APPLICATION NOTE

How Signal Generator Spectral Purity Affects Measurements

KEYSIGHT

What Is Spectral Purity?

Spectral purity represents a signal's inherent stability, particularly in frequency consistency, and considers both short-term and long-term stabilities. Spectral purity refers to the extent to which a signal is free from unwanted frequencies or noise.

Long-term stability, or drift, is measured over periods longer than one second. The rate at which a signal drifts off frequency can occur over minutes, hours, days, or even months. Modern signal generators are designed to offer proven long-term stability.

The primary concern is short-term stability, specifically frequency changes that occur in less than one second. These fluctuations come from non-deterministic signals like noise, shot noise, and 1/f flicker noise that modulates the carrier. As illustrated in Figure 1, these fluctuations affect both phase and amplitude.

This application note delves into the components of spectral purity in signal generator measurements, emphasizing its importance and impact on signal quality and measurement accuracy in different applications.

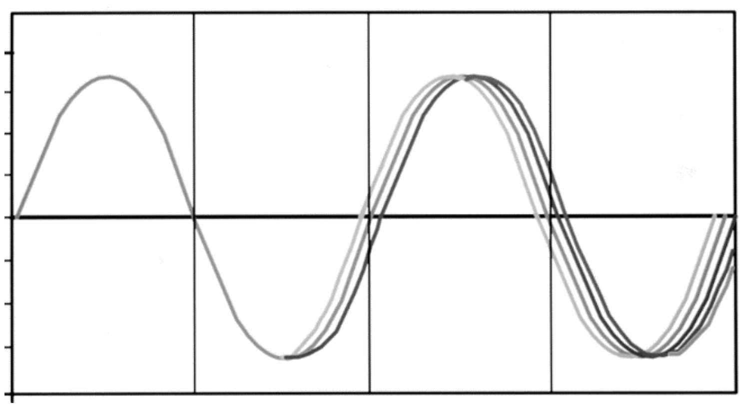

Figure 1. Oscilloscope display of short-term frequency fluctuations

What Are the Components?

Single-sideband phase noise

There are many ways to define spectral purity. Figure 2 illustrates the most common and meaningful method to specify short-term stability by plotting the signal generator's single-sideband (SSB) phase noise in a 1 Hz bandwidth versus the offset from the carrier. This example expresses the SSB phase noise in dB relative to the carrier (dBc). A 1 Hz bandwidth facilitates easy calculation and noise comparison in other bandwidths. This plot is a graphical representation of the phase noise distribution on one side of the carrier.

Spurious

Mixing and dividing signals to get the carrier frequency creates non-random or deterministic signals. Signals are harmonically related to the carrier and are subharmonics. The amplitude of the non-harmonic spectral line, known as spurious, is relative to the carrier (dBc).

Residual frequency modulation

Residual frequency modulation (FM) refers to the unwanted angular modulation or FM inherent in a signal generator when all the modulation is deactivated. This result includes spurious and phase noise effects, as shown in Figure 2. The integral or area under the single-sideband (SSB) curve, with limits set by the post-detection bandwidth, defines this modulation. Common bandwidths are 300 Hz to 3 kHz and 20 Hz to 15 kHz.

