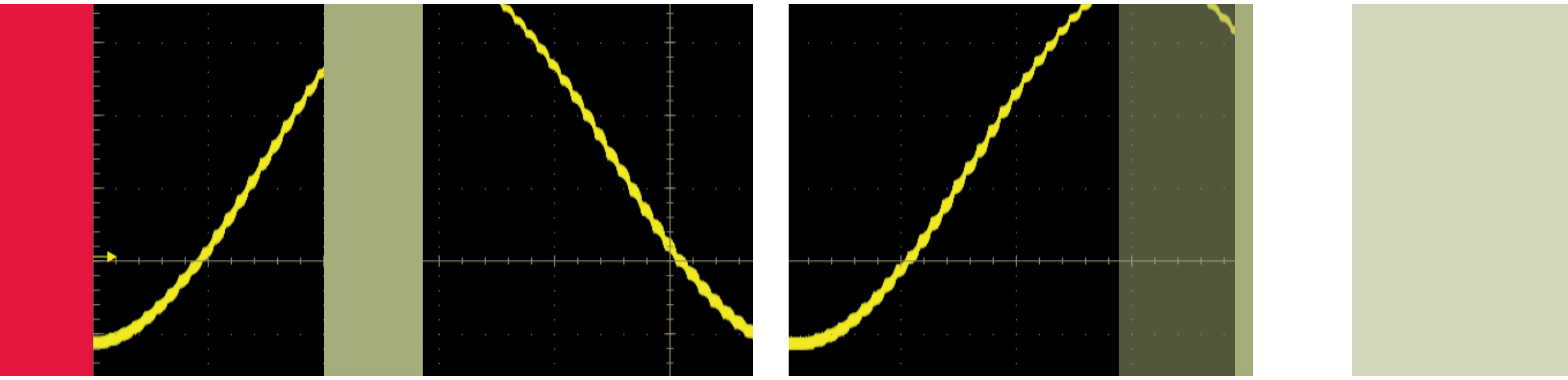

Improving Vertical Resolution in Tektronix Digital Phosphor Oscilloscopes

Technical Brief

When making high-resolution, low-voltage measurements, many oscilloscope users would benefit from a better understanding of oscilloscope operating modes and the performance characteristics of probes and oscilloscopes. This technical brief describes some of the fundamental measurement and signal-processing techniques used for high-resolution waveform acquisition in Tektronix digital oscilloscopes. Knowledge of the benefits and trade-offs will make it easier to choose and successfully apply Tektronix oscilloscopes and probing solutions.

Tektronix®

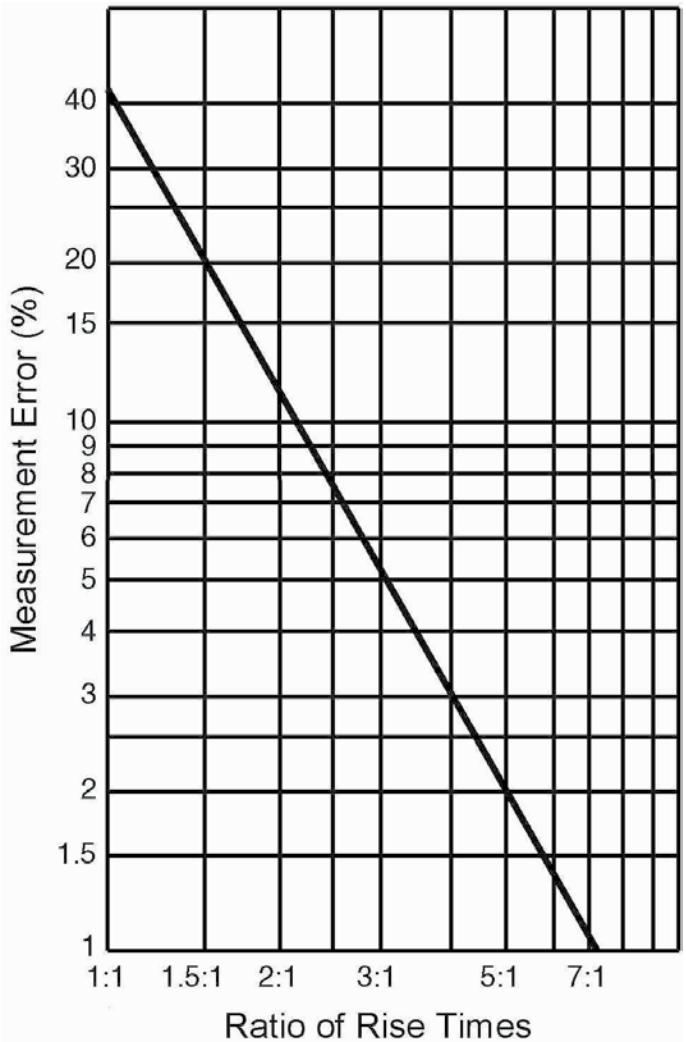

Figure 1. Rise Time Measurement Errors.

Measurement System Bandwidth

The first step in making good measurements is to choose the right measurement system. The analog bandwidth of the measurement system, including the oscilloscope and probes, must be adequate to capture the highest desired frequency in the signal, including harmonics. A good general rule is to use a measurement system with at least 5 times the bandwidth of the signal you want to measure. For example, to measure a 100 MHz digital clock signal, you will want the probe and oscilloscope to provide at least 500 MHz of bandwidth. This allows for capturing the most significant harmonics and limits the magnitude and phase measurement errors that occur near the band edge.

When making low-voltage measurements, be sure that you are evaluating the bandwidths of the equipment at a relevant sensitivity range, not just the best-case performance for the product. For example, a switchable-attenuation (e.g. 1X/10X) probe may have very high bandwidth in the 10X path, but very low bandwidth in the 1X path. Similarly, an oscilloscope may have a derated bandwidth spec at 1 mV/div, or it may not even offer that sensitivity (or just provide vertical zoom of a less-sensitive setting).

When measuring non-sinusoidal signals, a more relevant specification may be the rise time of the measurement system. The system rise time is calculated as the square root of the sum of the squares of the rise times of the oscilloscope and the probe. A good general rule is to use a measurement system with a rise time at least 5 times faster than the signal you want to measure. This will provide accurate timing parameter measurements to within 2%, as shown in Figure 1.

