Signal Generator Spectral Purity Considerations in RF Communications Testing

Today's wireless communications market, from cellular phones to wireless data, is expanding at an incredible rate. Along with this growth comes an increasing need for test equipment that verifies the performance of these devices and systems. Signal generators play a multifaceted role in the development of both receivers and transmitters. They are used for generating signals ranging from simple sinusoidal tones for LO substitution to fully modulated signals for receiver testing. This article focuses on the importance of using a signal generator with relatively high spectral purity for RF communications testing. The ideal signal generator would provide perfect sinusoids at carrier and sideband frequencies, but in reality all signals have imperfections. The foresight to take these flaws into account allows the engineer to select the appropriate signal generator and reduce development time.

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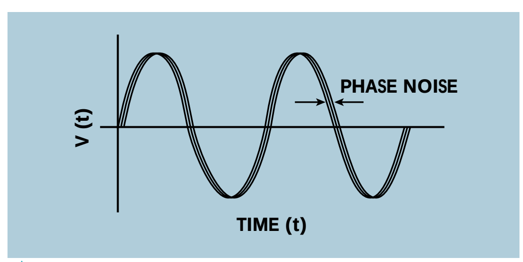
WHAT IS SPECTRAL PURITY?

Spectral purity is the inherent frequency stability of a signal. Stability is defined over a period of time: short or long term. Long-term stability, or drift, is usually defined as frequency changes over a period of time greater than one second. Short-term stability is defined as frequency changes over less than one second. Current signal generator technology generally offers good long- and short-term stability. For wireless communications testing, short-term stability is of greater concern. This article discusses key spectral purity components and the importance of spectral purity in testing wireless communications equipment. Implications of spectral purity are briefly covered for LO substitution, phase noise measurements, receiver performance tests and radar applications.

Phase Noise

Perhaps the most common method for specifying the spectral purity of a signal generator is its phase noise. In the time domain, phase noise is exhibited as a jitter in the zero crossings of a sine wave, as shown in ***Figure 1***. For a high performance signal generator, the phase noise is not usually discernible in the time domain. In the frequency domain, the phase noise appears as noise sidebands on the



▲ *Fig. 1 Time domain phase noise jitter.*

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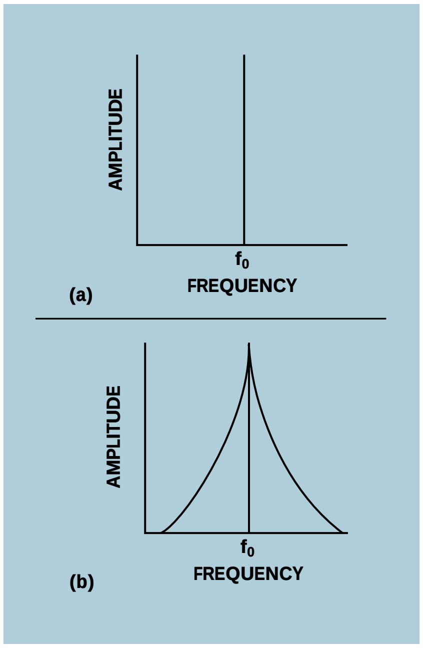
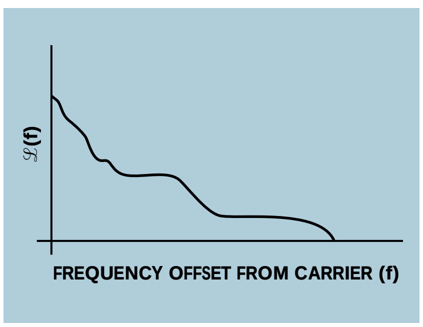


