Differentiating between Basic and Advanced Modes for AFG31000 Series Arbitrary Function Generators

APPLICATION NOTE

Tektronix®

Arbitrary Function Generators (AFGs) are widely used by researchers, design engineers and test engineers to simulate their devices under test (DUTs). Today's electronic designs are getting more and more complicated, which is leading users to demand that their AFGs offer a richer set of features, higher signal fidelity, greater flexibility and superior ease of use.

AFG31000 Series Arbitrary Function Generators offer a choice of waveform generation modes—Basic and Advanced—to accommodate a range of use cases to ensure the best test results and user experience.

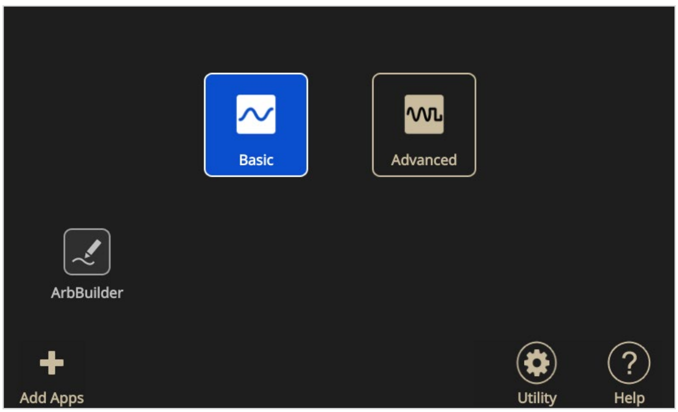

Figure 1. The AFG31000 Series home page.

Basic mode

In Basic mode, an AFG31000 works much like a traditional AFG, based on the Direct Digital Synthesis (DDS) technique. Although some might argue that DDS is an "out-of-date" technology with some weaknesses, it is still fundamental to almost all of the AFGs in the market today, and has a lot of advantages over the newer technologies.

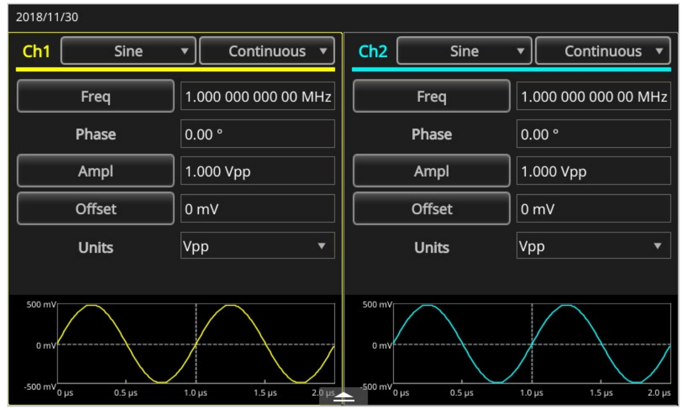

Figure 2. User interface of a dual-channel AFG31000 in Basic mode

Frequency agility

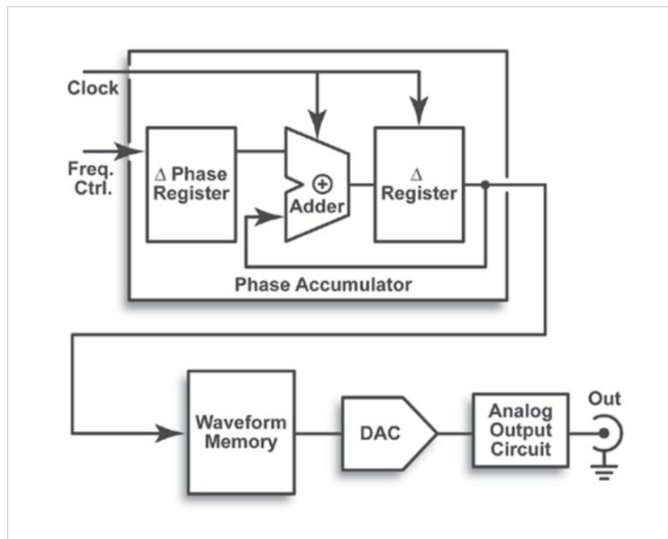

Figure 3. The simplified architecture of a DDS-based AFG

The following is fundamental to all digitized generators:

Output Frequency = Sample rate ÷ number of samples in one cycle (equation 1)

For DDS-based AFGs, the sample rate is fixed; when the user changes the output frequency, the number of samples in each cycle changes accordingly. The phase accumulator does this automatically by repeating or skipping points in the waveform memory.

