Ten Things to Consider When Selecting Your Next Oscilloscope

Application Note 1490

Introduction

You rely on your oscilloscope every day, so selecting the right one to meet your needs is an important task. Comparing the specs and features of scopes made by different manufacturers can be time-consuming and confusing. The concepts outlined in this article are intended to speed your selection process and help you avoid some common pitfalls. No matter who makes the scopes you are considering, carefully analyzing each one in relation to the ten issues discussed herein will help you evaluate the instruments objectively.

As you start the scope selection process, you probably have a price range in mind. The price of a scope will depend on many factors including bandwidth, sample rate, number of channels, and memory depth. If you shop for a scope based upon price alone, you may end up with one lacking the performance you need. Instead, think in terms of value. If your budget is tight, you may want to consider renting a scope or purchasing used equipment.

After reading this document, you should have all the information required to choose the best possible scope for your applications.

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Agilent Technologies

1 How much bandwidth do you need?

Bandwidth is the most important property of the oscilloscope as it determines the range of signals to be displayed and, to a large extent, the price. You need to balance present budget limitations with the expected needs of your lab over the lifetime of the scope when making your bandwidth decision.

In the present era of the digitizing oscilloscope, there is more to scope bandwidth than just the bandwidth of the analog amplifiers. To ensure a scope has enough bandwidth for your applications, take into account the bandwidths of the signals you expect to display with the scope. With modern digital technologies, the system clock is usually the highest-frequency signal the scope is likely to display. Your scope should have a bandwidth at least three times greater than this frequency in order to obtain a reasonable display of the waveform.

The signals' risetimes are another characteristic that determines the required bandwidth of your scope. Since it is likely you will be displaying more than pure sine waves, your signals will contain harmonics at frequencies beyond the fundamental one. For example, if you are viewing a square wave, the signal actually contains frequencies that are at least ten times the fundamental frequency of the signal. If you do not ensure proper scope bandwidth, rounded edges will be displayed on your scope instead of the clean, fast edges you were expecting. This, in turn, will affect the accuracy of your measurements.

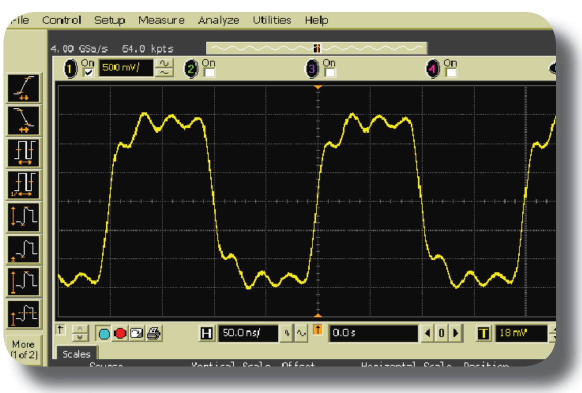
Fortunately, there are three very simple equations that will help in determining the proper scope bandwidth given your signal characteristics:

$$\textbf{signal bandwidth} = \frac{1}{2 \cdot \textbf{signal risetime}} \qquad (1)$$

$$\textbf{scope bandwidth} = 2 \cdot \textbf{signal bandwidth} \qquad (2)$$

$$\textbf{signal RTSR} = 4 \cdot \textbf{scope bandwidth} \qquad (3)$$

**RTSR = real-time sampling rate*



1 GHz oscilloscope

12 GHz oscilloscope

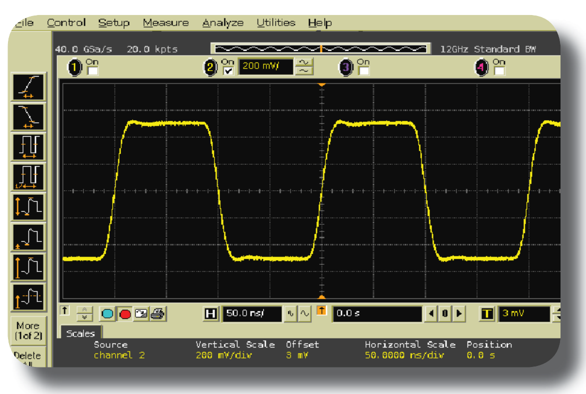


Figure 1: Identical square waves on oscilloscopes with different bandwidths

2 How many channels do you need?

The number of channels may seem like a simple issue if you think all oscilloscopes still come with only two or four channels. However, digital content is everywhere in modern designs and traditional two- and four-channel oscilloscopes do not always provide the required number of channels. If you have ever encountered this situation then you understand the frustration involved in either building external triggering hardware or writing special software to isolate activities of interest.

