HOW TO DETERMINE

Oscilloscope Signal Integrity

KEYSIGHT
TECHNOLOGIES

Introduction

Signal integrity continues to be a hot topic in the electronics world. Today's designs have shrinking margins and increasing data rates, which means measurements must be more accurate than ever. Every oscilloscope vendor has some sort of pitch around signal integrity: highest number of ADC bits, lowest noise floor, fastest sample rate, and the list goes on. While all these specifications are important, it is critical to understand the entire measurement system and not base your decision on just one of these specifications.

Educating yourself on what each of these specifications really means for your design saves you loads of time and heartache while testing. You'll know exactly what you need to be looking for to determine true signal integrity.

The advice and tips outlined in this eBook hold true for any oscilloscope you use from any vendor. Go ahead and test it out on the oscilloscope you already own, or better yet, demo multiple scopes and make the comparison yourself.

The Keysight Infiniium MXR-Series oscilloscopes get you from symptom to resolution fast with unprecedented simultaneous 8-channel performance.

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How to Determine Oscilloscope Signal Integrity

TIP 1

Understand ADC Bits and ENOB

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Understand ADC Bits and ENOB

The number of ADC bits in an oscilloscope is one of the most talked about specifications. Because of that, many engineers tend to rely on this as the sole spec that determines an oscilloscope's quality. While this is a very important specification, the number of ADC bits could be irrelevant if the rest of the oscilloscope isn't designed properly.

Just as important as the number of ADC bits is the system's effective number of bits (system ENOB). System ENOB is the number of bits that are actually effective while making a measurement. In any oscilloscope, some number of ADC bits will be useless – they only operate in the noise. Therefore ENOB, not ADC bits, determines the quality of measurements you are able to make on that oscilloscope. If the measurement quality is too poor, the results are inaccurate and non-repeatable, leading to incorrect assumptions in your design.

It's safe to argue that ENOB is a better indication of signal integrity because it takes the system error into account.

System ENOB usually isn't mentioned by oscilloscope vendors because designing for a high ENOB is not as easy as putting in a high-bit ADC. The front end and supporting circuitry around the ADC must be designed with a high degree of quality as well, which is no simple task.

Vendors naturally tend to market the specifications that make them look best. So, when you see a high number of ADC bits, it is a good sign, but you need to make sure you look at the other important components that go into signal integrity as well. The number of ADC bits is just a small part of the equation.

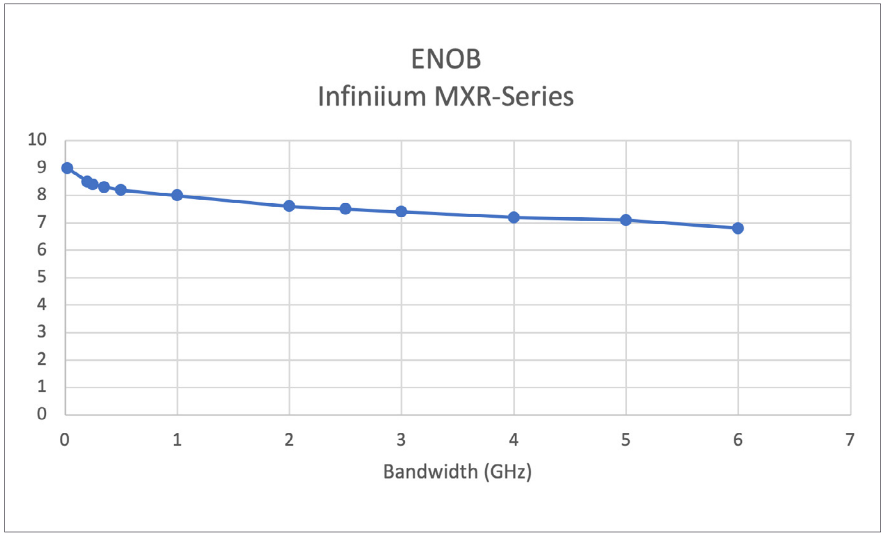

Figure 1. The ENOB of Keysight Infiniium MXR-Series oscilloscopes is as high as 9 bits, ensuring you always achieve the highest signal integrity.