For example, let us assume the sample rate is 1 MSa/s, and there are 1,000 samples in the memory. If a user sets the output frequency to 1 kHz, then 1 kHz = 1 MSa/s ÷ 1,000 samples.

That means each of the samples in the memory will be output once in each cycle.

However, if the user change the frequency to 2,000 Hz, the number of samples in one cycle will be 1 MSa/s ÷ 2 kHz = 500 samples.

That means the phase accumulator will skip one sample of every two samples to make the equation true. Conversely, if the output frequency is set to 500 Hz, each sample will have to be output twice to make 2,000 samples in each cycle.

The phase accumulator performs all these calculations automatically. Users need not worry about the complexity of matching frequency, the number of samples in a waveform and the sample rate. All they need to do is input the frequency they want via the user interface, and start testing.

This feature allows users to change the output frequency on the fly using the rotary knob or numeric keypad, and it will take effect instantly. This is known as “frequency agility,” a feature that many users find valuable.

Calibrated/compensated sine wave flatness across the frequency

Analog designers who characterize the frequency response of the filter/amplifiers expect sine waveforms (periodic with only the fundamental component) that have the same amplitude at different frequencies as inputs to their DUTs, and then measure the output amplitude to calculate the attenuation/gain of the DUTs at different frequencies.

However, in an AFG’s analog output circuit, there are also filters and amplifiers with frequency responses that are not flat across the frequency range. To ensure the built-in sine waveform output is as flat as possible, the output is calibrated/compensated before the AFG is shipped. However, the other function waveforms or arbitrary waveforms are all treated in the same way without flatness compensation; the output flatness depends on the performance of the analog output circuit, which cannot be guaranteed.

Figure 4 shows a built-in sine (yellow) and a user-defined sine as an arbitrary (blue), with both waveforms sweeping from 1 kHz to 100 MHz. The built-in sine has a better flatness performance across the range of frequency sweeping.

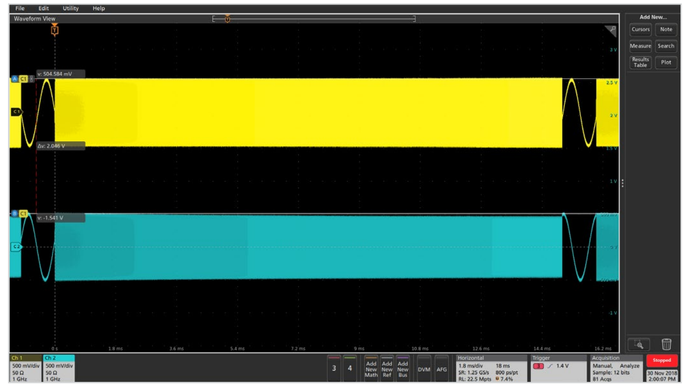

Figure 4. Flatness comparison between built-in sine and user-defined sine

Ease of use

In addition to the frequency agility, the built-in run modes (continuous, sweeping, modulation, burst) cover many use cases. All the user needs to do is set the parameters, like frequency, amplitude, modulation scheme, carrier/modulating waveforms, burst cycles, start/stop frequencies, etc., which makes the AFG31000 Series easier and more intuitive to use than some high-end Arbitrary Waveform Generators (AWGs), which treat every waveform as arbitrary. These AWGs require the use of dedicated waveform editing tools to create/edit the waveforms, and set the variable sample rate according to the waveform length and desired output frequency.

- Continuous mode – Generate periodic waveforms in a continuous manner
- Sweeping mode – Sweeping between start and stop frequencies
- Modulation mode – Supports frequently used modulation schemes, like FM/AM/PM/FSK/PWM
- Burst mode – Output a certain number of cycles of waveforms as a response to internal/external triggering events

Powerful pulse generation

Pulses are widely used in many applications. Edge times, duty cycle/pulse width and period are some of the key parameters for pulse waveforms.

