Solutions for

Using Time Sidelobe Measurements to Assess the Performance of Compressed-Pulse Radars

Application Note

Radar Measurement Series

Overview

In a radar system, the use of modulation on pulse for "compression" provides enhanced spatial resolution as well as extended range for a given output power level. Consequently, this technique is widely used in current- and next-generation radar systems.

Unfortunately, traditional RF pulse measurements become less effective predictors of performance in radars that use pulse compression. For example, the width of an uncompressed radar pulse is directly related to spatial resolution. In contrast, the resolution depends on pulse width, chirp bandwidth and chirp linearity in a compressed radar system that uses linear frequency modulated (LFM) chirp pulses.

Within the field of radar development, a technique called the time sidelobe level (SSL) measurement has emerged as a viable solution to predict performance. This method distills a wide range of potential signal impairments down to a simple metric that can be used to determine if radar performance will fit the intended application.

This application brief defines key problems related to measurements of compressed-pulse radars, describes the time sidelobe method, and outlines the practical uses of this approach.

Problem

As suggested above, the modulation parameters used in compressed radars clearly affect system performance. One of the overall problems is in the determination of "what's good enough?" with regard to the attributes of components used to build radar subsystems. Similarly, in a diagnostic scenario, it is difficult to assess overall performance without separately measuring the traits of individual components.

As an example, it can be difficult to judge the affect of component performance on any impairment added to a modulated pulse—and errors in these measurements routinely result in costly over-specifying of components. Consider a frequency-dependent mismatch reflection of an IF filter used in a radar receiver (Figure 1). Typically, lower-frequency IF filters have significant signal delays. When these combine with internal reflections from a desired radar pulse the result may be a "ghost" echo return. It might be very difficult to determine the effect of such a reflection when evaluating the overall functional performance of a frequency chirped, pulse compression radar.

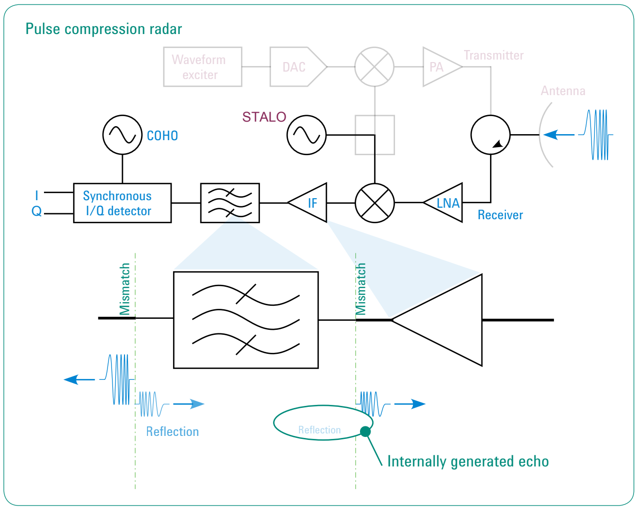

Figure 1. Mismatch reflections may cause ghost echo returns

Other problems from within the radar may involve other component impairments that can affect the results at the demodulator. Examples include unintended phase noise, amplitude modulation, reflections and group delay. These routinely distort what is actually detected in the receiver, limiting the dynamic range and detection accuracy of the radar.

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Solution

One way to meet these challenges is to distill the characterization of a wide range of potential signal impairments down to a simple metric, preferably one that can be used to determine if radar performance will fit the intended application. Time sidelobe measurements provide an effective way to use known-good test equipment—with internal impairments calibrated out of the measurements—and mathematically consistent processing of measurement data to accurately characterize the performance of a compressed-pulse radar.

What are time sidelobes?

Sometimes referred to as range sidelobes, time sidelobes are a result of using pulse compression techniques. They are produced when the ideal radar return is convolved with the response of the less than ideal correlation filter during the compression process or when a non-deal radar return is convolved with the response of the less than ideal correlation filter or some combination of the two. This causes some of the energy in the return pulse to lie outside the pulse bandwidth. In the time domain this is indicated by a spreading in range (time) of the return pulse, particularly in the presence of ground clutter or transmit signal anomalies caused by imperfections in the transmitter path.

Since the correlation filter in modern radar is nearly always implemented digitally within a DSP rather than with an analog Standing Acoustic Wave (SAW) filter, the resulting compressed pulse waveform is mathematically deterministic and repeatable and as such, easily optimized through simulation.