▲ *Fig. 2 A frequency carrier (a) without and (b) with phase noise sidebands.*

▼ *Fig. 3 A typical phase noise plot.*

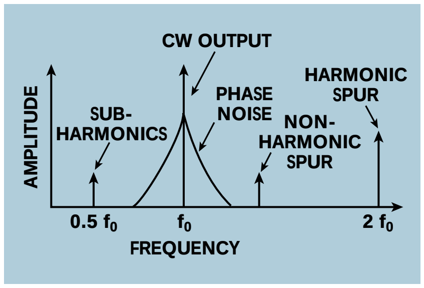


carrier, as shown in ***Figure 2***. The US National Bureau of Standards defines single-sideband (SSB) phase noise $\mathcal{L}(f)$ as the ratio of the noise power in a 1 Hz bandwidth at a frequency f away from the carrier to the signal power of the carrier:

$$\mathcal{L}(f) = \frac{\text{noise power in a 1 Hz bandwidth at a frequency f (Hz) away from the carrier}}{\text{power level of the carrier}}$$

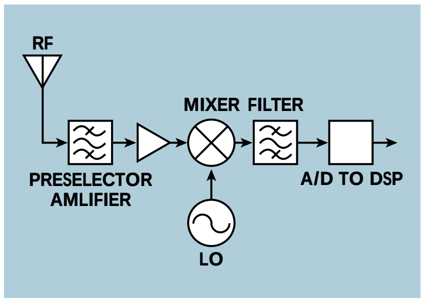
$\mathcal{L}(f)$ is expressed as decibels relative to the carrier per hertz (dBc/Hz). A 1 Hz bandwidth is used to allow the phase noise in other bandwidths to be easily calculated for comparison.

The SSB phase noise at a specified carrier frequency is often graphically represented on a log-log plot, as shown in ***Figure 3***. Phase noise can be conveniently displayed for a wide range of frequency offsets by using a log scale on the frequency axis.



▲ *Fig. 4 Harmonic, subharmonic and nonharmonic signals.*

▼ *Fig. 5 A simple communications receiver.*



Spurious: Harmonics, Subharmonics and Nonharmonics

Spurious signals are frequency spikes that appear in the spectrum. These spectral components may be divided into three categories: harmonic, subharmonic and nonharmonic, as shown in ***Figure 4***.

Harmonics are generated by device nonlinearities in the signal generator and are integer multiples of the carrier frequency. For example, a 100 MHz carrier frequency will have harmonics at 200 MHz, 300 MHz and so on. The amplitudes of the harmonics (relative to the amplitude of the carrier signal) are determined by the nonlinear characteristics of the components in the signal generator.

Subharmonics are generated when frequency multiplying to create the carrier frequency. The frequency being multiplied may leak through the signal path and appear at the output. For example, a 500 MHz signal multiplied by two to arrive at a 1 GHz carrier frequency might appear as a subharmonic.

Nonharmonics are frequency components that do not appear related to the carrier frequency. Although signal generator designers can determine the location of these spurious signals, they are unpredictable to the user. Today's signal generators are able to suppress harmonics, subharmonics and nonharmonics to a level acceptable for most applications.

Residual FM

Residual FM is another method commonly used to specify the frequency stability of signal generators. Residual FM includes the effects of both spurious signals and phase noise. It is the integral of the SSB curve with limits set by the post-detection bandwidth. Common bandwidths are 300 Hz to 3 kHz and 20 Hz to 15 kHz.

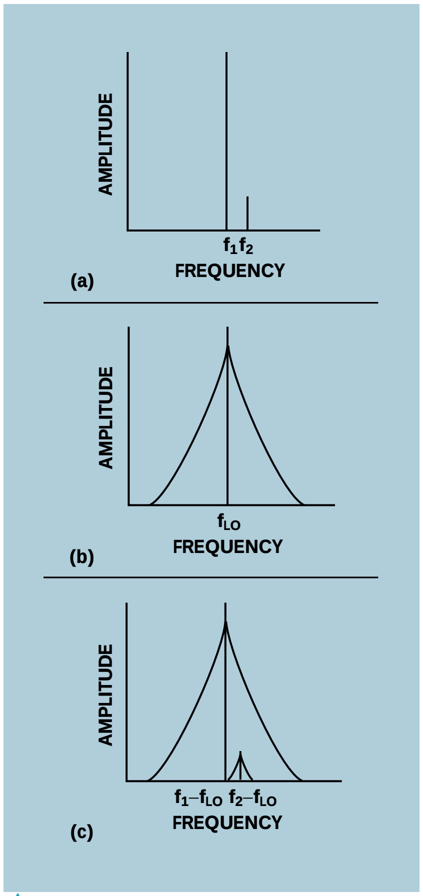
SPECTRAL PURITY CONSIDERATIONS IN RF RECEIVER DESIGN