In the Basic mode, leading and trailing edges are set independently. Together with the top and bottom parts, they form a full pulse waveform. While changing the duty cycle or period, the edge times are kept unchanged, rather than being stretched or compressed as those arbitrary waveforms.

For example, the chart in **Figure 5(a)** shows a typical pulse waveform. If the user changes the period, in Basic/DDS, the edge times will remain the same, as shown in **Figure 5(b)**. However, with variable sample rate generators, the whole pulse will be compressed with the same scale, so the edge time will be changed as well, as seen **Figure 5(c)**.

This feature is useful in the applications that require changing the edge times, duty cycle and period of the pulses. For example, to generate a pulse as a modulating signal to a modulator in a radar system, changing the period and duty

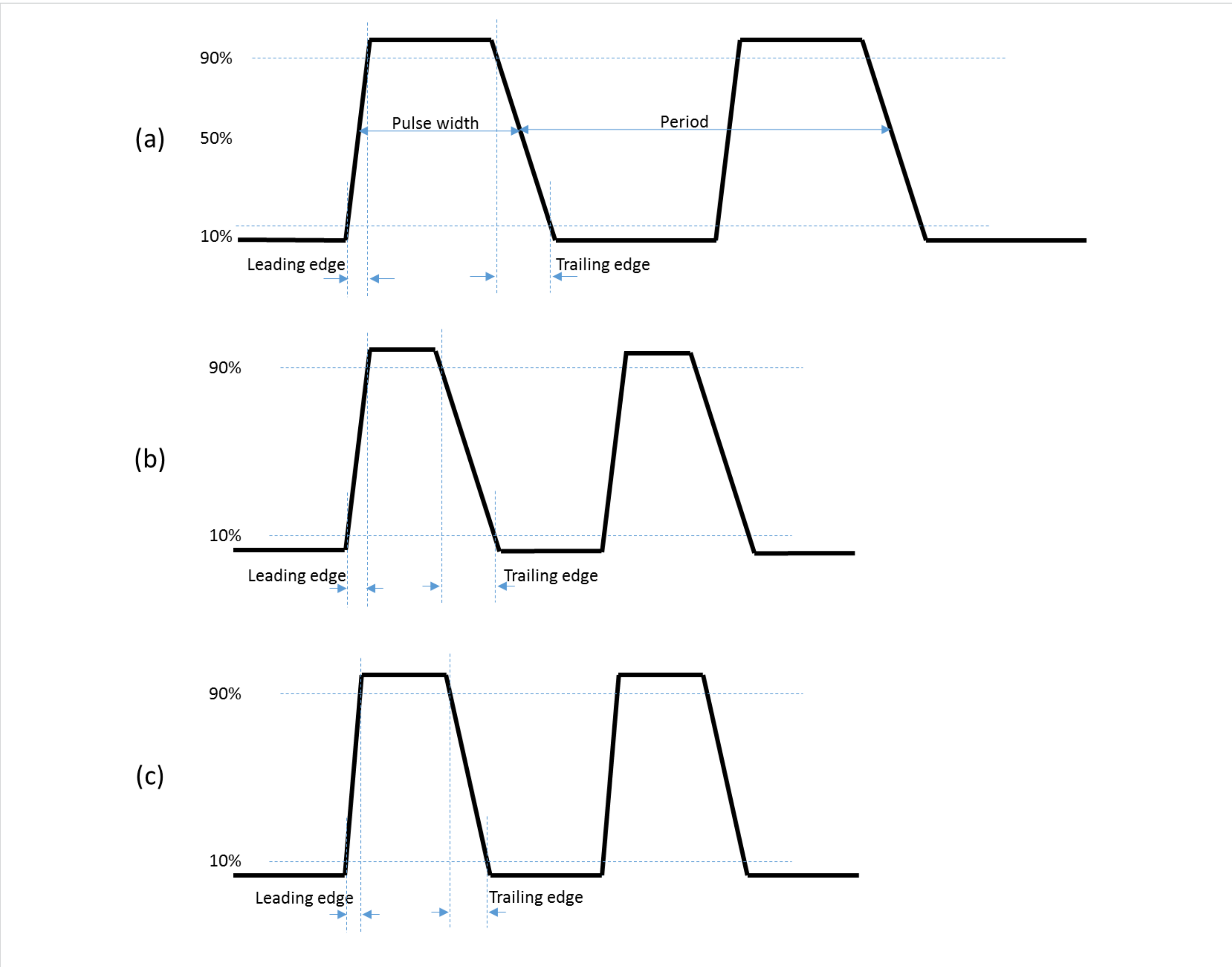

Figure 5. A typical pulse waveform (a). The pulses generated with DDS (b) and AWG (c)

cycle without interfering with the rising/falling edge times (which control the transmitting power ramp up/down times) is very beneficial for users.

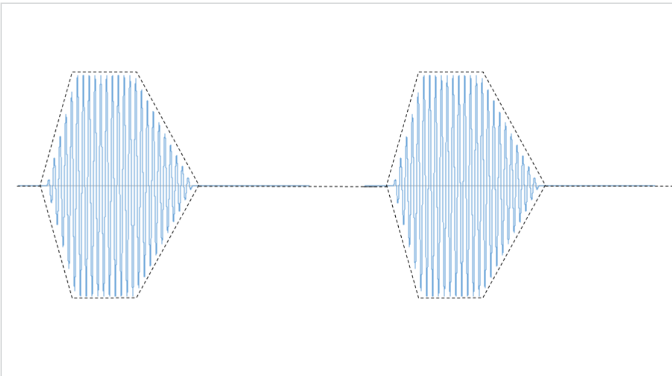

Figure 6. A pulse modulated sine wave

The Basic mode is mostly used in cases where:

1. Those general function waveforms, such as sine, square, pulse, etc., are needed;
