



Agilent Technologies

Digitizing Oscilloscope Basics

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Presented By:

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Agenda

Digitizing Oscilloscope Topics

- **Analog Bandwidth**
- **Sampling**
- **Memory Depth**
- **Display Quality**
- **Number of Channels**
- **Triggering Modes**
- **Ease of Use**

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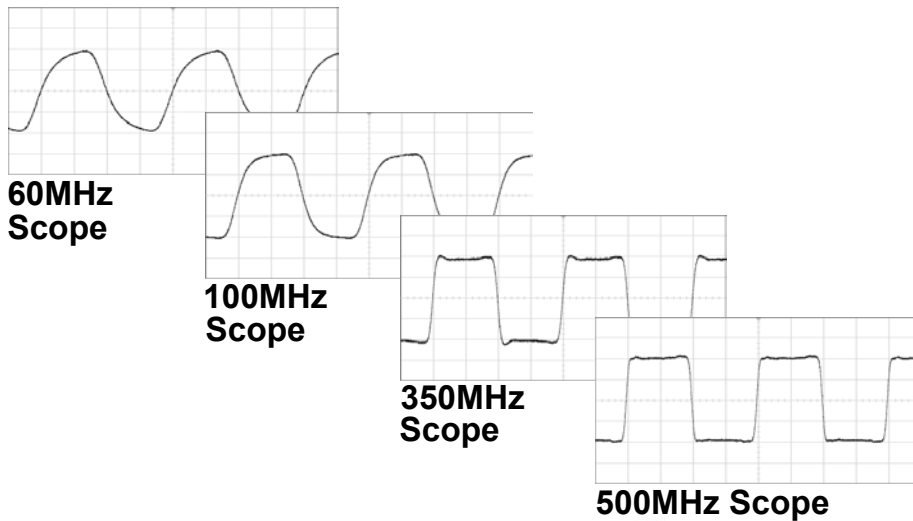
Throughout this presentation, we will be covering the following topics that one should consider when selecting the right oscilloscope for a particular application:

- **Analog Bandwidth**
- **Sampling (both Sampling Technique and Sample Rate)**
- **Memory Depth**
- **Display Quality**
- **Number of Channels**
- **Triggering Modes**
- **Ease of Use**

Each will be covered in detail throughout this presentation.

Analog Bandwidth

What does a 50MHz signal really look like?



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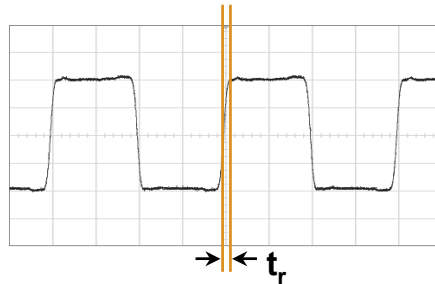
Analog Bandwidth

This first basic step in selecting the right oscilloscope is to determine the required analog bandwidth is needed for a particular application. Take this example where a 50MHz square wave signal is viewed by 4 different oscilloscopes with various analog bandwidths. The 500MHz scope allows the 50MHz square wave to be digitized very accurately. The 350MHz scope is slowing the rise-time of the signal and is causing a slight overshoot. The 100MHz scope, the square wave has become significantly rounded and edges slowed dramatically. Finally, with the 60MHz scope, the square wave input signal has become more of a sine wave than a square wave. The effects you see here are all because the oscilloscope's analog bandwidth is filtering off the square wave's higher frequency components. A 50MHz square wave does not just have frequency components up to 50MHz. In fact, there are frequency components much higher than 50MHz that must be considered before selecting the right oscilloscope to measure it We'll explore how to calculate those higher frequency components on an upcoming page.

Analog Bandwidth

Scope BW Can Affect Your Digitized Signal

- **Affects Signal by:**
 - **Slowing Rise Time**
 - **Attenuating Amplitude**



- **Caused by:**
 - **Attenuator/Amplifier**
 - **Also Account For Probing Accessories**

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Analog Bandwidth

Analog Bandwidth can affect your signal by slowing the rise time and by attenuating the amplitude. The slowing of a signal's rise time can be readily seen in the illustrations on this page. Analog bandwidth is caused by the oscilloscope's attenuators and amplifiers within the oscilloscope's front-end. Before the signal is even digitized, the signal must pass through the attenuators and amplifiers which can and will affect your signal if the proper oscilloscope analog bandwidth is not used. Outside the oscilloscope, one must also account for probing accessories that can also affect the system bandwidth and overall flatness of the response of the scope in combination with the probe. The probing topic deserves its own presentation and in fact, look for an upcoming presentation from Agilent that discusses oscilloscope probing in detail.

Analog Bandwidth

How Much Bandwidth is Enough?

- Know Your Signal's Fastest Rise Time, t_r
- Calculate Your Signal's Bandwidth, BW_{signal}
 - $BW_{\text{signal}} = 0.4 / t_r$ (20% to 80% Thresholds)
 - $BW_{\text{signal}} = 0.5 / t_r$ (10% to 90% Thresholds)
- Calculate Needed Scope Bandwidth, BW_{scope}
 - $BW_{\text{scope}} = 2 * BW_{\text{signal}}$
(for Gaussian Scope Frequency Response)
 - $BW_{\text{scope}} = 1.4 * BW_{\text{signal}}$
(for Flat Scope Frequency Response)

Analog Bandwidth

As stated before, a 50MHz square wave does not just have frequency components up to 50MHz. A digital signal's highest frequency component is directly related to the digital signal's rise time. There is a rule of thumb calculation that is accepted in industry and is based on a signal's fastest rise time. Therefore, first determine what your fastest rise time of your particular signal is. If you are working with a particular communication standard, often times you should be able to find what that standard specifies for fastest rise time. Some communications standards specify rise time from the 10% threshold to the 90% threshold and others specify from the 20% threshold to the 80% threshold. Or, sometimes standards already give you a specification for the highest frequency component, so this first calculation can be skipped. After the fastest rise time (t_r) has been identified, use the following calculation to determine the highest frequency component of the signal, also called the bandwidth of the signal (BW_{signal}) depending on what thresholds you are using:

$$BW_{\text{signal}} = 0.4 / t_r \text{ (20\% to 80\% Thresholds)}$$

$$BW_{\text{signal}} = 0.5 / t_r \text{ (10\% to 90\% Thresholds)}$$

Now that the highest frequency component, or signal bandwidth (BW_{signal}) has been calculated, use one of the second calculations (depending on what Agilent oscilloscope model number you are interested in) to find what analog bandwidth of the scope (BW_{scope}) is required to avoid attenuating any of the signal's frequency components:

$$BW_{\text{scope}} = 2 * BW_{\text{signal}} \text{ (for Agilent Scopes } \leq 500\text{MHz)}$$

$$BW_{\text{scope}} = 1.4 * BW_{\text{signal}} \text{ (for Agilent Scopes } > 500\text{MHz)}$$

Sampling

Three Sampling Techniques

- **Equivalent Time (Repetitive)**
- **Real Time (Single-Shot)**
- **Sequential Sampling (Repetitive)**

Sampling Techniques

There are three different types of sampling techniques available in digitizing oscilloscopes today. They are:

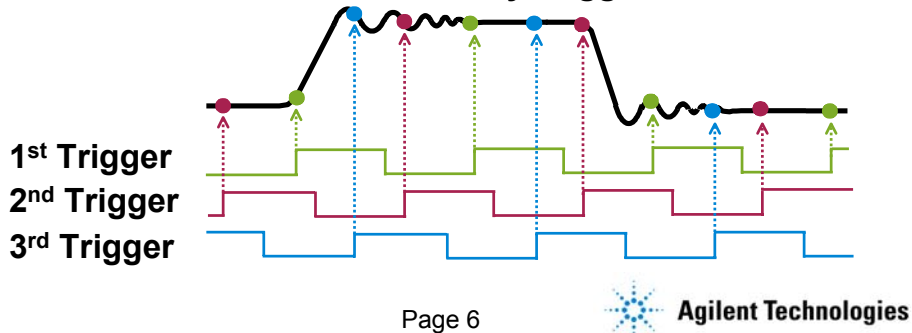
- 1) **Equivalent Time Sampling--also referred to as Random Repetitive Sampling**
- 2) **Real Time Sampling--also referred to as Single Shot Sampling**
- 3) **Sequential Sampling—also referred to as another form of Repetitive Sampling**

We will describe each of these techniques in detail on the following slides.

