Digital Storage Oscilloscope

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Contents

- An oscilloscope is an electronic test instrument that is used to observe an electronic signal (voltage) as a function of time. In other words it is a voltage versus time plotter.
- Oscilloscopes come in two basic types, analog and digital - in the analog device the voltage is shown in original form and in the digital device the voltage is first converted to string of digital values (digitized) and then displayed.
- In a DSO, the signal in addition to being digitized is also stored for future retrieval.

Working of DSO: Block Diagram

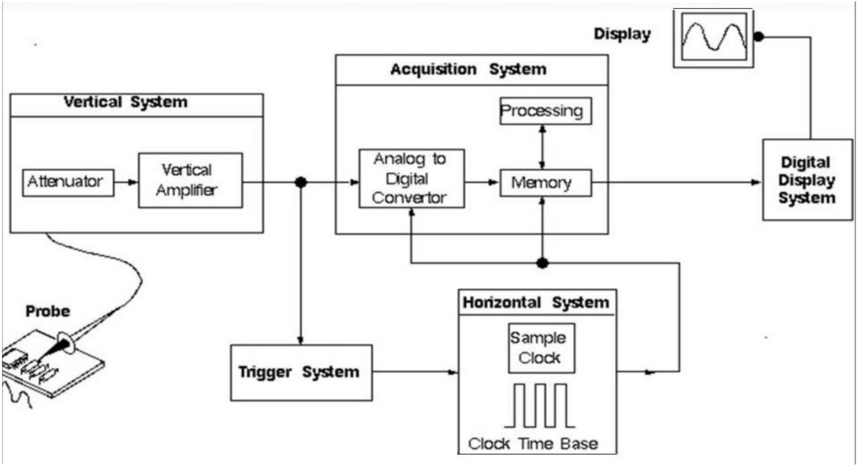

Figure 1: Block diagram of a DSO

Working of DSO: Block Diagram

- **Vertical System:** The signal that needs to be displayed is first given to this system, it changes the amplitude of the input signal to a level acceptable to the subsequent stages. The attenuator attenuates (decreases) and the vertical amplifier amplifies (increases) an input signal amplitude.
- **Acquisition System:** This system works on the signal of appropriate amplitude from the vertical system. It converts the original analog signal to a digital one using an Analog to Digital Converter (ADC) and stores the digital data in memory.
- **Horizontal System:** This system is associated with acquisition of an input signal - sample rate and record length are among the considerations here.
- **Trigger System:** This system synchronizes the horizontal sweep at the correct point of the signal, this is essential for clear signal characterization.

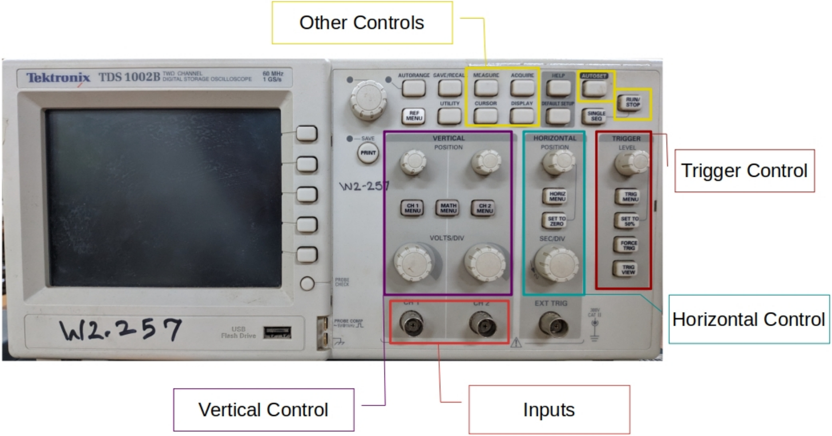

Figure 2: Front panel of a DSO

Functionality: Vertical Controls

1. **Vertical Controls:** The vertical (y) axis of the screen represents the amplitude of the voltage signal being measured.
   - The *vertical position control* lets you move the waveform up or down to exactly where you want it on the screen.
   - The *volts per division* (volts/div) setting varies the size of the signal on the screen. It is used to properly view a signal at a scale comparable to its magnitude. For example, if the setting is 1 volts/div then each horizontal division will be 1 volt.