2. Frequency must be changed on the fly, for example, in a clock with different frequencies in a digital design;
3. A flat sine across a wide range of frequency is needed for frequency response tests;
4. The basic modulation or burst is needed;
5. Pulses with independent edge times, duty cycle and period are needed.

Advanced mode

The Advanced mode offers several advantages over the Basic mode, but the downside of using it is increased complexity.

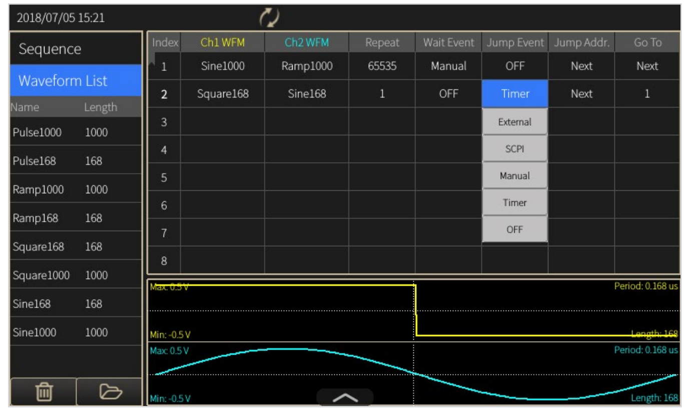

Figure 7. The Advanced mode user interface

Variable sample rate reduces jitter/phase noise

The Basic mode uses DDS with a fixed sample rate. When users set the output frequency of an arbitrary waveform, the sample rate may not be an integral multiple of (frequency × number of samples); in other words, the phase between the samples and the sample clocks accumulate and shift. Along with the phase shift, if a certain sample fails to catch a sample clock, it will be output at the next sample clock, which introduces jitter or phase noise for one sample clock.

Figure 8 shows an example of this kind of event. At the first rising edge, the sample with high level catches the sample clock, but the next sample at the next rising edge doesn't, so it is delayed to the next sample clock to output. So, over a longer timeframe, the rising edges shift between two consecutive sample clocks, which introduces the jitter/ phase noise.

