Understanding Key High-Performance Oscilloscope Specifications

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Understanding Key High-Performance Oscilloscope Specifications

Choosing an oscilloscope is a decision that can impact the efficiency of your work and the validity of your measurements. “Understanding Key High-Performance Oscilloscope Specifications” explains the most important oscilloscope performance characteristics and how they can affect your application. Although the emphasis here is on high-performance instruments, the same kinds of specifications define the performance of all oscilloscopes.

Contents

Introduction

The oscilloscope has been an indispensable tool in research and design for decades, enabling a steady stream of innovations in computers, communications technologies, video systems, semiconductor devices, and more.

High-performance oscilloscopes answer the engineering and scientific community's requirement for an instrument that can capture the most challenging signals in great detail, with accuracy and repeatability. Whether you are an engineer designing a high-speed digital network element, or a researcher measuring transient physical events, you count on your oscilloscope to tell you the truth about the characteristics of your signals.

Many aspects of oscilloscope performance are summarized in specifications verified with rigorously defined procedures. The pragmatic oscilloscope buyer chooses a solution based on published specifications that describe the instrument's bandwidth, sample rate, measurement accuracy, and many other parameters, as well as the conditions under which these specifications apply. In general, specifications are either:

- Performance figures obtained by following industry-standard procedures and definitions, such as those defined in the IEEE Standard for Digitizing Waveform Recorders, IEEE Std 1057-1994. (IEEE 1057 also provides test methods for verifying published specifications.)

or

- Manufacturers' performance figures that are repeatable and relevant to real-world applications, such as waveform capture rate.

Published specifications may appear in data sheets, user manuals, service manuals, Web sites, and to some extent, marketing literature such as brochures. It is common practice to include only a brief summary of specifications in most marketing literature. For details, you may need to refer to the instrument manual. [1]

When evaluating an oscilloscope for purchase, be sure to check for specifications that are relevant to your application. Likewise, while "banner specifications" are often used to classify and promote oscilloscopes, it is essential to look beyond these specifications to others that may affect the oscilloscope's usefulness.

High-Performance Oscilloscopes Answer Wide-Ranging Measurement Challenges

A high-performance oscilloscope should be judged on its ability to meet or exceed current-day measurement requirements, and its flexibility to address emerging needs.

Digital signal integrity measurements are some of the most challenging demands on a digital oscilloscope today. These require the instrument to detect transients, capture fast-rising edges faithfully, and characterize timing interactions and jitter. Signal integrity measurements are of interest to designers developing fast serial buses, LAN/WAN devices, communications network elements, digital video subsystems, and components including processors and memory devices.

In addition to signal integrity issues, today's designer must confront analog/digital interactions, noise and EMI problems, crosstalk, embedded clock signals, and more. The oscilloscope's performance in areas such as bandwidth, sample rate, triggering, and measurement accuracy determines its effectiveness in solving high-speed system design problems.

Digital Oscilloscope Overview

Modern digital oscilloscopes fall into one of three classes: digital storage oscilloscopes (DSO), digital phosphor oscilloscopes (DPO), and sampling oscilloscopes. All three have vertical, horizontal, acquisition, and triggering systems.

The vertical system is the entry point for the signals coming from the probe. It optimizes the amplitude of the incoming signal to the voltage range of the subsequent circuits, particularly the analog-to-digital converter (ADC). It should introduce no changes to the signal other than deliberate amplitude and offset adjustments.

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1 Many Tektronix oscilloscope manuals can be downloaded in an unabridged, printable format from: www.tektronix.com

The acquisition system encompasses the timebase (or horizontal) elements plus the actual digitizing and storage elements. It samples the signal voltage, acquiring numerous data points to display it. In a digital oscilloscope, the horizontal system contains the sample clock, which gives each voltage sample a precise time (horizontal) coordinate. The sample clock drives an analog-to-digital converter (ADC) whose output is stored in the acquisition memory. The capacity of this memory is known as the record length. Tremendous advancements in acquisition subsystem architecture have been made in the past few years, including breakthroughs such as DPX™ acquisition technology used in digital phosphor oscilloscopes.

The trigger system detects a user-specified condition in the incoming signal stream and applies it as a time reference in the waveform record. The event that met the trigger criteria is displayed, as is the waveform data preceding or following the event. In each case, the trigger event's position in time can be observed. The trigger system ensures that a stable, consistent waveform will be displayed on the screen. The trigger system looks for voltage thresholds, pulse widths, logic combinations (on multiple inputs), and many other conditions to qualify an acquisition.

