Generating Radar Waveforms with an Arbitrary Waveform Generator

APPLICATION NOTE

Tektronix®

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FROM THIS APPLICATION NOTE, YOU WILL LEARN:

- Why AWGs are ideal for generating radar test signals
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This application note uses a Tektronix AWG70000B Arbitrary Waveform Generator with software plug-ins to create a range of RF test signals. The methods discussed here are in general applicable to other Tektronix Arbitrary Waveform Generators.

This application note shows how Tektronix software is used with an Arbitrary Waveform Generator (AWG) to create a wide range of RF and baseband signals for the characterization and test of radar systems and subsystems. Radar is widely used to sense objects using radio frequency signals in a wide range of commercial, military, and government applications. Automotive radar allows cars to determine the distance and rate of closure to other objects, military and commercial avionics radar allows aircraft to determine their altitude and the location and velocity of aircraft and missiles, and weather radar can determine the location of storms, the relative content of hail and rain, and the velocity of tornadic winds.

AWG instruments are widely used to generate radar test signals because wideband test signals are needed to check the proper operation of radar amplifiers, antennas, receivers, and other subsystems. Many radar systems use very wide bandwidths and complex modulation which cannot be simulated by modulated analog RF signal generators. Many tests on radar systems require precise timing in the low nanosecond range which can only be generated using an AWG with low jitter triggering and marker timing outputs.

For creating waveforms to be output, software tools are needed. Modern software tools like an AWG's controlling UI or Tektronix's SourceXpress offer advanced features to simplify the process of creating waveforms to be output by an AWG. The waveforms and sequences created can be used for test and verification of the characteristics of radar systems and subsystems such as:

- Transmitter systems including upconverters, filters, and power amplifiers
- Receiver systems including downconverters, filters, preamplifiers, IF (intermediate frequency) amplifiers, AGC (automatic gain control), and signal digitization
- Radar signal demodulation systems
- Power amplifiers and associated filters
- T/R (Transmit/Receive) switches
- Transmission line and slipring systems
- Antennas
- Generating interference for testing system performance

Several different types of signals are required at different points to test these systems and subsystems. Tektronix AWG instruments can be used to provide many types of useful test signals.

- Pulsed and modulated radar signals at the operating frequency
- Pulsed and modulated radar signals at IF frequencies
- IQ (In-phase and Quadrature) baseband modulated radar signals
- Shaped analog baseband pulses with controlled rise and fall envelopes
- Fast digital pulses synchronized with the analog signals described above for gating, switching, and output amplifier bias control
- Slower digital control signals useful for controlling subsystems, such as frequency, attenuation, and antenna polarity switching

RECOMMENDED HARDWARE

The AWG models recommended for generating radar signals are:

- AWG70001B (one analog output channel at up to a 20 GHz signal frequency)
    - o Option AC (+18 dBm output amplifier, high-range step attenuator, and anti-aliasing filters)
- AWG70002B (two analog output channels at up to a 10 GHz signal frequency)
- AWGSYNC01 (synchronization hub which allows from two to four AWG70001B or AWG70002B instruments to be tightly synchronized, useful for generation of up to four 20 GHz signals or up to eight 10 GHz signals)
- AWG5202 (two analog output channels at up to a 2 GHz signal frequency)
- AWG5204 (four analog output channels at up to a 2 GHz signal frequency)

- AWG5208 (eight analog output channels at up to a 2 GHz signal frequency)

In some cases, one AWG is sufficient to test a subsystem. For example, a single channel high speed AWG could be used to generate a single 10 GHz fully-modulated radar signal, a high-speed digital control signal to provide fast bias control of the output amplifier, and several lower-speed digital control signals which are needed for a test. A two-channel AWG instrument can provide IQ baseband or low IF frequency signals as well as digital control signals. In other cases, it might be necessary to tightly synchronize multiple AWG instruments so that multiple signals at the same or different frequencies with controlled phase characteristics can be used for an advanced system test. Tektronix offers a synchronization hub which can lock up to four AWG70000 series instruments together with very low jitter and provide tightly aligned waveforms at the end of test cables using a calibration procedure.

A wideband AWG consists of a high-speed digital memory, control circuits, sampling clock, high-speed digital to analog converter (DAC), and in some cases output amplifiers, attenuators, and filters. This design architecture allows very wideband signals to be generated. For example, a pulsed signal with a linear FM chirp starting at 10 GHz and ending at 15 GHz can be created, and a pre-compensation procedure can be used to flatten the signal at the end of a test cable due to cable loss and sin(x)/x effects. Multiple signals can be superimposed on each other using one AWG, so it is possible to simulate multiple 4G and 5G transmitters and wideband noise as well as the desired radar test signal. A multi-channel test can be performed by using one or more single or multi-channel tightly synchronized AWG instruments. This could allow generation of a multi-channel test signal with stationary background interfering signals on each channel and a non-stationary moving signal simulated by amplitude and phase changes to one signal frequency component across the channels.

Tests on power amplifiers, high-level mixers, filters, and antennas can require more power than the DAC output can produce. Tests on receivers and IF amplifiers may need low test signal levels. For the single-channel AWG70001B instrument, Option AC is available to provide a much wider range of test signal powers. Output power of over +18 dBm in some cases is available, as well as a high-range step attenuator for generating low output power levels. Several filters are available to reduce DAC aliasing and other spurious outputs.

The AWG70000B Series uses two 10-bit DACs, while the AWG5200 series uses two, four, or eight 16-bit DACs. The triggering and sequencing details are also a bit different on the AWG70000B series and AWG5200 series instruments. The AWG70000B series provides much tighter timing of waveforms and marker signals and is to be preferred for most radar signal generation.

RECOMMENDED SOFTWARE

Several pieces of software are mentioned throughout this application note and can be used to for creating and editing RF waveforms. The first is the UI software of the AWG itself. The next is SourceXpress, optional software that only runs on an external PC but looks similar to the AWG UI. SourceXpress is available as a free download from www.tek.com/sourcexpress. Finally there are software plug-ins that can run on both SourceXpress and the AWG UI. Plug-ins enhance the capabilities of both SourceXpress and the AWG UI to allow the simple creation of more complex waveforms for specialty applications, like radar signal generation.

Most settings in the software plug-ins can be seen before an enabling license is installed, but without a valid plug-in license installed on that PC or instrument you will see a warning message near the top (directly below the **Plug-in**: selector). Licenses for plug-ins are installed using the Tools menu at the top of the screen.

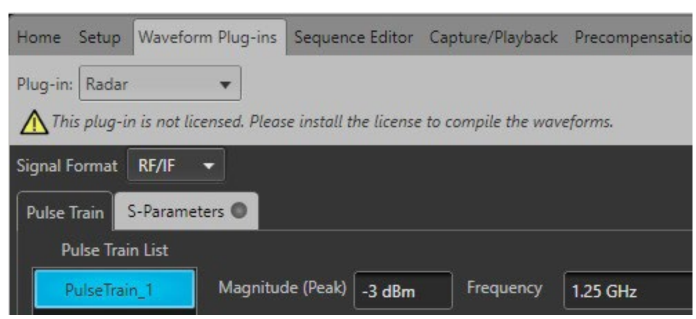

Figure 1: Plug-ins warning if not licensed.

The following software plug-ins are very useful for testing radar systems and components:

- The **Radar plug-in** assists you in creating a wide range of radar signals based on signal parameters such as pulse width, envelope shape, pulse repetition interval (PRI), modulation type, staggered PRI, and other details. This application note describes the basic use of this plug-in for generating several types of pulsed radar waveforms.

- The **S-parameter plug-in** allows the use of imported user S-parameter files to embed or de-embed known cable losses, test fixtures, and filters. For example, you can test an IF amplifier and receiver subsystem by generating waveforms simulating the effect on various radar signals due to the frequency response of IF amplifier filters which have not yet been constructed. Or you could use a VNA to measure the in-band passband ripple of an adjacent band protection filter situated at the output of a high-power amplifier, and separately measure a test cable connecting the AWG to the power amplifier. You can then de-embed both S-parameter responses from a wideband LFM chirp generated by an AWG to generate a high-power signal with flat response over the chirp bandwidth.
- The **Pre-compensation plug-in** can be used with an AWG and a wideband oscilloscope to very accurately flatten the output frequency response due to AWG sin(x)/x and output hardware roll off, connectors, and test cables. SourceXpress controls both the AWG and the oscilloscope to automatically create a system correction S-parameter file which can easily be applied to any waveform, including imported user waveforms.
- The **Environment plug-in** builds waveforms simulating real-world conditions within a complex RF environment which can interfere with radar system performance. For example, you could simulate the superposition of two radar signals at overlapping frequencies, an adjacent channel WiFi or cellular signal, four CW signals, and band limited AWGN noise. The frequency and amplitude of each of these signals can be changed. The software creates each signal at IQ baseband, upconverts each of them to the desired frequencies, then combines them at the desired amplitudes to create one resulting test signal. The parameters used to create the combined RF environment are saved, so you can recall this setup later, change the characteristics of one signal, and recompile a new test signal. The Environment plug-in can use the radar and other plug-ins and use user-provided baseband IQ waveforms.

Plug-ins, whether being used with SourceXpress or the AWG UI, require licenses to be installed to generate signals. A single license cannot be used by both the AWG UI and SourceXpress at the same time. All these plug-ins are available in either Node Locked (NL) or Floating (FL) versions. Visit **www.tek.com/products/product-license** for the most current descriptions of Tektronix product licenses. The most important plug-ins for radar applications are:

- Radar plug-in (RADARNL-SS01 or RADARFL-SS01 license) – described in detail in this application note
- S-Parameter plug-in (SPARANL-SS01 or SPARAFL-SS01 license)
- Environment plug-in (ENVNL-SS01 or ENVFL-SS01 license)
- Pre-compensation plug-in (PRECOMNL-SS01 or PRECOMFL-SS01 license)

Other plug-ins which generate RF signals are:

- RF Generic plug-in (RFGENNL-SS01 or RFGENFL-SS01 license)
- OFDM plug-in (OFDMNL-SS01 or OFDMFL-SS01 license)
- Multitone & Chirp plug-in (MTONENL-SS01 or MTONEFL-SS01 license)

Controlling AWG70000 and AWG5200 Instruments

There are two software options for controlling a Tektronix AWG5200 or AWG70000: The user interface installed on the AWG itself, or SourceXpress on an external Windows PC. The AWG UI can only control the single AWG it's installed on while SourceXpress has more options. When run on a Windows PC connected via a newtwork to an AWG, SourceXpress allows you to create and compile waveforms on your PC, then immediately upload and output them on the AWG. When used offline, SourceXpress allows you to emulate instruments and save software settings, compiled waveforms, and sequencer tables in .awgx setup files. These files can then be moved to the AWG which will be used to generate the signals.

You can control your AWG in four different ways:

1. Using the AWG user interface (see Figure 2 - AWG local use model)
   - o The user interface built into the AWG5200 and AWG70000 looks and feels much like SourceXpress, though it is distinct software. First install the

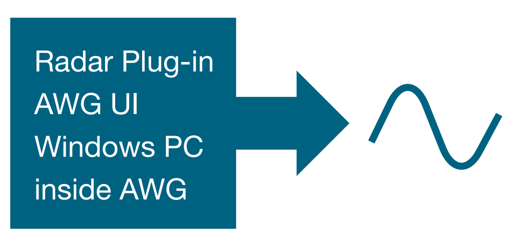

Figure 2: AWG local use model.

appropriate licenses (such as the radar and other plug-ins) on the AWG, since that is where the signals will be developed.

- o This is the only use case that requires any plug-in licenses to be installed on the AWG. For all other use cases, any licenses should be installed on the controlling PC.
- o You can then use the features described in this application note to compile radar waveforms and sequences directly on the AWG instrument and store them on the instrument SSD (solid state disk drive).
- o At run time, the waveforms and sequences are transferred from the AWG SSD to high-speed memory for use by the DAC to generate the analog waveforms, markers, and flags.
- o If waveforms are created on one AWG in this manner, they can be transferred manually to other AWG instruments (of that same model) using a LAN, USB memory stick, or DVD drives connected to each AWG instrument. The Radar plug-in license must be installed on the one AWG which is used to develop and compile the waveforms. No licenses for plug-ins need to be installed on an AWG to play a compiled waveform.

2. Use SourceXpress installed on an isolated user PC (see Figure 3 - Independent PC remote use model).

Figure 3: Independent PC remote use model.