Sampling

Equivalent Time (Repetitive) Technique

- Used **ONLY** with Repetitive Signals
- Samples From Previous Triggers Maintained
- Multiple Trigger Events Build Up Waveform
- Sample Rate is Not a Major Factor
- Best Resolution Determined by Trigger Hardware



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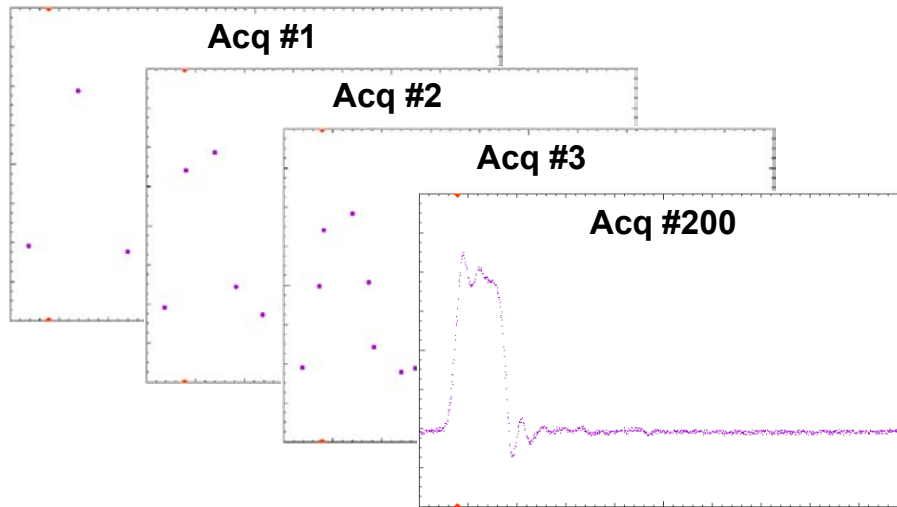


Sampling—Equivalent Time

Equivalent Time Sampling is a technique used **ONLY** with repetitive signals. With this technique, samples from previous trigger events are maintained. That means multiple trigger events actually build up the waveform. Equivalent Time Sampling is best understood visually with the illustration on this page. At the top of this illustration is the input signal. The square wave signals below represent the sample clock that each have a frequency of whatever the sample rate of the scope is. When the first trigger event is satisfied, the scope samples the waveform at the sample rate of the scope. The samples that are stored from this first trigger event are indicated in green. These samples are maintained and when the second trigger event is satisfied, the scope samples the waveform again at the sample rate of the scope. But, this second set of samples indicated in red are randomly offset from the first set of samples. Then, the previous two sets of samples from the first two trigger events are maintained when the third trigger event is satisfied. Again, this third set of samples shown in blue is randomly offset from the second set of samples. With many acquisitions, you see how a waveform is built up over time. Due to the fact that a waveform can be built-up from multiple acquisitions yielding very good resolution, sample rate of the scope is not a major factor in determining its performance. The best resolution between points is determined by the trigger hardware of the scope and how close it can accurately place multiple sets of sample points from multiple acquisitions.

Sampling

Equivalent Time: Build Up of Waveform



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Agilent Technologies

Sampling—Equivalent Time

The illustration on this page shows how a scope using the Equivalent Acquisition Sampling technique builds up the waveform over multiple acquisitions. After the first acquisition, there is only have about 3 sample points captured on a pulse. After the second acquisition, we have 5 sample points on a pulse. After the third acquisition, we have about 7 sample points on a pulse. Looking further out in time now at the 200th acquisition, you can see that we have many, many points on a pulse, which accurately characterizes that pulse.

Sampling

Equivalent Time (Repetitive) Example

- Fastest Rise Time, $t_r = 3\text{ns}$ (10% to 90% Thresholds)
- $BW_{\text{signal}} = 0.5 / t_r = 0.5 / 3\text{ns} = 167\text{MHz}$
- $BW_{\text{scope}} = 2 * BW_{\text{signal}} = 2 * 167\text{MHz} = 334\text{MHz}$
 - A 350MHz Scope is Available from Agilent
- Sample Rate Not a Factor in Equivalent Time

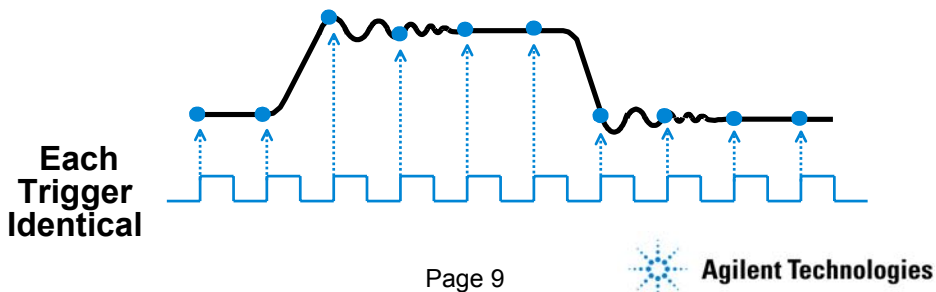
Sampling—Equivalent Time

Here is an example of the calculations that one must go through in order to calculate the needed analog bandwidth of a scope when a repetitive signal is being captured with Equivalent Sampling. In this example, I have found that the fastest rise time (t_r) of my signal is 3ns using 10% to 90% thresholds. Using the calculations show previously, the highest frequency component or signal bandwidth (BW_{signal}) is 167MHz. Therefore, the oscilloscope analog bandwidth (BW_{scope}) needed is 334MHz. A 334MHz oscilloscope is generally not available on the market, but a 350MHz is. As stated previously, sample rate is not a major factor when Equivalent Time Sampling technique is being used on a repetitive signal and thus does not need to be calculated.

Sampling

Real Time (Single Shot) Technique

- Used with either Repetitive or Single-Shot Signals
- All Samples Are Taken From a Single Trigger
- Samples from Previous Triggers are Erased
- Sample Rate May Limit Scope's Overall Bandwidth
- Best Resolution Depends Directly on Sample Rate



Sampling—Real Time

Real Time Sampling technique can be used with either repetitive signals or with single-shot signals. With this technique, all samples are taken from a single trigger event and all samples from previous trigger events are erased. Therefore, a waveform is not built up over multiple trigger events as with Equivalent Time Sampling. As shown in the illustration on this page, each trigger event is identical and thus the best resolution between points is just the inverse of the sample rate. Since samples are only taken from a single trigger event, the oscilloscope's overall bandwidth may be limited by the oscilloscope's sample rate. We'll show on the next slide how to calculate the needed sample rate in order to ensure that it does not affect the scope's overall bandwidth when using Real Time Sampling technique.

Sampling

Real Time (Single Shot) Example

- $SR_{scope} = 4 * BW_{scope}$
for Gaussian Scope Frequency Response
 - $SR_{scope} = 2.5 * BW_{scope}$
for Flat Scope Frequency Response
-
- Fastest Rise Time, $t_r = 3ns$ (10% to 90% Thresholds)
 - $BW_{signal} = 0.5 / t_r = 0.5 / 3ns = 167MHz$
 - $BW_{scope} = 2 * BW_{signal} = 2 * 167MHz = 334MHz$
 - A 350MHz Scope is Available from Agilent
 - $SR_{scope} = 4 * BW_{scope} = 1.3GSa/s$
 - 2GSa/s is Available in Agilent's 350MHz Scopes