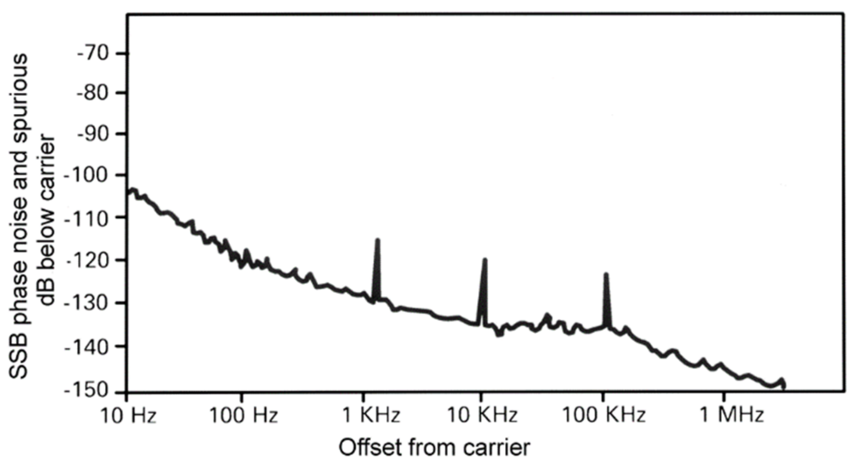

Figure 2. Signal generator SSB phase noise and spurious effects on one side of the carrier

Why Is Spectral Purity Important for Mobile Radio?

Narrower channel spacings

As available spectrum becomes increasingly scarce, radio channel spacings will decrease, imposing tighter constraints on receiver designers to design more selective receivers. Figure 3 shows higher spectral purity is required for smaller channel spacings. A signal generator must have good spectral purity to test receiver selectivity accurately and ensure you are testing your receiver instead of the generator.

Adjacent channel selectivity

One common measurement for testing receiver rejection of unwanted signals is adjacent channel selectivity. Figure 4 shows a receiver intermediate frequency (IF) passband with an in-channel signal at a specific sensitivity level. A second signal generator set one channel spacing away. The signal generator's amplitude increases until the signal passes through the passband and distorts the in-channel signal by a specified amount. Adjacent channel selectivity is the difference between the two signal levels.

