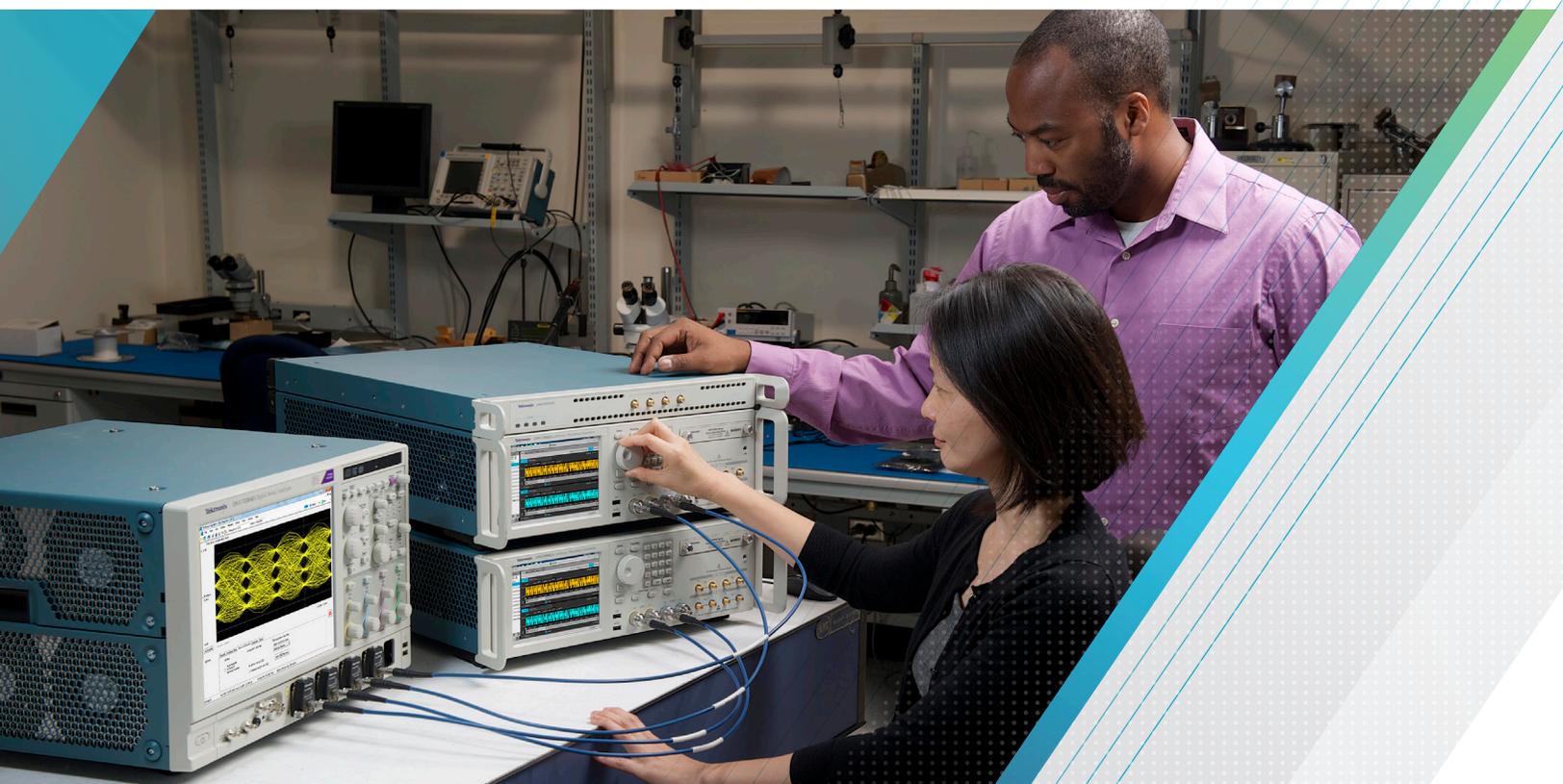


Using the Sequencer on Tektronix AWG70000B series instruments

APPLICATION NOTE



Arbitrary Waveform Generators (AWGs) are one of the most versatile and useful test and measurement products used today. With an AWG users can create real world signals that enable engineers to re-create anomalies and test signals that are difficult or impossible to re-produce. AWGs can also be used to mimic environments that enable engineers to test complex scenarios that would require multiple test benches filled with equipment or costly live interactions with other electronic devices. One of the features available on an AWG is what is called the sequencer. The sequencer mode allows users to string multiple waveforms together enabling very complex waveform generation. The sequencer also allows for branching and looping features that enable waveform generation without the need for extremely large memory requirements or external program control. In order to use the sequencer efficiently some basic understanding of how it works will greatly increase its usefulness. Some of the more common applications that the sequencer is used in are:

Radar – Used for simulation of transmitters and reflections to verify receiver can identify many different types of reflections and moving objects.