For today's increasingly digital world, a new breed of oscilloscopes has enhanced their utility in digital and embedded debug applications. These mixed-signal oscilloscopes (commonly referred to as MSOs) tightly interleave an additional sixteen logic timing channels with the two or four channels of a traditional oscilloscope. The result is a fully functional oscilloscope with up to twenty channels of time-correlated triggering, acquisition, and viewing.

An example of how a mixed-signal oscilloscope can be used for debugging is a common SDRAM application. To isolate an SDRAM write cycle, you would need to trigger on a combination of five different signals: RAS, CAS, WE, CS, and the Clock. A 4-channel scope by itself is not sufficient for this basic measurement.

Figure 2 shows how the sixteen logic timing channels were used to set a trigger on RAS high, CAS low, WE high, and CS. Scope channel 1 is used to view and trigger on the rising edge of the clock. Unlike a combined logic analyzer and oscilloscope solution where the logic analyzer can only cross-trigger the oscilloscope and vice-versa, a mixed-signal oscilloscope allows you to do full-width triggering across both the scope and logic timing channels.

Figure 2: Six-channel measurement: Data line during a write trigger on RAS, CAS, WE, CS and CLK.

3 What are your sample rate requirements?

Sample rate is a very important specification to consider when evaluating an oscilloscope. Why point this out? Most oscilloscopes can increase their sample rate by incorporating a form of interleaving. This is accomplished when two or more channels couple their A/D converters to provide a maximized sample rate on only one or two channels of a four-channel oscilloscope. The banner specification of the oscilloscope will emphasize this maximized sample rate and will not state that the sample rate applies to only one channel! If you are interested in purchasing a 4-channel scope, it is a given that you want full bandwidth on more than a single channel.

Recall from Equation 3 (page 2) that the sample rate of a scope should be at minimum four times greater than its bandwidth. The 4x multiplier is beneficial when the scope is using a form of digital reconstruction such as sin(x)/x interpolation. In cases where the scope is not employing a form of digital reconstruction, the multiplier should actually be 10x. Since most oscilloscopes employ some form of digital reconstruction, the 4x multiplier should be sufficient.

Consider an example using a 12 GHz oscilloscope that employs sin(x)/x interpolation. For this oscilloscope, the minimum per-channel sample rate to support a full 12 GHz bandwidth on each channel equals 4 x (12 GHz), or 48 GSa/s per channel. A 12 GHz scope may advertise a maximum 64 GSa/s sampling rate, but fail to point out that the 64 GSa/s sampling rate is applicable on one channel only. The per-channel sample rate of this scope, when using either three or four channels, is actually only 16 GSa/s—insufficient to support the 12 GHz bandwidth on more than a couple of channels.

Another way to look at sample rate is to determine the resolution desired between points of acquisition. Sample rate is simply the inverse of the resolution. For example, the sample rate that can provide 1 ns resolution between points is 1/(1 ns) = 1 GSa/s.

In conclusion, make sure the scope you consider has enough sample rate per channel for every channel that may be used simultaneously. This way each channel can support the rated bandwidth of the scope.

4 How much memory depth do you need?

As you read in the previous considerations, bandwidth and sample rate are closely related. Memory depth is also tightly related to sample rate. An A/D converter digitizes the input waveform and the resulting data is stored into the scope's high-speed memory. An important selection factor is to understand how the oscilloscope you are considering uses this stored information.

Memory technology enables users to capture an acquisition and zoom in to see more detail. Performing math, measurements, and post-processing functions on acquired data is also possible with this technology.

Many people assume an oscilloscope's maximum sampling rate specification applies to all time base settings. The price of such an oscilloscope would be huge as it would require a very large memory. In actuality, the memory depth is limited and, therefore, all oscilloscopes must reduce their sampling speed as the time base is set to wider ranges. The deeper the scope's memory, the more time can be captured at full sampling speed. You need to check the scope under consideration to see how its sampling speed is affected by the time base setting.