Windowing functions

Amplitude weighting of the output signals is generally used to reduce the time sidelobes to an acceptable level. As a side effect the signal weighting will result in the loss of signal to noise ratio. Some of the more commonly used windowing functions are shown in table 1 with their suppression levels and signal to noise losses.

Table 1. Popular windowing functions and their effects

Weighting Function	Peak Sidelobe Level (dB)	S/N Loss (dB)
Uniform	-13.2	0
Hamming	-42.8	1.34
Hann	-32	1.4
Blackman	-58	2.37
Blackman-Harris (3 term)	-67	2.33

Figure 2 graphically shows the characteristics of the Hamming function.

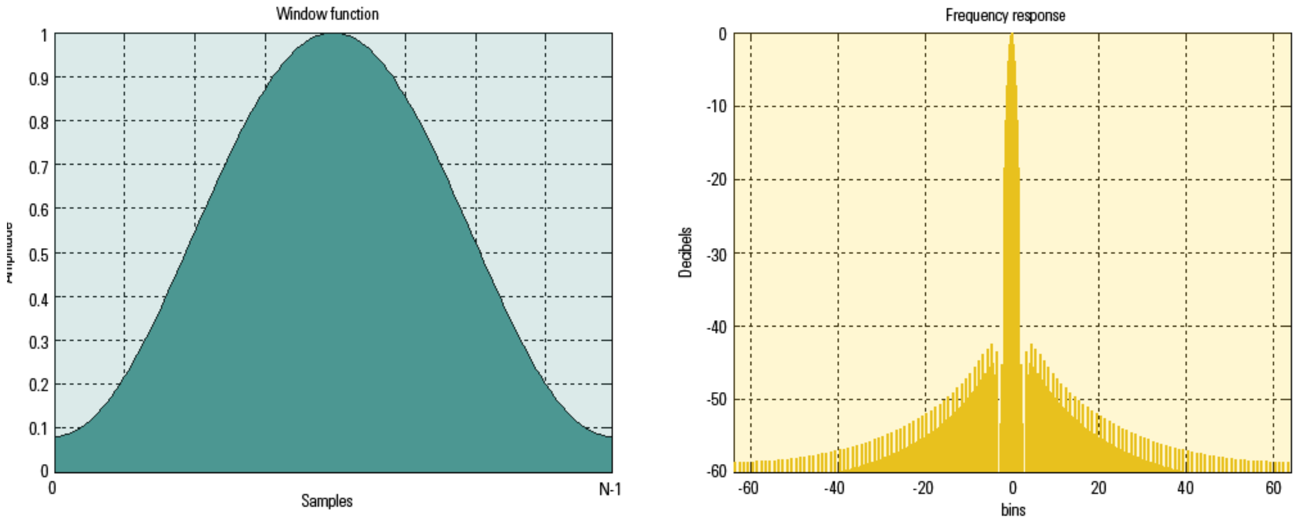

Figure 2. Hamming windowing function and associated frequency response

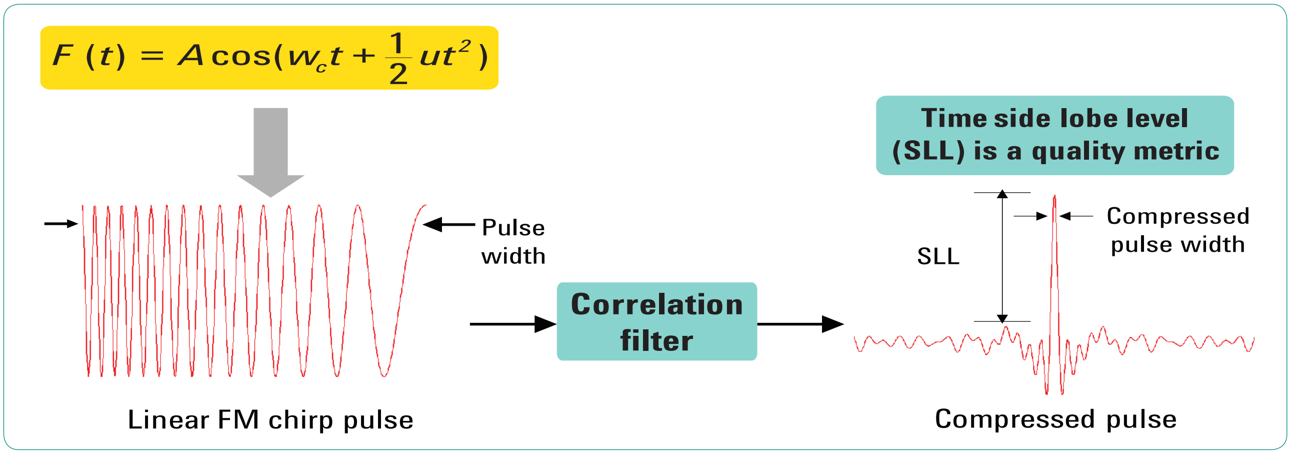

Figure 3. Pulse compression and the Time Side Lobe Measurement

Applying the time sidelobe method

The detector in a radar receiver correlates the transmitted signal with echoes and noise received over time. When the received signal matches the sent signal a correlation peak occurs and target detection is marked at that time.[1]

An ideal correlation peak would be infinitely narrow, have a value of one, and be surrounded by noise-like sidelobe levels. At the other extreme, the correlation between a pure signal and pure noise is zero. Figure 3 indicates the process of pulse compression and the time sidelobe measurement.

System impairments ranging from imperfectly generated compressed pulses to internal reflections from filters can cause correlation sidelobe levels well above the noise floor (Figure 4). Because it is difficult to judge the effect of such impairments on a compressed pulse, using the time sidelobe level technique provides quantitative measurements of transmitted pulse shapes and received signals.

An accurate measurement of SLL requires a filter that is perfectly correlated to the desired pulse shape. The first step is to build an ideal waveform that represents the desired compressed pulse: bandwidth, pulse width, and chirp or modulation characteristics are essential parameters. Modeling can be performed with software such as SystemVue or Signal Studio for pulse building from Agilent or MATLAB from The MathWorks. The mathematically generated, ideal (i.e., repeatable with no impairments added) representation of the compressed pulse can be stored in memory and recalled later to correlate measured waveforms and enable calculations of SLL.

The FM chirp pulse waveform for the SLL measurement and calculation should be designed to imitate the operational waveform of the radar system. For systems that feature multiple operating modes multiple waveforms should be used and multiple SLL measurements made. The pulse generation platform should provide repeatability when creating and recreating the pulses for the measurement stimulus and for the relative comparison measurement.