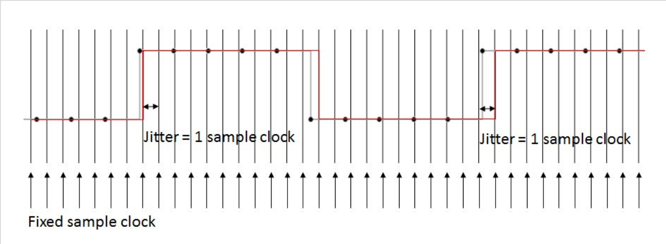

Figure 8. Basic/DDS mode with jitter of one sample clock

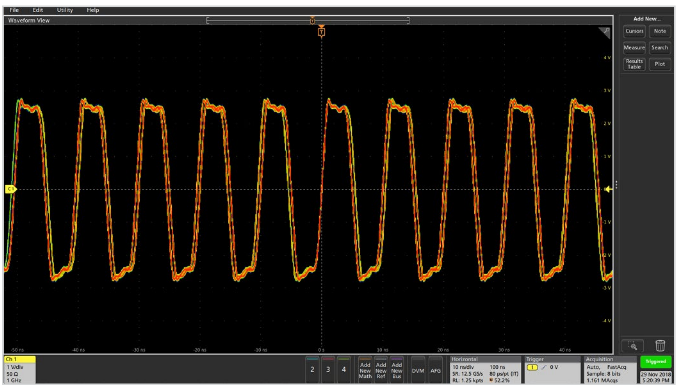

Figure 9. A 9.9 MHz square wave in Basic/DDS mode, with jitter of one sample clock

However, as variable sample rate is adapted in Advanced mode, the sample clock and the waveform samples are synchronized. Every sample is on the sample clock, there is no extra jitter or phase noise, and the performance depends only on clock stability.

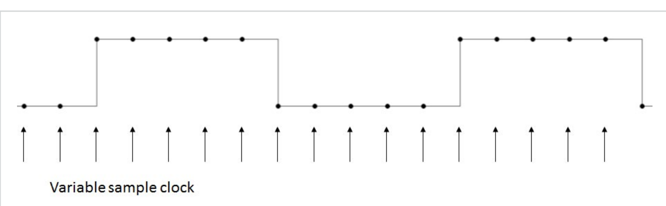

Figure 10. Advanced mode applies variable sample rate, samples fall at sample clocks

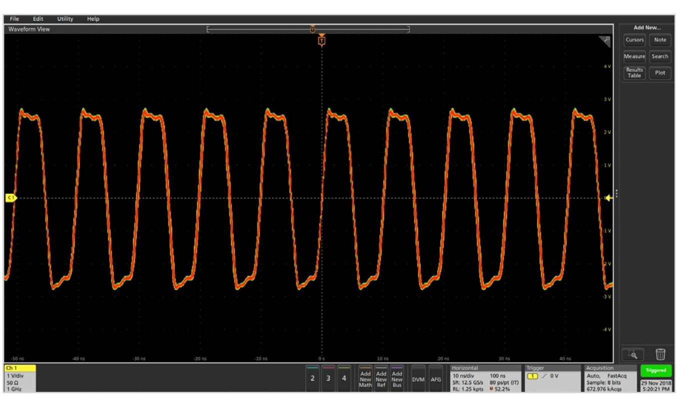

Figure 11. The same 9.9 MHz square wave in Advanced mode with a variable sample clock, with much lower jitter

Interpolation for better signal fidelity

DDS repeats/skips samples, while advanced mode interpolates to make the fundamental (equation 1) true. The advantage of doing so is it can greatly improve the output signal fidelity.

