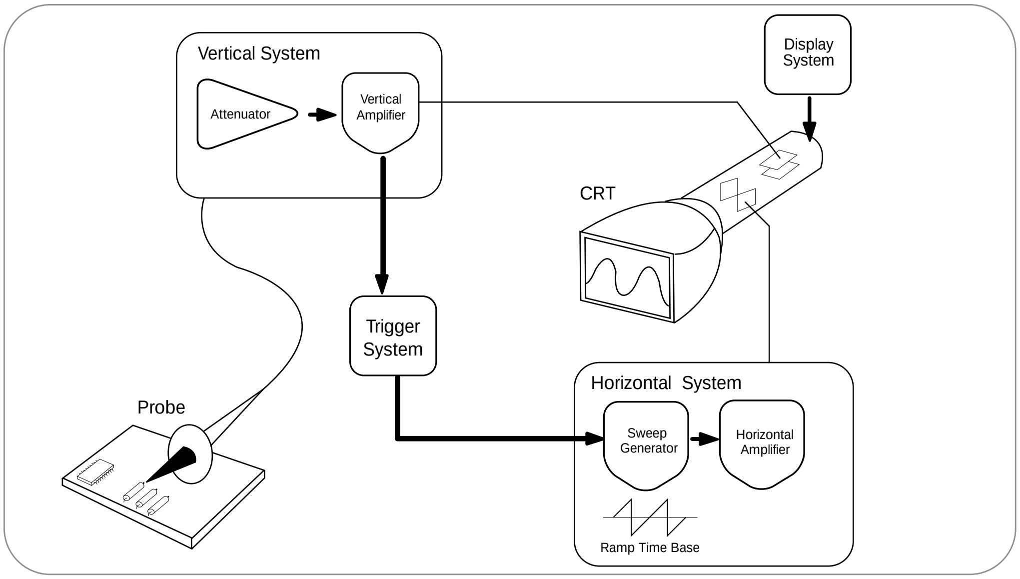


Figure 13. *The architecture of an analog oscilloscope.*

The Types of Oscilloscopes

Electronic equipment can be classified into two categories: analog and digital. **Analog** equipment works with continuously variable voltages, while **digital** equipment works with discrete binary numbers that represent voltage samples. A conventional phonograph is an analog device, while a compact disc player is a digital device.

Oscilloscopes can be classified similarly – as analog and digital types. For many applications, either an analog or digital oscilloscope will do. However, each type has unique characteristics that may make it more or less suitable for specific applications. Digital oscilloscopes can be further classified into digital storage oscilloscopes (DSOs), digital phosphor oscilloscopes (DPOs) and sampling oscilloscopes.

Analog Oscilloscopes

Fundamentally, an **analog oscilloscope** works by applying the measured signal voltage directly to the vertical axis of an electron beam that moves from left to right across the oscilloscope screen – usually a **cathode-ray tube** (CRT). The back side of the screen is treated with luminous phosphor that glows wherever the electron beam hits it. The signal voltage deflects the beam up and down proportionally as it moves horizontally across the display, tracing the waveform on the screen. The more frequently the beam hits a particular screen location, the more brightly it glows.

The CRT limits the range of frequencies that can be displayed by an analog oscilloscope. At very low frequencies, the signal appears as a bright, slow-moving dot that is difficult to distinguish as a waveform. At high frequencies, the CRT's **writing speed** defines the limit. When the signal frequency exceeds the CRT's writing speed, the display becomes too dim to see. The fastest analog oscilloscopes can display frequencies up to about 1 GHz.

When you connect an oscilloscope probe to a circuit, the voltage signal travels through the probe to the vertical system of the oscilloscope. Figure 13 illustrates how an analog oscilloscope displays a measured signal. Depending on how you set the vertical scale (volts/div control), an attenuator reduces the signal voltage and an amplifier increases the signal voltage.

Next, the signal travels directly to the vertical deflection plates of the CRT. Voltage applied to these deflection plates causes a glowing dot to move across the screen. The glowing dot is created by an electron beam that hits the luminous phosphor inside the CRT. A positive voltage causes the dot to move up while a negative voltage causes the dot to move down.