Vertical System

The oscilloscope's vertical system is essentially an instrumentation-quality analog voltage amplifier/attenuator. The key vertical system specifications are:

- Bandwidth/rise time
- Vertical (DC) gain accuracy
- Offset accuracy
- Resolution
- Dynamic range

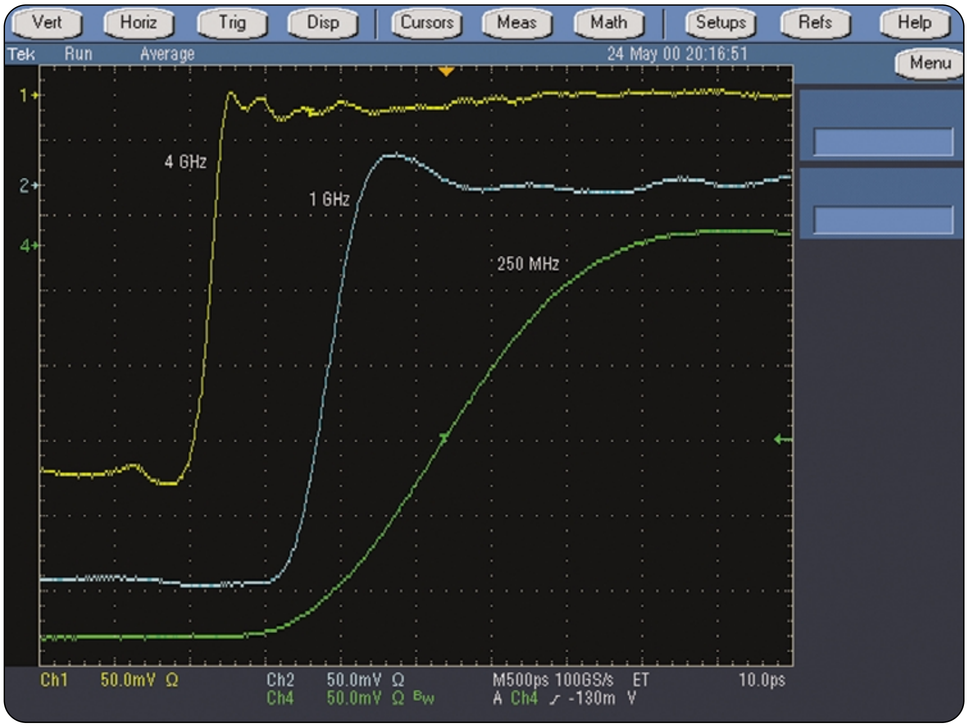


Figure 1. The higher the bandwidth, the more accurate the reproduction of your signal, as illustrated with a signal captured at 250 MHz, 1 GHz, and 4 GHz bandwidth levels.

Bandwidth/Rise Time

Bandwidth determines an oscilloscope's fundamental ability to measure a signal. As signal frequency increases, the capability of the oscilloscope to accurately display the signal decreases. This specification indicates the frequency range that the oscilloscope can accurately measure.

IEEE 1057 defines electrical bandwidth as the point at which the amplitude of a sine wave input is reduced by 3 dB (approximately 30%) relative to its level at a lower reference frequency. In other words, bandwidth is specified at the frequency at which a sinusoidal input signal is attenuated to 70.7% of the signal's true amplitude. Bandwidth is usually specified as follows:

> **Analog Bandwidth (–3 dB):** 6 GHz
> (from TDS6604 data sheet)

The optical bandwidth of a device or system is defined as the frequency at which the power out of the same device or system is one half as compared with a frequency near DC. The optical bandwidth, therefore, corresponds to the traditional electrical bandwidth of –6 dB. Examples of optical bandwidth specifications for both real-time and sampling oscilloscopes follow:

> **Analog Bandwidth (–3 dB):** 4 GHz
> **Optical Channel Unfiltered Bandwidth:** 2.4 GHz
> (from CSA7404 data sheet)

> **Minimum Optical Bandwidth:** >50 GHz
> (from CSA8000/80C06 optical sampling module data sheets)

Without adequate bandwidth, your oscilloscope will not be able to resolve high-frequency changes. To calculate the oscilloscope bandwidth needed for your application, simply multiply the highest-frequency component of the signals you will be working with by a factor of five. For example, if your bus frequency is in the 800 MHz range, you may need an instrument with 4 GHz bandwidth or higher. This "5 times rule" will give you less than ±2% error in your measurements – typically sufficient for today's applications. However, as signal speeds increase, it may not be possible to achieve this rule of thumb. Always keep in mind that higher bandwidth will likely provide more accurate reproduction of your signal, as shown in Figure 1.

The vertical system's rise time (or step response) goes hand in hand with its bandwidth. High-bandwidth oscilloscopes have fast rise times, as Figure 1 shows. Fast rise time performance ensures accurate measurements on the fast edges of today's high-speed busses.

