Application Note

Radar Signal Acquisition and Analysis Using High Speed Modular Digitizers

Radar signals which use pulsed waveform with short duty cycles, multiple modulation types, and critical timing require measurement systems that provide high bandwidth, proportional sample rate, long memory, and fast data transfer. High speed modular digitizers are ideally suited for acquiring and processing radar signals and offer multiple benefits fitted to these measurements. They offer high bandwidth, long acquisition memories, and special acquisition modes to maximize memory usage, these compact instruments provide high speed measurements and analysis of great accuracy. This article will highlight some of the advantages of using high speed modular digitizers for radar system measurements.

Radar systems rely on pulse modulated radio frequency (RF) carriers which generally include frequency, phase or complex modulation. The role of the measurement instruments is to acquire these pulsed waveforms with the greatest possible fidelity and measure the key parameters. Consider the radar signal in Figure 1. Here a basic pulse modulated 1 GHz RF carrier.

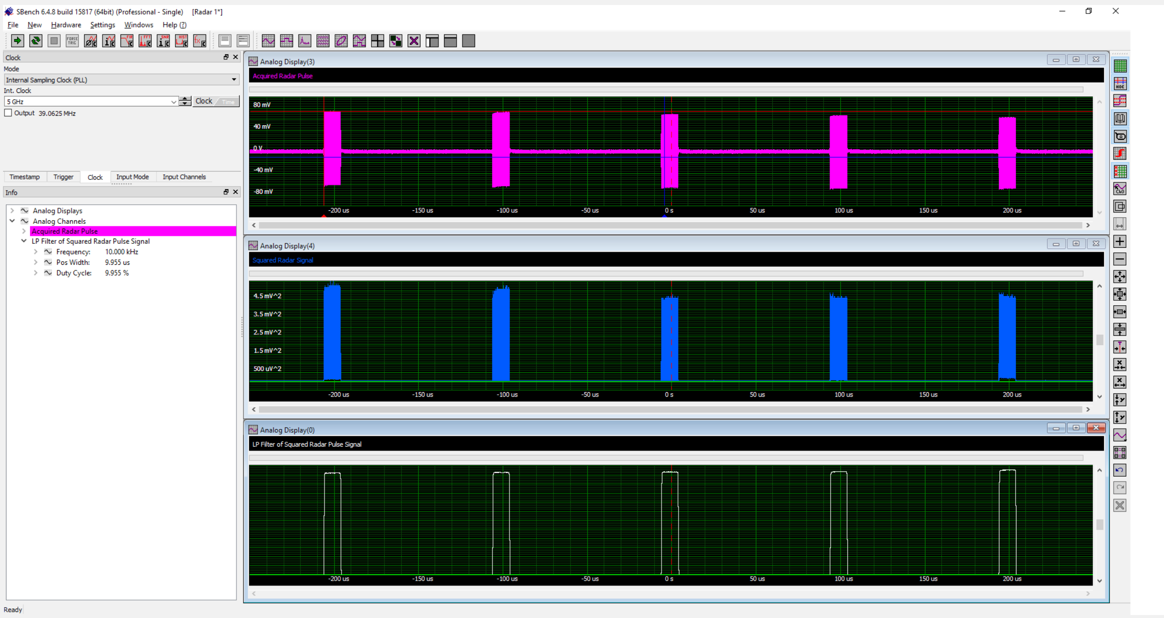

Figure 1: The acquisition of a basic pulsed RF radar signals and the steps to perform a simple RMS detection of the waveform in order to measure key timing parameters on the signal envelope.

The Signal in the top trace in Figure 1 was acquired on a Spectrum Instrumentation model M4i.2234-x8. This is a PCI Express based, four channel, 8-bit digitizer with a 1.5 GHz bandwidth, 5 GS/s maximum sample rate. This bandwidth and sample rate are compatible with direct acquisition of VHF and lower UHF radars and the intermediate frequencies of many higher frequency radars. This digitizer includes 4 Giga-Samples (GS) of acquisition memory. A 4 GS memory can acquire 800ms of data at the maximum sampling rate of 5 GS/s. This provides good time resolution over long acquisitions which is helpful in interpreting phase or frequency modulated signals. In this example the digitizer has acquired 500µs of data at the maximum sample rate of 5 Giga Samples per second (GS/s) using 2.5 Mega Samples (MS). While this example only acquired five pulses using the full memory over 8000 similar pulses could be acquired.