Although adequate bandwidth is necessary for good signal fidelity, more bandwidth does not necessarily enable better measurements. Greater bandwidth also captures increased noise along with the signal.

Oscilloscope Sample Rate

The oscilloscope's sample rate indicates how frequently the instrument samples the input signal. To accurately reconstruct a signal and avoid aliasing, the Nyquist theorem states that the signal must be sampled at least twice as fast as its highest frequency component. Accurate reconstruction of a signal depends upon the sample rate and the interpolation method used to reconstruct the signal. With sin (x)/x interpolation, a good general rule is to use a sample rate of 5 times the system bandwidth. When capturing single-shot and transient events, a lower sample rate will limit the oscilloscope's single-shot bandwidth.

Selecting the Optimum Probe

The choice of probing may seem obvious, but there are many critical tradeoffs to be made for optimal results, especially when measuring low-voltage signals. The passive probe which was shipped with the oscilloscope may not be the best solution for this application.

With low-voltage measurements, it is very important to maximize the signal amplitude while minimizing external noise. The probe selection is the first critical step. Voltage probes typically attenuate the input signal by forming a voltage divider with the oscilloscope's input impedance. This has the positive effect of increasing the measurement system's input impedance, but it reduces the signal level at the input of the oscilloscope. The oscilloscopes compensates for this attenuation by amplifying the signal, and, unfortunately, any noise that is added by the probe and the oscilloscope. From a signal-to-noise perspective, the optimum probe provides little or no attenuation. For example, consider the TPP0502 high-impedance passive probe, which provides 500 MHz bandwidth but with only 2X attenuation.

To minimize the loading effects on the signal, you will want to choose a probe with very high input resistance and very low input capacitance. (Minimizing input capacitance increases the resonant frequency caused by ground lead inductance, or, conversely, allows the use of longer ground leads without further loss in signal fidelity.) The lowest loading will likely be achieved using an active probe, though you may be trading off cost, noise, and dynamic range.

All voltage measurements are relative to a reference, often "ground". Accurate measurements, especially low-voltage measurements, are critically dependent upon a low-impedance path to the reference voltage. To minimize signal distortion and noise pick-up, you will want to use the shortest possible grounds. Although the long ground lead on a standard passive probe is convenient for browsing, the lead inductance resonates with the input capacitance, causing ringing on fast edges. A large loop area, formed by the probe tip and ground lead, allows magnetic coupling of noise into the signal. And, close proximity between the inductive reactance of the ground lead and noise sources such as switching devices allows electrostatic coupling of noise into the signal. The best solution is to minimize the length of the ground lead and connect it to a reference point as close as possible to the signal connection.

For further technical information on oscilloscope probes, please refer to the Tektronix ABCs of Probes Primer 60W-6053-XX on www.tektronix.com.

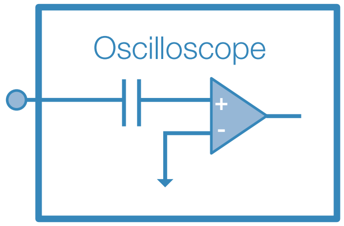

Figure 2. AC Coupling at the Oscilloscope Input Amplifier.

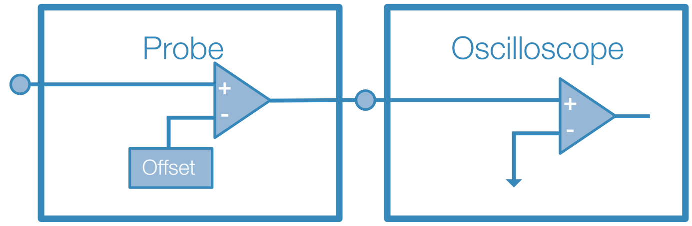

Figure 3. Adding DC Offset in the Probe.

Working with Large DC Offsets

Note: Whenever large voltages are involved, it is critical for your safety and the equipment's reliability to verify that the maximum voltages are well within the test system's "absolute" or "non-destruct" maximum input specifications. In addition, for accurate measurements, it is important that the signals remain within the nominal operating ranges (for example, within an active probe's linear or dynamic range).

Although low-level measurements near ground are challenging, measurements of low-voltage AC signals riding on large DC offsets are much more difficult. Whenever large voltages are involved, it is important to verify that the maximum voltages are well within the test system's maximum input specifications.

The simplest technique is to acquire the entire signal with a ground-referenced probe and then attempt to measure the AC component. This technique does not allow the AC signal measurements to take full advantage of the measurement system's dynamic range, and the signal-to-noise ratio will be poor. However, there are some signal processing techniques, discussed later in this document, which can improve the measurement resolution somewhat.

Another technique is to use AC coupling (or "DC block") at the oscilloscope's input. By inserting a capacitor in series with the input signal, AC coupling works well for removing DC components from the input signal as long as the signal is not being distorted, such as driving an active probe beyond its maximum range. And, although the capacitor will block a DC signal, it will only somewhat attenuate a low-frequency signal. Finally, AC coupling may not be available at all oscilloscope input termination settings, see Figure 2.

A better technique is to manually add a fixed DC offset voltage at the amplifier to compensate for the DC offset on the input signal. Offset may be applied in the amplifier in an active probe, see Figure 3.

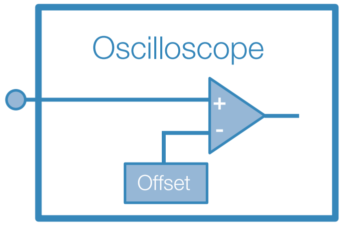

Figure 4. Adding DC Offset at the Oscilloscope Input Amplifier.

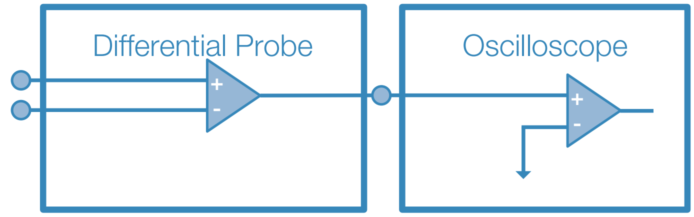

Figure 5. Differential Probing applies only AC signals to the Oscilloscope Input Amplifier.

Or it may be applied in the oscilloscope's input amplifier. Again, this works well for removing DC components from the input signal as long as the signal has not already been distorted (Figure 4).