Figure 12 is an example of an eight-sample sine wave being output in Basic/DDS mode. Because there are fewer samples than the sample clock in one period, DDS repeats the samples (black dots) at the sample clock to meet the desired output frequency. The actual output (red) is expressed as big steps, which are very different than the expected sine wave (green)

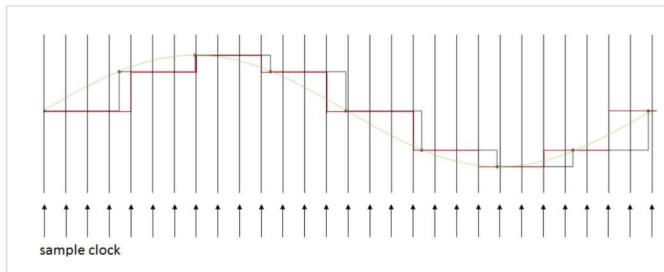

Figure 12. DDS in Basic mode generates steps while repeating samples

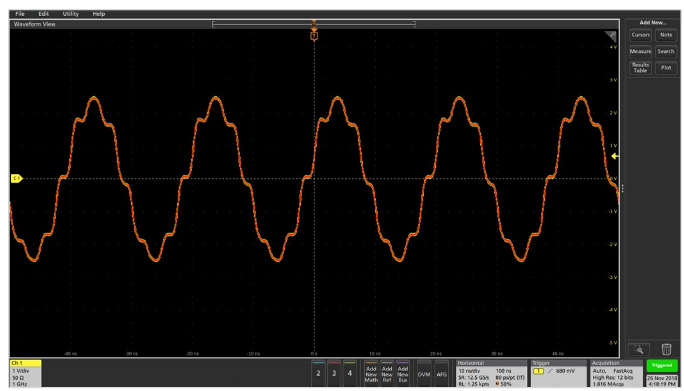

Figure 13. An eight-sample sine wave output in Basic/DDS mode, with the frequency set at 50 MHz

In the Advanced mode, at lower frequencies, linear interpolation is adopted between every two adjacent samples in memory at a higher sample rate. The AFG31000 draws a virtual straight line (the dotted blue lines) between samples, and it inserts more points along the line (**Figure 14**). This technique fragments the big stairs into smaller ones, making the actual output (the red curve) much closer to the desired sine wave (the green curve).

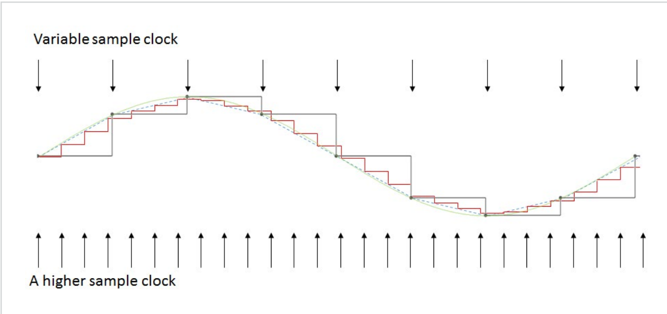

Figure 14. Interpolation in Advanced mode generates higher signal fidelity

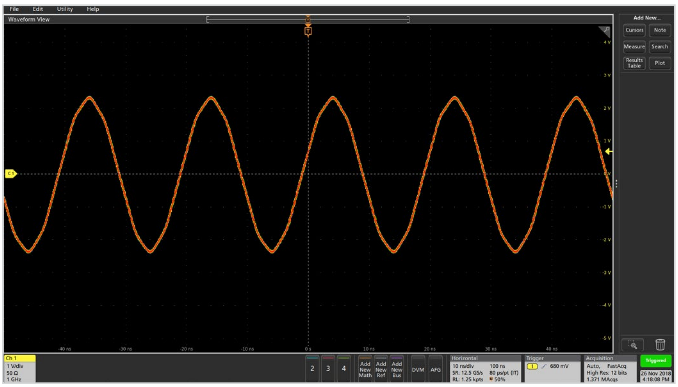

Figure 15. The output of the same eight-sample sine wave shown in Figure 13 in Advanced/Interpolated mode, frequency set at 50 MHz

Sequence with large memory for long waveform, multiple-waveform generation with high-resolution and flexible timing

In Advanced mode, the waveform memory is extended to a maximum of 128 Mpts per channel (optional, standard is 16 Mpts per channel), and the sample clock is variable from 1 μSa/s to 2 GSa/s (depending on model). Both are important to support long waveforms while sustaining high timing resolution.

For example, a waveform with 1 Msamples lasts one second when the sample rate is 1 MSa/s, and each sample represents 1 μs timing resolution. When 0.1 μs resolution is needed, it's necessary to increase the sample rate to 10 MSa/s and the number of samples to 10 Msamples in order to maintain the one-second output period.