Vertical rise time affects not only amplitude accuracy, but also time measurement accuracy. The edge rate (rise time) of the signal to be measured may mandate a faster oscilloscope than the signal's repetition rate might imply, because slow signals can have fast edges. Following is an example of a rise time specification:

Rise Time (typical): 70 ps
(from TDS6604 data sheet)

Bandwidth / rise time relationship

Historically, oscilloscope frequency response tended to approximately follow the rule: Bandwidth x risetime = 0.35. This corresponds to a 1- or 2-pole filter roll-off in the frequency domain. Today, at the high end, most real-time digital oscilloscopes more closely follow this rule: Bandwidth x rise time = 0.45. This corresponds to a much steeper frequency roll-off above the specified bandwidth. The steeper roll-off is more desirable in digital oscilloscopes that oversample by 4x, 3x, or even less because it prevents aliasing by eliminating any signal above the Nyquist frequency (1/2 the sample rate – the minimum sample rate required for accurate signal representation).

Vertical (DC) Gain and Offset Accuracy

Vertical (DC) gain accuracy is important in any measurement of voltage between two levels on a waveform, regardless of offset, ground reference, etc.

Many times, DC gain accuracy specifications are expressed as a percentage of full scale at the current attenuator setting. Yet most amplitude readings are made at something less than full scale. If for example, the accuracy specification is 2% of an eight-division scale and the signal occupies only four divisions, then the true accuracy of the measurement is 4%. When the instrument is specified in "full-scale" terms, the accuracy of the reading varies with the signal amplitude. In other words, when DC gain accuracy is specified at full scale, a smaller signal will have a larger possible error (than the specification).

Therefore, if you are making frequent amplitude measurements, DC gain accuracy specified as a percentage of the reading itself is the most reliable indicator of performance. For example, the following vertical gain accuracy specification is 2.5% of the reading:

DC Gain Accuracy: 2.5%
(from TDS6604 data sheet)

DC gain accuracy applies to dual-value voltage measurements such as peak-to-peak voltage, in which the measurement is the difference between the voltages at two points on the same waveform.

Offset is the voltage difference between the centerline of the oscilloscope screen and actual ground. This difference is generated by an internal offset voltage source whose degree of precision determines the offset accuracy. Following is the specification format:

Offset Accuracy, 2 mV/div to 9.95 mV/div:
±(0.2% x [net offset] + 1.5 mV + 0.1 div x Volts/div setting), where [net offset] = offset – (position x Volts/div)

Note that this specification applies to one of three possible scale ranges; each range has its own specification.

Vertical Position is a subset of offset, which explains its presence in the formula above. The Position control moves the vertical position of the ground reference. Offset adds a precision offset voltage to the ground reference without moving the reference on screen. An oscilloscope that offers both position and offset provides more flexibility when positioning dynamic waveforms under varying offset conditions.

Offset is important because it is a factor in voltage measurements such as Peak, Mean, Max, Min, and other measurements that use ground as a reference. Offset can be used to make precision single-valued voltage measurements such as these by matching the offset to the measurement, aligning the voltage to be measured to the reference mark.

Where measurement margins are critical, as in production testing, higher accuracy in amplitude measurements permits narrower guardbands. This improves yield by reducing false rejects. In design engineering, higher measurement accuracy means more reliable characterization, and can also help identify logic levels that "almost" cross their switching threshold.

Resolution and Dynamic Range

Resolution and dynamic range determine, respectively, the "granularity" of measurements and the largest measurement that can be made without clipping the waveform. Most digital oscilloscopes have 8-bit resolution. Eight bits provides 256 digitizing levels (2 to the 8th power) over the dynamic range. Tektronix instruments provide 10.24 divisions of dynamic range. This ensures that clipping will not occur for more than one division below the bottom and one division above the top of the display. Most Tektronix digital oscilloscopes also have a Hi-Resolution acquisition mode [2] that provides more than 8 bits of vertical resolution.

[2] See ***Appendix 1: Acquisition Modes***.

Horizontal (Timebase) System

The oscilloscope's horizontal system contains the sample clock. Its frequency limits, precision, and accuracy are the foundation of all timing measurements with the instrument. The key specifications for the horizontal system are:

- Sample rate and sample rate accuracy
- Delta-time measurement accuracy

Sample Rate And Sample Rate Accuracy

Each pulse of the sampling clock creates a data point that defines the incoming signal's voltage at that instant in time. To accurately reconstruct a waveform, the oscilloscope must sample at a minimum of twice the rate of the highest frequency component in the waveform. Today's high-performance oscilloscopes typically sample at 3 to 5 times their maximum bandwidth, and sometimes more.

