MEASUREMENT TIPS
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Comparing Function Generator Performance: Direct Digital Synthesis Versus Point-by-Point Technology

Snapshot

Engineers at a major consumer electronics manufacturer were working on a new design of a high-definition television (HDTV). The HDTV contained a serial flash memory device that used a serial peripheral interface (SPI) for data transmission. The engineers tested the data transmission and storage circuitry using an arbitrary waveform generator to create both a clock signal and a serial data stream. They tried an older DDS generator, but found that the relative timing of the signals was occasionally indeterminate, which caused errors in the stored data. This problem was a result of the combination of a fast clock and data stream jitter caused by the DDS implementation in the generator. The engineers then tried the Agilent 33522A dual-channel function/arbitrary waveform generator that uses PxP technology to produce waveforms. With this new generator, the engineers could reliably produce the clock and data stream waveforms, and the timing issues were eliminated.

Introduction

In 1939, Hewlett-Packard Company's founders, Bill Hewlett and Dave Packard, introduced HP's first product, the 200A audio oscillator. They used a Wien bridge resistance-tuned technology that included a light bulb for negative feedback circuit stabilization. More than 70 years later, Agilent Technologies, a spin-off of Hewlett-Packard that embodies the original test and measurement business, is still producing products related to that first HP oscillator, now called function/arbitrary waveform generators. The technologies used to produce the output waveforms have changed significantly – certainly, light bulbs are no longer used! Instead, the test and measurement industry has been using direct digital synthesis (DDS) as one technique for generating waveforms.

While DDS has served the industry well for many years, Agilent continues to innovate with its latest series of function/arbitrary waveform generators, the 33500 Series. These innovative instruments use a novel, patent-pending digital architecture that generates point-by-point (PxP) waveforms to provide high performance at low cost and low complexity. This measurement brief compares output performance features of a DDS function generator to those of a PxP generator.

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What are DDS and PxP?

DDS (direct digital synthesis) and PxP (point-by-point) are techniques used in function/arbitrary waveform generators to produce an analog waveform, such as a sine wave. Both techniques involve generating a time-varying signal represented in a digital format and then performing a digital-to-analog conversion to convert the digital data into an analog output.

DDS technology

With DDS technology, one cycle of the desired waveform is represented digitally in waveform memory. The contents of the waveform memory are read sequentially, which produces a stream of digital data representing the desired waveform. The stream of data drives the input of a digital-to-analog converter (DAC) whose analog output is a series of voltage steps closely approximating the desired waveform. Finally, the DAC output is applied to a low-pass anti-aliasing filter to smooth the voltage steps and produce the final output waveform. See **Figure 1** for a simplified block diagram.

DDS methodology sequentially reads waveform memory by using a high-resolution phase accumulator to drive the address input of the waveform memory. On every system clock pulse, the digital value in the phase accumulator is determined by adding a constant digital value, called the phase increment, to the phase accumulator's present value. The most significant bits of the phase accumulator's present value are clocked into the address input of the waveform memory. As a result, the phase increment determines how quickly the values in waveform memory are accessed, ultimately determining the frequency of the output waveform. With large phase increment values, one full cycle of data stored in waveform memory is accessed more quickly (some data points may be skipped) resulting in a higher-frequency output waveform. With small phase increment values, one full cycle of data stored in waveform memory takes longer to step through (some data points may be repeated), resulting in a lower-frequency output waveform.

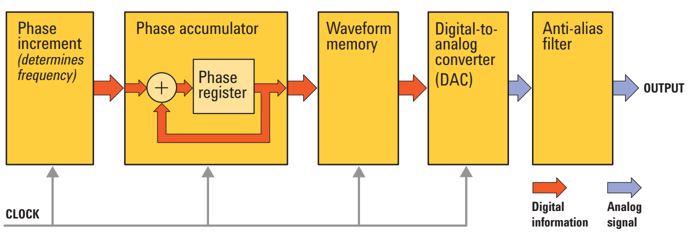

FIGURE 1. ***Simplified block diagram of DDS architecture***

The main performance advantages of using DDS technology are:

- Waveform frequency changes are phase-continuous
- Waveform frequency changes are very fast without unwanted effects
- Frequency resolution is digitally controlled and very good (μHz)
- Frequency modulation, phase modulation, and frequency sweeps are easily implemented
- Many of the drift problems associated with analog architectures are eliminated due to the digital nature of DDS

Despite all of the advantages of DDS, this technology does have a few significant disadvantages:

- The number of points in a waveform must be equal to an exact power of two
- Increased waveform jitter and distortion are possible

Since the number of points in waveform memory must be an exact power of two, the instrument must internally adjust the user-defined arbitrary waveform points to meet this requirement. As a result, the desired waveform is often modified in a way that changes its shape slightly. The increased jitter and distortion are even more serious disadvantages.