Serial Data Testing – Many serial data standards (USB, SATA, PCIE and others) require that the test instrumentation be able to put the Device Under Test (DUT) into a test mode or loop back mode in order to validate the device and do compliance testing. With the sequencer, the user can provide the signals required to put the device in loopback or test mode and then jump right to the stressed waveform in order to do the compliance or margin testing.

Manufacturing and Test – Many electronic manufacturing facilities need to automate complex testing scenarios where many different types of stimulus or waveforms are required in order to evaluate the performance of the DUT. These tests need to be done repeatedly and as fast as possible. Since the sequencer can have many waveforms loaded into memory the test time doesn't require the loading of each individual waveform during the test, thus enabling the fastest testing times possible.

In order to use the sequencer on the AWG70000 series there are two requirements regarding waveform creation.

1. The waveform length needs to be at least 2400 points on the AWG70002B and 4800 points on the AWG70001B instruments.
2. The total waveform length needs to be divisible by the granularity of the sequence buffer. This is not a factor on the AWG70002B but is 2pts on the AWG70001B.

With care in waveform creation, the sequencer can provide very useful waveform generation especially when you consider all the standard features that are available.

- **Maximum sequencing steps or waveforms 16,383**
- **Trigger or Wait**
Allows the sequence to wait at the defined index or waveform until an external trigger arrives using the external trig A or B input on the rear panel of the AWG, through the front panel or through program control. This mode is enabled by setting the Wait field in the sequence configuration to ON. Once it gets the trigger event, the sequence will play that waveform.
- **Flags**
Allows up to 4 signals per channel that can be set for a High, Low, Toggle or Pulse from the SMB connectors on the rear panel of the instrument.
- **Repeat**
The waveform repeats from 1- 1048576 times or infinitely.
- **Event Jump**
Allows for sequence to run a waveform until an external trigger arrives using the trigger inputs on the rear panel of the AWG or through program control. This mode is usually used with the repeat count set to infinite, such that a waveform will continuously run until an event comes in and then it will jump to a defined index. Event jump also allows the user to specify whether the sequence should jump as soon as it gets an event or wait until the waveform is finished before it jumps to the next defined index.
- **Go To**
This allows the user to define which index the sequencer will go to after the current waveform has finished. This is useful to run the whole sequence in a loop where go to is defined as 1 so the sequence will start over.
- **Sub Sequencing**
A subsequence is a sequence of waveforms with an optional repeat count that you can create and put into a sequence index. This allows the user to define a sub sequence that could be used several times within the main sequence, thus eliminating the need to repeat a particular set of waveforms individually.
- **Pattern Jump**
Pattern Jump allows the user to jump to a specified position in a sequence, depending on the jump table definition and using the external Pattern Jump input on the rear of the instrument. This allows up to 256 different addresses that can be used for specific jump index locations.
- **Streaming ID**
Streaming ID allows you to directly control the sequence of waveforms played out of a predefined sequence. You control the sequencer actions by streaming instructions directly to the sequencer via the 10/100/1000 Ethernet Streaming ID connector on the rear panel. Streaming jump instructions directly to the sequencer via Ethernet greatly enhances the speed at which jumps are performed.

	Wait	Track 1	Track 1 Flags	Track 2	Track 2 Flags	Repeat Count	Event Input	Event Jump to	Go to	Length	Time
1	Off	Wave_4		Wave_3		1	Off		Next	2.4 k	96.00...
2	Off	Wave_3		Wave_1		1	Off		Next	2.4 k	96.00...
3	Off	Wave_2		Wave_4		1	Off		Next	2.4 k	96.00...
4	Off	Seque...		Seque...		1	Off		Next	9.6 k	384.0...

FIGURE 1.

Creating a Sequence

Use the Sequence tab to create a new sequence or edit existing sequences.

