

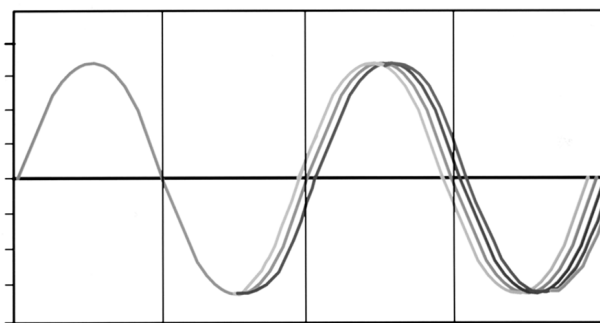
Achieve Accurate RF Measurements by Understanding Spectral Purity

This article examines the concept of spectral purity from various perspectives, including spurs, phase noise, and harmonics. All have implications for the accuracy of RF measurements in areas such as digital modulation, mobile radio, and in using signal generators to stand in for local oscillators.

Spectral purity is a signal's characteristic stability. For testing purposes, a signal must remain stable in the short and long term. Selecting a signal generator with high spectral purity ensures that the measurements describe the device under test's (DUT's) performance rather than the signal generator's limitations.

Drift or long-term stability is typically defined over a period of more than a second. Current signal-generator technology generally offers good long-term stability.

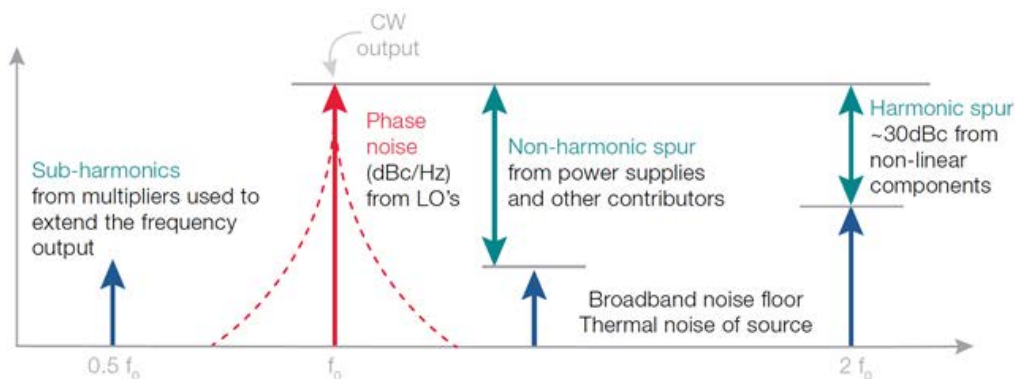
The primary concern is frequency changes in less than a second: short-term stability. These fluctuations are caused by non-deterministic signals like noise, $1/f$ flicker noise, and shot noise that modulates the carrier (Fig. 1). Such perturba-



1. This conceptual rendering depicts how short-term frequency fluctuations might appear on an oscilloscope's display.

2. Shown is a 1-GHz continuous-wave (CW) signal produced by a signal generator along with markers denoting harmonics and spurious emissions.





3. Here's a rendering of non-ideal spectral components such as phase noise, spurs, and sub-harmonics.

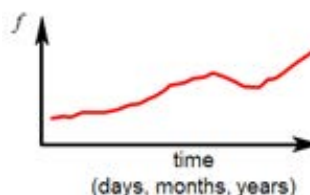
tions impact both amplitude and phase.

A tuning fork emits an almost perfect tone with which one might tune a musical instrument. It's a good analogy for demonstrating the importance of signal purity. A signal generator works like a tuning fork, emitting an almost perfect signal used in diverse RF applications such as clock references, RF power-amplifier testing, adjacent-channel sensitivity testing, and many more. The integrity of the signal-generator output is what we refer to as spectral purity.

Robust signal generators output signals with as little imperfection as possible. However, random amplitude and/or phase fluctuations occur in real-life waveforms. In the time domain, a waveform has amplitude and phase shifts. Meanwhile, the signal exhibits frequency and amplitude modulation in the frequency domain. The main measurements for spectral purity are spurs, phase noise, and harmonics.