- o Install SourceXpress and the appropriate licenses onto your PC.
- o You can then use the features described in this application note to design radar signals. Then compile them into waveforms and sequences which are saved onto the PC disk drive.
- o Compiled waveforms and sequences can be transferred from that PC to one or more AWG instruments using manual Windows networking features or a USB stick.
- o If site security rules do not permit use of networking or USB RAM storage devices, you can write the waveforms and sequences to a DVD using an internal or external DVD disk drive on the PC, close the DVD so it cannot be edited, scan the DVD at a security control office for viruses, then use a USB DVD drive plugged into the AWG to transfer the waveforms and sequences to the AWG. The DVD can then be destroyed for security reasons.
- o The PC and AWG can be at different locations with no interconnections.

3. Use SourceXpress installed on a user PC connected to the AWG (see Figure 4 - Connected remote use model)

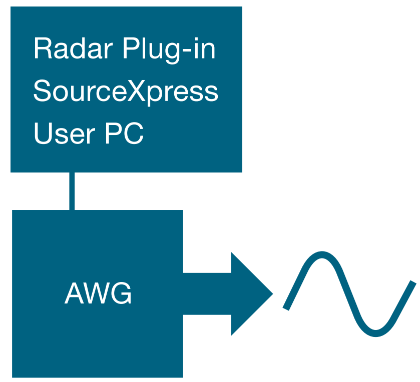

Figure 4: Connected remote use model.

- o Install SourceXpress and the appropriate licenses onto your PC.
- o The PC must be connected using a LAN to the AWG. Routers must allow the passage of certain packet types and port numbers for this feature to work properly.
- o You can then use the features described in this application note to design radar signals. When the signal is compiled, the compiled waveform and sequence files will be automatically transferred over the LAN and saved on the SSD in the AWG.
- o The experience is similar to running the Radar plug-in inside the AWG, but due to differences between the computing platforms this is a better use model for long and complex radar signals. It also allows you to be in an office environment designing radar signals while the AWG is in a remote lab. This feature has been verified to work between buildings in a campus.

4. Use SourceXpress installed on a user PC connected to an AWGSYNC01 synchronization hub (see Figure 5 - Synchronization hub use model)

- o Install SourceXpress and the appropriate licenses onto your PC.
- o The PC must be connected using a LAN to the AWGSYNC01 hub. Routers must allow the passage of certain packet types and port numbers for this feature to work properly.

- You can then use the features described in this application note to design radar signals. When the signal is compiled, the compiled waveform and sequence files will be automatically transferred over the LAN and saved on the SSD in the correct AWG instruments.
- The hub is connected to 2, 3, or 4 identical AWG70000A/B series instruments using custom RF and data cables which are supplied with the hub. You can treat the multiple AWG instruments as an AWG gang as shown in Figure 6 so they appear to act as a multichannel instrument in SourceXpress.
- To create a gang in a virtual setup (where the PC is not connected to the AWG instruments), first create multiple instances of appropriate virtual instruments and name them as desired. Multi-select the member AWG virtual instruments and right-select using the mouse, then choose 'Create Gang.' You can only create a Gang if the virtual instruments are of the same model.
- To create a gang in a live connected setup (where the PC is connected over a LAN to the AWG instruments), multi-select the member AWG instruments and right-select using the mouse, then choose 'Create Gang.' You can only create a gang if the instruments are of the same model.
- The AWGSYNC01 hub includes four front panel calibration ports with an automatic deskew feature. The single high-speed clock for all instruments is supplied either by one of the instruments or an external golden low jitter microwave clock between 6.25 and 12.5 GHz. The AWGSYNC01 distributes this clock and triggering signals cleanly to all instruments. This use model allows tightly synchronized and deskewed radar signals with low jitter to be generated on up to 4 channels using AWG70001B instruments or up to 8 channels using AWG70002B instruments.

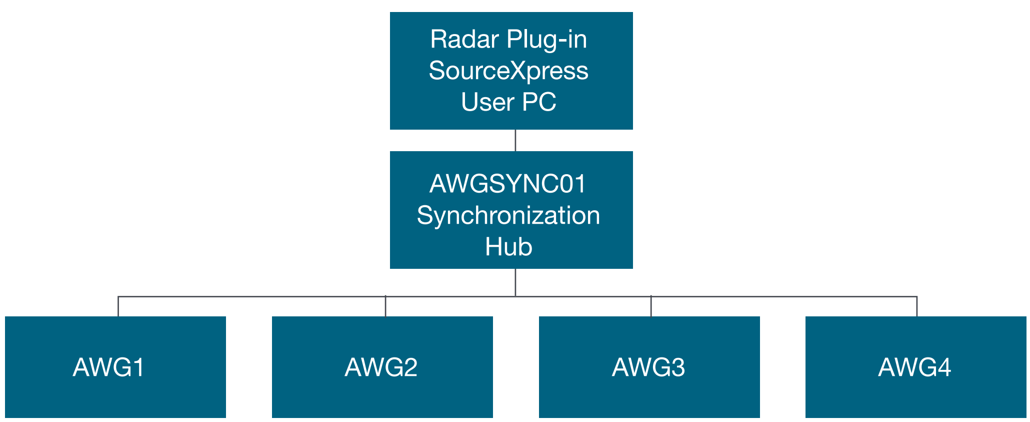

Figure 5: Synchronization hub use model

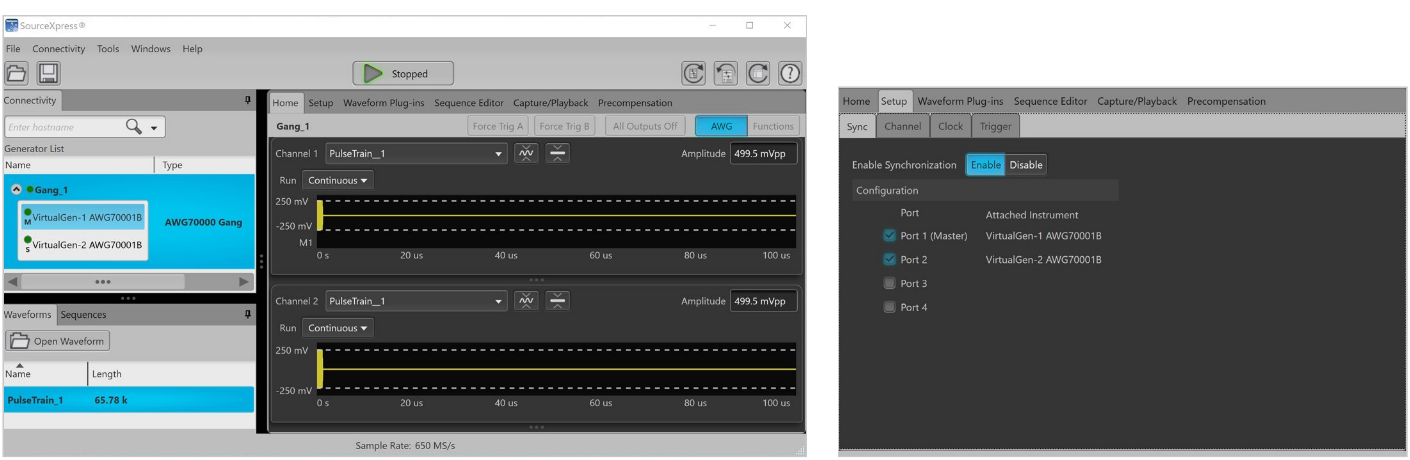

Figure 6: AWG gang setup.

AWG70000 Series Signal Generation Hardware Control

The following description is of the AWG70000B series hardware operation. The AWG70001B and AWG70002B models both have a standard waveform memory length of 2 GSamples for each channel, which can be upgraded using an option key to 32 GSamples on the AWG70001B or 16 GSamples per channel on the AWG70002B. The memory width is 10 bits and the digital to analog converter (DAC) also has 10 bits of resolution. In addition to the DAC for creating an analog voltage from each waveform memory word, there are two high speed digital **marker** outputs from the high-speed memory which can be made available for each channel. You have three choices for mapping the 10-bit memory words to the 10-bit DAC and two digital marker outputs:

- 10-bit DAC resolution with no markers active
- 9-bit DAC resolution with 1 marker active
- 8-bit DAC resolution with 2 markers active

The digital marker outputs have many uses, including:

- Triggering external test equipment (such as an oscilloscope) at a precisely controlled time within a waveform.
- Providing triggering, gating, and clocking signals to the device under test.

Marker timing resolution is governed by the DAC sampling clock. So, if the sampling clock is set to 1 GS/s, the minimum marker width is 1 ns, and possible widths would be 1, 2, 3, 4, 5, … ns. The marker could generate a square wave clock with a maximum frequency of 500 MHz with such as sampling clock setting. At the maximum sampling clock setting of 25 GS/s for each DAC, the marker timing resolution is 1/(25 GS/s) = 40 ps. The marker rise/fall time is <35 ps, so setting the marker bits to alternating high and low will produce a 12.5 GHz sine wave due to the limited rise and fall times.

The AWG70001B has one analog channel (formed by interleaving two 25 GS/s maximum sampling rate DACs) and two markers which can be configured as mentioned above. The AWG70002B has two analog channels (using one DAC for each channel with a maximum sampling rate option of 8, 16, or 25 GS/s per channel) and four markers (two assigned to each channel), and you can set the DAC resolution (and available markers) independently on each channel. Each waveform sample is read out to the DAC and markers by the sampling clock, which increments sequentially through the memory. Each analog channel is a differential pair of DC coupled outputs. The full-scale DAC voltage can be set over a range of 2:1 (6 dB). Lower amplitude signals can still be generated by either instrument model by creating waveforms which only use the lower significant bits of the DAC. Option AC (described below) provides a much wider range of output levels maintaining the full dynamic range (up to 10 bits) on the AWG70001B single channel model. On the two-channel AWG70002B instrument, the analog output maximum DAC level and marker output level can be independently controlled for each output.

Option AC amplified output is a feature only available for the AWG70001B model. This adds a single-ended AC coupled additional front panel output connector. Three power amplifier/attenuator stages allow the output full-scale power to be set as low as – 90 dBm or as high as +25 dBm (depending on frequency) with 1 dB steps over a range of 10 MHz to 18 GHz. Three anti-aliasing and anti-spur filters are also available. A microwave relay allows use of either the interleaved differential DC coupled outputs or the single AC coupled amplified and attenuated output. These features are all available using programmatic control.

Streaming ID is an optional feature which controls the hardware sequencer state using UDP control packets sent from an external user system, allowing your system to dynamically control which radar waveform is being generated. The streaming ID feature includes flow control and status packet support. In addition to the streaming option, a standard parallel 8-bit input port with strobe line feature can be used to control the state of the hardware sequencer from an external system.

High quality narrowband or wideband radar signals can be generated using SourceXpress with Tektronix Arbitrary Waveform Generators. Here are some other AWG70000B Arbitrary Waveform Generator features and what they provide:

AWG70000B Feature	Benefit
10-bit high resolution digital to analog converter (DAC)	Low spurious content and high amplitude resolution
Low phase noise wide range internal clock synthesizer	High resolution of distance and velocity in radar system
External golden microwave sampling clock input	State of the art timing and jitter performance
Sampling rates up to 50 GS/s	Generate wideband radar signals up to 20 GHz
1 ps resolution delay adjustment with 400 fs RMS jitter	Very tight timing of markers and analog outputs
Advanced hardware waveform sequencer	Generation of very complex and long pulse sequences
Internal trigger generator with variable timing menu	Quick front panel control of pulse repetition interval
Two external trigger inputs	Advanced synchronization with external equipment
Two high speed digital marker outputs per channel	Triggering and gating external equipment
Four digital flag hardware sequencer outputs per channel	Control of external devices such as bias and PIN switches
Option AC amplifier/attenuator/filter feature	Wide range of test signal powers with low spurious
Internal Windows 10 PC with 6 USB ports and LAN	Stand-alone operation with internal Radar Plug-in
Internal touch screen display	Stand-alone operation without using a mouse
VGA video output	Allows external larger monitor to be used
eSATA disk drive interface	Improved security and use of existing external drives
Front panel replaceable >1 TB SSD solid state drive	Improved security
Front panel trigger buttons (2)	Easy manual control of waveform sequencer
Front panel all outputs OFF button	Easily turn all RF outputs off for safety
Front panel knob and keypad	Easy manual operation
AWGSYNC01 synchronization hub for up to four AWGs	Multichannel phased array radar testing

AWG70000 Series Hardware Sequencer

The hardware waveform **Sequencer option** feature can repeat waveforms and create digital output control signals based on the current sequencer step. One level of sub-sequencing is also available, which allows several sequencing steps to be called similar to a software subroutine and looped. Two external trigger inputs can be used to trigger the sequencer at a particular step. An 8-bit parallel input with strobe line can cause the sequencer to jump to a different step. In addition to the two SMA connector front panel marker outputs available for each channel from the high-speed memory (stolen DAC bits), four SMB connector rear panel auxiliary outputs are available for each channel on the rear panel. The auxiliary outputs can be used as digital output flags controlled by the sequencer. These can be used to trigger external equipment based on the sequencer state. An internal user-adjustable interval timer with a range of 1 µs to 10 seconds can be used to trigger the sequencer and can be routed to an auxiliary output.

