Can Your Oscilloscope Capture Elusive Events?

Why Waveform Update Rate Matters

Introduction

Waveform update rate can be extremely important when evaluating oscilloscopes for purchase. Although this specification is often overlooked, it can have a direct impact on your ability to capture a random and infrequent event which occurs just once in a million occurrences of your signal. There are three reasons why fast update rates are important for today's oscilloscopes:

1. **Scope Performance.** If an oscilloscope updates waveforms very slowly, it makes using the oscilloscope very difficult. When you rotate the timebase control, you expect the oscilloscope to respond immediately — not seconds later after the scope has finished processing the data.
2. **Detailed Display.** A fast waveform update rate can improve the oscilloscope's display quality to show subtle waveform details such as noise and jitter with display intensity modulation.
3. **Glitch Capture.** A fast waveform update rate increases the scope's probability of capturing random and infrequent events in your signal that may be unreliable.

A Keysight InfiniiVision 4000 X-Series Mixed Signal Oscilloscope

Waveform update rate is an important specification, but the update rate specification itself may be misleading. Even if your oscilloscope's data sheet specifies a fast update rate, it still may not be able to capture a glitch in your system. Learn how to measure the actual update rate of your scope then compare glitch capture and update rates across oscilloscope brands.

Understanding Oscilloscope Dead Time

When debugging new designs, waveform and decode update rates are critical — especially when attempting to find and debug infrequent or intermittent problems. 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 oscilloscope dead time (sometimes referred to as "blind time"). All oscilloscopes have dead time, as shown in Figure 1. This is the time between the oscilloscope acquiring the signal and the scope processing the previously acquired waveform for display on the scope's screen. During this dead time, the scope is essentially "blind" to any signal activity that may occur within the design you are debugging.

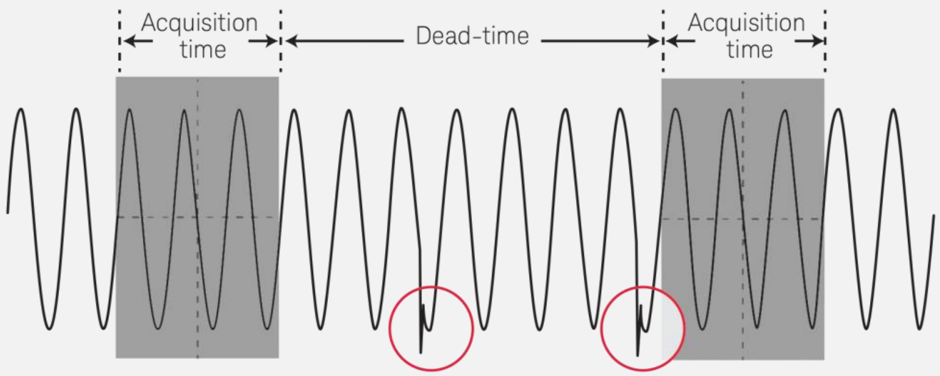


Figure 1. Oscilloscope dead time versus display acquisition time.

The highlighted glitches shown in Figure 1 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 simple once the instrument's update rate is known. A scope's dead time percentage is based on the ratio of the scope's acquisition cycle time minus the on-screen acquisition time, 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.

$$\%DT = \text{Scope's dead time percentage}$$

$$= 100 \times \frac{\left[\left(\frac{1}{U}\right) - W\right]}{\left(\frac{1}{U}\right)}$$

$$= 100 \times (1 - UW)$$

where

U = Scope's measured update rate

W = Display acquisition window

= Timebase setting x 10

An oscilloscope's deadtime is often orders of magnitude longer than its on-screen acquisition time — even in scopes that may specify remarkably fast update rates. This means capturing infrequent and elusive events on an oscilloscope is a gamble with odds, or probabilities, based on several different setup parameters. There is an analogy between the probability of capturing random events on an oscilloscope and the probability of rolling a specific number when rolling a die.

