GHz. The phase noise is quite consistent, but the spurious signals vary. Figure 4 illustrates one of the most annoying properties of spurious signals and that is the fact that spurious signals vary as a function of both manufacturing variations and the external environment, and may also vary with the output power level and other settings. Slight variations on gasket sealing or device parameters will influence the level of spurious signals, and many spurious signals are a result of external electro-magnetic interference, both conducted and radiated. Factors like heavy I/O bus activity may also have an effect, as noise can couple from the I/O bus into the analog and microwave hardware, so minimizing remote control communications during sensitive testing is a best practice.

While spurious signals in microwave signal generators are not always a function of output power level, harmonics are. When comparing harmonic specifications, be sure to check what output power level applies for the specifications. Note that for most microwave signal generators with a high power option, the harmonic levels increase, sometimes substantially, with the addition of the option. There is a strong argument for using external microwave power amplifiers rather than high power options as increased harmonics is only one drawback of the microwave signal generator high power option. See Giga-tronics' application note AN-GT111A *"Boosting RF Output Power – Signal Generator High Power Options versus External Power Amplifiers"* for a more detailed discussion of the advantages of using external microwave power amplifiers.



Summary

Spectral purity is one of the most important specifications to consider when selecting a microwave signal generator and is one of the more difficult set of specifications to fully understand. When comparing phase noise performance, it is important to realize that datasheet specifications can be misleading when you are just comparing the numeric values and that you also need to look at the phase noise plots and consider how they would apply to your specific application. In addition, harmonics and spurious signals are problematic, and that while one microwave signal generator may have a spurious signal in any specific measurement scenario and another microwave signal generator does not, the opposite will be true in a different application or even in the same application at a different setting. Lastly, be aware that the harmonics specifications may degrade significantly with the addition of a high output power option, and the use of external power amplifiers is often a better solution when higher output power levels are required.