From a user point of view, the AWG high-speed waveform memory is split into one or more waveform files. The waveform names can be set as desired. Many thousands of waveforms can reside simultaneously in high-speed hardware memory. At any moment, the AWG is either stopped (and perhaps waiting for a trigger) or is playing out one waveform by sequentially reading out the memory samples through the DAC and markers to the outputs. The base instrument can be set up to operate in continuous mode (repeating one waveform by looping), triggered mode (generating one waveform after each trigger), or continuous triggered mode (starting continuous looping of one waveform after a trigger).

The optional hardware waveform sequencer can dramatically reduce memory requirements and adds many capabilities. In a sequence, the high-speed memory is only used for one instance of each waveform listed in the sequence, no matter how many repeats or multiple entries referencing that waveform are used. For example, consider generating a radar signal using a single waveform with an AWG70001B instrument. If the goal is to generate a 10 GHz pulsed radar signal with a 1 µs pulse width and 100 µs PRI (Pulse Repetition Interval) and the sampling clock is set to 50 GS/s, the waveform length would be 100 µs and the length in samples of the total required waveform would be:

L_{total} = (100 µs) * (50 GS/s) = 5 M samples

The waveform length of each 1 µs pulse would be:

L_{pulse} = (1 µs) * (50 GS/s) = 50 K samples

The dead time between pulses has a waveform length of:

$L_{deadtime}$ = (99 µs) * (50 GS/s) = 4.95 M samples

It's obvious that 99% of the total waveform is dead time (zero voltage samples). If the hardware sequencer option is installed, a 1 µs long waveform of zero-volt samples can be used by the sequencer and looped 99 times to generate the 99 µs dead time. This is much more efficient use of high speed memory.

You could create a repeating 300 µs long signal consisting of the following pulses at a fixed 100 µs PRI at a 50 GS/s sampling rate in the following manner using the following four waveforms and the optional hardware sequencer:

wfm1: 1 µs wide RF pulse (50 K samples)

wfm2: 2 µs wide RF pulse (100 K samples)

wfm3: 3 µs wide RF pulse (150 K samples)

dead1: 1 µs wide all zero volts (50 K samples)

This sequence is shown in Figure 7 as it appears in the SourceXpress Sequence Editor screen. There are no entries in the Wait column, so as soon as the instrument is placed into the Play mode the sequencer will immediately execute step #1. The table should be read from left to right to understand how it is executed. The sequencer seamlessly moves between steps as indicated in the Go to column after playing the Track 1 waveform the number of loops indicated in the Repeat Count column. Note that after executing step #6, the sequencer immediately jumps to step #1 without a gap. The Track 1 Flags column indicates how flags are changed for each step. The Length column shows the length of one iteration of the waveform before looping.

The total waveform memory used by the example above is one copy of each waveform, no matter how many times the waveform is used in a step or looped. So the total memory used when employing the sequencer is:

L = (50 K) + (100 K) + (150 K) + (50 K) = 350 K samples

If instead we created one flat waveform with no looping, the memory used would be greater by a factor of about 43:

L = (300 µs) * (50 GS/s) = 15 M samples

This example also shows control of the rear panel SMB Flag outputs by the sequencer. Flag A is high during the 1 µs wfm1, flag B is high during the 2 µs wfm2, and flag C is high during the 3 µs wfm3. These flag output signals can be used to trigger external test equipment such as an oscilloscope to verify the output of a DUT when using only a particular pulse excitation.

In most cases the Radar plug-in can generate either a sequence with short deadtime waveforms as shown above, or a single much longer flat waveform file which does not require use of the sequencer. The sequencer length is up to 16,383 steps, and the waveform repeat count range in a step is 1 to 1,048,576. The repeat count can also be set to infinitively loop a waveform. An event from one of two external trigger inputs or the internal interval timer can be used to terminate a sequence step prematurely asynchronously or at the end of a waveform by jumping to a different sequence step. Two front panel buttons can generate the trigger A and trigger B events, as well as two rear panel inputs. A simple example of sequencer use would be to generate an infinite loop which is interrupted by the front panel trigger A button. You could use this with the previous 6-step sequencer table example by adding Event Input and Event Jump to entries and Go to entries so that pressing the front panel trigger A button would step between generating a 1 µs, 2 µs, and 3 µs wide radar pulse.

	Wait	Track 1	Track 1 Flags	Repeat Count	Event Input	Event Jump to	Go to	Length	Time
1	Off	wfm1	H L L L	1	Off		Next	50 k	1.000 u
2	Off	dead1	L L L L	99	Off		Next	50 k	99.000 u
3	Off	wfm2	L H L L	1	Off		Next	100 k	2.000 u
4	Off	dead1	L L L L	98	Off		Next	50 k	98.000 u
5	Off	wfm3	L L H L	1	Off		Next	150 k	3.000 u
6	Off	dead1	L L L L	97	Off		First	50 k	97.000 u

Figure 7: Sequencer settings for generating mixed pulse width radar signal with 1 µs, 2 µs, and 3 µs wide pulses with dead time repeated to cause a 100 µs pulse repetition interval.

One level of subsequencing is available. A subsequence is a series of sequencer steps which can be inserted into a main sequence step. Subsequences use redirection to save sequence memory and improve the ability to easily view and edit the flow of sequences.

- For example, let's say that you create a sequence named Alpha consisting of the 6 sequence steps shown in Figure 7, and you need to use this series of sequence steps in multiple places in your main sequence. In the Sequence Editor screen, open File>Rename and set this 6-step sequence name to Alpha. Then use File>New to start an empty screen to create your main sequence, which by default is named "Sequence".
- You can insert sequence Alpha as a subsequence as step #1 of your main sequence by either double-clicking the Track 1 field I step 1 and choosing Alpha under the Sequence tab or by dragging Alpha from the Sequences window to the Track 1 field of step 1. Now change the Repeat Count to 100. In the upper right part of the Sequence Editor screen, you can see that you have only used 7 steps (1 in the main sequence and 6 in the inserted subsequence) to generate a signal with 300 pulses (100 iterations of the three pulses of different widths). See Figure 8.
- If you double-click the triangle-shaped icon (indicating that this step contains a subsequence) adjacent to the step 1 index, you can open the subsequence, view it, and edit it. See Figure 9. Any changes you make to the subsequence will change the original subsequence you inserted. Use the large X in the upper right to close the subsequence display.
- Now double-click the Track 1 field of step #2 and insert waveform dead1 with a Repeat Count of 50,000. Since dead1 is a 1 μs long zero voltage dead time, this inserts a 50 ms gap in the generated signal. Then insert sequence Alpha into step #3 of the main sequence with a Repeat Count of 700. You will now only have used 9 steps (3 main sequence steps and the 6 subsequence steps inserted twice and repeated a total of 800 loops but counted only once). See Figure 10.
- Since there is only one hardware instance of a particular subsequence, if you edit a subsequence inside a main sequence step you are editing all uses of that particular subsequence in the sequencer. So if you edit the subsequence in this example, it will change Alpha in the Sequences folder and all uses of Alpha in that sequence.
- A subsequence step can only contain a waveform name, flag settings, repeat count, and Go to (within the subsequence steps). Within a subsequence you can not use a wait for trigger, an event jump, or a Go to jump outside the subsequence. The trigger event related features are restricted to the main sequence step which is the envelope containing that instance of the subsequence.

See **Using the Sequencer on Tektronix AWG70000B series instruments** for more details about use of the sequencer.

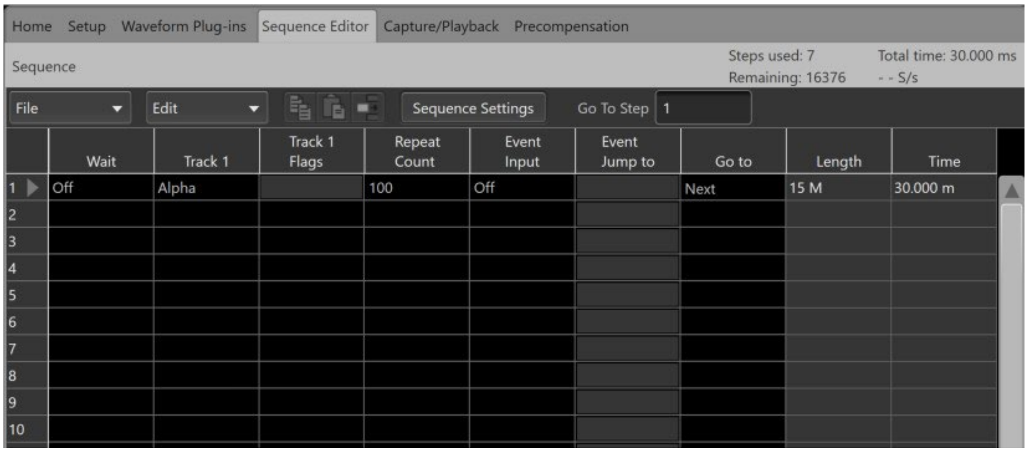

Figure 8: Subsequence Alpha with a repeat count of 100 inserted into the main sequence. The icon adjacent to step number indicates that this step contains a subsequence. Only 7 sequencer steps are used (6 in subsequence Alpha + 1 in the main sequence).

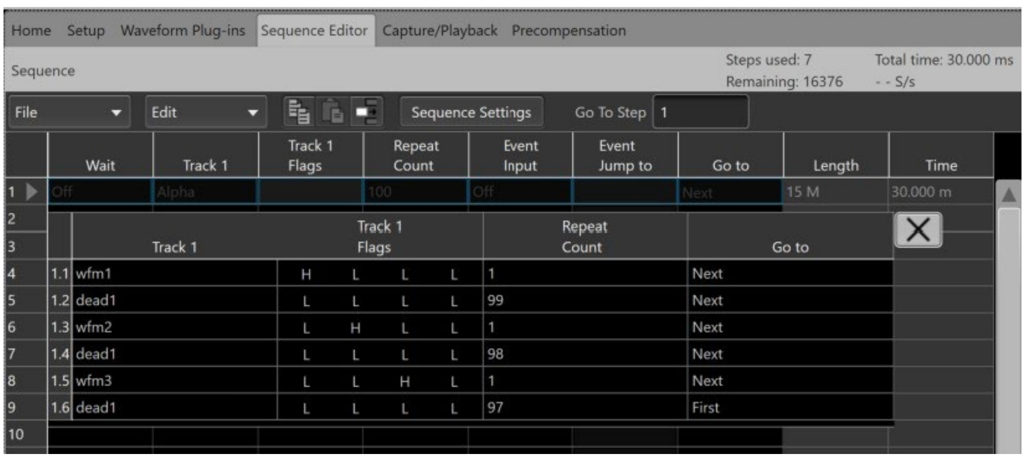

Figure 9: Opened subsequence showing steps 1.1 ... 1.6. Click large X to close subsequence display.

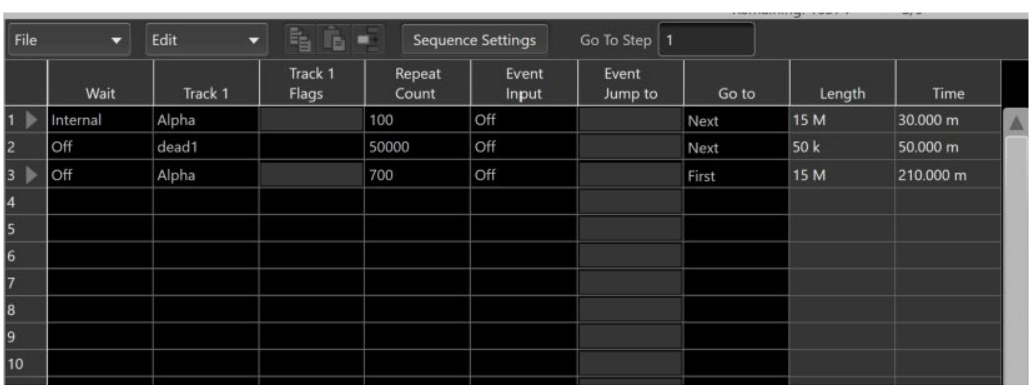

Figure 10: Steps 1 and 3 are subsequences but step 2 is a normal sequence step. Only 9 sequencer steps are used (6 in subsequence Alpha and 3 normal sequence steps) and 16,374 steps are still available. This sequence will be triggered from the internal trigger generator due to the Internal entry in the Wait column of step #1. After completing 100 repeats of the three pulses (100 x 300 μs = 30 ms), a delay (50,000 x 1 μs = 50 ms), and 700 additional repeats of the three pulses (700 x 300 μs = 210 ms) for a total of 290 ms, the sequence execution jumps back to step #1 and waits for the next internal trigger to continue.