Sampling—Real Time

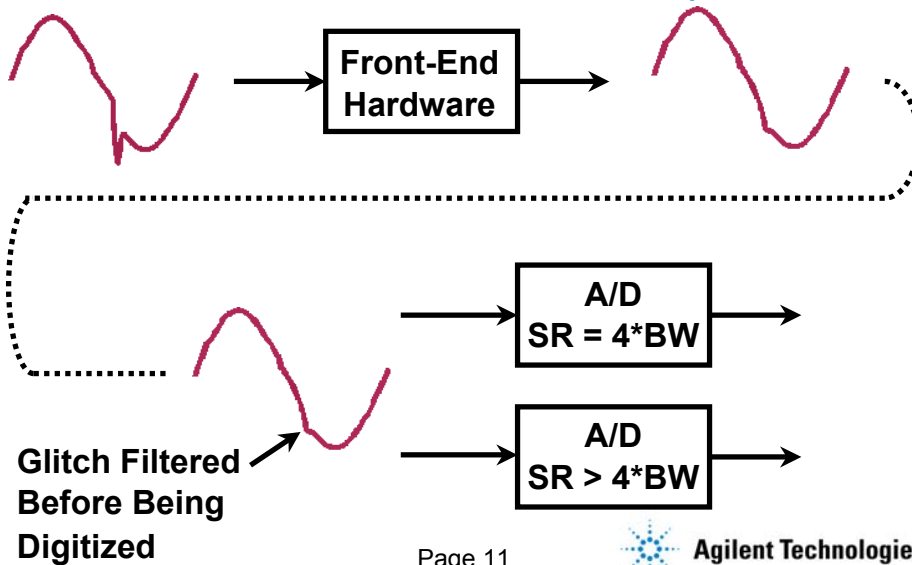
Now a third equation is employed when using Real Time Sampling because sample rate is important. The rule of thumb here is to multiply the oscilloscope's analog bandwidth by either 4 or 2 depending on the Agilent oscilloscope model that is in question. The reason for the difference lies in the analog bandwidth filter roll-off characteristics and the $\sin(x)/x$ interpolation algorithm. Basically, Agilent oscilloscopes $>2.25GHz$ have a steeper "brick-wall" filter than Agilent oscilloscopes $\leq 2.25GHz$. This means that these scopes $>2.25GHz$ insure that there are very minimal frequency components making it into the oscilloscope's A/D converter beyond the oscilloscope's bandwidth. Thus thus, less over sampling compared to the oscilloscope's bandwidth is needed to prevent these higher frequency components from making the signal "wobble" on screen. I very deep theoretical discussion on this topic can be made, but won't be discussed at this time.

Here is the same example as we showed before, only now we are using Real Time Sampling technique because the signal is NOT repetitive. The first two calculations are the same as before using 3ns as the fastest rise time (10% to 90%) in my signal. The highest frequency component or signal bandwidth (BW_{signal}) is again 167MHz. Using a factor of 2 in the second equation with an acceptable 3% error we find the needed analog bandwidth of the scope (BW_{scope}) is 334MHz (actually a 350MHz scope from Agilent). Since the bandwidth of the scope is 350MHz, the factor in the equation that I should use is 4 to determine the needed oscilloscope sample rate. In this case the needed sample rate is 1.3GSa/s. You probably will not find a scope on the market with exactly a 1.3GSa/s sample rate, but you will find a scope from Agilent that has 2GSa/s and 350MHz.

Note that using a factor of 2 or 4 applies when you have the $\sin(x)/x$ interpolation filter turned on. All Agilent oscilloscopes have $\sin(x)/x$ interpolation today. When $\sin(x)/x$ interpolation filter is turned off (which is selectable in the Infiniium 54800-series) use

Sampling

No Major Benefit of $SR > 4 * BW_{scope}$



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Sampling—Real Time

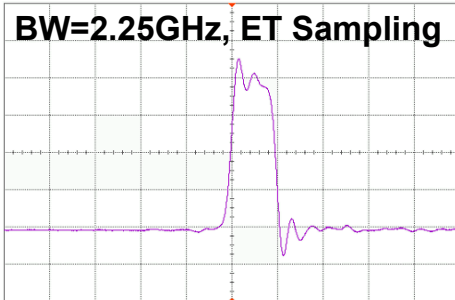
There is a common misconception that the higher the sample rate the better. Well, that is true up to a point and that point is when sample rate (SR) equal to 4 times the analog bandwidth of the scope (BW_{scope}). Having sample rate greater than 4 times the analog bandwidth of the scope (BW_{scope}) does NOT yield any extra benefits when trying to more accurately digitize a signal. One may think that having a higher sample rate would yield better resolution and thus allow one to more readily capture glitches or anomalies. This is not the way it works in real life, however. In this illustration, we can see that a signal coming into the scope has to pass through the oscilloscope's front-end hardware, which are the attenuators and amplifiers. This hardware contributes to the oscilloscope's analog bandwidth as discussed earlier. If you are inputting the maximum frequency signal that the scope's analog bandwidth can handle and a glitch riding on top of it, that glitch will be effectively filtered out before even reaching the analog to digital (A/D) converters to be digitized, stored in memory, and displayed. Therefore, the scope with $SR = 4 * BW_{scope}$ will characterize the signal just as well as the scope with $SR > 4 * BW_{scope}$.

Sampling

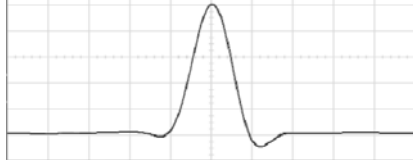
Example: No Major Benefit of $SR > 4 * BW$

Input Signal: 1ns Pulse With 200ps Rise Time

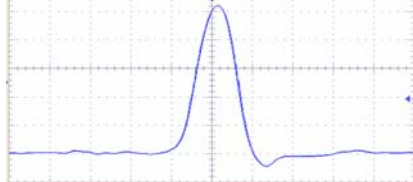
BW=2.25GHz, ET Sampling



BW=500MHz, SR=2GSa/s



BW=500MHz, SR=5GSa/s



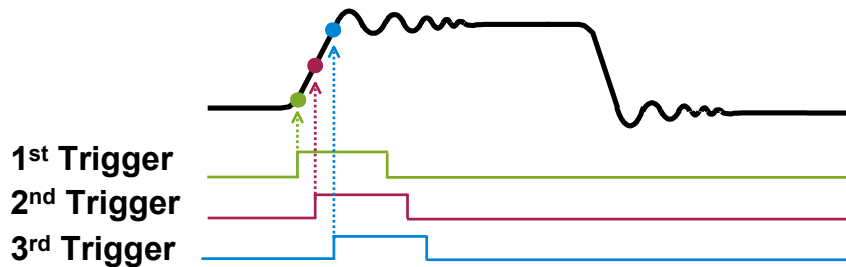
Sampling—Real Time

Here is a real example that illustrates the fact that having $SR > 4 * BW_{scope}$ does not yield any more information than an oscilloscope having $SR = 4 * BW_{scope}$. The same pulse was inputted into three different oscilloscopes. The waveform on the left is from one oscilloscope with high bandwidth (2.25GHz) using Equivalent Time Sampling mode because the input signal was a repetitive pulse. This oscilloscope shows the pulse as it actually appears coming from the device under test. The waveform in the upper right is from a 500MHz scope with 2GSa/s sample rate that is 4 times the analog bandwidth of the oscilloscope. The waveform in the lower right is from another 500MHz oscilloscope with 5GSa/s sample rate that is 10 times the analog bandwidth of the oscilloscope. Now, comparing the two waveforms on the right, you can see that they are nearly identical. Neither of them look like the original signal of course, but the oscilloscope with $SR = 10 * BW_{scope}$ yields very, very little or even NO extra information than the oscilloscope with $SR = 4 * BW_{scope}$.

Sampling

Sequential Sampling Technique

- Used **ONLY** with Repetitive Signals
- One Sample is taken for each Trigger
- Multiple Trigger Events Build Up Waveform
- Used in High Speed Applications with BW >10GHz
- No Pre-Trigger Information



Sampling—Sequential Sampling

Sequential Sampling technique is the final type of sampling in digitizing oscilloscopes today. This technique can **ONLY** be used with repetitive signals. With this method, only one sample is taken from each trigger event. As with Equivalent Time Sampling, multiple trigger events build up the waveform. Taking a look at the illustration on this page will help one to better understand how Sequential Sampling works. After the first trigger event is satisfied, the oscilloscope will store the first sample point shown in green at time zero. After the second trigger event is satisfied, the oscilloscope will offset some fixed time interval from the first sample point and will store the second sample point shown in red. Continuing on, after the third trigger event is satisfied, the oscilloscope will offset the same fixed interval now from the second sample point and will store the third sample point shown in blue. With many acquisitions, you can see how a waveform can be built-up over time using Sequential Sampling. Oscilloscopes that use this type of sample technique can obtain very high bandwidths greater than 10GHz. Remember, however, that this type of sampling only works with measuring repetitive signals. Another draw-back of this type of sampling is that you will have no pre-trigger information that would allow one to see what lead up to the trigger event.