Creating a sequence is as easy as dragging and dropping a waveform from the waveform list into the index Track that you want to use. Then continue building your sequence by assigning waveforms (or other defined sequences) to successive steps. By default, each step of a sequence plays in order of the numbered steps. When the sequence reaches the final step, the sequence naturally ends.

STEP EDITOR TOOLBAR ITEM	DESCRIPTION
Step number column	<p>The first column in the Sequence editor is the numbered steps. These step numbers define the play sequence and are used as the targets for the Event Jumps, Pattern Jumps, Force Jump, and Go to features.</p> <p>The maximum number of steps allowed in a sequence is 16,383 steps. This includes steps contained within subsequences. For example, a sequence numbering to 1000 steps would actually have 1500 steps if a subsequence of 500 steps is part of the sequence.</p> <p>When using a subsequence, the steps in the subsequence are only counted one time, meaning that you can reference the same sequence multiple times without increasing the step count multiple times.</p>
Wait	<p>Defines the condition required for the step to start playing the assigned waveform.</p> <ul style="list-style-type: none"> • Off: No waiting, the waveform plays immediately. • Trig A: The step does not start until a trigger signal is received on the Trigger A input or a Force Trigger A event is received. • Trig B: The step does not start until a trigger signal is received on the Trigger B input or a Force Trigger B event is received. • Internal: A jump occurs when the internal trigger event occurs.

STEP EDITOR TOOLBAR ITEM	DESCRIPTION
Track	<p>The Track columns contain the name of the waveform or subsequence to play at each step. Up to eight tracks are available for a sequence.</p> <p>To load a waveform into a step, open the Waveform List, select a waveform and drag the waveform into the track step.</p> <p>To load a subsequence into a step, open the Sequence List and drag a sequence name in the track step. This sequence now becomes a subsequence.</p> <p>Once a waveform or sequence is assigned to a step, you can use the copy and paste functions to populate other steps within the sequence.</p> <p>To add a new track, Right-click on any of the Track column headings and select Add Track. A new track is added after the last track.</p> <p>To remove a track, right-click on the Track column you want to remove and select Remove Track.</p> <p>To play a sequence track, you must assign the track to a channel, even if there is only one track in the sequence. <i>Use the Home tab to assign sequence tracks to channels.</i></p>
Flags	<p>The Flags column allows you to place indicators (flags) within a sequence to provide a status of the sequence. The flags are output to the Flag Outputs on the rear panel.</p>
Repeat	<p>The Repeat Count column defines how many times the waveform or subsequence plays for the step in the sequence.</p> <p><enter count>: Enter the number of times to repeat the waveform. The maximum repeat count for a step is 1048576.</p> <ul style="list-style-type: none"> • Use infinity to continuously play the waveform until a jump condition occurs. • 1: The waveform plays one time.
Event Input	<p>Defines the event which will cause a jump to occur in the sequence step. If an event triggers a jump, the sequence uses the Event Jump to definition and skips the Go to definition.</p> <ul style="list-style-type: none"> • Off: A jump is not active for the step. Off is the default setting. • Trig A: A jump occurs if a trigger signal is received on the Trigger A input or a Force Trigger A event is received. Otherwise, the sequence uses the Go to definition. • Trig B: A jump occurs if a trigger signal is received on the Trigger B input or a Force Trigger B event is received. • Internal: A jump occurs when the internal trigger event occurs.
Event Jump To	<p>Defines which step to jump to when the Event Input condition is met.</p> <p>The Event Input condition must be set before you can define the jump.</p> <p><enter step>: Enter the step number to jump to if the Event Input condition is met.</p> <ul style="list-style-type: none"> • Next: The sequencer jumps to the next step in the sequence. • First: The sequencer jumps to the first step in the sequence. • Last: The sequencer jumps to the last step in the sequence. • End: The sequence ends. The Analog and Marker outputs are set to the values defined in Output Options dialog screen.