All of the previous examples have used single-ended or ground-referenced probing. If the measurement is to be exclusively based on the AC component of the signal, a better choice may be to use a differential active probe that contains a differential amplifier which only responds to the voltage difference between its two inputs.

All of the guidance about probe specifications still applies, including maximum voltage limits. In addition, Common-mode Rejection Ratio (CMRR) is critical, as it represents the probe's ability to reject or ignore the DC component of the signal (or any signal that is common to both inputs), see Figure 5.

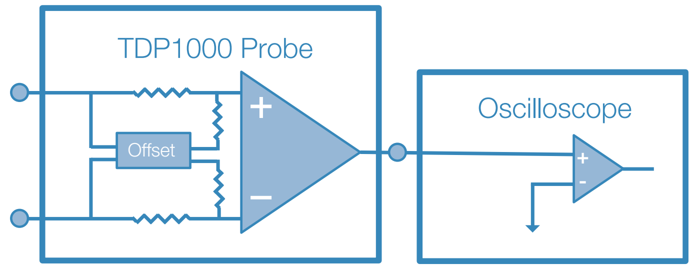

Figure 6. Automatic DC Offset Compensation in the TDP1000 Differential Probe.

Certain advanced probes, such as the Tektronix TDP1000 differential probe, build on the advantages of differential probing by replacing and improving upon the offset technique with the DC Reject mode. DC Reject automates the offset process by measuring the input signal and generating an internal offset that cancels the DC component of the signal. Because the input signal is always directly coupled to the amplifier, the DC Reject mode does not increase the common and differential mode dynamic ranges for DC components.

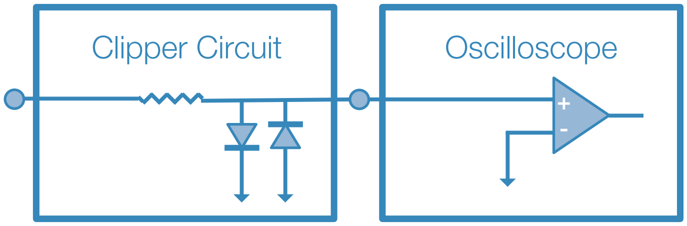

Figure 7. Simplified Clipper Circuit to Limit Input Dynamic Range.

Limiting Dynamic Range of Input Signals

Before returning to the topic of normal oscilloscope operation, it is important to consider one other alternative to making good small-signal measurements on large signals. Amplifiers in active probes and in the front ends of oscilloscopes are designed to operate in their linear range. Outside the linear range, the input signals may be distorted. (The linear dynamic range of active probes is typically specified in the data sheet. The linear range for an oscilloscope is approximately full-screen at the selected vertical scale setting.) When signals exceed the linear range, the amplifiers are over-driven and can take a significant amount of time to recover.

The key is to externally limit the signal's dynamic range, using one of the many standard signal clipping circuits found in textbooks and in industry literature. As an example, Figure 7 shows a simple diode clipping circuit that limits the signal amplitude at the oscilloscope input, enabling high-resolution measurements near ground, even when the signal's peak amplitudes are well beyond the oscilloscope's linear range.

Hardware Bandwidth Limiting

Most oscilloscopes and some advanced probes have a circuit that limits the measurement system bandwidth. By limiting the bandwidth, the noise on the waveform may be reduced, resulting in a cleaner display of the signal and more stable signal measurements. Noise approximately scales as the square root of bandwidth. A side-effect is that, while eliminating noise, the bandwidth limit can also reduce or eliminate high-frequency signal content.

Bandwidth limiting can also be implemented in software, often in combination with hardware bandwidth filtering to prevent aliasing. Software-based bandwidth limit filters can provide more filter bandwidth selections, better control of frequency and phase response, and sharper cut-off characteristics. As shown in the HiRes section below, software filtering can also substantially increase vertical resolution.

Vertical Resolution

Vertical Resolution is generally considered a measure of how precisely an Analog-to-Digital Converter (ADC) can convert input voltages into digital values. But more correctly, it is the granularity of the conversion process, and is measured in bits. For example, the vast majority of oscilloscopes are based on 8-bit-resolution ADCs, which represent samples of the input signal as one of 2^8 or 256 discrete quantization or digitizing levels.

Precision reflects the repeatability or consistency in measuring the amplitude of a signal. Ideally, the resolution of an N-bit ADC limits the measurement system's ability to discern and represent a small signal. This ability can be expressed as a signal-to-noise ratio (SNR):

$$SNR = 6.08 * N + 1.8$$

where: SNR is the signal-to-noise ratio, in dB

N is the number of bits in the digitizer

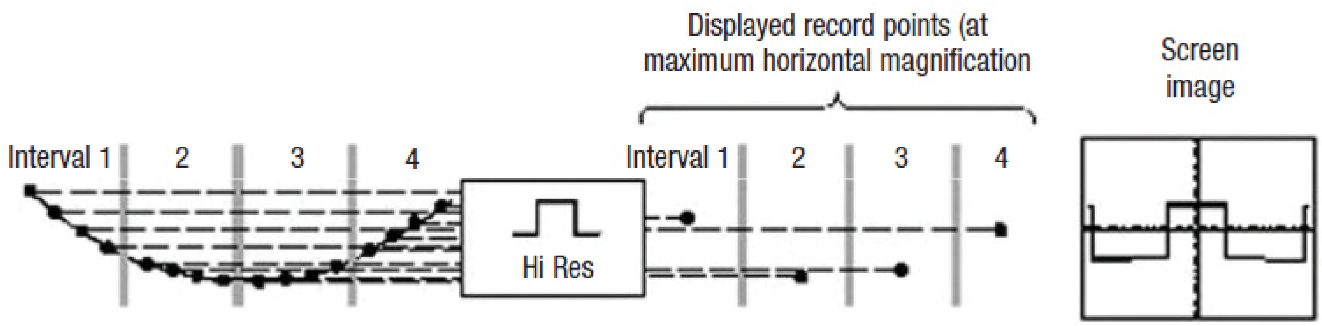

Figure 8. Sample Acquisition Mode retains one sample point from each acquisition interval

Vertical Accuracy

Before returning to the discussion of vertical resolution, it is important to contrast vertical resolution with vertical accuracy. Vertical accuracy reflects the closeness of an amplitude measurement to the signal's actual amplitude.