DDS methodology can skip or repeat points in the waveform memory lookup table, so arbitrary waveforms with sharp edges or narrow features such as square waves or pulses can suffer from significant jitter and distortion. See **Figure 2** for an example of jitter. The figure shows a scope screen shot of the output of a waveform generator set for a square wave created with the arbitrary waveform function using DDS technology. With the persistence of the scope set to infinite, it shows an accumulation of all scope traces (no scope trace is erased).

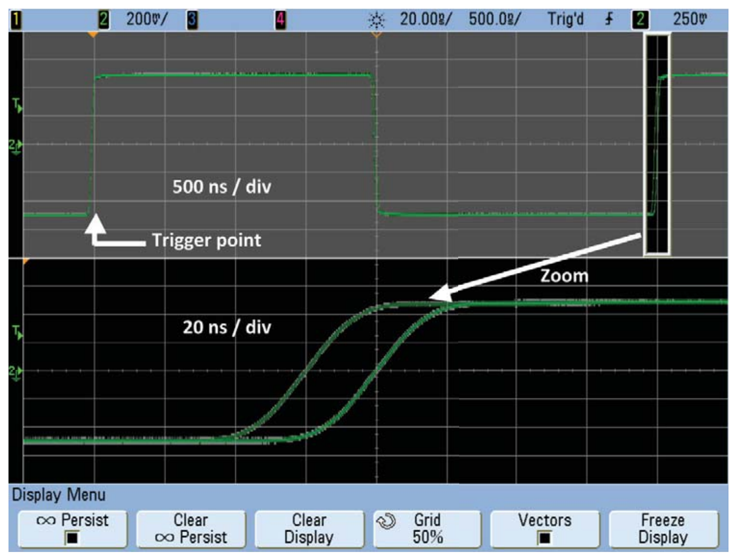

FIGURE 2. ***DDS technology shows 20 ns of jitter on a square wave created as an arbitrary waveform.***

The top half of the scope screen shows the square wave with the time base set to 500 ns/div while the bottom half is zoomed to 20 ns/div. The trigger point on the scope is very stable and does not move in time. However, you can see 20 ns of jitter at the beginning of the next cycle following each trigger. The jitter presents itself as two distinct starting points for that next cycle separated in time by the reciprocal of the frequency of the waveform generator reference clock. In this case, the reference clock is a 50-MHz clock, so the 20-ns uncertainty in the square wave cycles results from a single clock cycle regularly either skipping or repeating one data point in waveform memory due to the DDS methodology.

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If you are using a DDS arbitrary waveform generator such as the Agilent 33220A and you want to create a square wave or pulse function, for the best performance, use the built-in waveform instead of creating the waveform yourself with the arb function. The built-in square and pulse waveform generation techniques are different from the standard DDS technique. Agilent has carefully chosen these techniques to eliminate distortion due to aliasing at higher frequencies. The jitter shown in **Figure 2** on the square wave created as an arbitrary waveform would not be present using the built-in square wave function. Of course, the Agilent 33500 Series does not exhibit these waveform differences; the PxP technique used in the 33500 Series performs equally well when using either the built-in waveforms or the arb function. You will observe very low jitter in both cases.

PxP technology

As with DDS technology, PxP technology uses digital data in waveform memory to represent one cycle of the desired waveform. Also similar to DDS, a phase accumulator is used as the main component pacing the data to reproduce a waveform. Agilent's implementation of PxP adds to the design a patent-pending digital filtering technique that eliminates the most significant weakness of DDS. See **Figure 3.**

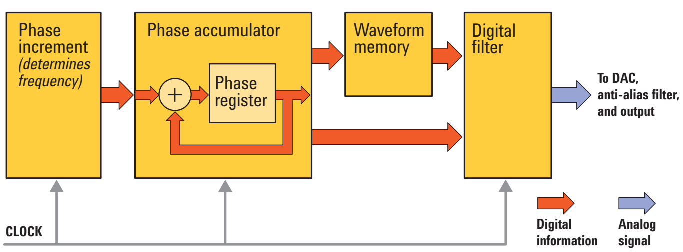

FIGURE 3. ***Simplified block diagram of PxP architecture***

As a result, PxP technology shares all of the performance advantages of DDS technology listed above. In addition, PxP offers the following significant advantages over DDS:

- Waveforms can have any length from 8 points to millions of points
- Arbitrary waveform reproduction is more accurate
- Waveforms have lower jitter, especially square waves and pulses
- Waveform segmentation and sequencing are possible

Since PxP methodology uses every point in waveform memory, no points are skipped or repeated, which means arbitrary waveforms are reproduced much more accurately. For a comparison of the performance of PxP and DDS, see **Figure 4**. It shows an example of an arbitrary waveform that consists of a square wave with nine spikes of diminishing magnitude added to the upper part of the waveform. The top waveform was created with a PxP generator (33521A) while the bottom waveform was created with a DDS generator (33220A). Identical arbitrary waveform data was loaded into each generator. The PxP generator reproduced the nine spikes accurately on every cycle while the DDS generator had different results on each cycle. As you can see in the figure, the DDS generator shows randomly missing spikes on some cycles, while other cycles had no spikes at all. Still other cycles had all nine spikes (not shown). The PxP generator reliably reproduced the entered waveform, while the DDS generator did not.