SourceXpress Home Tab and Waveform Display

The home display of a flat waveform (without using the sequencer) generated by SourceXpress using the radar plugin on a PC with a 9-bit DAC setting (one marker active) is shown in Figure 11. The three windows shown at the left side can be hidden or moved by using the Windows menu at the top of the screen, by selecting the pin in the upper right of an active window, or by dragging the window around the screen. The four buttons in the upper right of the screen can be used to reset to a default setup, reset the window setup, or read a version of the user manual for help.

In this example, SourceXpress is running as a stand-along application on the PC with no connection to an AWG. Note that the default M1 (marker 1) output signal in this case is a 50% duty cycle pulse with a rising edge at the start of the waveform interval. SourceXpress includes tools to change the marker output signal waveform and timing. One waveform is available in the SourceXpress waveform list, and it has been named PulseTrain_1 (by default) by the Radar plug-in. By right-clicking the PulseTrain_1 waveform you can rename the waveform, save it to the PC hard drive, assign it to an AWG channel for generation, remove it from the SourceXpress waveform list, change the default waveform properties (recommended sample rate and amplitude), copy the waveform to a new file in the waveform list with a modified name, apply a flatness correction to the waveform (using a .corr correction file created by the Pre-Compensation plug-in), modify the marker(s), or modify the waveform (such as by inverting, time reversing, changing the amplitude, shifting in time, changing the length, or resampling to a different effective sampling rate).

Note that the selected (highlighted) generator to be used is a virtual AWG70001B. The Virtual Generator can be customized to match the hardware characteristics of the AWG which will be used to play back the waveform. Right-click on a Virtual Generator to rename that generator, set it active, set it to be default when the Radar Plug-in is next used, or to remove that virtual generator. The Connectivity menu at the top of the screen is used to create a new Virtual Generator based on the target instrument model and options.

To compile and use a complex IQ waveform, you must use a Virtual Generator (or a real AWG) with at least two channels. The user interface will allow you to assign the I component to a channel and the Q component to a different channel.

In Figure 11 you can see a Run control near the upper left corner of the waveform display under the Channel label.

- In Continuous run mode, the waveform shown will be repeated and seamlessly generated continuously with no gaps while the instrument hardware is in Playing mode (the green triangular button at the top center). Of course,

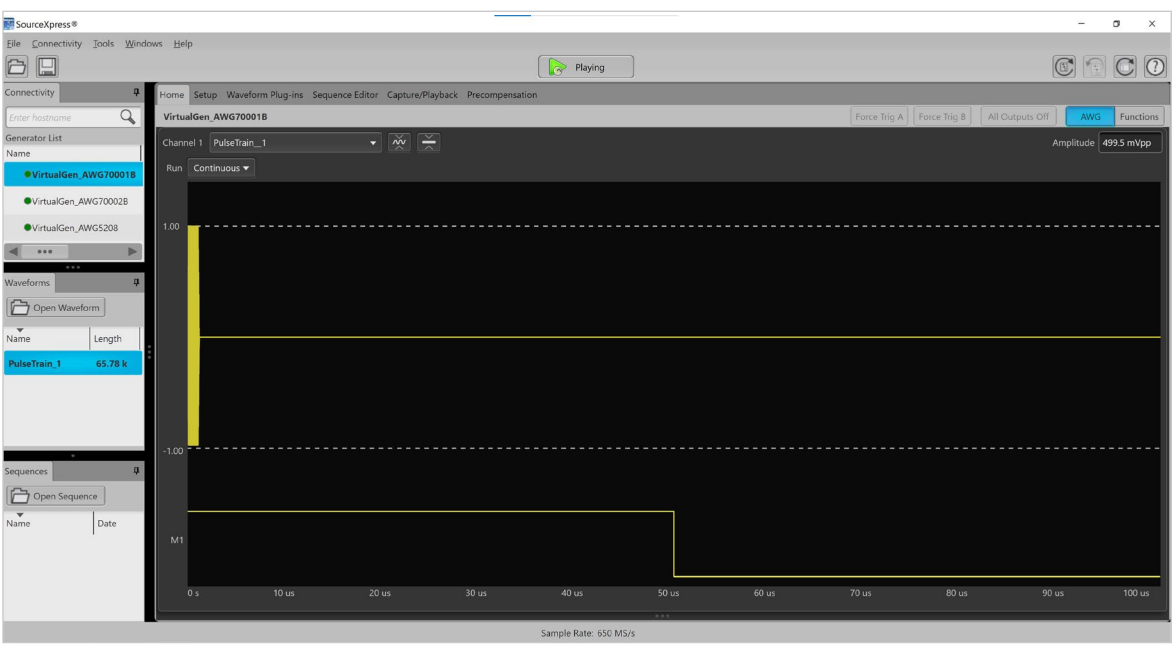

Figure 11: Home display of 1 μs pulse width 100 μs PRI radar signal.

the Play button only has an effect on the AWG output if SourceXpress is connected over a LAN to a target AWG or if this was running natively on the AWG itself.

- In Triggered run mode, the instrument will wait until a trigger is received, then generate one instance of the waveform every time it is triggered. The trigger source can be one of two rear panel connectors on the AWG (trigger input A or B) or an internal trigger source with a repetition interval of 1 µs to 10 seconds. In Triggered run mode the original PRI inherent in the waveform length is ignored, and the actual PRI will be established by the external or internal trigger rate. This is useful, since you can use a short waveform only containing the pulse with a short PRI interval in the Radar Plug-in, then use the internal trigger feature (or an externally supplied trigger signal) to change the generated PRI quickly without recompiling the waveform.
- In Triggered Continuous run mode, the instrument will wait until a trigger is received, then play the waveform as in Continuous mode with the PRI set by the length of the waveform.
- The AWG instruments have two physical buttons on the front panel which can be used to generate trigger A or trigger B signals even if no connection is made to the rear panel trigger inputs. This allows you to generate one waveform instance each time the appropriate front panel Force Trigger A or B button is pressed in Triggered mode or if the sequencer uses trigger events.
- When using the optional waveform sequencer, the Run control shown in Figure 11 is not used and a sequencer table will be shown in the Home screen so long as the sequencer is being used to generate a signal.

You can right-click the Waveforms list or Sequences list to perform actions on these lists, such as removing a particular file or removing all files. Since waveform files can be very long and you can include any number of them in the waveform list, the actual waveforms in the list are stored in Windows virtual memory, which resides on the disk drive. When you assign a waveform to a physical AWG output channel and click the Run button at the top (or load a sequence), the waveforms are copied from Windows virtual memory into the AWG physical memory.

Examples

Now that the basics of hardware and software have been covered, we can review three different examples of generating radar signals using the AWG70000B and SourceXpress.

EXAMPLE 1: INTRODUCTION TO THE RADAR PLUG-IN

Figure 12 shows the power vs time envelope of the RF, IF, or IQ pulse. You can control details of the pulse envelope, including shape (such as rectangular, trapezoidal, and raised cosine), pulse width, risetime, falltime, PRI/PRF (Pulse Repetition Interval or Pulse Repetition Frequency), droop, overshoot, ripple percentage, and ripple frequency.

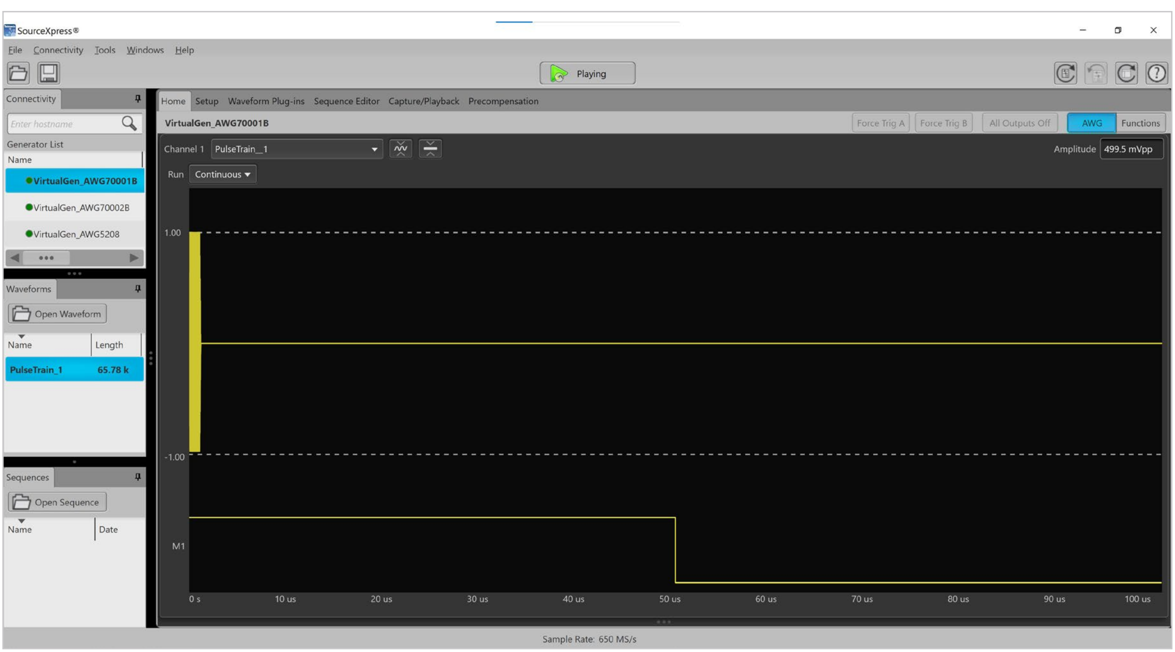

Figure 12: Radar Plug-in Pulse Envelope tab view.

To use the Radar plug-in, select the Waveform Plug-ins tab in the top menu and then choose RF>radar using the Plug-in: selector.

In the upper right corner of the Radar plug-in you will see a button to reset the plug-in to default conditions, and Help on the Radar Plug-in.

Beneath the **Plug-in**: selector you will see a **Signal Format** control.

- In **RF/IF mode** the Radar plug-in will compile a single real value RF or IF frequency waveform, like what is shown in **Figure 11**. Such signals can be generated by a single channel on any Tektronix AWG70000 or AWG5200 series instrument.
- In **IQ mode** the Radar Plug-in will compile a complex baseband IQ signal. These signals require two channels of a single AWG such as the AWG70002B or any AWG5200 series instrument. If you need to create a low IQ signal at an IF frequency (not strictly baseband), use the **Baseband Offset** control while in IQ mode. In the Home screen, you can open the IQ waveform so the I and Q components are visible, then either use **right-click>Assign to**… or dragging the waveform component to assign it to an AWG channel.

The **Pulse Train List** shows the names of the waveforms which will be created when the **Compile** button near the top center is clicked. You can right-click a pulse train entry to rename it, which will change the name of the new waveform created when you compile. You can right-click inside the Pulse Train List area to add a new pulse train waveform or to import a pulse train definition from a CSV file. If you click a particular entry in the Pulse Train List to select it, you will be able to change the settings for that specific pulse train. A Pulse Train consists of one or more Pulse Groups from the table at the right.

To the right of the Pulse Train List is a table showing the **Pulse Groups** which will be generated to create the chosen Pulse Train. The many editing features shown at the bottom portion of the screen refer to the pulse group index which is currently selected (highlighted in blue boxes). Use right-click to add, insert, copy, paste, or remove pulse trains. By default, the pulse groups are sequentially generated in the order shown in the table, starting at Index 1. But if you select multiple pulse groups (by holding the shift key which clicking several items) and right-click, you can use the **Combine Pulse Group** selection to overlap those pulse groups, so they are generated simultaneously. For example, you could use the Modulation and Offsets tabs with different pulse groups to create a Combined Pulse Group which causes multiple radar pulses at different frequencies with different modulations to be simultaneously generated with overlapping start times.

In addition to the **Pulse Envelope** tab features which affect the selected Pulse Group, you will see tabs allowing you to change the modulation, offsets (amplitude, frequency and/or phase), staggering the PRI, adding pulse impairments such as jitter, adding IQ impairments, simulating multipath, adding interference (bandwidth limited noise), frequency hopping among multiple pulses (which requires the Repeat count in the Pulse Group table to be set to greater than 1), and simulating antenna scans. All the entries in these tabs affect the Pulse Group which is highlighted at the top middle of the screen.