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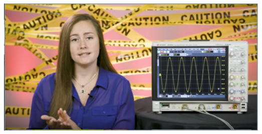

Watch this video to learn more about how and why ADC bits and ENOB are so different and what this can mean for your measurements.

TIP 2

ADC ENOB Versus System ENOB

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ADC ENOB Versus System ENOB

If you only know the ENOB basics and simply look for it in the data sheet, you may not realize there is actually a difference in ENOB specifications as well. Notice that the previous section talked about the system ENOB. This terminology is critical as there is a significant difference between system ENOB and ADC ENOB.

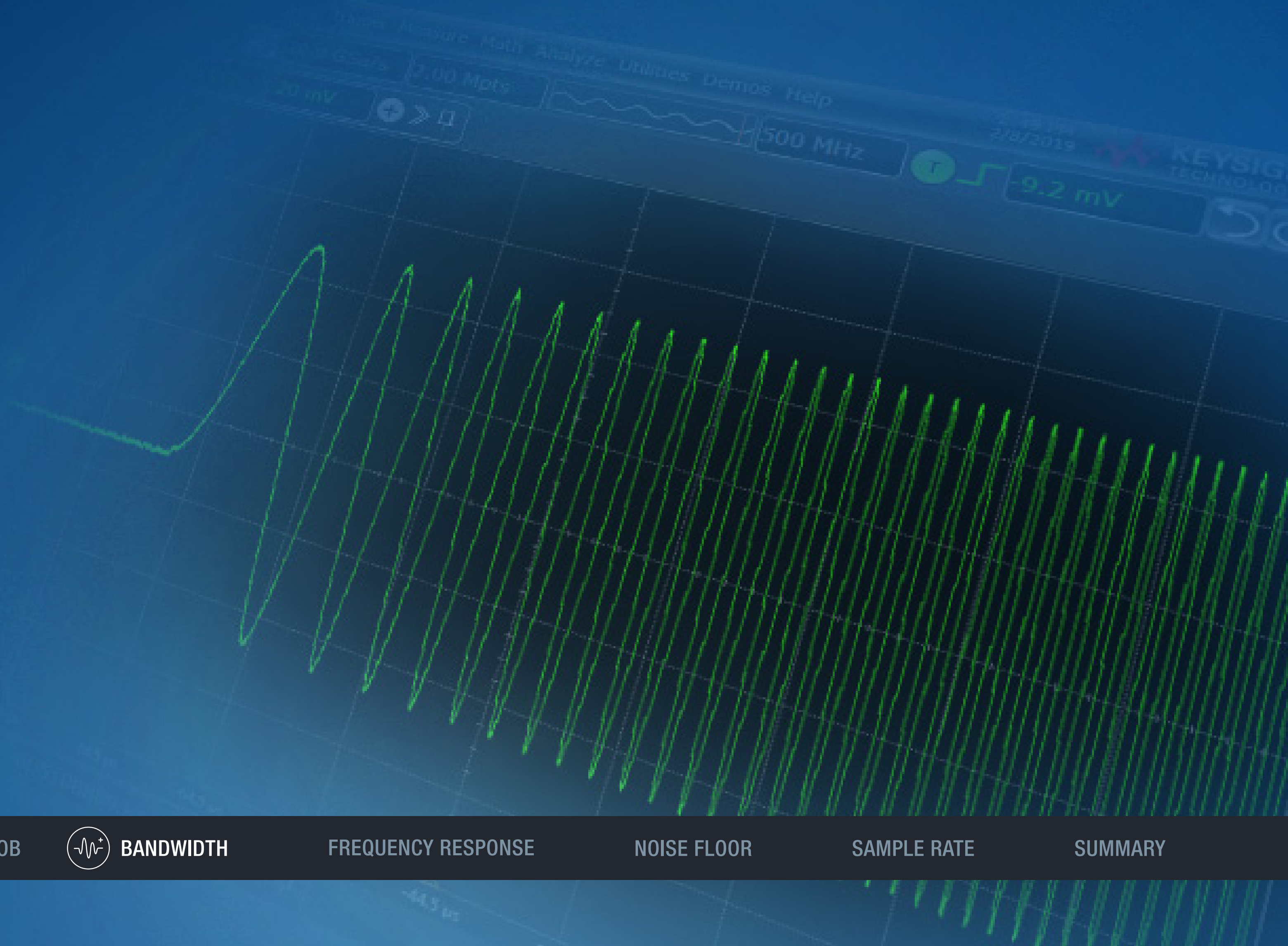
ADC ENOB refers to the effective number of bits in the ADC and only the ADC. However, an oscilloscope is made of an entire system, not just an ADC. The ADC ENOB specification is not representative of the number of bits that are effective in the entire oscilloscope, which is what really matters when you go to make measurements.