Using PxP, the jitter specification for the new 33500 Series is more than 25 times better than that of the previous generation of DDS products, such as the 33220A (less than 40 ps for the 33521A compared to more than 1000 ps for the 33220A). **Figure 5** shows virtually no jitter using PxP compared to the same conditions shown in **Figure 2** using DDS. Another advantage of PxP over DDS is that individual arbitrary waveforms can be combined into user-defined sequences to form longer, more complex waveforms.

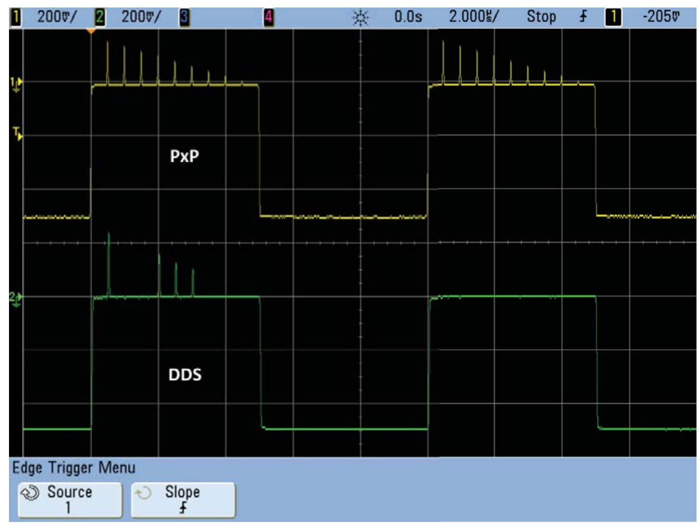

FIGURE 4. ***Comparison of PxP to DDS for an arbitrary waveform with nine spikes – DDS has spikes missing***

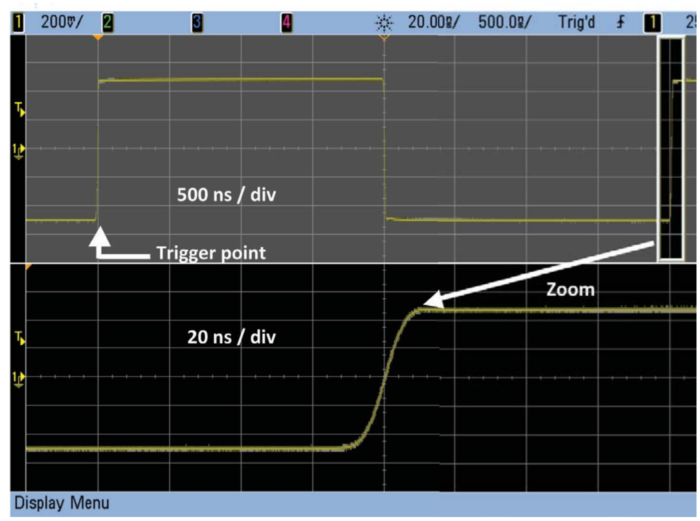

FIGURE 5. ***PxP technology shows virtually no jitter compared to the DDS waveform shown in Figure 2.***

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You can generate longer, more complex waveforms using waveform sequencing in an Agilent 33500 Series function/arbitrary waveform generator. PxP technology makes it possible to combine individual arbitrary waveforms (segments) into user-defined lists (sequences). You can choose from a variety of ways to control each segment in the list: play it a fixed number of times, play it once and then stop and wait for a trigger, repeat it until a trigger event occurs, or repeat it indefinitely. Additionally, you can specify the behavior of the sync output in each step. These choices provide you with great flexibility for creating complex arbitrary waveforms.

Conclusion

Direct digital synthesis (DDS) technology has served the function/arbitrary waveform generator industry very well for many years. This technology has been used by many instrument vendors to reproduce a wide range of waveforms, including sine, square, pulse, triangle, ramp, and user-defined arbitrary waveforms. While DDS is good in applications requiring dynamically changing frequencies, it has some serious drawbacks with respect to jitter and distortion. User-defined waveforms can have points added or points missing which produces undesired waveform characteristics. Starting with the 33500 Series function/arbitrary waveform generators, Agilent is now using point-by-point (PxP) technology to maintain all of the performance advantages of DDS and eliminate the disadvantages. Each point in waveform memory is used, and used only once, to produce the output waveform, which means waveforms are reproduced more faithfully. Jitter and distortion are significantly reduced. Additional capabilities such as waveform segmentation and sequencing are now possible. With this innovative and advanced technology, PxP should serve the function/arbitrary waveform generator industry very well for many years to come.

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