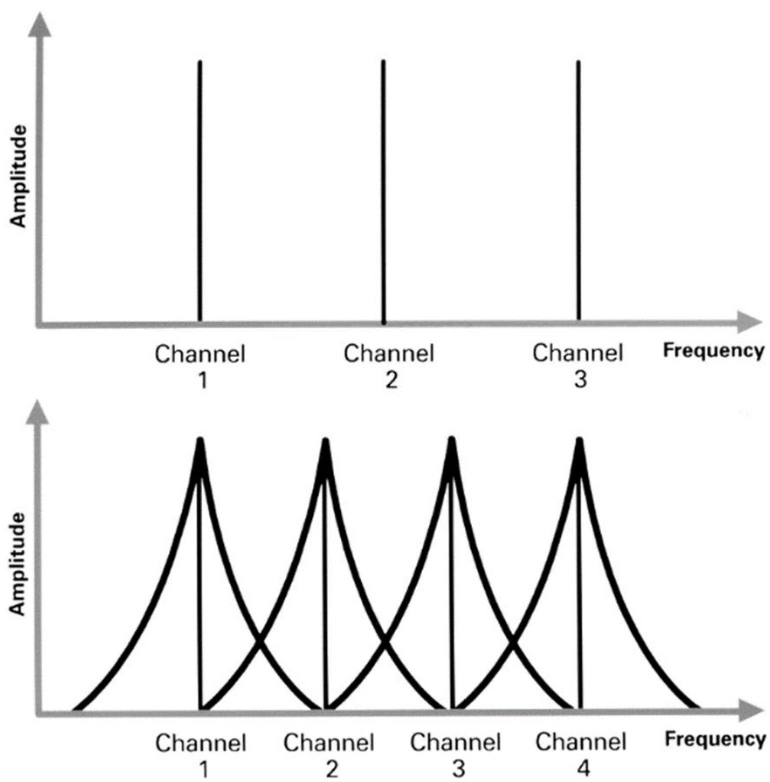

Figure 3. Smaller channel spacings increase the need for higher spectral purity

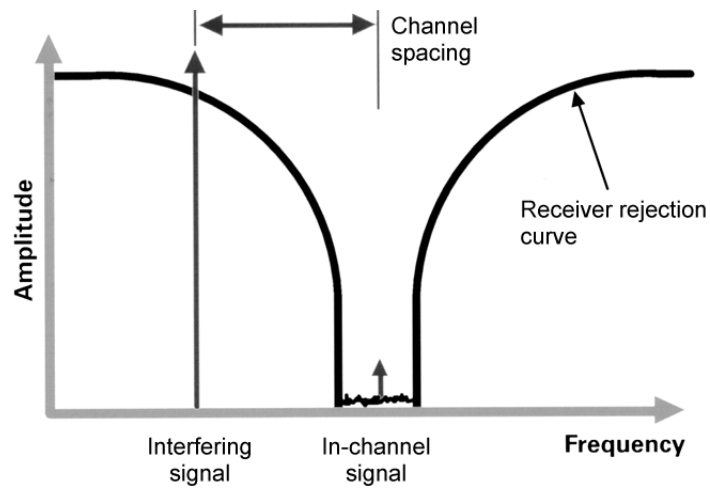

Figure 4. Receiver IF passband with in-channel signal present

How Signal Generator Spectral Purity Affects Measurements

The spectral purity of a signal generator is crucial for making accurate measurements across a wide range of applications. Choosing a signal generator with high spectral purity ensures that the measurements reflect the performance of the device under test (DUT) rather than the limitations of the signal generator itself.

Phase noise

Figure 5 shows what happens if the signal generator has high phase noise levels. The phase noise spills into the passband, creating higher distortion on the desired signal. The receiver's performance appears to be of inferior quality than it is.

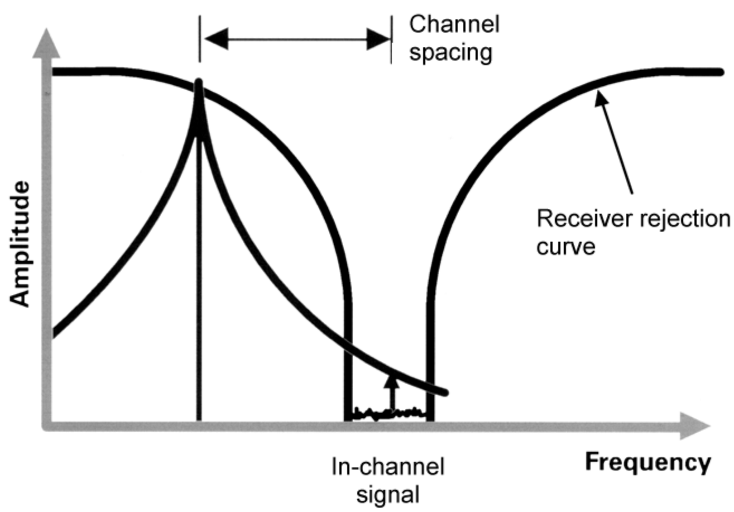

Figure 5. Out-of-channel phase noise causes in-channel distortion

Spurious

Spurious signals cause much of the same challenges as phase noise. Figure 6 illustrates that when a spurious signal appears in the channel spacing of the radio, you are measuring the difference in amplitudes of the spurious signal and the out-of-channel signal.

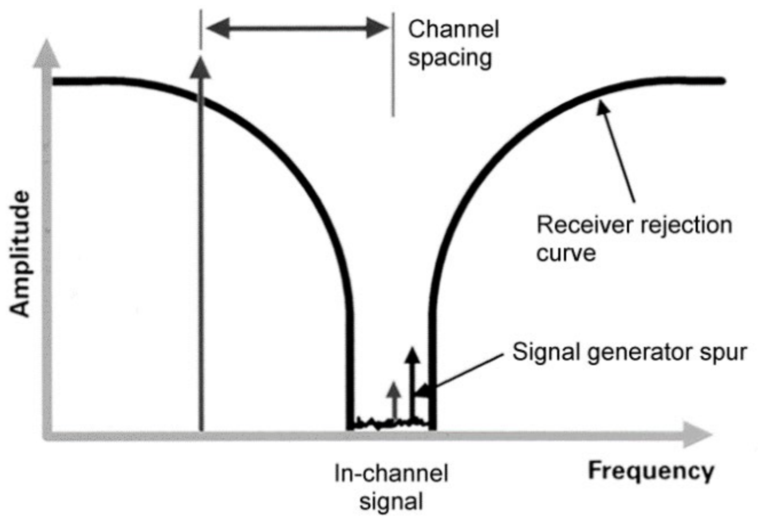

Figure 6. In-channel spurious signals make a receiver's performance appear more inadequate than it actually is

