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How to Select an Arbitrary Waveform Generator

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An arbitrary waveform generator (AWG) is a signal source that can generate any type of waveform. A basic AWG can include simple functions such as sine waves, triangular waves and square waves. A more advanced AWG can generate direct-to-RF signals including complex digital modulation schemes such as quadrature amplitude modulation (QAM) and orthogonal frequency modulation (OFDM). Both the basic and the advanced AWGs could create custom waveforms. Custom waveforms could represent simulated signals such as communication protocol signals, quantum physics pulse trains, different noise signals for signaling test, and low and high-frequency tones useful for applications ranging from power line susceptibility tests to RF amplifier intermodulation testing.

Modern AWGs can have a digitizer for real-time closed-loop signal processing applications. With a digitizer, the AWG becomes a software-defined radio for radar and communication system testing.

AWGs are sophisticated instruments and have an extensive set of specifications. This article will provide some clarity on some of the primary specifications and guidance for making decisions based on user requirements. The following paragraphs will start with an introduction to the basic components of an AWG and then discuss important specifications and features.

How An AWG Operates

Figure 1 presents an example block diagram of a basic AWG. The RAM memory is organized to allow the creation of sequences of custom waveforms. Waveform sequences can be generated multiple times. The field programmable gate array (FPGA controls the output and timing of the sequences). The DAC, Balun, Amplifier and Correction Filter converts the digital representation of the signals into an analog output.

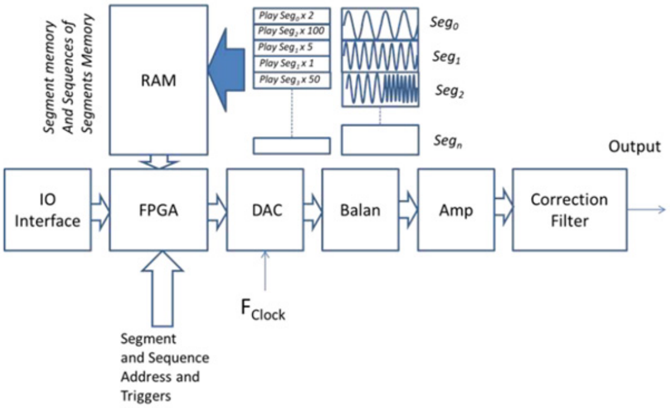

Figure 1. Simplified Block Diagram of a Basic AWG

Bandwidth

Obviously, the desired bandwidth required for an AWG is the first major decision that needs to be made. The application determines whether a baseband signal generator or an RF signal generator will satisfy the needed requirements. Baseband generators can extend into the MHz range and RF generators offer GHz bandwidths.

Signal Fidelity

Determining the maximum bandwidth of a signal is a function of the sampling rate of the AWG and whether the AWG allows output in multiple Nyquist zones. The Nyquist theorem states that a signal can be accurately created if the sampling rate is twice the highest frequency component of the signal. The maximum frequency of the output signal would be a signal with half the sampling rate of the instrument. However, with only two data points in each cycle, the waveform can easily be distorted. Figure 2 shows a plot on the left which is the output of a 1.125 GHz sine wave sampled at 2.25 Gsamples/s which yields two sample points/cycle. The plot on the right displays the same 1.125 GHz signal created with a sample rate of 9 Gsamples/s. The higher sampling rate provides 8 points/cycle which creates a higher quality sine wave.

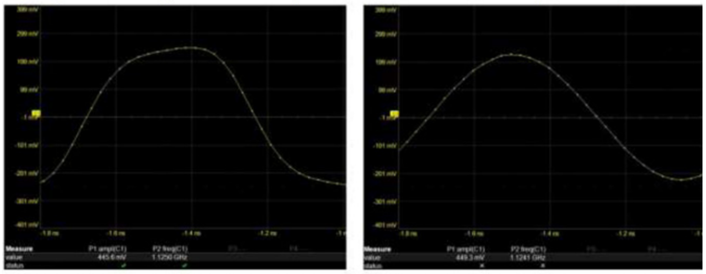

Figure 2. A 1.125 GHz sine wave created with a 2.25 Gsamples/s rate (left plot) and the same sine wave created with a 9 Gsamples/s sample rate (right plot)

A technique to improve signal fidelity with more samples per waveform cycle employs the use of Nyquist zones. Allowing output in the second Nyquist zone yields more samples per signal cycle and allows a higher frequency output. For example, if an AWG has a maximum sampling rate of 9 Gsamples/s, then the Nyquist theorem says that a 4.5 GHz signal can be reproduced. However, the waveform frequency is close to the Nyquist frequency so it will only have two data points per cycle. A better method is to generate a 500 MHz signal with a 5 Gsamples/s clock rate. Then output the signal in the second Nyquist zone which has a frequency of the sample clock minus the frequency of the generated signal or 5 Gsamples/s – 500 MHz = 4.5 GHz. The AWG then outputs a 4.5 GHz signal with 10 samples per cycle compared with 2 samples using the first Nyquist zone of the 9 Gsample/s sampled signal. For optimum signal fidelity, ensure the AWG has a sufficient clock rate to output a signal with at least 8 to 10 data points/cycle and verify the output stage has enough bandwidth to allow output in multiple Nyquist zones. Also, check that the AWG has a range of sampling rates to allow the creation of a wide range of signal frequencies without consuming memory with an excessive number of sample points for lower-frequency signals.