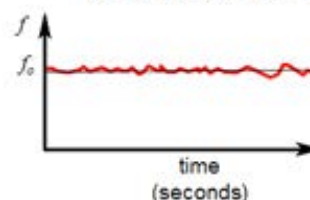
This article explores the concept of spectral purity and why it matters.

LONG-TERM FREQUENCY STABILITY



Slow change in average or nominal frequency

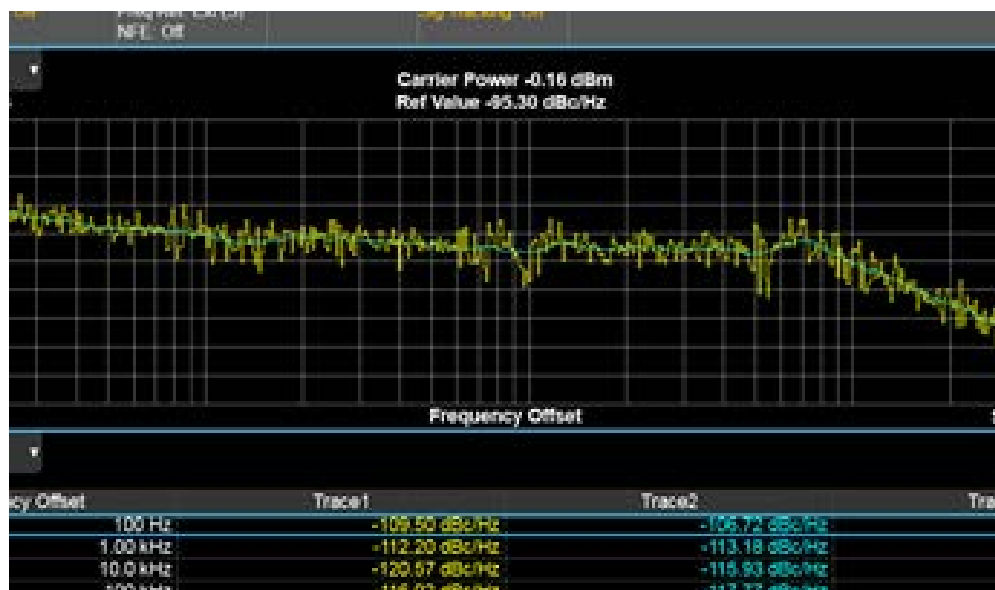
SHORT-TERM FREQUENCY STABILITY

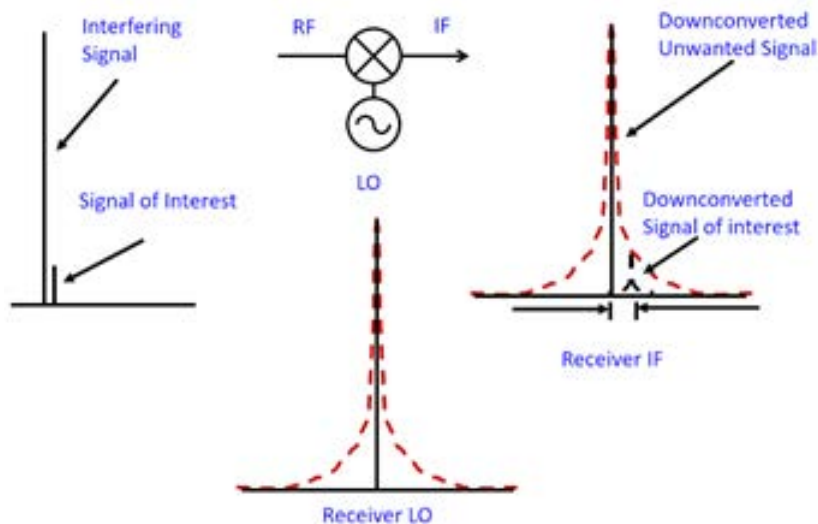


Instantaneous frequency variations around a nominal frequency

4. Long-term frequency stability is measured in periods of up to years; short-term frequency stability refers to instantaneous (or near-instantaneous) fluctuations.

5. Shown is an SSB phase-noise measurement with a log plot and decade table.





6. This image depicts how poor LO phase noise affects receiver sensitivity.

What are Harmonics, Spurious Emissions, and Phase Noise?

