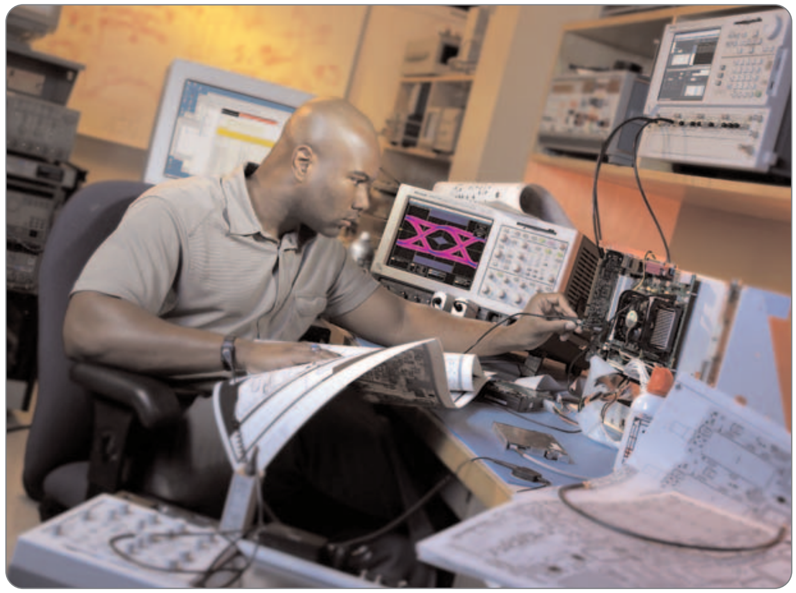
TDS5000B, TDS6000, TDS/CSA7000B Series Acquisition Modes