STEP EDITOR TOOLBAR ITEM	DESCRIPTION
Go To	<p>Defines the next step in the sequence to play when the step has finished playing its waveform. This is where the sequence continues if no other defined events occur.</p> <p><enter step >: Enter a specific step in the sequence to jump to.</p> <ul style="list-style-type: none"> • Next: The sequence goes to the next step in the sequence. This is the default setting. If Next is chosen for the last step in the sequence, the sequence ends. • First: The sequence jumps to the first step in the sequence. • Last: The sequence jumps to the last step in the sequence. • End: The sequence stops when finished with this step.
Length	<p>Displays the size of the waveform assigned to the step.</p> <p>NOTE. The Length display becomes invalid if the sequence has more than one track and the waveforms assigned to the step are different sizes.</p> <p>If you are attempting to play multiple tracks of a sequence on a two channel instrument, each step of the tracks must use identical length waveforms.</p>
Time	<p>The displayed time is based on the waveform size, sample rate, and the repeat count. If infinite is used for repeat count the time value will not be displayed.</p> <p>NOTE. The Time display becomes invalid if the sequence has more than one track and the waveforms assigned to the step are different sizes.</p>

Sequence settings

The sequence settings dialog box provides the following settings:

- **Jump Timing** – Jump timing determines when an event jump in the sequence occurs.
- **Enable Pattern Jump** – This enables the pattern jump event feature. A jump occurs when the system detects a defined digital pattern on the Pattern Jump connector on the rear panel. Use the Edit pattern jump table button to display the pattern jump table editor.
- **Recommended sample rate** – Use this setting to determine the sample rate you want to use when running the sequence. This is the recommended sample rate and the instrument will attempt to use this rate if the Manage Conflicts is set to Auto.
- **Repeat Flag** – Enabling the Repeat Flag feature causes the flag (or flags) for that step to repeat if the sequence step is set to repeat (using the Repeat Count setting).

The default setting is off (not enabled). This means that the flags are set the first time the waveform is played for a sequence step. Repeating the step will not cause the flag to repeat.

When enabled, the flag is set each time the waveform plays for each time the step is repeated.

NOTE. The Repeat Flag feature is only useful when using the Toggle or Pulse flags. Since flags remain in their set state (unless changed by another step or the sequence ends), repeating a high or low flag would not cause any change to the flag output.

Jump timing

Jump timing determines when an event jump in the sequence occurs. This affects all types of event jumps

You can access the jump timing settings in two ways: either from the Sequence Settings dialog screen in the Edit menu or directly from the Jump button.

Jump immediately – A jump occurs at the time the jump event occurs, stopping the playback of the waveform currently playing.

Jump at end of waveform – A jump occurs only after the currently playing waveform completes its playback.

If the waveform is defined to repeat (using the Repeat Count setting in the Sequence editor), the end of waveform occurs when the waveform finishes its current cycle.

Jump execution order

There are a number of ways that a jump can be initiated in a sequence. Some types of jumps take precedence over other types of jumps.

Below is the order in which jumps are executed by the system.

1. Force Jump – Pressing the Force Jump to... button (from the Home tab) allows you to initiate a jump anytime anywhere within the sequence. A force jump takes precedence over all other types of jumps regardless of the current step of the sequence.
2. Pattern Jump – If Pattern Jump is enabled and the defined pattern occurs, this jump takes precedence over the Event Jump or Go to jump. The Pattern Jump is independent of any step of the sequence.
3. Event Jump – If an Event Jump is defined for a step, this jump takes precedence over the Go to jump.
4. Go to Jump – Go to is the default jump destination for a step if no other jumps occur.
5. Streaming ID – Streaming ID allows you to directly control the sequence of waveforms played out of a predefined sequence. You control the sequencer actions by streaming instructions directly to the sequencer via the 10/100/1000 Ethernet Streaming ID connector on the rear panel. Streaming jump instructions directly to the sequencer via Ethernet greatly enhances the speed at which jumps are performed.

NOTE. All jump types are dependent on the Jump Timing setting, either causing the jump to occur immediately or at the end of the waveform currently playing.

Creating a Pattern jump

Pattern Jump is another type of event jump to cause a change in the sequencing of waveforms when an external digital pattern is applied to the Pattern Jump In connector on the rear panel.

As with any other event jump, Pattern Jump allows you to jump to a specified position in a sequence.

To define the pattern, display the pattern jump table. The Pattern Jump editing table is available from the Sequence Settings dialog screen (from the Edit button menu) and the Jump button in the Sequence tab.