Alternatively, the ideal compressed pulse could simply be created mathematically and compared to the measured pulse without ever physically generating it. The limitation here is that the relative comparison is always with the ideal which may not always be desired. At times there may be a need to measure SSL between two points within the system in trying to track down the specific source of an anomaly.

Three tools suggested for creating the pulsed waveform may use different methods but the end result is the same: a combined or separate I and Q waveform file(s) that can be directly downloaded into the waveform memory of an Arbitrary Waveform Generator (AWG).

SystemVue: A system modeling tool, SystemVue with the optional radar model library provides signal processing reference models for exploring trade-offs in radar system architectures for Pulsed Doppler, FMCW, Digital Array, and UWB Radars. It enables scenario modeling by adding targets, clutter, fading, noise, interferers, and the RF effects necessary for realistic system analysis and early R&D verification using connections to live test equipment. **www.agilent.com/find/SystemVue**

Signal Studio for pulse building: Enables flexible generation of complex, wideband pulse patterns using the E8267D PSG or E4438C ESG vector signal generators. Custom pulse shaping, modulation, antenna patterns, and user-defined pulse patterns are easily achieved with the straightforward graphical user interface or with your own test executive using the COM-based API. Add the N603xA/N824xA/M933xA wideband AWG to Signal Studio for pulse building such as signal processing, signal modulation, digital filtering, and curve fitting. **www.agilent.com/find/MATLAB**

MATLAB: A software environment and programming language created by MathWorks and now available directly from Agilent as an option with most signal generators and signal analyzers. MATLAB extends the capabilities of Agilent signal analyzers and generators to make custom measurements, analyze and visualize data, create arbitrary waveforms, control instruments, and build test systems. It provides interactive tools and command-line functions for data analysis tasks such as signal processing, signal modulation, digital filtering, and curve fitting. **www.agilent.com/find/MATLAB**

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[1] As a reminder, the time differential between “send” and “receive” is related to the distance between the radar and the target.

When measuring pulse waveforms that will be correlated for SLL calculations, instrument calibration and waveform correction are other important factors. The reason: The wideband nature of most compressed pulses gives rise to potential inaccuracies in both phase and amplitude versus frequency within the measurement instrument. To prevent these inaccuracies from affecting SLL measurements, a measuring receiver with built-in equalization and signal generation software or hardware with predistortion capabilities is essential.

