Oscilloscope Waveform Update Rate Determines Probability of Capturing Elusive Events

Application Note

How to Increase Your Odds of Finding Infrequent Glitches

Introduction

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Although often overlooked when evaluating performance of various oscilloscopes for purchase, waveform update rates can be extremely important—sometimes just as important as the traditional banner specifications including bandwidth, sample rate, and memory depth. Even though a scope's waveform update rate may appear fast and lively when viewing repetitively captured waveforms on your scope's display, “fast” is relative. For example, a few thousand waveforms per second will certainly appear lively and fast, but statistically speaking this can be very slow if you are attempting to capture a random and infrequent event that may happen just once in a million occurrences of a signal.

There are three reasons why fast update rates are important for today's oscilloscopes. First, if an oscilloscope updates waveforms very slowly, it can make using the oscilloscope very frustrating. If you rotate the timebase control, you expect the oscilloscope to respond immediately—not seconds later after the scope finishes processing data. Secondly, fast waveform update rates can improve oscilloscope display quality to show subtle waveform details such as noise and jitter with display intensity modulation. But most importantly, fast waveform update rates improve the scope’s probability of capturing random and infrequent events that may be keeping you up late at night.

Agilent’s InfiniiVision Series oscilloscopes not only provide the fastest waveform update rates when you use just the scope channels (up to 1,000,000 waveforms per second), but they also are the only MSOs in the industry that can maintain these fast update rates when you are using logic acquisition channels and/or serial bus decoding. Although other vendors may specify relatively fast banner waveform update rate specifications for their MSOs, when you use logic channels and/or serial bus decoding, these other scopes' update rates drop significantly.

This application note includes side-by-side measurement examples that compare the probabilities of capturing an anomalous event using various vendors’ MSOs. But let’s first review some of the factors that impact oscilloscope update rates, and then we will show you how to compute probabilities of capturing infrequent events.

Understanding Oscilloscope Dead Time

When you debug new designs, waveform and decode update rates can be critical—especially when you are attempting to find and debug infrequent or intermittent problems. These are the toughest kinds of problems to solve. Faster waveform and decode update rates improve a scope's probability of capturing elusive events. To understand why this is true, you must first understand what is known as oscilloscope "dead time" (sometimes referred to as "blind time.") All oscilloscopes have "dead time," as shown in Figure 1. This is the time between oscilloscope acquisitions when a scope processes the previously acquired waveform to display on the scope's display. During this processing or dead time, the scope is essentially "blind" to any signal activity that may be occurring within the design you are debugging.

Note the highlighted glitches shown in Figure 1 that occurred during the scope's dead time. After two oscilloscope acquisition cycles, these glitches would not be shown on the scope's display.

Determining an oscilloscope's dead-time percentage is pretty simple once you know the instrument's update rate. A scope's dead-time percentage is based on the ratio of the scope's acquisition cycle time minus the on-screen acquisition time, all divided by the scope's acquisition cycle time. The scope's acquisition cycle time is simply the inverse of the scope's waveform update rate, which must be measured for the particular setup condition used. The following equation summarizes how to compute an oscilloscope's dead-time percentage:

% DT = Scope's dead-time percentage
$$= 100 \times [(1/U) - W]/(1/U)$$
$$= 100 \times (1 - UW)$$
where
U = Scope's measured update rate
and
W = Display acquisition window = Timebase setting x 10

One ugly fact that most oscilloscope vendors won't readily admit is that an oscilloscope's dead-time is often orders-of-magnitude longer than its on-screen acquisition time—even in scopes that may specify remarkably fast update rates.

This means that capturing infrequent and elusive events on an oscilloscope is a gamble with odds or probabilities based on several different setup parameters. In fact, we can make a very close analogy between the probability of capturing random events on an oscilloscope to the probability of a specific side of a die landing up when rolling dice. Let's first address die rolling probabilities and then see how this relates to oscilloscope capture probabilities.

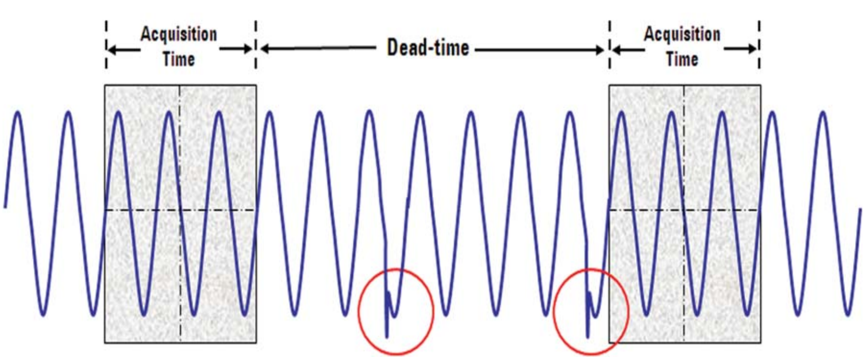

Figure 1. Oscilloscope dead-time versus display acquisition time.