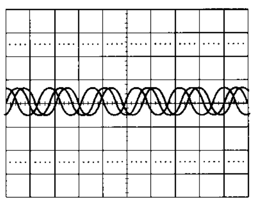


Figure 14. *The trigger stabilizes a repetitive waveform, creating a clear picture of the signal.*

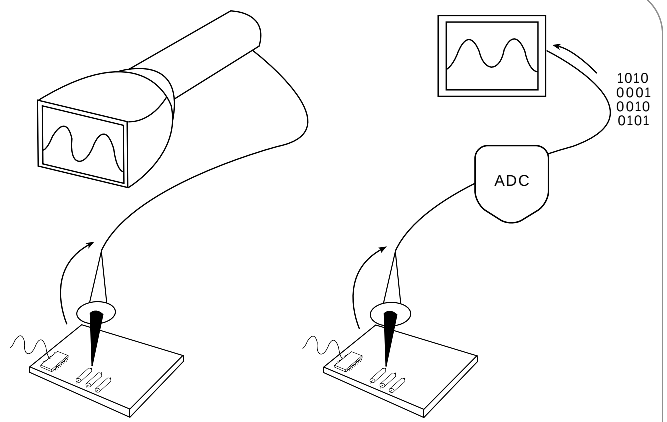


Figure 15. *Analog oscilloscopes trace signals, while digital oscilloscopes sample signals and construct displays.*

The signal also travels to the trigger system to start, or trigger, a **horizontal sweep**. Horizontal sweep refers to the action of the horizontal system that causes the glowing dot to move across the screen. Triggering the horizontal system causes the horizontal time base to move the glowing dot across the screen from left to right within a specific time interval. Many sweeps in rapid sequence cause the movement of the glowing dot to blend into a solid line. At higher speeds, the dot may sweep across the screen up to 500,000 times per second.

Together, the horizontal sweeping action and the vertical deflection action trace a graph of the signal on the screen. The trigger is necessary to stabilize a repeating signal – it ensures that the sweep begins at the same point of a repeating signal, resulting in a clear picture as shown in Figure 14.

In addition, analog oscilloscopes have focus and intensity controls that can be adjusted to create a sharp, legible display.

People often prefer analog oscilloscopes when it is important to display rapidly varying signals in “real time” – or, as they occur. The analog oscilloscope’s chemical phosphor-based display has a characteristic known as **intensity grading** that makes the trace brighter wherever the signal features occur most often. This intensity grading makes it easy to distinguish signal details just by looking at the trace’s intensity levels.

Digital Oscilloscopes

In contrast to an analog oscilloscope, a **digital oscilloscope** uses an analog-to-digital converter (ADC) to convert the measured voltage into digital information. It acquires the waveform as a series of samples, and stores these samples until it accumulates enough samples to describe a waveform. The digital oscilloscope then re-assembles the waveform for display on the screen. (see Figure 15)

Digital oscilloscopes can be classified into digital storage oscilloscopes (DSOs), digital phosphor oscilloscopes (DPOs), and sampling oscilloscopes.

The digital approach means that the oscilloscope can display any frequency within its range with stability, brightness, and clarity. For repetitive signals, the bandwidth of the digital oscilloscope is a function of the analog bandwidth of the front-end components of the oscilloscope, commonly referred to as the –3dB point. For single-shot and transient events, such as pulses and steps, the bandwidth can be limited by the oscilloscope’s sample rate. Please refer to the **Sample Rate** section under **Performance Terms and Considerations** for a more detailed discussion.