Questions and Answers

Q & A



Memory

Purpose of Memory In Digitizing Scopes

- Every Sample Must be Stored in Memory
- Deeper Memory Stores More Samples
- Longer Periods of Time Captured Also Means More Samples to Store if Sample Rate is to be Maintained



Memory

In a digitizing oscilloscope, every digitized sample from the analog to digital (A/D) converter must be stored into memory in order to be able to do analysis on the digitized waveform. The illustration on this page visually shows an incoming waveform to the scope being digitized by the A/D converter and each of those digitized points being stored into memory. If the oscilloscope has deeper memory, more digitized sample points can be stored. In order to capture longer periods of time while maintaining a high sample rate results in more digitized sample points to store. So, that is where the benefit of deep memory comes in.

Memory

Purpose of *Deep Memory*

- **Maintain High Sample Rate When Capturing Longer Periods of Time**
- **Higher Sample Rate =**
 - **More Accurate Reproduction of Signal**
 - **Better Resolution Between Points**
 - **Better Chance of Catching Glitches or Anomalies**

Memory

Deep memory's sole purpose in a digitizing oscilloscope is to maintain a high sample rate when capturing longer periods of time. When the oscilloscope maintains its sample rate, several benefits can be realized. Firstly, more accurate reproduction of the analog input signal is achieved. But, remember that sample rate greater than 4 times the analog bandwidth does not yield much of a benefit. Secondly, better resolution is obtained, which means that sample points are closer together in time. The result of having better resolution is that the scope is more likely to capture glitches and anomalies that may appear on the input signal.

Memory

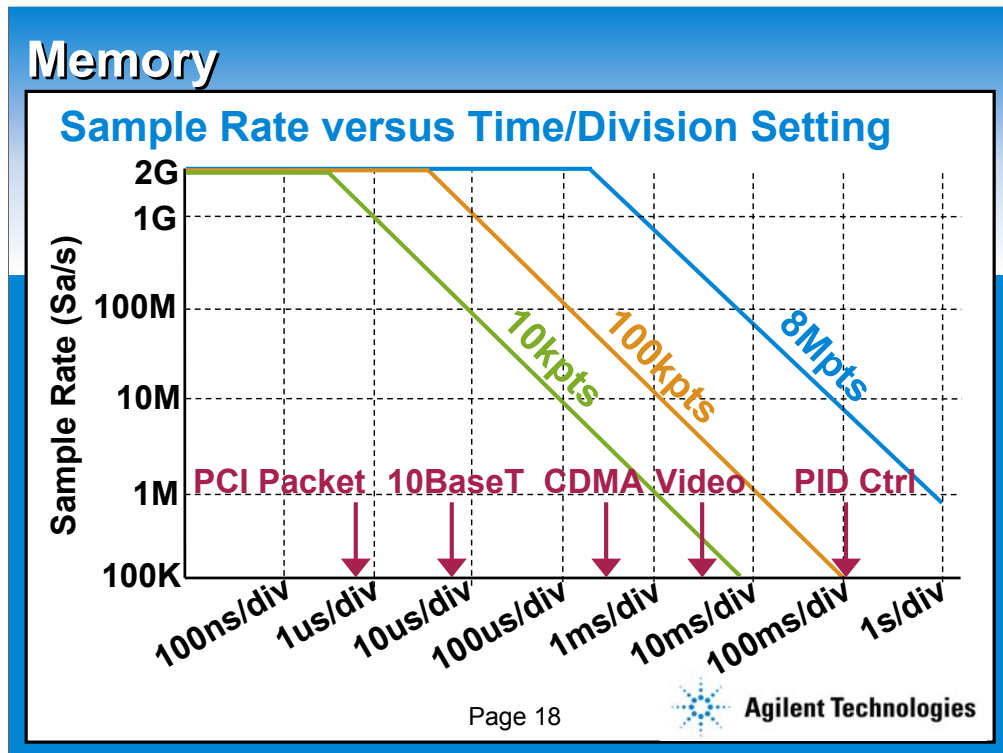
Purpose of *Deep Memory* (cont.)

- Capturing Longer Periods of Time
- Still be Able to Zoom In and See All the Details
- Deep Memory Especially Important In
 - Mixed Analog and Digital Applications
 - Serial Communication Applications

Memory

Deep memory is especially important when capturing longer periods of time across the oscilloscope display. But, even if the oscilloscope is capturing a longer period of time, all the details are still digitized because the oscilloscope's sample rate is maintained. Thus, one can zoom in and see all the details of the input signal. A general application in which deep memory is important is in mixed analog and digital applications. When debugging a mixed-signal design, one must capture longer periods of time to see the slower analog signals, but still maintain good resolution on the fast digital signals. With deep memory, this is possible. Another general application in which deep memory is important is in serial communication applications. Those doing debugging on this type of design may need to capture the entire transmit and/or receive signals on screen and then zoom in and see the details in the data packets. Again, with deep memory this debugging technique is possible.

Memory



Memory

The graph on this page generally illustrates how memory depth maintains sample rate at longer time/division settings. It is an example of three oscilloscopes with identical sample rate of 2GSa/s, but varying memory depths. The green line is an oscilloscope with only 10kpts of memory. As you can see, the 2GSa/s sample rate of this oscilloscope begins to be reduced at 500ns/division (or 5us across the display). The yellow line is an oscilloscope with 100kpts of memory. In this case, the 2GSa/s sample rate is maintain to 5us/division (or 50us across the display). The blue line is an oscilloscope with 8Mpts of memory. With this oscilloscope, the sample rate is maintained at 2GSa/s out to 400us/division (or 4ms across the display). Say you are using the oscilloscope at 100us/division (or 1ms across the display). If you have 10kpts of memory in your scope, the sample rate will only be 10MSa/s. If you instead have 8Mpts of memory in your oscilloscope, the sample rate is still maintained at 2GSa/s.

Memory

How Much Memory is Enough?

- Determine Required Resolution Between Samples, T_r
 - $1 / T_r \leq$ Scope Sample Rate (Real Time Mode)
- Determine Required Period of Time to Capture, T_p
- Calculate Required Memory Depth
 - Memory Depth = T_p / T_r

Memory

There is an easy calculation to determine the needed memory depth for a particular application. The first step is to determine what resolution is required between samples (T_r). You may have already gone through the calculations to determine required oscilloscope sample rate in real time acquisition mode. In this case, just take the inverse of the required real time sample rate in order to find the resulting resolution between samples. If you did not calculate real time sample rate but know what resolution between samples is required, just ensure that $1/T_r$ does not exceed the sample rate of the scope if you are in Real Time acquisition mode. If you are using Equivalent Time sampling mode, just determine what resolution between samples is required and don't worry about the real time sample rate of the scope. The next step is to determine what period of time across the display is required to capture the signal (T_p). Some applications require only a short period of time to capture, such as when looking at a single edge of a digital signal. Other applications require a relatively long period of time to capture such with a serial data packet or multiple cycles of a clock. With T_r and T_p determined, you can now calculate the required memory depth in the oscilloscope with the simple equation:

$$\text{Memory Depth} = T_p / T_r$$

Memory

Memory Depth Example

- Required Resolution Between Samples, $T_r = 500\text{ps}$
- Required Period of Time to Capture, $T_p = 2\text{ms}$
- Memory Depth = $T_p / T_r = 2\text{ms} / 500\text{ps} = 4\text{Mpts}$