The required memory depth you need is dependent upon the amount of time you want displayed, as well as the sample rate you want to maintain. If you are interested in looking at longer periods of time with high resolution between points, you need deep memory. A simple equation can tell you how much memory you will need, given time span and sample rate:

$$\textbf{memory depth} = \textbf{sample rate} \cdot \textbf{TAD} \qquad (4)$$

**TAD = time across display*

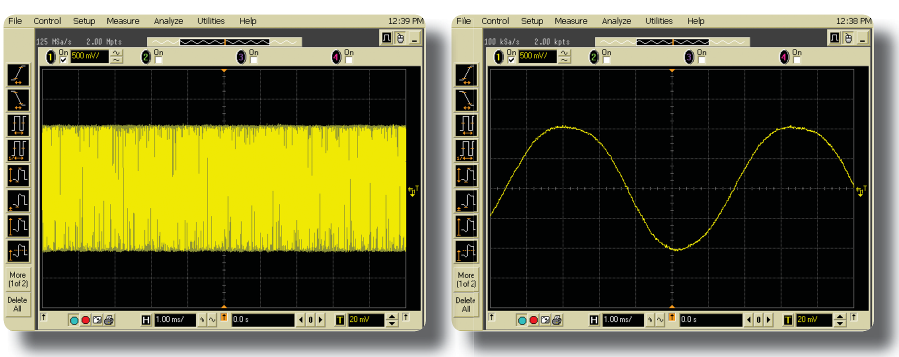


Figure 3: These images show an 80 MHz square wave acquired at a slow sweep speed (1 ms/div) on a scope with 2 Mpts memory setting (left) and a 2 kpts memory setting (right). The 2 Mpts deep memory maintains adequate sample rate to prevent aliasing. When the memory is reduced to 2 kpts, the sample rate drops by a factor of 1000. This reduced sample rate causes the scope to under sample the signal, resulting in an aliased signal of 155 MHz frequency. Although the waveform on the right looks correct, the frequency of the waveform is actually off by 79.9 MHz.

Ensuring a high sample rate across all time settings can protect you against signal aliasing and provide more detail on the waveforms should you need to zoom in and examine them more closely.

Once you have determined your memory depth, it is equally important to see how the scope operates when using the deepest memory setting. Scopes with traditional deep-memory architectures respond sluggishly which can negatively impact your productivity. Due to the slow responsiveness, scope manufacturers often relegated deep memory to a special mode and engineers typically used it only when deep memory was essential. Although scope manufacturers have made advances in deep memory architectures over the years, some deep-memory architectures are still slow and time-consuming to operate. Before you purchase a scope, make sure to evaluate the responsiveness of the scope in the deepest memory setting.

5 What display capability do you need?

Ultimately, all oscilloscope suppliers know they are selling the display of your waveforms. In the days of analog oscilloscopes, the design features of the scope's CRT display determined the quality of the picture. However, the modern digital oscilloscope's display performance is largely a function of digital processing algorithms and not the physical characteristics of the display device itself.

Today's digitizing oscilloscopes fall into two broad categories: waveform viewers and waveform analyzers. Those scopes designed for viewing are usually seen in test and troubleshooting applications. In these applications, it is the display of the waveform that provides all the necessary information. In waveform analysis applications, Microsoft® Windows® operating systems and advanced analysis functions allow additional levels of abstraction to determine how a system under test is performing.

One major factor in the quality of the display is the update rate of your oscilloscope. The update rate refers to the rate at which the oscilloscope is able to acquire and update the display of a waveform. Therefore, faster update rates improve the probability that infrequent events like the one seen in Figure 4 are captured. For example, the Agilent 6000 and 5000 Series oscilloscopes have update rates of up to 100,000 waveforms per second. This would enable you to capture a glitch twice per second on average if the glitch occurred every 50,000 cycles. On the other hand, some oscilloscopes possess update rates of 800 waveforms per second. It would take these oscilloscopes one minute on average to catch the same glitch.