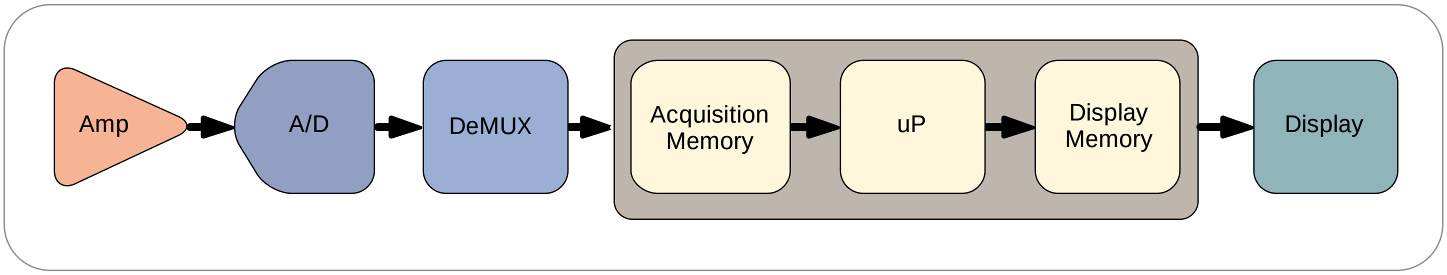


Figure 16. *The serial-processing architecture of a digital storage oscilloscope (DSO).*

Digital Storage Oscilloscopes

A conventional digital oscilloscope is known as a digital storage oscilloscope (DSO). Its display typically relies on a raster-type screen rather than luminous phosphor.

Digital storage oscilloscopes (DSOs) allow you to capture and view events that may happen only once – known as transients. Because the waveform information exists in digital form as a series of stored binary values, it can be analyzed, archived, printed, and otherwise processed, within the oscilloscope itself or by an external computer. The waveform need not be continuous; it can be displayed even when the signal disappears. Unlike analog oscilloscopes, digital storage oscilloscopes provide permanent signal storage and extensive waveform processing. However, DSOs typically have no real-time intensity grading; therefore, they cannot express varying levels of intensity in the live signal.

Some of the subsystems that comprise DSOs are similar to those in analog oscilloscopes. However, DSOs contain additional data-processing subsystems that are used to collect and display data for the entire waveform. A DSO employs a serial-processing architecture to capture and display a signal on its screen, as shown in Figure 16. A description of this serial-processing architecture follows.

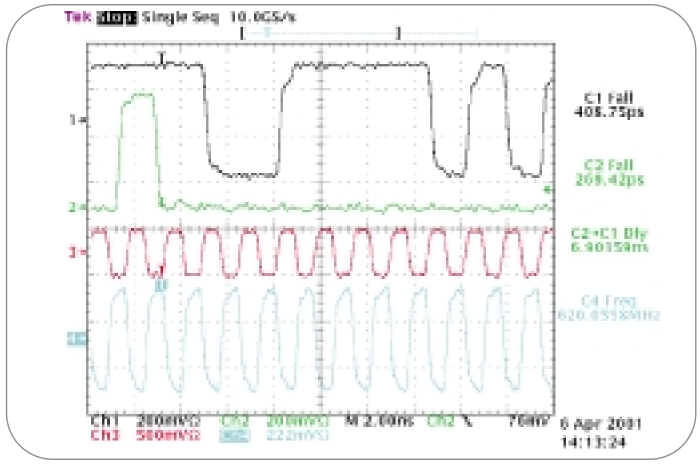
Serial-processing Architecture

Like an analog oscilloscope, a DSO's first (input) stage is a vertical amplifier. Vertical controls allow you to adjust the amplitude and position range at this stage.

Next, the analog-to-digital converter (ADC) in the horizontal system samples the signal at discrete points in time and converts the signal's voltage at these points into digital values called **sample points**. This process is referred to as **digitizing** a signal. The horizontal system's sample clock determines how often the ADC takes a sample. This rate is referred to as the **sample rate** and is expressed in samples per second (S/s).

The sample points from the ADC are stored in acquisition memory as **waveform points**. Several sample points may comprise one waveform point. Together, the waveform points comprise one waveform record. The number of waveform points used to create a waveform record is called the **record length**. The trigger system determines the start and stop points of the record.

The DSO's signal path includes a microprocessor through which the measured signal passes on its way to the display. This microprocessor processes the signal, coordinates display activities, manages the front panel controls, and more. The signal then passes through the display memory and is displayed on the oscilloscope screen.



