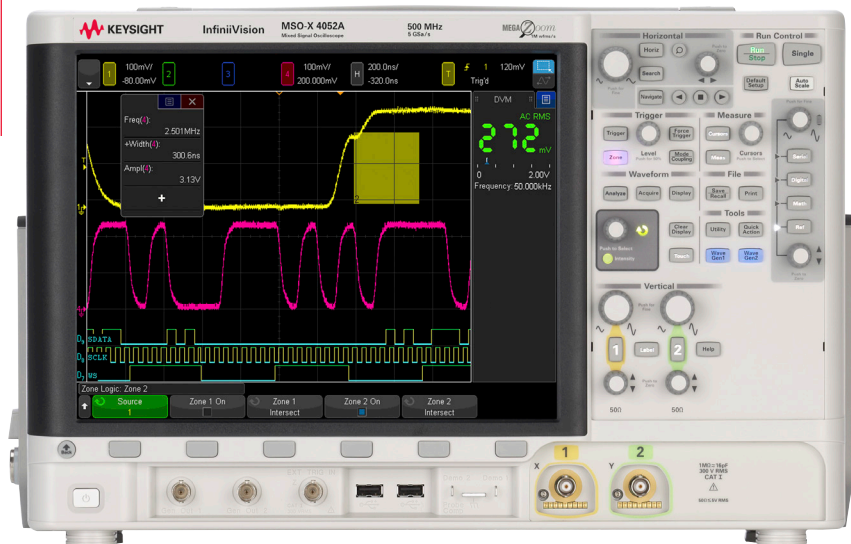


Keysight Technologies

How to Select Your Next Oscilloscope:

12 Tips on What to Consider
Before you Buy

Application Note





Introduction

You rely on your oscilloscope every day, so selecting the right one to meet your specific measurement needs and budget is an important task. Comparing different manufacturers' oscilloscopes and their various specifications and features can be time-consuming and confusing. The 12 oscilloscope selection tips presented in this application note are intended to accelerate your selection process and help you avoid some common pitfalls.

Tip #1: Bandwidth

Select an oscilloscope that has sufficient bandwidth to accurately capture the highest frequency content of your signals

There are a variety of oscilloscope specifications that determine how accurately signals can be captured and measured. But an oscilloscope's primary specification is its bandwidth. So what do we mean by "bandwidth"? All oscilloscopes exhibit a low-pass frequency response that rolls-off at higher frequencies, as shown in Figure 1. Most oscilloscopes with bandwidth specifications of 1 GHz and below typically have what is called a Gaussian frequency response, which approximates the characteristics of a single-pole low-pass filter. The lowest frequency at which the input signal is attenuated by 3 dB is considered the oscilloscope's bandwidth. Signal attenuation at the -3 dB frequency translates into approximately -30% amplitude error. In other words, if you input a 1 V_{p-p}, 100-MHz sine wave into a 100-MHz bandwidth oscilloscope, the measured peak-to-peak voltage using this oscilloscope would be in the range of 700 mV_{p-p} (-3 dB = 20 Log (0.707/1.0)). So you cannot expect to make accurate measurements on signals that have significant frequencies near your oscilloscope's bandwidth.

So how much bandwidth is required for your particular measurement applications? For purely analog signal measurements, you should choose an oscilloscope that has a bandwidth specification at least three times higher than the highest sine wave frequencies you may need to measure. At 1/3 of an oscilloscope's bandwidth specification, signal attenuation is minimal. But what about required bandwidth for digital applications, the main use of today's oscilloscopes? As a rule of thumb, Keysight Technologies, Inc. recommends you choose an oscilloscope that has a bandwidth at least five times the highest clock rate in your systems. For example, if the highest clock rate in your designs is 100 MHz, then you should choose an oscilloscope with a bandwidth of 500 MHz or higher. If your oscilloscope meets this criterion, it will be able to capture up to the fifth harmonic with minimum signal attenuation. The fifth harmonic of the signal is critical in determining the overall shape of your digital signals.

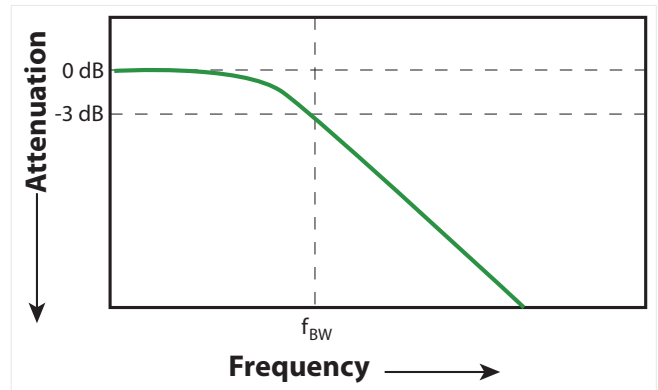


Figure 1. Oscilloscopes exhibit a low-pass frequency response that rolls-off higher frequencies.

Figure 2 shows an 100-MHz bandwidth oscilloscope capturing and displaying a 100-MHz digital clock signal. In this case, the oscilloscope attenuates the higher frequency components and basically just shows the 100-MHz sine wave fundamental frequency of this signal. This oscilloscope has insufficient bandwidth to capture this signal. Figure 3 shows the same 100-MHz clock signal captured on a 500-MHz bandwidth oscilloscope. We can now see and measure more details of this digital signal using this higher bandwidth oscilloscope.

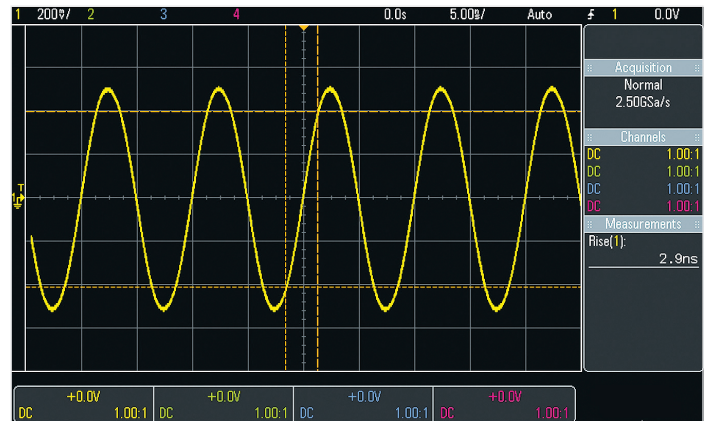


Figure 2. 100-MHz clock signal captured on a 100-MHz bandwidth oscilloscope.

Tip #1: Bandwidth (continued)

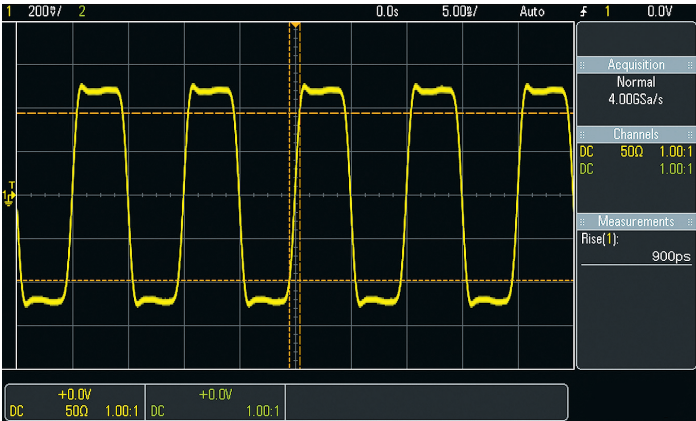


Figure 3. 100-MHz clock signal captured on a 500-MHz bandwidth oscilloscope.

Note that the 5-to-1 rule-of-thumb recommendation (oscilloscope bandwidth relative to clock rate) does not take into account lower clock-rate signals that have relatively fast edge speeds. These signals may contain significant frequency components beyond the fifth harmonic. To learn more about how to determine required bandwidth based on signal edge speeds, refer to Keysight’s application note **Evaluating Oscilloscope Bandwidths for Your Applications**, which is listed in the related literature section at the end of this document.

Protect your investment with bandwidth upgradability
Keysight Technologies’ InfiniiVision and Infiniium Series oscilloscopes come in various bandwidths ranging from 70 MHz to 63 GHz. Their bandwidths can also be upgraded after the initial purchase. This means you can now protect your oscilloscope investment. Perhaps a 100-MHz bandwidth oscilloscope is all you need and can afford today, but if your signal speeds increase in two years, you may then need a 500-MHz oscilloscope to make accurate measurements on your higher speed designs. No problem! If you purchase a Keysight InfiniiVision X-Series or Infiniium Series oscilloscope today, you can easily upgrade the bandwidth in the future.

Tip #2: Sample rate

Select an oscilloscope that has a maximum specified sample rate fast enough to deliver the oscilloscope's specified real-time bandwidth

Closely related to an oscilloscope's real-time bandwidth is its maximum specified sample rate. "Real-time" simply means the oscilloscope can capture and display signals commensurate with the oscilloscope's specified bandwidth in a single acquisition (not repetitive).



Dr. Harry Nyquist

Most engineers are familiar with **Nyquist's Sampling Theorem**. The theorem states that for a limited bandwidth (band-limited) signal with maximum frequency f_{\max} , the equally-spaced sampling frequency f_s must be greater than twice the maximum frequency f_{\max} , i.e., $f_s > 2 \cdot f_{\max}$ for the signal to be uniquely reconstructed without aliasing.

Today f_{\max} is commonly known as the Nyquist frequency (f_N). The mistake some engineers make is they sometimes assume f_{\max} or f_N is the same as f_{BW} (oscilloscope bandwidth). With this assumption, you might think the minimum required sample rate for an oscilloscope of a particular specified bandwidth is just twice the oscilloscope's real-time bandwidth specification, as shown in Figure 4. But, f_{\max} is NOT the same as f_{BW} , unless the oscilloscope had a brick-wall filter response.