The software used to view the data from the digitizers is Spectrum Instrumentation's SBench6 software. SBench6 is one way to configure, control, and view the data from the digitizer. It also includes built-in tools to measure and analyze the acquired waveforms. For instance, the carrier frequency of the signal is measured using the frequency measurement function, the result is displayed as 1.000GHz in the info pane on the left side of the figure. SBench6 also includes many numerical analysis tools including the Fast Fourier Transform (FFT) and finite impulse response (FIR) filtering.

The pulse repetition frequency (PRF) can be estimated from the screen but a much more accurate value can be obtained by using the software's measurement tools. Measuring the PRF, pulse width, and duty cycle accurately is best done by extracting the envelope of the pulse modulated waveform. This can be done by squaring the signal (middle trace) and then low pass filtering it (bottom trace). This operation performs a root mean square (rms) detection. The squared waveform in the center trace is proportional to the signals instantaneous power. If the power measurement is required, rescaling the data by dividing by the input impedance of 50 Ω and changing the units to Watts will accomplish that conversion.

After the filter operation the envelope of the pulse train is shown in the bottom trace. The software's measurement tools are again applied to read the PRF of the pulses, which is 10 kHz, the width, 9.955µs, and the duty cycle, 9.955%.

Modulated Pulses

Pulse compression is commonly used to improve the radar's distance resolution. Compression involves modulating the pulse carrier so that each instant in the pulse is different from each other instance. This is commonly done using frequency or phase modulation. The radar receiver provides the necessary digital signal processing to affect the pulse compression.

Sweeping or changing the frequency of the carrier during the pulse duration is a common technique and the resultant frequency modulated pulses are referred to as 'chirps.' Figure 2 shows an example of a linear swept radar chirp.

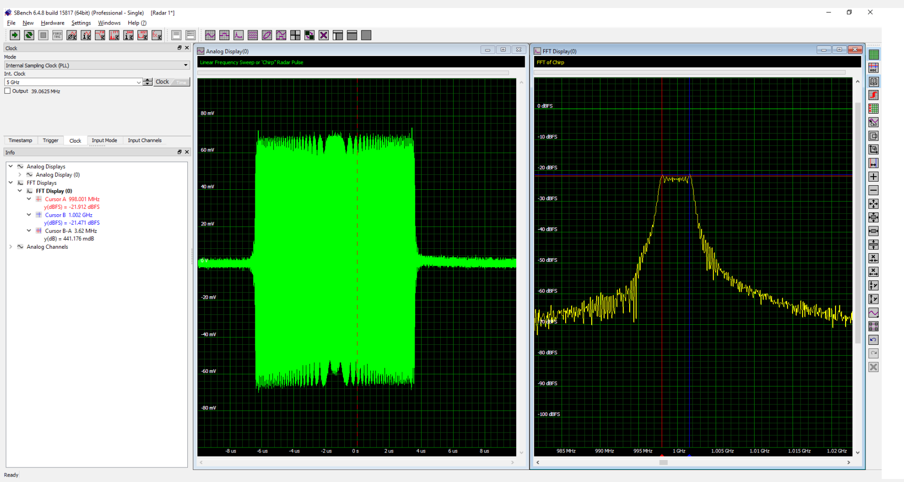

Figure 2: An example of the linear swept frequency radar chirp. The frequency spectrum of the pulse shows the nearly 4 MHz linear sweep range applied to the carrier frequency.

The modulated pulse is shown in the left-hand grid. During the pulse the carrier frequency is changed linearly from nominally 998 MHz to 1002 MHz. This is evident in the frequency domain view provided by the FFT shown in the right-hand grid. The flat-topped spectrum shows the variation in frequency during the sweep. Cursors on the frequency spectrum read the range of the frequency change in the carrier of 3.62 MHz.

Phase modulation can also be employed to implement pulse compression. The phase modulation technique breaks the pulse into segments, each of which is transmitted with a specific phase shift. The segments are of equal length. The selection of the phase shift is determined by a code. The common code is binary where the code value switches between +1 and -1 corresponding to a phase shift of 0° and 180° in accordance with the code sequence. The most commonly used code sequence is the Barker code which has a low autocorrelation with other sequences and produces spectra with low sidelobes.