▶ ***Figure 17.*** *The TDS694C delivers high-speed, single-shot acquisition across multiple channels, increasing the likelihood of capturing elusive glitches and transient events.*

Depending on the capabilities of your oscilloscope, additional processing of the sample points may take place, which enhances the display. Pre-trigger may also be available, enabling you to see events before the trigger point. Most of today's digital oscilloscopes also provide a selection of automatic parametric measurements, simplifying the measurement process.

A DSO provides high performance in a single-shot, multi-channel instrument (see Figure 17). DSOs are ideal for low-repetition-rate or single-shot, high-speed, multi-channel design applications. In the real world of digital design, an engineer usually examines four or more signals simultaneously, making the DSO a critical companion.

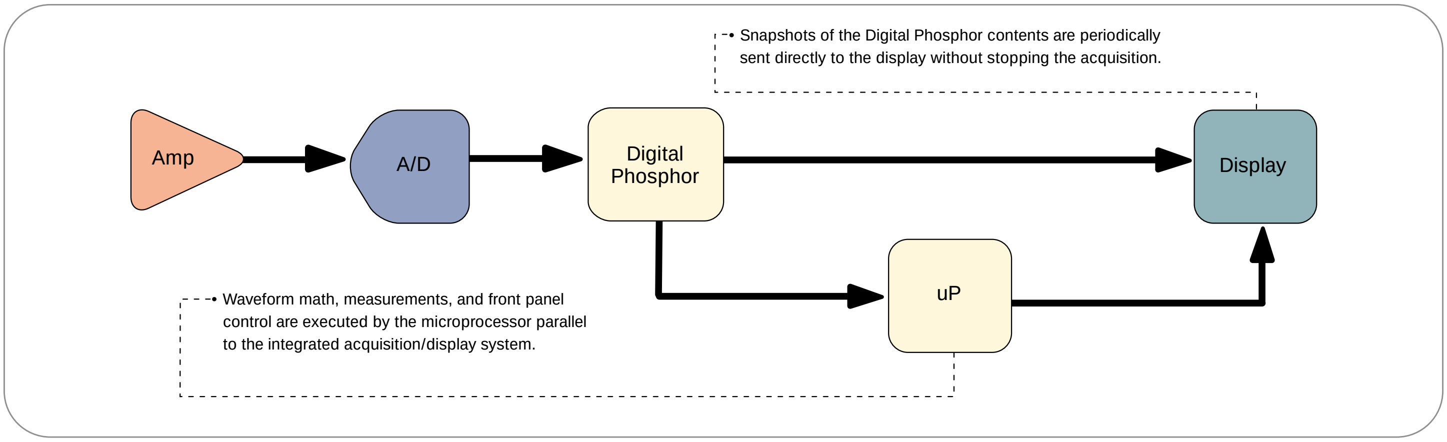


Figure 18. *The parallel-processing architecture of a digital phospor oscilloscope (DPO).*

Digital Phosphor Oscilloscopes

The digital phosphor oscilloscope (DPO) offers a new approach to oscilloscope architecture. This architecture enables a DPO to deliver unique acquisition and display capabilities to accurately reconstruct a signal.

While a DSO uses a serial-processing architecture to capture, display and analyze signals, a DPO employs a parallel-processing architecture to perform these functions, as shown in Figure 18. The DPO architecture dedicates unique ASIC hardware to acquire waveform images, delivering high waveform capture rates that result in a higher level of signal visualization. This performance increases the probability of witnessing transient events that occur in digital systems, such as runt pulses, glitches and transition errors. A description of this parallel-processing architecture follows.

Parallel-processing Architecture

A DPO's first (input) stage is similar to that of an analog oscilloscope – a vertical amplifier – and its second stage is similar to that of a DSO – an ADC. But, the DPO differs significantly from its predecessors following the analog-to-digital conversion.

For any oscilloscope – analog, DSO or DPO – there is always a holdoff 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-repetition event decreases as the holdoff time increases.

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.

The digital storage oscilloscope processes captured waveforms serially. The speed of its microprocessor is a bottleneck in this process because it limits the waveform capture rate.