As you learned in "Tip #1," oscilloscopes with bandwidth specifications of 1 GHz and below typically have a Gaussian frequency response. This means that although the oscilloscope attenuates the amplitude of signal frequencies above its -3 dB bandwidth frequency point, it does not entirely eliminate these higher frequency components. The aliased frequency components are shown by the red hashed area in Figure 4. Therefore f_{\max} is always higher than f_{BW} for an oscilloscope.

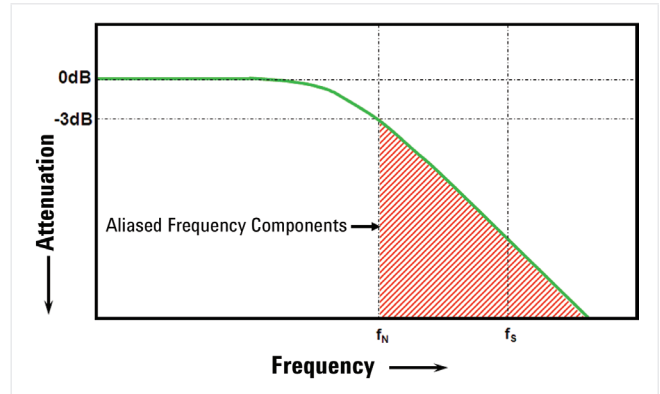


Figure 4. Aliased frequency components when the oscilloscope's bandwidth is specified at $\frac{1}{2}$ its sample rate for oscilloscopes that exhibit a Gaussian frequency response.

Keysight recommends an oscilloscope's maximum specified sample rate should be at least four to five times higher than the scope's specified real-time bandwidth, as shown in Figure 5. With this criterion, the oscilloscope's $\sin(x)/x$ waveform reconstruction filter can accurately reproduce the wave shape of higher speed signals with resolution in the tens of picoseconds range.

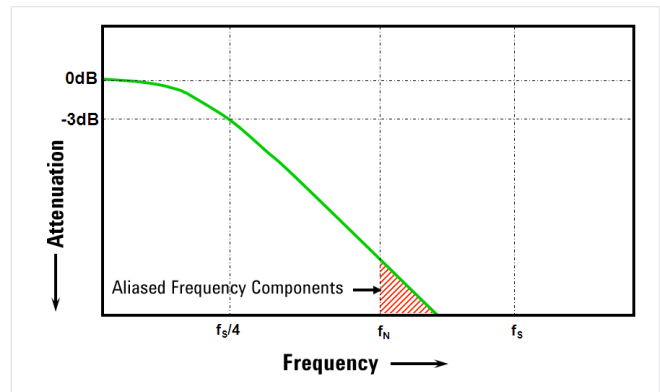


Figure 5. Aliased frequency components when the oscilloscope's bandwidth is specified at $\frac{1}{4}$ the oscilloscope's sample rate.

Tip #2: Sample rate (continued)

Many higher bandwidth oscilloscopes have a faster/sharper roll-off frequency response as shown in Figure 6. We call this type of frequency response a “maximally-flat” response. Since an oscilloscope with a maximally-flat response attenuates frequency components beyond the Nyquist frequency to a higher degree, and begins to approach the ideal characteristics of a theoretical brick-wall filter, not as many samples are required to produce a good representation of the input signal while using digital filtering to reconstruct the waveform. Oscilloscopes with this type of frequency response can theoretically specify the bandwidth at $f_s/2.5$.

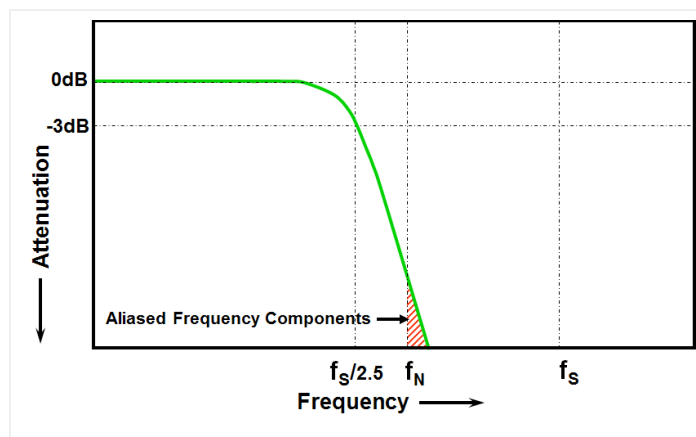


Figure 6. Aliased frequency components when the oscilloscope's bandwidth is specified at $1/(2.5)$ of the scope's sample rate for oscilloscopes that exhibit a “maximally-flat” frequency response.

To learn more about oscilloscope real-time sampling, refer to Keysight's application note **Evaluating Oscilloscope Sample Rates Versus Sampling Fidelity**, which is listed in the related literature section at the end of this document.

The core component of all digital storage oscilloscopes is the high-speed analog-to-digital converter (ADC) system. Keysight invests heavily in ADC technology and has the highest sample rate and highest fidelity monolithic ADCs in the oscilloscope industry. Keysight's entry-level 2000 X-Series InfiniVision oscilloscopes can sample at rates up to 2 GSa/s, and Keysight's higher performance 90000 Q-Series Infiniium oscilloscopes can sample at rates up to 160 GSa/s.

Tip #3: Memory depth

Select an oscilloscope that has sufficient acquisition memory to capture your most complex signals with high resolution

Closely related to an oscilloscope's maximum sample rate is its maximum available acquisition memory depth. Even though an oscilloscope's banner specifications may list a high maximum sample rate, this does not mean that the oscilloscope always samples at this high rate. Oscilloscopes sample at their fastest rates when the timebase is set on one of the faster time ranges. But when the timebase is set to slower ranges to capture longer time spans across the oscilloscope's display, the scope automatically reduces the sample rate based on the available acquisition memory.

For example, let's assume that an entry-level oscilloscope has a maximum sample rate of 1 GSa/s and a memory depth of 10 k points. If the oscilloscope's timebase is set at 10 ns/div in order to capture 100 ns of signal activity across the oscilloscope's screen (10 ns/div x 10 divisions = 100 ns time span), the oscilloscope needs just 100 points of acquisition memory to fill the screen while sampling at its maximum sample rate of 1 GSa/s (100 ns time span x 1 GSa/s = 100 samples). No problem! But if you set the oscilloscope's timebase to 10 μ s/div to capture 100 μ s of signal activity, the oscilloscope will automatically reduce its sample rate to 100 MSa/s (10 k samples/100 μ s time-span = 100 MSa/s). Maintaining the oscilloscope's fastest sample rate at the slower timebase ranges requires that the scope have additional acquisition memory. Determining the amount of acquisition memory you require involves a pretty simple equation based on the longest time span of a complex signal you need to capture and the maximum sample rate at which you want the oscilloscope to sample.

Acquisition Memory = Time Span x Required Sample Rate

In Figure 7, we show a Keysight 3000 X-Series oscilloscope capturing a complex digital signal at 100 μ s/div for a total capture time of 1 ms. Since this oscilloscope has up to 4,000,000 points of acquisition memory, it can maintain its maximum sample rate of 4 GSa/s at this timebase setting. In the upper half of the oscilloscope's display, we can see the entire captured waveform. In the lower half of the oscilloscope's display, we can see a "zoomed-in" display of a small portion of the captured waveform, revealing a runt pulse that is approximately 100 ns wide.

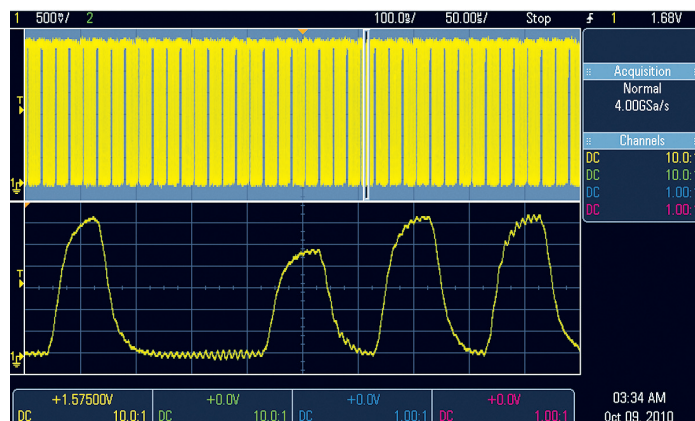


Figure 7. Capturing a complex stream of digital pulses using deep memory.

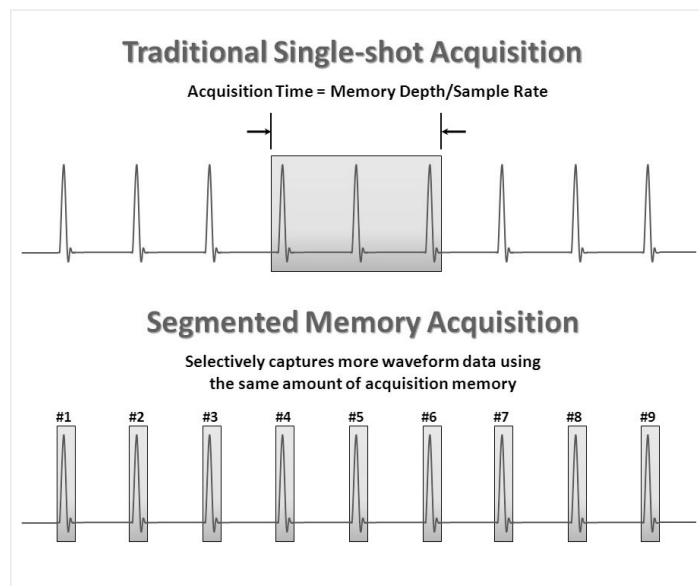
Although you may intuitively think deeper is always better, using deep memory often means making tradeoffs when using many oscilloscopes on the market today. First of all, oscilloscopes with deep memory are typically priced higher. Second, acquiring long waveforms using deep memory requires additional waveform processing time. This typically means waveform update rates will be reduced, sometimes significantly. For this reason, most oscilloscopes on the market today have manual memory-depth selections, and the typical default memory depth setting is usually relatively shallow (10 to 100 k). If you want to use deep memory, then you must manually turn it on and deal with the update rate tradeoff. This means you must know when it is important to use deep memory and when it is not.

