

# Keysight Technologies

Using Data Compression, Streaming  
and Decompression to Generate Radar  
Pulses with Maximum Bandwidth

Application Brief



## Introduction

The evolving requirements for advanced radar systems continue to pursue performance enhancements in key areas such as detection, ranging and tracking. As a result, frequencies keep reaching higher and signals are becoming increasingly agile. Signal formats and modulation schemes—pulsed and otherwise—continue to become more complex, and this demands wider bandwidth. These trends also have implications for those who create electronic-warfare systems.

Testing these systems—accurately and thoroughly—requires extremely realistic, phase-coherent signals. Those signals are part of very complex scenarios that have extremely long, perhaps infinite, play times. Arbitrary waveform generators (AWGs) are often the most effective solution.

To generate clean, wide-bandwidth radar pulses, an AWG must have 12- or 14-bit resolution coupled with sample rates that range from 8 to 12 GSa/s. Many current-generation AWGs can produce reasonably long signal scenarios through large memories and advanced sequencing capabilities. However, this may not be sufficient for the extremely long play times needed for radar testing. Instead, data compression combined with streaming from mass storage and high-speed decompression (in AWG hardware) is often the best way to produce virtually infinite play times.

This application note presents three data-compression methods that provide suitably wide bandwidths for these applications: idle insertion, digital upconversion and DSP-based modification. When used with a best-in-class AWG such as the Keysight Technologies, Inc. M8190A, pulsed radar signals with modulation bandwidths of up to 2 GHz can be streamed from a high-performance RAID array or solid-state disk (SSD).

## Defining the problem

AWGs typically offer a wide range of capabilities such as large sample memories and advanced sequencing capabilities. These can be used to create complex signal sequences with extended play times.

Although this approach can produce long signal scenarios, it has two major limitations. First, play time is still finite because it is a function of factors such as the required signal quality, the amount of built-in memory and the flexibility of the sequencing capabilities. For example, assume a 12 GSa/s signal and 16 GSa of built-in memory: this equates to just 1.33 s of playback time, which is inadequate in radar applications.

The second limitation: in most cases the sequence is predefined, and this means it cannot be altered on-the-fly in response to changes in the signal environment. This is a significant shortcoming in radar applications that require dynamic signal scenarios.

## Outlining the solution

To overcome these limitations, it is possible to stream radar pulses to an AWG. The stream of pulses can be either generated in real time or pre-calculated and played back from a storage device such as a RAID system or an SSD (Figure 1). Also, if it's necessary to modify radar pulses using a “capture, modify and play back” approach, then streaming is often the only option.

Streaming a waveform with 12-bit resolution at 12 GSa/s requires a data throughput rate of 144 Gb/s or 18 GB/s. Such high data rates can push a high-end PC beyond the limits of its computing power and easily exceed the throughput performance of the fastest mass-storage devices.

When coupled with a best-in-class AWG, the use of data compression makes it possible to stream radar pulses at the highest bandwidths. Three approaches provide the required performance:

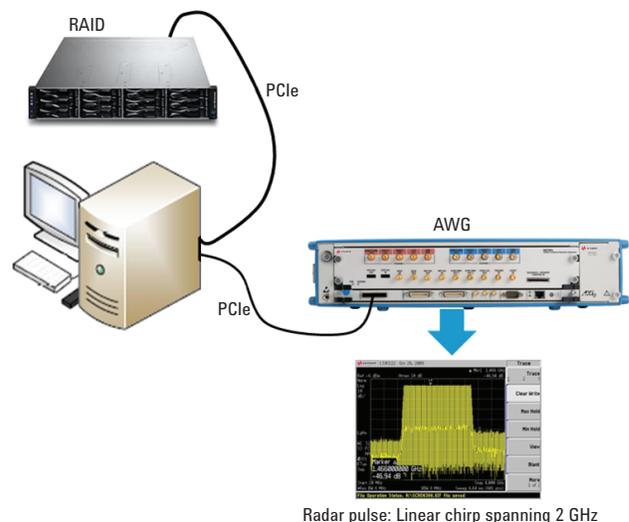
- Idle insertion, when used with external triggering, allows compression of periodic radar pulses
- Digital upconversion provides direct generation of IF radar pulses
- DSP-based compression enables modification of radar-pulse frequency and amplitude

The compressed information must be decompressed for play back at high fidelity. This is where the M8190A excels: it supports decompression of all three methods at full speed in hardware. As a result, compressed wideband radar pulses can be streamed to the AWG at the relatively low data-transfer rate of several gigabits per second. The AWG decompresses the stream in an ASIC and transmits wideband radar pulses with the highest signal quality at an IF of up to several gigahertz.