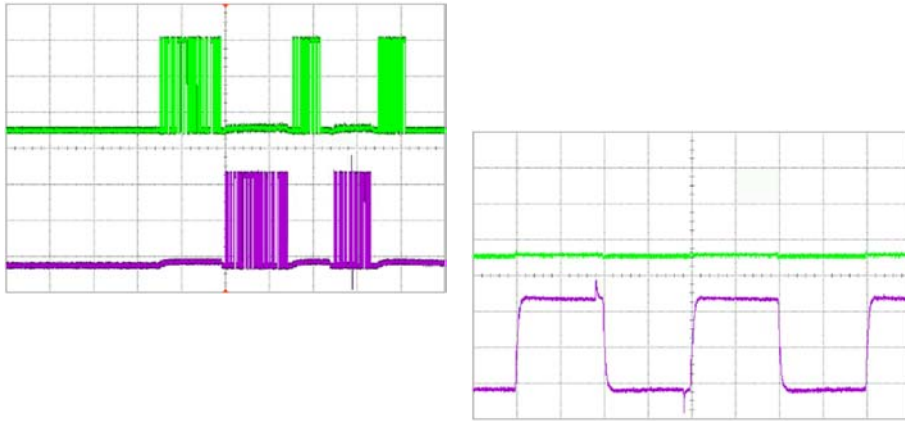
Memory

Here is an example of the calculation of required memory depth. Say that I've determined that 500ps is the resolution between samples required in order to accurately characterize my edge. This is equivalent to a 2GSa/s sample rate in real time acquisition mode. If one is in Equivalent Time sample mode, don't worry about the scope's sample rate. I've also determined that I need to capture 2ms across the display in order to capture a Bluetooth serial data packet. Therefore, the memory depth that I require in my oscilloscope is:

$$\text{Memory Depth} = T_p / T_r = 2\text{ms} / 500\text{ps} = 4\text{Mpts}$$

Memory

Example: $T_p = 2\text{ms}$ with scope at
2GSa/s and 4Mpts



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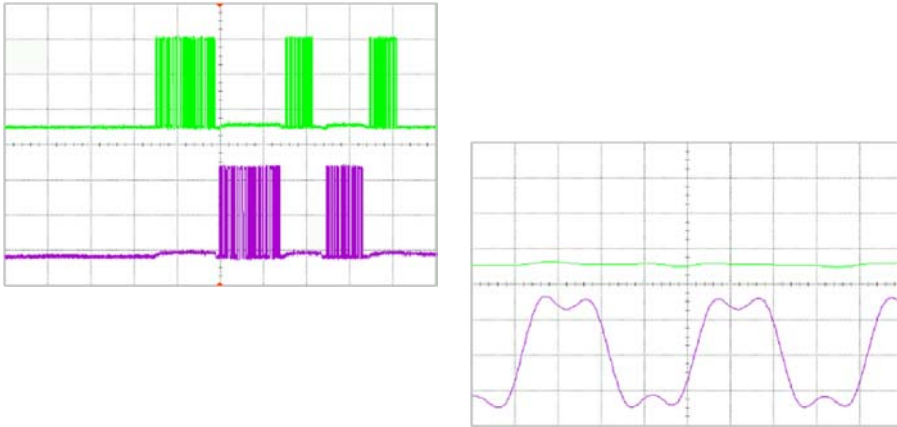


Memory

On this page, screen shots from an oscilloscope is a real example showing the importance of deep memory. In this example, we are capturing 2ms across the display in order to see the entire transmit and receive packets of Bluetooth serial signals. In order to capture this 2ms period of time with good resolution, one needs deep memory in the oscilloscope in order to maintain a high sample rate. In fact, with 4Mpts of memory I can maintain a 2GSa/s sample rate when capturing 2ms across the display. You can see that in the picture on the left, a glitch appears on the top and bottom of the second packet in the purple signal. The picture on the right shows a zoomed in version of the two glitches. The reason why the oscilloscope was able to capture 2ms of the Bluetooth signal with good resolution, and even capture the glitch appearing on it was because I had 4Mpts deep memory in the oscilloscope to maintain the 2GSa/s sample rate.

Memory

Example: $T_p = 2\text{ms}$ with scope at 4MSa/s and 8kpts



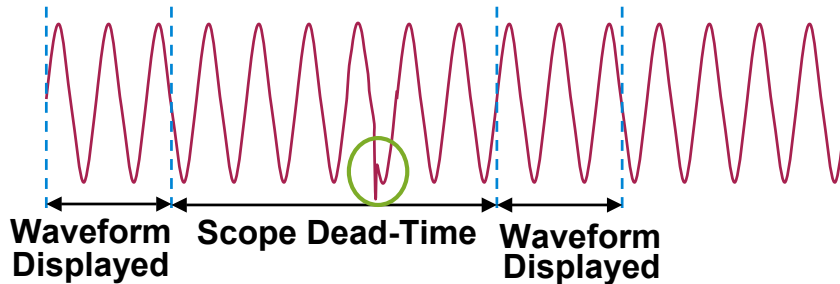
Memory

On this page, screen shots from an oscilloscope show the same input signals as before. Again, the oscilloscope is setup to capture 2ms across the display in order to see the entire transmit and receive packets of Bluetooth serial signals. In this example, however, the oscilloscope being used only has 8kpts of memory. With only 8kpts of memory when trying to capture 2ms across the display, the sample rate of the oscilloscope had to be reduced to 4MSa/s. The picture on the left looks very similar to the corresponding picture on the previous page. However, notice that the oscilloscope is no longer capturing the glitches on second packet of the purple signal. Zooming into the pulse where the glitches were supposed to occur, you can readily see that the signal has been seriously under sampled. So, not only am I missing the important glitches, but I'm also lacking the resolution between samples that would accurately reconstruct the signal. This is because the oscilloscope's sample rate is only 4MSa/s.

Memory

Possible Negative Implications of Deep Memory

- Slower Waveform Update Rate
- Slower User-Input Response Time
- Increased Dead-Time Between Acquisitions
- Missed Glitches and Anomalies during Dead-Time



Memory

So, now it has been established that having deep memory is important in a wide variety of applications in which longer periods of time need to be captured by an oscilloscope. But, there are several possible negative implications of deep memory in digitizing oscilloscopes. Since there is so many more sample points to be stored and processed in a deep memory oscilloscope, the processing power of the oscilloscope is readily used up and thus gets bogged down. This forces the waveform update rate of the scope to slow down and also the user-input response time to slow down when trying to make changes to oscilloscope settings. It is common to encounter several seconds between waveform updates or between when a user makes say, a time/division setting change, and when the oscilloscope actually responds to that change.

With a slower waveform update rate, there is an increased dead-time between acquisitions. Dead-time is referred to as the time from which the scope finishes the previous acquisition to the time when scope begins the next acquisition. The illustration on this page visually shows what dead-time is. Between the blue vertical bars is the acquisition time. The period between the acquisition times is the oscilloscope's dead-time. The major problem with oscilloscope dead-time is that important events (such as glitches or anomalies) could occur during that time and thus not be digitized by the oscilloscope. The longer the dead-time, the more likely the oscilloscope is to miss these events. If these events are not digitized, the user will not see them on the display and thus will not be able to take appropriate debugging action.

Memory

Solving the Dead-Time Problem in Deep Memory Oscilloscopes

- Custom ASIC Hardware Built Into Acquisition System
 - Agilent's MegaZoom Technology
- MegaZoom is a Memory Management Tool
 - Ping-Pong Acquisition Memory
 - Preprocessing of Data in Hardware
 - No Special Modes—Always On and Always Fast

Result is a fast waveform update rate with minimal dead-time between acquisitions and no processing bottlenecks.

Memory

Agilent has developed a solution to solve the dead-time problem in deep memory oscilloscopes. Instead of having the deep memory acquisition handled completely by a central processor, Agilent has developed a custom ASIC hardware built directly into the acquisition system of the oscilloscope. This custom ASIC is the key part in what Agilent calls MegaZoom technology. MegaZoom is a memory management tool that has several features associated with it. Firstly, when the oscilloscope is running, the acquisition memory is divided up into two halves. Half the acquisition is used for storing the current digitized waveform and the other half is used for displaying the previous acquisition. After this cycle is finished, the roles of each half of the memory is reversed so that the oscilloscope is always acquiring and displaying at the same time. This is what Agilent calls "ping-pong" acquisition memory. The second feature associated with MegaZoom is the preprocessing of display points from the acquisition memory. This means that the oscilloscope's central processor doesn't get bogged down processing an entire deep memory record for display purposes. The customer will always see points of interest along the displayed waveform outputted from the custom ASIC. Finally, MegaZoom is not a special mode and is rather part of the normal operation of the oscilloscope. That means fast deep memory is always on and always fast with no tradeoffs. The overall result of employing the MegaZoom technology is a fast waveform update rate with minimal dead-time between acquisitions and no processing bottlenecks at the central processor.

Display Quality

What is the Importance of the Display?

The display is the window between the human eye and the sampled waveform.

- **Analog Scope Displays**
 - Represent Waveforms That Can Be Trusted
 - Show Bright Spots Where Anomalies Exist
 - Yield Infinite Levels of Intensity Grading
- **Traditional Digitizing Scope Displays**
 - Appeared Grainy
 - Offered Very Little or No Intensity Grading

Display

The oscilloscope display system is an intricate part of the oscilloscope and is ultimately the window between the human eye and the digitized waveform. It is very important for users to be able to pick out points of interest from a displayed waveform so that more detailed analysis can be made. Analog oscilloscope displays do a very good job of representing waveforms that the user can trust. They display all the details of an input signal by showing bright spots where anomalies exist. The ultimate advantage of analog oscilloscope is that they yield infinite levels of intensity grading for the customer, which allows a 3rd dimensional view into the signal. Traditional digitizing oscilloscope displays appear grainy and offer very little or no intensity grading information. It is very difficult to spot signal details such as anomalies or glitches on these traditional digitizing oscilloscope displays.