You must be careful when comparing update rates as vendors quote the best possible update rate their scopes can achieve. However, special acquisition modes are often required to obtain these banner specifications. These special modes can severely limit the performance of the scope in areas such as memory depth, sample rate, and waveform reconstruction. The Agilent 6000 and 5000 Series oscilloscopes discussed above do not require any special acquisition mode to obtain the up to 100,000 waveforms per second update rate.

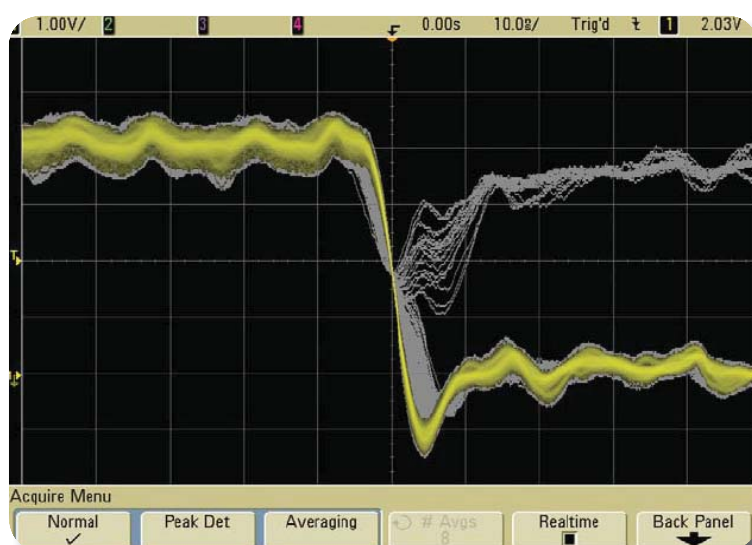


Figure 4: Infrequent event captured by an Agilent 6000 Series oscilloscope.

Numerous other factors, such as the number of channels being used, can also limit the update rate of your oscilloscope. Therefore, it is best to determine what performance and setups you will need and then test the oscilloscope's update rate for these specific conditions.

In general, judging an oscilloscope's display capabilties based solely upon specifications released from the vendor is unwise. Comparing the displays of multiple scopes requires a live demo in your lab to determine which scope has the ability to display exactly what you need to see.

6 What triggering capabilities do you need?

Edge triggering is widely utilized by general-purpose scope users. However, it may be helpful to have additional triggering power in some applications as advanced triggering allows you to isolate specific events. For example, in digital applications, it is very helpful to trigger on a certain pattern across channels. The mixed-signal oscilloscope enables you to trigger across a pattern of logic and scope channels. With a combined scope/logic analyzer solution, you can only cross-trigger the two instruments by means of cabling their respective in/out trigger signals together.

For serial designers, some oscilloscopes even come standard with serial triggering protocols for such standards as SPI, CAN, USB, I^{2}C, FlexRay, and LIN. These advanced triggering options can save a significant amount of time in day-to-day debugging tasks.

What if you need to capture an infrequent event? Glitch triggering allows you to trigger on a positive- or negative-going glitch, or on a pulse greater than or less than a specified width. These features are especially powerful when troubleshooting. as you can trigger on the fault and look back in time to see what caused the problem.

Additionally, many scopes on the market today provide triggering capability for TV, HDTV, and video applications. Using a scope's television trigger, you can trigger on the field and specific line you need to view.