The DPO rasterizes the digitized waveform data into a digital phosphor database. Every 1/30th of a second – about as fast as the human eye can perceive it – a snapshot of the signal image that is stored in the database is pipelined directly to the display system. This direct rasterization of waveform data, and direct copy to display memory from the database, removes the data-processing bottleneck inherent in other architectures. The result is an enhanced "live-time" and lively display update. Signal details, intermittent events, and dynamic characteristics of the signal are captured in real-time. The DPO's microprocessor works in parallel with this integrated acquisition system for display management, measurement automation and instrument control, so that it does not affect the oscilloscope's acquisition speed.

A DPO faithfully emulates the best display attributes of an analog oscilloscope, displaying the signal in three dimensions: time, amplitude and the distribution of amplitude over time, all in real time.

Unlike an analog oscilloscope's reliance on chemical phosphor, a DPO uses a purely electronic digital phosphor that's actually a continuously updated database. This database has a separate "cell" of information for every single pixel in the oscilloscope's display. Each time a waveform is captured – in other words, every time the oscilloscope triggers – it is mapped into the digital phosphor database's cells. Each cell that represents a screen location and is touched by the waveform is reinforced with intensity information, while other cells are not. Thus, intensity information builds up in cells where the waveform passes most often.

When the digital phosphor database is fed to the oscilloscope's display, the display reveals intensified waveform areas, in proportion to the signal's frequency of occurrence at each point – much like the intensity grading characteristics of an analog oscilloscope. The DPO also allows the display of the varying frequency-of-occurence information on the display as contrasting colors, unlike an analog oscilloscope. With a DPO, it is easy to see the difference between a waveform that occurs on almost every trigger and one that occurs, say, every 100th trigger.

Digital phosphor oscilloscopes (DPOs) break down the barrier between analog and digital oscilloscope technologies. They are equally suitable for viewing high and low frequencies, repetitive waveforms, transients, and signal variations in real time. Only a DPO provides the Z (intensity) axis in real time that is missing from conventional DSOs.

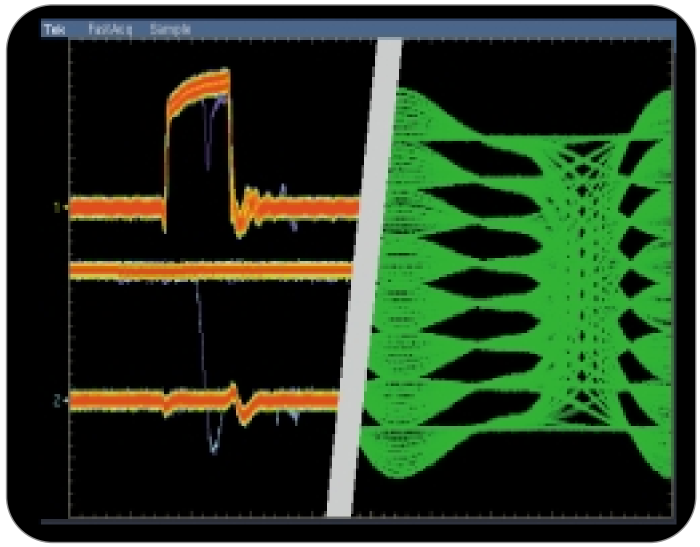


Figure 19. *Some DPOs can acquire millions of waveforms in just seconds, significantly increasing the probability of capturing intermittent and elusive events and revealing dynamic signal behavior.*

A DPO is ideal for those who need the best general-purpose design and troubleshooting tool for a wide range of applications (see Figure 19). A DPO is exemplary for communication mask testing, digital debug of intermittent signals, repetitive digital design and timing applications.