With Keysight's exclusive MegaZoom technology, you don't have to be an oscilloscope expert. MegaZoom automatically selects deeper memory when needed in order to maintain fast sample rates. And with this custom technology, the oscilloscope always remains responsive—even when using deep memory.

Tip #3: Memory depth (continued)

Segmented Memory

Some oscilloscopes have a special mode of operation called “segmented memory acquisition.” Segmented memory can effectively extend the oscilloscope’s total acquisition time by dividing its available acquisition memory into smaller memory segments as illustrated in Figure 8. The oscilloscope then selectively digitizes just the important portions of the waveform under test at a high sample rate and then time-tags each segment so you know the precise time between each occurrence of trigger events. This enables your oscilloscope to capture many successive single-shot waveforms with a very fast re-arm time – without missing important signal information. This mode of operation is especially useful when capturing burst of signals. Examples of burst-type signals would be pulsed radar, laser bursts, as well as packetized serial bus signals. To learn more about oscilloscope segmented memory acquisition, refer to Keysight’s application note, ***Using Oscilloscope Segmented Memory for Serial Bus Applications***, which is listed in the related literature section at the end of this document.



Segmented Memory acquisition is available on all of Keysight’s InfiniiVision X-Series and Infiniium Series oscilloscopes. When the absolute deepest memory is required, Keysight’s Infiniium Series oscilloscopes offer up to 2 GB of acquisition memory so you can capture the longest time-span at the oscilloscope’s maximum sample rate.

Tip #4: Number of channels

Select an oscilloscope that has a sufficient number of channels of acquisition so that you can perform critical time-correlated measurements across multiple waveforms

The number of oscilloscope channels you require will depend on how many signals you need to observe and compare in relationship to each other. At the heart of most of today's embedded designs is a microcontroller (MCU) as shown in the simplified schematic of Figure 9. Many MCUs are actually mixed-signal devices with multiple analog, digital, and serial I/O signals that interface to the real-world, which is always analog in nature.

As today's mixed-signal designs have become more complex, more channels of acquisition and display may be required. Two- and four-channel oscilloscopes are very common today. If more than four analog channels of acquisition are required, your choices become very limited. But there is another alternative: a Mixed Signal Oscilloscope (sometimes called an "MSO").

MSOs combine all of the measurement capabilities of oscilloscopes with some of the measurement capabilities of logic analyzers and serial bus protocol analyzers. MSOs have three primary attributes. The most obvious attribute is the ability to simultaneously capture multiple oscilloscope and logic signals with a time-correlated display of waveforms. Just think of it as having a few channels with high vertical resolution (typically 8 bits) plus several additional channels with very low vertical resolution (1 bit).

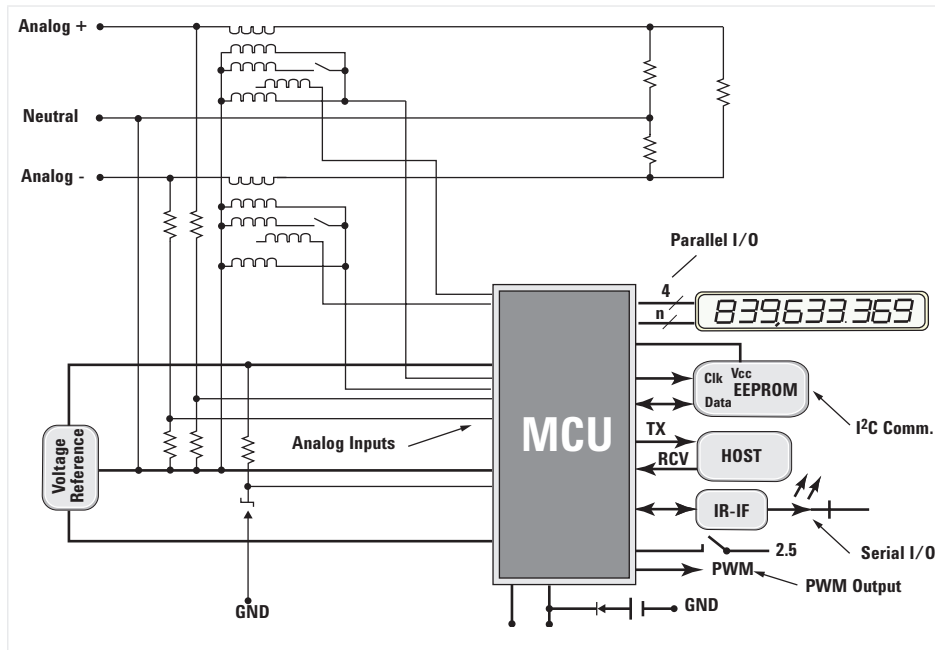


Figure 9. Typical MCU-based embedded design.

Tip #4: Number of channels (continued)

Another attribute is that although MSOs may lack the large number of digital channels of a logic analyzer, one of the MSO's primary advantages is its familiar use-model, which is that of an oscilloscope. And lastly, with the additional logic channels available in MSOs, users now have many more triggering possibilities that can be used to “zero-in” on specific parallel and serial bus I/O interaction in today's mixed-signal designs.

In Figure 10 we show a Keysight MSO capturing the input of a MCU-controlled digital-to-analog converter (DAC) using its digital channels of acquisition, while monitoring the output of the DAC with a single analog channel of acquisition. In this example the MSO was setup to trigger on a logical pattern condition of the input of the DAC when it was at its lowest value of 0000 1010 (1A_{HEX}).

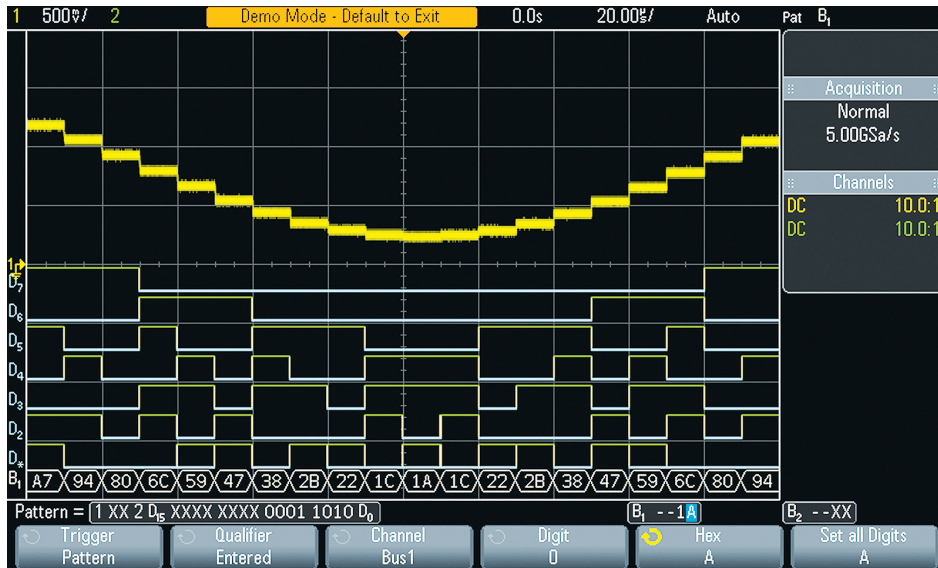


Figure 10. MSOs can capture and display multiple analog and digital signals simultaneously providing an integrated and time-correlated display of multiple waveforms.

To learn more about making measurements with a mixed signal oscilloscope (MSO), refer to Keysight's application note ***Evaluating Oscilloscopes to Debug Mixed-signal Designs***, which is listed in the related literature section at the end of this document.

Keysight's InfiniiVision and Infiniium oscilloscopes can be pre-configured and purchased as either DSO or MSO models. DSO models can also be easily upgraded to MSO models after purchase.

Tip #5: Waveform update rate

Select an oscilloscope that has a fast enough waveform update rate to capture random and infrequent events to help you debug your designs faster

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 an oscilloscope's waveform update rate may appear fast when viewing repetitively captured waveforms on your oscilloscope's display, “fast” is relative. For example, a few hundred waveforms per second will certainly appear lively, 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.

When you debug new designs, waveform 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 update rates improve the oscilloscope's probability of capturing illusive events.

All oscilloscopes have an inherent characteristic called “dead-time” or “blind time.” This is the time between each repetitive acquisition of the oscilloscope when it is processing the previously acquired waveform. Unfortunately, oscilloscope dead-times can sometimes be orders of magnitude longer than acquisition times. During the oscilloscope's dead-time, any signal activity that may be occurring will be missed as shown in Figure 11. Note the two glitches that occurred during the oscilloscope's dead time – not during its acquisition time.