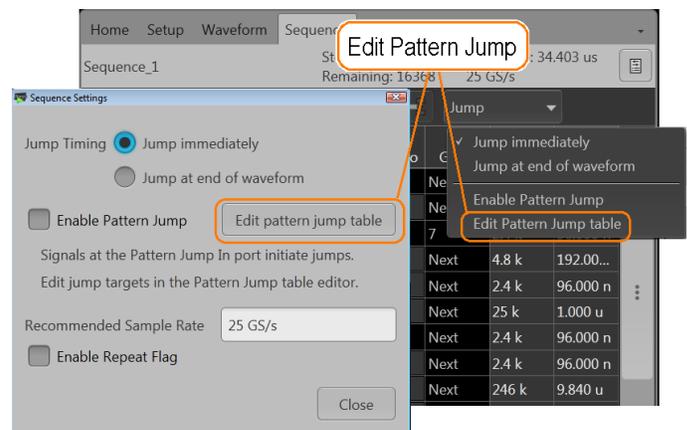


FIGURE 2.

Use the Pattern Jump Table to select the input patterns to use to initiate a jump. There are 256 Input Patterns that are predefined and are not editable. To use the table, simply go to a corresponding input pattern and select the step in the sequence you want the sequence to jump to when the pattern is applied to the Pattern Jump In connector.

A strobe signal is used to control the pattern input. Patterns are clocked in on the falling edge of the strobe signal.

NOTE. Be sure to assign valid step numbers in the "Jump to Step" column.

PATTERN JUMP CONNECTOR SPECIFICATIONS:

Characteristic	Description
Pattern Jump Input	
Connector	15-pin DSUB on rear-panel
Pin Assignments	Pin, Signal 1 GND 2 Jump Bit 0 Input 3 Jump Bit 1 Input 4 Jump Bit 2 Input 5 Jump Bit 3 Input 6 GND 7 Strobe Input 8 GND 9 GND 10 Jump Bit 4 Input 11 Jump Bit 5 Input 12 Jump Bit 6 Input 13 Jump Bit 7 Input 14 GND 15 GND
Input Impedance	1 k Ω pull-up to 5 V
Input Levels	3.3 V LVCMOS, 5 V TTL compliant
Number of Destinations	256
Strobe Polarity	Negative
Strobe Minimum Pulse Width (typical)	64 ns
Strobe Setup and Hold (typical)	Setup: 5 ns Hold: 5 ns
Latency to Analog Output (typical)	102,125 / sampling clock +20 ns \pm 20 ns
Holdoff Time	>18 μ s

FIGURE 3.

Sequence Flags

Sequence flags provide you the ability to add indicators within the sequence to help identify the state of the sequence. And since Flags are not part of a waveform file (unlike Markers), the waveforms are able to use the full resolution of the instrument.

A flag can be placed on any step within a sequence track. The flag signals the start of the waveform ployout for that sequence step. So if there is a wait condition, the flag is not set until the condition is met.

The flags column is divided into four sections, corresponding to the four output available (A, B, C, D). To help identify the flag locations, the following illustration shows that a flag has been set in each possible location.

To set a flag, either touch or double click on the flag cell. The following dialog appears:

There are four flag outputs (A, B, C, D) available for each channel. The flag outputs are located on the rear panel (Flag Outputs).

Each flag has the following possible states:

- No Action: This is the default state for all flags. The flag output is at 0 V at default.
- High: The designated flag output is set to high (3.3 V into 50 Ω).
- Low: The designated flag output is set to low (0 V).
- Toggle: The designated flag output toggles from its previous state, from High to Low or Low to High.
- Pulse: A pulse is sent to the designated flag output. The pulse direction is determined by the current state of the flag output. If the current state is low, the result is a positive pulse. If the current state is high, the result is a negative pulse.

The pulse width is determined by the sample rate with the formula: $600/\text{Sample Clock}$.

Flag outputs remain in their set state until the sequence ends or the flag is set again by another sequence step. You can quickly disconnect the flag outputs using All Outputs Off, either in the graphical interface or with the front panel button. (The output connectors are electrically floating while all outputs off is engaged.)

NOTE. Be careful when defining flag outputs. It's possible to redefine a flag's output within the same sequence, easily leading to undesired results.

All flag outputs are terminated into 50 Ω and have short circuit protection to ground.

Sequence flag timing

A sequence flag is initiated by the start of the waveform ployout associated with the step. The flag is set before the waveform ployout begins. The timing of the waveform ployout from a flag's transition change is illustrated below, followed with the formulas to calculate the delays.