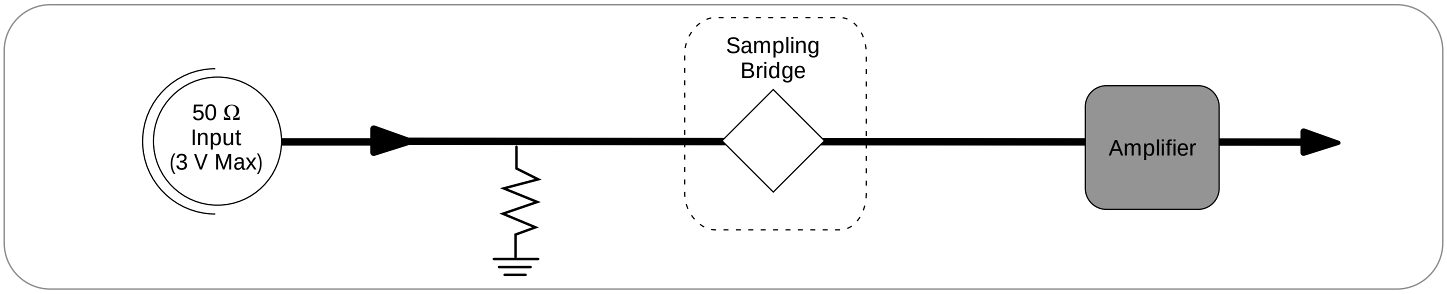


Figure 20. *The architecture of a digital sampling oscilloscope.*

Digital Sampling Oscilloscopes

When measuring high-frequency signals, the oscilloscope may not be able to collect enough samples in one sweep. A digital sampling oscilloscope is an ideal tool for accurately capturing signals whose frequency components are much higher than the oscilloscope's sample rate (see Figure 21). This oscilloscope is capable of measuring signals of up to an order of magnitude faster than any other oscilloscope. It can achieve bandwidth and high-speed timing ten times higher than other oscilloscopes for repetitive signals. Sequential equivalent-time sampling oscilloscopes are available with bandwidths to 50 GHz.

In contrast to the digital storage and digital phosphor oscilloscope architectures, the architecture of the digital sampling oscilloscope reverses the position of the attenuator/amplifier and the sampling bridge, as shown in Figure 20. The input signal is sampled before any attenuation or amplification is performed. A low bandwidth amplifier can then be utilized after the sampling bridge because the signal has already been converted to a lower frequency by the sampling gate, resulting in a much higher bandwidth instrument.

The tradeoff for this high bandwidth, however, is that the sampling oscilloscope's dynamic range is limited. Since there is no attenuator/amplifier in front of the sampling gate, there is no facility to scale the input. The sampling bridge must be able to handle the full dynamic range of the input at all times. Therefore, the dynamic range of most sampling oscilloscopes is limited to about 1 V peak-to-peak. Digital storage and digital phosphor oscilloscopes, on the other hand, can handle 50 to 100 volts.

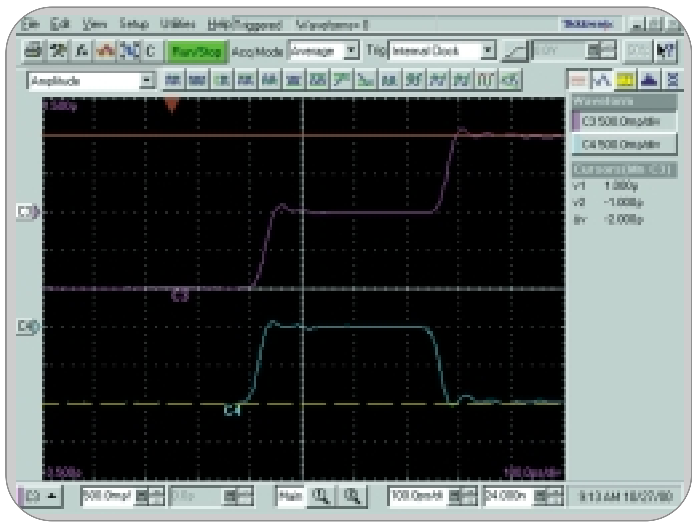


Figure 21. *Time domain reflectometry (TDR) display from a TDS8000 digital sampling oscilloscope and 80E04 20-GHz sampling module.*

In addition, protection diodes cannot be placed in front of the sampling bridge as this would limit the bandwidth. This reduces the safe input voltage for a sampling oscilloscope to about 3 V, as compared to 500 V available on other oscilloscopes.