

Sustained Sample Rate in Digital Oscilloscopes

At all but a few of the fastest sweep speeds, the acquisition memory depth and not the maximum sample rate determines the oscilloscope's actual sample rate. Peak detection capability, when used correctly, can make up for acquisition memory shortfalls.

by **Steven B. Warntjes**

One of the most basic specifications in digital oscilloscopes is the maximum sample rate. Oscilloscope users often understand the theory of signal sampling and signal reproduction, but often mistakenly assume that the oscilloscope always samples at its maximum sample rate. In reality, two specifications need to be considered: the maximum sample rate and the acquisition memory behind the signal sampler. At all but a few of the fastest sweep speeds, the acquisition memory depth and not the maximum sample rate determines the oscilloscope's actual sample rate and consequently how accurately the input signal is represented on the oscilloscope display. The deeper the acquisition memory, the longer the oscilloscope can sustain a high sampling frequency on slow time-per-division settings, thus increasing the actual sample rate of the oscilloscope and improving how the input signal looks on the oscilloscope screen.

The digital oscilloscope's peak detection specification is another often overlooked specification. This important feature, when used correctly, can make up for acquisition memory shortfalls. In addition, peak detection can be combined with deep acquisition memory to create unique advantages in digital oscilloscopes.

Digital Oscilloscope Sampling

Basic sampling theory states that for a signal to be faithfully reproduced in sampled form, the sample rate must be greater than twice the highest frequency present in the signal. This sample rate is known as the Nyquist rate.¹ For an oscilloscope, this means that if the user wants to capture a 100-MHz signal, the sample rate should be at least 200 MSa/s. While the theory states that greater than $2 \times$ sampling is sufficient, the practicality is that to reproduce the input signal with $2 \times$ sampling requires complex mathematical functions performed on many samples. *Reconstruction* is the term commonly given to the complex mathematical functions performed on the sampled data to interpolate points between the samples. In practice, oscilloscopes that do reconstruction typically have less than perfectly reproduced waveforms because of imperfect application of the mathematical theory,* and they may have a slow waveform update rate because of the time it takes to do the necessary computations.

One solution to the reconstruction problem is to sample the waveform at a rate much higher than the Nyquist rate. In the limit as sampling becomes continuous, as it is in an analog oscilloscope, the waveform looks "right" and requires no reconstruction. Consequently, if the digital oscilloscope can sample fast enough, reconstruction is not necessary. In practice, a digital oscilloscope rule of thumb is that $10 \times$ oversampling is probably sufficient not to require reconstruction. This rule dictates that a digital oscilloscope with 100 MHz of bandwidth would require an analog-to-digital converter (ADC) to sample the input signal at 1 GSa/s. In addition, the acquisition memory to hold the samples would have to accept a sample every nanosecond from the ADC. While memories and ADCs in this frequency range are available, they are typically expensive. To keep oscilloscope prices reasonable, oscilloscope manufacturers minimize the amount of fast memory in their oscilloscopes. This cost minimization has the side effect of dramatically lowering the real sample rate at all but a few of the fastest time-per-division settings.

The sampling theory presented above assumes that the sampler only gets one chance to "look" at the input signal. Another solution to the reconstruction problem is to use repetitive sampling. In repetitive sampling, the waveform is assumed to be periodic and a few samples are captured each time the oscilloscope sees the waveform. This allows the oscilloscope to use slower, less expensive memories and analog-to-digital converters while still maintaining very high effective sample rates across multiple oscilloscope acquisitions. The obvious disadvantage is that if the waveform is not truly repetitive the oscilloscope waveform may be inaccurately displayed.²

Digital Oscilloscope Memory Depth

Now that we understand digital oscilloscope sampling requirements, we can examine how memory depth in oscilloscopes affects the sample rate at a given sweep speed or time-per-division setting. The time window within which a digital oscilloscope can capture a signal is the product of the sample period and the length of the acquisition memory. The

* Errors are attributable to high-frequency components in the captured signal and a finite number of samples.

acquisition memory is measured by the number of analog-to-digital converter samples it can hold. Typically in digital oscilloscopes the length of the acquisition memory is fixed, so to capture a longer time window (adjust the oscilloscope for a slower time-per-division setting) the sample rate must be reduced:

$$t_{\text{CAPTURE}} = k_{\text{MEMORY}}/f_s,$$

where t_{CAPTURE} is the time window captured by the oscilloscope, k_{MEMORY} is the length of the acquisition memory, and f_s is the sample rate.