A few digital oscilloscopes have been built with higher-resolution ADCs. Although they are implied to be more accurate than 8-bit products, that is not necessarily true. And, in combination with available probing and signal processing, the measurement system performance should not automatically be assumed to be superior to an 8-bit-resolution system.

The other common oscilloscope specification is DC Accuracy, which is simply the accuracy with which the instrument can measure a DC value. The implication may be that an instrument with better DC Accuracy will be more accurate when measuring AC signals, but that is not necessarily true. Many other characteristics of the oscilloscopes and probes contribute to the overall accuracy.

A final and much more complex specification is Effective Number of Bits (ENOB), which is a specification of the ability of an instrument to accurately represent signals at various frequencies. ENOB is defined by the IEEE Standard for Digitizing Waveform Recorders (IEEE std. 1057). Like gain-bandwidth or Bode plots, ENOB varies with frequency, and generally decreases with frequency. This decline in digitizer performance can be described as an increased random or pseudorandom noise level on the signal. The sources of these errors include DC offset, gain error, analog nonlinearity, converter non-monotonicity and missing codes, trigger jitter, aperture uncertainty (sample time jitter), and random noise. The topic of effective bits is complex and beyond the scope of this document. For further information, please refer to the Tektronix Effective Bits Application Note 4HW-19448-XX on www.tektronix.com.

Oscilloscope Acquisition Modes

In Tektronix oscilloscopes, the term "acquisition modes" refers to the initial representation of waveform data, usually in 8- or 16-bit resolution. All subsequent processing operations (display, automated measurements, cursors, math, and applications) are based on the signal representation defined by the acquisition mode.

The default acquisition mode in most oscilloscopes is Sample Mode. This is the simplest acquisition mode, where the typical oscilloscope represents each point on the waveform with an 8-bit magnitude value, at the selected sample rate, up to the maximum sample rate, see Figure 8.

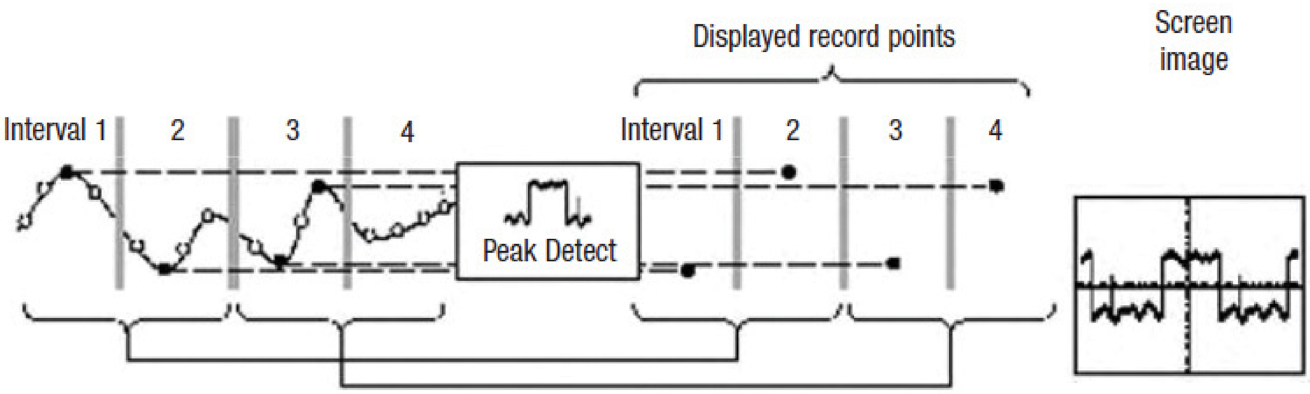

Figure 9. Peak Detect Acquisition Mode captures the highest and lowest values contained in two consecutive acquisition intervals.

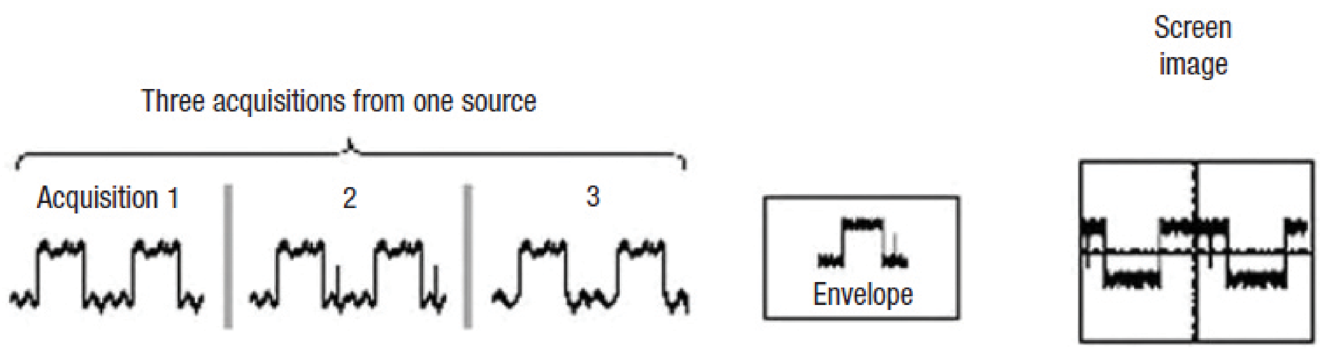

Figure 10. Envelope Acquisition Mode captures the highest and lowest record points over many acquisitions.

In Peak Detect mode, the oscilloscope represents each point on the waveform with a pair of 8-bit magnitude values corresponding to the maximum and minimum values of the waveform during the selected pair of sample intervals. Digital oscilloscopes with Peak Detect mode typically sample the signal at the maximum sample rate, even at very slow horizontal scale settings, and therefore can capture fast signal changes that would occur between points at the selected sample rate. In this way, Peak Detect mode is especially useful for seeing narrow pulses spaced far apart in time, such as glitches on a low-frequency signal, see Figure 9.

Envelope Mode is similar to Peak Detect mode, but accumulates the pairs of maximum and minimum waveform points from multiple acquisitions to form a waveform that shows min/max accumulation over time. Peak Detect mode may be used to acquire the values that are combined to form the envelope waveform, see Figure 10.