Display Quality

Agilent's High-Definition Display

- **32-Levels of Intensity Grading**
 - **Pixels Hit More Often Appear Brighter Than Others**
 - **Allows 3rd Dimensional View Into Signal**
- **Fast Waveform Update**
 - **Utilizes the MegaZoom Custom ASIC**
 - **Minimal Dead-Time Between Acquisitions**
- **Twice the Horizontal Resolution**

Results in a display system that you can trust, just like an analog scope display.

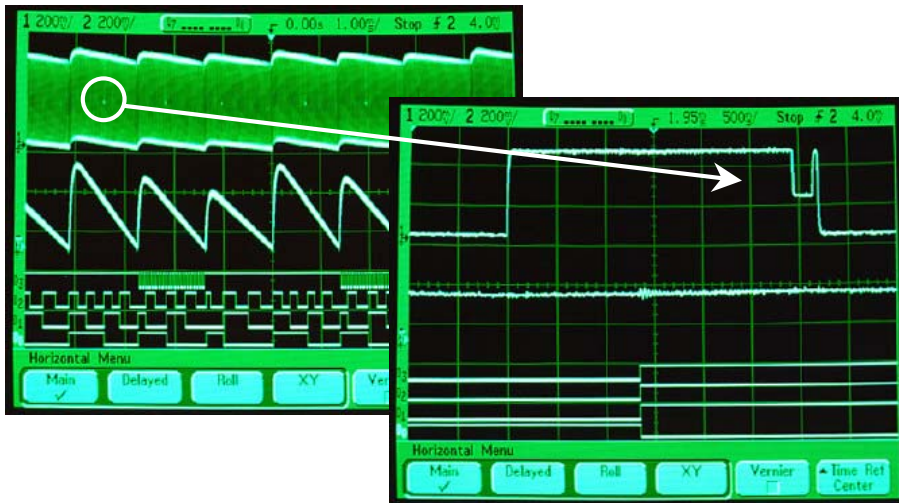


Display

Agilent has overcome the display limitations in digitizing oscilloscopes with its high-definition display technology. This display system offers 32-levels of intensity grading, very near to what the human eye can distinguish between. Pixels that are hit more often appear brighter than others which are hit less often. Having 32-levels of intensity grading allows the user to see that 3rd dimensional view into the signal. Waveform update rate with MegaZoom is very important in allowing the user to see all the details from a deep memory acquisition, very fast. Remember that having a fast waveform update rate results in minimal dead-time between acquisitions and better probability of capturing infrequent glitches or anomalies. Combine MegaZoom technology and 32-levels of intensity grading with twice the horizontal resolution of other digitizing oscilloscope and the result is a display system that you can trust, just like an analog oscilloscope display system.

Display Quality

Agilent's High-Definition Display



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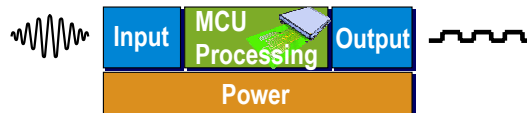
Display

The screen shots on this page show the advantages of the high-definition display system in the Agilent 54600-series. In the picture on the left, the oscilloscope is capturing a long period of time with deep memory. The high-definition display system allows the user to pick out a bright spot in the top waveform. Zooming in on this bright spot, the user can see that the falling edge of one pulse has a glitch on it (picture on the right). Without a high-definition display system, this glitch would have never been seen.

Number of Channels

How Many Channels Are Enough?

- Simple Debug May Require Only 2 Channels
- More Complex Debug Requires 4 or More Channels
- >70% of Hardware Designs Have Mixed Analog and Digital Content and Incorporate ADCs, DACs, MCUs, DSPs, etc.



- The Complexity of Digital Buses and Memory Incorporated into Embedded Designs Are Becoming More Complex and Difficult to Debug

Number of Channels

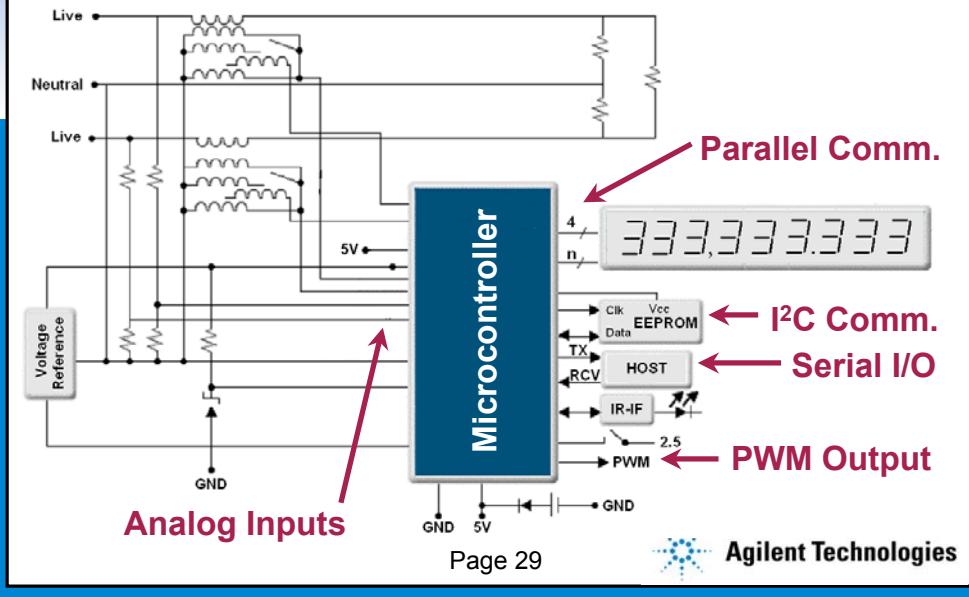
When selecting an oscilloscope, one of the basic selection criteria is determining how many channels are enough. Oscilloscopes are often times used in a multitude of applications at a single site. So often times, one would consider their most demanding application to determine how many channels are enough for selecting the right oscilloscope. Simple debug applications may require only 2 channels. More complex debug may require 4 channels...or even more!

Greater than 70% of designs today have both analog and digital content according to a recent customer survey done by Agilent. Such designers have to relate real-world analog input and output signals with complex digital signals for processing. The interface between analog and digital is typically done through analog to digital converters (ADCs), digital to analog converters (DACs), microcontroller units (MCUs), digital signal processing (DSPs) ICs, etc. In these types of mixed-signal design, a 4-channel oscilloscope most likely will not be enough.

Increasing complexity doesn't stop in the mixed analog and digital realm. The complexity of digital buses and memory which are pure digital in nature and being incorporated into embedded designs are also difficult to debug with a traditional 4-channel oscilloscope. An example will be coming up to explain this in more detail.

Number of Channels

Mixed Analog/Digital Design Example



Number of Channels

The illustration on this page shows a mixed analog and digital design example that is an electric meter. At the heart of this design is a microcontroller. At the left of the microcontroller unit, several analog signals are being inputted. On the right of the microcontroller unit, there is several digital and analog input and output signals. There is a 4-bit parallel output to an LCD display. There is an I²C serial path to EEPROM (memory). There is another serial I/O path to an external device or controller. And, finally there is a PWM output that could be used to drive another device. A designer may want to correlate one or more of these signals to see the cause and effect between them, which may result in complicated or even impossible debug with traditional test and measurement equipment.

