When is it Time to Transition to a Higher Bandwidth Oscilloscope?

Application Note

When purchasing an oscilloscope to test new designs, the primary performance specification that most engineers consider first is the scope's bandwidth. Another key consideration is always price. Unfortunately, there is a fairly linear relationship between these two characteristics of a scope; bandwidth and price. Since most of us must work within constrained capital equipment budgets, engineers tend to purchase test equipment that has just enough performance to meet their current needs. But with each new design-start, performance requirements often increase in order to stay competitive and to deliver newer, faster, and more feature-rich smart products that customers demand. So how do we determine how much bandwidth is required for today's projects, and when do we know when it is time to "move up"?

Although many of today's embedded designs are mixed-signal in nature (contain both analog and digital signals), it is usually the maximum speed of the digital signals (clock rate and edge transition times) within a design's central processing unit (CPU) system that determines how much oscilloscope bandwidth is required. And it is often the timing specifications of CPU memory that must be considered. The most common type of memory used in most of today's embedded designs is double data rate (DDR) memory. This type of memory clocks data into and out of memory on both the rising and falling edges of the clock signal.

Let's assume that in your last design project the CPU system in your embedded design was based around DDR1 memory technology with data transfer rates in 200 Mbps range. And if you used a 500-MHz bandwidth scope to capture and verify critical timing parameters of your CPU system running at this speed, this scope probably provided you with sufficient measurement accuracy. But now your next design will be based on higher speed DDR2 technology. Will you need to purchase a higher bandwidth scope? And how much bandwidth will be required?

Capturing Eye-Diagrams on DDR2-667 Memory

A very common measurement performed on read and write data signals of DDR memory is an eye-diagram measurement. Eye-diagrams displayed on a scope provide a composite picture of signal quality by overlaying high and low bits to determine when data is valid. Figure 1 shows an example of an eye-diagram measurement on a data signal representative of DDR2-667 memory using an Agilent 500-MHz bandwidth oscilloscope (MSOX3054A).

While the clocking rate of DDR2-667 memory is 667 MHz with clocking of the data occurring on both the rising and falling edges of the clock signal, the actual frequency of the clock signal is 333 MHz. And although the maximum specified data transfer rate of this type of memory is 667 Mbps, the maximum toggle rate of the data signal is also 333 MHz based on a maximum repeating 1-0-1-0-1... serial pattern. So one might assume that since the maximum signal switching rate of either the clock or data signal is just 333 MHz, a 500-MHz bandwidth scope would provide sufficient performance to capture and make accurate measurements on these signals. But as you can see in Figure 1, a 500-MHz bandwidth scope basically turns our digital bit stream into what appears to be an overlay of sinusoids. A 500-MHz bandwidth scope is not able to capture much beyond the 1st harmonic. This is why it looks sinusoidal. So clearly, capturing these signals with a 500-MHz bandwidth scope is insufficient.

Figure 2 shows the same DDR2-667 data signals captured as an eye-diagram display using Agilent's new MSOX3104A oscilloscope, which has a specified bandwidth of 1 GHz. We can now more clearly see the shapes and details of the overlaid digital bits using this higher bandwidth scope. So for this particular DDR2 measurement application, it is time to "move up" in bandwidth to 1 GHz.

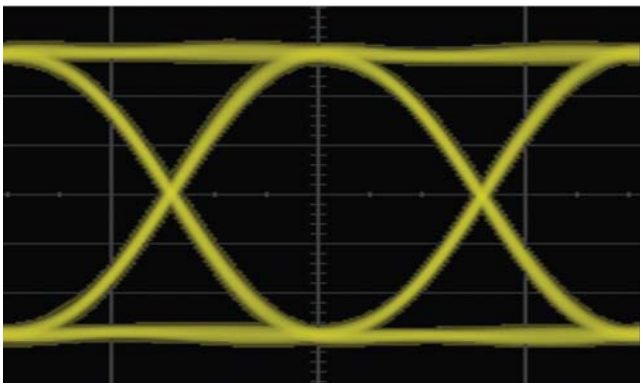

Figure 1: Capturing DDR2-667 data signals using an Agilent 500-MHz bandwidth scope.

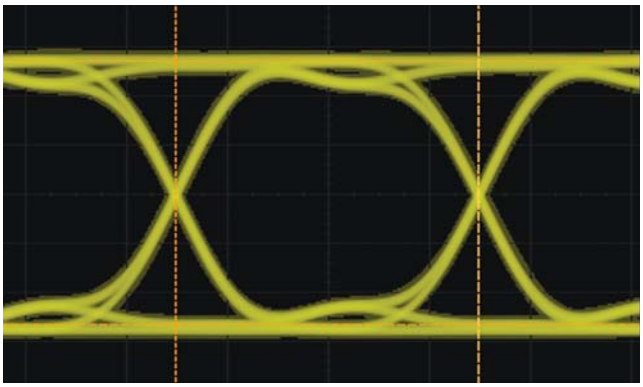

Figure 2: Capturing DDR2-667 data signals using an Agilent 1-GHz bandwidth scope.