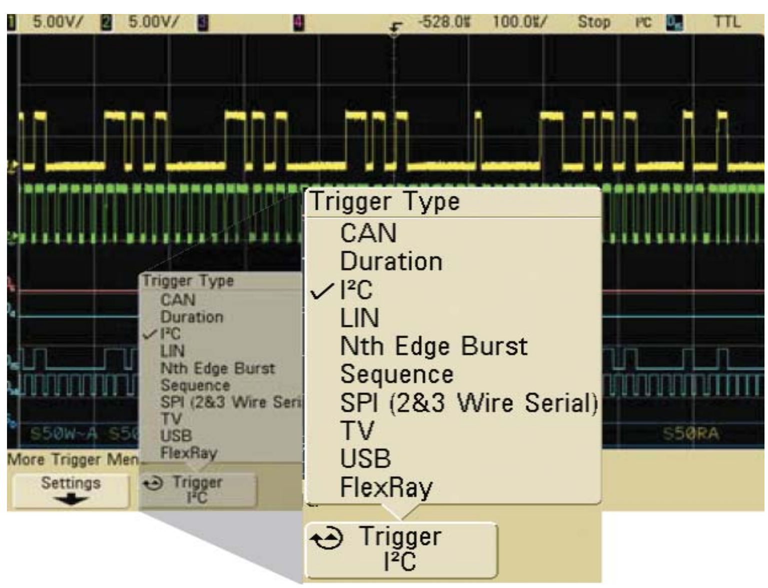


Figure 5: Trigger menu from an Agilent 6000 Series oscilloscope.

7 What is the best way to probe your signal?

The probe you choose is important because the system bandwidth—the bandwidth of the scope/probe combination—is limited by the lesser of the two bandwidths. Consider, for example, a 1 GHz scope coupled with a 500 MHz passive probe. The system bandwidth of the combination is 500 MHz. It is worthless to purchase a 1 GHz scope if you will only get 500 MHz bandwidth due to your probe!

Additionally, every time you connect a probe, the probe becomes part of the circuit under test. The probe tip is basically a short transmission line. This transmission line is a resonant L-C tank circuit and, at the 1/4 wave frequency of the transmission line, the impedance of the L-C tank circuit will be driven close to zero which will load your device under test. You can easily see the loading of the resonant L-C tank circuit in the slower risetimes and ringing on the signal.

Active probes not only provide greater bandwidths than passive probes, but they can also mitigate some of the transmission-line effects you see when you connect a probe to a device under test (DUT). Agilent Technologies has minimized the signal loading and resulting signal distortion by incorporating resistive "damped" tips and accessories with their active probes. These damped accessories prevent the resonant L-C tank circuit impedance from going too low—thus, preventing the ringing and signal distortion caused by loading the signal.

Additionally, the damped accessories enable the frequency response of the probes to remain flat throughout the entire bandwidth of the probe. With a flat response, you can ensure against signal distortion throughout the entire bandwidth of the probe.

With the signal distortion issue solved, the next step is to ensure your probe is capable of full bandwidth even when you are using probe head accessories. Agilent InfiniiMax probes optimize the probe bandwidth by using a controlled transmission line between the probe amplifier and probe tip. Using a single amplifier, you can connect a variety of differential or single-ended probe heads (including browsing, socketed, solder-in, and SMA) and obtain full system bandwidth. Additionally, the probe amplifier is actually separated from the probe tip by a controlled transmission line so you can easily obtain access to tight probing spaces.

The key here is to understand the bandwidth rating of the probe when using a variety of probe heads and accessories as these can significantly degrade a probe's performance.

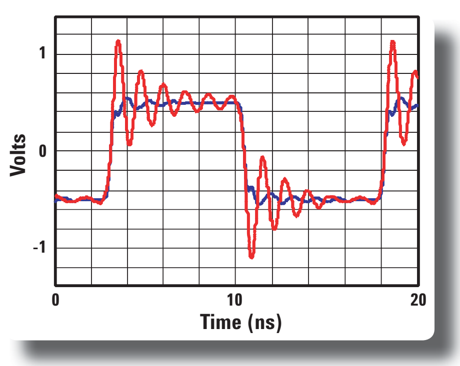


Figure 6: 250 ps risetime signal probed with a 2.5 GHz probe and an undamped 2 inch connection accessory.

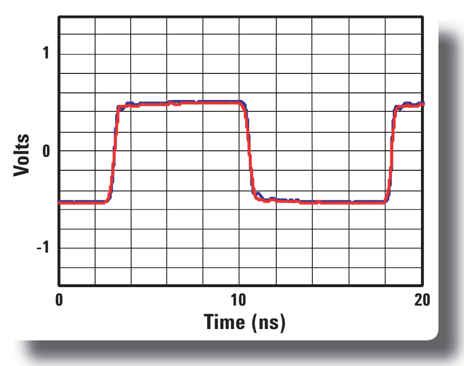


Figure 7: 250 ps risetime signal probed with a 2.5 GHz probe and a damped 2 inch connection accessory.

