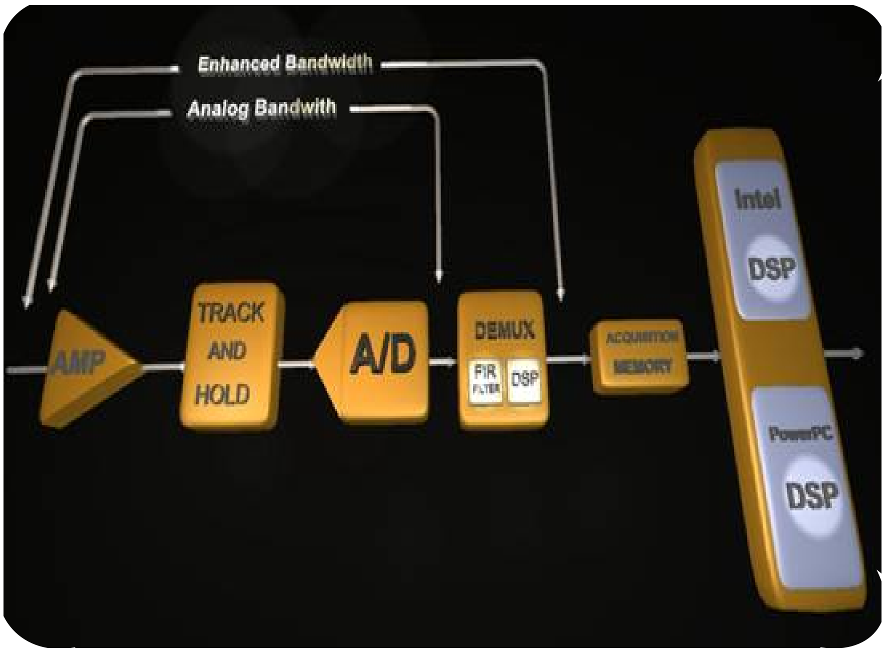
Bandwidth Alone ≠ Measurement Accuracy



Introduction

For accurate rise time measurements, Tektronix has always recommended the commonly quoted advice that the oscilloscope should be three to five times faster than the fastest signal to be measured. This is still prudent advice, but with enhanced characteristics of today's digital oscilloscopes, measurement accuracy can now be extended nearer the maximum specified bandwidth of the oscilloscope.

CLASSICAL FILTER RESPONSES

Classical filter texts stress the advantages of a Gaussian response for the time domain causing pulse signals to rise and fall smoothly, and rapidly settle to their final value. Gaussian response also has other many well-known characteristics, one being the simple relationship between rise time and bandwidth, as shown in Equation 1.

Equation 1: T_r =0.35/Bandwidth

Tektronix
Enabling Innovation

Using this equation, an 8 GHz Gaussian response filter, for example, has a rise time of 42.38 ps. Another very useful relationship is that the overall (measured) rise time of a Gaussian response oscilloscope and the rise time of an input signal can easily be calculated with a familiar formula (Equation 2):

Equation 2: Overall rise time = $\sqrt{}$oscilloscope rise time^2 + signal rise time^2)

These equations apply to an oscilloscope with an exact Gaussian response. The Gaussian response, however, is not always desirable in a real time digital oscilloscope intended to measure fast rise time digital signals. The reason for this can be seen in Figure 1. Notice, the Gaussian response in Figure 1 begins its gentle roll off already at low frequencies, exceeding 3% error at only 0.3 of the rated bandwidth. This gentle roll off continues above the –3dB bandwidth, leaving significant amplitude above the Nyquist frequency resulting in aliasing, leading to jitter and increased measurement uncertainty on single shot pulse edges.