Both harmonics and spurious emissions are deterministic (non-random) signals generated from mixing or dividing signals to create an output signal. These frequencies aren't desired in RF systems. The harmonics are integer multiples of the carrier frequency, while the spurious frequencies are non-integer multiples.

Figure 2 shows a 1-GHz carrier frequency and its harmonics, as well as spurious emissions. The 2nd harmonic (marker 2) is -64.36 dBc relative to the fundamental carrier (marker 1), and the 3rd harmonic (marker 3) is -72.83 dBc.

Markers 4 and 5 designate spurs.

It's crucial to select a signal analyzer with high dynamic range to measure harmonics and spurs. Otherwise, the detected harmonics and spurs may come from the signal analyzer itself and not the DUT.

Phase noise is the noise spectrum around an oscillator signal in the frequency domain. It describes an oscillator's frequency stability. In Figure 3, you can see a signal's phase noise and other non-ideal components.

Frequency stability has two components: long and short term (Fig. 4). Short-term fluctuations contribute to phase noise, while long-term drifts affect accuracy (see table).

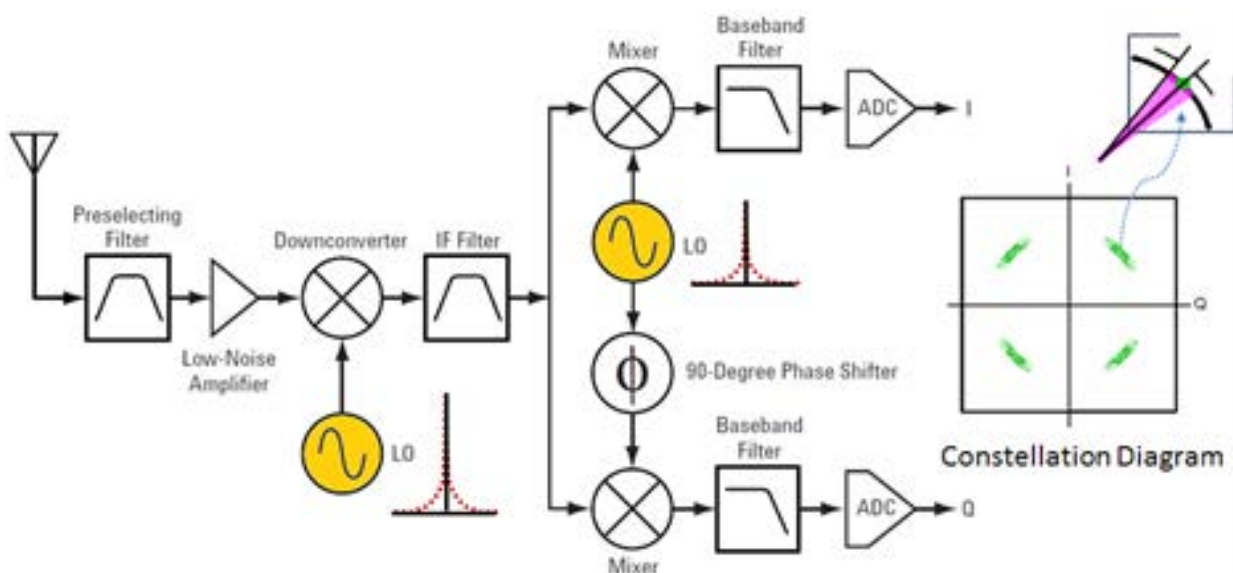
Phase noise is commonly defined as the amount of single-sideband (SSB) power contained within a 1-Hz bandwidth at a specific frequency away from the main frequency. This equation explains it:

$\mathcal{L}(f)$ = Noise power in a 1-Hz bandwidth / main frequency power where $\mathcal{L}(f)$ has units of dBc/Hz

