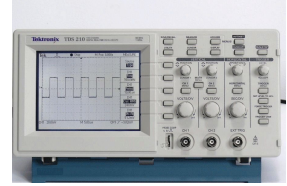


OSCILLOSCOPE BASICS

for the digital oscilloscope



The oscilloscope is a tool designed to rapidly measure the voltage applied to its input jacks and to display the measured voltage, usually as a function of time, on its screen. Because many physical phenomena can be precisely measured using sensors with a voltage output, and because of the fast response time of the oscilloscope, this tool counts among the most important for acquiring data in science and engineering.

We utilize two types of oscilloscopes, "scopes" for short, in our labs: old analog scopes, and newer digital scopes. Analog scopes have a cathode-ray tube (CRT) display. In the CRT models, a beam of electrons originating at the rear of the scope strikes the front screen, causing the phosphor to glow. In the usual use of this scope, this beam repeatedly sweeps across the front screen, starting from the trigger point at the left and ending at the right edge of the screen. The user sets the rate at which the beam sweeps across the screen with front-panel controls, and the input voltage is applied to a set of parallel plates that modulate the beam's vertical displacement via the Lorentz force. The digital scope, on the other hand, is essentially a computer optimized for voltage measurements. The input voltage is converted by an analog-to-digital converter into a series of bits that are processed by a computer chip, with the results displayed on the screen. Its controls and functions mimic those of the analog scope. You will learn to use the digital scope in this manual.

In this laboratory session, study Part I, and then carry out the procedures in Parts II to guide you through a series of exercises designed to acquaint you with some basic features of the scope.

Part I: Some Scope Fundamentals

The Oscilloscope Input: It is important to understand that the oscilloscope measures a *difference in voltage* between two electrical conductors, and that one of these two conductors is almost always directly connected to the Earth. Our oscilloscopes each have at least two input jacks, labeled channel one (CH1) and channel two (CH2), so that two signals can be simultaneously examined and compared. The jack, shown in Figure 3, is called a BNC connector, and it consists of an inner conductor (a 1 mm diameter gold-plated metal tube) and an outer conductor (a 1 cm diameter steel tube), separated by an insulator (teflon). The outer conductor is almost always the reference or *ground* level for the measurement. The voltage difference between the two conductors of the jack, as a function of time, appears as the *waveform* (also called the *signal* or *trace*) on the

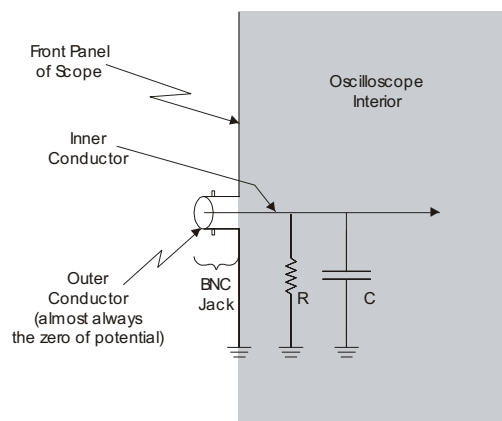


Figure 1. Schematic of an Oscilloscope Input Jack, seen from the side.

screen.

Important Note: The outer conductors of CH1 and CH2 are physically connected to one another as well as to the ground prong of the power plug which should be directly connected to a rod implanted into the earth.

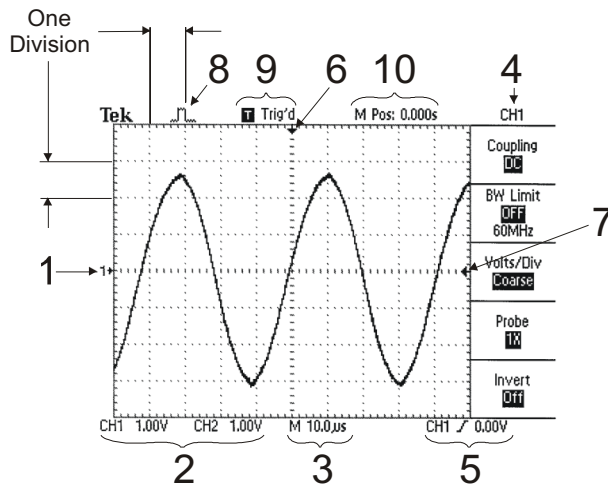


Figure 2. Digital Scope Display.