Here is a suggested order of the steps required to set up a complex radar signal:

1. Choose a waveform name in the Pulse Train List and select it (making it blue).
2. Select a Pulse Group in the pulse group table, causing it to have a blue outline.
3. In that index (row in the table), set the Repeat count, Start Time, and PRI. The Start Time of a Pulse Group is dead time inserted only before the first pulse in the waveform as shown in Figure 13. You can also change the PRI or PRF using the Pulse Envelope tab settings at the bottom.
4. Set any additional **Pulse Envelope** settings as needed. The Trapezoidal and Raised Cosine pulse shapes produce pulsed RF signals with user-controlled rise and fall times similar to an actual bandwidth limited radar system. You can view the shape of the pulse envelope at the right. The full wave rectified RF sinewave waveform peaks will follow the pulse envelope shown.
5. Move across the tabs from left to right, setting the Modulation, Offsets, Staggered PRI, and other pulse settings as needed. All the settings in the tabs at the bottom only affect a particular **Pulse Group** index which is part of the selected waveform from the **Pulse Train List**. Select a different Pulse Group to change its detailed settings, then if needed select a different Pulse Train List waveform name to change its Pulse Group details.

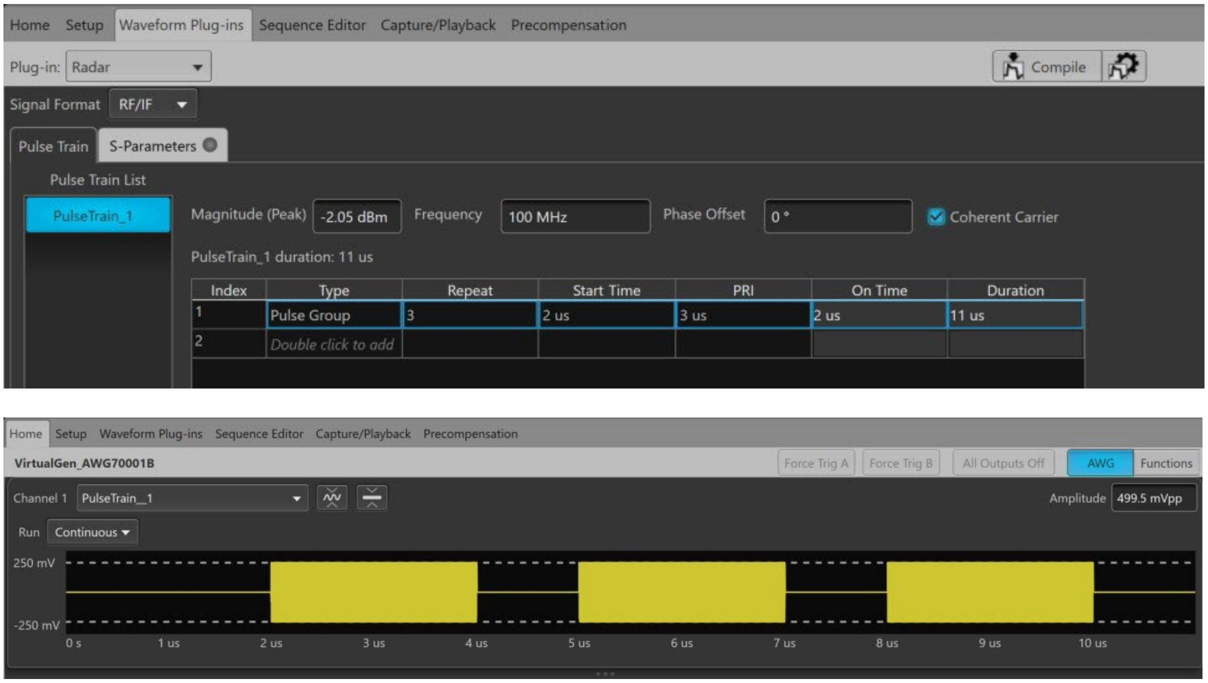

Figure 13: Pulse Group with 2 μs start time inserted before 2 μs wide pulse with 3 μs PRI and a repeat count of three.

6. Be sure that the parameters above the **Pulse Group** table are correct. These are global settings which affect all pulse trains in the pulse train list. For **RF/IF** Signal Format, **Magnitude** is the peak output power (defaulting to the maximum -2.05 dBm), **Frequency** is the center carrier frequency of the radar signal, and **Coherent Carrier** should be selected if you want the carrier phase of each repeated pulse group to be coherent from one iteration of the pulse group to the next. For **IQ** Signal Format, **Amplitude** is the peak output voltage (defaulting to the maximum of 500 mVpp) and **Baseband Offset** defaults to 0 Hz but can be set to an offset IF frequency. The **Phase Offset** setting rotates the relative phase of the compiled pulse train, which for example can allow signals simulating a phased array radar to be separately compiled with different phase offset settings.

7. If a particular Pulse Group needs to have a different amplitude, frequency, or phase than the global pulse train settings just described, select (click) the Index of a particular Pulse Group and at the bottom select the Offsets tab and change the amplitude, frequency, and/or phase offset as required. Just as with the other tabs, the Offsets tab only affects the particular Pulse Group from a Pulse Train selected at the moment.

8. After all these details are completed, click the **Compile settings** gear icon adjacent to the **Compile** button near the top center of the screen to open the Compile Settings window. In Compile Settings you will find a few more items which effect the waveforms and sequences produced by a compilation. The **Correction Files** area is for use of the Pre-compensation plug-in. If you want to create a flat single file without use of the hardware sequencer, be sure to not check "Create each Pulse Train as sequence". To instantly view your results in the Home tab and the AWG output, select "Compile and assign to channel" and "Play after assign. If you will be combining waveforms in any way, you will probably want to set a manual sampling rate so that all waveforms are compiled at that same rate. In general, the sampling rate should be at least 2.5 X the RF frequency, so you should set the sampling rate to at least 25 GS/s to generate a 10 GHz radar signal. In most cases the radar waveform fidelity will be best and spurious signals the lowest if the sampling rate is set to the maximum allowed by the hardware, but you can lower the sampling rate for lower frequency radar signal generation to reduce the waveform length, waveform loading time, and in some cases move aliases and other spurs away from critical frequencies for the DUT.

9. When you click **Compile** and if you are ***not creating a sequence***, each of the names listed in the **PulseTrain List** will be separately compiled into similarly named waveforms. This will create one or more new or overwritten waveforms in the waveform list. Depending on your compile settings, one of the waveforms may be displayed on the **Home** tab.

10. When you click **Compile** and have chosen to ***create a sequence***, each of the names listed in the **Pulse Train List** will be separately compiled into similarly named sequences and waveforms. This will create one or more new or overwritten sequences and waveforms in the waveform list. Depending on your compile settings, one of the sequences may be displayed on the **Home** tab.

11. To display a different waveform or sequence in the Home tab, right-click the waveform or sequence in the Waveforms or **Sequences** lists and choose **Assign to Channel** or use the selector control adjacent to the channel number in the upper left portion of the viewing area for the desired channel. You can also drag a waveform (from the **Waveforms** list) or sequence (from the **Sequences** list) into the desired channel viewing area on the **Home** tab.

12. When compiling in sequence mode, a main sequence (such as "PulseTrain_1") will be created which will contain a subsequence for each pulse group. Each pulse group will cause another sequence to be created (such as "PulseTrain_1-PulseGroup1") which contains just the subsequence required to generate that one pulse group. So in general you want to use the main PulseTrain sequences (which do not contain "PulseGroup" in their name) to create

13. The main PulseTrain sequence by default contains no wait for trigger and a Go to First at the end which causes the sequence to repeat indefinitely with no breaks. To change this behavior, right-click the sequence and choose "Modify Sequence". The Sequence Editor will open with that sequence loaded. If you want to generate that pulse train with a 10 ms repetition interval, double-click the step #1 Wait entry and change it to "Internal". Then go to **Setup>Trigger** and change the Internal Trigger Interval to 10 ms. Now when the Playing button is active at the top, the pulse train sequence will be triggered by the internal trigger generator and after the sequence has completed the sequencer will jump back to the first step and wait for the next internal trigger. If you change the Wait source to "TrigA" you will get a pulse train output every time you press the front panel **Force Trigger A** button or a trigger edge is recognized which is applied at the rear panel Trigger A input.

14. To save the current setup, select the disk icon in the upper left or use **File>Save Setup**… to save the complete setup in the .awgx format which contains the SourceXpress base software settings, all waveforms in the Waveforms list, and all sequences in the Sequences list.

15. To recall a previously saved setup, select the folder icon in the upper left (below File) or use **File>Open Setup**… to recall a previously saved .awgx file to load the SourceXpress base settings, load saved waveforms into the Waveforms list, and load saved sequences into the Sequences list.

16. To clear all files from the Waveforms or Sequences windows, right-click the appropriate file display area and select **Remove All**. You will be given the choice to save the waveforms or sequences to a setup file on the PC before they are removed from the list.

17. To reset the Radar plug-in to default conditions, use the "Reset Plug-in" button in the upper right of the plug-in.

18. To reset SourceXpress (which resets all settings except those in the plug-in), use the "Reset to Default Setup" button, which is the leftmost of the four icons in the upper right corner of the application.

EXAMPLE 2: STAGGERED PRI WITH LFM MODULATION

An example will now be shown of generating a 1 GHz radar signal with staggered PRI and LFM (linear FM ramp) modulation. The Pulse Repetition Interval of radar systems is often staggered (changed in a predictable fashion) to remove range ambiguity and accidental or purposeful jamming. Modulating the frequency of the radar signal allows long pulses to be used to limit the peak power of the transmitter to reasonable levels while spreading the pulse energy over time and frequency. The radar receiver uses knowledge of the PRI stagger and modulation to reduce uncertainty in the range to the target.

1. Choose the **AWG70001B virtual generator**. Right-click it and use **Set to Active** if it is not already active. If an AWG70001B is connected to SourceXpress, you could use it rather than the virtual generator.
2. Click the **Reset to Default Setup** icon (left-most of the four icons in the upper right of the screen).
3. In the **Setup>General** tab, you may want to select "Enable all channels on play" if you are using a live physical generator. This setting will automatically enable all channels containing appropriate waveforms to be activated when the Play button is selected. If this setting is not made, you must manually enable each channel which is to be used.
4. In the **Setup>General** tab, select "Apply recommended settings on assignment". This setting will apply the hardware settings embedded within a waveform when that waveform is assigned to a channel. You can see these recommended settings by right-clicking a waveform in the waveform list and viewing the properties. Recommended values for the sample rate, amplitude, and DC offset are inserted into the waveform properties by a plug-in when compiling a waveform. If you do not use the recommended settings automatically, you will need to manually change these three parameters when playing a waveform.
5. In the **Setup>Channel** tab, set the **Resolution (bits)** to "9+1 Mkr". This "steals" the least significant bit from the data driving the DAC and sends that bit to Marker 1. If the resolution is set to 10 bits you will not be able to use any markers.
6. In the Waveform Plug-ins tab, select the "RF>radar" plug-in.
7. Reset the Radar Plug-in using the button in the upper right of the plug-in.
8. In the Pulse Train List, right-click the default "PulseTrain_1" and rename it to "Staggered_LFM". Set the Frequency to "1 GHz".
9. Select Pulse Group Index 1 and set the Repeat count to "10".
10. In the **Pulse Envelope** tab, set the Pulse Shape to "Raised Cosine", the Pulse Width to "10 μs", the Rise Time to "500 ns", the Fall Time to "200 ns", and the PRF to "1 kHz". Note that the PRI changes to "1 ms" in both the Pulse Envelope tab at the bottom and the Pulse Group row at the top. The pulse envelope waveform shows the raise cosine slow rise and faster fall pulse power profile.
11. In the **Modulation** tab, set the modulation type to Frequency>LFM. Set the Sweep Range to "50 MHz" and the Frequency Sweep to "High to Low".
12. In the **Staggered PRI** tab, check the "Turn On" box. Set the Deviation Type to "Ramp", the Slope Type to "Up", and the slope to "2" Degrees. Note that the Min Deviation is calculated to be about 34.9 μs. The Staggered PRI tab will now show a blue indicator showing that this feature is active.
13. Click the **Compile Settings** gear icon. Disable "Create each Pulse Train as sequence". Enable "Overwrite existing waveform(s)/sequence(s)", "Compile and assign to channel", "Play after assign", and "Auto calculate". Click **Compile** at the bottom of the window. The "Staggered_LFM" waveform should appear in the Waveforms list.
14. Click the **Home** tab. You should see a display similar to what is shown in Figure 14.
15. Right-click the **Staggered_LFM** waveform in the list and choose **Properties**. The waveform length is about 75.24 M points. The recommended sample rate (set by the Radar Plug-in) is 6.5 GS/s. Click OK.
16. Go to the **Setup>Clock** tab. You can see that indeed the AWG clock sample rate is set to 6.5 GS/s due to our earlier choice at Setup>General "Apply recommended settings on assignment". Unless you have changed it, the clock should be set to Internal.
17. Go back to the **Home** tab. You can see that we do have the 10 pulses we specified in the radar Plugin Pulse Group #1 **Repeat** count. The initial PRI visually appears to be 1 ms, but you can see that by the end of the 10th PRI interval the waveform length is much longer than (1 ms) * (10) = 10 ms. Let's verify the staggers on this screen.
18. Right-click in the middle of the waveform display area and choose "Show cursors". You will see two cursors at the left edge which are labelled 1 and 2 at the bottom. Click

the mouse on the cursor 1 or 2 handle at the bottom (the diamond box) or anywhere along a vertical cursor dotted line and you will see that the mouse cursor changes to a <-> shape. Click the cursor and drag it to the right near the center of the screen. Now you can see the two cursors and can drag each of them independently. The two cursors are shown at the top as C1 and C2, and their times from the start of the waveform and the delta time between them are also shown. You can drag the two cursors to measure the delta between any two radar pulses and see that the PRI is increasing across the screen.