Lessons in Rolling a Die

When you roll a single six-sided die one time, the probability of the die landing with a specific side up is one part in six. Pretty simple calculation! So what is the probability of obtaining a specific side up at least once if you roll the die two times? Intuitively, some might say two parts in six, or 33.3%, before completely thinking through this situation. But if this rationale were true, if you rolled the die 10 times you would have greater than a 100% probability of a specific side landing up at least once, which is not possible. The probability (P_N) in percent of a specific side of an "S" sided die landing up at least once after "N" rolls of the die is...

$$P_N = 100 \times (1 - [(S-1)/S]^N)$$

To understand this equation, it's actually easier to think of computing the probability of not obtaining a specific side as opposed to computing the probability of obtaining a specific side. The probability of not obtaining a specific side after one roll of the die is based on the "(S-1)/S" factor. So for a 6-sided die this is 5/6. The more times the die is rolled (N), the odds of not obtaining a specific side at least once go down exponentially. This means that the odds of obtaining a specific side up at least once go up, but these odds will never reach or exceed 100% probability.

For oscilloscope capture probabilities, "S" is the ratio of the average occurrence time of an anomalous event relative to the oscilloscope's

Figure 2. A multi-sided die with a "glitch" on just one side

display window time. So for example, if a glitch occurs once every 10 ms (100 times per second) and you have the oscilloscope's timebase set at 20 ns/div, then the on-screen acquisition time is 200 nanoseconds and S = 10 ms/200 ns, or 50,000.

In this example we effectively have a 50,000-sided die—as you might try to imagine by referring to the multi-sided die shown in Figure 2—that has a waveform anomaly on just one side. The odds of capturing a glitch once after just one acquisition are just 1 part in 50,000, and the odds of not capturing the glitch are 49,999 parts in 50,000.

To improve the scope's probability of capturing the infrequently occurring glitch during a fixed period of time requires that the scope try to acquire the signal multiple times—and as fast as possible. This is where the scope's waveform update rate factors into the equation. "N," which is now the number of oscilloscope acquisitions, is equal to the scope's waveform update rate multiplied times a reasonable observation time. The observation time is the time that you might be willing to view a waveform on the scope's display to determine if it is normal or not before moving your probe to another test point. So for an oscilloscope, the anomalous event capture probability equation reduces to...

$$P_t = 100 \times (1-[1-RW]^{(U \times t)})$$

where

- P_t = Probability of capturing anomaly in "t" seconds
- t = Observation time
- U = Scope's measured waveform update rate
- R = Anomalous event occurrence rate
- W = Display acquisition window = Timebase setting x 10

Side-by-Side Glitch Capture Comparisons

Using the above probability and dead-time equations we will make some measurement comparisons between two 500-MHz bandwidth oscilloscopes of similar performance characteristics and price range.

For this measurement comparison we used a real circuit that generated a random metastable state (infrequent glitch) approximately five times per second. We began with a Default Setup on each scope. Since the width of the glitch that we needed to observe was in the range of 5 to 15 ns wide, the optimum timebase setting for this particular measurement was 10 ns/div. No special functions such as measurements, waveform math, serial bus analysis, or digital channels of acquisition were turned on in order to maximize each scope's update rate. However, we did turn on five seconds of variable persistence on each scope, which did not affect either scope's best-case waveform update rate. Using each scope's default rising edge trigger condition with the trigger level set to +1.40 V, if the metastable state occurred during the scope's acquisition, then it should be observable near center-screen. To determine the probability of capturing the glitch on each scope, we assumed that 5 seconds was a reasonable observation time for our calculations.

In Figure 3 you can see that Agilent's 3000 X-Series scope reliably captured multiple occurrences of the random and infrequent metastable state within five seconds while updating waveforms at 1,000,000 waveforms/s.