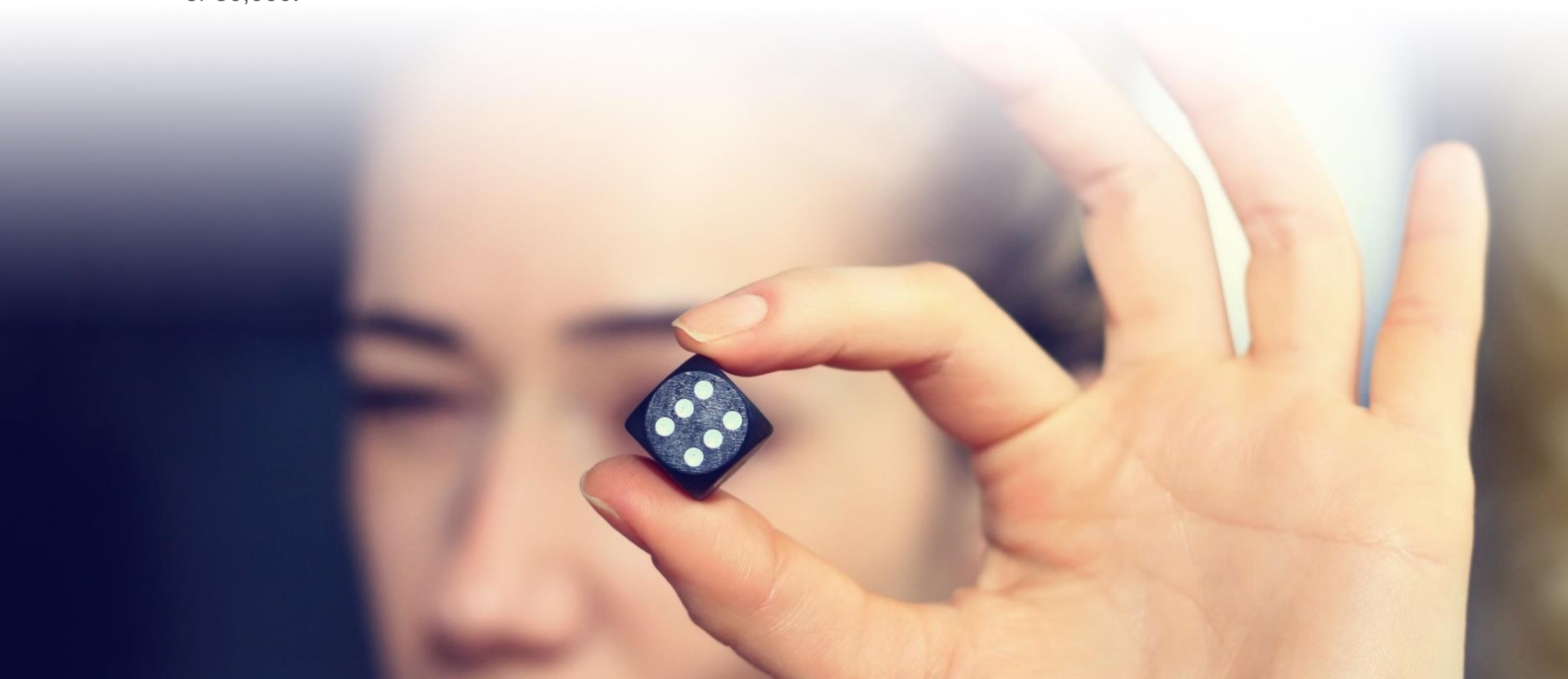
Lessons in Rolling a Die

When you roll a six-sided die once, the probability of the die landing with a specific side up is one part in six. So what is the probability of obtaining a specific side up at least once if you roll the die two times? Some might say two parts in six, or 33.3%. If this rationale were true, rolling the die 10 times would have a greater than a 100% probability of a specific side landing up at least once. However, this is not possible. The probability (P_N) percentage of a specific side of an "S" sided die landing up at least once after "N" rolls of the die can be determined by the following equation:

$$P_N = 100\ x\ \left(1 - \left[\frac{(S-1)}{S}\right]^N\right)$$

To understand the equation, think of computing the probability of not 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 goes down exponentially. This means the odds of obtaining a specific side up increases; 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 display window time. For example, if a glitch occurs once every 10 ms (100 times per second), and the oscilloscope's timebase is set at 20 ns/div, then the on-screen acquisition window is 200 nanoseconds (since 10 divisions are present on-screen) and S = 10 ms/200 ns, or 50,000.