Hum and noise

Both hum and noise can significantly impact the accuracy and clarity of the received signal, making it essential to minimize these interferences for optimal receiver performance. Hum and noise measurements determine a receiver's signal-to-noise ratio. This ratio compares a strong RF signal with audio present to the same signal without audio measured in dB.

Residual FM

Figure 7 illustrates that the high noise from a signal generator directly adds to the receiver's noise, resulting in a lower hum and noise ratio. This result makes the receiver noise appear inferior to what it is.

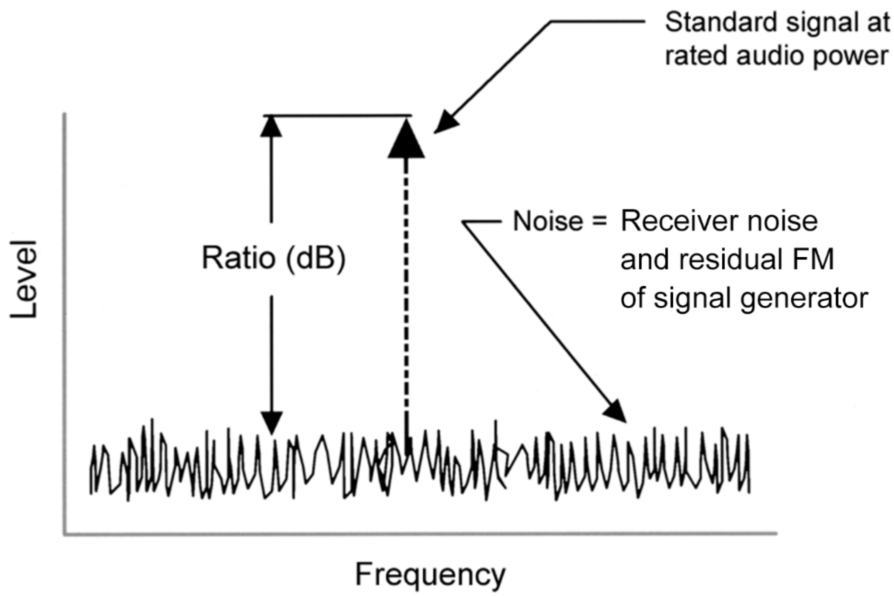

Figure 7. Signal generator residual frequency modulation adds to the receiver noise levels

Why Is Spectral Purity Important for Local Oscillator Substitution?

A signal generator used as a local oscillator (LO) requires spectral purity. For example, let us examine two signals, f1 and f2, in Figure 8. Figure 10 shows how the LO signal (Figure 9) mixes these signals to an intermediate frequency (IF), where highly selective IF filters can separate one of the signals for amplification, detection, and baseband processing. If the desired signal is the larger signal, there should be no difficulty recovering it.

Phase noise

Any phase noise on the local oscillator signal is translated directly to the mixer products. If the desired signal is the smaller of the two mixed signals, the translated noise in the mixer output may completely mask the smaller signal.

Even though the receiver's IF filtering may be sufficient to remove the larger signal's mixing product, the smaller signal's mixing product is no longer recoverable. This effect worsens in receivers with high selectivity and wide dynamic range.

Spurious

Spurious signals on a local oscillator can cause phase variations in the desired output at the IF frequency, potentially leading to intermodulation products.

Residual FM

The signals at the mixer's output directly add residual FM or noise, which becomes increasingly critical as the signals get closer together.