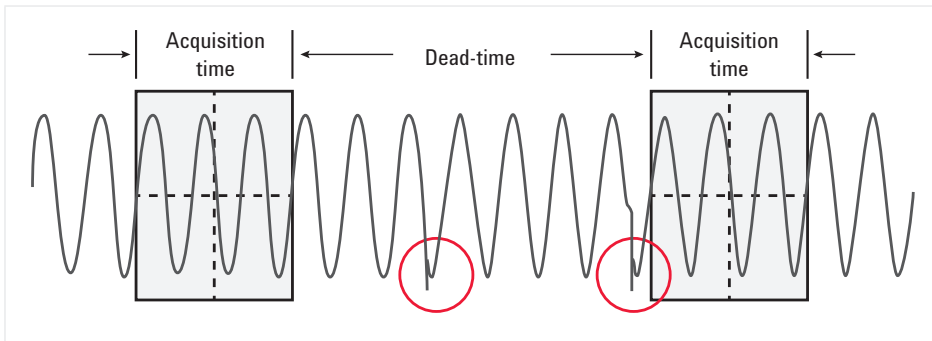


Figure 11. Oscilloscope dead-time versus display acquisition time.

Tip #5: Waveform update rate (continued)

Because of oscilloscope dead-time, capturing random and infrequent events with an oscilloscope becomes a gamble — much like rolling dice. The more times you roll the dice, the higher the probability of obtaining a specific combination of numbers. Likewise, the more often a oscilloscope updates waveforms for a given amount of observation time, the higher the probability of capturing and viewing an elusive event — one that you may not even know exists.

In Figure 12 we show a Keysight InfiniiVision X-Series oscilloscope capturing an infrequent metastable state (glitch) that occurs approximately 5 times per second. With a maximum waveform update rate of more than 1,000,000 waveforms per second, this oscilloscope has a 92% probability of capturing this glitch within 5 seconds. In this example, the oscilloscope captured the metastable state several times.

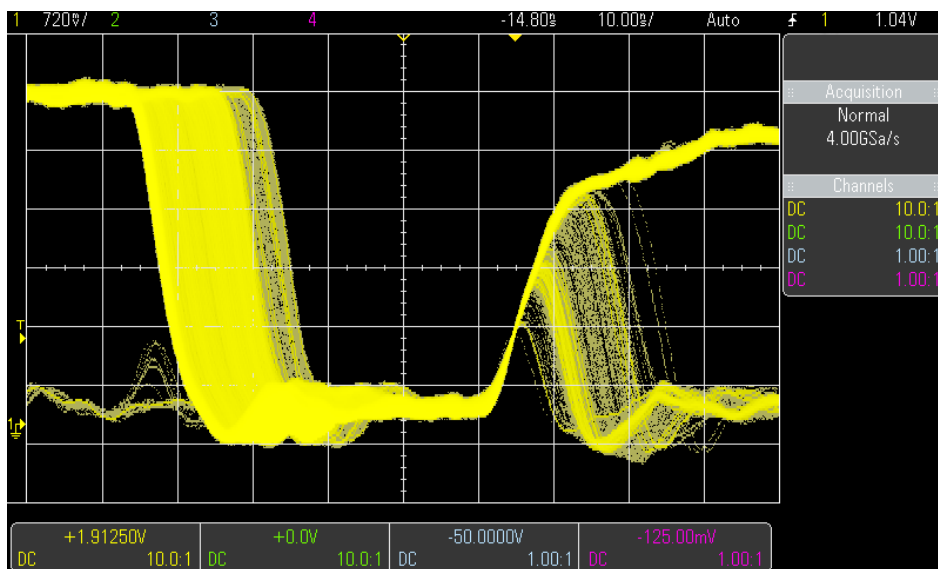


Figure 12. The Keysight MSO/DSO3000 X-Series oscilloscope reliably captures the infrequently occurring metastable state while updating at 1,000,000 waveforms per second.

Other oscilloscopes in this class may update waveforms only 2000 to 3000 times per second. This means that these oscilloscopes would have less than a 1% probability of capturing and displaying an infrequent glitch such as this within 5 seconds. To learn more about oscilloscope waveform update rates and how to compute statistical glitch capture probabilities, refer to Keysight's application note, **Oscilloscope Waveform Update Rate Determines Probability of Capturing Elusive Events**, which is listed in the related literature section at the end of this document.

Tip #6: Triggering

Select an oscilloscope that has the types of advanced triggering that you may need to help you isolate waveform acquisitions on your most complex signals

An oscilloscope's triggering capability is one of its most important aspects. Triggering allows you to synchronize the oscilloscope's acquisition and display of waveforms on particular parts of a signal. You can think of oscilloscope triggering simply as synchronized picture taking.

The most common type of oscilloscope triggering is that of triggering on a simple edge crossing. For example, trigger on a rising edge of channel-1 when the signal crosses a particular voltage level (trigger level) in a positive direction as shown in Figure 13. All oscilloscopes have this capability, and it is probably still the most commonly used type of triggering. But as today's digital designs have become more complex, you may need to further qualify/filter your oscilloscope's triggering on particular characteristics or combinations of input signals in order to zero-in, capture, and view a particular portion of a complex input signal.

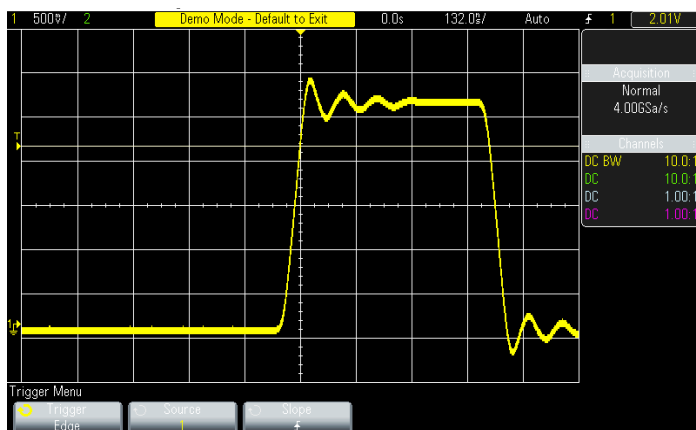


Figure 13. Triggering on a rising edge of a digital pulse.

Some oscilloscopes have the ability to trigger on pulses that meet a particular timing qualification. For example, trigger only when a pulse is less than 20 ns wide. This type of triggering (qualified pulse-width) can be very useful for triggering on unsuspected glitches.

Another type of triggering that is common in many of today's oscilloscopes is pattern triggering. Pattern triggering allows you to set up the oscilloscope to trigger on a logical/Boolean combination of highs (or 1s) and lows (or 0s) across two or more input channels. This can be especially useful when using a Mixed Signal Oscilloscope (MSO), which can provide up to 20 analog and digital channels of acquisition.

More advanced oscilloscopes even provide triggering that can synchronize on signals that have parametric violations. In other words, trigger only if the input signal violates a particular parametric condition such as reduced pulse height (runt trigger), edge speed violation (rise/fall time), or perhaps a clock to data timing violation (setup and hold time trigger).

Figure 14 shows a Keysight oscilloscope triggering on a positive pulse with reduced amplitude using the oscilloscope's Runt triggering selection. If this runt pulse occurred just once in a million cycles of the digital pulse stream, capturing this signal while using standard edge triggering would be like looking for a needle in a haystack. This scope can also trigger on negative runts, as well as runt pulses of a specific pulse width.



Figure 14. Triggering on a reduced amplitude pulse using Runt triggering.

Tip #6: Triggering (continued)

Even with advanced parametric triggering capability in an oscilloscope, determining which special trigger mode to select and how to set it up can sometimes be confusing. This is where Keysight's hardware-based InfiniiScan Zone Trigger steps in. Figure 15 shows an example of an infrequent non-monotonic edge while the oscilloscope is set up to trigger on any rising edge of the input signal.

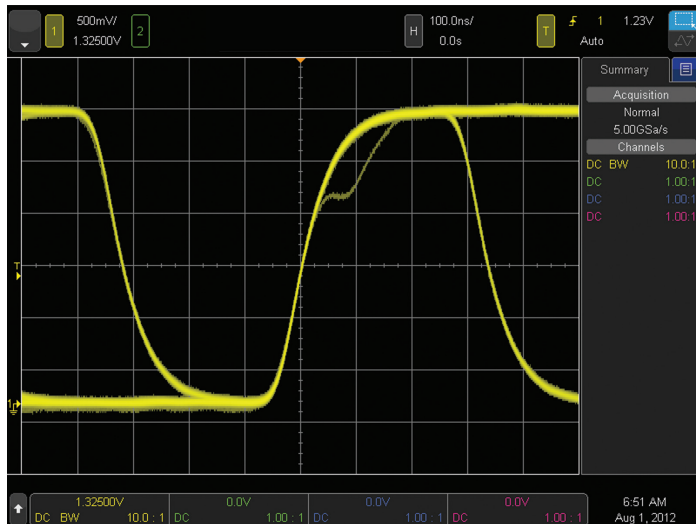


Figure 15. The oscilloscope's fast waveform update rate reveals an infrequent non-monotonic edge.

With Zone Trigger, you can simply draw a box (zone) in the region of the anomaly, and then the oscilloscope isolates just the infrequently occurring edges with the non-monotonic edge as shown in Figure 16.