For the purposes of measuring low-voltage signals, there are other oscilloscope acquisition modes which should be considered. Two of the most useful techniques are discussed in more detail below; averaging and HiRes. (For additional technical information on oscilloscopes, please refer to the Tektronix XYZs of Oscilloscopes Primer 03W-8605-XX on www.tektronix.com.)

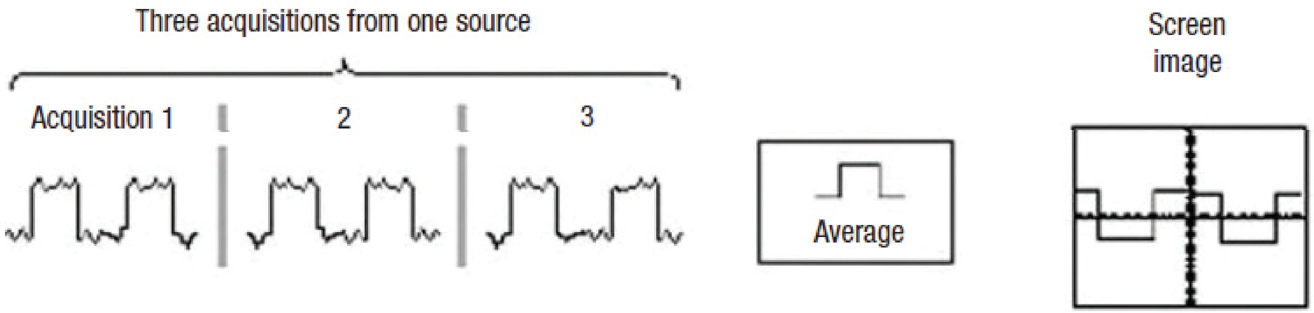

Figure 11. Average Acquisition Mode calculates the average value for each record point over many acquisitions.

Averaging

Average mode is one of the basic noise-reduction signal processing techniques in an oscilloscope's acquisition system. It relies upon multiple triggered acquisitions of a repetitive signal. Using the data from two or more acquisitions, this mode averages the corresponding data points in these acquisitions on a point-by-point basis to form the output waveform. Average mode improves the signal-to-noise ratio, removes noise that is uncorrelated to the trigger, increases the vertical resolution, and makes viewing of repetitive signals easier, see Figure 11.

The conventional method of computing an average waveform is to simply sum corresponding samples from all acquisitions and divide by the number of acquisitions. However, this method would wait until all of the N desired waveforms have been acquired before displaying the average. This delay would be unacceptable to most users, and the volume of acquisition data would quickly overwhelm the oscilloscope's memory capacity.

$$A_N = (1 / N) * (x_0 + x_1 + x_2 + \dots + x_{n-1})$$

where: A_N is a point in the averaged acquisition
N represents the total number of averages requested
x_n is a point in acquisition **n**
n represents the acquisition number

The conventional average algorithm can be modified to display intermediate results each time another waveform is acquired, addressing the delay in displaying the averaged waveform. However, the storage issue for the data remains. The stable averaging algorithm is:

$$a_n = (1 / n) * (x_0 + x_1 + x_2 + \dots + x_{n-1})$$

where: a_n is a point in the current averaged acquisition
x_n is a point in the new acquisition **n**
n represents the acquisition number

Note that, to get a summation average of exactly N acquisitions, simply put the oscilloscope into Single Sequence mode. In this mode, when n reaches N, acquisitions stop and the averaged waveform contains exactly N acquired waveforms.

Tektronix oscilloscopes use an exponential average algorithm, which allows the intermediate results to be updated on the display with each acquisition, and significantly reduces the required storage. The exponential averaging process uses the following equation to create a newly averaged waveform $\mathbf{a_n}$ from a new acquisition $\mathbf{x_n}$ and the previous average waveform $\mathbf{a_{n-1}}$:

$$a_n = a_{n-1} + (1/p)*(x_n - a_{n-1}) = a_{n-1} * ((p - 1) / p) + (x_n / p)$$

where: **n** represents the acquisition number
N represents the total number of averages requested
$\mathbf{a_n}$ is the new point in the averaged acquisition
$\mathbf{a_{n-1}}$ is a point in the past averaged acquisition
$\mathbf{x_n}$ is a point in the new acquisition
p is the weighting factor
If (**n<N**) then **p = n** else **p = N**

The resulting averaged waveform is the same, independent of which of these averaging algorithms is used. But consider how much more efficient the exponential average algorithm is for both computation and storage of the acquired and averaged waveforms.

Some oscilloscopes combine the two previous techniques to calculate the average. The first acquisition is displayed, stable averaging is used for the next N-1 acquisitions, and exponential averaging is used after N acquisitions.

Both algorithms readily display the effect of consistent trends in the waveform. You can easily see this with a slow signal. If the signal is stable, you will see a successive reduction of noise during the first N acquisitions. After N acquisitions, the signal will still change, but there will no longer be an improvement in overall noise reduction or vertical resolution.

Averaging increases the vertical resolution of the signal. This enhancement, measured in bits, is a function of the total number of averages:

$$\textbf{Enhanced resolution} = 0.5 \log_2(N)$$

where: **N** represents the total number of averages requested

Table 1 shows the ideal resolution enhancement available from waveform averaging.

Number of Averages	Enhanced Resolution (bits)	Total Vertical Resolution (bits)
1	0.0	8.0
2	0.5	8.5
4	1.0	9.0
8	1.5	9.5
16	2.0	10.0
32	2.5	10.5
64	3.0	11.0
128	3.5	11.5
256	4.0	12.0
512	4.5	12.5
1024	5.0	13.0
2048	5.5	13.5
4096	6.0	14.0
8192	6.5	14.5
10000	6.64	14.64

Table 1. Enhanced vertical resolution due to averaging.

Again, the values in Table 1 are ideal. In many Tektronix oscilloscopes, the averaging algorithm is implemented with fixed-point math. The maximum number of averages is 10,000, which limits the total bits of resolution to an ideal maximum value of 14.64. In practice, the fixed-point math, noise, and jitter errors reduce the maximum resolution to somewhat less.