8 What documentation and connectivity features do you need?

Many digitizing oscilloscopes now have the connectivity you find on personal computers including GPIB, RS-232, LAN, and USB 2.0 interfaces. Therefore, it is much easier to send pictures to a printer or transfer data to a PC than it was in the past.

Do you often transfer scope data to your PC? If so, then it will be important for your scope to have at least one of the connectivity options listed above. A built-in CD-ROM or CD-RW drive can also help in transferring data, although using them typically requires more effort than sending a file from your scope over a USB or LAN connection.

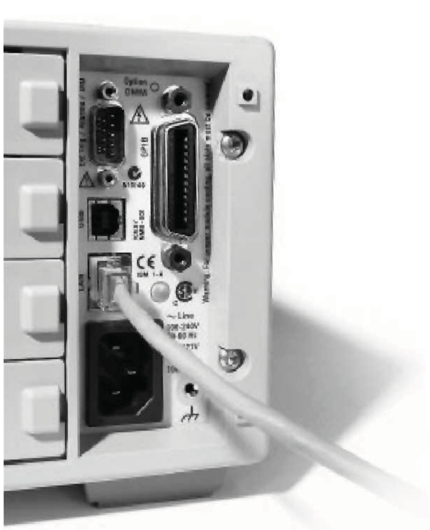
For affordable scopes that do not have some of the connectivity options like LAN and USB, scope manufacturers often provide software packages that enable you to easily transport the waveform images and data to a PC via GPIB or RS-232. If your PC does not have a GPIB card or you want an easy way to transfer the waveform to a laptop PC, you might consider a USB/GPIB or LAN/GPIB interface. Oscilloscopes also usually come with multi-GB hard drives that can be used for data storage and removable hard drives are now available as well.

Another connectivity option is setting up a secure wireless LAN (WLAN). This is helpful if you are constrained by the length of the cables required by a wired connection.

Shared access via a LAN connection may prove useful as several users can access the same oscilloscope via a company intranet or the Internet. This allows oscilloscopes to remain in a centralized location and for teams that are widely dispersed to work together on specific prototypes.

Some oscilloscopes, such as the Agilent 6000 Series, allow you to remotely control, display, and perform waveform analysis via a PC from any java-enabled web browser. Figure 8 shows an example of the Virtual Panel for an Agilent 3000 Series oscilloscope displayed on a PC. Remote access to an oscilloscope could, for example, enable a user to calibrate a scope from home so the instrument was ready when the user arrived at work.

Determining ahead of time what degree of connectivity and documentation capability you will need from your scope can drastically reduce the amount of time you end up spending transferring and storing data.



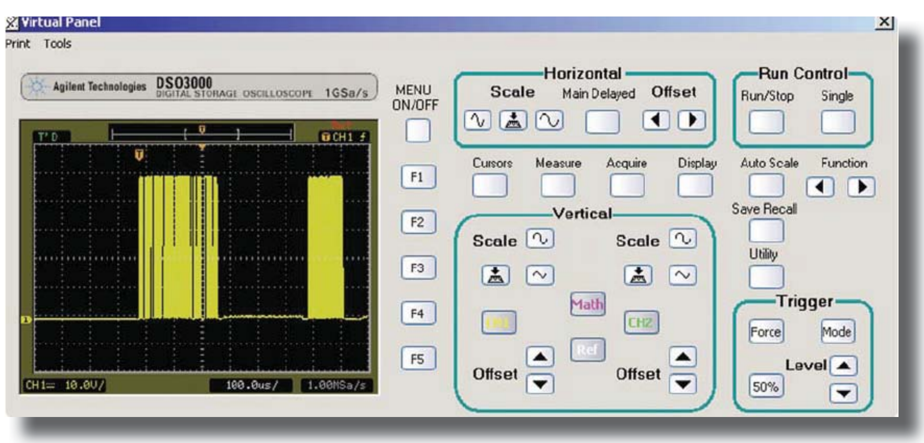


Figure 8: Agilent 3000 Series oscilloscope's Virtual Panel allows you to have the look and control of an oscilloscope while remotely controlling it from your computer.