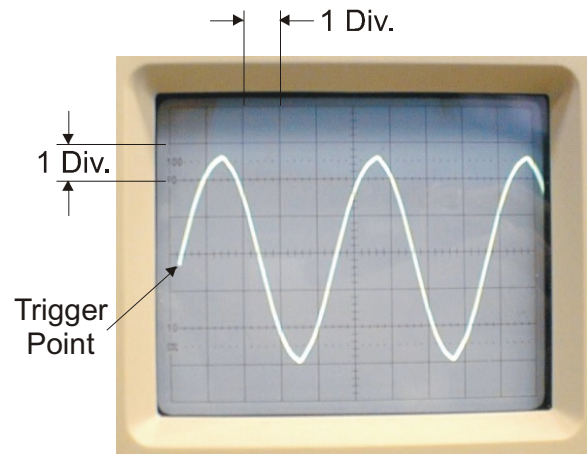


Figure 3. Display of the analog CRT Oscilloscope.

The Digital Scope Screen Output. Figure 2 shows the display screen for the digital scope, the Tektronix TDS 210. As you can see, the screen is divided by gridlines called *graticules*. One *division* is the spacing between adjacent graticules. The zero voltage, or *ground*, reference level is shown by Marker (1) in Figure 4, and the vertical scale factor is given by Readout (2), in units of volts per division. [The scale factor for CH2 is also shown, even though the CH2 is off.] Thus, the signal in channel 1 varies from -3.0 to $+2.6$ volts (\pm about 0.2 V). One adjusts the vertical scale factor with the CH1 VOLTS/DIV knob, and the ground reference level with the CH1 Vertical Position knob; both knobs are on the front panel (see Fig. 4). The horizontal scale is given by Readout (3), in units of time interval per division. From this figure we see that the waveform has a period of $(4.2 \pm 0.1$ divisions) \times 10.0 microseconds/division, or 42 ± 1 microseconds (e.g., 23.8 ± 0.6 kHz). The horizontal scale is adjusted with the SEC/DIV knob. The column (4) is the *menu* for Channel 1. There are 10 *menu buttons* on the oscilloscope. Pressing a menu button brings up a menu of up to five entries that are displayed in the area of Column (4). Each entry has a button to its right (shown in Fig. 4) to allow one to choose among the selections.

The Analog Scope Screen: Figure 3 shows the screen of the analog oscilloscope with same signal that is displayed in Fig. 2. The analog scope's screen is far less informative than the digital screen. The vertical and horizontal scale factors must be read from the settings for the VOLT/DIV and TIME/DIV knobs on the scope's front panel (shown in Fig. 5). For the analog oscilloscope, the trigger location is where the trace begins at the left of the screen, as shown.

Triggering with the digital scope: Items (5) through (10) in Fig. 2 are related to *triggering*. You direct the oscilloscope when and where to start collecting and displaying data (the voltage as a function of time) by setting the *trigger condition*. Readout (5) displays the current trigger condition: it is when the signal in CH 1 rises above 0.00 volts. The Markers (6) and (7) show the coordinates of the trigger condition on CH 1. That is, the oscilloscope displays the data starting from these coordinates and continuing to the right edge of the screen. Because it has a memory, the TDS 210 recalls the data collected prior to the trigger condition, and it displays this data from the left of the screen up to the trigger point. If the trigger condition does not occur, then either the waveform will not be displayed, or else an unstable waveform will appear (one that rolls across the screen, for example). Icon (8) shows the trigger acquisition mode (whether it is sampling, peak-detecting, or taking an average of many waveforms—usually you will work in sampling mode). Icon (9) shows the trigger status. Readout (10) describes the trigger vertical marker location, relative to the center vertical graticule.

There are three trigger modes, which you access from the TRIGGER MENU button. In Single mode, the oscilloscope acquires one waveform each time the RUN/STOP button is pressed and the trigger condition is detected. In Normal mode, the oscilloscope displays a waveform each time it detects a trigger. In Auto mode, the oscilloscope acquires and displays a waveform even when not triggered, but the waveform may be unstable.

In Figure 2, the trigger condition is set on the potential difference appearing in channel one, as indicated by Readout (5), but it can also be set on a waveform in channel two, from a separate signal applied to the EXT TRIG input jack on the front panel, or from the AC line signal. Commonly it is set on the signal in channel one or two. You set this choice in the trigger menu.