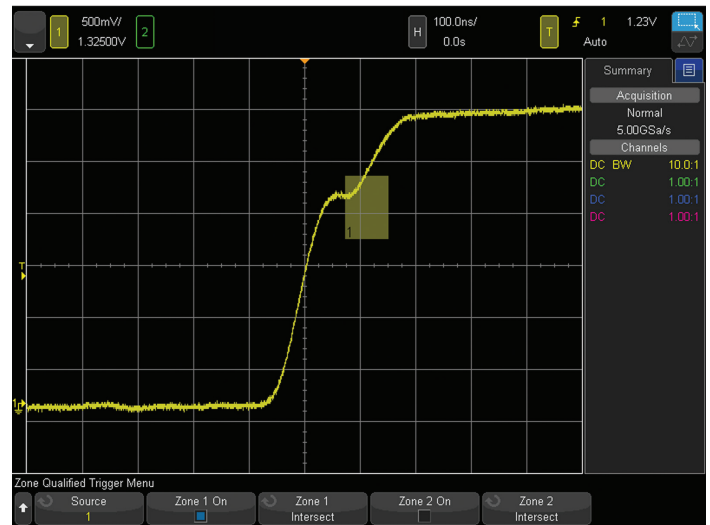


Figure 16. InfiniiScan Zone trigger isolates the infrequent non-monotonic edge.

To learn more about InfiniiScan Zone triggering, refer to Keysight's application note ***Synchronizing on Infrequent Anomalies and Complex Signals using InfiniiScan Zone Trigger***, which is listed in the related literature section at the end of this document.

Tip #7: Display quality

Select an oscilloscope that provides multiple levels of trace intensity gradation in order to display subtle waveform details and signal anomalies

The quality of your oscilloscope's display can make a big difference in your ability to effectively troubleshoot your designs. If your oscilloscope has a low-quality display, you may not be able to see subtle waveform details. An oscilloscope that is capable of showing signal intensity gradations can reveal important waveform details in a wide variety of both analog and digital signal applications, including relative distribution of noise, jitter, and signal anomalies.

Engineers have traditionally thought of digital storage oscilloscopes (DSOs) as two-dimensional instruments that graphically display just voltage versus time. But there is actually a third dimension to an oscilloscope: the z-axis. This third dimension shows continuous waveform intensity gradation as a function of the frequency-of-occurrence of signals at particular X-Y locations.

In analog oscilloscope technology, intensity modulation is a natural phenomenon of the oscilloscope's vector-type display, which is swept with an electron beam. Due to early limitations of digital display technology, this third dimension, intensity modulation, was missing when digital oscilloscopes began replacing their analog counterparts. But some of today's digital storage oscilloscopes (DSOs) now provide similar – and sometimes superior – display quality using custom digital signal processing technology.

Figure 17 shows a Keysight InfiniiVision X-Series oscilloscope that is set up to monitor jitter on a digital signal. With the oscilloscope's fast waveform update rate (up to 1,000,000 waveforms/sec) along with 64 levels of trace intensity gradation, we can make qualitative judgments about the nature of the distribution of noise and jitter. We know traces that appear bright occur most often, while traces that appear dim occur least often.

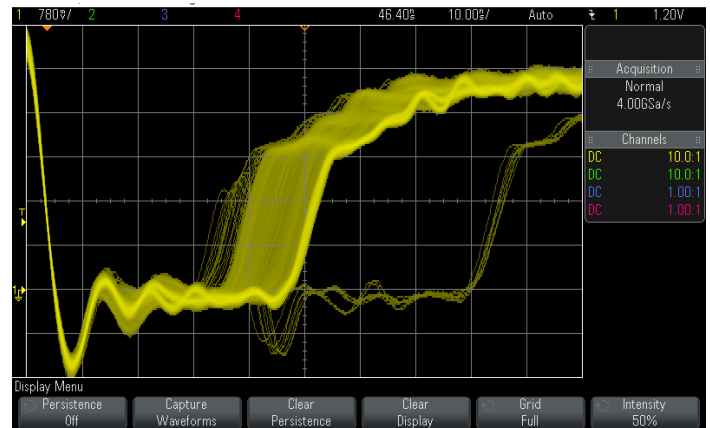


Figure 17. Multiple levels of trace intensity gradation reveals distribution of jitter.

Tip #7: Display quality (continued)

First generation digital storage oscilloscopes (DSOs), as well as most of today's entry-level oscilloscopes provide just 1 to 2 levels of trace intensity gradation as shown in Figure 18. This makes it impossible to make qualitative judgments about complex signal modulation since all traces have the same exact intensity. Does the jitter have a Gaussian or even distribution? Does the jitter include deterministic components? We don't know.

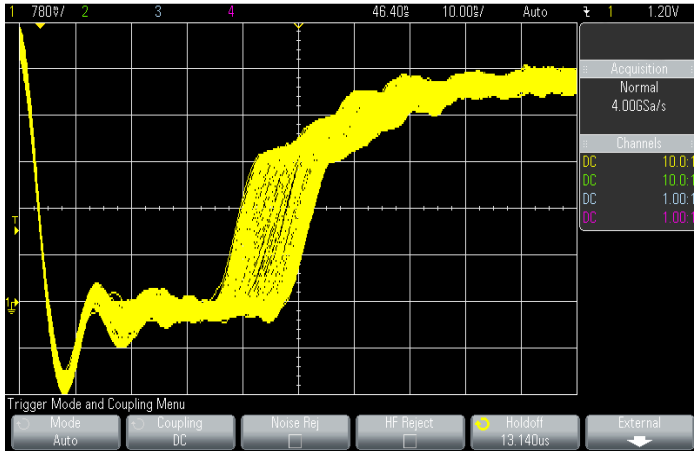


Figure 18. Most entry-level scopes provide just one or two levels of trace intensity gradation.

Trace intensity gradation is also extremely important when capturing and monitoring complex modulated analog signals, such as video. Figure 19 shows an InfiniiVision X-Series oscilloscope displaying three fields of an NTSC video signal, along with a zoomed-in display of a single line of interlaced video.

In addition to the number of levels of trace intensity gradation, other factors that should be considered regarding an oscilloscope's display quality include update rate, display size, display resolution, viewing angle, color versus monochrome, and user-selectable display modes such as variable and infinite persistence.

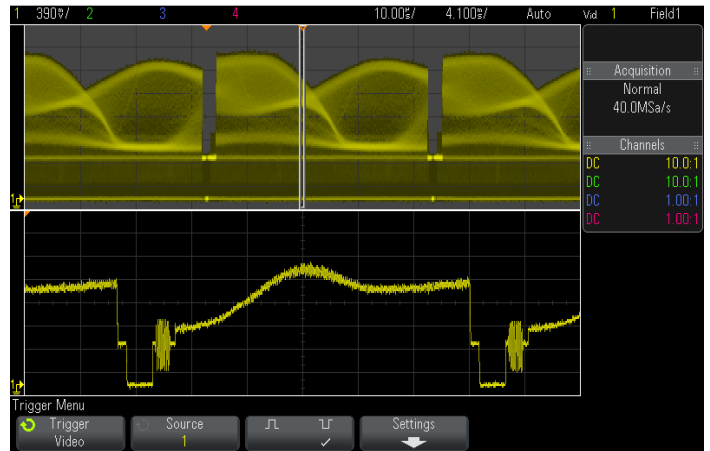


Figure 19. High levels of display quality are required when viewing complex modulated signals such as video.

To learn more about oscilloscope display quality, refer to Keysight's application note **Oscilloscope Display Quality Impacts Ability to View Subtle Signal Details**, which is listed in the related literature section at the end of this document.

Tip #8: Serial bus applications

Select an oscilloscope that can trigger on and decode serial buses to help you debug your designs faster

Serial buses such as I²C, SPI, RS232/UART, CAN, USB, etc., are pervasive in many of today’s digital and mixed-signal designs. Verifying proper bus communication along with analog signal quality measurements requires an oscilloscope. Many engineers and technicians verify serial bus communication with an oscilloscope using a technique known as “visual bit counting”. But this manual method of decoding a serial bus can be time consuming and prone to errors. However, many of today’s DSOs and MSOs have optional built-in serial bus protocol decode and triggering capabilities. If your designs include serial bus technology, then selecting an oscilloscope that can decode and trigger on these buses can be a significant time-saver to help you debug your systems faster.

Most oscilloscopes on the market today that have serial bus analysis capabilities utilize software-based decoding techniques. With software-based decoding, waveform and decode update rates tend to be slow (sometimes seconds per update). This is especially true when using oscilloscopes with deep memory, which are often required to capture multiple packetized serial bus signals. And when analyzing multiple serial buses simultaneously, software techniques can make protocol-specific decode update rates even slower.

Keysight’s InfiniiVision X-Series oscilloscopes utilize hardware-based decoding to provide virtual real-time updates. Faster decoding with hardware-based technology enhances oscilloscope usability and, more importantly, the probability of capturing infrequent serial communication errors.

Figure 20 shows a Keysight InfiniiVision X-Series oscilloscope capturing and decoding a CAN (Controller Area Network) serial bus, which is commonly used in many automotive and industrial machinery applications, including medical diagnostics equipment. Below the waveform is the time-correlated decode trace that shows the contents of a single packet/frame of data. The upper half of the oscilloscope’s display shows the “lister” display, which provides decoded information in a more familiar tabular format; like a traditional protocol analyzer. The lister display can also be used to search and automatically navigate to specific packets of interest.

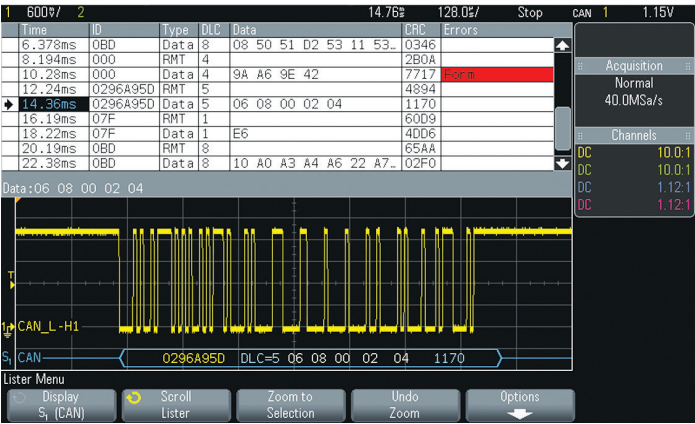


Figure 20. Triggering on and decoding a CAN serial bus using a Keysight InfiniiVision X-Series oscilloscope.