A spectrally pure signal generator provides high value to those designing and verifying analog and digital communications devices. As an example, a simple communications receiver, shown in ***Figure 5***, is used to illustrate the effects of phase noise and spurious signals on practical applications and measurements. Three major applications discussed here are LO substitution, phase noise measurements and receiver performance tests. All of these applications require the use of a signal generator with sufficient spectral purity.

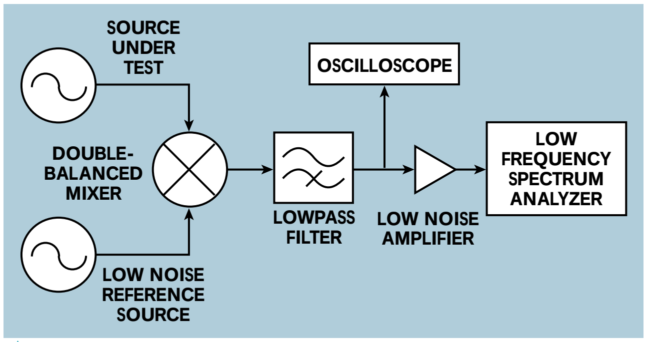
LO Substitution

In receiver development, as well as transmitter development, a spectrally clean LO is required for upconversion and downconversion of signals. A signal generator is often used to substitute an onboard LO for testing and system troubleshooting. Looking at the downconversion in the receiver, the importance of spectral purity for LO substitution is readily apparent. Suppose that two signals are present at the input of the receiver, as shown in ***Figure 6***. These signals are mixed with an LO signal down to an intermediate frequency (IF) where highly selective IF filters separate one of the signals for amplification, detection and baseband processing. If the desired signal is the larger signal, there is no difficulty in recovering it.

On the other hand, a problem might arise if the desired signal is the smaller of the two because any phase noise on the LO signal is translated directly to the mixer products. Notice that the translated noise in the mixer output completely masks the smaller signal. Even though the receiver's IF filtering might be sufficient to remove the larger signal's mixing product, the smaller signal's mixing product is no longer recoverable due to the translated LO noise.



▲ *Fig. 6 Phase noise effects at the mixer; the (a) RF input, (b) LO and (c) mixer output spectra.*



▲ *Fig. 7 Basic measurement setup for the two-source phase detector technique.*

Phase Noise Measurements

Eventually, the signal generator that is substituting as the LO must be replaced by the actual LO. The phase noise of this onboard oscillator must be measured to ensure a quality signal. In this case, a low phase noise signal generator can be used to make the measurement.

Many methods exist to measure phase noise. One of the most sensitive measurement techniques is the two-source phase detector technique. Here, the signal under test is downconverted to 0 Hz and examined on a low frequency spectrum analyzer. A low noise LO is required as the phase detector reference. The basic measurement setup for measuring phase noise using the two-source technique is shown in ***Figure 7***.

The noise measured by this two-source technique represents the combined noise of both the source under test and the reference source. This level is the upper limit for the phase noise of either device. Therefore, if the phase noise of the reference is better than the source under test, the phase noise of the source under test can be determined.

Receiver Performance Tests

After the design of the receiver is complete, various tests must be performed to confirm design parameters. The primary goal of most receiver tests is to measure the receiver's ability to maintain a certain sensitivity level in the presence of unwanted signals.

