



Techniques to Achieve Oscilloscope Bandwidths of Greater Than 16 GHz

Application Note

Infiniium's 32 GHz of bandwidth versus techniques other vendors use to achieve greater than 16 GHz



Banner specifications are an integral part of oscilloscope design. The three key banner specifications are bandwidth, sample rate, and memory depth. Of the three banner specifications, bandwidth is where oscilloscope vendors invest millions of dollars, hoping to become the market leader. In 2007, Tektronix introduced the world's first 20 GHz oscilloscope (70000 Series) which featured 16 GHz of analog bandwidth and 20 GHz through a digital signal processing technique known as digital signal processing (DSP) boosting. In 2009, LeCroy introduced the first 30 GHz oscilloscope which featured 16 GHz of pre-amplifier bandwidth and

achieved 30 GHz utilizing a frequency interleaving technique which LeCroy termed digital bandwidth interleaving (DBI). Agilent Technologies then introduced the world's first 32 GHz bandwidth oscilloscope in 2010 using raw hardware performance. The Infiniium 90000-X Series oscilloscope has 32 GHz of true analog bandwidth enabled by its Indium Phosphide-designed front end. While all three techniques achieve the bandwidth specified by the vendor, it is important to understand the techniques used to achieve the specifications as they will influence the representation accuracy of the signal the oscilloscope is measuring.



Agilent Technologies

Raw Hardware Performance (True Analog Bandwidth)

The most expensive method to achieve high bandwidths is through raw hardware performance (true analog bandwidth). Raw hardware performance requires investing in multiple semiconductor chips (including the pre-amplifier and trigger chip) that are able to meet the high bandwidth specification. Oscilloscope vendors also must be able to design in this state of the art chip process.

Raw hardware performance can be directly tied to the pre-amplifier bandwidth. The 90000 X-Series is rated to the full 32 GHz. The hardware of the DSAX93204A is able to achieve the full 32 GHz on its own merit, without the tradeoffs that will be discussed from frequency interleaving and DSP boosting. Both Tektronix and LeCroy pre-amplifier bandwidths are equal to 16 GHz.

As a result of its true analog bandwidth, the 90000 X-Series has the exact same noise density from 1 to 2 GHz as it does from 31 to 32 GHz (the industry's lowest noise density). It is also able to achieve an extremely flat frequency response over the full 32 GHz as shown in Figure 3. Agilent spent multiple years designing low noise chips which, from an oscilloscope's perspective, correspond to a truer representation of the signal.

