# Effective Radar Characterization and Fault-Finding Using Local Oscillator Substitution

Radar is used in various military and civilian applications, integral to national defense and surveillance, weather monitoring, and air traffic control (ATC) management and guidance, among other critical use-cases. This whitepaper will first provide an overview of radar functionality, including a general summary of RF and microwave signal paths for both transmit and receive operations. It will then analyze the role of the local oscillator (LO) and how its performance can affect the system overall. Lastly, this whitepaper will reveal how to characterize LO behavior accurately with the LO substitution method using a high-performance signal generator.

## Radar System Operation

Radar antennas emit radio waves that strike objects of interest, such as aircraft or vehicles. These targets scatter some of the energy back toward the radar antenna. The radar system captures, processes, and analyzes the reflection to determine information about the target. For example, the power of the returned signal can indicate target size. When factoring in the time between transmission and recapture, the system can calculate the target's range.

Using a phenomenon called the Doppler effect, Doppler radar provides more detailed target information, such as the direction of movement. Compared to the initial radar pulse, objects moving toward the stationary radar system will reflect energy that shifts to a higher frequency, while objects moving away from the system will return lower frequency signals.

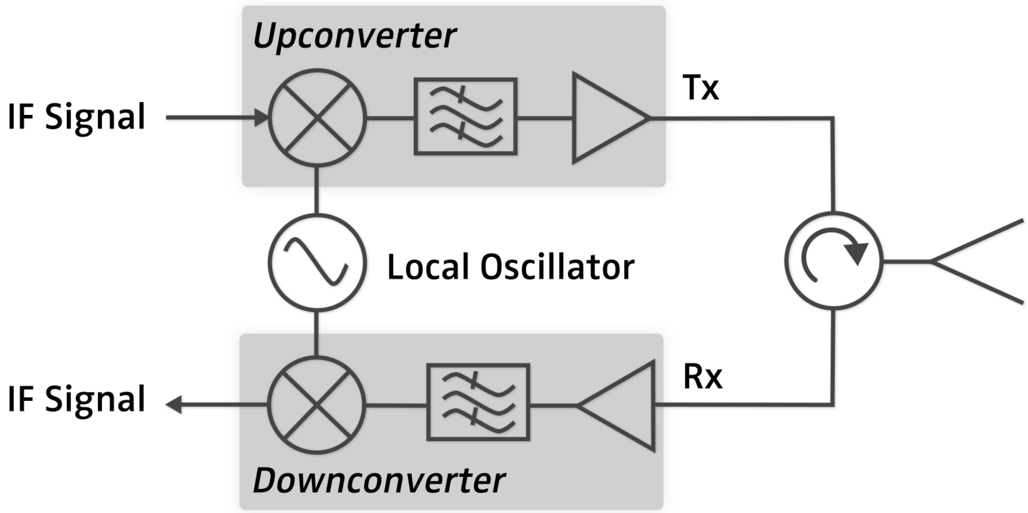


*Figure 1: Simplified block diagram of a radar system's up and downconversion chains.*

Figure 1 shows a simplified block diagram of a radar system to illustrate its basic components. Radar systems often use one antenna for both transmit and receive operations. In these cases, a component called a duplexer enables two-way communications while sharing a single antenna. A circulator plays the role of duplexer in Figure 1, managing transmit and receive signals.

Upconversion consists of various stages that process the radar signal for transmission. A mixer combines the lower intermediate frequency (IF) transmit signal with a highly stable and spectrally pure RF signal generated by an LO. The LO signal is used to upconvert the IF radar signal to a higher frequency. Bandpass filters remove unwanted mixing products. Lastly, a high-power amplifier (HPA) enables the radar pulse to reach the required power levels, amplifying the power of the transmission. This ensures that the radar system can meet its range and minimum target radar cross section requirements.

After the radar antenna receives the reflected energy from its target, the signal is routed through several stages. A low-noise amplifier (LNA) amplifies the signal's power while limiting the amount of noise introduced, maintaining the signal-to-noise ratio (SNR). Again, frequency filtering isolates the desired frequency bands while rejecting those outside the intended range. At this stage, a mixer takes the radar return and combines it with a signal generated by an LO. The LO uses its output to downconvert the received signal to a lower frequency IF that is more optimal to manipulate during subsequent processing stages.