Tip #8: Serial bus applications (continued)

In addition to triggering on and decoding serial buses, it is often necessary to perform eye-diagram mask test measurements on serial bits. This is especially important for higher speed differential buses and/or buses that communicate over a long network. With an eye-diagram display, all serial bits are overlaid and compared to a pass/fail mask based on published industry physical layer standards/specifications. Figure 21 shows an eye-diagram mask measurement on a CAN serial bus, which is commonly used in all of today's automobiles. With a mask test rate of up to 200,000 waveforms/sec, the scope quickly captures bits that exhibit excessive jitter as shown by the traces color coded in red.

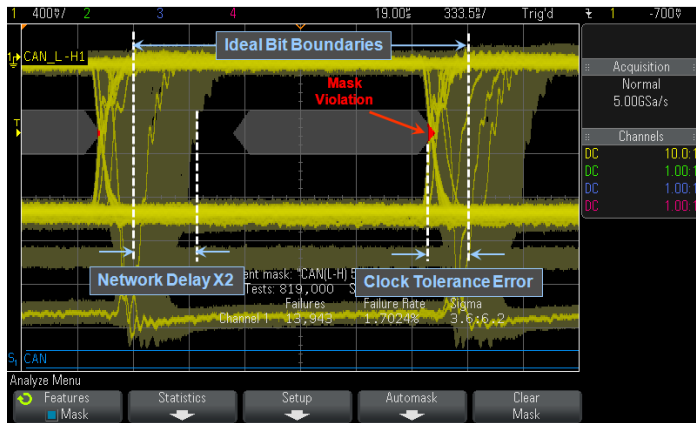


Figure 21. Eye-diagram mask test on a CAN serial bus using a Keysight InfiniiVision X-Series oscilloscope.

Keysight's InfiniiVision and Infiniium Series oscilloscopes offer a broad range of serial bus protocol trigger/decode options including:

- I²C/SPI
- RS232/UART
- USB
- CAN/CAN FD/LIN
- SENT
- FlexRay
- I²S
- MIL-STD 1553/ARINC 429
- JTAG (IEEE 1149.1)
- MIPI D-Phy
- PCI Express
- SATA

For many higher-speed serial buses such as USB 2.0/3.0, PCIe, and Gigabit Ethernet, automatic pass/fail compliance testing against published industry standards/specifications is often required. Keysight's Infiniium oscilloscopes offer a broad range of optional serial bus compliance test packages. Figure 22 shows an automated USB 2.0 hi-speed compliance test using a Keysight Infiniium Series oscilloscope. Also available with the various compliance test packages is complete report generation.

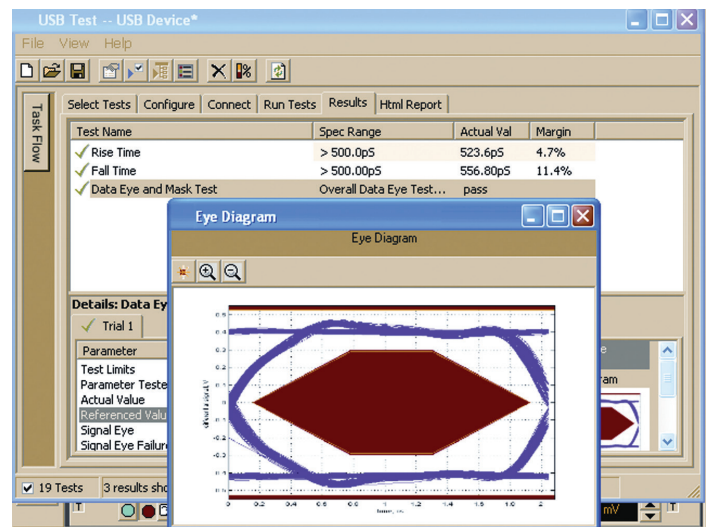


Figure 22. USB 2.0 hi-speed compliance test performed using a Keysight Infiniium Series oscilloscope.

To learn more about oscilloscope serial bus applications, refer to Keysight's data sheet **Serial Bus Options for InfiniiVision X-Series Oscilloscopes**, which is listed in the related literature section at the end of this document.

Tip #9: Measurements and analysis

Select an oscilloscope that can automatically perform your required parametric measurements and waveform math operations so you can characterize your designs faster

One of the major advantages of today's digital storage oscilloscopes (DSOs) over older analog oscilloscope technology is that they have the ability to perform various automatic measurements and analysis on digitized waveforms. You will find that digital oscilloscopes from various vendors have a wide variety of measurement capabilities. But nearly all of today's DSOs provide manually-controlled cursor/marker measurement capabilities as well as a minimum set of automatic pulse parameter measurements such as rise time, fall time, frequency, pulse width, etc. as shown in Figure 23.

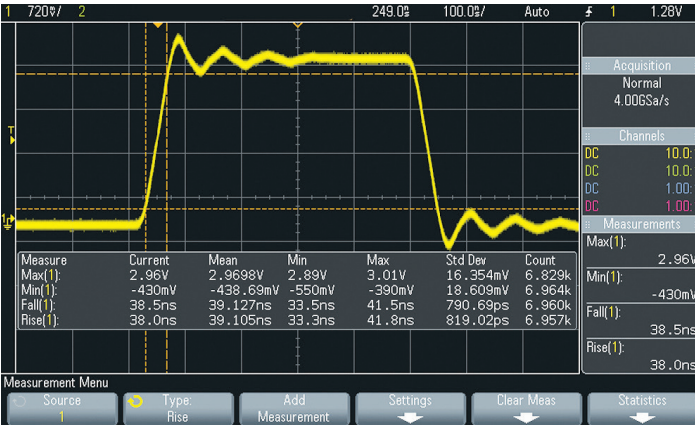


Figure 23. Performing automatic parametric amplitude and timing measurements using a Keysight oscilloscope.

As you move up in price and performance, you will find that higher-end oscilloscopes typically have more measurement and analysis capabilities such as advanced waveform math, automatic pass/fail mask testing, and application-specific compliance testing.

Whereas pulse parameter measurements typically perform a timing or amplitude measurement across a small portion of a waveform to provide an “answer,” such as the rise time or peak-to-peak voltage, an oscilloscope’s waveform math function performs a math operation on an entire waveform or pair of waveforms to produce yet another waveform.

Figure 24 shows an example of an Fast Fourier Transform (FFT) math function that was performed on a clock signal (yellow trace). This produced the frequency domain waveform (purple trace) that shows amplitude in dB on the vertical axis versus frequency in Hertz on the horizontal axis. Other common math operations that can be performed on digitized waveforms include sum, difference, differentiate, integrate, etc.

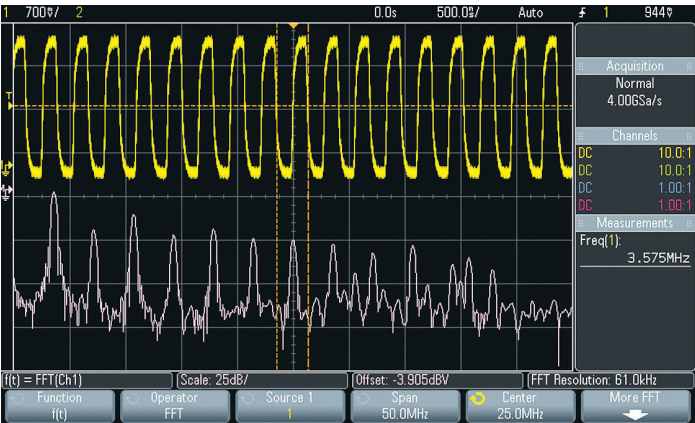


Figure 24. Performing an FFT math operation on a digital clock waveform using a Keysight oscilloscope.

Although most advanced waveform math functions can also be performed offline on a PC using software like MatLab, having this capability embedded in the oscilloscope not only makes it easier to perform these types of advanced math functions, but can also provide a updated display of waveform math functions in order to show dynamic signal behavior.

Tip #9: Measurements and analysis (continued)

Some of today’s oscilloscopes can also perform automatic pass/fail testing based on published industry standards/specifications. Figure 25 shows an example of a pass/fail current harmonics compliance test on a switch mode power supply (SMPS) using an optional Power Measurements analysis package. If any harmonics of the input signal (up to the 40th harmonic) exceed specified standards, they are clearly marked in the test results table shown in the upper half of the oscilloscope’s display.

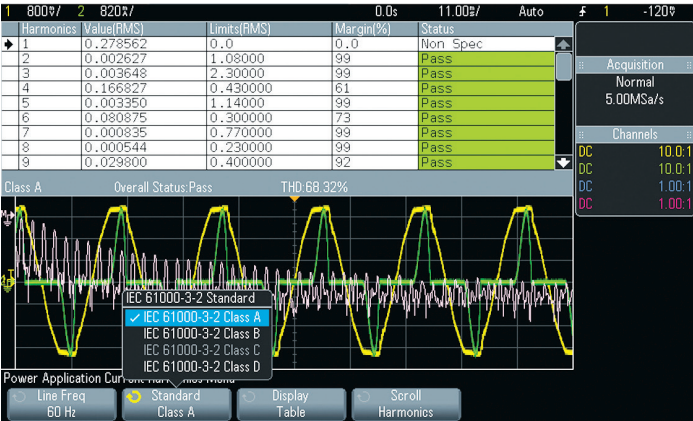


Figure 25. Automatic pass/fail compliance testing using a Keysight oscilloscope.