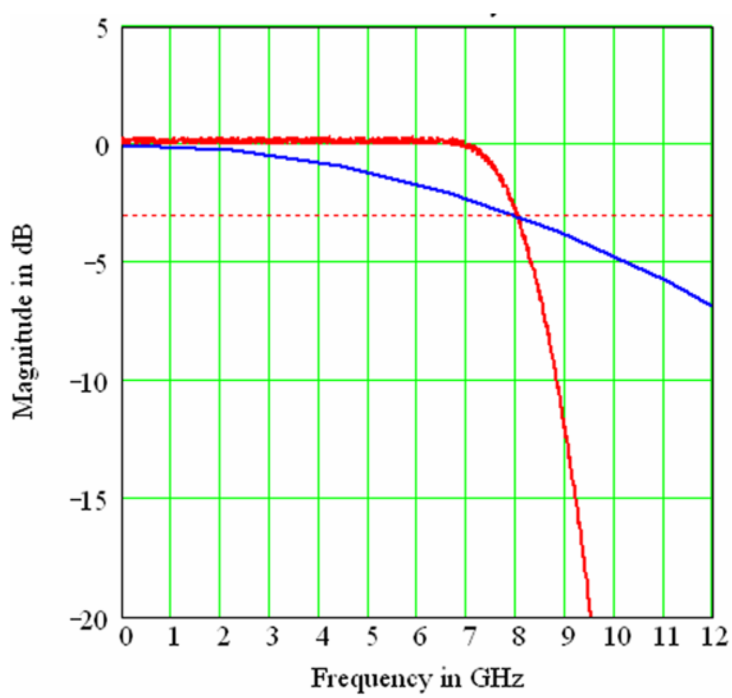


***Figure 1**. Gaussian response.*

Aliasing can be reduced by using another filter class known as Maximally Flat Amplitude (MFA) that has more accurate amplitude below the –3dB bandwidth and simultaneously more rapid attenuation above –3dB than a Gaussian filter of the same bandwidth. This reduces the frequency content above the Nyquist frequency which in turn reduces aliasing. Unfortunately, the abrupt change in phase below the –3dB bandwidth in the MFA filter response causes other measurement inaccuracies.

Another approach for real time digital oscilloscopes, that has distinct advantages over the above approaches, is using a filter response that combines the flatness and alias attenuation characteristic of an MFA with the linear phase characteristic of a Gaussian filter. This approach is used in the Tektronix TDS6804B DSO.

MAXIMUM USABLE FREQUENCY OF AN OSCILLOSCOPE

To analyze the suitability for high speed digital data, Howard Johnson[1] uses the concept of knee frequency, which is the frequency below which most energy in digital pulses concentrates. Subsequently, the usable frequency for an oscilloscope extends to this knee:

Equation 3: $F_{\text{Maximum Usable}} = 0.5/T_r$

where T_r is the pulse rise time. An oscilloscope with flat amplitude, as well as linear phase to or beyond this frequency, should pass a digital signal practically undistorted. Using this relationship, it should therefore be possible with an 8 GHz instrument to accurately capture rise times as fast as 63 ps.

ACTUAL MEASUREMENTS

To test this, we used the Tektronix TDS6804B DSO and high quality 100 ps and 75 ps filters from Picosecond Pulse Labs. First the 75 ps rise time was measured with a Tektronix 20 GHz bandwidth 11800 sampling oscilloscope with a SD24 sampling head. This combination is 3-5 times faster than the signals being measured, and reflects the classic relationship recommended for Gaussian response oscilloscopes. Next, the same rise time was measured using the TDS6804B.