The accuracy of the sample clock is important because all measurements – from simple amplitude readings to complex histograms and delay measurements – assume the sampled points are a fixed distance (time) apart. The interpolation and the resulting waveform reconstruction and/or analysis both depend on uniform time intervals between sample points.

The long-term sample rate accuracy of many modern high-performance oscilloscopes typically falls in the ±2.5 parts per million (PPM) range. The long-term sample rate and delay time accuracy specification shown below (±2.5 ppm over ≥100 ms interval) indicates overall sample rate accuracy. This means that time measurements will be accurate to within 2.5 PPM, even over intervals of 100 ms or longer. This is more than sufficient for timing measurements in long records, or time measurements using long delay times, such as propagation delay measurements over long data transmission paths, timing in mechanical systems, low-frequency "wander" in telecommunications data signals, or capturing "frames" of data.

Long Term Sample Rate and Delay Time Accuracy:
±2.5 ppm over ≥100 ms interval
(from TDS6604 data sheet)

Delta-time Measurement Accuracy

Emerging standards such as PCI-Express (3GIO), HyperTransport and InfiniBand operate at extreme clock speeds and minimal timing margins. Accurate time interval (delta-time) measurements (see Figure 2) are critical when characterizing setup and hold time, skew, and jitter at the high frequencies/data rates common to these technologies.

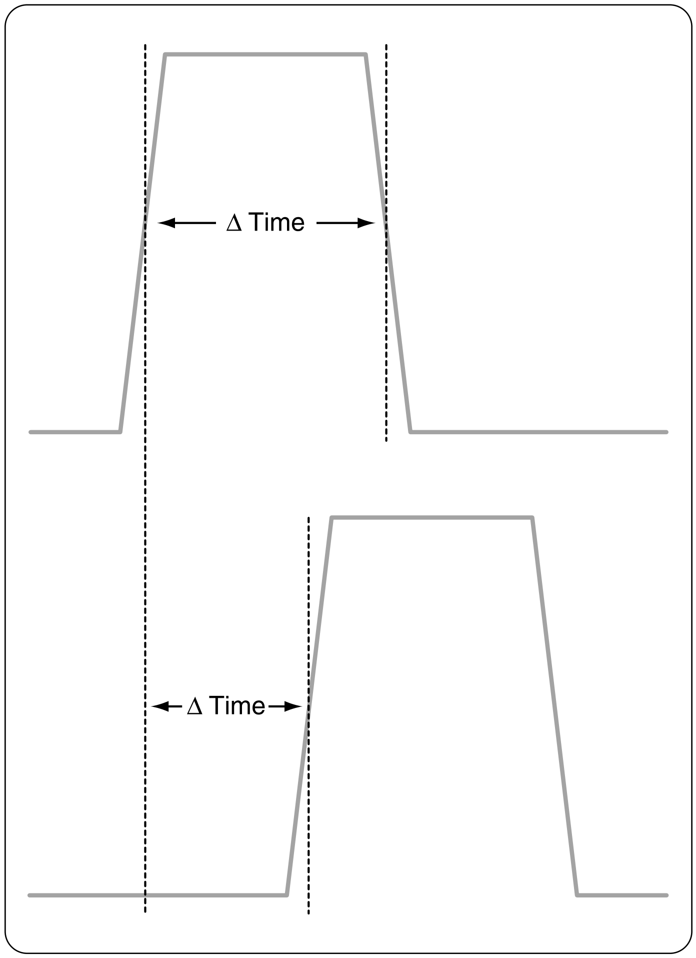


Figure 2. *Delta-time refers to the difference in time between two events: two points on a single waveform (as in a pulse width measurement), or the time between points on two different waveforms (as in setup and hold measurements).*

Delta-time accuracy is the most important specification for single-shot timing measurements because it specifies a timing measurement's worst-case deviation from the actual value. It is based upon factors that include timebase accuracy, sample interval, and the aggregate performance of the entire digitizing system. It takes into account both repeatability and resolution specifications and includes effects from both the horizontal and vertical systems.