Determining Required Bandwidth

For digital applications, the amount of required oscilloscope bandwidth depends on the speed of the fastest signal transitions in your designs that need to be measured. Once you know what the fastest edge speeds are in your system, you can then convert these edge speeds into a maximum practical frequency. We will call this f_{MAX}. But don't confuse this f_{MAX} with the f_{MAX} that Nyquist refers to. The reason I say maximum "practical" frequency is because fast transitions are theoretically composed of an infinite spectrum of frequencies. However, there comes a point where the higher components of frequencies contribute insignificantly into creating the shape of a fast edge. Once we know what f_{MAX} is, we can then determine the required bandwidth.

So how do you determine what the fastest edge transitions are? It appears that we have a chicken & egg situation here. Digital devices utilized in today's designs typically have input and/or output rise time specifications. These rise time specifications (RT) have traditionally been specified relative to 10% to 90% threshold criteria. However, more of today's digital devices specify their rise times relative to 20% to 80% threshold criteria. Once you have determined the fastest rise times of your devices, use one of the following simple formulas to compute f_{MAX}[1].

Converting Rise Time (RT) to f_{MAX}

$$f_{MAX} = 0.5/RT_{(10\text{-}90)}$$

$$f_{MAX} = 0.4/RT_{(20\text{-}80)}$$

You may discover that some of your devices specify a maximum signal slew rate (SR), as opposed to specifying a rise time. This is true for most DDR memory devices. If this is the case, then you can approximate the 20% to 80% rise time using the following formula:

Converting Slew Rate (SR) to Rise Time (RT)

$$RT_{(20\text{-}80)} = 0.6\ (V_H - V_L)/SR$$

Once you've determined f_{MAX}, you could use a scope with a specified bandwidth of this same frequency to capture and perform rise time measurements with reasonable accuracy — perhaps 20% error. But if you wanted to perform rise time measurements with 5% accuracy or better, then you should select a scope with a specified bandwidth that is 1.5 to 2 times higher than f_{MAX}.

Converting f_{MAX} to Scope Bandwidth

$$BW = 2 \times f_{MAX}$$

Let's now walk through a simple example. Assume that you've determined that the fastest rise times in your latest design are 800 ps (based on 20% to 80% threshold criteria). f_{MAX} is then 0.4/800ps = 500 MHz. If your budget is limited and you can also tolerate up to 20% timing error when performing rise time measurements, then you could use a 500-MHz bandwidth scope for your measurement applications. In other words, if you attempt to measure the rise time of an 800 ps edge, the scope might measure something more in the range of 1 ns. But if you need more accuracy than this, then perhaps a 1-GHz bandwidth scope would be a better choice.

To learn more about how to select the appropriate bandwidth scope for your specific measurement applications, download Agilent's application note titled, "Evaluating Oscilloscope Bandwidths for your Application" listed at the end of this document.

Summary

As you saw in the first part of this application note, if you are attempting to capture and measure high-speed digital signals using your current oscilloscope, but captured waveforms are beginning to look more sinusoidal as opposed to digital in nature, then it's probably time to move up in oscilloscope bandwidth. But there is a more accurate method to determine the amount of bandwidth you need — besides just evaluating the shapes of captured waveforms. Based on the fastest edges that you need to measure, you can convert edge speed into maximum practical frequency (f_{MAX}). You can then select a scope with a bandwidth specification ranging from f_{MAX} to 2X f_{MAX} depending upon the level of accuracy you require — as well as the amount capital equipment budget you have.

If you think it's time to move up in bandwidth, Agilent's newest 1-GHz bandwidth oscilloscopes in the InfiniiVision 3000 X-Series start at the lowest prices in the industry. In addition, if you already own one of Agilent's lower bandwidth 3000 X-Series scopes (100 MHz, 200 MHz, 350 MHz or 500 MHz bandwidth models); your investment has been protected. The 3000 X-Series oscilloscopes are fully upgradable — including bandwidth — up to the new 1-GHz performance level. The performance of these oscilloscopes grows as your measurement needs grow from design-start to design-start.

[1] High-Speed Digital Design, A Handbook of Black Magic, Howard Johnson, Martin Graham, 1993, Prentice Hall PTD, Prentice-Hall, Inc, Upper Saddle River, New Jersey 07458

Related Literature

Puiblication Title	Publication Type	Publication Number
Agilent InfiniiVision 3000 X-Series Oscilloscopes	Data sheet	5990-6619EN
Agilent InfiniiVision 7000 Series Oscilloscopes	Data sheet	5990-4769EN
Agilent Infiniium 9000 Series Oscilloscopes	Data sheet	5990-3746EN
Evaluating Oscilloscope Bandwidths for your Applications	Application note	5989-5733EN
Evaluating Oscilloscope Sample Rates vs Sampling Fidelity	Application note	5989-5732EN
Understanding Oscilloscope Frequency Response and its Effect on Rise Time Accuracy	Application note	5988-8008EN
Advantages and Disadvantages of Using DSP Filtering on Oscilloscope Waveforms	Application note	5989-1145EN
Evaluating Oscilloscopes for Best Waveform Update Rates	Application note	5989-7885EN

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