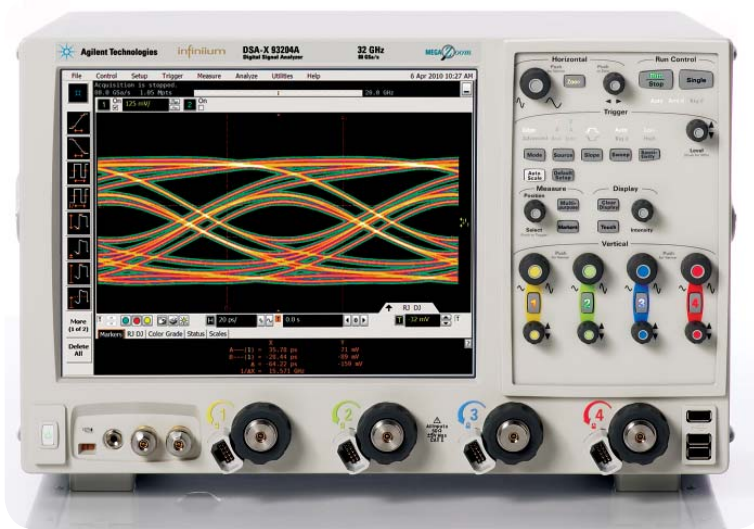


Figure 1: Agilent Infiniium 90000 X-Series

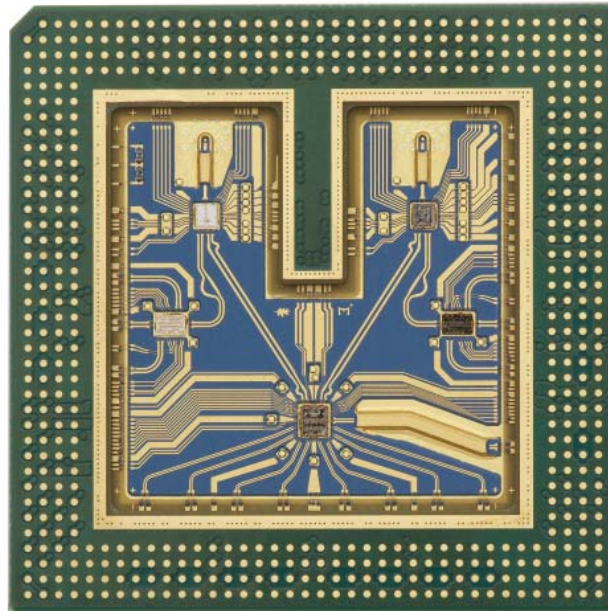


Figure 2: Multi chip module developed by Agilent for its 90000 X-Series oscilloscope

Raw Hardware Performance (True Analog Bandwidth)

Another benefit of using raw hardware performance to achieve high bandwidth is that the probing can use the same chip process and achieve high bandwidths as well. This enabled Agilent to develop the Infiniimax III probing system which achieves 30 GHz of bandwidth.

It should be pointed out that while the benefits of using raw hardware performance to attain high bandwidths are significant, it is still very important to understand how well it was designed. The front end of the oscilloscope could still have high noise and jitter if not designed correctly.

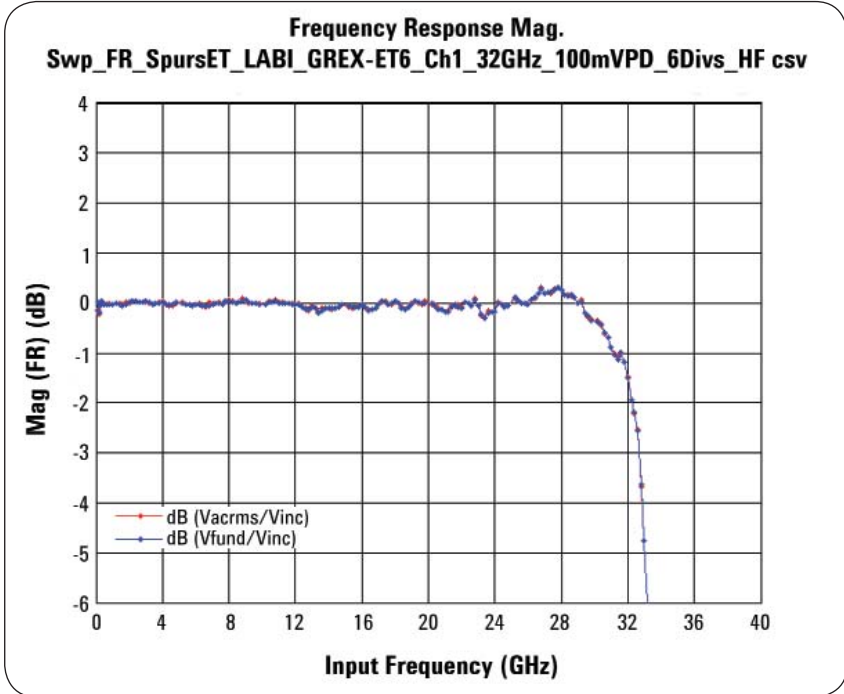


Figure 3: 90000 X-Series frequency response (notice that the response is within +/- 0.25dB to 29.5 GHz)

Frequency Interleaving

LeCroy introduced a 30 GHz oscilloscope using a technique known as frequency interleaving (digital bandwidth interleaving). Frequency interleaving is different than the traditional interleaving of the ADCs used by oscilloscope vendors because it requires additional hardware and advanced digital signal processing to achieve the bandwidth performance. The key thing to remember is that the pre-amplifier bandwidth does not meet the bandwidth of the oscilloscope.