Following is an example of what you can expect to see in a typical delta-time specification:

> **Δ Time Measurement Accuracy:**
> (0.06/sample rate) + (2.5 ppm * reading) RMS
> (from TDS6604 data sheet)

The first term in this expression, 0.06/sample rate, pertains to how accurately the acquisition system estimates the signal's activity between sample points. This is a major factor in delta-time accuracy because the term incorporates several error contributors into one figure:

- Vertical errors
  - Vertical Noise
  - Non-Linearity
  - Digitizing errors (pattern error, bit error)
- Horizontal errors, such as:
  - Interleaving errors
  - Aperture uncertainty (sample time jitter)
- Software error, including:
  - Interpolation uncertainty
  - Round-off errors

The delta-time accuracy specification gives you the formula to calculate the error on a measurement. For example, suppose you are measuring the skew on a device, with a measured skew of 100 ps:

$$\pm\left[\left(\frac{0.06}{20\ \text{GS/s}}\right) + (2.5\ \text{ppm x } 100\ \text{ps})\right] = 3\ \text{ps} + 0.25\ \text{fs} = \pm 3.00025\ \text{ps}$$

In this example, the error margin is ±3.00025 ps (3%). The actual skew will be between 96.99975 ps and 103.00025 ps.

The second term in the delta-time accuracy specification is timebase stability, also known as timebase accuracy. It's based on the long term stability of the sample rate clock. Of the two terms that make up the delta-time measurement accuracy specification, the acquisition system component is by far the most important when making measurements on high-speed signals. The effect of the timebase accuracy term almost disappears. In the example above, it adds less than a femtosecond (1 x 10^{-15} second) of error to a measurement in the 100 ps range. Only when measuring very long durations does the timing accuracy term have much effect. On durations longer than approximately 1 µs (with an oscilloscope operating at 20 GS/s sample rate), timebase stability becomes the dominant error contributor.

A clear and comprehensive delta-time measurement accuracy specification is an important way to distinguish between oscilloscopes with similar bandwidth and sample rate specifications.

Acquisition System

The acquisition system works hand-in-hand with the timebase clock. Acquisition elements include the analog-to-digital converter (ADC), acquisition memory, and other components such as the buffer memory in addition to proprietary innovations such as Tektronix digital phosphor oscilloscope technology.

The key specifications for the acquisition system include:

- Record length
- Waveform capture rate
- Acquisition modes [3]

Record Length

The amount of the acquisition memory determines the oscilloscope's maximum record length and time duration you can acquire at any given sample rate setting. The concept is best explained by a simple formula:

$$\text{Duration} = \frac{\text{Record Length}}{\text{Sample Rate}}$$

For example, a DSO set to a 10 GS/s sample rate and with a 32 megabyte acquisition memory can store 3.2 milliseconds' worth of samples.

A few applications require single-shot capture of very long, continuous records. These include disk-drive read channel measurements which must capture an uninterrupted "track" of disk data in its entirety and some telecommunications signal measurements which must capture entire data packets for analysis.

However, most high-speed edge and timing interval measurements such as setup and hold times require just a few nanoseconds of record length. In these cases, the instrument's sample rate and delta-time accuracy are most important. Moreover, record length is not the best tool for troubleshooting intermittent events, as the following ***Waveform Capture Rate*** summary explains.

Waveform Capture Rate

For any oscilloscope, there is always a hold-off time during which the instrument processes the most recently acquired data, resets the system, and waits for the next trigger event. During this time, the oscilloscope is blind to all signal activity. The probability of seeing an infrequent or low rep-rate event decreases as the hold-off time increases:

$$\text{Probability of Capture} = \frac{\text{Acquisition Time}}{\text{Acquisition Time} + \text{System Holdoff Time}}$$

It should be noted that it is impossible to determine the probability of capture by simply looking at the display update rate. If you rely solely on the update rate, it is easy to make the mistake of believing that the oscilloscope is capturing all pertinent information about the waveform when, in fact, it is not.

However, the probability of capturing infrequent events, such as asynchronous faults in digital systems, increases along with your oscilloscope's waveform update rate. Consider the challenge of finding an elusive anomaly in your circuit. The device's behavior proves that there is an error, but you don't know what it looks like, so you have no way to set the trigger to capture it. In this case, your oscilloscope's waveform update rate can mean the difference between minutes and hours spent observing your signal.

Digital phosphor oscilloscopes (DPOs) are ideal for design and debug applications because their high waveform capture rate provides the highest probability of witnessing transient problems that occur in digital systems such as runt pulses, glitches, and transition errors. DPOs are equally suitable for viewing high frequencies, low repetition rate waveforms, transients, and signal variations in real time. An example of a waveform capture rate specification follows:

Waveform Capture Rate: >400,000 wfms/sec
(from TDS7404 data sheet)

[3] See ***Appendix 1: Acquisition Modes***.