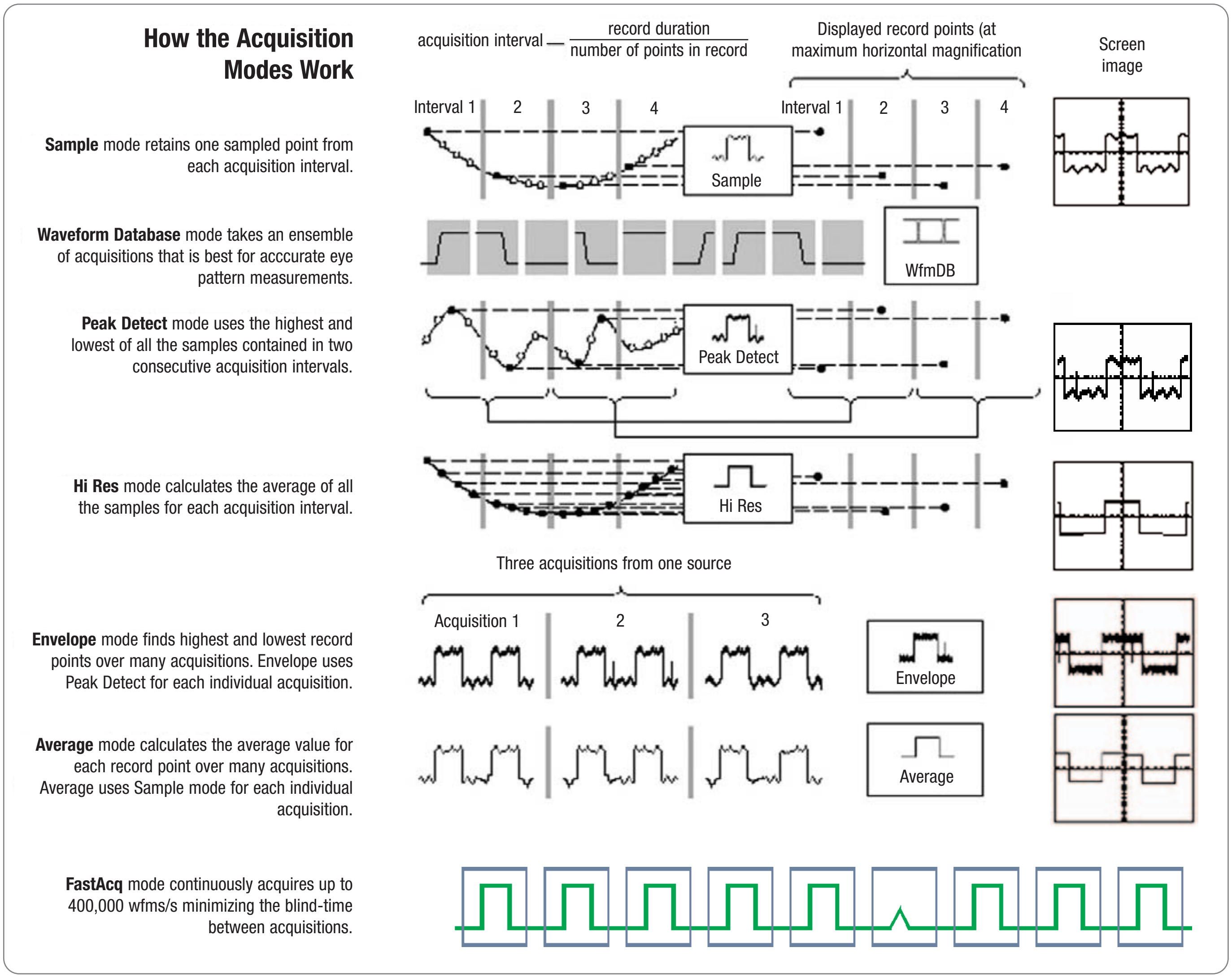


▶ Tektronix oscilloscopes provide several different acquisition modes. While this gives the user great flexibility and choice, each mode is optimized for a different task in mind and it can therefore sometimes be difficult for a user to know what mode to choose under what circumstance. This document is intended to provide a brief insight into the different acquisition mode with both their pros and cons.

Acquisition Basics

Digital oscilloscopes use analog-to-digital converters (ADC) that sample the signal at discrete points in time to convert the signal's voltage at these points into digital values called sample points. ADCs in the TDS5000B, TDS6000 and TDS/CSA7000B Series products can run as fast as 5 GS/s (one sample every 200 ps) and 20 GS/s (one sample every 50 ps), respectively. Depending on how the oscilloscope is set up, some or all of these sample points will become waveform points used to draw the resulting waveform on the oscilloscope's display. The ADCs in digital oscilloscopes from Tektronix are always running at full speed. If the oscilloscope is set to one of the fastest sweep speeds (where the sample rate displayed on screen matches the sample rate specification of the oscilloscope), then all sampled points are being shown on the display. When a slower sweep speed is selected, the sample rate shown in the display window decreases. The oscilloscope is still sampling at the fastest rate it can, but it is now "throwing away" some of the sample points. The reason for this is that the oscilloscope is able to store a longer window of time, but at a lower resolution.

Acquisition modes do not affect the data sampling itself, but they do affect the way the oscilloscope combines the sample points into waveform points for display.


How the Acquisition Modes Work
acquisition interval — record duration / number of points in record
Displayed record points (at maximum horizontal magnification
Screen image
Interval 1
2
3
4
Sample mode retains one sampled point from each acquisition interval.
Sample
Waveform Database mode takes an ensemble of acquisitions that is best for acccurate eye pattern measurements.
WfmDB
Peak Detect mode uses the highest and lowest of all the samples contained in two consecutive acquisition intervals.
Peak Detect
Hi Res mode calculates the average of all the samples for each acquisition interval.
Hi Res
Three acquisitions from one source
Acquisition 1
Envelope mode finds highest and lowest record points over many acquisitions. Envelope uses Peak Detect for each individual acquisition.
Envelope
Average mode calculates the average value for each record point over many acquisitions. Average uses Sample mode for each individual acquisition.
Average
FastAcq mode continuously acquires up to 400,000 wfms/s minimizing the blind-time between acquisitions.

▶ ***Figure 1.***

What type of acquisition modes do the TDS5000B, TDS6000 and TDS/CSA7000B oscilloscopes offer?

These oscilloscopes offer seven acquisition modes:

- Sample mode
- Peak Detect mode
- Envelope mode
- High Resolution mode
- Average mode
- Waveform Database mode
- Fast Acq mode (TDS5000B and TDS/CSA7000B Series)

Advantages of Sample Mode

In Sample mode, the ADCs run at full speed and depending on the sample rate the user selects, some or all of these points are stored as waveform points for display. If the ADC's maximum rate is 5 GS/s but the sample rate displayed on the oscilloscope screen is 500 MS/s, then only one out of every 10 sampled points is saved as a waveform point. The information between samples is lost. Through the rest of this paper, sample interval is defined to be 1/sample rate. Sample mode is the simplest, most predictable operation and most useful in providing uniformly sampled data for signal processing. Sample mode also provides the highest accuracy for timing measurements.

A drawback of Sample mode is that it can be "fooled" by aliasing because the bandwidth of the displayed data is proportional to the sample rate, which is determined by the time/division setting. As the Nyquist Theorem predicts, the bandwidth of the data drops as you slow the time base. One solution to this problem is to use deeper memory at slower sweep speeds which forces the sample rate higher, thus minimizing the chances of aliasing. Another solution is to use the Peak Detect acquisition mode, which is described next.