Flags also have a repeatability window. This means there may be a slight difference in the delay time of a flag's transition in successive changes. See the timing illustration below to help explain these delays.

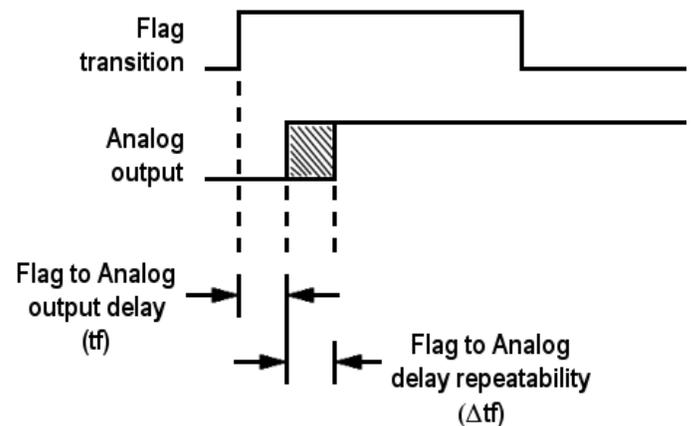


FIGURE 4.

Flag timing calculations

Use the formulas below to calculate the actual flag delay and flag repeatability window.

- Flag to Analog output delay (tf):

$$\text{Flag to Analog output delay (tf)} = \frac{-291.5}{\text{sampling clock} \times 2} + 9.76 \text{ ns } (\pm 5 \text{ ns})$$

- Flag to Analog output delay repeatability (Δtf):

$$\text{If } \frac{\text{Waveform length}}{240} = \text{Integer value, then } (\Delta\text{tf}) \leq 200 \text{ ps}$$

$$\text{If } \frac{\text{Waveform length}}{240} = \text{Noninteger value, then } (\Delta\text{tf}) \leq \frac{120}{\text{sampling clock}}$$

Subsequences are simply a sequence that is inserted as part of another sequence. This feature allows the user to imbed another sequence of steps into a main sequence thus making the sequence much easier to view and effectively reducing the number of steps required.

There are two methods to edit a subsequence:

- Open the sequence (to be used as a subsequence) directly from the Sequence List. This opens the sequence in the main sequence editor.
- Open the subsequence from within the main sequence. When a sequence is being used as a subsequence, a subsequence editor is provided. The subsequence editor provides you with only the functions subsequencing supports.

To edit a subsequence with the subsequence editor, display the main sequence in the Sequence window. When a sequence is being used as a Subsequence, an arrow icon is displayed in the step number. Touch and hold or double-click the icon to display the subsequence editor.

Subsequence editing is performed the same as editing any sequence, but with the following limitations:

- Subsequences do not use any Wait conditions. If a wait condition is built into a sequence, the wait conditions are ignored if the sequence is used as a subsequence.
- Subsequences do not support Event Jumps or Pattern Jumps. If a jump is built into a sequence, the jumps are ignored if the sequence is used as a subsequence.
- You cannot jump or go to a step to the main sequence from a subsequence.
- If the subsequence uses a step definition of End (end of sequence) in the Go to column, it is redefined as Last (last step of the subsequence)
- If a sequence containing wait conditions and jump conditions is loaded into a sequence (thus becoming a subsequence), the wait conditions and jump conditions are ignored.