Functionality: Horizontal Controls

2 **Horizontal Controls:** The horizontal (x) axis represents time

- The *horizontal position control* moves the waveform from left or right to exactly where you want it on the screen.
- The *seconds per division* (sec/div) setting lets you select the rate at which the waveform is drawn across the screen (also known as the time base setting or sweep speed). This setting is a scale factor. For example, if the setting is 1 ms, each horizontal division represents 1 ms and the total screen width represents 10 ms (ten divisions). Changing the sec/div setting lets you look at longer or shorter time intervals of the input signal.

Functionality: Trigger Controls

3. **Trigger Controls:** Signals to be displayed on an oscilloscope must be referenced to a start time. The setting of this time is called triggering. The trigger is determined by setting the oscilloscope to find the point at which the signal crosses (either rising or falling) a particular voltage. If a trigger is not set (or incorrectly), the waveform appears to jump around on the display. This is due to the oscilloscope sampling the input at different times and, since the signal is time varying, displays an animated waveform. To set the trigger the following controls are available:
    - The *Trigger Menu* button gives you an option of selecting the channel that will be the source of the trigger and selecting the edge (typically rising) to trigger on.
    - The *Trigger Level* dial, lets you adjust the trigger level until the waveform is stable. Note, the trigger level is indicated by an arrow to the right of the screen.

Functionality: Cursor

4 **Cursor:** It provides the user with a functionality to make measurement of the signal being displayed on the oscilloscope, by showing the difference in the value between the two cursor lines.
To activate the cursor press the cursor button on the front panel. The cursors will appear as either a horizontal or vertical lines on the screen. The cursors are controlled using the Select button, the dial near the top of the scope and the context menu. The context menu buttons are used to choose between the vertical and horizontal cursors. The vertical cursor will measure the difference in time and the horizontal cursor will measure the difference in voltage levels. The context menu also gives you a choice of selecting the source the cursor is supposed to follow.

Functionality: Measure

5 **Measure:** It allows the user to take upto five automatic measurements (the device does all the calculations for you). It is more accurate than cursor measurement as it uses waveform record points. Automatic measurements use readouts to show measurement results.These readouts are updated periodically as the oscilloscope acquires new data. Once the measure button is pressed choice of source and type of measurement is given to the user in the context menu.
Measure type can be frequency, period, mean, peak-peak, cycle RMS, min, max, rise time, fall time, positive width and negative width. Option for choosing the source of measurement is also available in the context menu.

Functionality: Acquire

6 **Acquire:** When you acquire a signal, the oscilloscope converts it into a digital form and displays a waveform. The acquisition mode defines how the signal is digitized and the time base setting affects the time span and level of detail in the acquisition. The acquisition modes are:

- *Sample:* the oscilloscope samples the signal in evenly spaced intervals to construct the waveform, it gives an almost accurate representation of the signal. However, this mode does not acquire rapid variations in the signal that may occur between samples. This can result in aliasing and may cause narrow pulses to be missed.
- *Peak Detect:* the oscilloscope finds the highest and lowest values of the input signal over each sample interval and uses these values to display the waveform. In this way, the oscilloscope can acquire and display narrow pulses, which may have otherwise been missed in Sample mode. Noise will appear to be higher in this mode.
- *Average:* the oscilloscope acquires several waveforms, averages them, and displays the resulting waveform. You can use this mode to reduce random noise.

Functionality: Display

7 **Display:** Push the DISPLAY button to choose how waveforms are presented and to change the appearance of the entire display.