Also, in conjunction with the large memory, the sequencer can generate multiple waveforms and long waveforms with complex timing.

The sequencer breaks up the memory into 256 entries, with the length of each separately configurable. Each entry includes an arbitrary waveform (per channel) and settings for how the waveform is played in terms of Wait Event, Repeat, Jump Event and Go To, with external, SCPI command, manual or timer triggering events (refer to **Figure 7**.).

Waveform list – A list of waveforms that can be added into entries of the sequence.

Index – The index of the entry, starting from 1 and up to 256.

Ch1 WFM – The waveform for channel 1.

Ch2 WFM – The waveform for channel 2 (must be with the same length as ch1 waveform in the same entry); can be left blank in all entries if only ch1 is needed.

Repeat – The number of times the waveform is looped before moving to the Go To address. It can be set between 1 and 1,000,000, or infinite. However, the procedure could be interrupted by a Jump Event if it is enabled, and would jump to a specified entry.

Wait Event – If enabled, the waveform will not be output until the Wait Event happens.

Jump Event – If enabled, during the output procedure of current waveform, the sequencer will jump immediately to the Jump Addr.

Jump Addr – The index in the sequence to which the sequencer will jump when the Jump Event occurs.

Go To – The index in the sequence to which the sequencer will go after the output of the current entry is complete.

Sequence mode

Sequence mode is fundamental to all run modes in Advanced mode. It could include one or more entries in the sequencer, and users can define how the waveforms in those entries are played.

The flow chart in **Figure 16** shows a general case of an entry in a sequence. It could include all the controls listed above (i.e., Wait Event, Repeat, Jump Event or Goto).

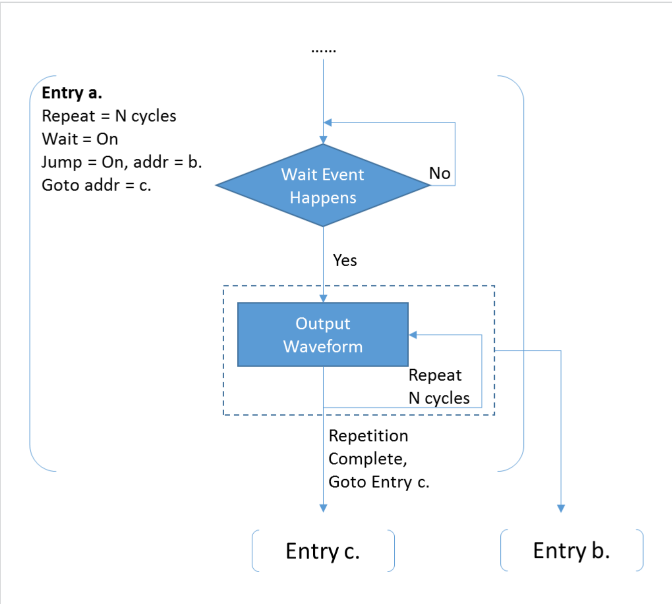

Figure 16. Sequence mode flow chart

Continuous mode

Continuous mode (**Figure 17**) is a special case in which there is only one entry in the sequence. The sequencer plays the waveform in the entry repeatedly, without stopping until the user directs it to do so.

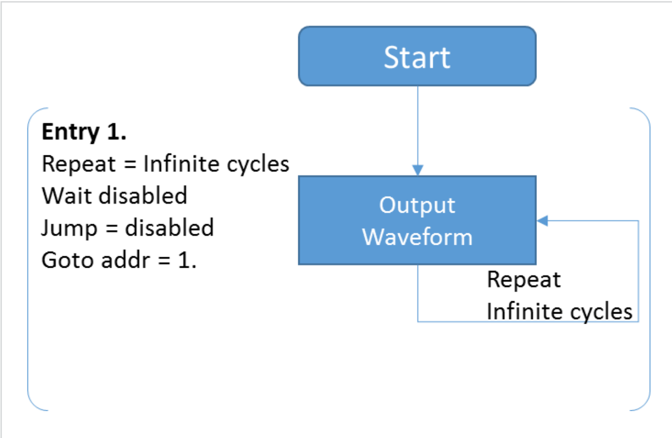

Figure 17. Continuous mode flow chart

Triggered mode

Triggered mode (**Figure 18**) is another special case of sequence mode with just one entry. With the Wait Event being enabled, the waveform in the entry will be output once if the wait event happens, then it will go back to the beginning and prepare for the next trigger.