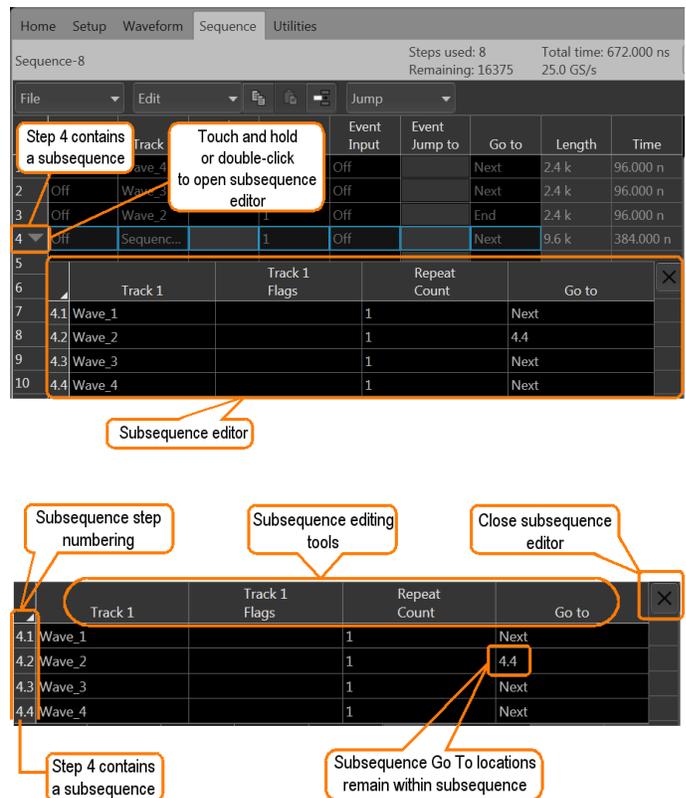


FIGURE 5.

Streaming ID

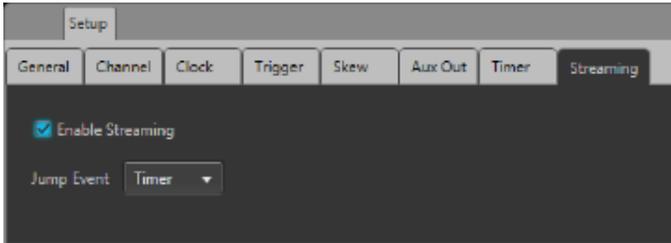


FIGURE 6.

Streaming ID allows you to directly control the sequence of waveforms played out of a predefined sequence. You control the sequencer actions by streaming instructions directly to the sequencer via the 10/100/1000 Ethernet Streaming ID connector on the rear panel. Streaming jump instructions directly to the sequencer via Ethernet greatly enhances the speed at which jumps are performed.

The jump commands are stored in an FIFO buffer. A jump event signal is used to step through the commands stored in the buffer. The jump event can either use an internal Timer or use the external A or B Trigger inputs.

To use Streaming ID:

- A sequence must be preloaded and placed into the Sequence List. The sequence track must be assigned to a channel.
- The sequence must be playing.

NOTE. When Streaming ID is enabled, the event jumps defined in the sequence tracks are ignored.

Please see AWG online help for more info on defining streaming packets and Sequencer control messages.