Increasing the scope's probability of capturing the infrequently occurring glitch during a fixed period of time requires the scope to acquire the signal multiple times, 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 by a reasonable observation time. The observation time is the time that you would be willing to view a waveform on the scope's display to determine if it is normal before moving your probe to another test point.

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

where

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

Figure 2. A multisided die with a "glitch" on just one side.

Determining a Scope's Actual Waveform Update Rate

Many factors affect an oscilloscope's waveform update rate. A scope's timebase setting is usually the primary setup condition that affects update rates as it determines the acquisition display window of time. When 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). So, what is the actual update rate of your scope?

In order to know your scope's actual waveform and decode update rates, you must measure the rates under the various setup conditions that you anticipate using.This is an easy task as 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. The test began by defaulting each scope's setup condition with only one channel turned on. 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. This function is automatic with Keysight's MegaZoom technology.

Measured Waveform Update Rates (100-MHz Bandwidth Oscilloscopes)

Timebase	Keysight 2000 X-Series	Tek DPO20000 Series	Tek TDS2000 Series	LeCroy WaveJet
2 ns/div	236,000	140	60	1,000
5 ns/div	236,000	130	60	1,000
10 ns/div	236,000	130	60	1,000
20 ns/div	246,000	160	60	1,000
50 ns/div	241,000	220	60	1,000
100 ns/div	209,000	6,200	50	1,000
200 ns/div	168,000	5,500	100	1,000
500 ns/div	113,000	4,200	100	1,000
1 µs/div	62,000	2,300	100	625
2 µs/div	31,300	2,000	100	300
5 µs/div	13,500	2,000	100	150
10 µs/div	6,800	1,400	100	70
20 µs/div	3,400	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	180	80	140	25
1 ms/div	90	60	80	20
2 ms/div	45	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 and 1 GHz Bandwidth Oscilloscopes)

Timebase	Keysight 3000 X-Series	Tek MDO3000 Series (normal/DPO acquisition)	Tek MDO3000 Series (w/ FastAcq mode on)	LeCroy WaveSurfer
1 ns/div	960,000	2,300	280,000	490
2 ns/div	960,000	2,300	280,000	470
4 ns/div	N/A	2,300	280,000	N/A
5 ns/div	960,000	N/A	N/A	485
10 ns/div	1,030,000	2,200	280,000	480
20 ns/div	960,000	69,000	280,000	420
40 ns/div	N/A	64,000	280,000	N/A
50 ns/div	570,000	N/A	N/A	410
100 ns/div	340,000	64,000	260,000	400
200 ns/div	170,000	59,000	190,000	250
400 ns/div	N/A	51,000	120,000	N/A
500 ns/div	74,000	N/A	N/A	220
1 µs/div	38,000	35,000	62,000	190
2 µs/div	19,000	24,000	34,000	145
4 µs/div	N/A	15,000	18,000	N/A
5 µs/div	7,800	N/A	N/A	75
10 µs/div	3,900	6,600	7,300	50
20 µs/div	2,000	3,500	3,700	25
40 µs/div	N/A	1,800	1,800	N/A
50 µs/div	780	N/A	N/A	12
100 µs/div	780	730	740	6
200 µs/div	450	370	370	6
400 µs/div	N/A	190	190	N/A
500 µs/div	170	N/A	N/A	6
1 ms/div	60	75	75	~6
2 ms/div	43	37	37	~6
4 ms/div	N/A	19	19	N/A
5 ms/div	18	N/A	N/A	~5
10 ms/div	9	~7	~7	~4
20 ms/div	~5	~4	~4	~3
40 ms/div	N/A	~2	~2	N/A
50 ms/div	~2	N/A	N/A	~1.5
100 ms/div	~1	~1	~1	~0.8

Table 2. Best-case waveform update rates of competitively priced, 500 MHz and 1 GHz bandwidth oscilloscopes.