9 What additional application software do you need?

Automatic measurements, built-in analysis capability, and additional application software can save time and make your job easier. Digitizing oscilloscopes frequently come with an array of measurement features, analysis options, and software that are not available on analog scopes.

Math functions typically available include addition, subtraction, multiplication, division, integration, and differentiation. Measurement statistics (min, max, and average) can quantify measurement uncertainty - a valuable asset when characterizing noise and timing margins. Many digitizing scopes offer FFT capability as well.

For the “power user” interested in waveform analysis, oscilloscope manufacturers are providing greater flexibility in mid-range and high-performance scopes. Some manufacturers offer software packages that enable you to customize complex measurements, perform math functions, and do post-processing directly from the scope’s user interface. You can write a measurement routine in C++ or Visual Basic, for example, and execute it from a menu on the scope’s graphical user interface (GUI). This functionality eliminates the need to transfer data to an external PC, which can save a significant amount of time for those interested in waveform analysis.

Application software can also save a tremendous amount of time and allow you to make measurements that would otherwise be very difficult. One example of this software is Agilent's InfiniiScan. InfiniiScan is an identification software that quickly identifies signal integrity issues. It accompolishes this by scanning through thousands of waveforms and then isolating any anomalies in the signal.

PCIe compliance and validation software offered by Agilent is another piece of application software. This software allows you to debug and test PCIe 1.1 and 2.0 designs. Other examples include software for serial data analysis and vector signal analysis.

It is important to investigate what additional software is available so you do not find yourself needing a function or measurement that your oscilloscope's software cannot handle.

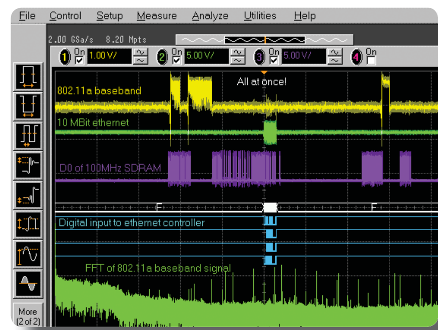


Figure 9. Analog and RF designers typically find advanced math functionality and FFT capability important features for their everyday scopes.

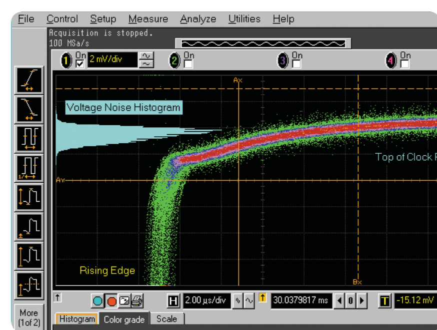


Figure 10. Digital designers commonly use measurements such as histogramming to evaluate signal integrity.

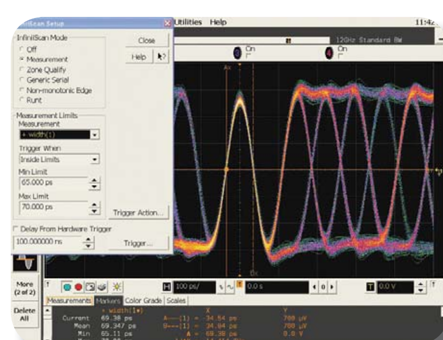


Figure 11: Infiniiscan measurement finder identifies a glitch that occured between 65 ps and 75 ps.

10 Last but not least—demo, demo, demo!

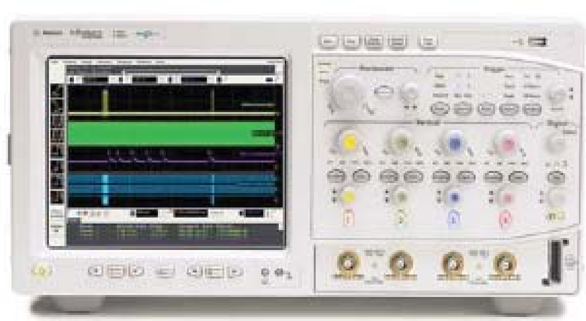
Thinking through the previous nine considerations most likely enabled you to narrow the field to a limited number of oscilloscopes that meet your selection criteria. Now is the time to try them out and perform a side-by-side comparison. Borrow the scopes for a few days so you have time to evaluate them thoroughly. Some factors to consider as you use each scope include:

Ease of use: During your trial, evaluate each scope's ease of use. Are there dedicated knobs for often-used adjustments like vertical sensitivity, time base speed, trace position, and trigger level? How many buttons do you need to push to go from one operation to the next? Can you operate the scope intuitively while concentrating on your circuit under test?