Making time sidelobe measurements

The measurement process starts with detailed knowledge of the ideal compressed pulse, as described above. The next requirement is a suitable broadband signal analyzer, oscilloscope or logic analyzer with vector signal analysis (VSA) software. Example instruments include Agilent's PXA and MXA signal analyzers, Infiniium 90000X-Series oscilloscopes and 16900 series logic analyzers. These all support the Agilent 89600 VSA software, which supports more than 70 signal formats and is capable of implementing the mathematics needed to make and display the time sidelobe measurement. The VSA software can run on a PC or inside instruments such as those mentioned here.

The instrument is used to acquire and digitize the measured waveform. The VSA software can be configured to use the time cross-correlation identity, an approach that is much less cumbersome than performing a time-domain cross correlation between data files. Using the identity makes it possible to take the measured frequency data and multiply it by the ideal pulse created earlier. Before making the measurement, the ideal pulse must be imported into the VSA software and transformed into the VSA's file format. One important note: To ensure a successful SLL measurement, the imported file and the measured data must use the same sample rate.

Once these preparations have been complete, the measurement can be performed. Within the VSA software, the measured frequency data (real and imaginary) is multiplied by the ideal pulse. This result is processed with the inverse fast Fourier transform (IFFT) function to produce the time cross correlation needed for the SLL measurement.

$$\text{Measured }(t) \otimes \text{Ideal }(t) = \text{IFFT }[\text{Measured}(f) * \text{conj}[\text{Ideal}(f)]]$$

Where

$$\text{Measured }(f) = \text{window} * \text{FFT }(\text{Measured }(t))$$

$$\text{Ideal }(f) = \text{window} * \text{FFT }(\text{Ideal }(t))$$

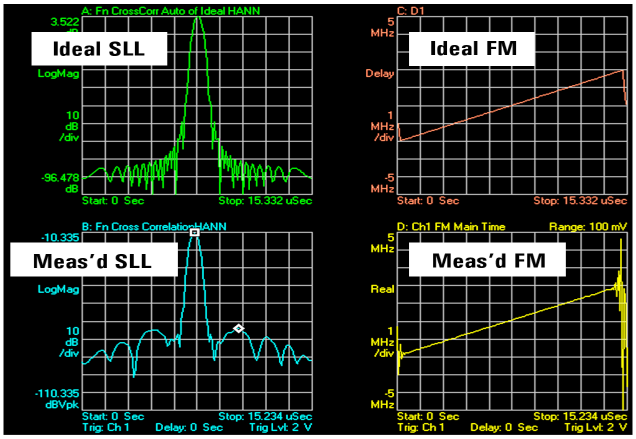

Figure 4. The SLL measurement

Results

Radar engineers and test professionals have found many practical uses for SLL measurements. Examples include characterization of radar spatial resolution and dynamic range. It is also being used to help identify problems in analog components.

Spatial resolution is often an essential part of the system acceptance criteria. Because the time from the main correlation lobe to the minimum discernable sidelobe is directly related to the minimum spatial resolution, SLL offers an effective go/no-go assessment of a radar system's field performance. SLL also provides assurance that no other internally generated sidelobe will affect the overall threshold performance of the radar.

The correlation function is also directly tied to the probability of target detection. From this, a sufficiently low SLL value ensures the radar hardware under test will have dynamic range wide enough to detect weak target signals.

At the component level, time sidelobe testing can help identify problems with analog microwave components. The typical approach is to patiently work through the process of measuring parametric characteristics and then sifting through the results and identifying potential problems. Instead, time sidelobe levels can be evaluated for impairments at any point within a system—and this makes it possible to rapidly assess if the radar pulses can deliver the desired level of performance.

This ability to assess pulse quality virtually anywhere within a radar system—from transmitter to receiver detector—makes SLL a valuable diagnostic tool. For example, one quick SLL measurement at the transmitter output can instantly pinpoint either the transmitter or receiver as the source of problems. Subsequent measurements can quickly isolate signal impairments that are preventing radar performance from meeting system requirements.

Conclusion

Time sidelobe measurements are easy to perform with popular Agilent signal analyzers, oscilloscopes and logic analyzers equipped with the 89600B VSA software. Preparation for the measurement requires creation of the ideal pulse waveform, importation of the ideal pulse into the VSA software, and some trace math. Once the setup is complete, time sidelobe measurements are easy to perform and can be used to gauge key performance traits, isolate signal impairments, diagnose system problems, and find problems at the component level.

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