The data stream can originate from a variety of data sources. Two are well-suited to radar applications:

- A RAID array that includes multiple hard disk drives (HDD) can provide storage capacity of up to several hundred terabytes. Read performance is often in the range of 1 to 2 GB/s.
- High-end SSDs offer up to 1 TB of storage and read performance of 3 to 4 GB/s.

The radar pulses streamed from these devices must be calculated in advance and stored for later playback. As a result, the host PC in the streaming system can be one with a lower-performance CPU.



Radar pulse: Linear chirp spanning 2 GHz

Figure 1. A typical streaming configuration includes a PC, a RAID array and an AWG.

In applications that require real-time modifications in response to external events, radar-pulse parameters must be modified on the fly. This is called algorithmic data generation in real time. With this technique, the streamed waveform data is calculated in real time by an external CPU. Two factors determine the performance of the system: the processing power of the CPU and the sophistication and efficiency of the algorithm.

The AWG also plays a role: it must have the capability to compensate for variations in PC-to-AWG download performance. This can be done by using a ring-buffer structure in the waveform memory within the AWG. With this capability, the PC can write radar pulses to the ring buffer while the AWG simultaneously reads from the buffer and sends the information to its digital-to-analog converter (DAC), which outputs the signal.

## Sketching the operation of each compression method

A brief look at the three methods—idle insertion, digital upconversion and DSP-based—will highlight the strengths and weaknesses of each.

### Idle insertion with triggered streaming

In many cases, radar pulses have on/off ratios in the range of 1:5 to 1:100. Because no signal is sent during the off phase, compression of the waveform can be achieved by streaming only the on-state pulse information to the AWG. As a result, the compression factor is identical to the on/off ratio.

Each pulse is generated by applying a periodic trigger signal to the AWG at the pulse repetition rate. This is enabled by a “triggered streaming” mechanism within the AWG. Radar pulses are decompressed and produced by the AWG at the repetition rate initiated by the periodic trigger signal.

The waveform memory in the M8190A AWG is organized as a ring buffer divided into separate segments. In this case, each segment contains a single radar pulse that was streamed from the PC (Figure 2). When the first trigger is received, radar pulse 1 is generated. Between subsequent pulses, the AWG transmits a predefined value; on the next trigger, the next pulse in the ring buffer is generated.

This method can be quite effective. For example, to generate a signal with a 2-GHz bandwidth, the AWG must operate at a sample rate of 4.8 GSa/s. At 14-bit resolution, the uncompressed data rate would be 67.2 Gb/s for a stream of radar pulses. If the on/off ratio is 1:20, the compressed data rate is 3.36 Gb/s, which PCIe® can handle.

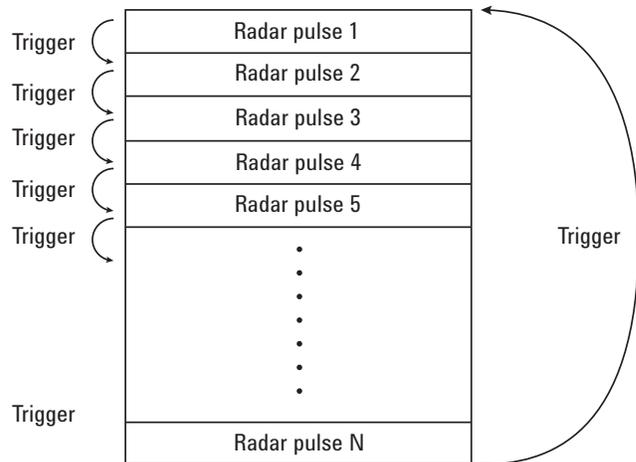


Figure 2. The triggered-streaming mechanism leverages the ring-buffer organization of M8190A memory.

## Digital upconversion and interpolation

Upconversion is typically performed in one of three ways: analog, software or digital. Analog upconversion is the traditional method. The platform is a vector signal generator that accepts in-phase/quadrature (I/Q) data and outputs a modulated signal at the required carrier frequency. This has two drawbacks: the upconversion process creates distortion such as images and carrier feed-through; and it takes time to correct such problems by manually adjusting imbalances along the upconversion path.

Software upconversion uses applications such as MATLAB to calculate I/Q data, mathematically upconvert it to IF and download the waveform to the AWG. Signal quality can be quite good, but at the expense of play time. For example, if the application requires a signal in the 1.9 to 2.0 GHz range with 100 MHz bandwidth, the required AWG sample rate is determined by the maximum IF frequency: 2.4 times 2.0 GHz is 4.8 GSa/s. Compare this to the I/Q baseband signal: 2.4 times 100 MHz is just 240 MSa/s. As a result, available playback time is 20 times smaller at IF, given the same memory size.

