APPLICATION NOTE 401

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True Arbitrary Waveform Generators Offer More Than Function Generators with Arbitrary Capability

Introduction

The purpose of this article is to provide an understanding of the basic differences between True and DDS Arbitrary Waveform Generators.

For the past decade or so, Arbitrary Waveform Generators (AWGs) have been used to replace an increasing variety of signal generation devices. These devices range from pulse generators, function generators, and sweep generators to low distortion oscillators. The main reasons for this trend is the multi-functional capability of today's AWGs and the growing demand for specialized signal creation. AWGs have the ability to serve as the traditional single-function generator of the past but with the added capability of arbitrary wave creation. Most engineers welcome this benefit for almost no difference in price.

With AWGs, there are two fundamental design variations: DDS (Direct Digital Synthesis) and True (Traditional) Arbitrary Waveform Generators. [2] Each design variation has its own unique advantages and disadvantages. Because the application determines instrument selection, an understanding of the basic differences between True and DDS AWGs is highly beneficial. .

DDS - Direct Digital Synthesis

The DDS–type AWG is more common than the traditional design or true AWG. It is usually combined with a function generator in the same box. We can speculate that the reason for the DDS's popularity is due to its simplicity and slightly lower cost. However, the simplicity and lower cost do not come without compromise. Because of the fundamental operation of a DDS device, it cannot be labeled as a True Arbitrary Waveform Generator. [4] A more appropriate term would be a function generator with arbitrary capability.

The DDS device operates with a fixed sample clock. [1,4] The shortcoming of this architecture is that when the user is attempting an arbitrary output and wishes to vary the output frequency, the instrument must compromise waveform data in order to compensate for the fixed sample clock. It does this by incorporating the use of a phase accumulator and phase increment register. [1] The exact operation and intricate description of how these devices operate is not important. Of most importance is the end result. A simple illustration and logic will make the same point. Consider the basic relationship between waveform output frequency, sampling rate and waveform data:

$$\text{OUTPUT FREQUENCY} = \frac{\text{SAMPLING RATE}}{\text{\# OF DATA POINTS}}$$

FIGURE 1: Simplified relationship between output frequency, sampling rate, and waveform data.

A DDS device generates a waveform at a certain frequency by outputting data from a lookup table at a rate determined by the sample clock. If the output frequency must be increased and the sample rate cannot change, then the number of output samples per waveform cycle must decrease. The DDS generator will skip wave data points in order to increase output frequency. [1,4]

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Similarly, if the output frequency must decrease and the sample rate remains unchanged, then the number of samples must increase. The DDS generator simply repeats data points. [1,4] This action alters the original scheme of waveform data resulting in a modified or compromised waveform.

The bottom line is that skipping or repeating data points may or may not be acceptable to the test engineer. In most cases, engineers would require that the data defining the wave shape would be accurately reproduced and not compromised in any way. This is especially true for precise simulations or pulse applications.

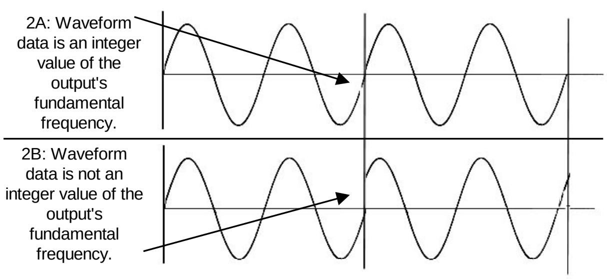

FIGURE 2: Illustration of phase truncation in the time domain.

Other errors associated with DDS-type generators are phase truncation and spectral leakage. [1] These wave replication errors are closely related and are caused by the limitations of a fixed sample clock or a limited useable amount of waveform data. The inconsistencies of phase truncation and spectral leakage are remedied in DDS devices by providing filters at the instrument's output. However, for detail-oriented waveforms, these problems must be addressed *before* they occur at the output. Otherwise, valuable waveform data becomes non-repeatable or lost. Thus, by design limitation, the DDS generator becomes inadequate for many applications requiring high-resolution and repeatable waveform production.

DDS generators do have some advantages over True AWGs. In fact, DDS designs have a much better ability to perform real-time, frequency sweeps. [4] They are also easier to use than True AWGs because there are less variables to control. And finally DDS devices typically cost less than a true AWG, which makes them very attractive for high volume, general-purpose applications.