Ideally, waveform averaging maintains the full analog bandwidth of the signals – a substantial advantage over some other signal processing techniques. However, sample mode acquisitions are not dejittered. That is, the timing of the waveform samples is not aligned with the trigger. In fact, the relative positions (which is the definition of jitter) can be off by 1 sample interval. When the frequency is equal to half of the sample rate, this is a 180 degree phase error. The peak value of the average of such a signal is 0.637 of the signal amplitude, or -3.9 dB. The amplitude error due to jitter can be minimized by significantly oversampling the signal.

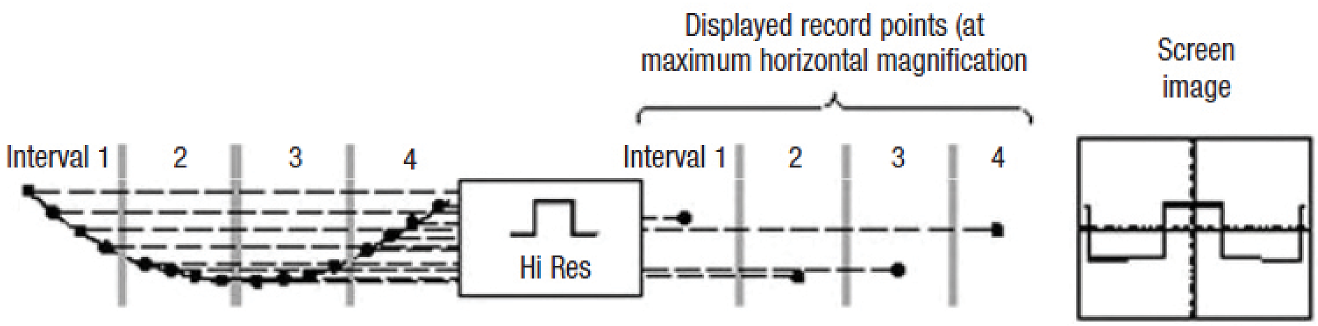

Figure 12. HiRes Acquisition Mode calculates the average of all the samples for each acquisition interval.

HiRes Acquisition Mode

HiRes mode is a Tektronix-patented acquisition process that calculates and displays the average of all sequential sample values in each sample interval. Like Peak Detect mode, HiRes mode provides a method for trading off over-sampling for additional information about the waveform. In the case of HiRes mode, the additional horizontal sampling information is traded off to provide greater vertical resolution and a reduction of bandwidth and noise. One key advantage of HiRes mode over Average is that HiRes mode can be used even on single-shot acquisitions.

The bandwidth limiting and the increase in vertical resolution due to HiRes vary with the maximum sample rate and the actual (selected) sample rate of the instrument. The actual sample rate is typically displayed near the bottom of the screen, and the maximum sample rate can be found in the product data sheet. The increase in bits of vertical resolution is:

$$0.5 * \log_2(D)$$

where: **D** is the decimation ratio, or the maximum sample rate / actual sample rate

The resulting -3 dB bandwidth (unless further limited by the measurement system's analog bandwidth) is:

$$0.44 * SR$$

where: **SR** is the actual sample rate

Sample Rate	Averages	Bits of Resolution	-3 dB Bandwidth
6.25 GS/s	1	8.0	2.75 GHz
3.125 GS/s	2	8.5	1.38 GHz
1.25 GS/s	5	9.2	550 MHz
625 MS/s	10	9.7	275 MHz
250 MS/s	25	10.3	110 MHz
125 MS/s	50	10.8	55 MHz
62.5 MS/s	100	11.3	27.5 MHz
25 MS/s	250	12.0	11 MHz
12.5 MS/s	500	12.5	5.5 MHz
5 MS/s	1,250	13.1	2.2 MHz
2.5 MS/s	2,500	13.6	1.1 MHz
1 MS/s	6,250	14.3	440 kHz
500 kS/s	12,500	14.8	220 kHz
250 kS/s	25,000	>15	110 kHz
100 kS/s	62,500	>15	44 kHz
50 kS/s	125,000	>15	22 kHz
25 kS/s	250,000	>15	11 kHz
10 kS/s	625,000	>15	4.4 kHz
5 kS/s	1,250,000	>15	2.2 kHz
2.5 kS/s	2,500,000	>15	1.1 kHz
1 kS/s	6,250,000	>15	440 Hz

Table 2. Enhanced vertical resolution due to HiRes with a 6.25 GS/s oscilloscope.

Sample Rate	Averages	Bits of Resolution	-3 dB Bandwidth
5 GS/s	1	8.0	2.2 GHz
2.5 GS/s	2	8.5	1.1 GHz
1 GS/s	5	9.2	440 MHz
500 MS/s	10	9.7	220 MHz
250 MS/s	20	10.2	110 MHz
100 MS/s	50	10.8	44 MHz
50 MS/s	100	11.3	22 MHz
25 MS/s	200	11.8	11 MHz
10 MS/s	500	12.5	4.4 MHz
5 MS/s	1,000	13.0	2.2 MHz
2.5 MS/s	2,000	13.5	1.1 MHz
1 MS/s	5,000	14.1	440 kHz
500 kS/s	10,000	14.6	220 kHz
250 kS/s	20,000	>15	110 kHz
100 kS/s	50,000	>15	44 kHz
50 kS/s	100,000	>15	22 kHz
25 kS/s	200,000	>15	11 kHz
10 kS/s	500,000	>15	4.4 kHz
5 kS/s	1,000,000	>15	2.2 kHz
2.5 kS/s	2,000,000	>15	1.1 kHz
1 kS/s	5,000,000	>15	440 Hz

Table 3. Enhanced vertical resolution due to HiRes with a 5 GS/s oscilloscope.

For an oscilloscope with a maximum non-interleaved sample rate of 6.25 GS/s, HiRes provides the following performance (see Table 2).

For an oscilloscope with a maximum non-interleaved sample rate of 5 GS/s, HiRes provides the following performance (see Table 3).

As with averaging, the values in Tables 2 and 3 are ideal. In many Tektronix oscilloscopes, the averaging algorithm is implemented with fixed-point math, yielding the maximum resolution value of approximately 16 bits. The observed improvement in resolution may be somewhat less and does vary by application, but this signal processing technique can be extremely valuable for a number of applications.

The examples on the following pages demonstrate the technique.

