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 specs and features of scopes made by different manufacturers can be time-consuming and confusing. The concepts outlined here 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 10 issues discussed here will help you evaluate the instruments objectively.

After you have read through this document, you should have the information you need to choose the best possible scope for your applications.

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 on the basis of price alone, you may not end with 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.

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1 How much bandwidth do you need?

Now that we are in the era of the digitizing oscilloscope, there's more to scope bandwidth than just the bandwidth of the analog amplifiers alone. To ensure that your scope has enough bandwidth for your application, you need to take into account the bandwidths of the signals you will be looking at with the scope.

Bandwidth is the most important characteristic of the oscilloscope, as it determines the range of signals to be displayed, and to a large extent, the price you'll need to pay. When making your bandwidth decision, you need to balance today's budget limitations with your expected needs over the life of the scope in your lab.

In today's 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 shape of this signal.

Another characteristic of the signals in your system that determines the bandwidth requirements of your scope is the signals' risetimes. Since it's likely you will not be looking at just pure sine waves, your signals will contain harmonics at frequencies beyond the fundamental frequency of your signal. For instance, if you are looking at a square wave, the signal actually contains frequencies that are at least 10 times the fundamental frequency of the signal. If you don't ensure proper scope bandwidth when looking at a signal such as a square wave, you will see rounded edges on your scope display instead of the clean, fast edges you were expecting to see. This, in turn, will affect the accuracy of your measurements.

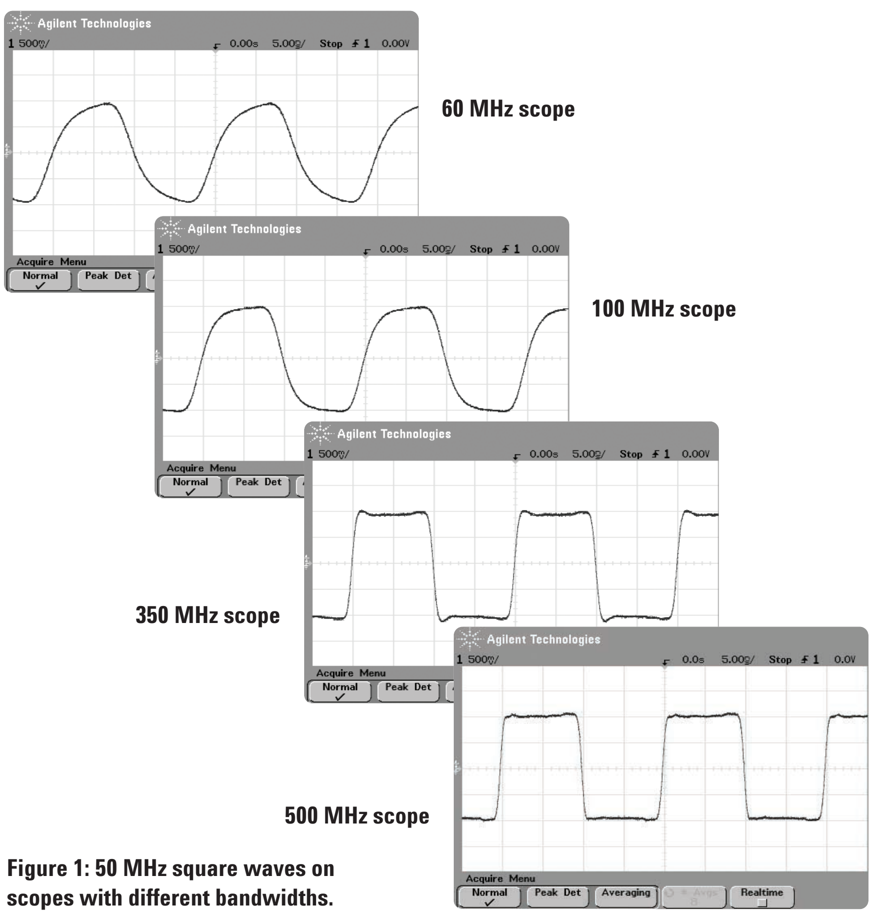

Figure 1: 50 MHz square waves on scopes with different bandwidths.

Fortunately, we have a few very simple equations that will help you to determine proper scope bandwidth, given your signal characteristics:

1. **Signal bandwidth = 0.5/signal risetime**
2. **Scope bandwidth = 2 x signal bandwidth**
3. **Scope real-time sample rate = 4 x scope bandwidth**

Now that you've determined the proper scope bandwidth, you need to take into account the sample rate for every channel you intend to use at the same time on the scope. As outlined in equation 3 above, you need to ensure a sample rate of four times the scope bandwidth for each channel you intend to use, in order for those channels to fully support the rated bandwidth of the scope. We'll discuss this in more detail later.