- Type: *Vectors* fills the space between adjacent sample points in the display. *Dots* displays only the sample points.
- Persist: Sets the length of time each displayed sample point remains displayed.
- Format: *YT format* displays the vertical voltage in relation to time (horizontal scale). XY format displays a dot each time a sample is acquired on channel 1 and channel 2. Channel 1 voltage determines the X coordinate of the dot (horizontal) and the channel 2 voltage determines the Y coordinate (vertical).

Functionality: Autoset

8 **Autoset:** When you push the AUTOSET button, the oscilloscope identifies the type of waveform and adjusts controls to produce a suitable display of the input signal. The Autoset function examines all channels for signals and displays corresponding waveforms. Autoset determines the trigger source based on the following conditions:

- If multiple channels have signals, channel with the lowest frequency signal.
- No signals found, the lowest-numbered channel displayed when Autoset was invoked.
- No signals found and no channels displayed, oscilloscope displays and uses channel 1.

Functionality: Run/Stop

9 **Run/Stop:** When you press the Run/Stop button it toggles between Continuously acquiring waveforms or stopping the acquisition.

Functionality: Coupling

10 **Coupling:** Coupling means to connect an electrical signal from one circuit to another. In the context of oscilloscopes it refer to the way in which the circuit under test is connected to the input stage of the scope. The option to change the type of coupling is available in the context menu that appears upon pressing the channel menu button. The types of coupling are:

- *Ground Coupling:* Disconnects the input, the screen will show a line corresponding to zero line.
- *DC Coupling:* Passes both AC and DC components of the input signal. If the input signal is not a pure AC, but has a DC component as well then the signal will be seen to have an offset.
- *AC Coupling:* Passes AC but blocks the DC component of the input signal and attenuates signals below 10 Hz. The signal will be displayed symmetrically (in area) about the zero line.

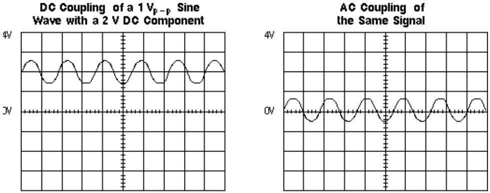

Figure 3: DC and AC coupling[4]

Voltage characteristics:

- *Amplitude:* It is a measure of the magnitude of a signal. The various amplitude measurements are *peak-to-peak* amplitude, which measures the absolute difference between a high and low voltage point of a signal and *Peak* amplitude, measures how high or low a signal is past 0V.
- *Max and Min voltages:* The scope can tell you exactly how high and low the voltage of your signal gets.
- *Mean and average voltages:* The scope can calculate the average or mean of your signal, and it can also tell you the average of your signals minimum and maximum voltage.
- *Root Mean Square (RMS) voltages:* RMS of an AC voltage denotes an equivalent DC voltage value that will produce the same heating effect, or power dissipation, in circuit, as the AC voltage.

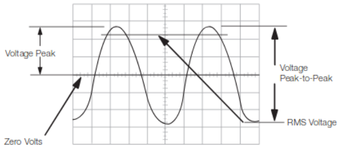

Figure 4: Voltage characteristics of a sine wave[4]

Measurable Quantities: Time characteristics

Time characteristics:

- *Frequency and period:* Frequency is defined as the number of times a waveform repeats per unit time. And the period is the reciprocal of that (time taken to complete one full cycle).
- *Duty cycle:* It is the ratio of 'on' time to period ('on' time + 'off' time) of a periodic waveform.
- *Rise and fall time:* Time taken by a signal to go from low to high state (high to low) is called rise (fall) time. These characteristics are important when considering transient response of a circuit.