The system ENOB is the number of bits that are effective in seeing the signal on screen, making measurements, and using analysis features. If this specification isn't in the data sheet or the vendor's documentation, ask for it.

System ENOB can make or break your tests. If your system ENOB isn't high enough, you never get the clarity you need to achieve a stable design.

TIP 3

More Bandwidth is **NOT** Better



TIP 3

More Bandwidth is **NOT** Better

There is such a thing as too much bandwidth. If your instrument's bandwidth is too high, it could alter your measurements. A high bandwidth oscilloscope will pick up high frequency noise. Use the lowest bandwidth possible while still having enough to accurately capture your signal. If necessary, limit the bandwidth with the oscilloscope's built-in hardware or software filters.

Your system's ENOB is greatly affected by the amount of noise present. The more noise, the lower the ENOB.

As an example, figure 2 shows what a 20 MHz signal looks like when captured at two different bandwidths. With the appropriate bandwidth of 100 MHz (bottom), the result is a clean signal. Whereas the 6 GHz bandwidth capture (top) presents more noise, resulting in a thicker signal and incorrect peak measurements.

> The higher the bandwidth, the lower the ENOB. Use filters to limit bandwidth and maximize performance.

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Application Note: *Evaluating Oscilloscope Bandwidths*

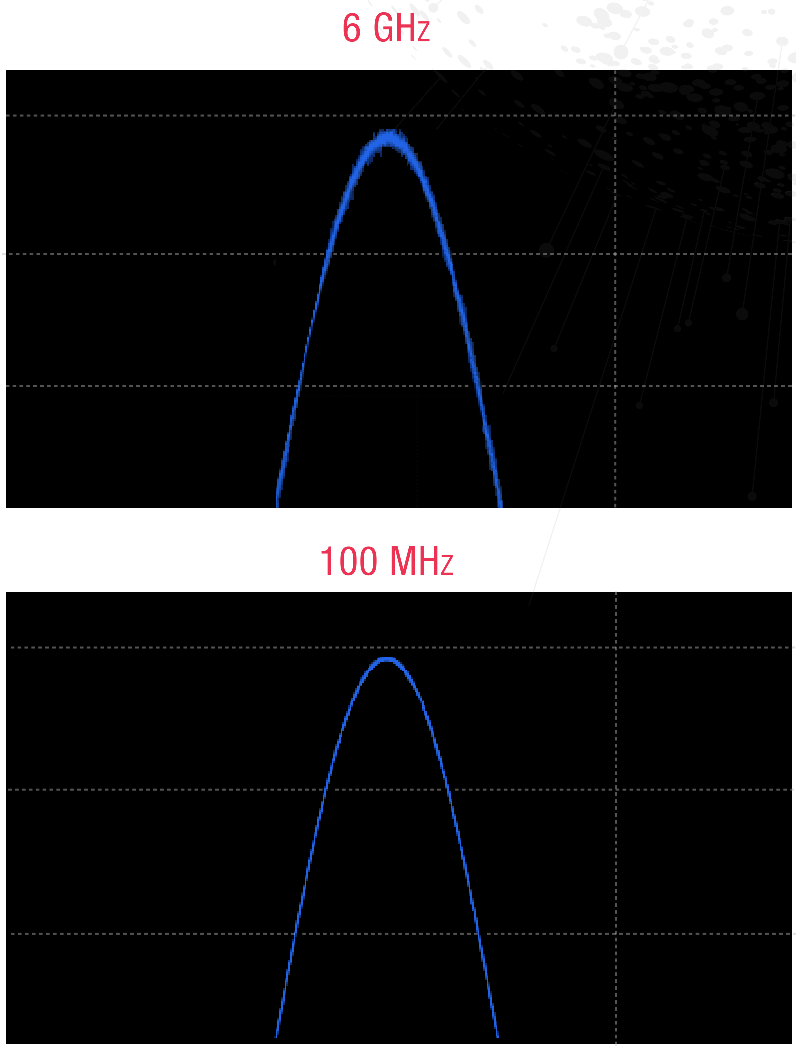
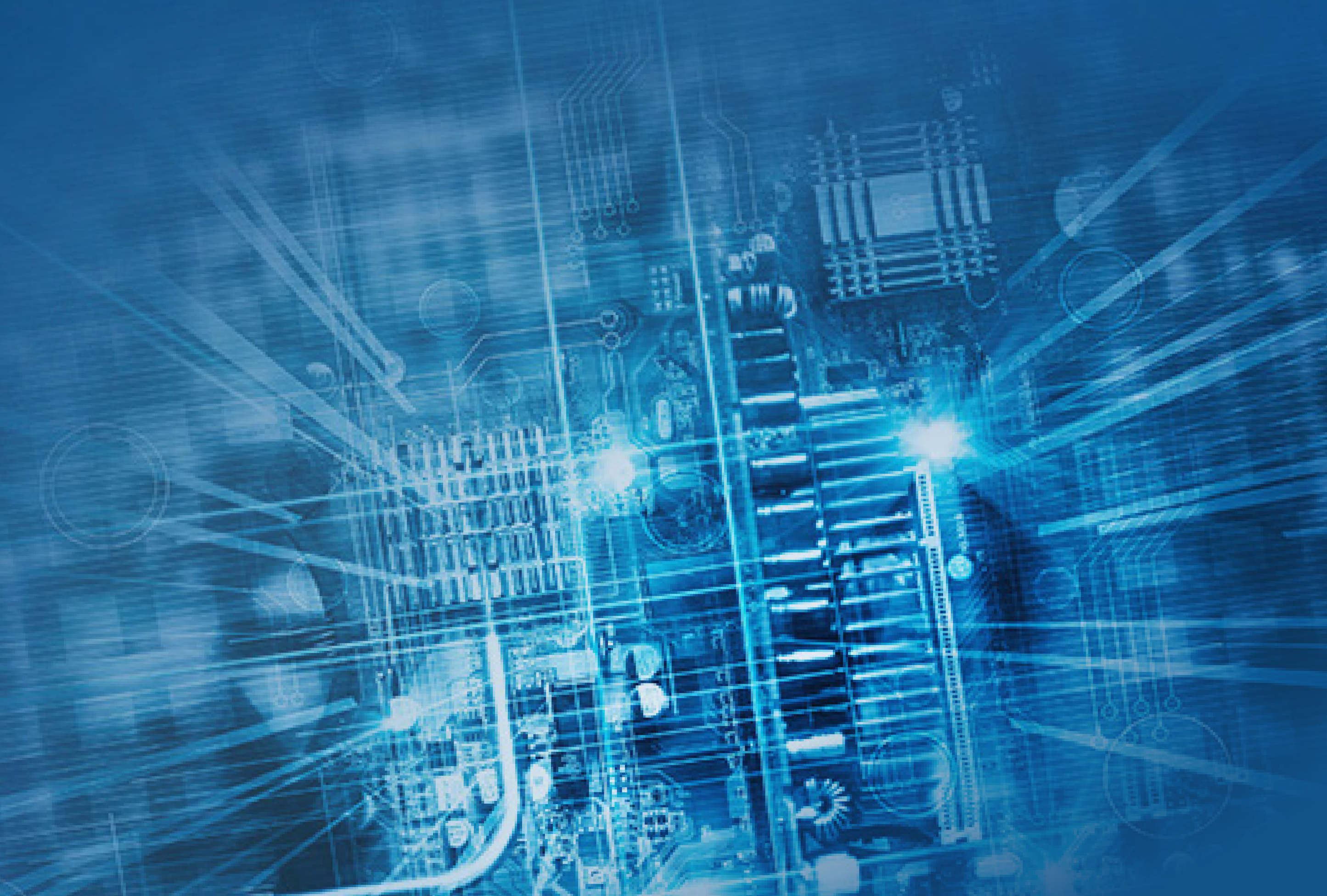


Figure 2. A 20 MHz signal tested at both 6 GHz (top) and 100 MHz (bottom)

TIP 4

All Bandwidth is **NOT** Created Equal



TIP 4

All Bandwidth is **NOT** Created Equal

The frequency response of an oscilloscope shows you the truth: not all bandwidth is created equal.