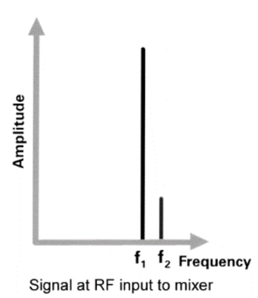

Figure 8. Two signals are ready to be down-converted with a local oscillator

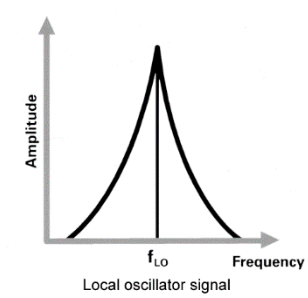

Figure 9. Local oscillator with phase noise

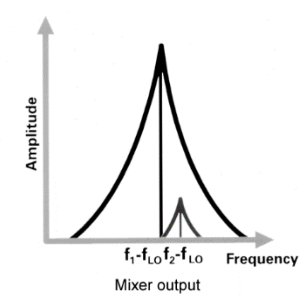

Figure 10. Phase noise masks the lower amplitude signal

Spectral Purity in Local Oscillator Applications

Testing radar

Radar systems continue to demand greater target resolution, which places higher requirements for spectral purity on local oscillators / signal generators.

For example, airborne and over-the-horizon radars aim to detect slow-moving surface vehicles. They must detect very low-level return signals, which have small Doppler shifts.

Figure 11 shows signals from the ground return and the smaller Doppler-shifted return from the moving vehicle. The example also shows the effect of phase noise on the return signal, which can mask the return or smaller signal.

Making phase noise measurements

Another application where spectral purity is critical for a LO is in phase noise measurements. One of the most sensitive measurement techniques is the two-source phase detector technique. A signal is down-converted to 0 Hz using a LO and then examined on a low-frequency spectrum analyzer. This proven technique requires a local oscillator with phase noise that is as good as, or better than, the device under test. The phase noise is directly added to the measurement.

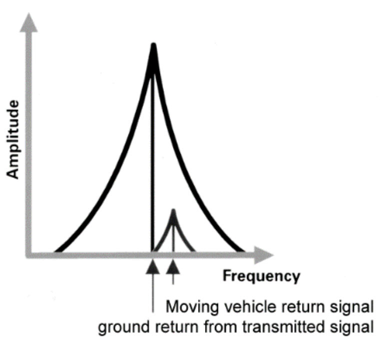

Figure 11. The effect of phase noise on radar

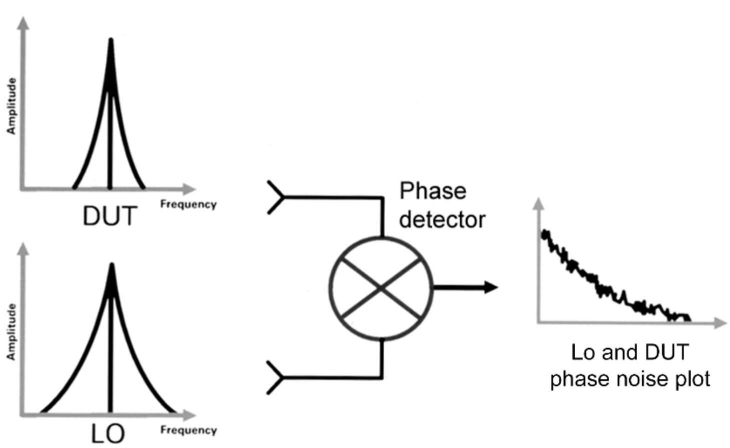

Figure 12. Local oscillator noise adds to the noise on the DUT

Conclusion

Spectral purity is a critical performance factor for signal generators, affecting measurement accuracy in various applications such as wireless communications and radar systems. Understanding spectral purity and selecting the right signal generator is key for ensuring accuracy in critical testing environments.

Additional Resources

- Keysight UXG X-Series Agile Signal Generators
- Keysight VXG Vector Signal Generators
- Keysight X-Series MXG / EXG / CXG Vector Signal Generators
- Keysight Compact Signal Generators