The dead-time percentage of this measurement on the Agilent 3000 X-Series scope was determined to be:

$$\% DT = 100 \times (1 - ^{(1{,}000{,}000/s \times 100\ ns)}) = 90\%$$

Even though the dead-time percentage of this scope was approximately 90% with the timebase set at 10 ns/div—which intuitively may appear to be excessively long—the probability of capturing the glitch within 5 seconds was actually very high, as determined by the following probability calculation:

$$P_{(5s)} = 100 \times (1 - [1 - (5/s \times 100\ ns)]^{(1{,}000{,}000/s \times 5s)}) = 91.8\%$$

Using Tektronix' DPO/MSO3000 Series oscilloscope, the measurement results were significantly different, as shown in Figure 4. Although the "banner" waveform update rate of this scope is specified to update at rates up to 55,000 waveforms/s, when operating at 10 ns/div, the maximum update rate is just 2,600 waveforms/s. Below is the dead-time percentage of the Tektronix MSO3000 Series oscilloscope for this same measurement:

$$\% DT = 100 \times (1 - ^{(2600/s \times 100\ ns)}) = 99.97\%$$

The reason we failed to see the infrequent metastable state after five seconds of observation time using the Tektronix scope was because the probability of capturing the glitch was low due to the long dead-time. If you suspect that your signals may have a problem, and if you are willing wait long enough, this scope will eventually capture the metastable state. Below is the probability calculation of capturing the glitch after a five second observation time using the Tektronix DPO/MSO3000 Series oscilloscope:

$$P_{(5s)} = 100 \times (1 - [1 - (5/s \times 100\ ns)]^{(2600/s \times 5s)}) = 0.65\%$$

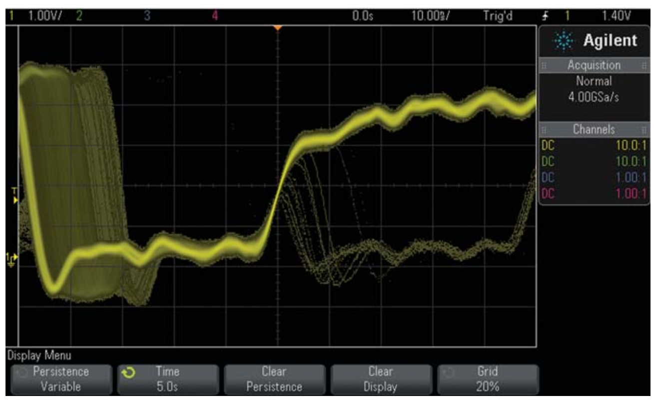

Figure 3: The Agilent MSO/DSO3000 X-Series oscilloscope reliably captures the infrequently occurring metastable state while updating at 1,000,000 waveforms per second.

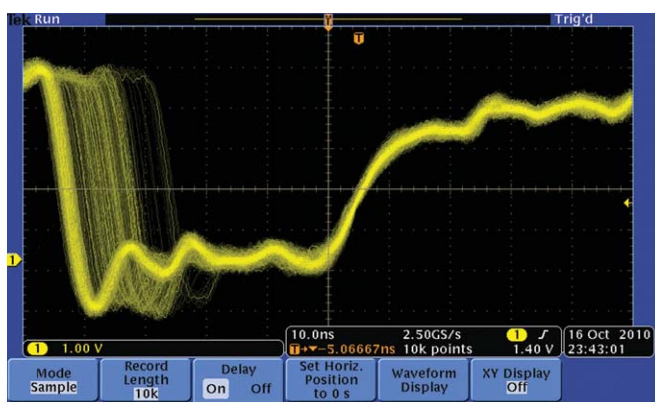

Figure 4: The Tektronix DPO/MSO3000 Series scope virtually never captures the infrequently occurring metastable state while updating at just 2,600 waveforms per second.

Determining a Scope's Actual Waveform Update Rate

There are many factors that can affect an oscilloscope's waveform update rate. Oscilloscope vendors will typically highlight just the scope's "banner" or best-case waveform update rate, which is often obtained under a very limited set of setup conditions.

A scope's timebase setting is usually the primary setup condition that affects update rates. This is because the timebase setting determines the acquisition display window of time. As you adjust the scope's timebase to longer time-per-division settings, the scope will digitize longer waveforms. For instance, at 2 ms/div the scope's on-screen acquisition time is 20 ms. If a scope had zero dead time, which is theoretically impossible, the absolute best-case waveform update rate would be 50 waveforms per second (1/20 ms).

If it is important for you to know what your scope's waveform and decode update rates are, then it must be measured under the various setup conditions that you anticipate using. Don't simply rely on the scope vendor's banner update rate claim.

Measuring a scope's update rate is not that difficult. Most scopes provide a trigger output signal—typically used to synchronize other instruments to the scope's triggering. You can measure a scope's update rate by measuring the average frequency of this output trigger signal using an external counter. Remember, the potential trigger rate of the signal used as an input trigger source for the scope must exceed the scope's anticipated update rate. Otherwise the scope's update rate will be limited by the slower trigger rate.