## Critical LO Specifications

LOs are critical components for both the up and downconversion chains of radar systems. There are several important attributes used to characterize LO behavior and performance, two of which include phase noise and frequency switching.

## Phase Noise

If an LO were to behave ideally, it would generate a perfectly stable signal at a specific frequency. The output of LOs used in practical, real-world systems will contain some imperfections such as random variations in the signal's phase (i.e., phase noise).

Phase noise can have a significant impact on a radar system's performance, including limiting a receiver's ability to resolve Doppler-shifted target information. Received signal power depends, in part, on the size of the target. Smaller or stealthier targets reflect less of the initial radar pulse, meaning these return signals have lower energy compared to larger targets with greater radar cross section.

Aside from the object of interest's reflection, natural or man-made features also reflect a portion of the initial radar pulse back toward the antenna, known as clutter. Unwanted radar returns can emanate from the sea surface (sea clutter), atmospheric effects (weather clutter), and ground-based features like mountains or buildings (ground clutter). Competing, higher-power reflections from undesired returns can obscure weaker signals from small objects of interest, thus increasing their susceptibility to phase noise.

Figure 2 shows how phase noise from a large clutter return can conceal a Doppler-shifted return from a small flying aircraft.

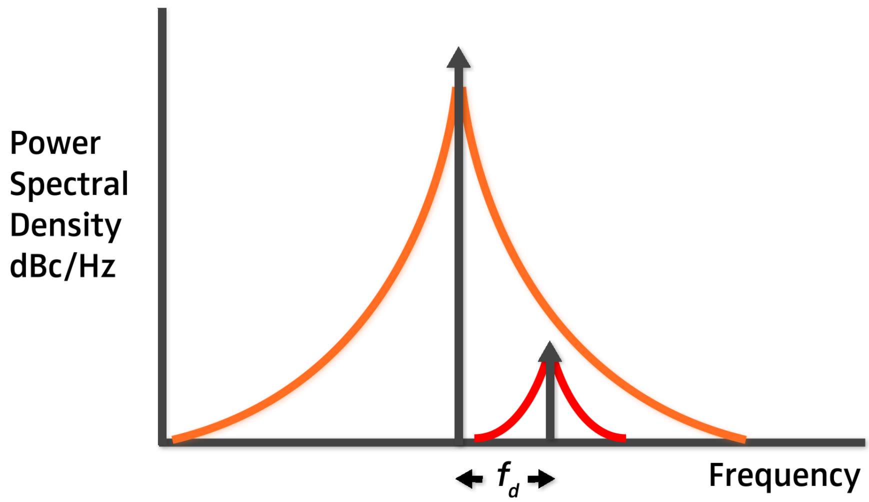


*Figure 2: The phase noise of a clutter return (orange) impedes successful target detection.*

LOs that introduce minimal phase noise increase receiver sensitivity during the downconversion process.

## Switching Speed

Frequency agility describes a system's ability to switch the operational frequency, changing between various frequencies quickly and pseudo-randomly during use. Frequency-agile radar offers an increased resilience to adversarial electronic jammers, which try to disrupt performance by emitting compromising, interfering signals. Moving between different operating frequencies enables radar systems to avoid the specific frequency targeted by jamming attacks. Shifting to clear patches of spectrum also avoids interference in dense wireless environments with multiple systems operating concurrently.

Accurate frequency conversion relies on the LO. When used in frequency-agile radar, LOs must be able to switch to the required frequency to receive and process dynamically changing signals.

When switching between frequencies, it takes a certain amount of time for the signal to settle or reach a steady state at the new frequency. The settling time interval can include signal artifacts like overshoot and ringing before stabilization, which can affect certain systems such as compressed high intensity radiated pulse (CHIRP) radar.

CHIRP radar meets range and resolution requirements by utilizing frequency modulated (FM) signals that exhibit a linear, or in some cases non-linear, frequency increase or decrease during the entirety of the pulse. Processing the radar return involves pulse compression, collapsing it into a narrower pulse of shorter duration.

Unwanted artifacts referred to as time sidelobes occur on either side of the main lobe after downconversion and compression. While time sidelobes occur naturally, the LO can exacerbate this phenomenon. Additional time sidelobes caused by insufficient LO frequency settling time increase the likelihood of false target detection.