For these reasons and more, digital upconversion is the preferred approach. As shown in Figure 3, the M8190A AWG's implementation of digital upconversion is enhanced with interpolation that uses digital reconstruction filters with factors of 3 to 48. The numerically controlled oscillator (NCO) is used for digital upconversion. This mechanism has two noteworthy advantages:

- DSP-based interpolation, filtering and I/Q modulation can be extremely accurate and this minimizes the creation of spurious signals or “spurs” (Figure 4).
- To reduce the required streaming bandwidth, interpolation can be used as a mechanism for data compression and decompression.

When used in combination with interpolation, digital filtering and digital I/Q modulation, this approach provides the benefits of IF signal generation—but without the distortion—along with excellent utilization of memory (Figure 4).

Using the previous example for software upconversion, the I/Q sample pairs must be generated at 120 MSa/s to produce a signal with 100-MHz bandwidth. The AWG can be operated in interpolation mode 48, which means the DAC will operate at 48 times 120 MSa/s or 5.76 GSa/s. The NCO can be adjusted to generate a center frequency of 1.95 GHz. The result: Compared to software upconversion, digital upconversion would require 20 times less data throughput through the streaming interface.

## DSP-based modification of pulse parameters

Moving radar targets produce reflections that exhibit the Doppler Effect, which is evidenced by very small frequency changes in the returned pulses. These can be generated by modifying the NCO settings during signal generation.

The NCO in the M8190A has 72-bit resolution, which translates into frequency resolution of a few picohertz. As a result, it is not necessary to stream radar pulses that differ only by small variations in carrier frequency. The more-efficient alternative is to stream this kind of pulse just once from the PC to the AWG, modify it on the fly with DSP in the AWG and send it out multiple times at slightly different carrier frequencies.

In a similar manner, amplitude can be changed using an internal amplifier in the AWG's DSP engine. Again, if consecutive pulses are identical other than variations in amplitude, then the radar pulse need be streamed just once and the amplitude can be modified in real time using DSP within the AWG.

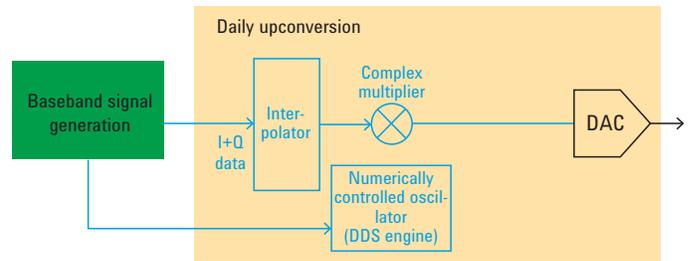


Figure 3. This block diagram illustrates the implementation of digital upconversion in the M8190A AWG.

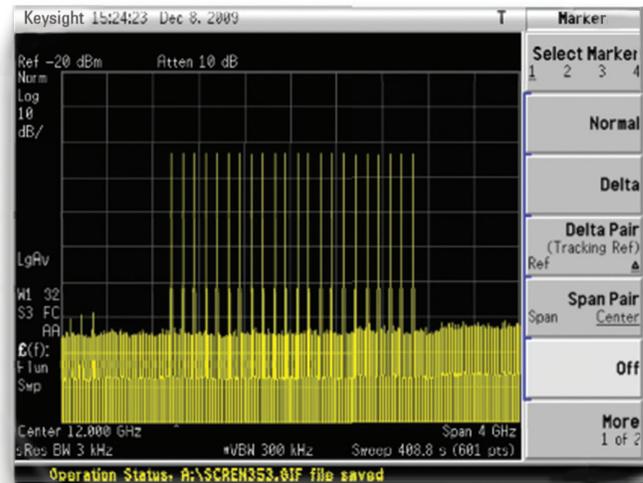


Figure 4. Digital upconversion produced this multi-tone signal with 20 tones spanning 2 GHz.

## Conclusion

Data compression is especially effective with radar pulses. As a result, lower transfer rates are needed to stream pulse data from a PC controller to the AWG. With an AWG such as the M8190A that supports on-board decompression, compression factors of 10 or more are possible. Using the streaming methods described in this application note, modulation bandwidths of up to 2 GHz can be achieved in the testing of pulsed radar systems.

## Related information

- Data sheet: *Keysight M8190A Arbitrary Waveform Generator*, publication 5990-7516EN
- Application note: *Baseband Upconversion to Desired Intermediate Frequency with Regard to Signal Quality and Play Time*, publication 5991-1649EN
- Application note: *Frequency-Agile Complex Signal Simulation with the Keysight M8190A Arbitrary Waveform Generator*, publication 5991-1656EN

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