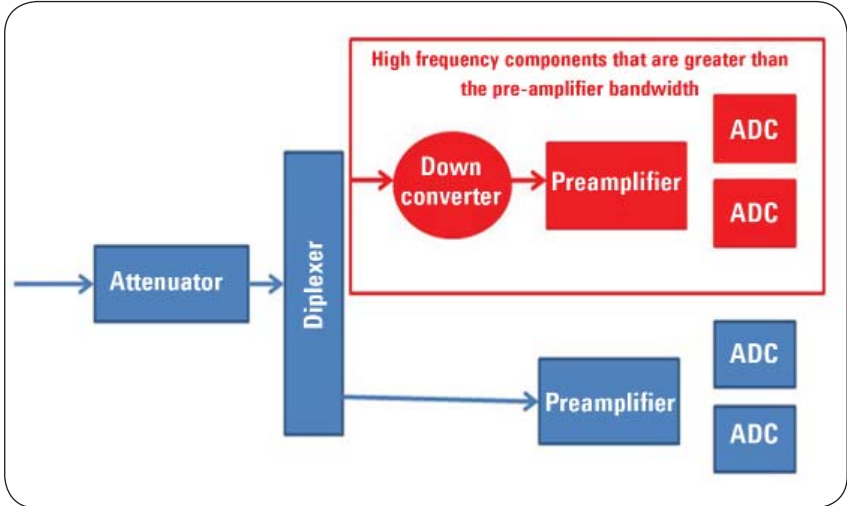


Figure 4: Signal path of a frequency interleaved oscilloscope

To understand how frequency interleaving works, consider how the signal travels through a frequency interleaved oscilloscope from front end to back end. To begin, the signal enters the oscilloscope and is immediately attenuated. The attenuated signal is then split by a diplexer (special hardware designed to split signals into multiple frequency bands) into high frequency components (greater than pre-amplifier bandwidth) and low frequency components (less than pre-amplifier bandwidth). This means that the low frequency components are equivalent to the actual analog performance of the oscilloscope. In

the case of the LeCroy WaveMaster 8Zi, it is limited to 16 GHz. The high frequency components at this point cannot enter the pre-amplifier or they would be lost. Essentially the oscilloscope becomes a low pass filter and cuts off the high frequency components. As a result, the components greater than 16 GHz are immediately down-converted to frequency content the pre-amplifier can handle. One of the reasons to purchase a high bandwidth oscilloscope is to avoid down-conversion and yet, the down-converter is a major component of a frequency interleaved oscilloscope! So, at this stage, the single signal

has been split into two frequency components and the high frequency component is down-converted. Each component then runs through a separate pre-amplifier (see figure 4). The two frequency components then go through significant digital signal processing to ensure the high frequency component was correctly acquired. The low and high frequency components are finally recombined to nearly double the analog bandwidth of the oscilloscope.

Frequency Interleaving

All oscilloscope vendors currently interleave channel resources such as memory and ADCs to form high sample rate and deeper memory depth. However, until the use of frequency interleaving, the interleaving techniques were only done post acquisition and could be tightly controlled using highly accurate clocks inside of the oscilloscope system. Even in these tightly controlled environments, interleaving errors would still occur. Interleaving errors cause increases in the oscilloscope's total harmonic distortion (THD) and erode effective bits. Frequency interleaving takes this idea to a whole new level as not only does a vendor interleave after the acquisition has taken place, but during the acquisition itself. This means that a signal is actually interleaved twice during the entire acquisition process. Figure 5 shows the effects of frequency interleaving as large as 10dB of gain can be seen at the frequency interleaved point. This plot is easily created by simply looking at the FFT of the noise of a frequency interleaved oscilloscope. Notice the interleaving errors are also clearly visible.



Figure 5: Noise density of a frequency interleaved oscilloscope (notice the noise spike around 15 GHz and 30 GHz)

Frequency Interleaving

Figure 6 than shows the noise floor comparisons between an oscilloscope with raw hardware performance to 32 GHz and a frequency interleaved oscilloscope.