Number of Channels

SDRAM Bus Example--Isolate Write Cycle

- Need **At Least 4 Digital Signals to Isolate a Particular Cycle: RAS, CAS, WE, & CS**
- Need to Look **At Least the Clock Signal & Another Signal (i.e. Address, Data or Control) with Analog Channels to Verify Timing and Signal Integrity**

SDRAM Bus Commands

Command	RASN	CASN	WEN
No Operation (NOP)	H	H	H
Active (ACT)	L	H	H
Read (RD)	H	L	H
Write (WR)	H	L	L
Burst Terminate (BT)	H	H	L
Precharge (PCH)	L	H	L
Autorefresh (ARF)	L	L	H
Load Mode Register (LMR)	L	L	L

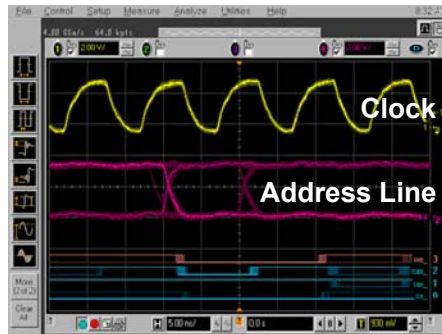
Number of Channels

Today memories such as SDRAM are much more complex than those twenty years ago which a 4-channel could debug with ease. The explosion of memory speed and size has led to radically different organizations. The address lines are multiplexed to reduce pin count. To operate at higher speed, memory access is pipelined and burst oriented. A command is sent, then an row is charged, then a burst read or write occurs. You still need to check signal integrity and timing of individual cycles, but a 4-channel scope just runs out of steam. In this example an designer incorporating SDRAM into their embedded design wants to isolate a write cycle to verify signal integrity on some address and data lines. To do this, the designer needs at least 4 digital signals to isolate a particular cycle. Those signals are Row Address Select (RAS), Column Address Select (CAS), Write Enable (WE), and Chip Select (CS). With a 4-channel scope, you've already ran out of channels to make any signal integrity measurements. In this case, the customer still needs to trigger on and view the Clock and wants to view signal integrity measurements on address and data lines to verify timing and signal integrity.

Number of Channels

SDRAM Bus Example--Isolate Write Cycle

- Using the Agilent MSO, a 6-Channel Measurement Can Be Made
 - Trigger on RAS, CAS, WE, CS, & Clock
 - Verify Signal Integrity of Address Line during a Write
- Not Possible Using a Traditional 4 Channel Oscilloscope



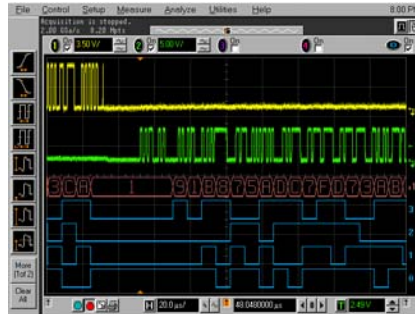
Number of Channels

With the Agilent MSO, this 6-channel measurement is possible with its 2 or 4 analog channels and 16 digital timing channels. We can connect 4 of the digital channels the RAS, CAS, WE, and CS signals and cross trigger them with analog channel 1 connected to the Clock. We are now able to isolate the write cycles and build up eye diagrams for signal integrity and timing measurements on the various address and data lines. Note that SDRAM is a 32-bit system and 16 digital timing channels in the Agilent MSO was more than enough to help this designer isolate the complex memory cycle that he or she was interested in.

Number of Channels

Viewing and Triggering on >4 Channels

- **Agilent Mixed-Signal Oscilloscopes (MSO)**
 - 2 or 4 Analog Channels
 - *Plus* 16 Digital Channels
 - All Channels On Same Timebase for Cross Triggering and Viewing
 - Up to 1GHz & 4GSa/s for High-Speed Apps.
- **Correlates Fast Digital and Slow Analog Using MegaZoom Deep Memory**



Number of Channels

Agilent has a solution for designers in the mixed analog and digital market who need more than 4 channels to effectively debug their circuit. The solution is a Mixed-Signal Oscilloscope (MSO) that contains 2 or 4 analog channels and 16 digital timing channels. All channels are on the same timebase with a host of cross triggering capabilities between analog and digital signals. The Agilent offering of MSOs range from 60MHz to 1GHz analog bandwidth and 200MSa/s to 4GSa/s sample rate. The higher performance MSOs are ideal for higher speed mixed-signal designs involving DSPs in addition to embedded digital busses and memory while the affordable MSO models fit well into the multitude of lower speed 8/16-bit microcontroller-based designs. When debugging mixed-signal circuits, a customer is most likely is correlating fast digital signals with slower analog signals. This is a direct requirement for deep memory which enables a long period of time to be captured for slow analog signals while maintaining a high sample rate for the fast digital signals. Agilent's MSOs have MegaZoom technology for fast, usable capture of deep memory acquisitions.

Triggering Modes

What Triggering Capabilities Are Needed?

- **Edge Triggering**
- **Signal Integrity Triggering**
 - Pulse Width
 - Setup and Hold
 - Transition
- **Parallel Logic Triggering**
 - Pattern/State
 - Sequence
- **Serial Triggering**
 - SPI
 - I²C
 - CAN
 - USB
 - LIN

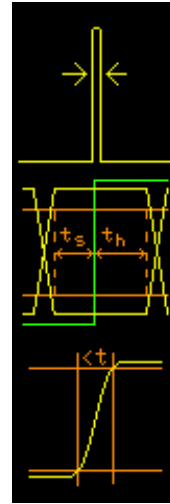
Triggering

Oscilloscope triggering is an important feature that should not be overlooked when selecting the right product for effective debugging purposes. Triggering essentially places the point of interest or trouble spot at the center, left side, or right side of the display for viewing. There are many triggering capabilities built into digitizing oscilloscopes today and can be grouped into four main categories: Edge, Signal Integrity, Parallel Logic, and Serial. Edge triggering is pretty self-explanatory as it is the most basic and most used type. Simply stated, when a signal crosses a defined threshold either positive going or negative going, trigger the scope's acquisition and place the crossing point on the display at the scope's trigger point.

Triggering Modes

Signal Integrity Triggering

- **Pulse Width**
 - Find a Pulse Too Narrow, Too Wide, or Within a Range
- **Setup and Hold**
 - Find a Pulse Without Proper Setup and/or Hold Times
- **Transition**
 - Find Edge Too Fast or Too Slow



Triggering

Signal Integrity triggering is important in digital design applications. It is a type of triggering in which the oscilloscope will find a point in the signal that violates certain condition(s) specified by the user. Three types of signal integrity triggering are Pulse Width, Setup and Hold, and Transition.

Pulse Width triggering will find a pulse in the waveform that is either too short (narrow), too long (wide), or within a range of time limits.

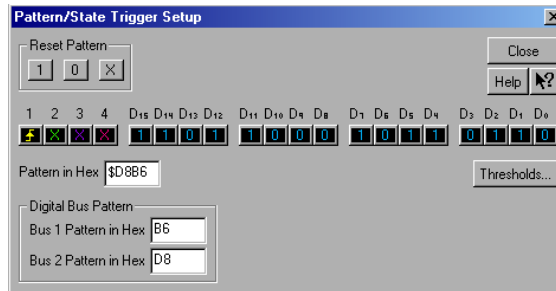
Setup and Hold triggering will find a point in the waveform where a data line violates the setup and/or hold times. The figure just to the right shows the data line in yellow and the clock line in green.

Transition triggering will find a transition (either rising or falling edge) that occurs too fast or too slow.

Triggering Modes

Parallel Triggering—Powerful in MSO Models

- **Pattern/State**
 - Find a Specific Parallel Logic Pattern
- **Sequence**
 - Find Consecutive Parallel Logic Patterns



Triggering

Parallel triggering is also important in digital design applications when looking at multiple lines of a bus. It is a very powerful triggering capability in the Agilent Mixed-Signal Oscilloscope (MSO) products due to the fact that they can look at up to 20 channels at the same time all time-aligned. Two types of Parallel triggering are Pattern/State and Sequence.

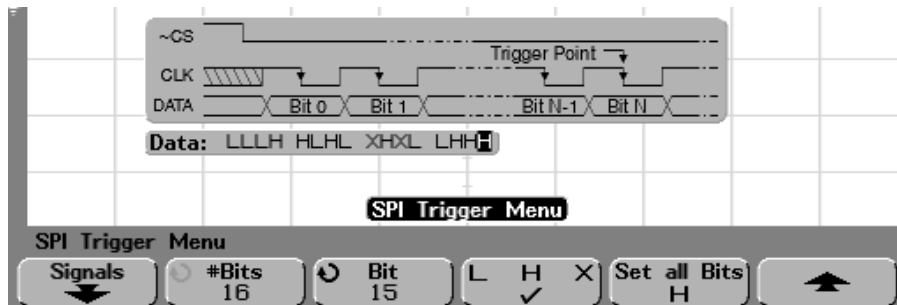
Pattern/State triggering allows the user to specify a parallel logic pattern across many channels for the oscilloscope to trigger on.