Measured Waveform Update Rates (1 GHz Bandwidth Oscilloscopes)

Timebase	Keysight 4000 X-Series	Tek MDO4000 Series (normal/DPO acquisition)	Tek MDO4000 Series (w/ FastAcq mode on)	LeCroy WaveRunner
500 ps/div	1,020,000	2,600	340,000	490
1 ns/div	1,010,000	2,900	340,000	490
2 ns/div	1,000,000	2,900	340,000	470
4 ns/div	N/A	2,900	340,000	N/A
5 ns/div	990,000	N/A	N/A	485
10 ns/div	1,030,000	2,800	340,000	480
20 ns/div	880,000	78,000	330,000	420
40 ns/div	N/A	76,000	330,000	N/A
50 ns/div	490,000	N/A	N/A	410
100 ns/div	280,000	72,000	270,000	400
200 ns/div	140,000	65,000	200,000	250
400 ns/div	N/A	55,000	130,000	N/A
500 ns/div	60,000	N/A	N/A	220
1 µs/div	30,000	37,00	62,000	190
2 µs/div	15,000	25,000	34,000	145
4 µs/div	N/A	15,000	17,000	N/A
5 µs/div	6,300	N/A	N/A	75
10 µs/div	3,200	6,700	7,200	50
20 µs/div	1,600	3,500	3,700	25
40 µs/div	N/A	1,700	1,800	N/A
50 µs/div	1,300	N/A	N/A	12
100 µs/div	900	730	740	6
200 µs/div	430	370	370	6
400 µs/div	N/A	190	190	N/A
500 µs/div	170	N/A	N/A	6
1 ms/div	85	75	75	~6
2 ms/div	40	38	38	~6
4 ms/div	N/A	19	19	N/A
5 ms/div	18	N/A	N/A	~5
10 ms/div	9	~7	~7	~4
20 ms/div	~5	~4	~4	~3
40 ms/div	N/A	~2	~2	N/A
50 ms/div	~2	N/A	N/A	~1.5
100 ms/div	~1	~1	~1	~0.8

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

Glitch Capture Comparisons

Using the above probability and dead time equations, measurement comparisons were made between two 1 GHz bandwidth oscilloscopes of similar performance characteristics and price range. Our comparison consisted of a circuit that generated a random metastable state (infrequent glitch) approximately five times per second with the Default Setup option on for each scope. Since the width of the glitch was between 5 to 15 nanoseconds wide, the optimum timebase setting for this particular measurement was 10 ns/div. Special functions such as measurements, waveform math, serial bus analysis, or digital channels of acquisition were not activated in order to maximize each scope's update rate.

In addition, five seconds of variable persistence for each scope was activated, which did not affect either scope's best-case waveform update rate. Each scope's default "rising edge" trigger condition was used with the trigger level set to ~68 mV so the metastable state could be observable near center screen should the glitch occur during the scope's acquisition. To determine the probability of capturing the glitch on each scope, five seconds was demmed a reasonable observation time for our calculations.

In Figure 3, the Keysight's 3000 X-Series scope was able to consistantly capture and display the random and infrequent metastable state within five seconds.