Frequency interleaving does allow for faster times to market; however, its signal integrity issues must be considered. Another trade-off is in the total harmonic distortion. The signal is not only interleaved to increase sample rate, but is also interleaved a second time at the beginning of the acquisition. Additionally, a down conversion must occur and significant digital signal processing has to be done. All of this processing adds distortion and the additional hardware increases the signal path and noise (see figure 6 for noise comparisons). These tradeoffs ultimately lead to less accurate measurement results.

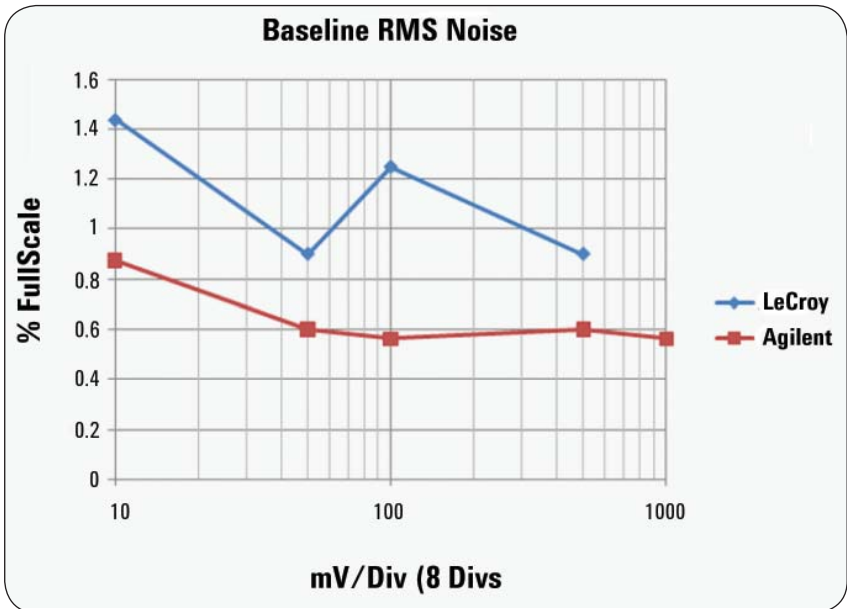


Figure 6. Noise floor comparison

DSP Boosting

The world's first 13 GHz oscilloscope used a technique known as DSP boosting to boost its hardware from 12 to 13 GHz. At the time (2004), many argued that it was technique that caused too much noise and it was not accepted as "real" bandwidth. However, in 2007, the first 20 GHz oscilloscope DSP boosted from 16 to 20 GHz. Suddenly the arguments against DSP boosting seemed to ease as two of the oscilloscope vendors were now "boosting" and even more importantly it was the only way to achieve 20 GHz of bandwidth. The first 20 GHz oscilloscope was very well received in the market as designers needed to make higher bandwidth measurements on 6 and 8 Gbps signals.

So what is DSP boosting? DSP boosting is a processing technique where the high frequency content of an oscilloscope is pumped with software. One important point to note is that DSP boosting needs to be distinguished from other types of DSP correction that oscilloscope vendors use today. To understand DSP boosting, first remember that a signal can be broken down into its numerous frequency components. Using software, you can amplify the higher frequency components of the signal. If you look at Figure 7, the red trace represents a typical oscilloscope frequency response. The green trace is the software filter used to amplify the high frequency components (which results in the increased bandwidth).