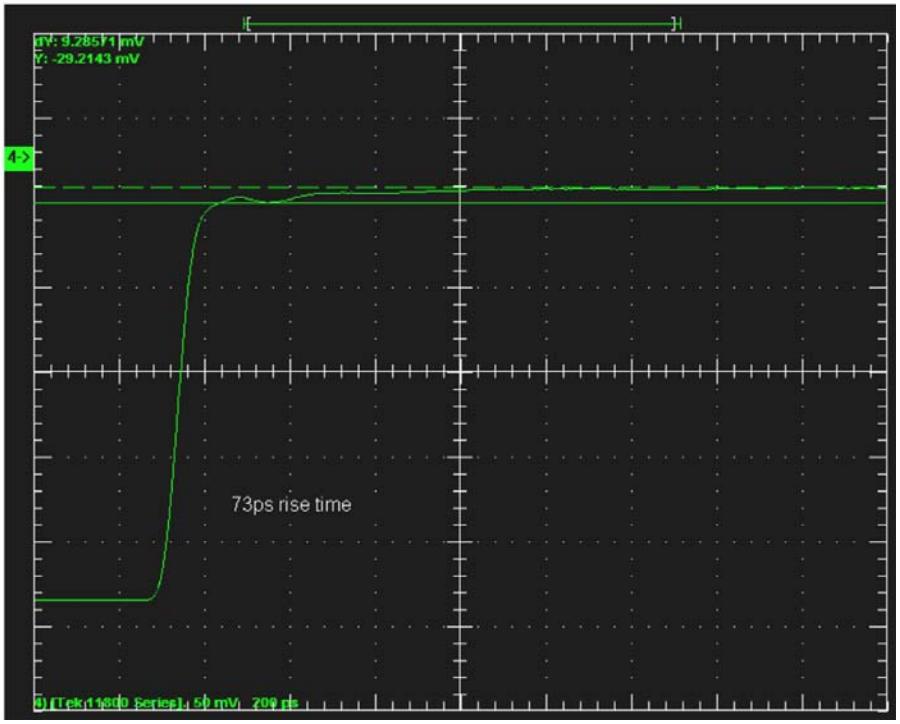


Figure 2. *Tektronix 11800 sampling oscilloscope mainframe with SD24 sampling head gives 20 GHz bandwidth and measures the nominal 75 ps filter rise time as 73.4 ps.*

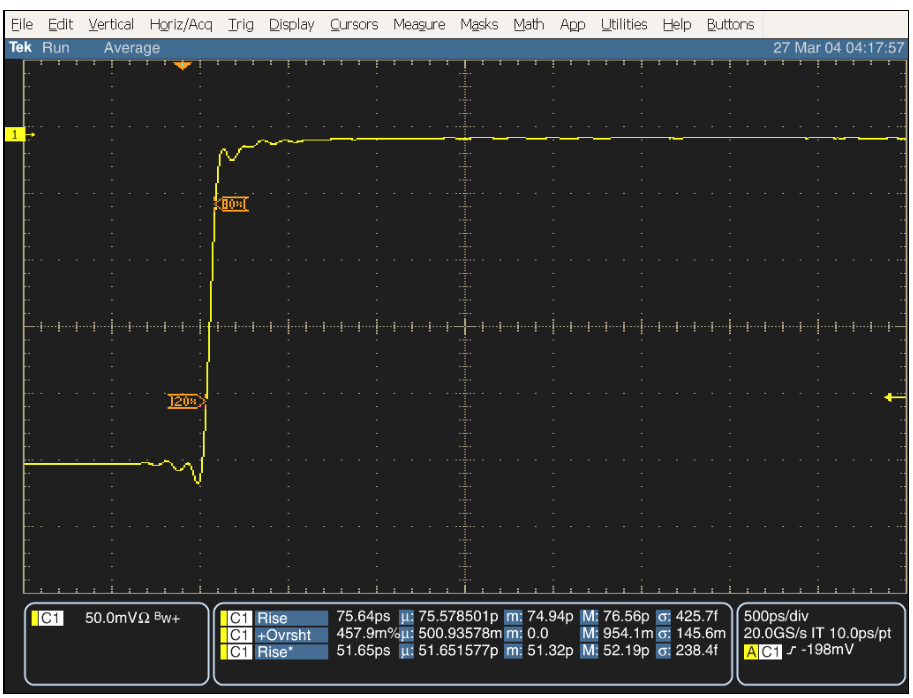


Figure 3*. Tektronix TDS6804B measures the nominal 75 ps filter rise time as 76.64 ps; within 5% of the 20 GHz sampling oscilloscope measurements.*

While the rise time measurement with the TDS6804B didn't match the exact measurements made with the 20 GHz bandwidth sampling oscilloscope, it is nevertheless very impressive and within 5% of the measurement made with the 11800 sampling oscilloscope.

Next the 100 ps filter was used with both the 20 GHz 11800 and the TDS6804B 8 GHz oscilloscope.

