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# Generating Frequency Agile and Custom Waveforms

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This note reviews methods and performance issues for generating custom test waveforms in an arbitrary waveform generator

There is considerable interest in generating complex waveforms to test radar and communications systems. To create these waveforms, an arbitrary waveform generator (AWG) is one of the most flexible methods of signal simulation. Any signal that can be mathematically described can be output from the AWG. The waveform description can be performed using common mathematical tools (such as Matlab®), or by using customized software, such as the Agilent N7509A waveform generation toolbox used for wideband signal simulation.

The AWG output signal waveform can be used to evaluate portions of a system transmitter. For example, a dual-channel generator can be used to drive the I and Q baseband inputs of a microwave I/Q modulator up-converter. Alternatively, the baseband or up-converted output of the waveform generator can be used to evaluate the performance of complex radar or communications receivers.

To be of the most use in these test applications, the arbitrary waveform generator should exhibit three major characteristics: accurate analog output performance; a flexible sequencer to store and extend mathematical descriptions of the waveform; and powerful, easy-to-use waveform generation software.

## Analog Output Requirements

The signal quality of a waveform produced by an AWG is only as good as the intrinsic performance of the internal digital to analog converter (DAC). Nyquist sampling limitations together with the need to provide realizable, high-performance reconstruction filters (to eliminate out-of-band aliased signal content) limit the upper frequency of an AWG. Typically, the maximum modulation frequency is ~40% of the sample rate. Higher DAC sample rates are constantly required with the ever-increasing modulation bandwidth requirements of today's systems. At higher sample rates, the dynamic range—also expressed as the number of effective bits—typically decreases. Several factors can lead to degradations in the spurious free dynamic range (SFDR) including: harmonic distortion, clock artifacts or other spurious signal content. In addition the noise performance, often expressed as phase noise, usually degrades at higher sample rates. There are exceptions. At a 1.25 GS/s sample rate, the Agilent N6030A provides 15-bit resolution with –65 dBc SFDR, which corresponds to ~11 effective bits. This is adequate dynamic range to accurately render most complex radar simulation waveforms.

Even with carefully designed hardware, there are basic physical limitations in waveform generation using a DAC. These include the *sin x/x* roll-off due to zero-order hold in the DAC, and deviations from linear phase in the reconstruction filters. Correction software can be used to remove the effects of these and other residual linear impairments in the AWG output. A correction algorithm is applied to the waveform on download, based on factory measurements of the overall linear system response of the AWG. Without this correction software, a mathematical description of a waveform will differ significantly from the observed analog output. For example, on the N6030A, without corrections the overall roll-off versus frequency is ~6 dB up to the maximum modu-