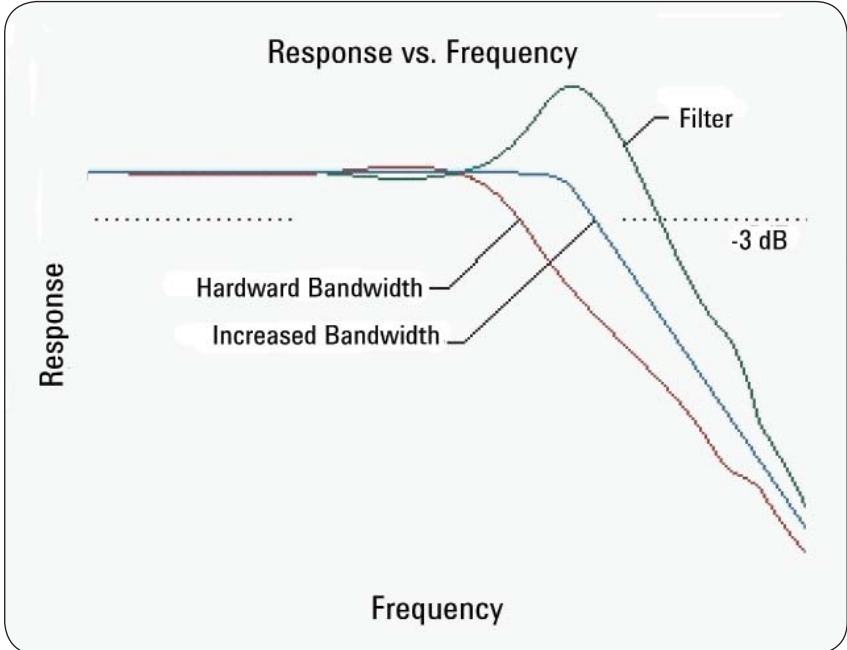


Figure 7: Bandwidth-enhancement filtering

At this point, everything looks fine. However, there is one major drawback to DSP boosting and that is the noise performance of the boosted signal. When the signal is amplified, so is the noise of the oscilloscope. Depending on how much boosting is done, the technique could actually degrade the signal and give worse results than a lower bandwidth, non-boosted signal. This is the single most important reason to really analyze how much boosting is occurring and then understand whether the bandwidth-for-noise trade-off is acceptable.

DSP Boosting

Figure 8 shows the effects of DSP boosting on the noise of an oscilloscope boosting from 16 to 20 GHz.

The increased noise means less accurate measurements. Another major problem with DSP boosting is that the effective bits are eroded at the fundamental frequency of the DSP boosted oscilloscope. For instance if an oscilloscope boosts to 20 GHz, the effective bits would be severely degraded at 10 GHz. This is clear from Figure 10, where the 16 GHz oscilloscope maintains significantly higher effective bits than the 20 GHz DSP boosted version of the same oscilloscope. Notice how the Agilent oscilloscope maintains high effective bits to 20 GHz as it has no DSP boosting and utilizes only true analog bandwidth.

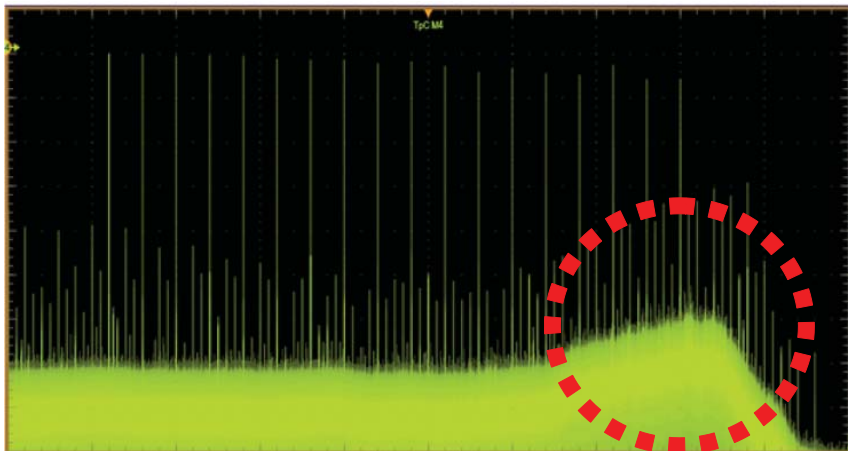


Figure 8: Sine wave sweep with DSP boosting, notice the noise "boost" at high frequency"