19. It's easy to zoom in and view an individual pulse. In an area not close to a cursor, click and drag to the right, which will zoom in to that area. You can do this repeatedly to view one shaped pulse, the rising or falling edge of a pulse, or the actual RF voltage waveform. Click and drag to the left to unzoom. If you click and drag a small distance to the left you will unzoom back to the full waveform display. If you click and drag a larger distance (such as half a screen) you will unzoom by a smaller factor.

20. This waveform is centered at 1 GHz with a 50 MHz high to low linear FM chirp. You can't visually see this chirp because the sweep range is only 5% of the center frequency.

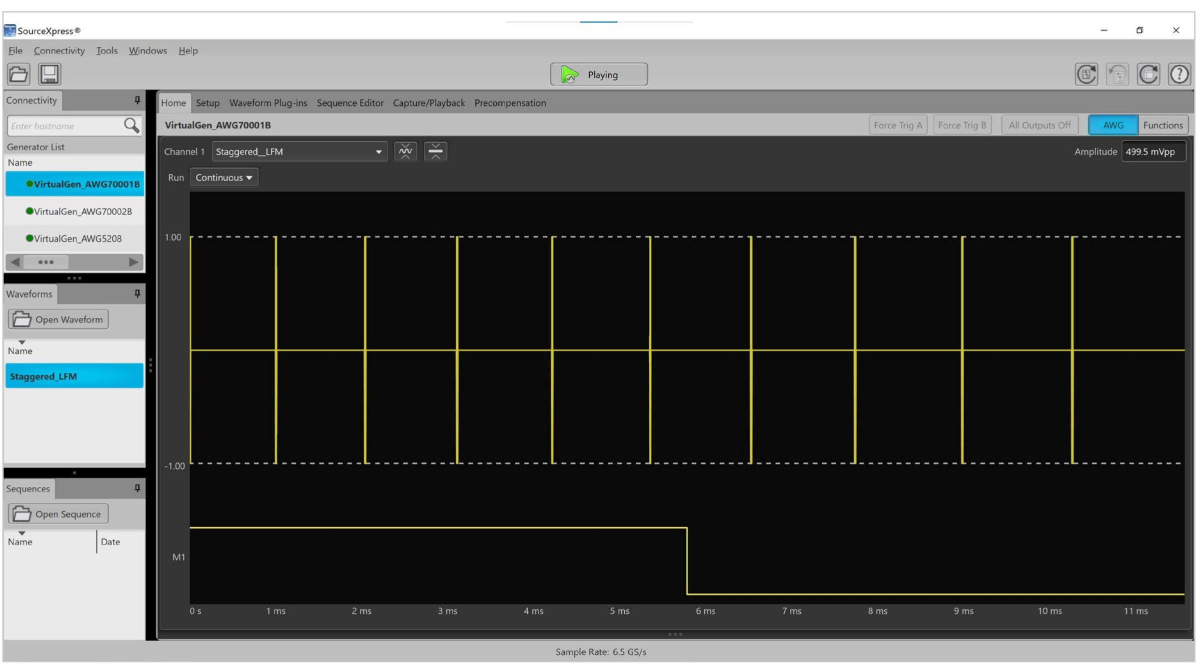

Figure 14: Staggered PRI full waveform view.

The marker is enabled because we changed the **Setup>Channel>Resolution** to “9+1 Mkr”, and by default the Radar Plug-in sets it to a 50% duty cycle. We can move it to coincide with the “on” time of the third pulse as follows:

21. Right-click the Staggered_LFM waveform name in the waveform list and select **Modify Markers**. You should now be in the Modify Waveform pop-up window Pattern tab.

22. Set the **Pattern Type** to “Low”. In the **Apply Modifications To** area select only “Marker 1” and deselect other choices. Set the Range to **All Samples**. At the bottom, select **Create New Waveform** then click **Compile**. You should see a new “Staggered_LFM_1” waveform in the waveform list and the Modify Waveform pop-up with M1 set to all zeros.

23. Set the Pattern Type to “High”. And the **Range** to “Between Cursors”. As described earlier, zoom in to the third pulse by dragging the mouse (with the left button held down) to the right across the third pulse so that it’s zoomed out to at least half of the display width. You can click and drag to the left to unzoom. This might require several zoom/unzoom steps. Then move cursor 1 to the left rising edge of the pulse and cursor 2 to the falling edge. You can change the horizontal scale of these displays to time or sample points by right-clicking the display black background and choosing **X Axis > Seconds or Samples**. On my display my choice results in a delta C between the cursors of about 10.4 μs or 67.6 k samples.

24. At the bottom, select **Overwrite Waveform** then click **Compile**. The “Staggered_LFM_1” waveform should be overwritten with marker M1 set high only around the third pulse. Click **Close**.

25. Drag the new “Staggered_LFM_1” waveform from the waveform list to the Home screen waveform area. You should see a single M1 marker pulse at the third pulse on time. If you zoom into that third pulse, you should see something similar to Figure 15. Note that since we set the Raised Cosine pulse shape with a 500 ns rise and 200 ns fall, the rising and falling edges are not symmetrical. You could use the Marker 1 pulse to trigger an oscilloscope only on that third pulse, to apply a gating pulse to circuitry in your radar transmitter or receiver.

26. If you save the setup as “Example 2.awgx”, you can recall both the original and modified marker waveforms, Radar Plug-in settings we made, and the SourceXpress miscellaneous changes we made at a later time.

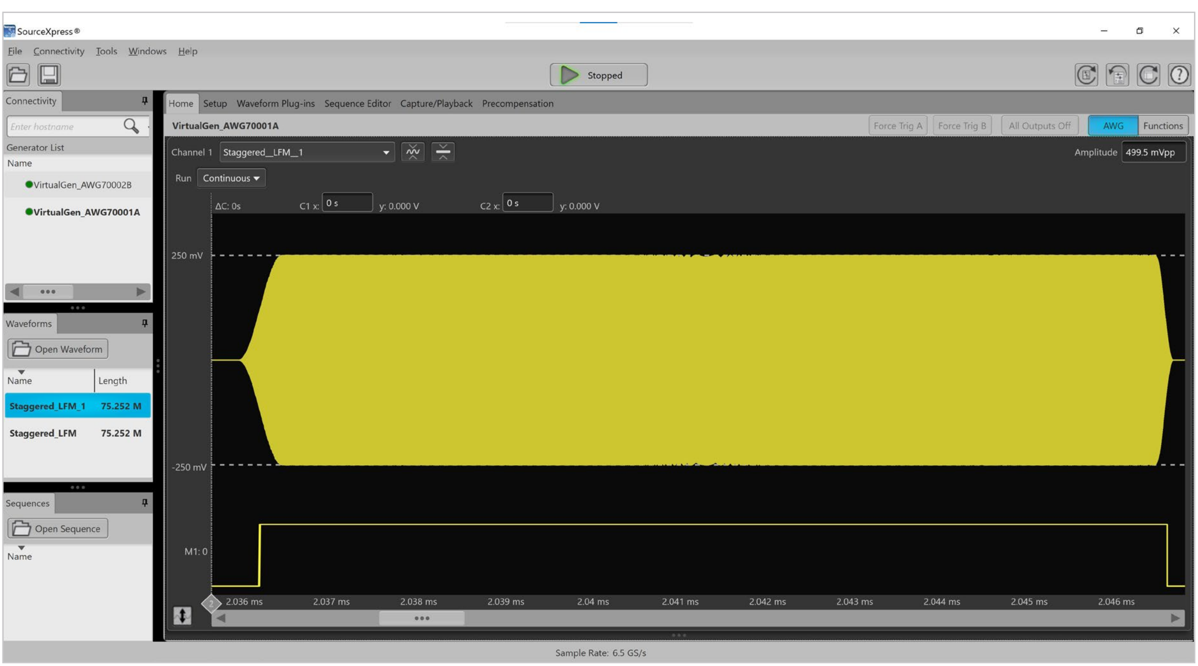

Figure 15: Third staggered PRI pulse RF voltage waveform and modified Marker 1 zoom view. Note that the marker has been moved in time to coincide with the third RF pulse.

EXAMPLE 3: BASEBAND IQ GENERATION WITH AND WITHOUT SEQUENCING

This example will show how to generate an IQ baseband radar signal with stepped frequency modulation and various impairment for testing a receiver.

1. Choose the **AWG70002B virtual generator.** Right-click it and use **Set to Active** if it is not already active.
2. Click the **Reset to Default Setup** icon (left-most of the four icons in the upper right of the screen).
3. In the **Setup>General** tab, select both “Enable all channels on play” and “Apply recommended settings on assignment”.
4. In the **Setup>Channel** tab, select Channel 1 and set the **Resolution (bits)** to “9+1 Mkr”. Then select Channel 2 and set the Resolution (bits) to “10+0 Mkr”.
5. In the Waveform Plug-ins tab, select the “RF>Radar” plug-in.
6. Reset the Radar Plug-in using the button in the upper right of the plug-in.
7. Set the **Signal Format** to “IQ” in the upper left corner of the plug-in.
8. In the Pulse Train List, right-click the default “PulseTrain_1” and rename it to “IQ_step_FM”. Note that you could set a Baseband Offset if you needed to generate an IQ signal with two channels at an IF frequency.
9. Select Pulse Group Index #1 and set the Repeat count to “1”. In the **Pulse Envelope** tab, set the Pulse Shape to “Raised Cosine”, the Pulse Width to “50 μs”, the Rise Time to “1 μs”, the Fall Time to “1 μs”, and the PRF to “1 kHz”. Note that the PRI changes to “1 ms” in both the Pulse Envelope tab at the bottom and the Pulse Group row at the top. In the Modulation tab, set the Modulation type to “Frequency>Step Frequency”. Set the Step Count to “4”, the Initial Offset to “10 MHz”, the Frequency Offset to “10 MHz”, the Ramp Function to “Cosine”, and the Ramp Duration to “10%”.
10. Now double click the Pulse Group index #2 Type field and choose “Pulse Group” in the pop-up. Leave the Repeat count set to “1”. While that second pulse group is highlighted, in the **Pulse Envelope** tab at the bottom set the Pulse Shape to “Trapezoidal”, the Rise Time and Fall Time to “10 μs”, the Pulse Width to “100 μs”, and the PRF to “2 kHz”. In the **Modulation** tab, set the Modulation to “Frequency>Up-Down Chirp”. Set the Sweep Range to “10 MHz” and the Up-Down Count to “1”.
11. Click the **Compile Settings** gear icon. Disable “Create each Pulse Train as sequence”. Enable “Overwrite existing waveform(s)/sequence(s)”, “Compile and assign to channel”, “Play after assign”, and “Auto calculate”. Click **Compile** at the bottom of the window. You should see one new waveform named “IQ_step_FM”.
12. In the Home tab, you should see the I component in the Channel 1 window and the Q component in the Channel 1 window. Click the up/down icon adjacent to the “IQ_step_FM” waveform in the waveform list to view the I and Q component labels. You can right-click I or Q and then save that signal component waveform or assign it to an AWG channel. Due to **Signal Format** being set to “IQ” in the Radar plug-in, the I and Q waveforms were automatically assigned to the two channels after compilation. If you zoom into the first pulse group and then the second pulse group you can see the step FM and linear up/down chirp FM modulation.
13. Marker 1 on Channel 1 is by default active in the first 50% of the first pulse group only. In the Channel 1 waveform selector at the top of the waveform display window, select Modify Markers. Choose to Apply Modification to “Marker 1 only”, set the Range to “All Samples”, set the Pattern Type to “Pulse”, set the Start Level to “Low”, set High Steps to “20 Samples”, set Low Steps to “20 samples”, set “Create New Waveform”, and click Compile. Then click Close.
14. Open the IQ selector on the “IQ_step_FM_1” new waveform in the waveform list. Right-click I and assign it to Channel 1, and in a similar fashion assign Q to Channel 2. Right-click the black waveform background and Show Cursors, then set the X axis to Seconds. Zoom in so you can see the Channel 1 Marker 1 spread out and use the cursors to measure the period. It should be 100 ns, since we set the marker waveform to 20 samples high and 20 samples low, and in the Setup>Clock menu you can see that the Sample Rate was automatically set to 400 MHz. So the Marker 1 frequency is 400 MHz / 40 samples = 10 MHz, a 100 ns period. This clock signal provided by Marker 1 is phase synchronized to the signal RF waveform and modulation, and could be used to provide a clock input for a receiver DUT.
15. See the result in Figure 16. Save this example as “Example 3 flat.awgx”, since it is a “flat” single non-sequenced waveform file.