Advantages of Peak Detect

As mentioned earlier, unless a sweep speed is selected that requires the fastest sample rate of the ADC, sample points are being thrown away. Peak Detect takes advantage of those "extra" samples by repeatedly extracting the highest and lowest data values from two consecutive sample intervals and using them as waveform points to build the display waveform. This results in a waveform that looks like an envelope and contains high frequency information that would have otherwise been missed due to lower sampling rates, thus making Peak Detect a solution for the aliasing problem mentioned earlier. Peak Detect provides the most value at slow sweep speeds because it enables the user to identify high frequency information (noise, glitches) without, for example, increasing the memory depth. Continuing our earlier example, if the ADC's maximum rate is 5 GS/s and the oscilloscope is currently set to 500 MS/s, then each pair of waveform points drawn on the screen represent the high and low vertical (voltage) values over two sample intervals, each containing 10 sample points.

Advantages of Envelope Mode

The easy way to think of Envelope mode is that it is Peak Detect mode over multiple acquisitions. Envelope mode produces a cumulative set of minimums and maximums at each time point, for either single-shot (one envelope) or repetitive signals.

Because this mode removes the timing information from the data, enveloping data is typically not suitable for FFT (Fast Fourier Transform) analysis. Another disadvantage is that this mode obscures the statistical distribution of the samples that occurred between the minimum and maximum values. However, this can partially be overcome by using a persistence display mode. An "envelope of 1" is the equivalent of a Peak Detect mode acquisition, and an "envelope of ?" is a continuous envelope.

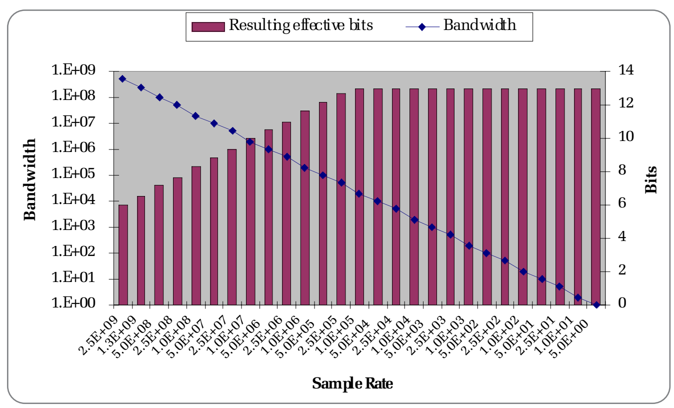
Advantages of High Resolution Mode

Similar to Peak Detect, the Tektronix patented High Resolution mode also takes advantage of the "throw-away" sample points that are digitized by the ADC but not used as waveform points. The difference is that with High Resolution mode, all the extra points are averaged together to form the waveform point that is displayed, rather than storing the highest and lowest values as in Peak Detect mode. Continuing our earlier example where the ADC is running at its maximum rate of 5 GS/s and the oscilloscope is set to 500 MS/s sample rate, High Resolution mode will average ten sample points to create each waveform point for display. The High Resolution mode, which is also available for single-shot signals, offers two key advantages in the form of increasing vertical measurement resolution by providing additional bits of information and it can be used to filter high frequency noise from low frequency signals.

Figure 2 compares improvement in the signal to noise ratio (SNR) to sweep speed (which determines the number of samples available for averaging). The chart shows that the resolution and signal-to-noise ratio increases as you slow down the time/div setting.

How Much Vertical Resolution Increase Can Be Expected From High Resolution Mode

Theoretically, the increase is 0.5 Log (base 2) N, of the samples taken in the waveform interval. As a practical matter, the 2-byte memory depth limits this increase. Two bytes are 16 bits. One of these bits is reserved as a sign bit, which leaves 15 bits for data numbers. Round-off errors cause the 14th and 15th bits to be random, leaving the practical limit as 13 bits. The improvement is not added to 8 bits, because, again as a practical matter, an 8-bit digitizer "effectively" never has more than 6 to 7 "effective" bits resolution due to noise, non-linearity, missed digitizing levels, and aperture uncertainty. These errors tend to increase at high frequencies, thus the improvement curve starts at about 6 bits at the highest sample rates and frequencies, (no improvement) and gets no better than 13 bits at the slowest sample rates. High Resolution mode becomes Sample mode at time base settings faster than the highest setting on the chart.



▶ ***Figure 2.*** *TDS7104 High Resolution Mode.*

One drawback of High Resolution mode grows from the use of a "box-car" averaging technique that causes the frequency response to roll off quickly. The low pass filter acts like a one pole filter, with -3dB bandwidth at the displayed sample rate divided by 2.5.