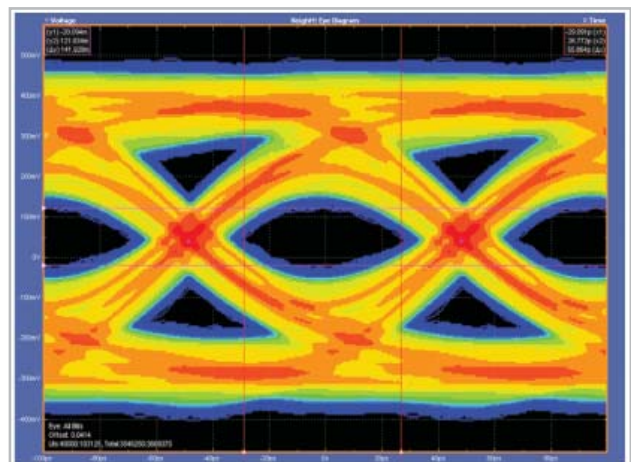
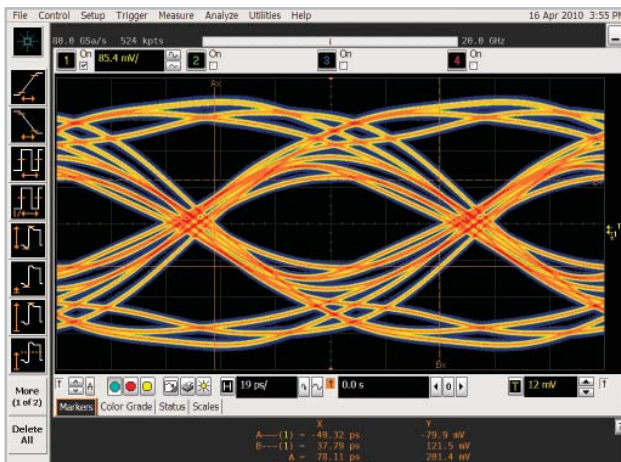


Figure 9: Comparison of 10.3125 Gbps PRBS7 signal with ISI added (raw hardware versus DSP boosting). The raw hardware performance yields over 25% more eye height and width

DSP Boosting

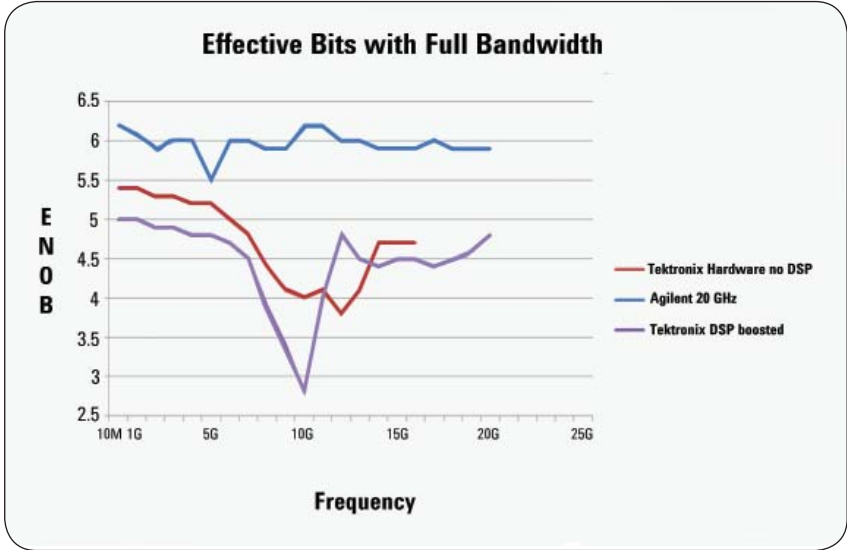


Figure 9. ENOB comparison

Conclusion

Two oscilloscopes from different vendors may both say 20 GHz on the front label, but not all bandwidths are the same. There are three technologies used to achieve high bandwidths today: raw hardware performance, frequency interleaving, and DSP boosting. While all three are able to achieve the bandwidths specified in the data sheet, it is important to understand the trade-offs. The 90000

X-Series, which uses raw hardware performance to achieve 32 GHz of bandwidth, maintains the industry's lowest jitter measurement and noise floor. It also does not suffer from noise density increases due to signal processing. As a result, when bandwidths are equal, it will feature the most accurate measurement of any real time oscilloscope in the industry.



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