True Arbitrary Waveform Generators

True Arbitrary Waveform Generators are usually bundled with a basic function generation capability. The standard function generator waveforms are actually created by predefined arbitrary waveform algorithms stored in waveform memory. This way the user has easy access to some of the more common wave shapes and can modify their parameters by simple data entry.

True AWGs cost slightly more than DDS Generators because their architecture is open and allows for expanded capabilities. It is good practice to invest into a system with open architecture. This allows the test system to be versatile and to accommodate future changes or upgrades with minimal effort. Some of the expanded capabilities of a true AWG include a variable sample clock, waveform sequencer and programmable synchronous outputs

A True AWG permits full control of the sample clock rate. Unlike a DDS generator, this allows the output waveform to be produced at varying frequencies without compromising waveform integrity. In a true AWG, if 1000 data points are used to define a waveform, every single data point is represented at the output and the waveform is consistently reproduced exactly the same way for every cycle. As a result of this consistency, a stable waveform is produced at the instrument's output with essentially no jitter and complete repeatability.

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Unlike DDS generators, True AWG waveform memory may be divided into to smaller segments of data. [3,5] Numerous independent waveforms can be created, stored and re-called independently.

True AWGs also have sequencers. A sequencer allows a series of waveform instructions to be created and stored into what is called a waveform sequence. A waveform sequence can be viewed as a wave execution program. Within a sequence, there are a number of steps. Each step calls a wave segment and instructs the address counter to loop the waveform a finite number of times.

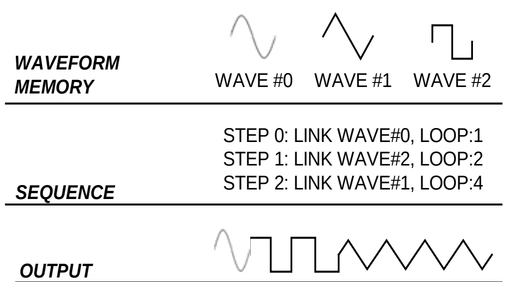

FIGURE 3: Example of how a sequencer builds waveforms from individual wave segments.

Once the looping is complete, the sequencer proceeds to the next step and loops the next segment and so on. [5] The sequencer adds tremendous leveraging power to a True AWG's memory and is very useful in applications that require extended waveform lengths.

Programmable synchronous outputs are provided in some AWGs and they allow multiple instruments to be controlled by a single AWG. Because they are fully programmable, synchronous outputs do not limit triggering to the start or end of a waveform. A trigger pulse may be initiated by any data point of the arbitrary waveform. [5]

In addition, some synchronous outputs allow an unlimited number of sync pulses to be generated for each sync output. This feature allows complex interaction between multiple instruments with respect to the arbitrary waveform and is very popular among integrators and test engineers. Some instruments provide up to four fully programmable synchronous outputs.

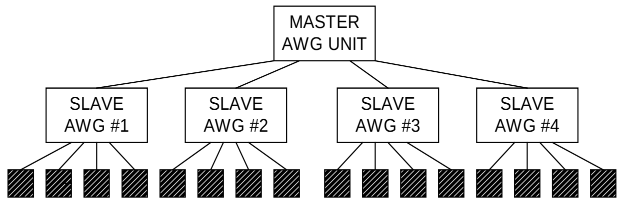

FIGURE 4: Multiple synchronous outputs can be used to cascade an unlimited number of instruments.

Similarities and Differences

True Arbitrary Waveform Generators and DDS Function Generators with Arbitrary Capability are similar in many ways. Both instruments are priced similarly and have built-in function generators for general-purpose applications.

Most models have waveform creation software that allows the user the flexibility of importing waveform data from a DSO (Digital Storage Oscilloscope) spreadsheet or other common data format. The software is also a useful tool for creating waveforms using standard waveform profiles with variable parameters, math functions or transfer functions. These tools add more capability to the waveform creation process and make AWGs preferable over traditional signal generation instruments.

In addition, DDS and True AWG designs both store waveform data in memory and produce an output at a rate determined by the sample clock. But this is where the similarities end.

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The most significant difference between the two design types is in the way that they execute the waveform data and produce their respective outputs. As we discussed, the DDS unit compensates for a fixed sample clock by using a phase accumulator. A true AWG will produce every data point at the output independent of the output frequency.

The phase accumulation technique does give the DDS generator an advantage over a True AWG. A DDS generator can produce manual frequency sweeps or adjustments much more efficiently than an AWG. A sweep function is also easier to setup in a DDS device since a DDS device's output frequency is independent of the number waveform data points wherein a True AWG it is not.