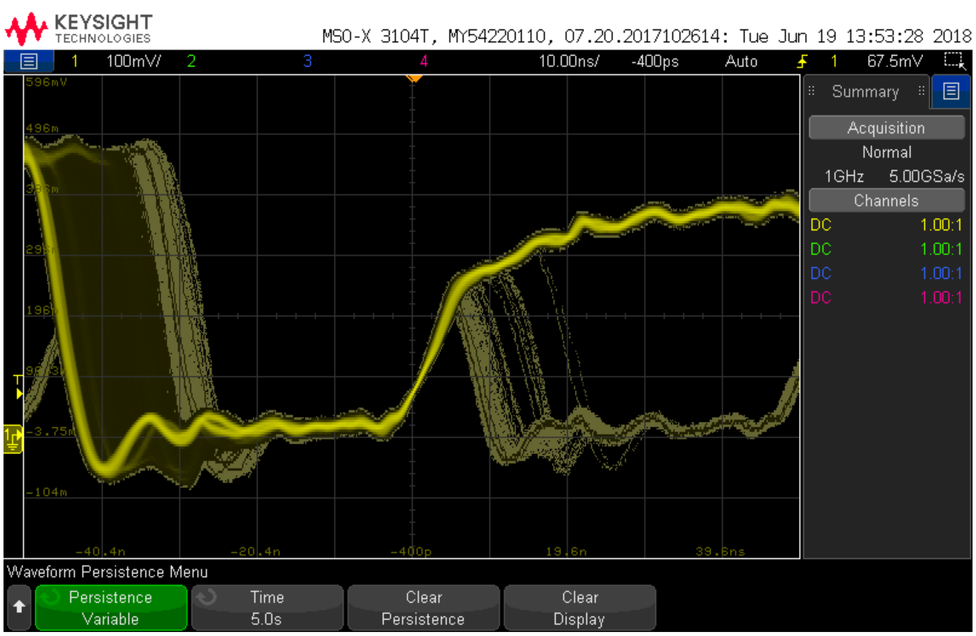


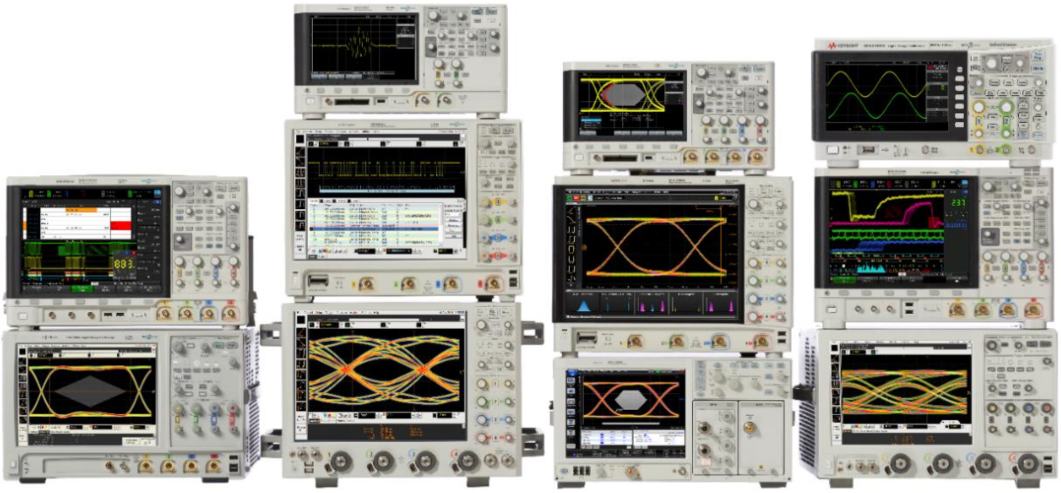
Figure 3. The MSO3000 X-Series oscilloscope reliably captures the infrequently occurring metastable state while updating at 1,030,000 waveforms/s.

The dead time percentage of this measurement on Keysight's 3000 X-Series scope was determined to be:

$$
\begin{aligned}
\%DT &= 100\ \times (1 - UW) \\
U &= 1{,}030{,}000\ waveforms/s \\
W &= 10\frac{ns}{div} \times 10\ divisions \\
&= 100\ ns = 0.0000001s \\
\%DT &= 100\ \times \big(1 - (1{,}030{,}000 \times 0.0000001)\big) \\
&= 89.70\%
\end{aligned}
$$