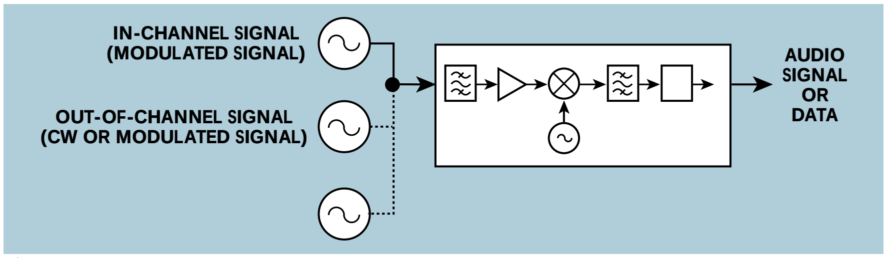
Receiver performance verification tests may be divided into in-channel and out-of-channel tests. Common in-channel tests include sensitivity and co-channel rejection. Common out-of-channel tests are spurious and intermodulation rejection, and adjacent-channel selectivity. All of these tests, except for sensitivity, require a modulated or unmodulated interfering signal with allowable uncertainties, phase noise and spurious content as defined in the communications standard. ***Figure 8*** shows the test setup for co-channel or out-of-channel rejection measurements.

For analog receivers, sensitivity is defined as the minimum power level at which the receiver can successfully detect and demodulate the incoming signal. For digital receivers, sensitivity is defined as the median level of the received signal that produces a specified bit error rate when the signal is modulated with a pseudorandom binary sequence of data. The important specification of the signal generator for sensitivity tests is power level accuracy (rather than spectral purity).

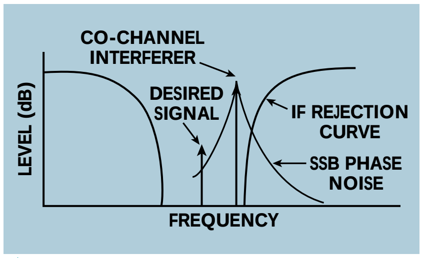
Co-channel rejection is the ability of the receiver to maintain sensitivity in the presence of an in-channel interfering signal. Frequently, this co-channel interfering signal will be a continuous-wave (CW) signal, as shown in ***Figure 9***. The specific communications standard defining this test will set phase noise and spurious signal requirements for the CW tone.

Spurious immunity is a measure of the ability of the receiver to receive a modulated input signal in the presence of unwanted input signals at frequencies other than those specified for adjacent- and alternate-channel tests. The specific communications standard defines the spurious signal frequency location and tolerable phase noise level.

Intermodulation rejection is a measure of the capability of the receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of two or more unwanted signals with a



▲ *Fig. 8 The test setup for co-channel or out-of-channel rejection measurements.*



▲ *Fig. 9 Co-channel rejection.*

specific frequency relationship to the wanted signal frequency. Typically, two out-of-channel CW tones are placed so that their third-order intermodulation distortion product falls on top of the desired signal, as shown in ***Figure 10***. Intermodulation rejection measures how well the receiver rejects this unwanted distortion.

Adjacent-channel selectivity measures a communications receiver's ability to process a desired signal while rejecting a strong signal in an adjacent channel. Alternate-channel selectivity is a similar test where the interfering signal is spaced two RF channels away from the passband of the receiver. These tests are very important for both analog and digital units where channel spacings are narrow and many signals may be encountered in a small geographical area.