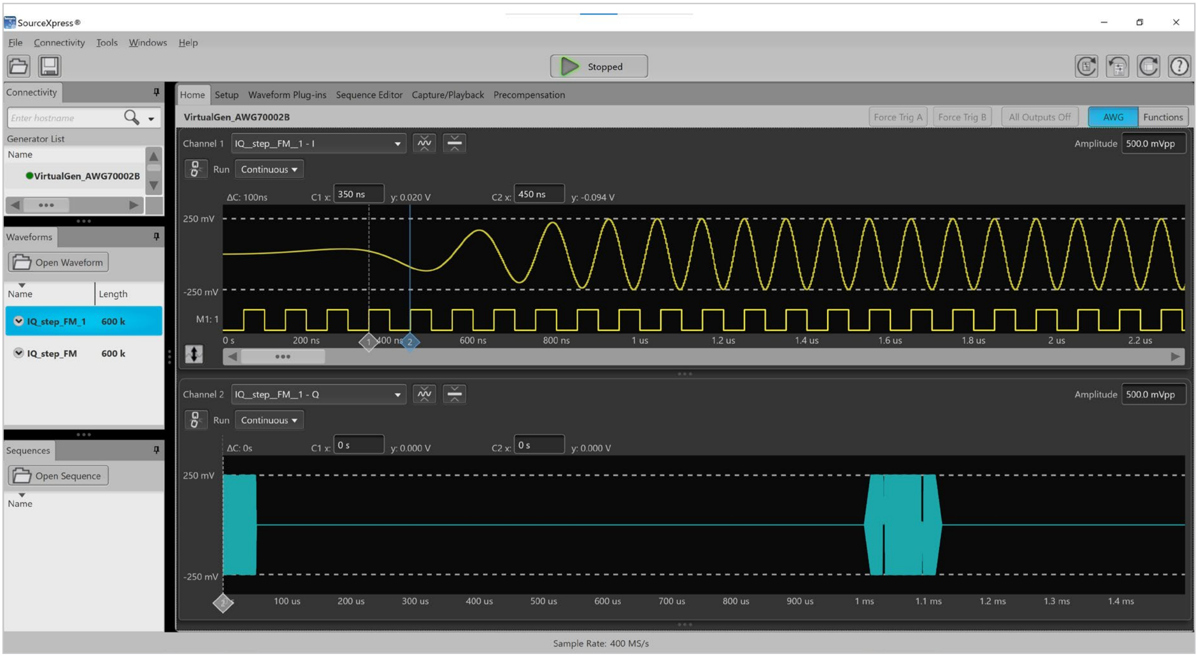

Figure 16: Baseband IQ example flat single waveform with zoom showing Marker 1 (10 MHz clock output).

16. Now let's see what happens if we compile the same signal as a sequence. To compile a signal which makes use of the sequencer, either an AWG with the sequencer option installed must be connected or a Virtual Generator with **Option 03 – Sequencing** checked must be active.

17. Right-click both the Sequences and Waveforms windows and remove all files. Then select the Waveform Plug-ins tab and enable "Create each Pulse Train as a sequence", then click Compile and Close.

18. Four waveforms should appear in the Waveforms list and three sequences in the Sequences list.

19. The waveforms are:

    a. Pulse Group #1: pulsed step frequency step modulated IQ baseband waveform

    b. Pulse Group #1: zero volt short waveform which is repeated to generate the off time

    c. Pulse Group #2: pulsed up-down frequency chirp modulated IQ baseband waveform

    d. Pulse Group #2: zero volt short waveform which is repeated to generate the off time

20. The sequences are:

    a. IQ_step_FM: The main sequence which generates the baseband IQ signals

    b. IQ_step_FM-PulseGroup1: The subsequence required to generate the first pulse group (FM step modulated)

    c. IQ_step_FM-PulseGroup2: The subsequence required to generate the second pulse group (up-down frequency chirp modulated)

21. We can look at the main sequence in the Sequence Editor and modify it. Right-click the "IQ_step_FM" sequence and select "Modify Sequence". Then open the Sequencer Editor tab.

22. If you double-click the triangle adjacent to the step 1 and step 2 index, you can see the subsequences, which consist of the IQ modulated waveform followed by a repeated short off zero volt waveform. Click the large X at the right to close the subsequence display.

23. The automatically generated sequence will immediately start when you enable Play and will then play one instance of pulse group #1, followed by one instance of pulse group #2. This could be changed in the pulse group definition, but we can also make changes quickly in the Sequence Editor and add some triggering and flag output features.

24. In sequence step #1, change Wait to "Internal". Change the Repeat Count to "8". Then double-click the icon to open the subsequence, and change Flag A to "Toggle" (which

displays as “T”). Then click X to close the subsequence display.

25. Then select **Sequence Settings** and enable “Flag Repeat”. This will cause the flag A toggling to occur every time that sequence step #1 is repeated. Since the repeat count is 8, this should cause the flag A output to produce 4 output pulses during the repeating pulse group #1 time.

26. Go to the Setup>Trigger tab and change the Internal Trigger Interval to “100 ms”. Now the following will happen 10 times per second:

    a. The pulse group 1 IQ baseband waveform will be output, lasting 8 ms per iteration. It will be repeated 8 times. The Flag A output will be set high on iterations 1, 3, 5, and 7, and will be set low for iterations 2, 4, 6, and 8.

    b. The pulse group 2 IQ baseband waveform will be output 1 time, lasting 500 µs.

    c. The sequencer then jumps to the first step and waits for the next trigger.

27. The resulting sequence and subsequence should look like:

    a. Figure 17 - Baseband IQ example main sequence

    b. Figure 18 - Baseband IQ example subsequence showing flags

    c. Save this example as “Example 3 seq.awgx”, since it uses the sequencer.

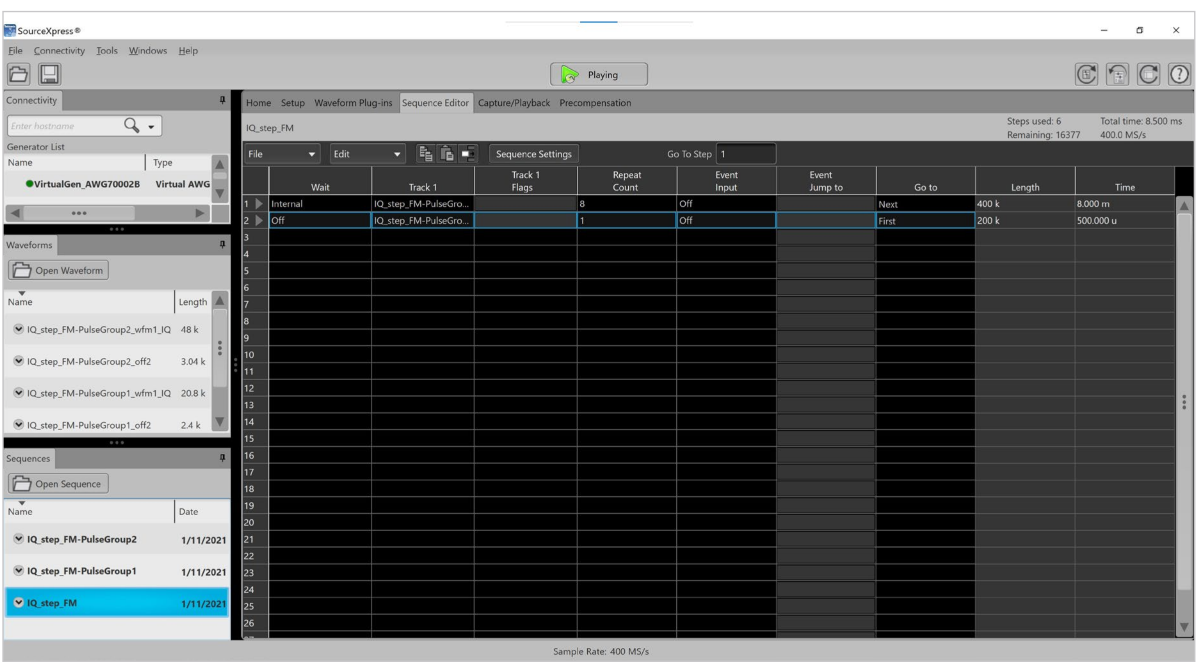

Figure 17: Baseband IQ example main sequence.

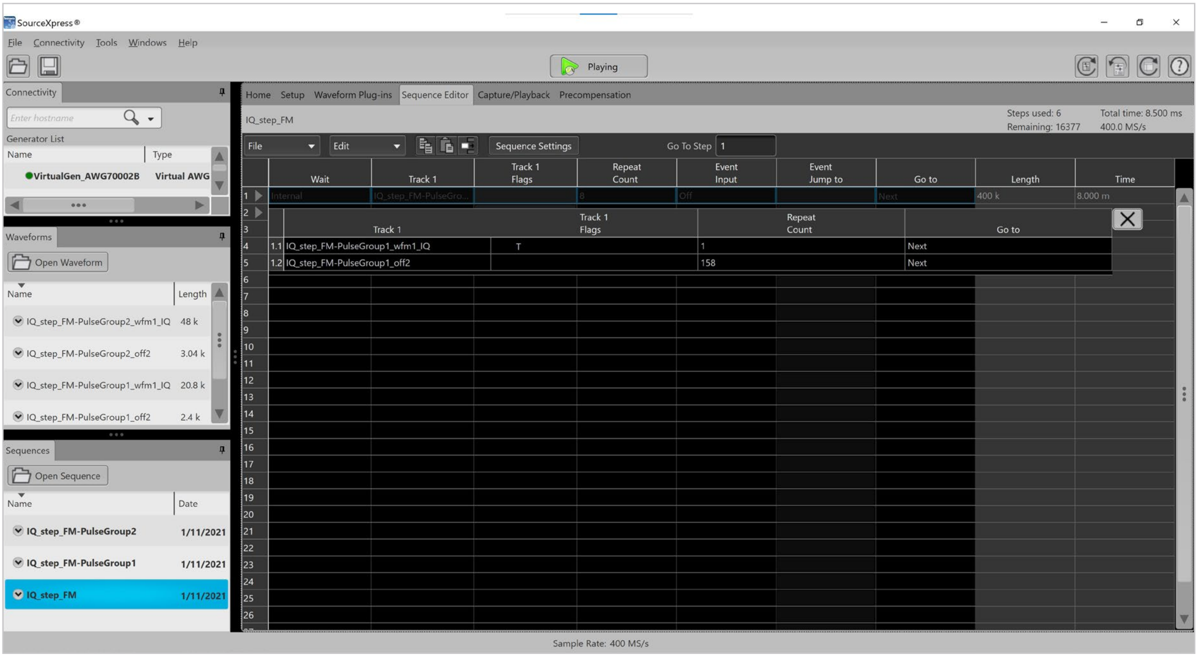

Figure 18: Baseband IQ example subsequence showing flags.

Conclusion

The Tektronix AWG70000B instrument can generate high-quality radar signals thanks to its advanced 10-bit SiGe DAC with low spurious output, a low phase noise architecture allowing use with golden external microwave clocks, and a high-performance real-time hardware waveform sequencer. Options offer a wide range of output power and tightly synchronized multi-channel operation for a wide range of scenarios. SourceXpress software provides control of the instrument and local or offline generation of advanced radar test signals with the ability to correct for signal flatness due to test cable and other causes. These features together provide a robust platform for simple definition and generation of not only complex radar signals, but any RF or time domain waveform.

Further Reading

Radar Signal Generation with a High-Performance AWG provides background information on radar signal modulation and high quality test signal generation using AWG direct synthesis.

Using the Sequencer on Tektronix AWG70000B Series Instruments provides more detailed information on the hardware sequencer option.