Athough the dead time percentage of this scope was approximately 90% with the timebase set to 10 ns/div — which may appear to be excessively long — the probability of capturing the glitch within five seconds is actually very high. The probability for this scope was determined by the following calculation where U and W are the same values as above:

$$
\begin{aligned}
P_t &= 100\ \times \big(1 - [1 - RW]^{(U \times t)}\big) \\
R &= 5\ waveforms/s \\
t &= 5\ s \\
P_{5s} &= 100\ \times \big(1 - [1 - (5 \times 0.0000001)]^{(1{,}030{,}000 \times 5)}\big) \\
&= 92.38\%
\end{aligned}
$$



Using Tektronix MDO3000 Series oscilloscope, the results are significantly different, as shown in Figures 4 and 5. Although the banner waveform update rate of this scope in normal/DPO acquisition mode is >50,000 waveforms/s, when operating at 10 ns/div, the maximum update rate is just 2,200 waveforms/s, as found in Table 2 above. This is about 468 times slower than the Keysight 3000 X-Series scope mentioned before.

Enabling FastAcq acquisition mode increases the update rate to 280,000 waveforms/s but slows the scope down and hinders its ability to perform other functions simultaneaously. For example, the 'Snapshot All Measurements' functionality is disabled while FastAcq is in use.

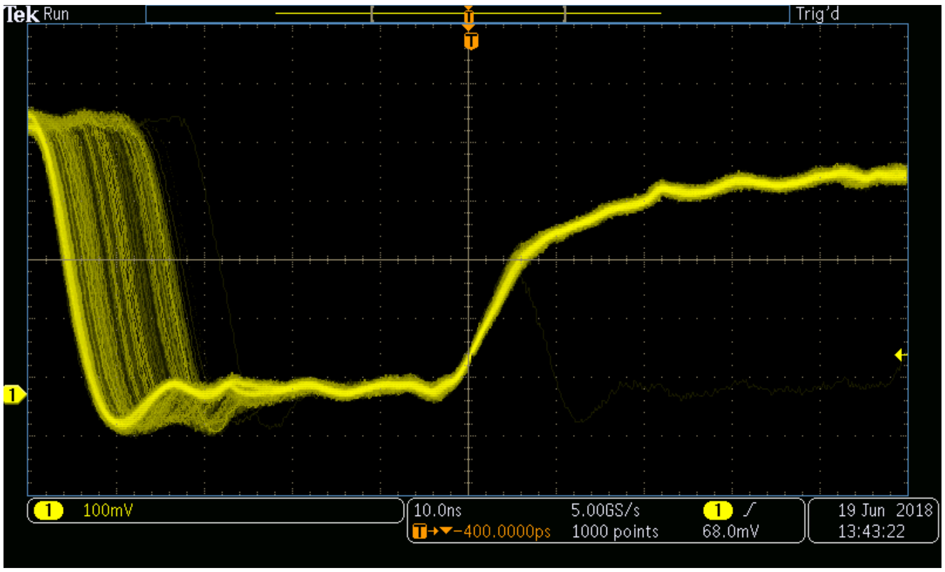


Figure 4. Tektronix MDO3000 Series scope marginally captures the infrequently occurring metastable state while updating at 2,200 waveforms per second.