The tradeoff in using multiple Nyquist zones is a loss of amplitude. In some AWGs the coding of the digital waveform data results in a sin(x)/x output across the Nyquist zones. The output is attenuated by the sin(x)/x function. Figure 3 illustrates the frequency domain output of a signal filtered by the sin(x)/x function. When considering an AWG that uses this technique, verify that the magnitude of the output is sufficient for the application.

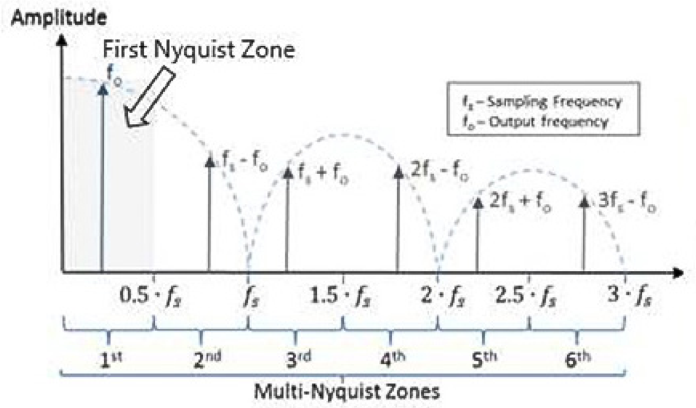

Figure 3. Nyquist Zones Allow a Higher Fidelity Signal at the Expense of the Maximum Amplitude Output

Also, the number of bits the DAC has determines the resolution of waveform steps for an amplitude range. The number of bits, N, allows the DAC to output 2N levels. The greater the number of levels, the more detail the waveform will have. Again, the sampling rate and the number of DAC bits represent a tradeoff. While sampling rates can exceed 10's of Gigahertz, the number of DAC bits can range from 8 bits for high sample rates and 16 bits for lower sampling rates.

Memory Requirements

The amount of memory determines the length of a signal that can be generated. If the sample rate is 1 GS/s and the segment memory is 16GS, then the maximum playout time would be 16 seconds.

Also, the organization of the memory determines how much flexibility an instrument has when playing complicated waveform sequences. AWG memories are often divided into segments as shown in Figure 1. An efficient use of memory would be for example to define a common waveform in a segment and use the instrument's segment sequencer to play repeatedly a single segment. This makes memory management efficient, increasing the overall playout time.

Signal Purity

The quality of the signal determines how much margin the AWG has compared with the device- or system-under-test to properly qualify the device or system. Three specifications define signal purity. The three specifications are harmonic distortion, Spurious-Free Dynamic Range (SFDR), and phase noise.

Harmonic distortion adds harmonics, integral multiples of the signal's fundamental frequency. Harmonics arise from the amplification stage, the power output stage. Efficient operation of the power amplifier borders on contributing detectable harmonics in the output waveform. The addition of harmonics distorts the output waveform. False failures in production testing can occur when some DUTs are sourced with a waveform with a high harmonic content. Look for harmonic distortion of at least -50 dBc at an AWG's highest output frequency.

In addition to harmonics, the magnitude and quantity of spurious components in a generated signal affect the purity of the signal. Spurs result from a wide range of sources including digital transitions from instrument clocks and the DAC, switching power supply transitions and noise, and fan motors. The SFDR defines the magnitude of the signal output that does not have any spurious content. SFDR is related to the signal-to-noise ratio (SNR). An approximation of the SNR in dB is 6.02 x the number of DAC bits +1.76. For a 16-bit DAC, the theoretical SNR equates to 98 dB. Figure 3 illustrates an SFDR of an AWG output that has a 16-bit DAC. SFDR is specified relative to the output signal in dBc. A high-performance AWG will have an SFDR of -70 dBc or better.