Appendix A: Additional Features

ADDITIONAL RADAR PLUG-IN FEATURES

The Radar Plug-in includes a number of other features not addressed in the examples in this document. Here are features which can be chosen for each pulse group independently:

- Modulation types:
  - o CW (Continuous Wave, i.e. unmodulated)
  - o Frequency modulation: Linear FM (LFM), Chirp Sequence, Up-Down Chirp, Piecewise linear LFM, Step frequency, user defined step FM/AM, and non linear FM (Taylor weighted symmetrical, Taylor weighted non-symmetrical, user defined FM polynomial coefficients)
  - o Phase modulation (Barker Code, Frank Code, Polyphase Codes, P1 Polyphase Codes, P2 Polyphase Codes, P3 Polyphase Codes, P4 Polyphase Codes, user defined step PM/AM)
  - o Digital modulation (BPSK, QPSK) on pulse
  - o Custom IQ modulation (import of text or MATLAB generated IQ file)
- Offsets (Amplitude, Frequency, and Phase): Each pulse group can have a different offset. If the pulse group is repeated, either a linearly changing offset per step or a user-defined varying offset per step can be used.
- Staggered PRI (Pulse Repetition Interval): The PRI can be staggered using a deviation list (linear ramp, values from a table, or values from a file).
- Edge and width jitter impairment with a Gaussian or Uniform distribution and user selected deviation
- IQ Impairments: Swap I & Q, add carrier leakage, invert I and/or Q signal, quadrature phase error, IQ amplitude imbalance
- Fixed MultiPath impairment: Up to 10 paths with settable delay, amplitude, and phase
- Additive noise with selectable S/N ratio and bandwidth. This noise can be applied to the whole signal or only to the pulse on time
- Frequency Hopping (Custom, Pseudo Random over a specified range, Pseudo Random over a frequency hop list
- Antenna scan: Either a custom scan using amplitude values from a file, or a simulated circular scan assuming a Gaussian or Sin(x)/x beam profile

S-PARAMETER PLUG-IN SUPPORT

If the S-Parameter license is installed, the Radar Plug-in can use imported Touchstone S-Parameter files to embed or de-embed external networks between the AWG output and the DUT. Either a single (non-cascading) or multiple (up to 6 cascading) S-Parameter files can be used to precompensate generated radar signals. This feature can correct for known cable losses, filters, antenna S-Parameters, and other existing or simulated non-existing hardware.

ENVIRONMENT PLUG-IN SUPPORT

The Environment plug-in gives you an additional screen in SourceXpress which allows multiple RF signals to be simulated and digitally combined into an output waveform which can produce an effect similar to a real-world environment. Emitter types include:

- Analog modulation (AM, FM, PM)
- Bluetooth (LE 1M, LE 2M, LE Coded, BR, EDR)
- CDMA forward and reverse links
- Digital Modulation (many PSK types including QPSK/BPSK/SOQPSK/etc., APSK, QAM, FSK, CPM, ASK, GMSK, OOK)
- DVB-T
- GSM
- LTE
- Noise (while and band limited)
- OFDM
- P25 phase 1 and phase 2
- Basic RF pulses
- Radar features from the Radar Plug-in
- Tones (multiple carriers)
- User imported waveforms
- W-CDMA
- WiFi (802.11a/b/g)
- WiMax

Up to 50 scenarios can be built. Each scenario can contain up to 100 emitters. The frequency and duration of each emitter can be specified.

PRE-COMPENSATION PLUG-IN SUPPORT

The Pre-compensation plug-in allows you to flatten the amplitude and phase response over frequency of the AWG, including a test cable. The measurement plane is the far end of that cable, which is connected to a wideband Tektronix oscilloscope during the test. The Pre-Compensation plug-in automatically generates an RF frequency wideband signal which is measured by the oscilloscope, and a S-parameter correction file is created which can be used to pre-compensate any signal generated by the Radar plug-in. This feature enables wideband radar signals to be generated with flat amplitude and phase response at the end of the test cable.

ADDITIONAL SOURCEXPRESS FEATURES

Besides the Radar plug-in, SourceXpress has many other features that may be useful for engineers working with radar systems.

Base features:

- The Capture/Playback feature allows IQ files to be digitally upconverted to an output frequency. A list of such signals can be provided, and they will be converted and concatenated in time.
- The AWG can be used as a function generator using SourceXpress features.
- Equation Editor: This feature lets you create waveforms from equations and combine waveforms.
- Table editor: Waveforms and markers can be viewed and edited on a point by point basis.
- Batch CSV file import: Allows simple waveforms and sequences to be externally defined.

Optional features:

- RF generic plug-in option: This feature can generate a wide range of digitally modulated signals, including multi-carrier signals.
- OFDM plug-in option: OFDM signal generation, mainly based on 802.11a WiFi and 802.16 WiMax
- Multitone plug-in option: This feature creates a grid of carriers or a frequency chirp.
- Optical plug-in option: This is used to generate waveforms suitable for modulating single or dual polarization optical communication signals.
- High speed serial data signal creation plug-in option: This is used to generate commonly used serial signal formats including NRZ, NRZ-I, and PAM with the ability to add scrambling, controllable risetime and falltime, and duty cycle distortion. Markers can be used to generate clocks or base patterns. Transmitter and channel impairments may be added, and jitter can be included.

ADDITIONAL AWG70000B HARDWARE FEATURES

Pattern jump: This is a parallel 8-bit digital input with strobe signal which forces the sequencer to jump to one of 256 predefined sequence steps.

Skew: The timing skew between the marker outputs and the two analog waveforms on the AWG70002B two-channel model can be adjusted with 1 ps or better resolution.

Marker amplitude: The marker outputs can be set to generate 500 mV to 1400 mV P-P over a range of -1400 mV to +1400 mV.

External sampling clock support: The AWG70000B instruments have a low phase noise internal clock synthesizer. But in some cases even lower phase noise is required. A 6.25 to 12.5 GHz external golden clock can be supplied to a rear panel input on the AWG70000B instruments. This allow state-of-the-art low phase noise to be achieved for generating radar signals. The AWGSYNC01 synchronization hub can distribute this golden low phase noise clock signal among up to 4 AWG70000B instruments for very low phase noise multichannel radar test signal generation.

Signal quality: The AWG70000 single-channel series has been certified to meet SEI (specific emitter identification) test signal requirements in the US, including use of the option AC amplifier/attenuator. (See Figure 19.)

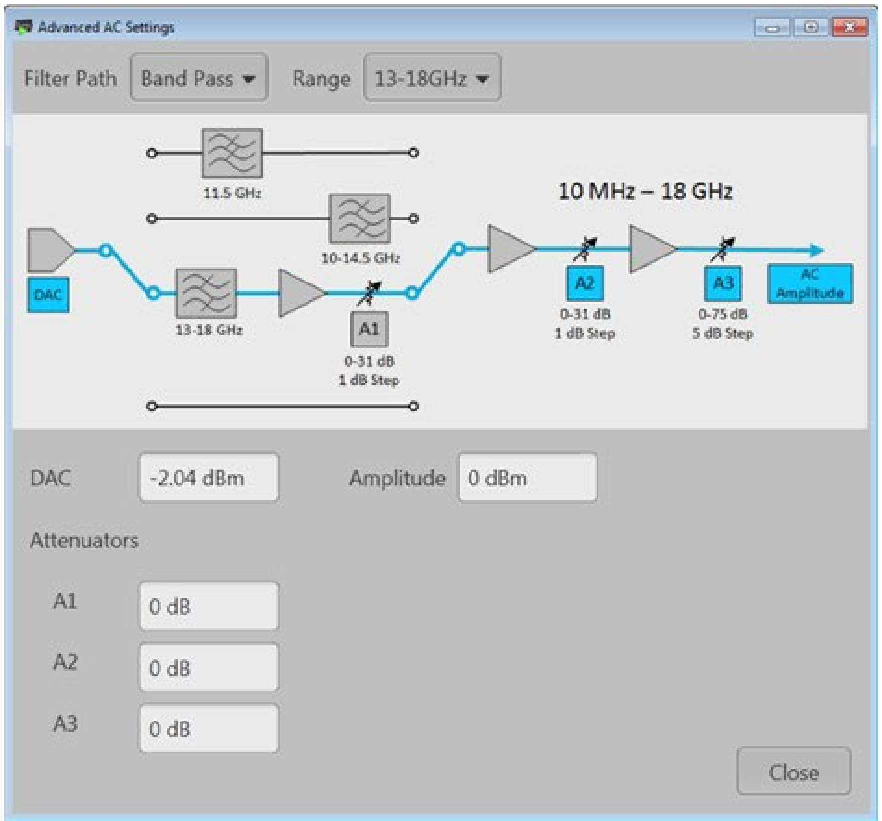

Figure 19: Option AC amplifiers and filters.

Appendix B: AWG70000B Hardware Block Diagram

The AWG70000B Series has an internal Windows® 10 PC for running software without any external equipment. The internal display screen isn't very large due to the small size of the instrument, so it is suggested that an external display be used if creating waveforms or sequences using the standard instrument software as shown in Figure 2. The SourceXpress software features are easier to use for significant projects on a recent Windows 10 PC as shown in the remote use models:

- Figure 3 - Independent PC remote use model
- Figure 4 - Connected remote use model
- Figure 5 - Synchronization hub use model

The AWG70001B and AWG70002B instruments each have two 10-bit 25 GS/s DAC subsystems which convert 10 bits of data from an internal high speed memory word into a differential analog voltage. Zero, one, or two bits of the 10 bit memory word pulled from memory can be sent to the Marker 1 and Marker 2 front panel digital outputs. A high speed clock at half the sample rate is sent to the DAC subsystem, which is clocked on both the rising and falling edges of the external clock. Since the maximum sample rate for each DAC is 25 GS/s, the maximum high speed clock frequency is 12.5 GHz, and it can be supplied by an internal frequency synthesizer or an external 6.25 to 12.5 GHz clock input. A binary divider inside the DAC subsystem generates lower sample rates.

On the AWG70002B two channel 25 GS/s maximum sample rate model, each DAC subsystem differential output is directly connected to the DC coupled front panel output connectors. On the AWG70001B one channel 50 GS/s maximum sample rate model, the two DAC subsystem outputs are summed and sent to the DC coupled single differential output channel, and the clocks to the two DAC subsystems are skewed by 180 degrees (half a clock cycle). The result is an interleaved single output at 50 GS/s maximum sampling rate.

Option AC is only available at purchase of the AWG70001B model. The normal two output connectors are still present for a DC coupled differential output. An internal mechanical microwave relay disconnects these connectors and routes the interleaved DAC outputs through a wideband balun to a series of filters and amplifiers providing around +18 to +25 dBm maximum output power from 10 MHz to 18 GHz through a single AC coupled front panel output. Lower output levels can be set using internal step attenuators as shown in Figure 19.

Waveform data from the high-speed memory is read into the DAC subsystems and the DAC is clocked at the chosen sampling rate. By default, the memory is sequentially read from the first to the last point of the chosen waveform. Depending on the settings and use of the hardware sequencer, at the end of the waveform the instrument can stop, seamlessly loop back to start playing from the starting point of that same waveform, or seamlessly start playing out a different waveform. The hardware waveform sequencer controls how the memory is read out, and it also controls the hardware output flags. Two external trigger inputs and a programmable internal trigger rate generator provide additional control over the hardware sequencer.

A basic block diagram of the AWG70001B with option AC is shown in Figure 20.

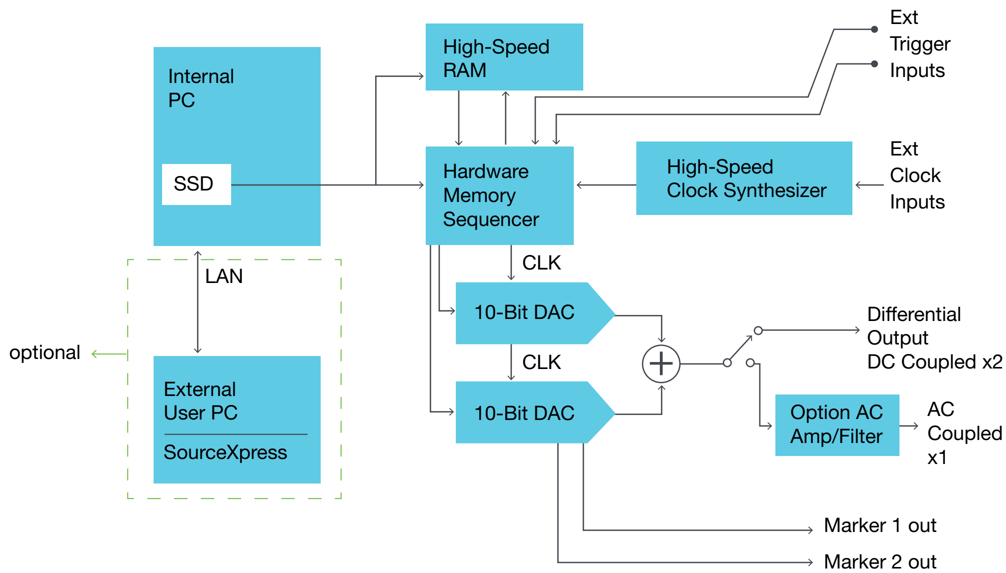

Figure 20: AWG70001B + option AC block diagram.

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