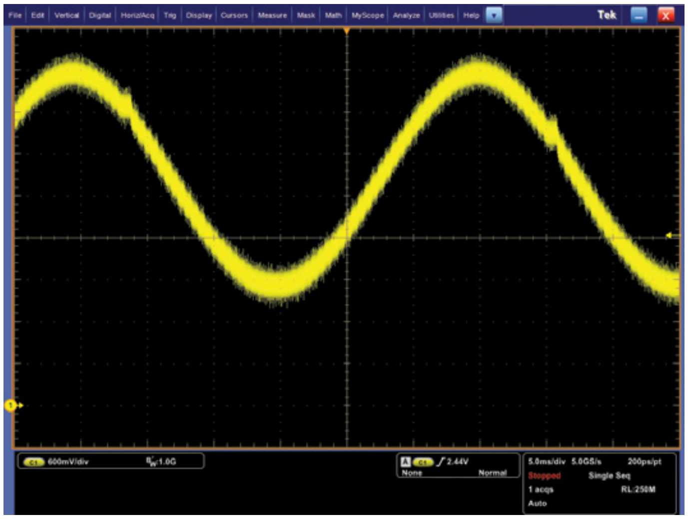

Figure 13. Sample Acquisition Mode shows the DAC output sine wave, with random noise and an uncorrelated signal step.

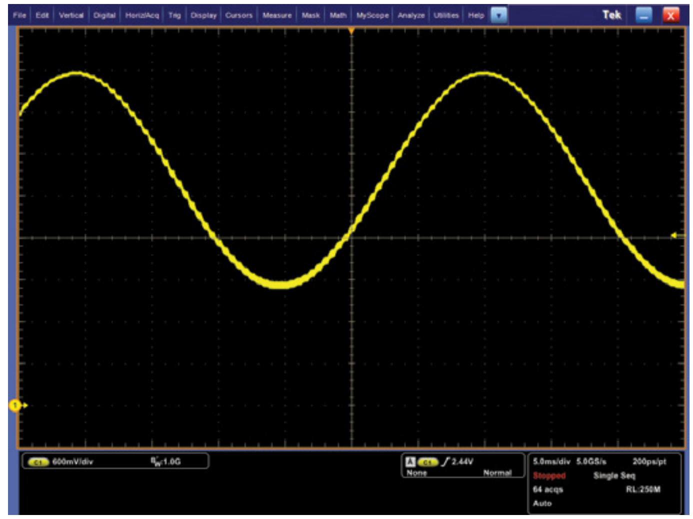

Figure 14. 64-waveform Average Acquisition Mode effectively attenuates random noise, and also the uncorrelated signal step.

Verifying DAC Output Signals

The first application is monitoring signal quality at the output of a Digital to Analog Converter (DAC). As shown in Figure 13, the low-frequency sine wave has considerable higher-frequency random noise riding on it, as well as some type of a step signal. On a live display it is more obvious, but the frequency of the step signal is not the same as the sine wave frequency.

Because the DAC has no low-pass reconstruction filter on its output, the signal is expected to show discrete voltage steps. However, these steps are obscured by the noise on the signal.

Figure 14 shows the results of averaging 64 waveforms, a very time-consuming process with very long records. As expected, the random noise is significantly attenuated and the DAC's discrete voltage steps begin to become visible. And, since the sample rate is extremely high, the full measurement bandwidth is preserved. But, because the step signal is uncorrelated to the trigger signal, averaging also removes the step signal from the averaged display.

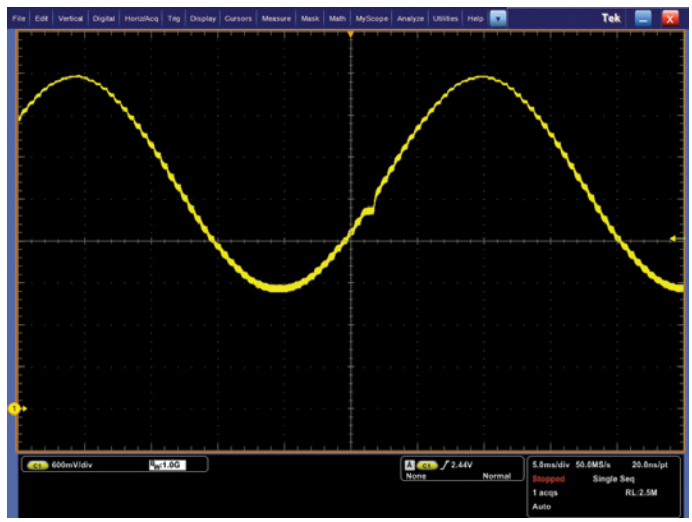

Figure 15. Single-shot HiRes Acquisition Mode also effectively attenuates random noise, but preserves the signal step.

Figure 15 shows similar noise-reduction results with a single-shot HiRes acquisition. However, since this is a single-shot processing technique, the low-frequency step signal is preserved. And, with the use of HiRes Acquisition Mode, vertical resolution has been increased to over 11 bits, and the measurement bandwidth has been reduced to about 22 MHz.

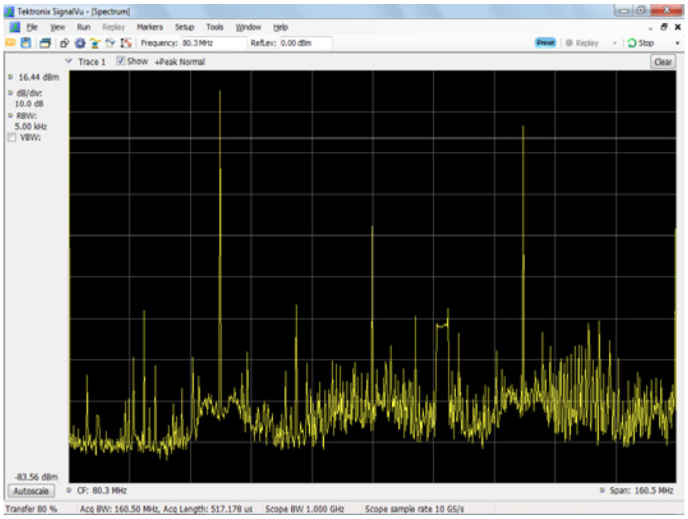

Figure 16. Spectrum of a 40 MHz digital clock in sample mode, where random baseline noise and other signals complicate the display.