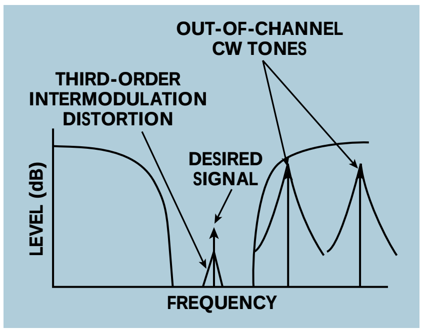
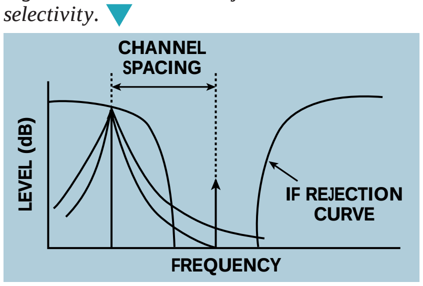


Fig. 10 Intermodulation rejection.

Fig. 11 Phase noise in adjacent-channel selectivity.



PHASE NOISE REQUIREMENTS FOR ADJACENT-CHANNEL SELECTIVITY

For many receivers, the SSB phase noise of the signal generator used to produce the interfering signal is a critical spectral characteristic. If the phase noise energy inside the passband of the IF filter is excessive, the receiver might appear to fail the test. This case is shown in ***Figure 11***.

The required signal generator SSB phase noise may be calculated using

$$\Phi_n = 10\log\left(\frac{1}{B_e}\right) - P_{ac} - P_{mar}$$

where

Φ_n = signal generator SSB phase noise (dBc/Hz) at the channel spacing offset

B_e = receiver noise-equivalent bandwidth (Hz)

P_{ac} = adjacent- or alternate-channel selectivity specification (dB)

P_{mar} = test margin (dB)

Since B_e and P_{ac} are fixed by the specifications or design, the test margin determines the power that the signal generator phase noise is allowed to contribute to the IF passband of the receiver. A large test margin increases confidence that the receiver operates properly in the presence of signal-to-noise degradation due to fading in the channel or imperfections in receiver components. For a system using a new technology or new operating frequencies, a large test margin should be used to compensate for uncertainties.

For a receiver with a noise-equivalent bandwidth of 14 kHz, P_{ac} at the adjacent channel of 70 dB, margin of 10 dB and channel spacing of 25 kHz, the required SSB phase noise is –121 dBc/Hz at 25 kHz offset. This condition is typical for an analog FM receiver. Unlike the FM receiver in this example, most digital communications receivers have adjacent-channel selectivity values less than 15 dB. For a GSM receiver with a noise-equivalent bandwidth of 200 kHz, a P_{ac} at the adjacent channel of 9 dB, margin of 10 dB and channel spacing of 200 kHz, the required SSB phase noise is –72 dBc/Hz at 200 kHz offset. The required SSB phase noise is driven primarily by P_{ac}.

Table 1 lists the values of adjacent- and alternate-channel selectivity for various communications systems as well as the required signal generator SSB phase noise. A 10 dB test margin was used. Clearly, for adjacent- and alternate-channel selectivity testing on many digital RF communications formats, the signal generator SSB phase noise is not as important as for analog FM systems.

For selectivity tests, the spectral shape of the signal is the characteristic of primary importance. The digital modulation formats used by GSM, CDMA, North American Digital Cellular (NADC) and personal digital cellular (PDC) characteristically leak a small amount of power into the adjacent channels. ***Figures 12***, ***13*** and ***14*** show amplitude vs. frequency for the selectivity values specified previously. The impact of the spectral shape on the adjacent and alternate channels of the receiver is evident. To properly test a digital radio receiver, the adjacent-channel power of a signal generator must be below the re-

Fig. 12 A GSM adjacent- and alternate-channel selectivity spectrum.