Display responsiveness: As you evaluate the scopes, pay attention to display responsiveness whether you are using it for troubleshooting applications or for gathering large quantities of data. When you change V/div, time/div, memory depth, and position settings, does the scope respond quickly? Try the same thing with measurement features turned on. Is the response noticeably slower?

Conclusion

After you have considered all these issues and have evaluated the scopes, you should have a good idea of which models will truly meet your needs. If you are still unsure, you may want to discuss the choices with other scope users or call the manufacturer's technical support staff.



Glossary

Aliased signals A signal (normally electrical) sampled below the Nyquist Rate (twice the maximum frequency content of the signal) so that the frequency content of signal is erroneously rearranged.

CAN Controller area network, a robust serial communication bus standard popular in automotive and industrial applications.

Digitizing oscilloscope an oscilloscope that uses a high-speed analog-to-digital converter (ADC) to measure signals and then displays them on a screen (CRT or LCD) using standard computer graphics techniques.

GPIB General-purpose instrument bus, also known as the IEEE-488 bus, widely used as an interface for connecting test instruments to computers and for providing programmable instrument control.

Harmonics a frequency component of a signal that is an integral multiple of the fundamental of that signal.

I^2C Inter integrated circuit bus, a short-distance serial communication bus standard consisting of two signals (clock and data), popular for talking between several integrated circuits on the same printed circuit board.

Interleave A technique used in digitizing oscilloscopes whereby ADCs of different analog channels are used together, normally resulting in higher sample rate or more memory depth when you are using fewer channels.

L-C tank circuit A circuit consisting of inductance and capacitance, capable of storing electricity over a band of frequencies continuously distributed about a single frequency at which the circuit is said to be resonant or tuned.

LIN Local interconnect network, a short-distance serial communication standard that is often found in systems also containing the CAN bus. LIN is slower and less complex than the CAN bus.

Mixed-signal oscilloscopes (MSOs) Digitizing oscilloscopes that have a larger number of channels than usual for looking at both analog and digital signals. MSOs typically have two or four analog channels and at least 8 bits of vertical resolution. There are usually 16 digital channels but they typically have only 1 bit of vertical resolution.

SDRAM Synchronous dynamic random-access memory, the most popular form of digital memory today. It differs from previous-generation DRAM in that all signal timing is relative to one clock.

SPI Serial peripheral interface, a very simple short-distance serial communication bus standard consisting of either two (clock and data) or three (clock, data and strobe) signals, popular for reading data from microcontroller peripherals such as ADCs.

USB Universal serial bus, an interface for connecting peripherals, including test instruments, to computers.

Related Literature

Publication Title	Publication Type	Publication Number
Agilent 5000 Series Portable Oscilloscopes	Data Sheet	5989-6110EN
Agilent 6000 Series Oscilloscopes	Data Sheet	5989-2000EN
Agilent Infiniium 8000 Series Oscilloscopes	Data Sheet	5989-4271EN
Agilent Infiniium 80000B Series Oscilloscopes	Data Sheet	5989-4604EN
Infiniium Oscilloscope Probes, Accessories, and Options	Data Sheet	5968-7141EN
Agilent 5000 and 6000 Series Oscilloscope Probes and Accessories	Data Sheet	5968-8153EN
Agilent 82357A USB/GPIB Interface for Windows	Data Sheet	5988-5028EN
Deep Memory Oscilloscopes: The New Tools of Choice	Application Note	5988-9106EN
Evaluating Oscilloscope Sample Rates vs. Fidelity: Accurate Digital Measurements	Application Note	5989-5732EN
Choosing an Oscilloscope with the Right Bandwidth for your Application	Application Note	5989-5733EN

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www.lxistandard.org
LXI is the LAN-based successor to GPIB, providing faster, more efficient connectivity. Agilent is a founding member of the LXI consortium.

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