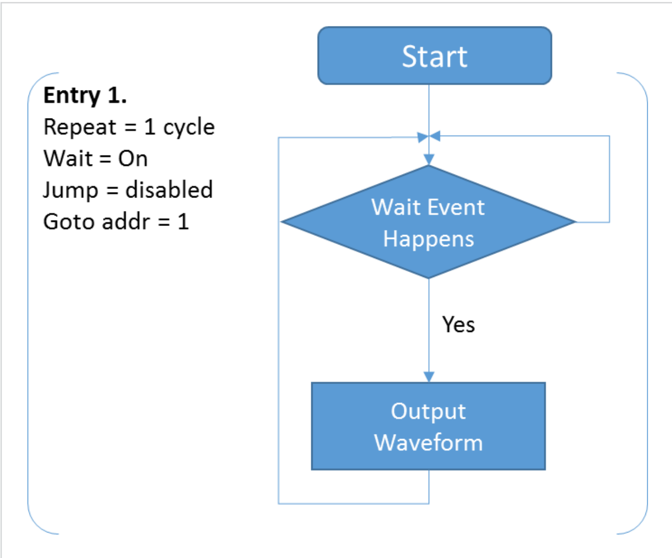

Figure 18. Triggered mode flow chart

Gated mode

Gated mode (**Figure 19**) is also another special case of sequence mode with one entry only. With both Wait and Jump Events being enabled, the waveform in the entry will be output with infinite cycles once the Wait Event happens (gate opened), and stopped until the Jump Event happens (gate closed). Then the sequencer will go back to the beginning and wait for the next Wait Event.

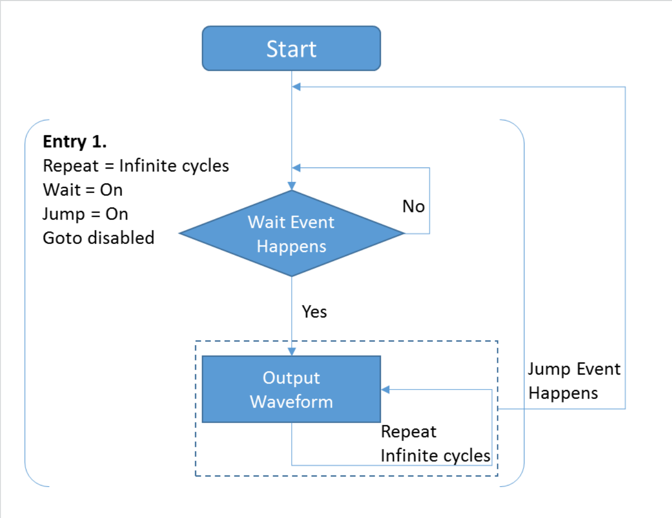

Figure 19. Gated mode flow chart

The advanced modes are mostly used in situations where:

1. Signal fidelity is critical to the test result: for example, baseband IQ modulation and serial data, which are sensitive to jitter/phase noise specifications;
2. Long waveforms are needed: for example, to generate modulated signals or to simulate sensor for a long period;
3. Multiple waveforms are needed to complete a test; for example, to output a serial of packets on a serial data bus, to put together different waveforms into a longer and more complex one, or to serialize multiple test cases in a sequence to improve test productivity;
4. A long waveform is needed when high timing resolution is also desirable;
5. There are very limited samples in the waveform, when high signal fidelity is desirable.

Summary

With its Basic and Advanced modes, the AFG31000 Series provides versatility to accommodate users' various waveform generation requirements to get their test jobs done. However, users need to keep the differences between them in mind. Choosing the appropriate mode before getting involved in developing a test can save development time and improve test results.

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