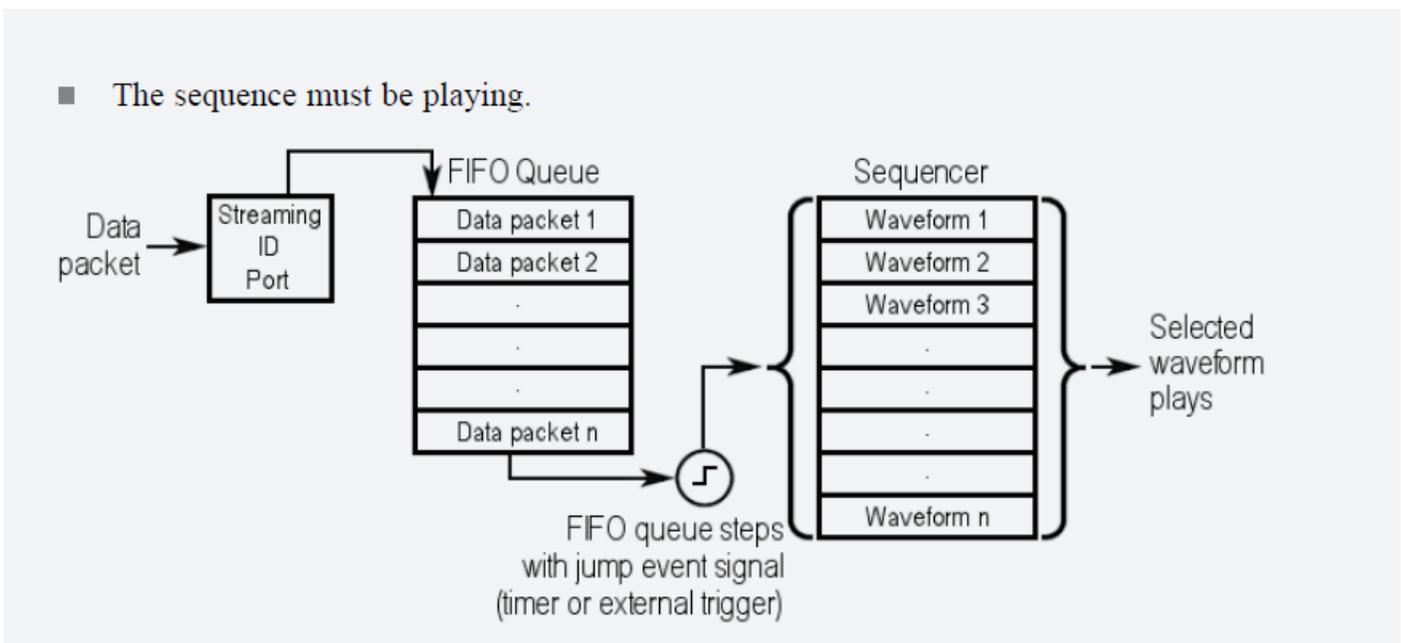


FIGURE 7.

Batch Sequence Compiler

The batch compiler provides a method to create sequences outside of the AWG70000 Series application using an Excel spreadsheet (.CSV file type). The comma delimited file type (.CSV) must be used.

To import the batch compiler file, you must use the Open File menu from the toolbar. Opening the file compiles all defined waveforms and loads the sequence into the Sequence List and loads all waveforms into the Waveform List.

Creating a batch compile file (.CSV)

The .csv file must be created with very specific information in the proper cells. Deviating from this design will likely create an invalid file. Following defines the rows, columns, and cell content required to create the batch file.

Header information. The first four lines in column A must use the content as shown.

BATCH COMPILER HEADER INFORMATION LINE	COLUMN A	COLUMN B
Line 1	AWG Sequence Definition	blank
Line 2	Sequence Name	Enter a name for your sequence. If omitted, the system will generate a unique name.
Line 3	Sample Rate	Enter the sampling rate to use. If omitted, the system calculates the sample rate based on the waveform frequency specified.
Line 4	Waveform Name Base	<p>Enter the base name for the waveform files. Use the following syntax:</p> <p><base name> [#Frequency_#Length_#Marker1_#Marker2]</p> <p>The base name is used for all waveforms. Optionally, you can include the additional waveform information.</p> <p>If omitted, the system will generate unique names.</p>

Track information. Following the header information is the start of the track definitions. You can create up to eight tracks containing multiple waveforms.

Each new track definition must start by creating a row with the name “Track” in cell A. This is where the definition of the track begins.

The following row contains the headings for the waveform parameters.

The rows following the parameter headings are the waveform definitions. The waveform definitions continue for the Track until another “Track” row is encountered.

BATCH COMPILER HEADER INFORMATION LINE		
A	Wait	Optional wait condition. Defaults to Off if not specified.
B	Repeat	Optional repeat element. Defaults to 1 if not specified.
C	Event Input	Optional event input. Defaults to Off if not specified.
D	Event Jump to	Optional event jump. Defaults to Next if not specified.
E	Go To	Optional go to element. Defaults to Next if not specified.
F	Flags	Optional flag element. Defaults to No Change if not specified.
G	Waveform Name	Optional waveform name. This supercedes the Waveform Name Base in the header information. If omitted, the Waveform Name Base is used.
H	Frequency	Specifies the frequency of the waveform to be compiled.
I	Length	Specifies the length in sample points of the waveform to be compiled. If omitted, the system calculates the length.
J	Marker1	Optional marker1 value. Defaults to 0 if not specified.
K	Marker2	Optional marker2 value. Defaults to 0 if not specified.
L	Editor	Optional Editor to use to compile waveform. If Editor is defined as Basic Waveform, then the following waveform parameters can be defined.
MNO	Parameters	Function: Defines the type of waveform to create. Defaults to Sine Wave. Amplitude: Sets the peak-to-peak amplitude. Defaults to 500 mVpp. Offset: Set the offset. Defaults to 0 V.

Conclusion

As you can see from this document, the sequencer option on the AWG70000B series enables and improves waveform output capabilities dramatically. Not only does it allow the user to run a series of waveforms automatically but it also allows for complex/pattern jumping, flag outputs, subsequences and batch compilation. The uses for this option are without a doubt one the main features of the AWG70000B series that set it apart from other AWG products.

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