Although today’s higher performance oscilloscopes provide a broad array of built-in and advanced measurement functions, sometimes you may require a special math/measurement function that is just not available in any oscilloscope.

With Keysight’s N5430A User-defined Function (UDF) licensed on an Infiniium Series oscilloscope, you can install MATLAB on your oscilloscope, add your favorite MATLAB.m scripts as function operators, and then use them as standard waveform math functions as illustrated by the Signal Equalization measurement shown in Figure 26.

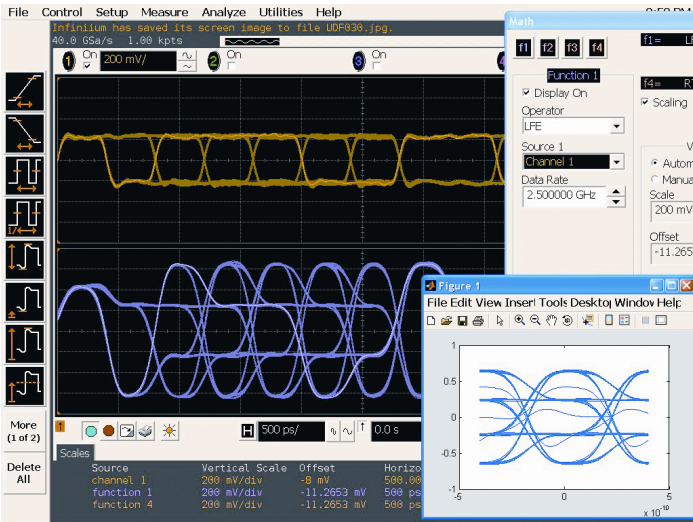


Figure 26. User-defined Signal Equalization measurement using the N5430A UDF option on an Infiniium Series oscilloscope.

Tip #10: Connectivity and documentation

Select an oscilloscope that meets your particular hardware connectivity, test automation, and electronic documentation requirements

Many of today's digital oscilloscopes are used in automated test environments in both R&D and manufacturing. Automated testing requires that the oscilloscope be connected to a computer via various possible connectivity ports. Most older DSOs were limited to GPIB and/or RS232 connectivity. Most of today's DSOs and MSOs use USB or LAN connectivity. If you need to use your oscilloscope in an automated test environment, make sure the oscilloscope you select has the required hardware connectivity ports and is fully programmable. In other words, make sure any measurement that can be performed using the oscilloscope's front panel and menu controls can also be programmed remotely.

Keysight's InfiniiVision X-Series and Infiniium Series oscilloscopes are all fully programmable via SCPI commands as well as National Instruments IVI drivers.

When you perform manual oscilloscope measurements on the bench, it is often important to document/save test results. One method of documenting test results is to simply send a screen image to a printer connected directly to the oscilloscope. But a more common method of documenting test results today is to save data. In addition to being able to transfer data to a PC via a direct USB or LAN connection, most of today's digital oscilloscopes have the ability to save images and waveform data in various formats directly to a USB memory stick, as shown in Figure 28. Saved images (screen-shots) and data (waveforms) can then be easily imported into various word processors, spreadsheets, and applications such as MATLAB.

Keysight's N8900A InfiniiView offline analysis software lets you easily capture waveforms on your oscilloscope, save them to a file, and recall the waveforms into the application.



Figure 27. Automated test rack.

Tip #10: Connectivity and documentation (continued)



Figure 28. Quickly and easily save waveform data and screen-shots to your personal USB drive.

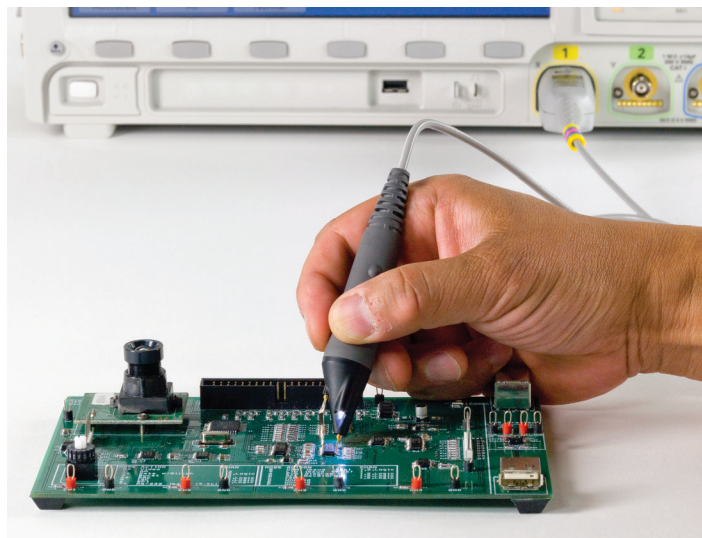
Some of today's digital oscilloscopes even have built-in Web browsers. This makes it easy for engineers around the globe to access "live" oscilloscope measurements that may reside in another part of the world. For instance, Figure 29 shows an example of an engineer in his office in the U.S.A. remotely controlling and making measurements on an oscilloscope connected to a device-under-test in China.



Figure 29. Keysight's InfiniiVision's built-in Web browser with the virtual remote front-panel user interface makes it easy to control and access "live" oscilloscope measurements from anywhere in the world.

Tip #11: Probing

Select an oscilloscope from a vendor that can provide the variety of specialty probes you may require



Your oscilloscope measurements can only be as good as what your probe delivers to the oscilloscope’s BNC inputs. When you connect any kind of measurement system to your circuit, the instrument (and probe) becomes part of your device-under-test. This means it can “load” or change the behavior of your signals to some degree. Good probes should not disturb the input signal and should ideally deliver an exact duplicate of the signal that was present at the probe point before the probe was attached.

When you purchase a new oscilloscope, it typically comes standard with a set of high-impedance passive probes – one probe for each input channel of the oscilloscope. These types of general-purpose passive probes are most common and enable you to measure a broad range of signals relative to ground. But these probes do have limitations. Figure 30 shows an electrical model of a typical 10:1 passive probe connected to the high-impedance input (1-MΩ input of an oscilloscope).

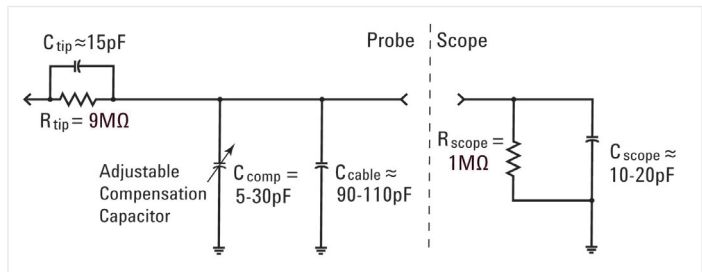


Figure 30. Typical model of a 10:1 passive probe.

Inherent in all oscilloscope probes and inputs are parasitic capacitances. These include the probe cable capacitance (C_{cable}), as well as the oscilloscope’s input capacitance (C_{scope}). “Inherent/parasitic” simply means these elements of the electrical model are not intentionally designed-in, but are just an unfortunate fact of life in the real world of electronics. The amount of inherent/parasitic capacitance will vary from oscilloscope-to-oscilloscope and probe-to-probe. Also included in this electrical model are designed-in capacitive elements that are used to compensate for low-frequency pulse response.

The electrical model of any probe (passive or active) and oscilloscope can be simplified down to parallel combination of a single resistor and single capacitor. Figure 31 shows a typical oscilloscope/probe loading model for a 10:1 passive probe. This is essentially what gets connected in parallel with your DUT when making oscilloscope measurements with a probe. For low frequency or DC applications, loading is dominated by the 10-MΩ resistance, which in most cases should not be a problem. Although 13.5 pF may not sound like much capacitance, at higher frequencies the amount of loading contributed by this capacitance can be significant. For instance, at 500 MHz the reactance of 13.5 pF in this model is just 23.6 Ω, which could contribute to significant “loading” and signal distortion.

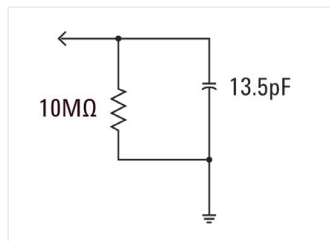


Figure 31. Simplified probe/oscilloscope electrical model.

Tip #11: Probing (continued)

For higher frequency measurement applications, active probes should be used, such as Keysight's InfiniiMode Series differential active probe shown in Figure 32. "Active" means that the probe consists of an amplifier near the probe's tip. This can significantly reduce the amount of capacitive loading and increase probing bandwidth. But the tradeoff with high-frequency active probes is often reduced dynamic range as well as price.



Figure 32. Keysight's InfiniiMode Series differential active probe.

Besides high-frequency active probes, there are many other specialty probing applications that should be considered. If you need to make measurements on a high-speed differential serial bus, then you should consider using a high-frequency differential active probe. If you need to make measurements on very high voltage signals, you should consider using a high-voltage probe. If you need to make current measurements, you should consider using a current probe.

To learn more about oscilloscope probing, refer to Keysight's application note ***Eight Hints for Better Scope Probing***, which is listed in the related literature section at the end of this document.

Keysight Technologies offers a broad range of passive, active, differential, and current probes that will meet your particular probing measurement needs. Refer to the Keysight probes data sheets listed at the end of this document to learn more about Keysight's various probing solutions.

Tip #12: Ease-of-use

Select an oscilloscope that can improve your measurement productivity with an intuitive user-interface



Ease-of-use. Usability. User-friendly. Intuitive. These are important oscilloscope characteristics. Although we have addressed ease-of-use last in our list of 12 tips, sometimes the usability of an oscilloscope can be just as important as specified performance characteristics, such as bandwidth, sample rate, and memory depth.