2 How many channels do you need?

At first glance, the number of channels seems like a simple issue. After all, don't all oscilloscopes come with two or four channels? Not any more! Digital content is everywhere in today's designs, and whether the digital content is low or high in your design, traditional 2- and 4-channel oscilloscopes do not always provide the channel count necessary to trigger on and view all signals of interest. If you've come across this situation, you understand the frustration involved in either building external triggering hardware or writing special software to isolate activity of interest.

For today's increasingly digital world, a new breed of oscilloscopes has enhanced the utility of the oscilloscope in digital and embedded debug applications. Mixed-signal oscilloscopes (commonly referred to as MSOs) tightly interleave an additional 16 logic timing channels with the 2 or 4 scope channels of a typical oscilloscope. The result is a fully functional oscilloscope with up to 20 channels of time-correlated triggering, acquisition, and viewing.

Let's take a common SDRAM application as an example of how a mixed-signal oscilloscope can be used for everyday debug. 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.

As you can see in Figure 2, the 16 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 in which 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?

As we mentioned earlier, sample rate is a very important specification to consider when evaluating an oscilloscope. Why point this out? Most oscilloscopes incorporate a form of interleaving, in which sample rates can be increased 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 only this maximized sample rate and will not tell you that the sample rate applies to one channel only! If you're interested in purchasing a 4-channel scope, it's a given that you want to use and have full bandwidth on more than a single channel only.

Recall from the equations given in consideration 2 that the sample rate of the scope should be at minimum four times greater than the bandwidth of the scope. 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.

Let's consider an example using a 500 MHz oscilloscope that employs sin(x)/x interpolation. For this oscilloscope, the minimum per-channel sample rate to support a full 500 MHz bandwidth on each channel equals 4 x (500 MHz), or 2 GSa/s *per channel*. Some 500 MHz scopes on the market today advertise a maximum 5 GSa/s sampling rate, but fail to point out that the 5 GSa/s sampling rate is applicable on one channel only. The per-channel sample rate of these scopes, when using either three or four channels, is actually only 1.25 GSa/s—insufficient to support the 500 MHz bandwidth on more than a couple of channels.

Another way to look at sample rate is to determine the resolution you want between points of your acquisition. Sample rate is simply the inverse of the resolution. For example, say you are interested in 1 ns resolution between points. The sample rate that can provide this resolution is 1/(1 ns) = 1 GSa/s.

In conclusion, make sure that the scope you consider has enough sample rate per channel for all channels you want to use simultaneously, so each channel can support the rated bandwidth of the scope.

4 How much memory depth do you need?

As you read above, 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're considering uses this stored information. Memory technology enables you to do things like capture an acquisition, and zoom in to see more detail, or perform math, measurements, and post-processing functions on the acquired data.

Many people assume that the oscilloscope's maximum sampling rate specification applies to all time base settings. This would be a good thing, but it would require such a large memory that nobody would be able to afford such a scope. Because the memory depth is limited, all oscilloscopes must reduce their sampling speed as the time base is set to wider and wider ranges. The deeper the scope's memory, the more time can be captured at full sampling speed. There is currently a popular oscilloscope on the market with a sampling speed of several gigasamples per second and 10,000 points of memory. This oscilloscope is forced to reduce its sampling speed to kilosamples per second when the time base is set to 2 ms/division and slower. You need to check the scope in question to see how its sampling speed is affected by the time base setting. The scope referred to here will have a bandwidth of only a few kilohertz when operating at sweep speeds required to display a full cycle of a system's operation.

The required memory depth you need is dependent upon the amount of time you want to look at on the display, as well as the sample rate you want to maintain. If you're 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:

Memory depth =
Sample rate x time across display

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

Once you have determined your memory depth, it is equally important to see how the scope you are considering operates when you are 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.