Tables 1, 2, and 3 show side-by-side measured waveform update rates of competitively priced 100-MHz, 500-MHz, and 1-GHz bandwidth scopes respectively. The test began by defaulting each scope's setup condition. Only one channel of the scope was turned on for these tests. Memory depth was optimized at each timebase range by selecting the minimum amount of acquisition memory that would also provide the maximum available sample rate. Note that with Agilent's Mega*Zoom* technology, this is automatic.

Measured waveform update rates (100-MHz bandwidth oscilloscopes)

Timebase	Agilent 2000 X-Series	Tek DPO2000 Series	Tek TDS2000 Series	LeCroy WaveJet
2 ns/div	54,000	140	60	1,000
5 ns/div	54,000	130	60	1,000
10 ns/div	54,000	130	60	1,000
20 ns/div	54,000	160	60	1,000
50 ns/div	54,000	220	60	1,000
100 ns/div	52,000	6,200	50	1,000
200 ns/div	49,000	5,500	100	1,000
500 ns/div	43,000	4,200	100	1,000
1 µs/div	35,000	2,300	100	625
2 µs/div	26,000	2,000	100	300
5 µs/div	18,000	2,000	100	150
10 µs/div	9,000	1,400	100	70
20 µs/div	4,500	1,200	100	35
50 µs/div	1,800	400	90	35
100 µs/div	900	180	90	35
200 µs/div	460	120	200	35
500 µs/div	170	80	140	25
1 ms/div	60	60	80	20
2 ms/div	43	30	40	15
5 ms/div	~18	~20	~20	~10
10 ms/div	~9	~8	~10	~7
20 ms/div	~5	~4	~4	~4
50 ms/div	~2	~2	~2	~2
100 ms/div	~1	~1	~1	~1

Table 1: Best-case waveform update rates of competitively priced, 100-MHz bandwidth oscilloscopes

Measured waveform update rates (500-MHz bandwidth oscilloscopes)

Timebase	Agilent 3000 X-Series	Tek DPO3000 Series	Tek TDS3000 Series	LeCroy WaveSurfer
1 ns/div	960,000	2,500	670	490
2 ns/div	960,000	2,500	670	470
5 ns/div	960,000	2,500	670	485
10 ns/div	1,030,000	2,600	770	480
20 ns/div	960,000	2,200	770	420
50 ns/div	570,000	46,000	770	410
100 ns/div	340,000	46,000	770	400
200 ns/div	170,000	46,000	770	250
500 ns/div	74,000	43,000	770	220
1 µs/div	38,000	7,300	770	190
2 µs/div	19,000	4,400	770	145
5 µs/div	7,800	2,500	770	75
10 µs/div	3,900	200	500	50
20 µs/div	2,000	200	500	25
50 µs/div	780	150	430	12
100 µs/div	780	25	330	6
200 µs/div	450	18	250	6
500 µs/div	170	18	160	6
1 ms/div	60	16	77	~6
2 ms/div	43	14	42	~6
5 ms/div	18	11	~20	~5
10 ms/div	9	6	~10	~4
20 ms/div	~5	~4	~5	~3
50 ms/div	~2	~2	~2	~1.5
100 ms/div	~1	~1	~1	~0.8

Table 2: Best-case waveform update rates of competitively priced, 500-MHz bandwidth oscilloscopes

Measured waveform update rates (1-GHz bandwidth oscilloscopes)

Timebase	Agilent 4000 X-Series	Tek DPO4000 Series	LeCroy WaveRunner
500 ps/div	1,020,000	2,500	490
1 ns/div	1,010,000	2,500	490
2 ns/div	1,000,000	2,500	470
5 ns/div	990,000	2,500	485
10 ns/div	1,030,000	2,500	480
20 ns/div	880,000	58,000	420
50 ns/div	490,000	58,000	410
100 ns/div	280,000	58,000	400
200 ns/div	140,000	48,000	250
500 ns/div	60,000	10,000	220
1 µs/div	30,000	4,700	190
2 µs/div	15,000	2,500	145
5 µs/div	6,300	360	75
10 µs/div	3,200	290	50
20 µs/div	1,600	150	25
50 µs/div	1,300	25	12
100 µs/div	900	17	6
200 µs/div	430	11	6
500 µs/div	170	11	6
1 ms/div	85	10	~6
2 ms/div	40	9	~6
5 ms/div	18	8	~5
10 ms/div	9	5	~4
20 ms/div	~5	~3	~3
50 ms/div	~2	~2	~1.5
100 ms/div	~1	~1	~0.8

Table 3: Best-case waveform update rates of competitively priced, 1-GHz bandwidth oscilloscopes

Summary

If finding and debugging random and infrequent problems is important to you, then waveform update rates are an important consideration in choosing the oscilloscope for your measurements. Update rates directly determine an oscilloscope's probability of capturing and displaying random circuit problems.