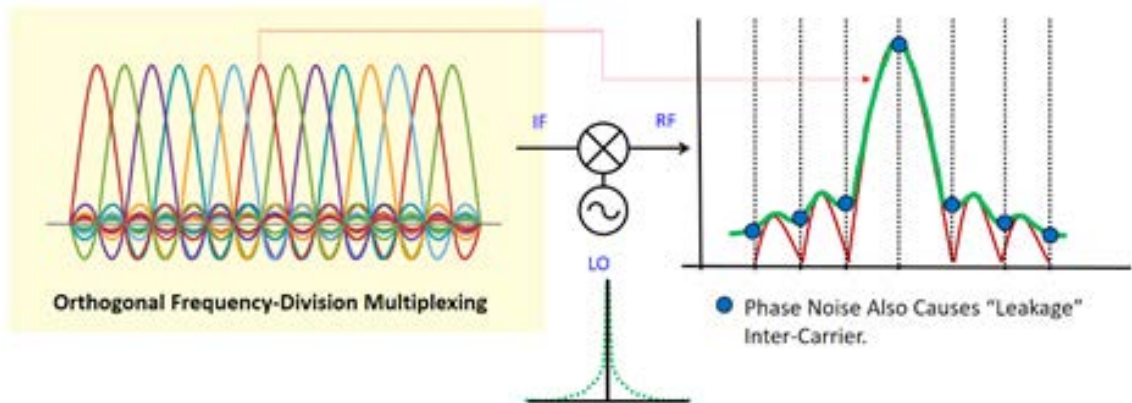
Figure 5 shows a signal generator's SSB phase-noise measurement. The yellow trace indicates instantaneous power measurements, and the blue trace is the average result.

When Phase Noise Matters

Understanding the impact of phase noise on measurements is vital for getting the right test performance level.



7. In this simplified digital receiver block diagram, we see how phase noise creates radial smearing of symbols in the constellation diagram. This can translate into poor receiver sensitivity at higher-order modulation schemes.

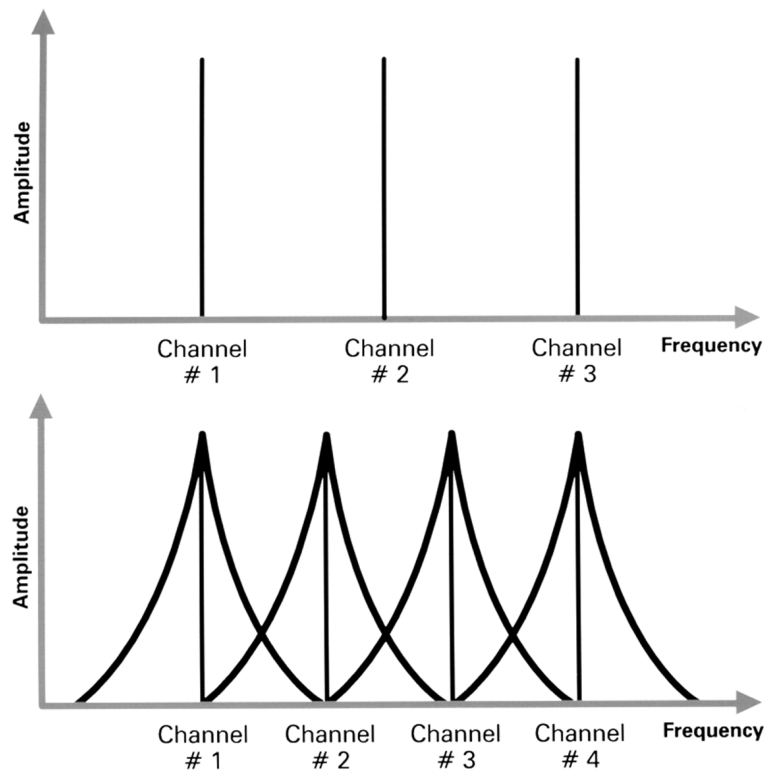


8. In OFDM schemes, LO phase noise causes the subcarriers' phase noise to interfere with other subcarriers, degrading the modulation quality of the OFDM signal.

High phase noise obscures weak signals close to the main frequency.

Let's look at how this applies to radar applications. Radar systems require excellent phase noise. A radar sends pulses at a defined frequency and measures how the returning pulse's frequency has changed. Changes in frequency tell us about the target's velocity as defined by the Doppler effect. A slow-moving object generates a slight shift in the returning pulse's frequency.

In Figure 6, the "signal of interest" is the moving target's returning pulse, and the "interfering signal" is the fixed object's returning pulse. The radar receiver can't identify the moving object if the phase noise masks the downconverted signal of interest.