The word "coupling" appears on the trigger menu. This coupling, distinct from the AC/DC/GND coupling described below, allows you to filter the trigger signal used to trigger an acquisition of data. We will always use DC coupling, which passes all components of the signal to the trigger circuitry.

AC/DC/GND Coupling: As shown in Fig. 2, the first entry for the CH 1 menu is "Coupling." This coupling determines what part of the signal in CH1 passes into the oscilloscope. Your choices are AC, DC, and GND (ground). With DC coupling, the entire signal is transmitted into the oscilloscope. With AC coupling, any constant-voltage component of the signal is effectively subtracted, so that only the time-varying component is shown. With ground coupling, the trace on the screen is for 0 volts.

In Fig. 2, the displayed voltage is:

$$V = -0.2 + 2.8 \sin \left[\frac{2\pi}{42 \mu\text{s}} (t + 1 \mu\text{s}) \right] \text{ volts.}$$

The signal has a constant voltage component (−0.2 volts) that shifts the time-varying component of the signal (by two-tenth of a volt) below the ground level. Were the signal to be AC coupled, this shift would not appear. The signal is said to have a *dc offset* of −0.2 V.

Other Digital Scope Settings: To more closely examine and analyze your waveform, use the

capabilities accessed through the ten menu buttons. For example, you can fine-tune the vertical scale for channel 1 by first pressing the CH 1 menu button and then pressing the VOLTS/DIV selector button on this menu, changing the entry from coarse to fine. Manipulating the VOLTS/DIV knob on the front panel now makes only incremental changes in the vertical scale.

The signal-to-noise ratio of your waveform is improved by averaging your data. Use the ACQUIRE menu to select the AVERAGE mode, and set the number of averages high.

You can squint and count graticules to find waveform amplitudes. Or, you can use the MEASURE menu to select a parameter (amplitude, period, etc.) and have the oscilloscope measure and display these parameters for you. Great care must be exercised to interpret these values correctly. The digital oscilloscope only makes measurements on the set of data displayed on the screen. Always double check any parameters measured by the oscilloscope by the squint and count method, to verify the validity of any numbers obtained from the measurement menu.

The SAVE/RECALL menu allows you to save your setup or your waveforms to memory. Saved waveforms will be displayed only if you select REF A (or B or 1, etc.) to be ON at the bottom of the save/recall menu.

Describing Waveforms: The best way to characterize a waveform is to sketch the wave and label its parts. Almost always, the amplitude and frequency (or period) should be labeled. For trains of pulses, the pulse width and the separate between pulses should be labeled. The pulse width is specified by its full width at half-maximum amplitude.

Part II: Activities with the Digital Scope

IIA. Initialize the Scope to a known initial configuration:

- > Turn on the oscilloscope.
- > Disconnect the BNC cable from the CH1 input jack.
- > Press the SAVE/RECALL menu button twice.
- > Press the Setups Waveforms button (this is the first entry on the SAVE/REC menu at the right on the oscilloscope screen) so that Setups is selected (i.e., highlighted).
- > Press the RECALL FACTORY button. After a moment you should see a single trace at the center of the screen. Channel one should now be set for 1 Volt/Div and the timebase for 500 μ sec/div.

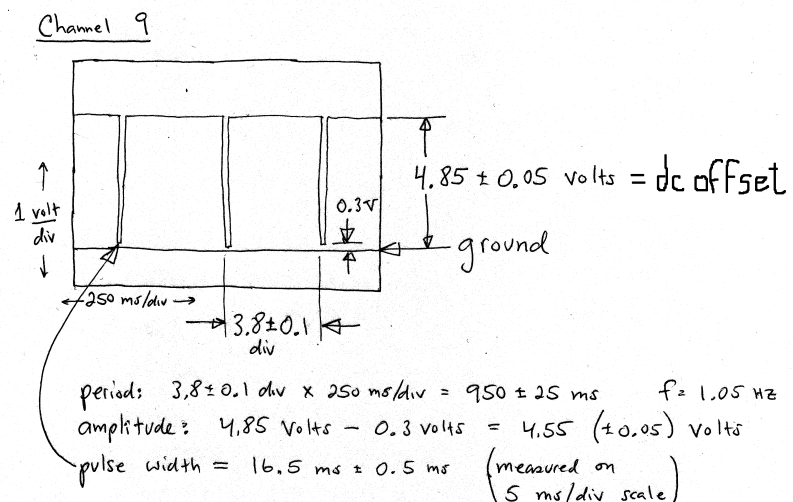


Figure 4. Example notebook entry for Parts IID and IIID.