Sequence triggering is an extension of Pattern/State triggering by allowing the user to specify a series of consecutive parallel logic patterns before the oscilloscope triggers.

Triggering Modes

Serial Triggering—Powerful in MSO Models

- SPI
 - Serial Peripheral Interface
 - Comm. Within a Design
- I²C
 - Inter-Integrated Circuit
 - Comm. Within a Design



Triggering

Serial communication is becoming more and more of a common place in a wide variety of applications. Remember in the example circuit of an electric meter how many different signals types were present, including analog, parallel, and serial. The fact that serial communication is present in many mixed-signal designs makes serial triggering especially important in Agilent's MSO products. Thus, the 54600-series products contain widely used protocol-specific serial triggering capabilities.

One of the supported serial protocols in the 54600-series products is Serial Peripheral Interface (SPI). This is a type of serial communication that takes place within a design, in other words, between components on the same IC. Such components that utilize SPI communications are MCUs and DSPs talking to their various peripherals such as A/Ds or memory banks. The triggering capability in the oscilloscope allows the user to trigger on a data pattern during a specific framing period.

Another supported serial protocol is Inter-Integrated Circuit (I²C). Like SPI, this is a type of serial communication that takes place within a design and between components on the same IC. The same type of applications hold for I²C as there are for SPI. The triggering capability in the oscilloscope for I²C allows the user to trigger on several different types of communication frames such as a start/stop condition, restart condition, missing acknowledge, EEPROM data read, or read/write frame specifying device address and data value.

Triggering Modes

Serial Triggering—Powerful in MSO Models

- **CAN**
 - Controller Area Network
 - High Reliability Automotive Systems & Industrial Systems
- **LIN**
 - Local Interconnect Network
 - General Purpose Automotive Systems
- **USB**
 - Universal Serial Bus
 - PC Peripheral Connectivity

The logo for Controller Area Network (CAN) consists of the letters 'CAN' in a bold, blue, sans-serif font.The logo for Local Interconnect Network (LIN) features the lowercase letters 'lin' in a stylized, cursive font. The 'l' is blue, the 'i' is red, and the 'n' is orange.

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Triggering

A third supported serial protocol is Controller Area Network (CAN). This is a type of serial communication that is widely used in industrial designs where digital components and communication lines are exposed to very harsh environments. The automobile industry has standardized on CAN for the multitude of critical digital controls and sensors used throughout the vehicle such as the Anti Lock Brake System (ABS). CAN is a type of protocol used to communicate between designs that are spread over relatively long distances. The standard triggering capability of the oscilloscope allows the user to trigger on a generic start of frame. However, more advanced triggering capabilities are added to the 54600-series MSO products when used with the N2758A (CAN ID and Data content) module. This module allows easy connection to a CAN network while providing the ability to trigger on specific CAN address and data content.

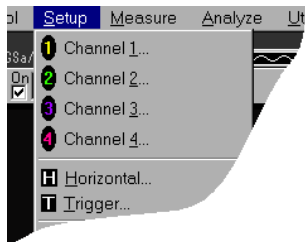
A fourth support protocol that is being highly integrated into many automotive systems is Local Interconnect Network. When the highest reliability communication is not demanded for some automotive systems like window mirror or seat controls, LIN is a very cost effective communication solution. As with CAN, LIN is a type of protocol used to communicate between designs that are spread over relatively long distances. The standard triggering capability of the oscilloscope allows the user to trigger on a generic start of frame.

A fifth supported serial protocol is Universal Serial Bus (USB). This is a well-known serial communication protocol that is used for a variety of PC peripheral connectivity to the PC itself. The triggering capability of the oscilloscope allows the user to trigger on several different communication frames such as a Start/End of Packet, Reset Complete, and Enter/Exit Suspend.

Ease of Use

What Affects Ease of Use?

- **Waveform Update Rate**
- **Display Quality**
- **User Input Control Response Time**
- **Measurement and Math Function Capabilities**
- **Intuitive Front Panel Layout**
- **Intuitive Menu Structure**
- **PC Connectivity**



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Ease of Use

Ease-of-use is an important criteria in selecting an oscilloscope that should not be overlooked. An oscilloscope that one can sit down in front of and effectively use instead of fighting, can be a big asset when trying to bring a design to market. There are several factors that play into the ease-of-use concept.

Having a fast waveform update rate is important when trying to visually uncover problems in a design. The faster the waveform update rate, the more likely the oscilloscope will uncover important glitches and anomalies embedded in a signal.

Display quality is also an important factor to consider that ties directly into the oscilloscope's ability to uncover glitches and anomalies.

If an oscilloscope has a slow user input control response time, it can become very frustrating just trying to make setting changes from the oscilloscope's front panel. In some deep memory oscilloscopes on the market, a user may have to wait more than 5 seconds before the display will reflect a user input control, such as a simple turn of the time/division knob.

Measurements and math functions are capabilities that may be very helpful during the debug process of a design. So, it is important to note what functions an oscilloscope has as either standard or as an option.

Having an intuitive front panel layout and menu structure is very important in rating how efficient an oscilloscope is to use. Basic controls should be in an easily accessed location and advanced features should be easy to navigate to and use. This is a very objective criteria and should be experienced in a live demonstration. If

Summary

When Selecting the Right Digitizing Scope:

- From Signal's Rise Time, Calculate Bandwidth
- Determine Sampling Technique To Be Used
 - In Real Time Sampling, Calculate Sample Rate
- From Required T_r and T_p , Calculate Memory Depth
- Account for Display Quality to View Signal Details
- When 4 Channels Are Not Enough, Look to an MSO
- Account for What Triggering Modes are Required
- Evaluate for Ease of Use

Summary

Throughout this seminar, the criteria that one should follow in selecting the right digitizing oscilloscope has been presented. The first step is calculating the needed oscilloscope bandwidth from your signal's fastest rise time. Then, determine what sampling technique is needed to be used in your particular application. If real time sampling is needed for single-shot measurement, then calculate the needed sample rate. Next determine the memory depth needed from the required sample resolution and period of time to capture. Account for display quality which allows you to effectively view signal details. Remember that when a 4 channel oscilloscope is not enough for complex debug, mixed-signal oscilloscopes (MSOs) can offer the best solution. Account for what triggering modes may be required to capture on the display the point of interest where problems exist or when conditions are met. Finally, evaluate (through a live demonstration) an oscilloscope for ease of use to ensure it will be an effective debug tool in your application.

Summary

When Selecting the Right Digitizing Scope That is $\geq 1\text{GHz}$ Bandwidth:

- Probing Considerations Must be Made
- Passive Probes:
 - Are More General Purpose
 - Have Higher Capacitive Loading on Circuit
 - Limited to 600MHz Bandwidth or Less
- Active Probes:
 - Have Less Dynamic Range
 - Offer Lowest Capacitive Loading on Circuit
 - Provide a Full System Bandwidth = BW_{scope}



Summary

When you find that your application demands $\geq 1\text{GHz}$ bandwidth, probing consideration must be made in order to get the best performance out of your scope.

Passive probes are more general purpose in their use model. They provide a large dynamic range for large signal amplitudes. However, passive probes have the negative characteristic of having higher capacitive loading on your device under test (DUT). Passive probes are also limited to 600MHz bandwidth or less in part because of their higher input capacitance. Thus, a passive probe cannot be used to obtain $>600\text{MHz}$ bandwidth.

Active probes on the other hand can provide full system bandwidths when used with their corresponding high performance scope. Take for instance the 1156A 1.5GHz active probe that provides a 1GHz system bandwidth when connected to the 54832B 1GHz scope. As another example, take the 1134A 7GHz active probe that provides 6GHz system bandwidth when connected to the 54855A 6GHz scope. Active probes have the additional benefit of having the least intrusive loading on your device under test (DUT) by maintaining a very low input capacitance. Active probes have the disadvantage compared to passive probes of not having as much dynamic range to measure higher voltage, more general purpose signals. However, since higher speed signals requiring an active probe have smaller amplitudes, a smaller dynamic range is not a big issue. For more of a detailed explanation of Agilent active probing, see the "Achieving Higher Bandwidth Connectivity with High Speed Active Probes" presentation.

Questions and Answers

Q & A



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