As you move up in bandwidth on a Keysight oscilloscope, the frequency response remains flat. This is because it uses hardware correction filters, which means your signal is barely attenuated. What is on the screen is true to what is coming out of your device. This ensures you get accurate measurements across the entire bandwidth spectrum of the oscilloscope.

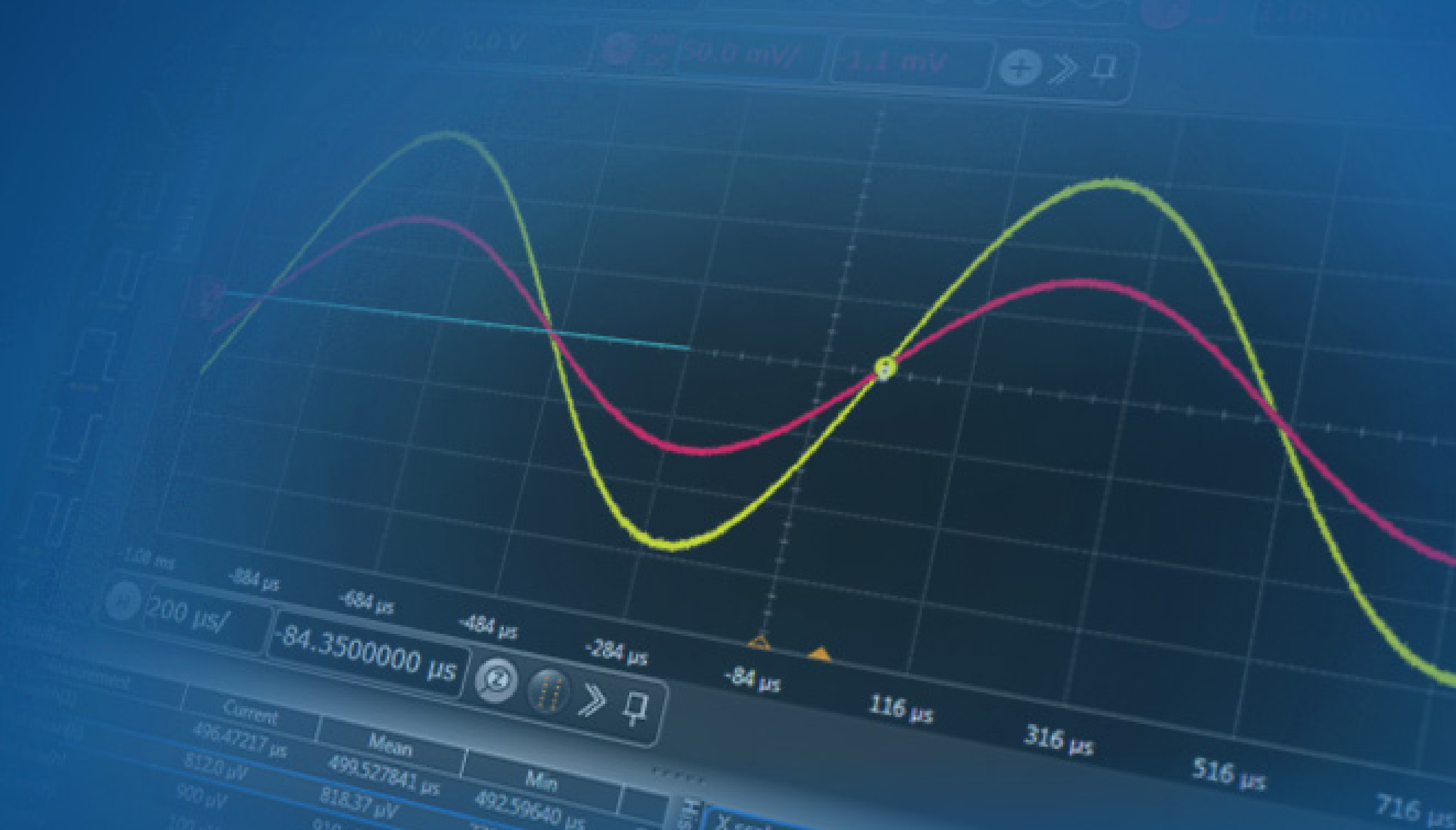
On the other hand, some vendors do not use correction filters. This means the instrument may give higher frequency components a small boost. The boost happens because your higher frequency signal is being attenuated in order to fall within the measurable bandwidth range. In the end, this affects the signal that you see on screen and skews any peak measurements.