Advantages of Average Mode

Average mode makes signal viewing easier for repetitive signals. Average mode calculates a numerical average of the vertical (voltage) values for each point on the waveform over the number of acquisitions specified. Another advantage of Average mode is that it removes uncorrelated noise and improves the signal-to-noise ratio. A disadvantage of Average mode is that trigger jitter degrades the timing information in the acquired data. Another disadvantage is that the signal must be repetitive. Most scopes today use weighted averaging, where the present displayed acquisition result is compared (point by point) to the next acquisition, and converged toward this next acquisition by the difference (point by point) divided by the averaging (weighting) number (factor). This technique allows for continuous viewing of the averaging process as it happens, acquisition by acquisition.

Advantages of Waveform Database Mode

Unlike normal acquisition modes, which can produce only a two-dimensional view, the Waveform Database adds a third dimension call sample density. Sample density is represented on the display with color grading using a persistence display mode. Colors are assigned according to the number of times each point on the waveform is acquired relative to the number of times all other waveform points in the same graticule are acquired.

The oscilloscope keeps track of the number of times each waveform point is sampled with an on-board statistical database (Waveform Database). An array of 64 bit software counters (64-bit words) is used to count the number of times each waveform point is "hit". The number of samples taken per trigger event is dependent on if the oscilloscope is operating in real-time sampling (up to a maximum sample rate of 20 GS/s) or acquiring, using Equivalent Time sampling. The real performance however comes from being able to derive quantitative results using the measurement system, histograms, statistics and mask analysis. The database can be stored as a reference waveform and later recalled to compare prior test results and make additional measurements. If required the database can also be transferred over the Ethernet or GPIB interfaces for external analysis or data storage.

Advantages of FastAcq Mode

The FastAcq mode is the best visual debug tool because it gathers more waveforms in less time by continuously acquiring up to 400,000 waveforms per second, in addition to providing the shortest and fastest processing path in bringing these waveforms to the display screen.

The abundance of data that the FastAcq mode provides, gives the user a detail-rich display in seconds rather than minutes and therefore enables the user to quickly see signal anomalies and intermittent faults, that can then be further investigated. FastAcq also minimizes the effects of aliasing.

Unlike persistence display modes, which use "stop and go" post processing to control the display pixel color grading and cannot reveal real-time details in three dimensions, the FastAcq mode, as part of the acquisition process builds an image database of frequency-of-occurrence providing color graded amplitude, time and distribution of amplitude over time information.

Aside from its ability to reveal transient information, the FastAcq mode also provides the user with signal information throughput in eye and constellation diagrams due to the high waveform capture rate.

Although FastAcq is a supreme mode for signal debug tasks, in-depth measurements and analysis of an eye-diagram using histograms, for exmaple, is better performed using the waveform database mode due to being optimized for more comprehensive statistical analysis.

Real-Time (RT) and Equivalent-Time (ET) Sampling

Real-time sampling acquires all samples from a signal in one acquisition cycle. The signal may be either a single or repetitive event. The sample rate must be high enough to allow the oscilloscope to acquire sufficient data to reconstruct the waveform. The advantage of real-time sampling is that it captures single-shot events. The disadvantage is that the bandwidth of the displayed waveform is limited by the sample rate used. This is the Nyquist limit. (Nyquist states that the sample rate must be at least twice the highest frequency to be measured. Accurate amplitude measurements require more samples, depending on the interpolation algorithm used to connect the samples.)

Equivalent–time sampling acquires a few samples from each triggered waveform, over many acquisition cycles. The advantage of equivalent-time sampling is that it allows the bandwidth to exceed the Nyquist criteria for repetitive signals. The main disadvantage is that ET mode cannot be used with single-shot signals.

Do All Modes Work With Both Single-shot and Repetitive Signals

Sample, Peak Detect, and High Resolution modes operate in real time on single trigger events (assuming the sample rate is high enough).

Waveform Database, Envelope, Average, and FastAcq modes operate after the oscilloscope takes two or more acquisitions. For example, Average mode averages the corresponding data points on two or more waveforms, not the waveforms as a whole. Envelope mode builds an envelope from the lowest minimum values and the highest maximum values for each point on a succession of waveforms. FastAcq preserves the data in a database building a “real-time” content rich display. Waveform Database mode also builds a database of sample hits for each pixel in the display, but it is optimized for statistical analysis. Each of these modes will operate as a Single-Sequence for a set N number of acquisitions.

Summary

In this technical brief different acquisition modes were discussed. While the abundance of alternatives is a clear benefit for the user to get the most out of an oscilloscope, it is important to understand the basic differences between the different acquisition modes as each of them have their advantages and disadvantages.

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