IIB "Capture" the signal from Channel 1 of the Teachscope:

Set the settings so that they match the signal being applied (correct input jack and probe)

Connect the coaxial cable from the Teachscope BNC jack to the scope's CH2 input jack.

Note: CH1 on many of our TDS210 scopes have broken; so it safer to use CH2

Set the Teachscope to Channel one.

Press the Oscilloscope's CH2 menu button.

On the CH2 on-screen menu, set "Probe" to 1X.

Zoom out to a maximum value of volts/division, and use the longest sec/div scale, and the work your way in to the signal by decreasing the volts/div and the sec/div while adjusting the trigger.

Eventually you will observe the signal shown in Figure 2 and 3. At that point, the VOLTS/DIV knob will be around 1 V and the SEC/DIV about 10 μ s.

IIC. Explore the Digital Scope Controls:

Press the trigger menu button:

What is the current trigger condition?

On what signal is the trigger condition set?

What is the threshold voltage for triggering?

Rising or Falling?

What is the trigger mode?

Where on the screen is the start of the signal?

Set "slope" to "falling." Describe what happens to the waveform. Reset to "rising."

Set "source" to "CH1." Describe what you observe. Return to "CH2"

Set "mode" to "Single." Note that the trigger acquisition mode icon now reads "Stop."

Explanation: The trigger was set, and then the signal was captured, once. Now, even though the signal is being repeatedly input, the screen is frozen.

Remove the cable from the CH2 scope input jack to confirm. Replace it.

Press the RUN/STOP button several times and watch the screen carefully.

What do you observe happening? Why?

Reset "mode" to "AUTO."

Note: Leave the trigger menu coupling set for "DC."

Rotate the Trigger Level knob and observe what happens to the signal. Notice how the trigger coordinate markers [(6) and (7) in Fig. 4.] move as you adjust the trigger level.

Rotate the Horizontal Position control and observe the movement of the horizontal location of the trigger coordinates.

Press the CH2 menu button, and set coupling to "AC." What happens to the signal?

What happens when you set the coupling to "GND?" Return the coupling to "DC."

Note that pressing the CH2 button repeatedly toggles the display for CH2 on and off.

Press the HORIZONTAL MENU button. These menu entries allow you to examine a portion of the signal up close. Select the "window zone" entry, and use the two knobs in the horizontal section (SEC/DIV and HORIZONTAL POSITION) to adjust the vertical cursors to that only they frame about $\frac{1}{4}$ wavelength of the waveform.

Note: Many controls on the front panel, like the SEC/DIV knob, have multiple functions, depending on what menus are currently selected.

Select the "window" entry from the horizontal menu. You are now looking at the section of the signal that you framed.

Return to "main" in the horizontal menu.

Press the ACQUIRE menu button. Select "average" from the menu.

What happens to the signal?

Return to "sample" mode.

Press the CURSOR MENU button.

Set "Type" to voltage, and notice the horizontal cursors on the screen.

The two vertical POSITION knobs move the cursors.

Use these cursors to measure the peak-to-peak amplitude of your signal and record the amplitude (including uncertainty!).

Turn the cursors off.

IID. Test your Skill: "Capture" and Identify the 12 signals from the Teachscope.

Your challenge is to "capture" and describe the remaining 11 waveforms from the Teachscope. The trick is to intelligently search for the correct settings, especially for the VOLTS/DIV, TIME/DIV, and Trigger settings, that will display the waveforms. For each waveform, you should be able to

- match them with the signals shown in the appendix;
- determine indicate the amplitude, period, and DC offset;
- indicate the pulse width (FWHM) of each pulse in the waveform; and
- indicate any other information that deemed relevant to describe the waveform.

If you are at all uncertain about any of your findings, have a colleague check your results.

There are sometimes problems distinguishing between actual signals and "noise." In this exercise, signals with amplitudes of 50 mV or less are usually pulses of noise (or unwanted signals) from the microprocessor that generates the signals inside the Teachscope. Your instructor may have suggestions to ease any difficulties in capturing the signals.