This throws off all your results and may lead to confusion as you can't figure out what's wrong with the design, when in reality it was just the oscilloscope's poor signal integrity all along.

> Ask your vendor for the frequency response graph for the specific bandwidth model you are interested in. They are rarely shared in a data sheet, but the information is available and should be provided if asked for.

TIP 5

Noise Floor at Different Offsets



TIP 5

Noise Floor at Different Offsets

This one mind boggles many engineers: Did you know an oscilloscope's noise floor changes depending on where the signal sits on the screen?

When a signal is directly in the center of the screen, it is most likely to experience the ideal, lowest noise floor. However, depending on the quality of the ADC in your instrument, you could experience different noise levels at different vertical offsets on the screen. This has to do with the number of quantization levels that are needed to display at that offset.

This happens with every oscilloscope, and the difference really is just how much that affects your signal and measurements. The change in noise is very low on the Infiniium MXR-Series, as you can see in figures 3 and 4, but there are some instruments from other vendors where this problem is exceptionally bad.

It is important to analyze the noise floor of your oscilloscope at various points on the screen to be sure it doesn't affect your signal.

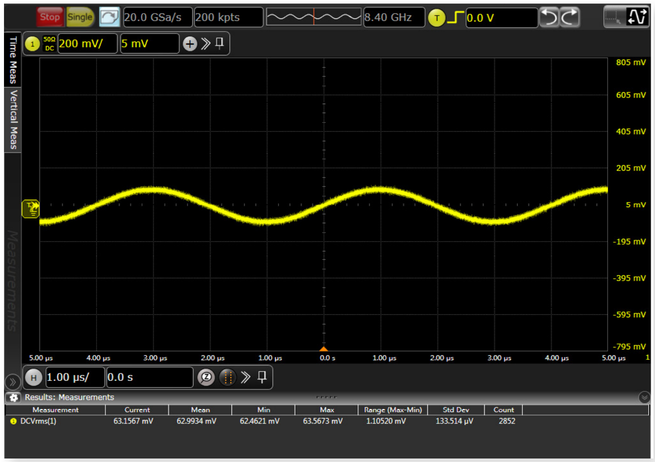


Figure 3. Noise at center screen

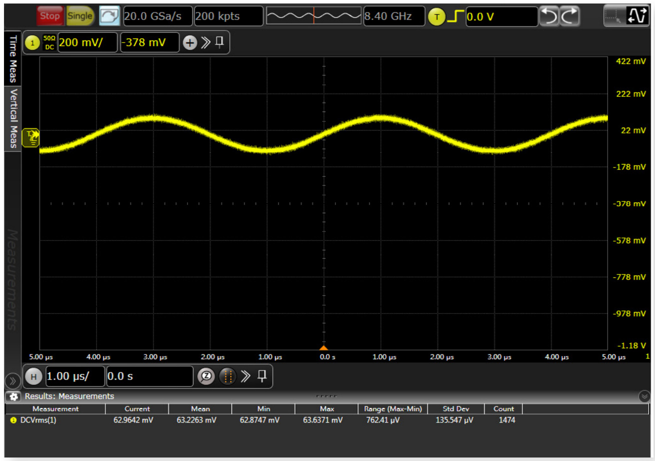


Figure 4. Noise increased on top half of screen

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Check out this video for tips on how to measure your system's noise floor.