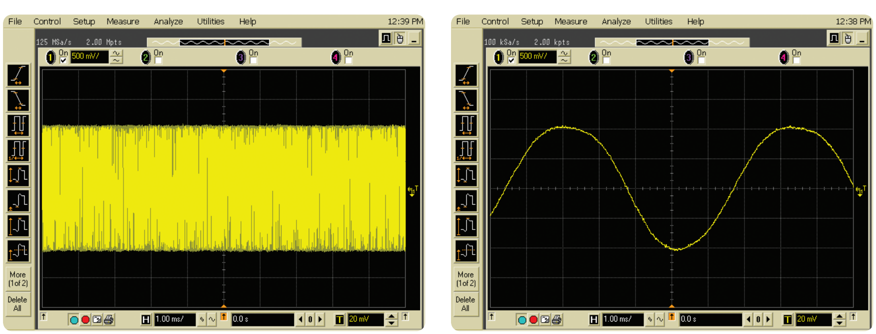

Figure 3: These images show an 80 MHz square wave acquired at a slow sweep speed (1 ms/div) on a scope with 2 Mpts memory setting (left) and a 2 kpts memory setting (right). The 2 Mpts deep memory maintains adequate sample rate to prevent aliasing. When the memory is reduced to 2 kpts, the sample rate drops by a factor of 1000. This reduced sample rate causes the scope to undersample the signal, resulting in an aliased signal of 155 Mz frequency. Although the waveform on the right looks correct, it is not. The frequency of the waveform is off by 79.9 MHz.

5 What display capability do you need?

All oscilloscope suppliers know that they are selling the picture of your waveforms. Back in the days of analog oscilloscopes, the design features of the scope's CRT display determined the quality of the picture. In today's digital world, the oscilloscope's display performance is largely a function of digital processing algorithms and not the physical characteristics of the display device. Some oscilloscope manufacturers have added special display modes to their product in an attempt to overcome some of the differences between traditional analog oscilloscope displays and digital displays. There is no good way to determine which is best in your lab by studying the scope's specifications. Only a live demo on your bench, viewing *your* waveforms, will determine which scope is best for your needs.

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 picture of the waveform that gives you all the information you need.

In waveform analysis applications, you see things like Microsoft® Windows® operating systems and advanced analysis functions that allow additional levels of abstraction to be applied to determine how a system under test is performing. Again, it is very difficult to determine how well an oscilloscope will be able to meet your needs from only the product's data sheet. It takes a live demo in your lab to determine if the scope in question has the ability to show you exactly what you need to see.

6 What triggering capabilities do you need?

Many general-purpose scope users get by using edge triggering. However, you may find it helpful in some applications to have additional triggering power. Advanced triggering gives you the power to isolate the events you wish to view. For example, in digital applications, it is very helpful to trigger on a specific pattern across channels. The mixed-signal oscilloscope, as discussed earlier, enables you to trigger across a pattern of logic and scope channels—unlike a combined scope/logic analyzer solution, in which 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^2C, and LIN. Again, 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 you are troubleshooting. You can trigger on the fault and look backward in time (using the delay or horizontal position knob) to see what caused the problem.

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

7 What is the best way to probe your signal?

Things begin to change at 1 GHz and above. Since passive probes are typically limited to 600 MHz, obtaining full bandwidth out of your scope can be an issue. 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'll only get 500 MHz bandwidth because of your probe!

Additionally, every time you connect a probe to a circuit, 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 low—close to zero—and 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.

Now with the signal distortion issue solved, the next step, if you are probing high-speed signals, is to ensure that 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. And, because the probe amplifier is actually separated from the probe tip by a controlled transmission line, 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. Accessories can degrade a probe's performance, and you do not want to spend thousands of dollars needlessly on a high-bandwidth active probe that may have severely degraded performance in the probing configuration you prefer.

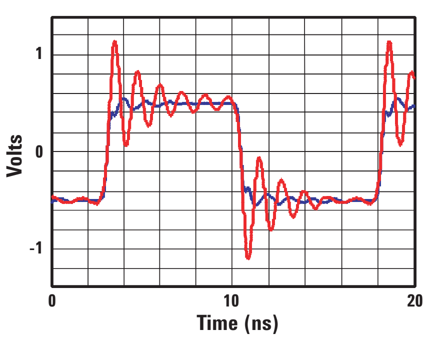

Figure 4: 250 ps risetime signal probed with a 2.5 GHz probe and an undamped 2 inch connection accessory.

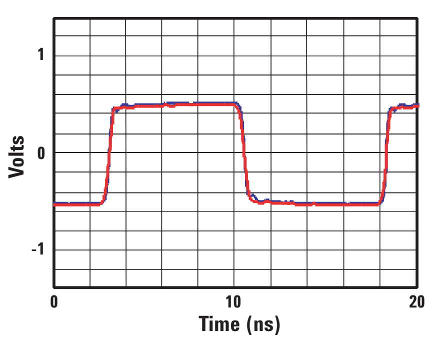

Figure 5: 250 ps risetime signal probed with a 2.5 GHz probe and a damped 2 inch connection accessory.