In Fig. 1 we have oscilloscope A with a maximum sample rate of 200 MSa/s and an acquisition memory depth of 1K samples. Oscilloscope A samples at its maximum sample rate specification of 200 MSa/s or 5 nanoseconds per sample from 5 ns/div to 500 ns/div. As the time-per-division increases beyond 500 ns/div we see that the sample rate drops. At 1 millisecond per division the oscilloscope's sample rate has dropped to 10 μ s per sample or 100 kSa/s. This dramatic drop in sample rate at slower sweep speeds leads to oscilloscope displays of fast signals that don't accurately represent the input signal.

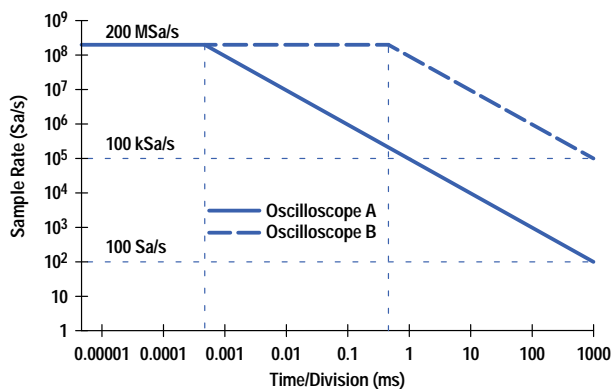


Fig. 1. Effect of memory depth on the maximum sample rate of a digital oscilloscope. Oscilloscope A has a memory depth of 1000 samples. Oscilloscope B has a 1,000,000-sample memory.

Fig. 1 also shows the sample rate behavior of oscilloscope B, which differs from oscilloscope A only in that the memory depth has been increased from 1,000 samples to 1,000,000 samples. Oscilloscope B samples at its maximum sample rate of 200 MSa/s from 5 ns/div to 500 μ s/div. On fast time base settings, oscilloscopes A and B both sample at 200 MSa/s. An important difference shows up at the slower time base settings. At 1 millisecond per division we see that oscilloscope B samples at 100 MSa/s or 10 nanoseconds per sample while oscilloscope A has dropped to 100 kSa/s. We can clearly see that the deeper memory ($\times 1000$) gives us the ability to capture events 1000 times faster at the slower time-per-division settings. The effect of deeper memory is the ability to sustain the maximum sample rate at much slower sweep speeds, in our example from 500 ns/div to 500 μ s/div, and sustain faster sample rates at sweep speeds where the sample rate must be reduced because of memory depth limitations. This effect of increased acquisition memory gives the oscilloscope higher sampling performance over a wider range of oscilloscope operation.

Digital Oscilloscope Peak Detection

Peak detection is a powerful feature that compensates for lack of memory depth in digital oscilloscopes. In peak detection mode the oscilloscope looks at many samples but stores only the maximum and minimum voltage levels for a given number of samples. The effective sample rate of the oscilloscope in peak detection is normally the maximum sample rate of the oscilloscope on all sweep speeds.* This enables the oscilloscope to capture fast input signal amplitude variations by sampling at the maximum sample rate, yet save memory space by storing only the significant signal deviations. The value of peak detection is best illustrated with a simple example. In Fig. 2 we have a display of a long time window with short-duration changes in signal amplitude. We are at a time-per-division setting of 20 seconds per division and are showing a 100-nanosecond event. To detect this event without peak detection would require at least a $1/(100 \text{ ns}) = 10\text{-MSa/s}$ sample rate. Likewise, to capture 200 seconds ($20 \text{ s/div} \times 10 \text{ div}$) of information with 100-ns sampling would require a memory depth of $200/(100 \text{ ns})$ or two billion samples. Clearly, peak detection is useful for catching short-duration signal changes over long periods of time without large amounts of oscilloscope acquisition memory. In many instances peak detection can make up for acquisition memory shortfalls.

Traditional digital oscilloscope peak detection has two significant disadvantages. First is the lack of timing resolution of the stored peak detected samples. As described above, the net peak detection sample rate is the maximum oscilloscope sample rate divided by the number of samples searched for minimums and maximums. This leads to a lack of timing resolution because the oscilloscope only stores maximum and minimum values. This 1-out-of-n selection results in a loss of information

* Some oscilloscopes with digital peak detection do not use every possible sample in peak detection mode.