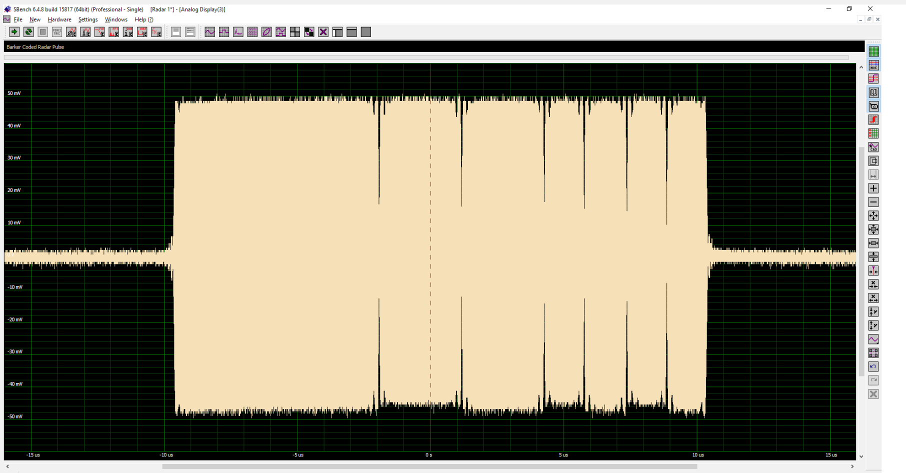

Figure 3: A phase modulated pulse using a Barker code of length 13. Phase reversals are obvious as notches in the waveform.

Figure 3 is an example of a phase modulated pulse using Barker code of length 13.

Demodulation of the phase modulated pulse is best done in the host computer which allows more sophisticated data analysis. Third party software such as MATLAB or LabVIEW or even custom programming in C, C++, or Python can be used. These third-party programs offer the ability to demodulate these signals rapidly. The programs can be customized to match the application and they offer great flexibility and allow much more complex analysis. This capability for processing outside of the digitizer is enhanced by the M4i.2234-x8 digitizer's PCI Express x8 Gen 2 interface. This interface, using Spectrum's drivers can achieve data transfer rates of greater than 3.4 GB/s with suitable host computers. This transfer rate is very essential when dealing with a digitizer like this that can acquire up to 4GB of data as it allows rapid transfer of the data to the host computer.

Even greater processing power is available for those with intermediate level programming skills, in the form of the Spectrum CUDA access option for parallel processing (SCAPP) which allows a direct connection between the digitizer and a CUDA based graphics processing unit (GPU). This makes the GPU's multiple processing core and super-large memory available for advanced high-speed signal processing. In this application it can provide significantly faster calculation times.

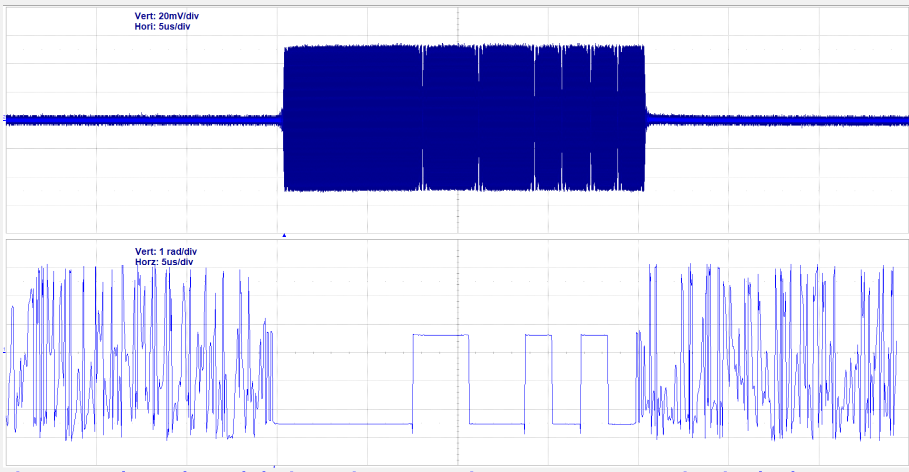

Figure 4: Phase demodulation using a proprietary program running in the host computer. The demodulated waveform is only valid in the presence of the carrier.