As oscilloscope vendors have packed more and more advanced features and capa-

bilities into today's digital storage oscilloscopes, many engineers believe oscilloscopes have become more difficult to use. Even if a new oscilloscope has an advanced measurement capability that is intended to improve measurement productivity, if the advanced feature is too difficult to find because it is buried deep in a sub-menu of the oscilloscope or if it is too difficult to set up because it includes tons of advanced settings that the user doesn't clearly understand, then most engineers will simply grab the old oscilloscope off the shelf and perform the measurement the old way.

Although most oscilloscope vendors will claim that their oscilloscopes are the easiest to use, usability is not a specified parameter that you can compare against in a product's data sheet. Ease-of-use is subjective, and you must evaluate it for yourself. Of course the easiest oscilloscope for you to use today is probably the one that you are currently using. This is simply because you are familiar with it and may be hesitant to change. This is human nature, though it is worth looking into how vendors have improved usability to make your job easier and faster.

The following are some important usability factors that we believe you should consider.

Knobs

Engineers like knobs on their oscilloscopes. Oscilloscopes should have knobs that directly control all key variables including vertical scaling (v/div), vertical position, timebase scaling (s/div), horizontal position, and trigger level as shown in Figure 33. Some oscilloscopes have multiplexed knobs, such as just one set of vertical scaling knobs as opposed to scaling knobs for each input channel. Some oscilloscopes also "bury" key variables such as horizontal position and/or trigger level within menus.



Figure 33. Oscilloscope front panels should include knobs for all key setup variables.

Tip #12: Ease-of-use (continued)

Responsiveness

Responsiveness is important. Setting up an oscilloscope is often a random and iterative process. Turn this knob... turn that knob... turn another knob until the waveform is properly scaled on the screen. But if the oscilloscope is unresponsive because it's busy processing captured data from the previous acquisition, setting up the oscilloscope can become a frustrating experience.

Built-in HELP

Turning on and using advanced features shouldn't require an advanced degree. Engineers are reluctant to read manuals and user's guides, even if they could find them. Some oscilloscopes have built-in HELP screens that provide short setup tips about specific features. For example, on many Keysight oscilloscopes, you can access built-in HELP by simply pressing and holding down any front panel key or menu button. Figure 34 shows a Keysight Runt Triggering HELP screen.

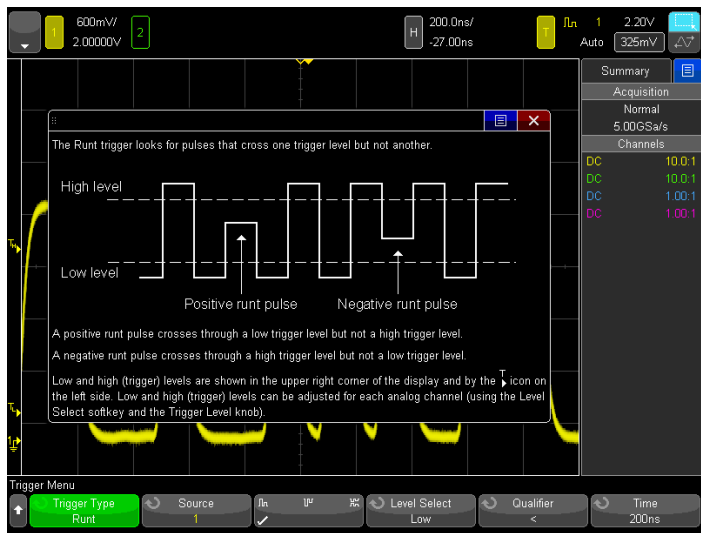


Figure 34. Built-in HELP screens assist users in setting up advanced measurements.

Larger Color Displays

Today's oscilloscopes can display lots of measurement information besides just waveforms. Larger displays with color can help clear the clutter so your eyes can focus on what's most important.

Keysight has found some innovative ways to use touch-screen technology to improve oscilloscope usability, such as InfiniiScan Zone triggering, which is available on the InfiniiVision 3000T, 4000 and 6000 X-Series. It uses the same capacitive-touch technology found in tablet computers on the market today. Simply use your finger to draw a box around the waveform that you want to trigger on, and the oscilloscope triggers on that unique signal without the hassle of setting up a complex trigger condition



Figure 35. The 4000 X-Series oscilloscope's touch screen and InfiniiScan Zone help you quickly set up complex trigger conditions.

Related literature

Title	Document type	Publication number
Keysight InfiniiVision 2000 X-Series Oscilloscopes	Data sheet	5990-6618EN
Keysight InfiniiVision 3000T X-Series Oscilloscopes	Data sheet	5992-0140EN
Keysight InfiniiVision 4000 X-Series Oscilloscopes	Data sheet	5991-1103EN
Keysight InfiniiVision 6000 X-Series Oscilloscopes	Data sheet	5991-4087EN
Keysight Infiniium S-Series Oscilloscope	Data sheet	5991-3904EN
InfiniiVision Oscilloscope Probes & Accessories	Data sheet	5968-8153EN
Infiniium Oscilloscope Probes and Accessories	Data sheet	5968-7141EN
Serial Bus Options for InfiniiVision X-Series Oscilloscopes	Data sheet	5990-6677EN
Evaluating Oscilloscope Bandwidths for your Applications	Application note	5989-5733EN
Oscilloscope Sample Rates versus Sampling Fidelity	Application note	5989-7885EN
Using Oscilloscope Segmented Memory for Serial Bus Applications	Application note	5990-5817EN
Oscilloscope Waveform Update Rate Determines Probability of Capturing Elusive Events	Application note	5989-7885EN
Synchronizing on Infrequent Anomalies and Complex Signals using InfiniiScan Zone Trigger	Application note	5991-1107EN
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
Eight Hints for Better Scope Probing	Application note	5989-7894EN

To download these documents, insert the publication number in the URL:
<http://literature.cdn.keysight.com/litweb/pdf/xxxx-xxxxEN.pdf>

Keysight's InfiniiVision and Infiniium Series Oscilloscopes

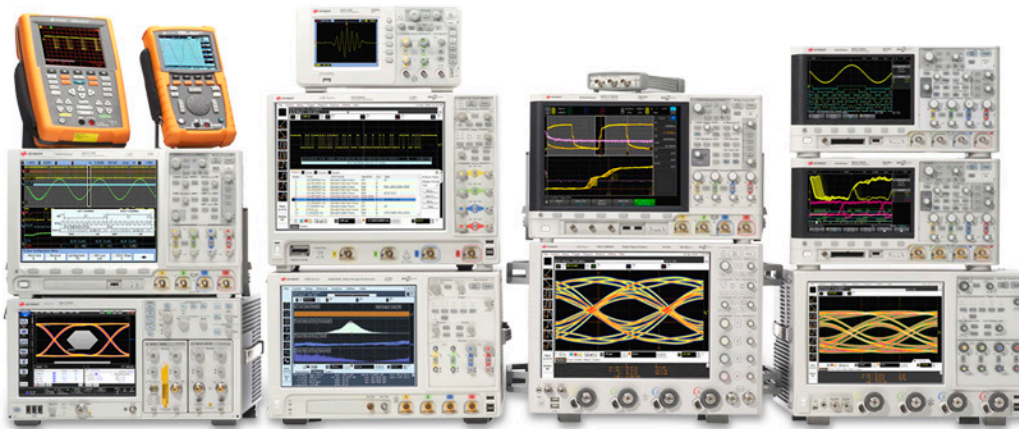
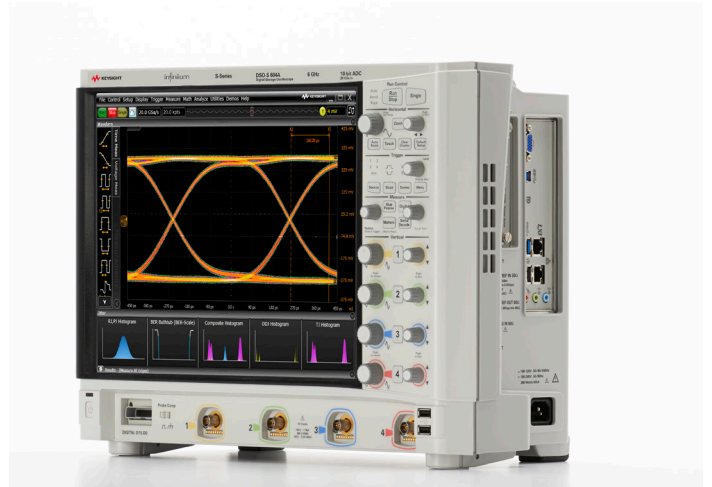
InfiniiVision X-Series Oscilloscopes

Keysight's mid-range performance InfiniiVision 2000, 3000, and 4000 X-Series oscilloscopes have been optimized for bench-top debug and troubleshooting. These oscilloscopes come in bandwidth models ranging from 70 MHz up to 1.5 GHz. With the fastest waveform update rates in the industry (up to 1,000,000 waveforms per second), these oscilloscopes can capture and display infrequent signal anomalies that other oscilloscopes miss.



Infiniium Series Oscilloscopes

Keysight's higher-performance Infiniium S-Series and 90000 Series oscilloscopes are Windows-based instruments that have been optimized for advanced waveform analysis. These oscilloscopes come in bandwidth models ranging from 500 MHz up to 63 GHz. The Infiniium Series oscilloscopes also have the deepest available acquisition memory in the industry (up to 2 Gpts). Also available on these oscilloscopes is a wide range of industry-standard compliance test packages, as well as advanced measurement options such as jitter analysis.



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