Acquisition Modes

Real-time oscilloscopes operating in real-time acquisition mode capture an entire waveform in a single trigger event. This method guarantees a sample rate that is fast enough to get all the samples required to accurately reconstruct the waveform. However, some situations call for higher timing resolution. This can be achieved through equivalent-time sampling. There are two types of equivalent-time sampling:

1) a real-time oscilloscope operating in random equivalent time sampling mode
2) the sequential sampling of a sampling oscilloscope

In random equivalent-time mode, a real-time oscilloscope acquires portions of waveforms during multiple trigger events. Over time, these portions are assembled into a complete waveform. While equivalent-time sampling provides higher timing resolution and accuracy (even in very high bandwidth signals), it requires a repetitive waveform and therefore cannot be used for single-shot acquisitions.

Using sequential equivalent-time sampling, sampling oscilloscopes acquire one sample from each trigger event, with a fixed interval between each acquisition. Over time, the instrument accumulates enough samples to reconstruct the waveform. This type of sampling provides the extremely high bandwidths (65 GHz and higher) and timing resolution needed for telecommunications and device characterization needs.

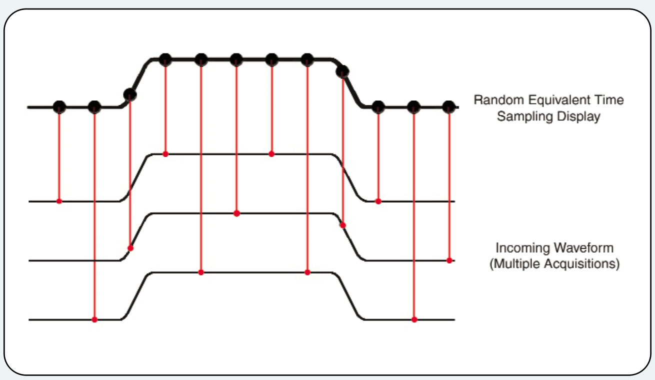


Figure A. *Random equivalent time sampling reconstructs the input waveform from multiple acquisitions using multiple points per acquisition (red lines simulate points where samples are taken).*

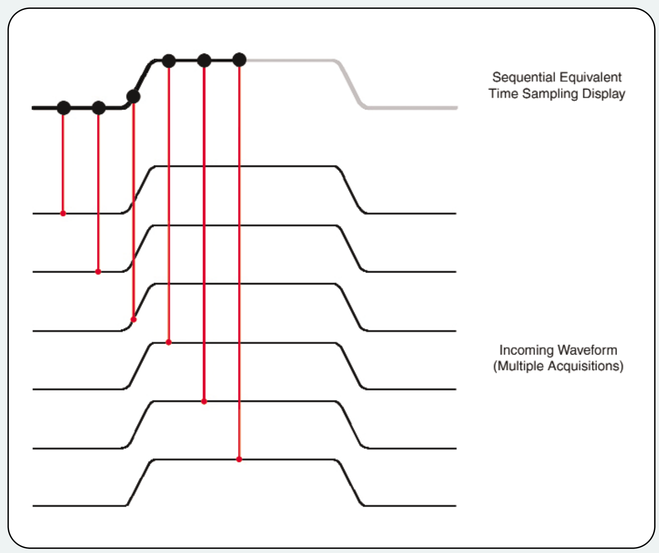


Figure B. *Sequential equivalent time sampling reconstructs the input waveform from multiple acquisitions of a single point per acquisition (red lines simulate points where samples are taken).*

Trigger System

An oscilloscope's triggering performance determines what you can capture, view, and measure with the instrument. Triggering can help you locate suspected problems, capture specific types of events, and verify quantitative measures such as setup and hold times. Critical trigger system specifications include:

- Sensitivity
- Trigger coupling
- Jitter
- Trigger type

Trigger Sensitivity

Trigger sensitivity is a critical attribute when capturing high-speed digital signals. An oscilloscope's trigger sensitivity determines its ability to react to specified edge trigger conditions over a range of frequencies. The specification takes the following form:

> **Trigger System Sensitivity, Internal DC Coupled:**
> 0.35 div DC to 50 MHz, increasing to 1.5 div at 3 GHz (guaranteed); 2.7 div at 4 GHz (typical)
> (from TDS7404 DPO data sheet)

The oscilloscope will trigger on a signal of 0.35 divisions amplitude p-p in the range of frequencies from DC to 50 MHz. As the frequency goes beyond 50 MHz, the signal must be larger (higher in amplitude) to trigger the instrument. At 3 GHz, the signal must be at least 1.5 divisions in amplitude. Trigger sensitivity is specified with a sine wave input.

Trigger sensitivity is an important consideration if your application involves fast, low-amplitude signals. If you are working with high-speed bus interfaces, for example, evaluate the oscilloscope's trigger amplitude requirements at the clock and data rates that you are likely to encounter. Remember that you may need to trigger on glitches or impaired pulses that are far smaller in amplitude than the surrounding pulses in the stream.