What Does Spectral Purity Mean for Digital Modulation?

Figure 7 illustrates a simplified quadrature phase-key-shifting (QPSK) digital receiver block diagram. The local oscillator (LO) signal's phase noise is translated into the mixer's output. Phase noise creates radial smearing of the symbols (shown in green) on the constellation diagram. Overlapping radial smears for closely spaced symbols in a higher-order modulation scheme, such as 256 QAM, results in poor receiver sensitivity.

Orthogonal frequency-division multiplexing (OFDM) is a common modulation scheme for wideband digital communication. It uses many closely spaced orthogonal subcarrier signals to transmit data in parallel (Fig. 8). LO phase noise causes the subcarriers' phase noise to interfere with other subcarriers, degrading the OFDM signal's modulation

9. In mobile radio scenarios, smaller channel spacings mean a greater need for spectral purity.

quality.

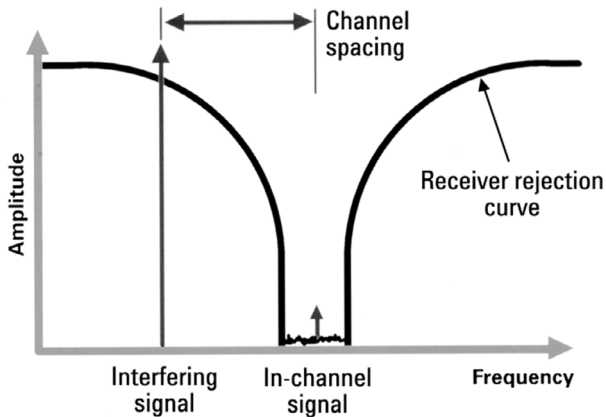
You can adjust phase noise at the synthesizer section of sophisticated signal generators. This allows you to reduce the phase-noise performance and helps in assessing your receiver design's sensitivity.

Implications of Spectral Purity for Mobile Radio Applications

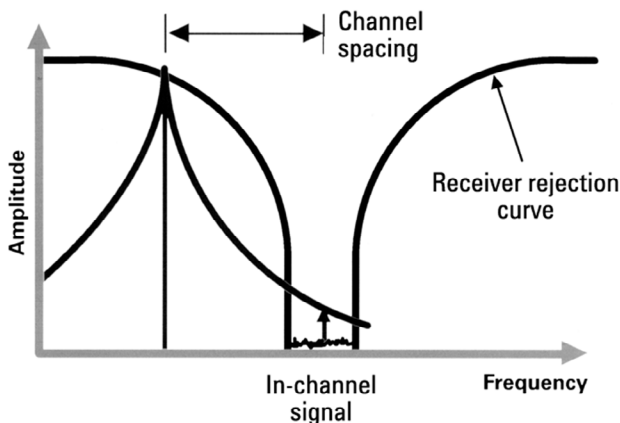
Radio channel spacings will decrease as the available spectrum becomes scarcer (Fig. 9). This puts a tighter con-

straint on engineers to design more selective receivers. To test receiver selectivity, a signal generator must have good spectral purity. If not, you'll be testing your signal generator and not your receiver.

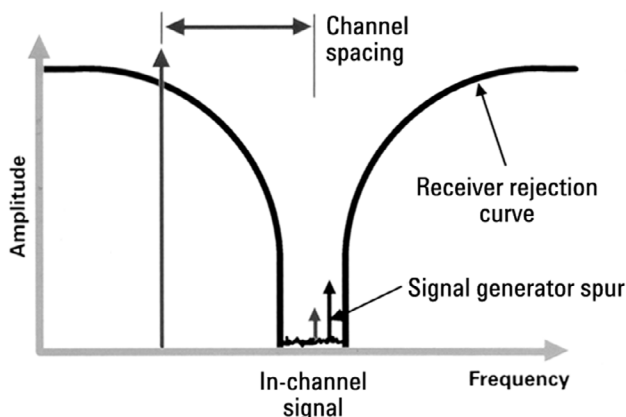
Adjacent channel selectivity is one common measurement