Appendix: The Teachscope Waveforms

There are twelve different models of the Teachscope scattered throughout the laboratory. Channels 1 and 2 are identical on all models. Channel one is a sine wave and channel two is a square wave. Channels 3-12 are scrambled (by channel number, frequency, dc offset, amplitude, pulse widths, and repetition rates) among the different Teachscope models. The ten scrambled waveforms are as follows:

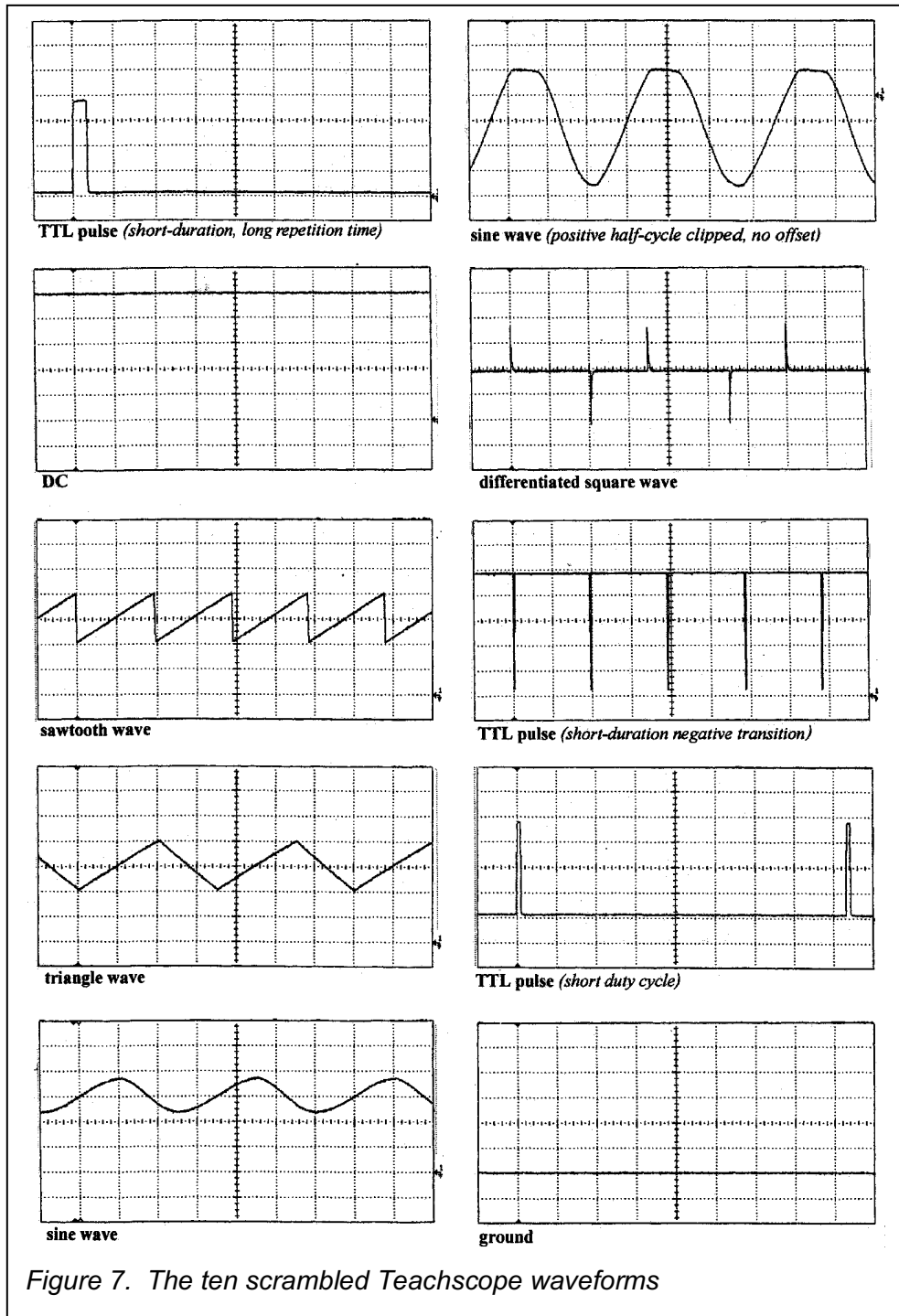


Figure 7. The ten scrambled Teachscope waveforms