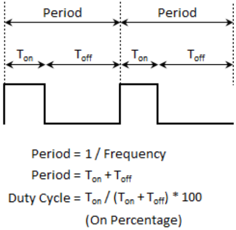

Figure 5: Duty cycle, Period and Frequency

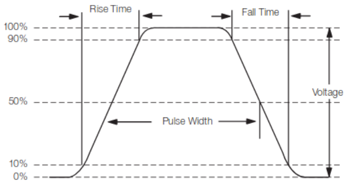

Figure 6: Rise time and Fall time of a pulse[4]

Measurable Quantities: Phase

Phase:
Phase is measured relative to a reference and phase difference is used to describe the difference in degrees or radians when two or more alternating quantities reach their maximum or zero values. DSO can be used to find the phase difference between two signals (of same frequency) given as inputs to the two channels of the DSO - one signal will act as the reference relative to which the phase of the second is described. There are various ways to measure the phase:

Measurable Quantities: Phase

- *Time-difference method:*

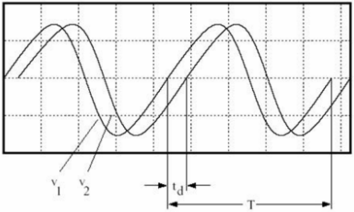

Figure 7: Phase difference between two sine waves

Time-difference method is not limited to sinusoidal waveforms but can be used for measuring phase difference between any periodic waveforms of same period T. In this method the waveforms are scaled so that at least one full cycle of the two waveforms are observable on the screen simultaneously, the vertical position control is used to align their zeros or peaks. Now, the vertical cursor is used to measure the time difference t_d between the two zeros or peaks. The phase difference ϕ is then calculated using the formulae:

$$\phi = 2\pi * \frac{t_d}{T} \tag{1}$$

Measurable Quantities: Phase

- *Lissajous method:*

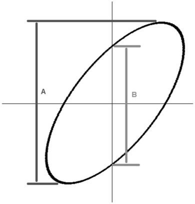

Figure 8: Lissajous figure with vertical height A and zero crossing height B

Lissajous method can only be used for sinusoidal signals of the same frequency. In this method the signals are viewed in XY mode, each channel is grounded separately and the line on the screen is adjusted to the center (vertical or horizontal) axis of the display. Both the channels are AC coupled to view the ellipse, measure the vertical height A and the zero crossing height B. The phase difference ϕ between the two waves are then measured using the formula:

$$\phi = \begin{cases} \arcsin \frac{B}{A} & \text{if top of the ellipse is in the first quadrant} \\ \pi - \arcsin \frac{B}{A} & \text{if top of the ellipse is in the second quadrant} \end{cases} \tag{2}$$

Probe

Oscilloscope probes are used to interface the voltage signals to be measured with the scope. Probes are specially designed to minimize noise and interference, while also creating a known load effect on the circuit. Most passive probes have some degree of attenuation factor, such as 10X, 100X, and so on.

- *Attenuation factors* are represented as 10X, have the X after the factor.
- *Magnification factors* are represented as X10, have the X before the factor.

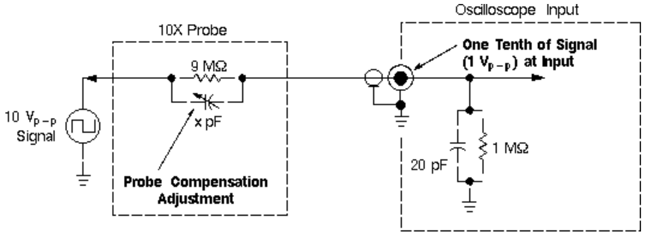

Figure 9: Equivalent circuit of a DSO probe

The equivalent circuit of a probe is as shown above, compensation adjustments are provided for proper impedance matching.

Probe check

The probes have to be checked before they are used for measurement. This is done to verify that the probes themselves are not distorting the signal. The DSO has an inbuilt way to do this using the probe check terminal. The probe check terminal generates a constant square wave (1kHz, 5V). To check the probe connect the ends of the probe to the probe check terminals, do autoset and observe the signal on the DSO screen. If the observed waveform is a square wave of 5V amplitude, 1kHz frequency and without any deformation then the probes are working properly. If the waveform observed is deformed or noisy or of a different amplitude then the probes are not working properly.