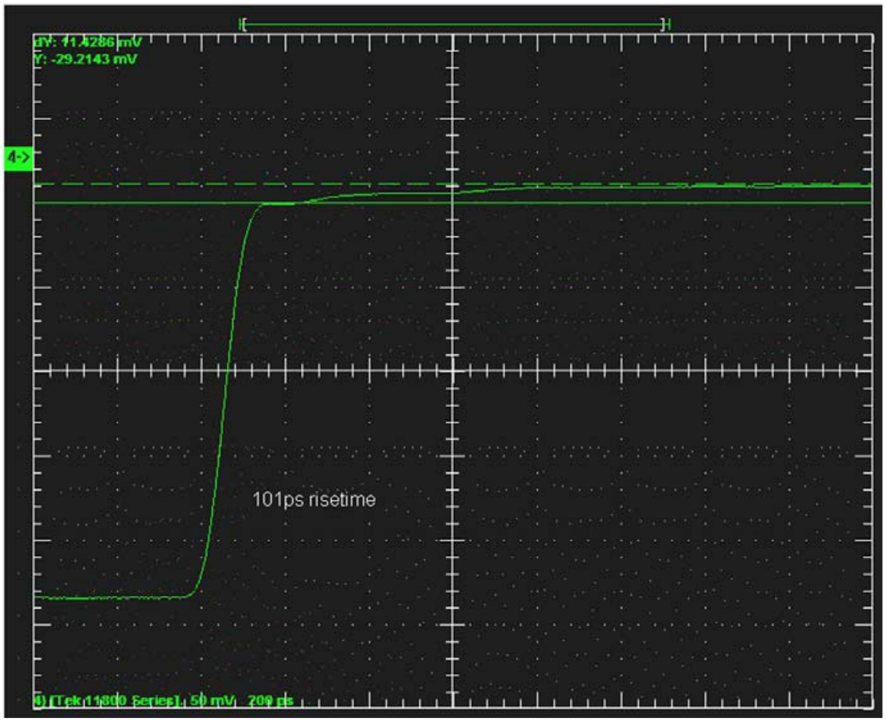


Figure 4. *Tektronix 11800 sampling oscilloscope mainframe with SD24 sampling head gives 20 GHz bandwidth and measures the nominal 100 ps filter rise time as 101 ps.*

Tektronix
Enabling Innovation

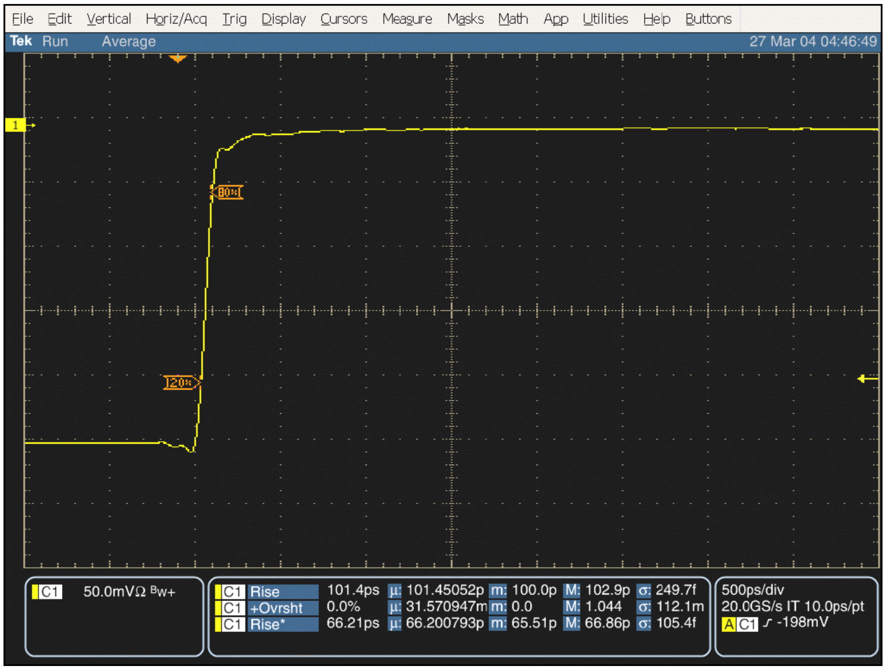


Figure 5. *Tektronix TDS6804B oscilloscope gives 8 GHz bandwidth and measures the nominal 100 ps filter rise time as 101.4 ps.*

When measuring a nominal 100 ps rise time, the measurement results for the two instruments are within 0.5%, indicating that the energy of the signal is nearly all contained within the 8 GHz bandwidth of the TDS6804B. This demonstrates that the real timeTDS6804B is more able to accurately perform fast rise time measurements, than previously possible with a real time oscilloscope.