## LO Substitution & High-performance Signal Generation

LOs must meet phase noise and switching speed standards, among other performance metrics, to ensure the accuracy of the overall system. One up and downconverter path testing technique involves replacing the LO with a signal generator that operates at the highest performance standards, a process referred to as LO substitution. Engineers can zero-in on the system LO as the culprit for system faults or failures if the swapped-in signal generator resolves performance issues. After identifying the malfunctioning LO or if the component is unavailable for any reason, engineers can still test the up and downconversion chains accurately with the clean output from the signal generator.

Often, signal generators cannot provide both low phase noise and fast switching signals that also fall within the confines of budgets without some degree of performance trade-offs. Table 1 correlates these important signal generator parameters with three main frequency synthesis architectures – direct analog synthesis (DAS), direct digital synthesis (DDS), and indirect synthesis that uses phase-locked loops (PLLs).

| Parameter | DAS | DDS | Indirect Synthesis |
|---|---|---|---|
| Phase Noise | Low | Low | Dependent on PLL bandwidth setting. Potential switching speed trade-off |
| Frequency Switching Speed | Fast | Fast | Dependent on PLL bandwidth setting. Potential phase noise trade-off |
| Cost | Large due to high component count | Low (but depends on output frequency) | Medium |

*Table 1: A look at how different frequency synthesis methods affect parameters critical for LO substitution.*

DAS can achieve nanosecond switching speeds and low phase noise, but the various components required for this method of frequency generation increase cost, form factor, and complexity. DAS involves multiplying, dividing, mixing, and filtering the output of various oscillators to produce the desired output.

DDS produces signals via a digital circuit by utilizing a reference oscillator, phase accumulator, and digital-to-analog converter (DAC). DDS offers switching speeds generally in the microsecond range and low phase noise. This architecture, however, can contain a high level of spurious signals and its cost is largely dependent on the output frequency. Lower frequencies typically equal a lower cost.

A signal generator that offers a unique combination of DDS and DAS, such as the Boonton SGX1000 Series, can achieve both low phase noise and fast switching speed at a surprising low cost. Enabling users to test advanced radar systems via LO substitution with confidence (Figure 3).

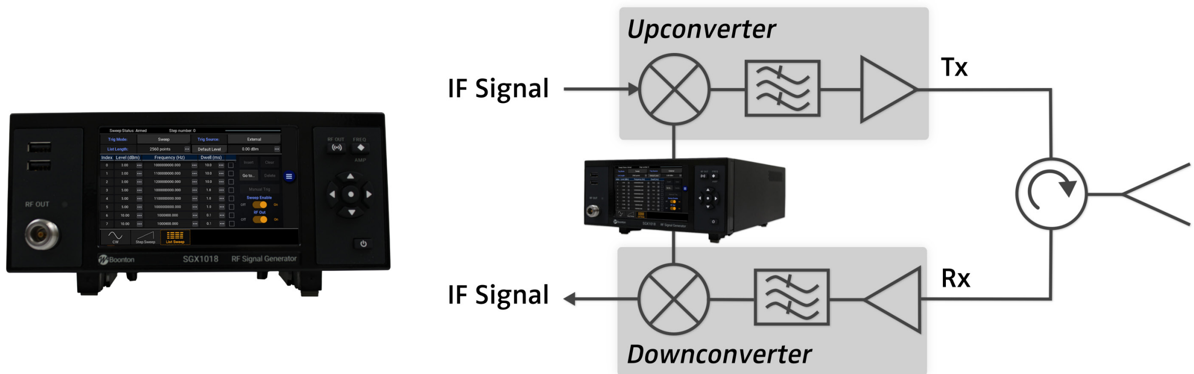


*Figure 3: A high-performance signal generation solution (left) and the SGX1000 Series serving as an LO substitute (right).*

## LO Substitution Solutions for Radar Testing

LO performance greatly impacts the operation of the overall radar system, especially in terms of phase noise and frequency agility. Excessive phase noise can reduce receiver sensitivity and mask lower power radar returns, while inadequate frequency switching can compromise frequency agility or generate artifacts that can cause false target detection. The use of a high-performance signal generator during LO substitution can help to pinpoint problems and enable effective up and downconversion characterization. Signal generation solutions, such as the SGX1000 Series, offer ultra-low phase noise and fast frequency switching speed in a low-cost, compact form factor. This compromise-free performance ensures effective and accurate up and downconverter testing in radar systems of all types.

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