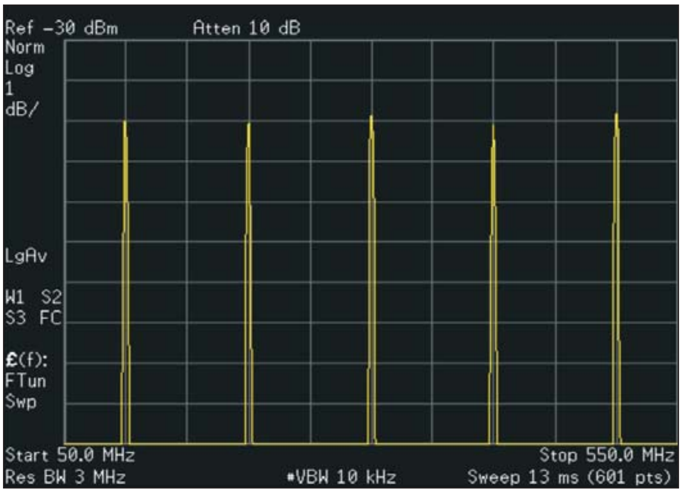


**Figure 1 · 500 MHz-wide multi-tone waveform sequence with linear corrections applied on download.**

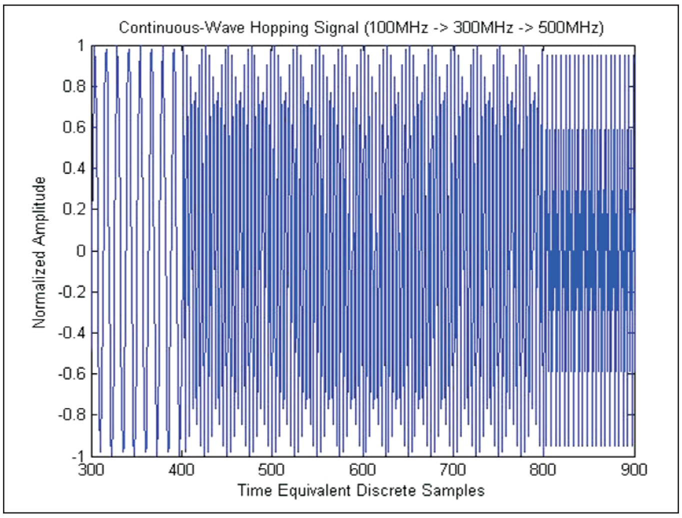


**Figure 2 · A multi-tone frequency hopping scenario.**

lation frequency of 500 MHz. Figure 1 shows a multi-tone waveform spanning 500 MHz of baseband frequency, with corrections applied on the N6030A. Multi-tone signals are often used for noise power ratio (NPR) measurements in satellite receiver testing. The correction software results in an amplitude flatness of better than 0.5 dB, as shown in Figure 1. The phase response is not observable in this measurement, but is also corrected to ~2 degrees.

## Signal Simulation Using a Sequencer

Secure radios often utilize frequency hopping to reduce the probability of intercept. An AWG can be used to create this time varying signal. In addition, other signals such as chirped and conventional radar pulses have distinct characteristics in the time domain. Signals such as these can be created on an AWG in several ways. The desired waveform can be derived mathematically and written once to the waveform memory. One limitation of this approach is that if the AWG memory is fairly large (16 MSamples, in the case of the N6030A), the sample rate is also very high, 1.25 GS/s. This results in only 12.8 ms of unique play time. To "compress" the signal waveform data and extend the playtime, a sequencer is used. Sections of the waveform memory can be repeated and looped to create long scenarios with rich content. In addition, multiple AWG channels can be synchronized together to create phased array signal test suites, and external triggering can be used to control the evolution of the sequence scenario. In considering the waveform sequencer it is informative to describe some of the limitations and requirements to successfully employ it:

- Waveforms are read from memory in fixed granularity segments. In the case of the N6030A, this is eight samples per segment. If jumps in the waveform being played are requested by the sequencer, they occur on the segment boundary.
- When creating CW tones in the sequencer by repeating a fixed number of cycles, phase continuity is required at the repetition boundary or spurious energy will be produced at the loop repetition rate.
- Considerable memory can be saved in producing pulsed radar scenarios by looping the "off" time between pulses and conserving waveform memory.

A multi-tone scenario is shown in Figure 2. This can be produced as a single waveform. Alternatively, it can be constructed with the sequencer. A limited number of cycles at each frequency can be looped and the different frequency segments cascaded in time to produce the same scenario with significantly less waveform memory.

In summary, the application of an arbitrary waveform generator to produce flexible testing scenarios has been shown. With high-performance hardware, realistic signal simulations can be modeled and played with minimal distortion. These test suites can be used to characterize a wide variety of transmitters and receivers, both at baseband and with up-conversion to RF and microwave frequencies.

## Author Information

Roger L. Jungerman is an R&D design engineer with Agilent Technologies in Santa Rosa, California, and is the hardware architect of the N6030A Arbitrary Waveform Generator. He has over 20 years of experience in high-speed digital design, RF and microwave measurements, fiber optics, sampling oscilloscopes, jitter, SAW devices, and phase noise. After receiving his PhD from Stanford University in 1985, his work with Hewlett-Packard and Agilent has resulted in numerous major product introductions. Dr. Jungerman has authored 50 technical papers, holds more than 40 patents and is a Senior Member of the IEEE.