10. This image depicts a receiver's IF passband with an in-channel signal present.



11. Here's how out-of-channel phase noise causes in-channel distortion in a receiver's passband.



12. In-channel spurious signals make a receiver look worse than it is.

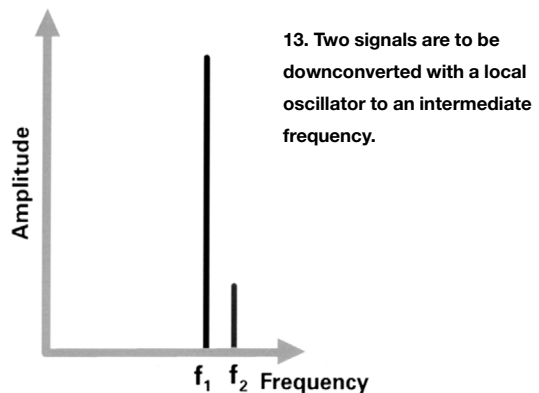
of whether the receiver rejects unwanted signals. *Figure 10* shows a receiver intermediate frequency (IF) passband with an in-channel signal set to a specific sensitivity level. A second signal generator is fixed one channel spacing away. The signal's amplitude is increased until it breaks through the passband and distorts the in-channel signal. The difference between the two signal levels is called adjacent channel selectivity.

Figure 11 shows what occurs when a signal generator has high phase-noise levels. The phase noise crosses into the passband, distorting the desired signal and making the receiver look worse than it is.

Spurious signals cause problems like those of phase noise (*Fig. 12*). Suppose a spurious signal shows up in the radio channel spacing. In that case, you will measure the amplitude difference between the spurious signal and the out-of-channel signal generator.

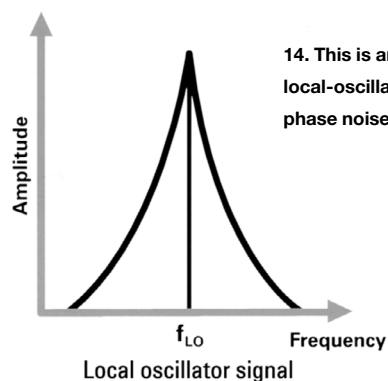
Phase Noise Affects Local-Oscillator Substitutions

Signal generators used as LOs need low phase noise. Let's look at two signals, f_1 and f_2 , in *Figure 13*. These signals will be mixed with a local-oscillator signal (*Fig. 14*) down to an IF, where highly selective IF filters can separate one of the signals for amplification, detection, and baseband pro-

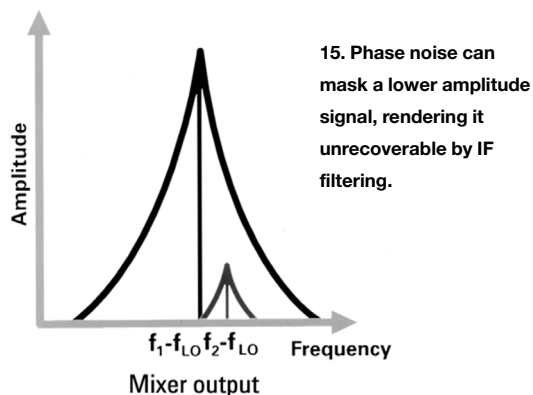


13. Two signals are to be downconverted with a local oscillator to an intermediate frequency.

Signals at RF input to mixer



14. This is an example of a local-oscillator signal with phase noise.



cessing. Recovering the desired signal should be easy if it's the larger signal.

Any phase noise on the local-oscillator signal is translated directly to the mixer products. If the smaller signal is preferred, the translated noise in the mixer output may completely hide it (Fig. 15).

The smaller signal's mixing product is no longer recoverable, even though the receiver's IF filtering removes the larger signal's mixing product. This effect worsens in highly selective receivers with a wide dynamic range.

Wireless devices are adding more advanced RF capabilities, with more test setups under varying conditions. Testing additional frequency bands, more advanced standards, and antennas increases production and verification testing challenges.

For example, 6G's proposed requirements of ultra-fast download speeds, highly complex modulation schemes, and wider bandwidths will make signal purity even more critical. Therefore, test results must be generated quickly and reliably, which requires signal generators to produce pure and precise signals.

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