TIP 6

Understand Sample Rate and Interleave Distortion

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Understand Sample Rate and Interleave Distortion

Typically, the higher the sample rate, the more signal detail you see. However, this depends on exactly how the oscilloscope is achieving that high sample rate.

Some oscilloscopes can reach incredibly high sample rates. To do this, two or more ADCs must be interleaved, i.e. synchronized with clock phase delays in a 'one fires then the other' pattern. This effectively doubles the maximum sample rate.

But there's a catch. With this technique, synchronization between ADCs needs to be extremely precise. Unfortunately for many oscilloscope users out there, it is not always done correctly. If the phase delay clocks are not properly aligned, samples are collected at uneven intervals. This leads to the waveform appearing distorted once it is reconstructed and shown on screen, such as the waveform in figure 5.

Luckily this will not happen with the Keysight Infiniium MXR-Series because the ADCs are properly synchronized, but proper synchronization is important to look for when evaluating oscilloscopes. Some high-end oscilloscopes, like Keysight's Infiniium UXR-Series, can achieve up to 128 GSa/s without interleaving ADCs, allowing for the most precise measurements.

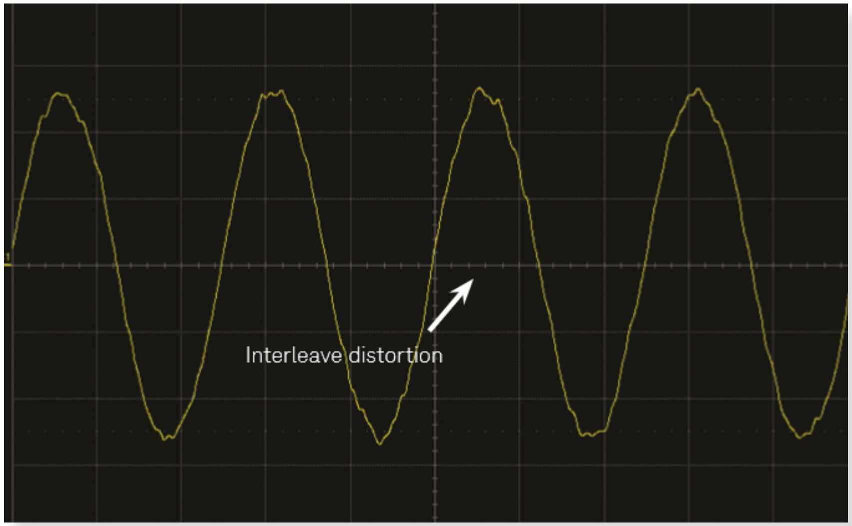

Figure 5. Distortion will occur in your signal if you have poorly interleaved ADCs.

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White Paper: *Everything You Need to Know About Sample Rate*

Summary

It's important to stay educated. Understanding what really matters when it comes to signal integrity allows you to avoid the problems that arise when you believe common signal integrity misconceptions. It is critical to know how the entire measurement system functions. If you know what to look for, you can easily find the truth about every oscilloscope's performance.

Remember these key lessons as you move forward with your measurements or in your search for the perfect oscilloscope:

1. Always ask for the system ENOB information to determine overall measurement quality
2. Remember to look for system ENOB, not just ADC ENOB
3. Decrease noise by only using the bandwidth you really need and nothing more
4. Ask for frequency response graphs to ensure the oscilloscope's response stays flat across the entire bandwidth range
5. Check noise floor at all different offsets on the oscilloscope screen to make sure it isn't significantly affecting your measurements
6. Be cautious of extremely high sample rates and incorrectly interleaved ADCs

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Application Note: *Evaluating Oscilloscope Signal Integrity*

SEE MORE. DO MORE. SAVE TIME.

You want your design to shine, and that means seeing more signals in new ways. Be ready with a Keysight Infiniium MXR-Series oscilloscope: it's your window into the intricate interactions of complex designs. Get from symptom to resolution fast by coupling the efficiency of an 8-in-1 bench solution with unprecedented simultaneous 8-channel performance.

Learn more about the Infiniium MXR-Series oscilloscopes and request a quote.

Need more bandwidth and even better performance? **Check out the Infiniium UXR-Series oscilloscopes (5 to 110 GHz).**