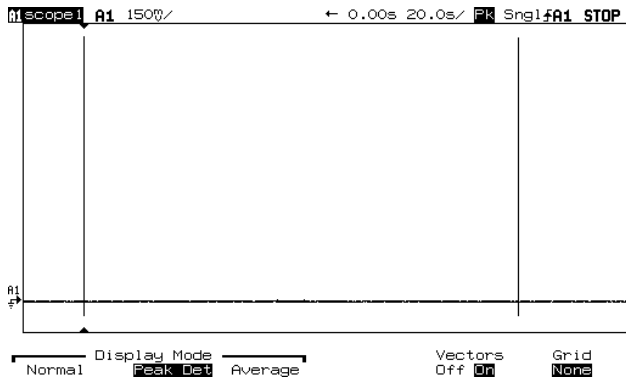


Fig. 2. A display of a long time window in peak detection mode, showing a 100-nanosecond event at a time-per-division setting of 20 seconds per division. To detect this event without peak detection would require at least a 10-MSa/s sample rate and a memory depth of two billion samples.

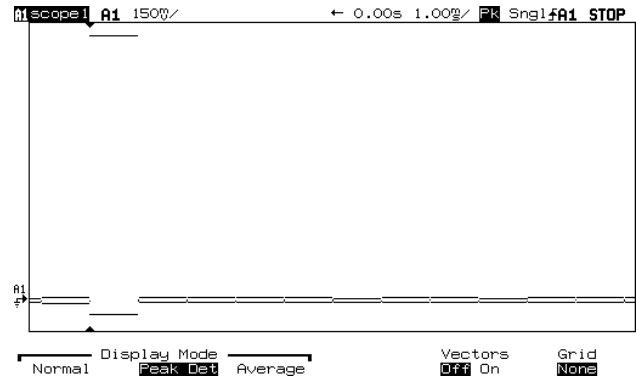


Fig. 3. The waveform of Fig. 2 with the time scale expanded to display the maximum value. The maximum value is shown as a solid bar; the available timing resolution. The 100-ns pulse captured across 200 seconds shows only approximately 1 ms of timing resolution.

as to whether the maximum occurred on the first, last, or *m*th sample of the samples searched for the maximum and minimum voltage values. In Fig. 3 we have taken our Fig. 2 waveform and expanded the time scale to display the maximum value. (The maximum value is shown as a solid bar, the available timing resolution.)

The second peak detection disadvantage is the apparent noise on the oscilloscope display. The storage of only maximum and minimum voltage levels has the effect of making the input waveform appear to contain more noise or signal aberrations than are actually present. This is because the peak detection algorithm stores only these peak values, and not normal signal voltage levels. Traditional digital oscilloscope peak detection gives the user a biased view of the input signal by overemphasizing the signal's infrequent amplitude deviations.

Having considered traditional peak detection advantages and disadvantages, what do deep acquisition memory and sustained sample rate contribute to the peak detection problem? Deep memory has three benefits when applied to peak detection. First is that peak detection is needed less frequently. Deep acquisition memory allows the analog-to-digital converter to sustain a higher sample rate at all sweep speeds. This means that the user is required to switch into peak detection less often to catch short-duration signal variations reliably. The second advantage is increased timing resolution of the peak detected samples, since the benefits of memory depth also apply to the peak detected samples. The deep-memory oscilloscope can store many more minimum and maximum pairs over a given time period, yielding a shorter time interval between the peak detected samples. The third deep memory peak detection advantage consists of the addition of regular (not peak detected) data displayed with the traditional peak detected information. In this case the acquisition memory is segmented and both peak detected samples and regular samples are stored. The HP 54645 deep-memory peak detection display contains regular and peak detected samples. This has the effect of deemphasizing the peak detected samples since they appear as only a subset of the waveform display. While the displayed waveform still differentiates signal amplitude variations by always displaying peaks, it also gives the user a feel for the signal baseline by displaying normal waveform information.

Summary

Conventional digital oscilloscopes achieve their maximum sample rate only on their fastest sweep speeds. We have examined two key features (memory depth and peak detection) that sustain this sample rate over a wider range of oscilloscope operation. Increased amounts of acquisition memory afford the user a much higher sample rate across sweep speeds that are not at the oscilloscope's maximum sample rate and sustain the maximum sample rate of the oscilloscope to a larger number of time-per-division settings. This produces a more accurate waveform representation of the input signal on the digital oscilloscope display across many sweep speed settings. We have also described the advantages and disadvantages of traditional digital oscilloscope peak detection and pointed out some unique sustained sample rate and deep-memory peak detection advantages.

Acknowledgment

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References

1. L.C. Ludeman, *Fundamentals of Digital Signal Processing*, Harper & Row, 1986.
2. R.A. Witte, "Sample Rate and Display Rate in Digitizing Oscilloscopes," *Hewlett-Packard Journal*, Vol. 43, no. 1, February 1992, p. 18.

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