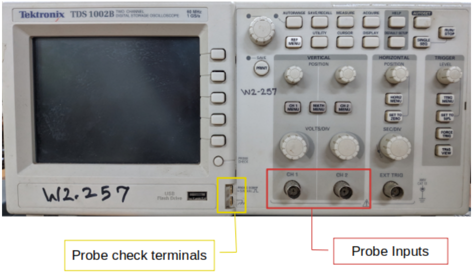

Figure 10: Probe check

Probe check

- *Deformed waveform* means that the probes are not properly compensated. Probe compensation is required to properly match the input impedance of the oscilloscopes input channel circuitry. This input impedance is typically 1 Meg ohm shunted by a small capacitance. The oscilloscope probe contains a variable capacitor that is used to tune the probes cable and distributed capacitance to match the input impedance of the scope.

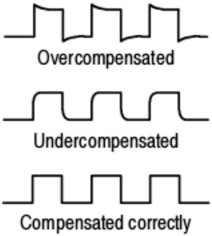

Figure 11: Waveforms observed and their corresponding conditions[1]

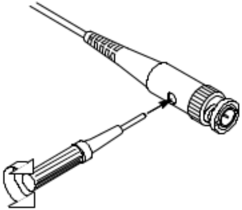

Figure 12: Manual probe compensation[1]

- *Waveform with noise* can be due to loose contact or a faulty probe, try changing the probe.

Probe check

- If the observed *Waveform is of a different amplitude* (other than 5V) then check the attenuation setting of the probe, it may be in 10X or 1X mode. (When the Attenuation switch is set to 1X it will also limits the bandwidth (7Mhz) to use the full bandwidth of the oscilloscope attenuation have to be set to 10X). If the amplitude is different even after changing the attenuation setting on the probe, check the channel menu for amplification applied.

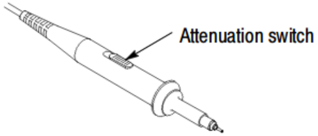

Figure 13: Attenuation settings on a probe[1]

DSO Specifications

Oscilloscopes have specification and performance parameters which dictates the usability of a particular instrument in a particular case. The performance parameters include:

- **Bandwidth:** The bandwidth specification tells you the frequency range for which the oscilloscope accurately measures.
- **Rise Time:** Rise time may be a more appropriate performance consideration when you expect to measure pulses and steps. An oscilloscope cannot accurately display pulses with rise times faster than the specified rise time of the oscilloscope.
- **Vertical Sensitivity:** The vertical sensitivity indicates how much the vertical amplifier can amplify a weak signal. Vertical sensitivity is usually given in millivolts (mV) per division.
- **Sweep Speed:** For analog oscilloscopes, this specification indicates how fast the trace can sweep across the screen, allowing you to see fine details. The fastest sweep speed of an oscilloscope is usually given in nanoseconds/div.

DSO Specifications

- **Gain Accuracy:** The gain accuracy indicates how accurately the vertical system attenuates or amplifies a signal.
- **Time Base or Horizontal Accuracy:** The time base or horizontal accuracy indicates how accurately the horizontal system displays the timing of a signal.
- **Sample Rate:** On digital oscilloscopes, the sampling rate indicates how many samples per second the ADC can acquire. Maximum sample rates are usually given in megasamples per second (MS/s). The faster the oscilloscope can sample, the more accurately it can represent fine details in a fast signal.
- **ADC Resolution Or Vertical Resolution:** The resolution, in bits, of the ADC indicates how precisely it can turn input voltages into digital values.
- **Record Length:** The record length of a digital oscilloscope indicates how many waveform points the oscilloscope is able to acquire for one waveform record.

References

- [1] TDS1000- and TDS2000-Series Digital Storage Oscilloscope, User Manual
- [2] Digital Storage Oscilloscope, Thomas Grocutt, April 2000
- [3] Introduction to the Digital Storage Oscilloscope (DSO), Dick Krieger, March 2017
- [4]Oscilloscope Fundamentals, Tektronix