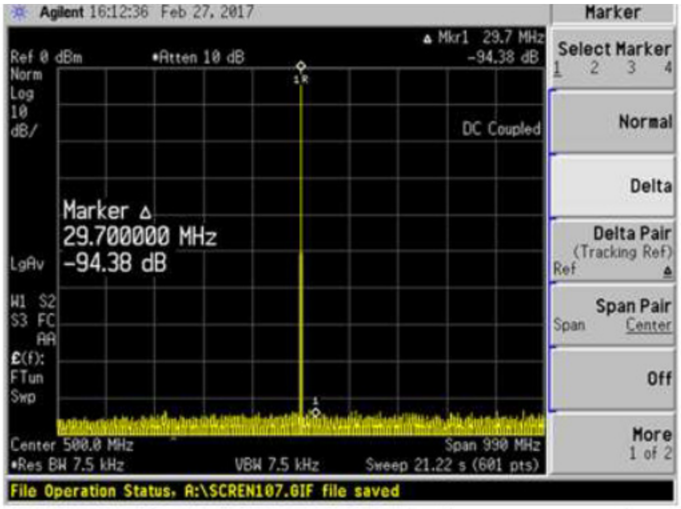

Figure 4. Spectrum Analyzer Plot of a Signal with -94 dB of Spur Free Dynamic Range

The third component of signal purity is phase noise. Phase noise introduces jitter in generated signals. The quality of the components and the synthesis techniques used in the AWG determine its phase noise. Phase noise is defined as an output at an offset from a center frequency and specified in dBc/Hz.

Figure 5 shows an example phase noise output of a 2 GHz signal. For excellent performance, consider selecting an AWG with a phase noise at a 10 kHz offset of lower than -100 dBc/Hz.

Figure 5. Phase Noise Plot of 1 GHz Signal

Multiple Channels

If multiple outputs are needed, select an AWG with at least the number of outputs required for your application. AWGs can have as few as two channels to hundreds of channels. Pay attention to the skew between channels in case channel synchronization is a critical requirement. Determine if an AWG's skew can be manually adjusted if a small phase shift between channels is needed. A quality multiple-channel AWG will have a skew under 20 ps.

Fast Waveform Generation

For applications in which the waveform output is based on a measurement or a series of measurements and a fast response to the data is required, the AWG needs the ability to output different waveforms quickly. Electronic warfare testing and qubit control in quantum computing are two examples where a specific waveform output depends on measured data. The necessary response involves fast loading of waveforms from memory into the signal chain. Another fast response method allows streaming data into the instrument in real-time. Real-time streaming of external data requires a high-speed bus such as PCIe Gen-3. PCIe Gen-3 offers data transfer rates on the order of 7.9 GB/s compared with Gigabit Ethernet and USB 3.0 with transfer rates around a GB/s and 4.8 GB/s respectively. If real-time streaming and making fast waveform changes is an essential requirement, ensure the AWG selected has:

- a high-speed bus, preferably a PCIe Gen-3 bus
- a specified streaming mode
- low latency, under 1 µs, between a control signal and a signal output

Integrated Receiver

Complementing the fast waveform generation capability is a real-time receiver that some AWGs can have. The receiver combines with the signal generation to iterate fast Control-Measure-Adjust operations. One example of the need for a receiver integrated into the AWG is optimizing qubit performance which requires a high-speed control loop.

Upconverter

AWGs can upconvert waveforms to RF frequencies. To generate complex modulation protocols on RF carriers, select an AWG that has an IQ modulator.

Software for Waveform Creation and Editing

Investigate how easily the AWG manufacturer enables the creation and editing of waveforms. Before deciding on a specific AWG, experiment with the manufacturer's software to ensure comfort with the implementation of waveform generation and editing. If the software is difficult to learn quickly and waveform generation is time-consuming, you may want to consider another manufacturer's product.

Connectivity

Make sure that the PC interface you want to use is available on the AWG you select. USB and Ethernet are common PC interfaces on many instruments. If you require real-time streaming, you will want to consider having a PCIe Gen-3 interface.

Verify that the manufacturer offers drivers to control the AWG. The manufacturer should have LabView and Python drivers. They will often have MatLab and IVI drivers as well. Drivers, especially well-written drivers, ease the task of coding for instrument control.

When interfacing an AWG with other test instrumentation, you may need markers and trigger signals to communicate and synchronize with other instruments. Ensure that the AWG you select has sufficient digital I/O and marker outputs for the intended application.

Size and Form Factor

AWGs come in a variety of sizes. If your application is research and development, you may find a benchtop model with a display and pushbutton access to all controls convenient. For production testing, PXI models offer space-saving, automated testing. You will want a small, lightweight portable enclosure for field testing and field service. A manufacturer that can offer all the options eases the task of transitioning a new product from design to manufacturing. The tests with an AWG used by the design team to validate the performance of the design can simplify and speed up production test development and test system verification if the test system contains an AWG with similar operability and performance.

The Many Considerations for Selecting an AWG

An AWG can have an extensive amount of functionality; and, as a result, it is a complex instrument. This article offers suggestions for important criteria to consider when selecting an AWG to address waveform generation applications. When investigating AWGs, consider the Tabor Electronics Proteus series AWGs. The family has sampling rates up to 9 Gsamples/s and an effective output bandwidth greater than 10 GHz. Models can have as many as 12 channels and can have real-time streaming. The series includes benchtop, desktop, and PXI form factors. Learn more about the Tabor Proteus line at Arbitrary Waveform Generators - Proteus Series.