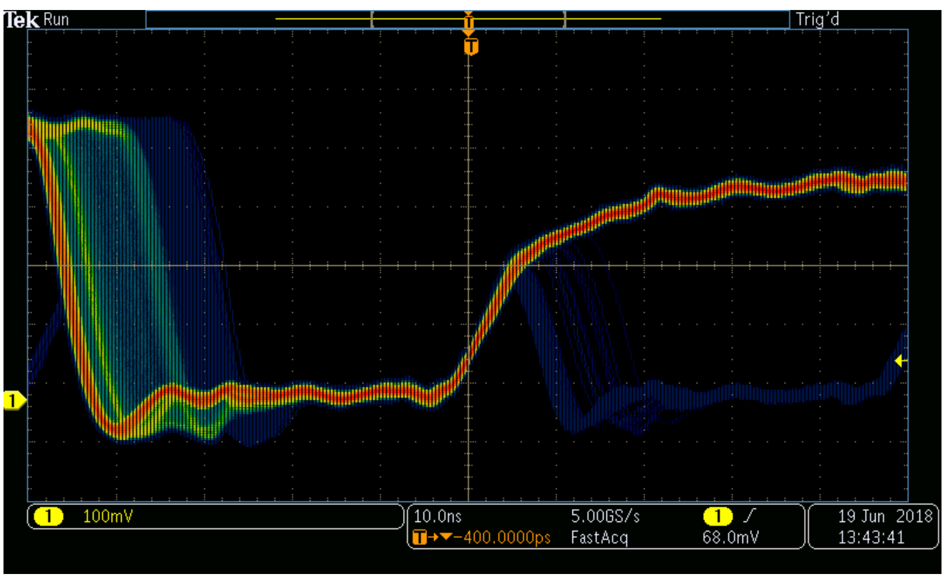
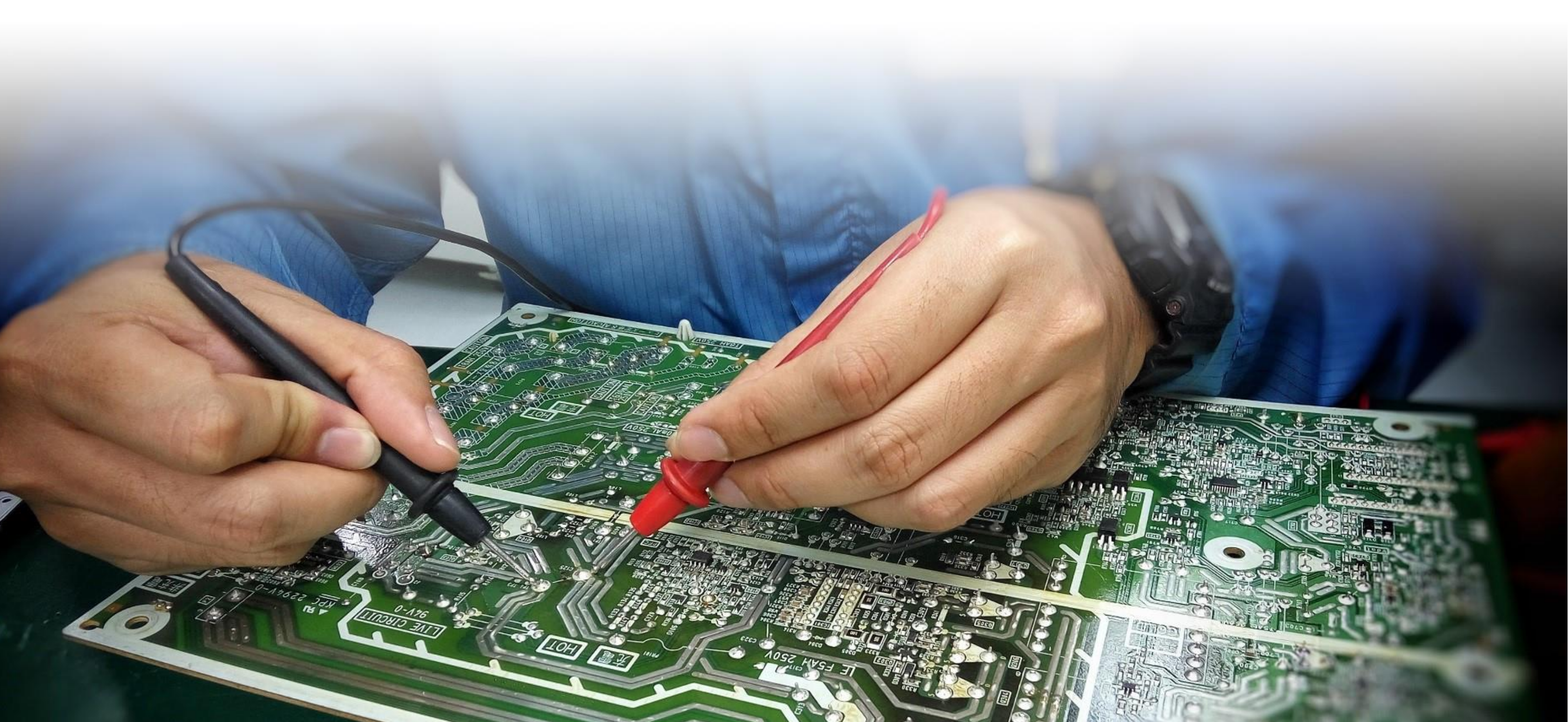