Trigger Coupling

An oscilloscope's selection of trigger coupling enables triggering under a wide variety of signal and noise conditions. For example, Tektronix instruments provide the following choices:

- DC coupling – all components of the signal are directed to the trigger circuit.
- AC coupling – only the AC component of the signal is directed to the trigger circuit. The DC component and very low frequencies (below 100 Hz) are blocked. This is useful for triggering on an AC signal in the presence of large DC or slowly varying AC signals.
- Low Frequency (LF) Reject – similar to AC coupling, except the low-frequency cut off is higher, at 200 kHz. This coupling mode will totally reject power-line hum interference.
- High Frequency (HF) Reject – similar to DC coupling, except the high frequencies (usually those above 20 kHz) are rejected. This is useful for triggering on low-frequency signals that have high-frequency noise or other high-frequency components "riding" on the main signal.
- Noise Reject – similar to DC coupling, except the sensitivity is reduced to minimize false triggering on very noisy signals.

Trigger Jitter

Jitter affects the stability and accuracy of the trigger system. Especially in the case of sampling oscilloscopes (which must build up a waveform from sequences of individually triggered events), trigger jitter can affect the timing and shape of the displayed waveform. Figure 3 shows a measurement of trigger jitter.

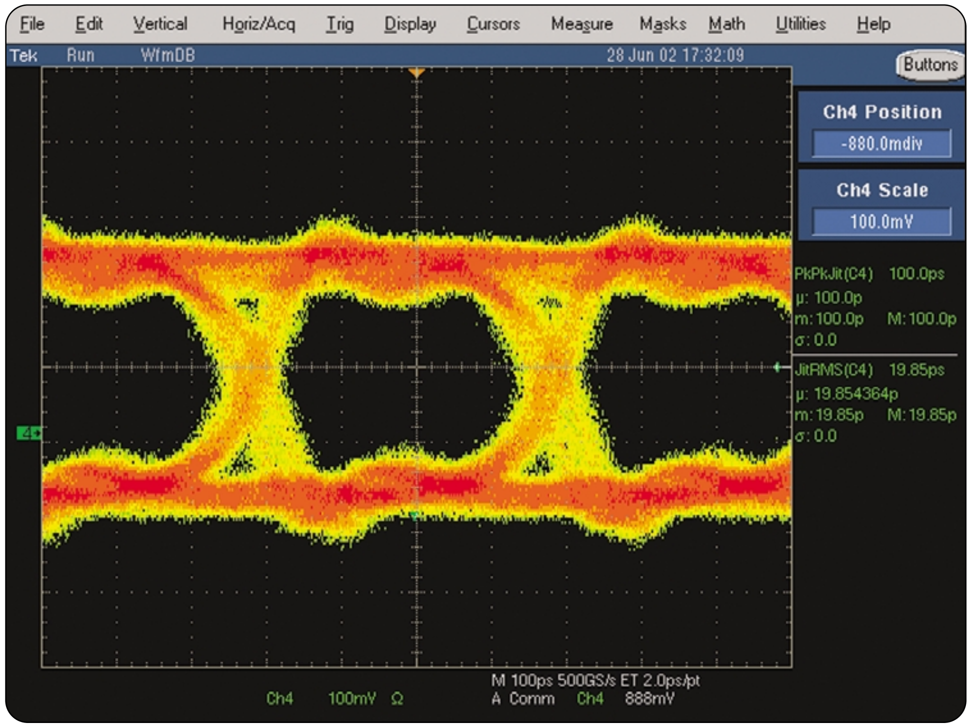
Trigger jitter is a factor for repetitive waveform acquisitions, but typically not for single-shot acquisitions. Therefore, it can affect rise time measurements if averaging is used, and can make edge placement uncertain in some display modes because it tends to "widen" the edge over repeated acquisitions. Following is a trigger jitter specification:

> **Trigger Jitter:** 6 ps RMS (typical)
> (from TDS7404 data sheet)

Trigger Types

Trigger types fall into two general categories: edge and advanced triggers. Edge triggers are those that occur when a voltage threshold is crossed once. Advanced triggers apply many more qualifications pertaining to voltage, timing, and logic conditions. A high-performance oscilloscope should offer a range of triggering choices. Some examples are listed below (for definitions, see ***Appendix 2: Trigger Types***):

- Edge
- Glitch
- Width
- Pulse
- Runt
- Timeout
- Transition
- Setup/Hold
- Pattern
- State
- Serial pattern
- Delayed (by time or events)
- Comm



► ***Figure 3.*** *A TDS7404 DPO uses its waveform database to make an eye-pattern crossing jitter measurement on a 2.5 Gb/s signal. The oscilloscope provides ±3% accuracy on a 21 ps jitter measurement by triggering on the recovered clock.*

Summary

Before selecting a high-performance oscilloscope, become familiar with the specifications that are meaningful to your application, and look closely at tolerances and disclaimers. Many oscilloscope specifications are defined in published IEEE standards.