HOW WOULD AN 8 GHZ GAUSSIAN-RESPONSE OSCILLOSCOPE COMPARE?

An 8 GHz Gaussian response oscilloscope has, by definition, a 43.75 ps rise time (Equation 1). Equation 2 also shows that a Gaussian response oscilloscope with this rise time will measure the 75ps rise time pulse as 86.143 ps. But why is the 8 GHz Gaussian-response oscilloscope less accurate for these measurements? Comparing the magnitude of a TDS6804B to an 8 GHz Gaussian response in Figure 6 gives some insight.

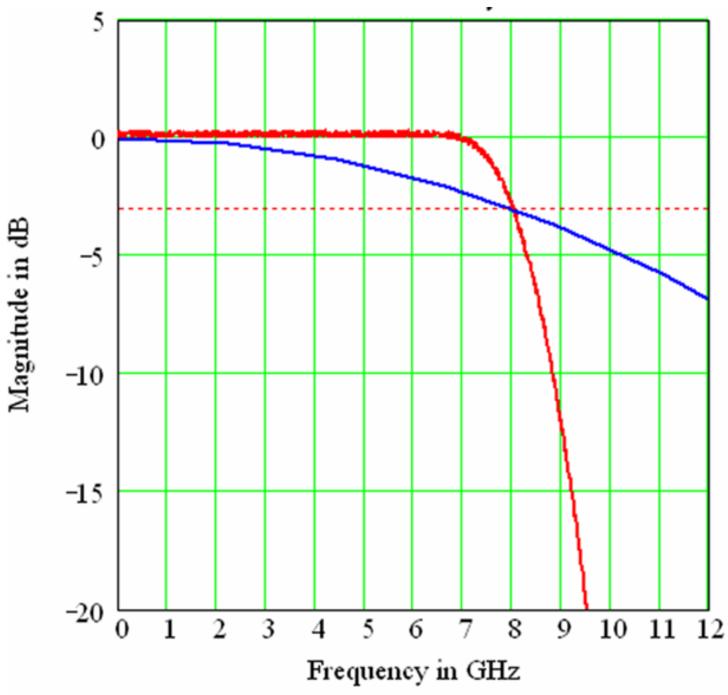


Figure 6. *The Gaussian response, blue trace, has a gentle roll off beginning at low frequencies. The TDS6804B response (red trace) has improved accuracy below 8 GHz.*

At frequencies below 2 GHz and near 8 GHz the two have equivalent magnitude, but between approximately 2 GHz to 8 GHz the TDS6804B clearly has an improved accuracy.

As you can see, the Gaussian filter response has an amplitude advantage above 8 GHz. This will result in a faster rise time measurement of a signal with significant energy above 8 GHz but with. decreased accuracy because of the aliasing phenomenon previously discussed. The conclusion drawn shows that when an oscilloscope with higher bandwidth than the fastest signal to be measured is used, oscilloscopes with flat magnitude and linear phase (such as the TDS6804B), have the advantage of improved accuracy and repeatability over Gaussian-response oscilloscopes of the same bandwidth.

CONCLUSIONS AND SUMMARY

It remains good advice to use an oscilloscope that is 3-5 times faster than the fastest signal to be measured. This is, however not always possible with today's fast digital signals. To determine the accuracy of an oscilloscope for signals within the bandwidth of the oscilloscope, faster rise time measurements on infinitely fast steps do not necessarily indicate better accuracy because a typical Gaussian response oscilloscope captures more information above the bandwidth increasing the risks of the negative aliasing effects.

Rather than using the bandwidth banner specification as a determination of measurement accuracy, a better way of predicting the accuracy is by looking at the oscilloscope's magnitude flatness and phase linearity An oscilloscope with a flat magnitude and linear phase response is more likely to make more accurate measurements than a Gaussian-response oscilloscope, in cases where the signal is within the bandwidth of the oscilloscope.

.

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

55W-19248-2