Figure 5. Tektronix MDO3000 Series scope captures the event with FastAcq acquisition mode on while updating at a rate of 280,000 waveforms/s.

The dead time percentages of the Tektronix MDO3000 Series oscilloscope for both the normal/DPO acquisition mode and FastAcq acquisition mode:

$$\begin{aligned}
\%DT_{normal} &= 100 \times (1 - UW) \\
U &= 2{,}200\ waveforms/s \\
W &= 10\frac{ns}{div} \times 10\ divisions \\
&= 100\ ns = 0.0000001s \\
\%DT_{normal} &= 100 \times \left(1 - (2{,}200 \times 0.0000001)\right) \\
&= 99.98\%
\end{aligned}$$

$$\begin{aligned}
\%DT_{FastAcq} &= 100 \times (1 - UW) \\
U &= 280{,}000\ waveforms/s \\
W &= 10\frac{ns}{div} \times 10\ divisions \\
&= 100\ ns = 0.0000001s \\
\%DT_{FastAcq} &= 100 \times \left(1 - (280{,}000 \times 0.0000001)\right) \\
&= 97.20\%
\end{aligned}$$



Below are the probability calculations of capturing the glitch after a five second observation time using the Tektronix MDO3000 Series oscilloscope for both the normal/DPO acquisition mode and the FastAcq acquisition mode. W is the same value as.

$$P_{t\ normal} = 100\ \times \left(1 - [1 - RW]^{(U \times t)}\right)$$

$$R = 5\ waveforms/s$$

$$W = 10\frac{ns}{div} \times 10\ divisions$$

$$= 100\ ns = 0.0000001s$$

$$t = 5\ s$$

$$P_{5s\_normal} = 100\ \times \left(1 - [1 - (5 \times 0.0000001)]^{(2{,}200 \times 5)}\right)$$

$$= 0.5485\%$$

$$P_{t\ FastAcq} = 100\ \times \left(1 - [1 - RW]^{(U \times t)}\right)$$

$$R = 5\ waveforms/s$$

$$W = 10\frac{ns}{div} \times 10\ divisions$$

$$= 100\ ns = 0.0000001s$$

$$t = 5\ s$$

$$P_{5s\ FastAcq} = 100\ \times \left(1 - [1 - (5 \times 0.0000001)]^{(280{,}000 \times 5)}\right)$$

$$= 50.34\%$$

The infrequent metastable state did not display after five seconds of observation time using the Tektronix scope because the probability of capturing the glitch was low due to the long dead time and slow update rate. In a real application setting, the Tektronix scope will eventually capture an infrequent glitch only if you suspect your signal may have a problem — and you can wait for it to be captured.

Conclusion

Update rates directly determine an oscilloscope's dead time pecentage and probability of capturing and displaying random circuit problems. Be aware of the banner update rate specifications encountered when comparing oscilloscopes as that rate may not be attainable in certain applications.

Although this white paper focused primarily on best-case waveform update rate comparisons while using analog channels of acquisition, know that waveform update rates on most scopes degrade significantly when using digital channels of acquisition and/or serial bus decoding — especially when deep memory is enabled.

The Keysight InfiniiVision Series oscilloscopes has the fastest waveform update rates in the industry when you use just the scope channels (>1,000,000 waveforms per second), and 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. InfiniiVision DSOs and MSOs achieve fast, uncompromised update rates through a higher level of hardware integration (MegaZoom technology) that minimizes oscilloscope dead time and increases your chances of catching a glitch in your system.

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