The True AWG allows more freedom in the creation and execution of waveform data by allowing the user to access a larger number of wave-defining variables including the number of samples per waveform and sample clock rate.

It adds even more capability with the addition of a sequencer and programmable synchronous outputs. Naturally, the addition of more capabilities and features means added complexity. But in many cases, the added capabilities and features are well worth the learning curve.

FIGURE 5: TEGAM-Pragmatic Model 2414B True AWG. Includes Variable Clock Rate, Sequence Generator and Multiple Programmable Sync Outputs.

Make the Best Choice

There are many features and functions to consider when evaluating a waveform generator for a specific application. If your application is complex, significant time should be invested in determining which instrument will be the best solution for the job.

FIGURE 6: TEGAM-Pragmatic Model 1404A DDS Function Generator. Includes Extended Sweep capabilities for applications such as ABS and Communications Testing.

Begin the instrument selection process by creating an accurate description of your waveform requirements. Draw the waveform(s) on a piece of graph paper and note the minimum and maximum frequency ranges, amplitude ranges and other characteristics that are absolutely necessary. Create a separate list of functions and features that are preferred, but not necessary.

It is very important that you define the requirements in terms of the waveform, not instrument specifications. This is because there is usually more than one way to perform a particular task.

For example, we made a general statement that a DDS generator would perform sweep functions better than a True AWG would. This is true in most cases. However, if the sweep function was limited to a single waveform, the swept waveform could be created with wave creation software and then reproduced with an AWG with no compromise in performance.

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On the other hand, it would be cumbersome to manually adjust the waveform's frequency sweep range with an AWG on a regular basis because the sweep function and frequency range must be calculated as a function of the variable clock rate. The ultimate factor in determining whether a True AWG or DDS generator would be a suitable solution is the application itself.

Consider the long-term use of the instrument. Weigh the advantages of expandability and open architecture . Is waveform detail critical or would a general purpose instrument be adequate? Would a sequencer ever be of value? Will there be interaction between the generator and external instruments? Will you ever need to upgrade the application and will the current design allow for the upgrade? Many secondary issues can be addressed early on to add to the expandability and versatility of your test design in the long term.

Summary

There are a number of pros and cons associated DDS and True AWG designs. The proper method of instrument selection requires a thorough understanding of the application and the differences between DDS and True AWG design. In many cases, either instrument will meet the required function but there is likely to be a compromise in waveform quality, user friendliness, efficiency or long-term versatility if improper selection is made. The involvement of a waveform Applications Engineer in the selection process is usually productive and is recommended for those who are restricted in time or expertise.

True AWG	DDS Function Generator
Variable Sample Clock	Fixed Sample Clock
Sequencer Option for Looping & Linking	No Sequencing Capability
Limited Sweep Capability	Versatile Sweep Capability
Best for Detail-Oriented, Repeatable and Stable Waveforms	Not Good for All Detail-Oriented Waveforms
Reproduces Entire Waveform Memory Contents Independent of Output Frequency	Output Frequency Determines Whether Waveform Data is Skipped or Repeated
Multiple Programmable Synchronous Outputs	Single, Non-Programmable Synchronous Output
More Complex to Use Due to More Control Parameters	Simple to Use Due to Less Parameters
Variable Filters – Usually User Selectable	Fixed Filters for Fixed Sample Clock Rate – Auto Selected
Waveform Memory can be partitioned into numerous segments and addressed separately.	Waveform memory cannot be partitioned. Entire contents are used.
Typically have lower distortion and noise levels for non-sinusoidal waves.	Typically have higher levels of distortion and noise for non-sinusoidal waves.
Typically require multiple filters at output due to variable sample clock.	Typically have a single filter at output.

FIGURE 7: A comparison between the common differences between True Arbitrary Waveform Generators and DDS Function Generators with Arbitrary Waveform Capability.

[1] HP 33120A Function Generator/ Arbitrary Waveform Generator User's Guide. August 1997.

[2] Rowe, Martin. "Differences Between Traditional and DDS-Based AWGs." Test & Measurement World May 1995: p.58

[3] Rowe, Martin. "Don't Let AWG Specs Confuse You" Test & Measurement World May 1995: pp.57-62

[4] Strassberg, Dan. "Choosing a Waveform Generator: The Devil is in the Details" EDN Magazine September 1, 1998

[5] TEGAM-Pragmatic Model 2411B 2MS/s Arbitrary Waveform Generator Operation Manual. 2000, REV B.

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