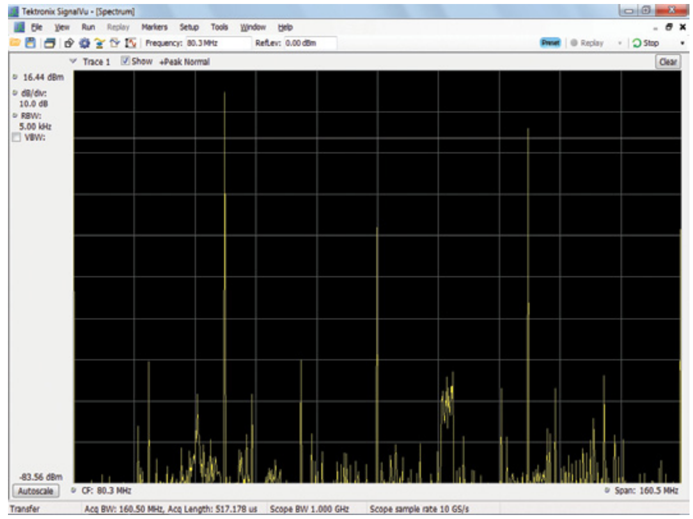

Figure 17. Spectrum of a 40 MHz digital clock based on an average of 64 waveforms, showing the harmonics much more clearly.

Measuring 40 MHz Clock Spectrum

The second application is spectrum analysis of a 40 MHz digital clock. Digital signals transmit most of their information in the time-placement of the edges of the signal (measured where they cross a threshold) rather than signal amplitude. Waveform Averaging is very effective at removing random noise from continuous signals like this.

Spectral analysis, partly due to its logarithmic vertical scale, provides a very sensitive measurement of the noise reduction caused by averaging. Notice that the vertical scales in Figures 16 and 17 are 10 dB/div.

In Figure 17, you can see that the magnitudes of the fundamental and odd harmonics remain fairly constant, but the averaging lowers the baseline noise 10-20 dB, and also lowers many of the other components, making it easier to identify the clock's harmonics and other interfering signals.

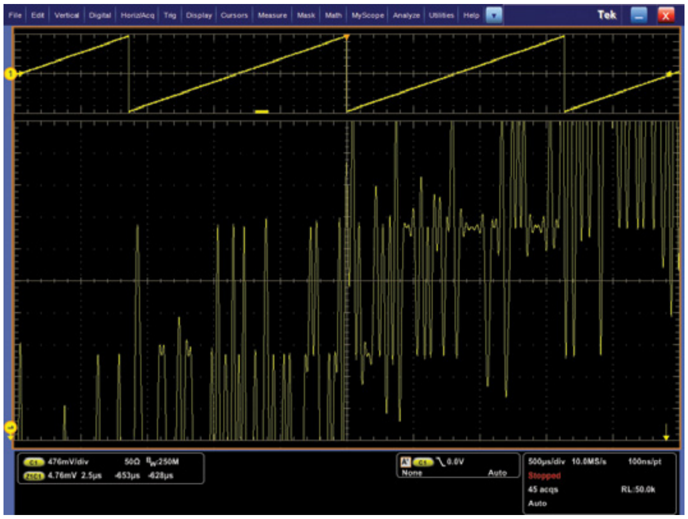

Figure 18. Zoomed display of a high-resolution digital ramp signal, showing digitizing noise due to limited resolution in the 8-bit ADC.

Figure 19. Zoomed display of the same high-resolution ramp signal, based on a large number of averages, showing significantly higher vertical resolution.

Verifying DAC Resolution

The third example is a method to illustrate the actual vertical resolution improvement using a high-resolution DAC, or, in this case, a high-resolution AWG7000 Arbitrary Waveform Generator. Figure 18 shows a zoomed display of a ramp signal with 10 bits of vertical resolution. Although discrete 8-bit steps can be seen in the lower section of the display, there is sufficient noise on the signal to cause occasional ±1 bit errors. At this 8-bit resolution, those errors are significantly larger than the 10-bit steps on the ramp signal.

Figure 19 shows the dramatic improvement possible with waveform averaging. In this case, the individual 10-bit steps clearly emerge from the digitizing noise, demonstrating the ability of an 8-bit ADC to provide at least 10 bits of vertical resolution with the help of signal processing such as waveform averaging.

Conclusions

This technical brief has described some of the basic measurement and signal-processing techniques used for high-resolution waveform acquisition in Tektronix digital oscilloscopes and shown the benefits with a few simple examples. Knowledge of these benefits and trade-offs will make it easier to choose and successfully apply Tektronix oscilloscopes and probing solutions to make better high-resolution measurements.

Contact Tektronix:

ASEAN / Australasia (65) 6356 3900
Austria* 00800 2255 4835
Balkans, Israel, South Africa and other ISE Countries +41 52 675 3777
Belgium* 00800 2255 4835
Brazil +55 (11) 3759 7627
Canada 1 (800) 833-9200
Central East Europe and the Baltics +41 52 675 3777
Central Europe & Greece +41 52 675 3777
Denmark +45 80 88 1401
Finland +41 52 675 3777
France* 00800 2255 4835
Germany* 00800 2255 4835
Hong Kong 400-820-5835
India 000-800-650-1835
Italy* 00800 2255 4835
Japan 81 (3) 6714-3010
Luxembourg +41 52 675 3777
Mexico, Central/South America & Caribbean 52 (55) 56 04 50 90
Middle East, Asia and North Africa +41 52 675 3777
The Netherlands* 00800 2255 4835
Norway 800 16098
People's Republic of China 400-820-5835
Poland +41 52 675 3777
Portugal 80 08 12370
Republic of Korea 001-800-8255-2835
Russia & CIS +7 (495) 7484900
South Africa +27 11 206 8360
Spain* 00800 2255 4835
Sweden* 00800 2255 4835
Switzerland* 00800 2255 4835
Taiwan 886 (2) 2722-9622
United Kingdom & Ireland* 00800 2255 4835
USA 1 (800) 833-9200

*** If the European phone number above is not accessible, please call +41 52 675 3777**

Contact List Updated 10 February 2011

For Further Information
Tektronix maintains a comprehensive, constantly expanding collection of application notes, technical briefs and other resources to help engineers working on the cutting edge of technology. Please visit **www.tektronix.com**

03/13 EA/WWW 48W-27802-1