Although this application note focused primarily on best-case waveform update rate comparisons while using just analog channels of acquisition, you should be aware that waveform update rates on most scopes degrade significantly when using digital channels of acquisition (MSO models) and/or serial bus decoding—especially when deep memory is enabled.

Agilent's fourth-generation InfiniiVision Series oscilloscopes provide the fastest waveform and serial decode update rates in the oscilloscope industry (up to 1,000,000 waveforms per second). InfiniiVision MSOs do not compromise update rates when you use logic channels and serial bus decoding capabilities. Agilent's InfiniiVision DSOs and MSOs achieve fast, uncompromised update rates through a higher level of hardware integration (Mega*Zoom* technology) that minimizes oscilloscope dead-time.

Glossary

Dead time the time an oscilloscope uses to process digitized waveforms for display; during dead time, the scope is essentially "blind" to any signal activity

Mega*Zoom* IV technology an Agilent-proprietary acquisition and display technology that provides extremely fast waveform and serial bus decode update rates (more than 1,000,000 real-time waveforms per second on InfiniiVision 3000 X-Series oscilloscopes), while automatically optimizing memory depth and sample rate

Metastable state an unstable output condition of a digital circuit usually exhibited as a glitch and caused by a setup and/or hold-time violation of the inputs

Mixed signal oscilloscope (MSO) an oscilloscope with additional channels of logic timing analysis with direct time correlation and combinational logic/pattern triggering across both analog and digital inputs

Waveform update rate the number of waveforms an oscilloscope can capture and display in one second

Related literature

Publication title	Publication type	Publication number
Agilent InfiniiVision 2000 X-Series Oscilloscopes	Data Sheet	5990-6618EN
Agilent InfiniiVision 3000 X-Series Oscilloscopes	Data Sheet	5990-6619EN
Agilent InfiniiVision 4000 X-Series Oscilloscopes	Data Sheet	5991-1103EN
Agilent InfiniiVision Series Oscilloscope Probes and Accessories	Data Sheet	5968-8153EN
Oscilloscope Sample Rates vs. Sampling Fidelity	Application Note	5989-5732EN
Evaluating Oscilloscope Vertical Noise Characteristics	Application Note	5989-3020EN
Evaluating Oscilloscope Bandwidth for your Applications	Application Note	5989-5733EN
Oscilloscope Display Quality Impacts Ability to View Subtle Signal Details	Application Note	5989-2003EN
Evaluating Oscilloscopes to Debug Mixed-Signal Designs	Application Note	5989-3702EN

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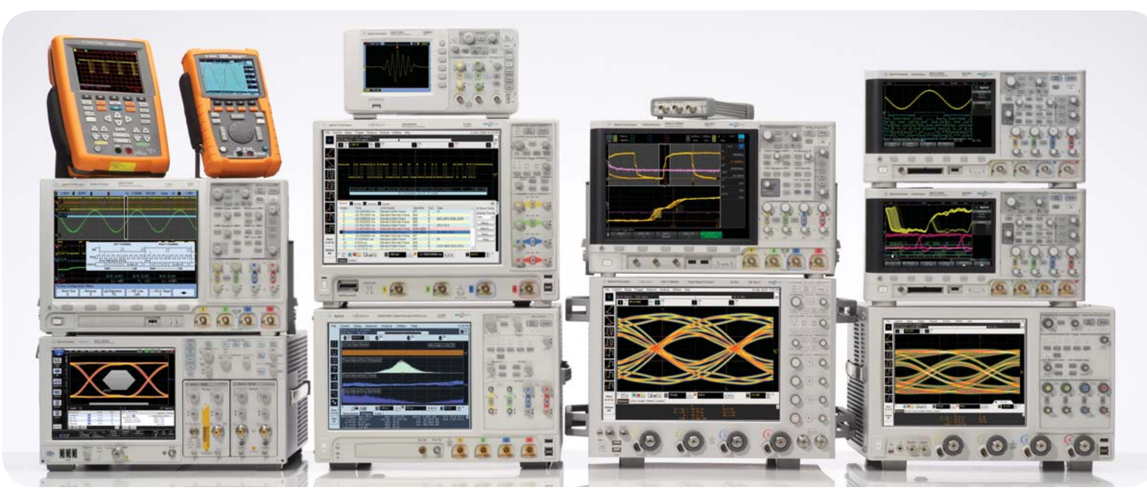

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