Tektronix specifications are derived and verified in accordance with these standards. In all cases, published specifications are demonstrable and repeatable.

Appendix 1: Acquisition Modes

Digital oscilloscopes acquire far more sample points than their screens can display; each illuminated pixel may represent thousands of stored data points. Acquisition modes, explained below, control the way the oscilloscope combines samples into a meaningful data value for display.

Sample mode: The most basic of all the modes, sample mode delivers the highest accuracy for timing interval measurements. It retains and displays the first point from each sample interval, discarding the others. In many DSOs, sample mode interleaves the digitizers of two or more channels to achieve the instrument's maximum sample rate.

Peak Detect mode: Determines the highest and lowest values for each sample interval, then displays all the samples between the two values, inclusive. Especially useful at slower sampling rates, Peak Detect allows you to see any extremes that occurred during the sample interval.

High Resolution (Hi-Res) mode: A Tektronix-patented process that calculates and displays the average of all the values in each sample interval. It runs at the highest sampling rate of the digitizer, providing maximum detail in the acquired waveform. It does not interleave channels. Because it works with more data per sample interval, Hi-Res mode increases the effective vertical measurement resolution.

Sample, Peak Detect, and Hi-Res modes operate in real time, using the acquired data from one trigger event. Therefore these modes are suitable for the most demanding, single-shot measurements at frequencies up to the oscilloscope's upper bandwidth limit. The remaining modes require a repetitive signal.

Waveform Database mode: The waveform database is a three-dimensional accumulation of source waveform data over several acquisitions. In addition to amplitude and timing information, the database includes the number of times a specific waveform point (time and amplitude) has been acquired. Using waveform database technology, the real-time oscilloscope processes a much larger sample of data than when using the sample acquisition mode.

DPO FastAcq mode: FastAcq optimizes the oscilloscope for analysis of dynamic signals and capture of infrequent events.

Average mode: Using the data from two or more acquisitions, this mode averages the corresponding data points on a point-by-point basis. Average mode improves the signal-to-noise ratio, removes uncorrelated noise, and makes viewing of repetitive signals easier.

Envelope mode: Builds a waveform "envelope" from the highest maximum values and lowest minimum values among the corresponding samples from two or more trigger events (acquisitions). Envelope mode is similar to Peak Detect mode (and in fact uses some Peak Detect capabilities) but is best used on repetitive waveforms, where it minimizes aliasing effects.

Random Equivalent Time (ET) mode: Accumulates a waveform record from acquisitions over many trigger events. The samples from any one trigger occur randomly with respect to samples from any other trigger, so eventually, samples will fill all parts of the waveform record. ET mode may capture several samples during any one acquisition, but cannot be used on single-shot signals. ET mode requires a repetitive waveform that remains consistent from trigger to trigger. In a DSO, random ET sampling allows sampling at rates higher than the oscilloscope's nominal Nyquist frequency limits.

Appendix 2: Trigger Types

Type	Trigger Condition	Polarity	Other
Edge	Voltage threshold crossing	Positive or negative	
Glitch	Specified width or less	Positive or negative	Can also be set to reject glitches
Width	Within or outside selectable limits	Positive or negative	
Runt	Crosses one voltage threshold but does not reach a second threshold before crossing the first again	NA	May include time qualification
Timeout	Event stays high or low or does not change for a specified time		
Transition	Trigger on edge rates that are faster or slower than specified	Positive or negative	
Setup/Hold	Trigger on violations of setup and hold time between two channels		
Pattern	Trigger when pattern (up to four bits wide) is true (or false) for a specified time		Boolean conditions: AND, NAND, OR, NOR
State	Trigger on any logical pattern of channels		Clocked by Channel 4
Serial Pattern	Trigger when a specified symbol occurs within a serial pattern		
Delayed	Trigger cannot occur until delay time has elapsed or number of events has occurred		
Comm	Select among isolated positive or negative one, zero pulse form or eye pattern as applicable to standard		

In addition, it may be necessary to set up a trigger condition that recognizes when a specified event does not occur – an exclusionary (timeout) trigger. Most high-performance oscilloscopes that offer a diverse range of programmable triggers can be set to recognize exclusive conditions.

Appendix 3: Index to Terms

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► ***Tektronix High-Performance Oscilloscopes.*** *Clockwise from far left: TDS7000, CSA7000, TDS8000B, CSA8000B, TDS6000 Series.*

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**

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