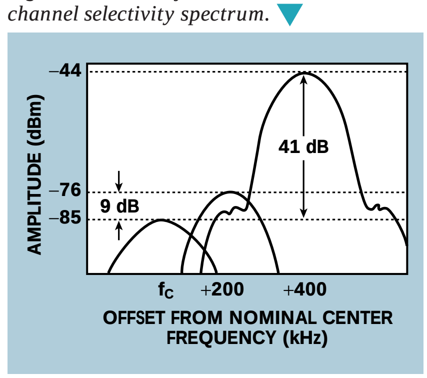


TABLE I

MAXIMUM TOLERABLE SSB PHASE NOISE

	Analog FM	GSM	NADC	PDC
Channel spacing (kHz)	25	200	30	25
Approximate receiver noise bandwidth (kHz)	14	200	35	33
Adjacent-channel selectivity (dB)	70	9	13	1
Maximum SSB phase noise at offset (dBc/Hz)	–121 at 25 kHz	–72 at 200 kHz	–68 at 30 kHz	–56 at 25 kHz
Alternate-channel selectivity (dB)	–	41	42	42
Maximum SSB phase noise at offset (dBc/Hz)	–	–104 at 400 kHz	–97 at 60 kHz	–97 at 50 kHz

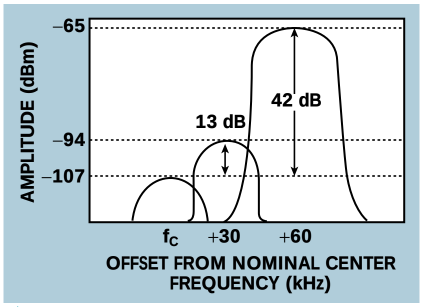


Fig. 13 An NADC adjacent- and alternate-channel selectivity spectrum.

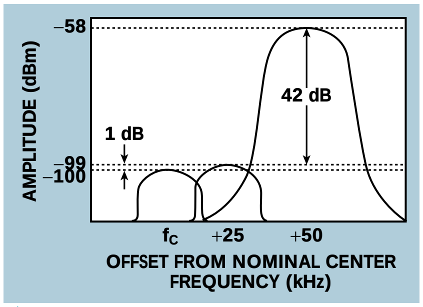


Fig. 14 A PDC adjacent- and alternate-channel selectivity spectrum.

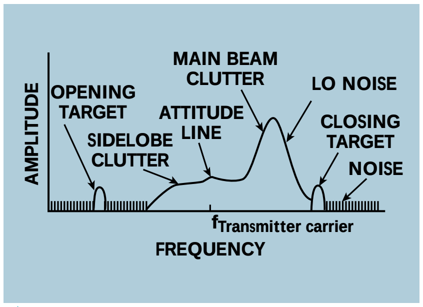


Fig. 15 An airborne pulsed-Doppler radar's typical return frequency spectrum.

quired system specification plus the desired test margin.

RADAR

Radar applications have traditionally required spectrally clean signal generators. Doppler radars determine the velocity of a target by measuring the small Doppler shifts in frequency undergone by the return echoes. Return echoes of targets approaching the radar are shifted higher in frequency than the transmitted carrier, while return echoes of targets moving away from the radar are shifted lower in frequency. Unfortunately, the return signal includes much more than just the target echo. In the case of airborne radar, the return echo also includes a large clutter signal that is basically unavoidable frequency-shifted echoes from the ground.

Figure 15 shows the typical return frequency spectrum of airborne pulsed-Doppler radar. In some situations, the ratio of main-beam clutter to target signal might be as high as 80 dB. This problem is aggravated when the received spectrum has frequency instabilities, specifically phase noise, caused by either the transmitter oscillator or the receiver LO. Such phase noise on the clutter signal can partially or totally mask the target signal, depending on the relative level of the target signal and its frequency separation from the clutter signal.

CONCLUSION

As the wireless communications revolution moves forward and the frequency spectrum becomes increasingly crowded, the bandwidth requirements for signals become tighter and tighter. Systems must be designed such that only the desired signal is detected in the presence of adjacent-channel signals and other channel interference. More stringent tests on communications devices must be passed. At the same time, test equipment must also meet these strict requirements. A spectrally pure signal generator complements the other test equipment on a development engineer's bench and is highly valued for applications such as LO substitution and receiver testing. ■

Reference

1. "Testing and Troubleshooting Digital RF Communications Receiver Designs," Hewlett-Packard Application Note 1314 (Literature # 5968-3579E).

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