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 interfaces. It's now far easier to send pictures to a printer or transfer data to a PC or server than it was in the past. Do you often transfer scope data to your PC? Then it will be important for your scope to have at least one of the connectivity options listed above. A built-in floppy drive or CD-ROM drive also can help you transfer data, although using them typically requires a little 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 more advanced connectivity options like LAN and USB, scope manufacturers often provide software packages that allow you to easily transport the waveform images and data to a PC via GPIB or RS-232. If your PC doesn't have a GPIB card, or you want an easy way to transfer the waveform to a laptop PC, you might consider a GPIB-to-USB converter. Many oscilloscopes also come with multi-GB hard drives that you also can use for data storage. Determine ahead of time what degree of connectivity and documentation capability you will need from your scope.

If you need to connect the oscilloscope as part of an automated test system, make sure the scope comes with adequate software and a driver to suit your programming environment.

9 How will you analyze your waveforms?

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

Math functions include addition, subtraction, multiplication, division, integration, and differentiation. Measurement statistics (min, max, and average) can qualify measurement uncertainty, a valuable asset when you're 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 let you customize complex measurements, and perform math functions and 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.

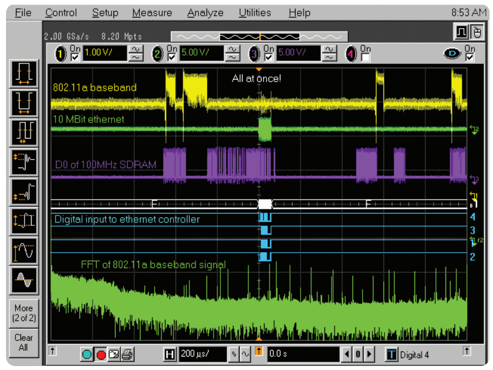

Figure 6. Analog and RF designers typically find advanced math functionality and FFT capability important features for their everyday scopes.

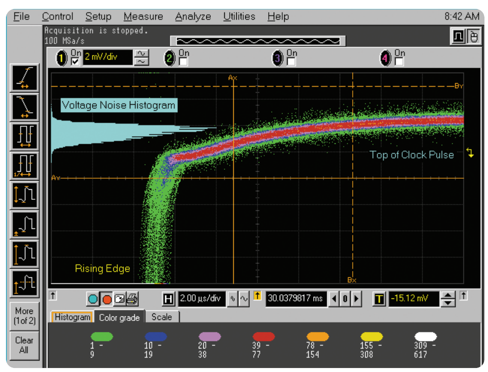

Figure 7. Digital designers commonly use measurements such as histogramming to evaluate signal integrity.

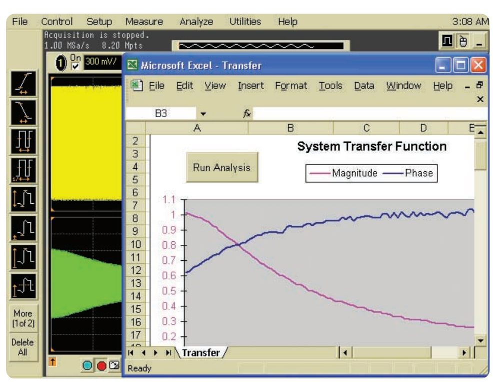

Figure 8. Even more advanced waveform analysis is available through software packages such as Agilent's My Infiniium Integration Package. My Infiniium allows engineers to launch their customized applications directly from the oscilloscope's front panel or graphical user interface.

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

If you have thought through the previous nine considerations, you have most likely narrowed the field to a limited number of scopes that meet your criteria. Now is the time to try them out and do 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:

Ease of use: During your trial, evaluate each scope's ease of use. Are there easy-to-use 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—a critical factor—whether you're using your scope 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 response noticeably slower?

Conclusion

After you have thought about all these issues and have evaluated the scopes, you should have a good idea of which models will truly meet your needs. If you're 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 know 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 Technologies Infiniium 54830 Series Oscilloscopes	Brochure	5988-3788EN
Infiniium 54800 Series Oscilloscope Probes, Accessories, and Options	Selection Guide Data Sheet	5968-7141EN
Agilent Technologies 54600 Series Oscilloscopes	Data Sheet	5968-8152EN
Agilent Technologies 54600 Series Oscilloscope Probes and Accessories	Selection Guide Data Sheet	5968-8153EN
Agilent 82357A USB/GPIB Interface for Windows	Data Sheet	5988-5028EN

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