Figure 4 shows the result of using a proprietary demodulation program on the acquired phase modulated pulse.

The demodulated waveform, which is only valid in the presence of the signal carrier, shows the Barker code sequence values. The 13-bit Barker Code (+1 +1 +1 +1 +1 –1 –1 +1 +1 –1 +1 –1 +1) can be seen, the +1 represents 0° and the -1 represents 180°. This is the longest available Barker code sequence. The spectrum sidelobe level for this code is -22.3 db.

Third party software packages like LabVIEW and MATLAB offer application packages specifically designed for radar analysis. A good example is the Radar Waveform Analyzer application which is included in the MATLAB Phased Array System toolbox by The Mathworks. Spectrum provides drivers and example programs to interface these programs with its digitizers.

This modular digitizer also offers multiple acquisition modes that are intended to use acquisition memory efficiently and decrease the dead time between acquisitions especially with signals, like those in radar applications, that occur at a low duty cycle.

The Multiple Recording or segmented mode, shown in Figure 5a, allows the recording of multiple trigger events with an extremely short re-arm time (about 6.5 ns at 5 GS/s sample rate). The acquisition memory is divided into several segments of equal size. One segment is filled for each trigger event. The acquisition stops between segment trigger events saving available memory. The user can program pre- and post-trigger intervals within the segment. The number of acquired segments is only limited by the memory used and is unlimited when using first-in first-out (FIFO) acquisition mode. Significant data associated with multiple triggers is stored in the acquisition memory in the contiguous segments. Data associated with the dead-time between events is not recorded. Each trigger event is time stamped so the precise location of each trigger is known. Figure 5b shows a graphical view of the time stamp operation for the Multiple Recording mode. The timestamps are stored in an extra FIFO memory that is located in hardware on the card. It can be read out if needed.

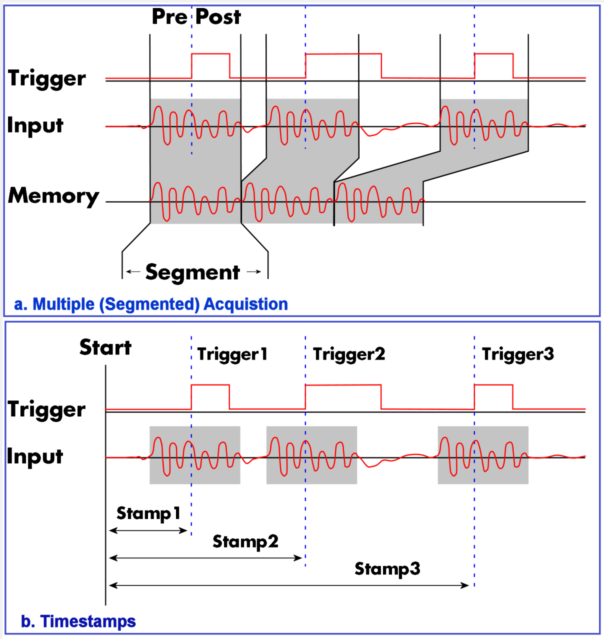

Figure 5: The acquisition memory can be used more efficiently by acquiring waveforms in Multiple Acquisition mode. This mode acquires multiple waveforms, each in its own segment. This eliminates dead time between significant events. Time stamps record the time at each trigger.

The multiple acquisition mode saves memory space by not recording the dead time. This gives a greater number of significant events in the available acquisition memory. The pulses in figure 1 are about 10μs wide with 90μs of dead time so in multiple acquisition mode that 90μs would not be recorded and an additional 9 pulses could be acquired and stored. This mode is useful in studying pulse to pulse variations in the radar operation. There are several other acquisition modes that provide more effective control of data acquisition in the digitizer.

Radar signals can be challenging to measure but modular digitizers are well adapted to the acquisition and analysis of these signals. Digitizers offer excellent signal integrity and an extensive variety of tools to analyze the acquired waveforms. The ability to quickly transfer the data to the host computer makes a wider range of analysis tools available yielding very flexible radar measurement systems.