

# California State University, Fresno

## Department of Electrical and Computer Engineering

### ECE 90L Principles of Electronic Circuits Laboratory

#### Experiment No. 1: Introduction to the Digital Storage Oscilloscope

### Introduction

Welcome to the Principles of Electronic Circuits Laboratory. You will find the following equipment on your lab bench:

- Tektronix TDS 210 or 1002 Two Channel Digital Real-Time Oscilloscope
- GW Instek GDM-8245 Digital Multi-Meter (DMM)
- GW Instek SFG-1013 DDS Function Generator
- Mastech DC Power Supply HY3005D-3 Function Generator
- Dual  $\pm 12$  V power supply with breadboard

Within the cabinets are: BNC cables, banana plug adapters, variable resistors, capacitors, and inductors, additional power supplies, and other equipment that will be made available to you over the course of the semester as you perform your experiments. Identify all of the equipment (listed above) on the lab bench before proceeding.

### Objective

The first experiment is intended to be an introduction to some of the hardware available to you in the laboratory—specifically the Tektronix TDS 210 or 1002 oscilloscope, the GW Instek GDM-8245 Digital Multi-Meter (DMM), and the GW Instek SFG-1013 DDS Function Generator. An oscilloscope (scope) is an electronic instrument that displays a voltage input as a function of time, and is typically used to display and measure repetitive waveforms or transient signals. It is one of the important diagnostic tools that can be used by an Electrical or Computer Engineer. In the process of learning about the functionality of an oscilloscope, you will also learn how to measure the voltage and period/frequency of various signals.

### The Tektronix TDS 210 Oscilloscope

Oscilloscopes are used by engineers and technicians to display voltage waveforms and signals as a function of time. Older displays consist of a glass cathode ray tube (CRT), an electron gun,  $x$ - and  $y$ -deflection plates, and a phosphor screen that emits light when struck with a focused electron beam. The spot of light can be moved by horizontally and vertically deflecting the beam of electrons — if moved rapidly enough, the moving spot will have the appearance of displaying an image on the screen. Horizontal deflection typically occurs from left to right at a constant speed called the sweep rate, while vertical deflection occurs in response to the strength of the applied voltage, resulting in a plot of the waveform. The horizontal sweep is generated by applying a triggered, sawtooth voltage waveform (created internally) across the  $x$ -deflection plates. Although newer LCD screens on digital oscilloscopes do not use a CRT, understanding the principles of older oscilloscopes is beneficial toward learning how the current generation of digital scopes operate.

Figure 1 illustrates the “sawtooth” voltage waveform applied to the horizontal deflection points. At point  $A$  of the cycle, the beam starts to sweep the screen, uniformly, from left to right. At point  $B$ , the beam passes through the center of the screen and, at  $C$ , moves to the end of its trace on the right. The beam then quickly “jumps” back to the starting point at  $A'$  within a few nanoseconds, where a new cycle begins. Both the sweep rate and the vertical sensitivity can be adjusted by using controls on the front panel of the oscilloscope, an example of which is shown in Figure 2.

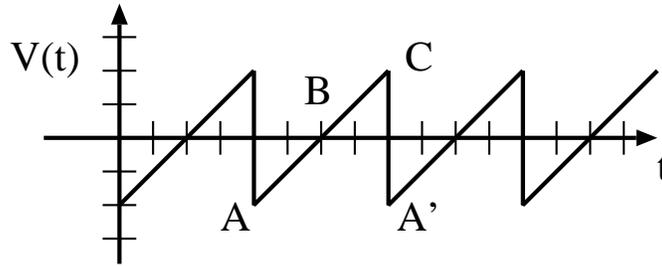


Figure 1: The “sawtooth” shape of the sweeping voltage  $V(t)$ . At point  $A$  of the cycle, the beam starts to sweep the screen, uniformly, from left to right. At point  $B$ , the beam passes through the center of the screen and, at  $C$ , is at the right end of the trace. The beam then quickly “jumps” back to the starting point at  $A'$  within a few nanoseconds, where a new cycle begins.

### Display Controls

To begin, turn on the oscilloscope by pressing the **POWER** button on the top of the device. Because the Tektronix 210/1002 is a dual input oscilloscope, you can choose to display a voltage waveform from either 1 of 2 inputs (or both simultaneously), which are marked **CH1** and **CH2**, respectively, on the front panel. Repeatedly pressing the **MENU** button for **CH 1** will turn the scope trace for Channel 1 **ON** and **OFF**. Likewise, pressing the **MENU** button for **CH 2** will turn the scope trace for Channel 2 **ON** and **OFF**. You have the option of displaying one of the scope traces at a time, or both simultaneously if multiple signals need to be measured. Initially, we are only interested in looking at the voltage on Channel 1, so press the appropriate **MENU** buttons to turn **CH 1 ON** and **CH 2 OFF**. Under the **TRIGGER MENU**, make sure that the **Auto** option is selected (you can toggle between options under **Mode** using the 2nd soft key button from the bottom, just to the right of the LCD). Also, make sure that the **Edge** option is selected, you are using a **Rising Slope**, your Source input is **CH1**, and you are using **DC Coupling**. Next turn the **SEC/DIV** knob to  $250 \mu\text{s}$ , and make sure the **VOLTS/DIV** knob for **CH 1** is turned all the way to the left.

After the scope warms up, you will see a horizontal line on the screen. If you cannot find the beam, use the **VERTICAL POSITION** knob to center the line at **0.00 divs (0.00 V)**. Because we are only looking at **CH1**, only the left-hand knob for the **VERTICAL POSITION** will be useful. Rotating the knobs applies a constant (negative or positive) voltage across the horizontal/vertical deflection plates, causing the beam to move horizontally/vertically on the screen—depending on the applied voltage (how far you turn the knob). Experiment with the knobs for a bit to move the trace to arbitrary locations on the display. Can the display be completely moved off the screen? What happened, and why? Explain this in your lab notebook.

Once the trace has been centered, use the **DISPLAY** option to adjust the brightness of the trace using the **Contrast Increase** and **Contrast Decrease** buttons. Repeat the process for **CH 2** as necessary, but this time center the trace toward the top of the screen. Once **CH 2** has been adjusted, press the **MATH MENU** button and select the **-** Operation. Select **CH1-CH2** and you will see a third trace displayed on the screen, which is the algebraic subtraction of the two signals. This corresponds, physically, to the vector subtraction (or interference) of two parallel signals. You can also select **CH2-CH1** if you wish, or choose to add the two signals together by selecting **+** under Operation. By adjusting the **VERTICAL POSITION** of either beam, you will see the vector addition or subtraction move as well. Once finished, press the **MATH MENU** soft key button once more to turn off the Math Operation.

Next, press the **CH 1 MENU** button and be sure that the Coupling is set to **Ground**. Repeat for **CH 2**. Then adjust both **VERTICAL POSITION** knobs so that the beams are exactly centered at **0.00 div (0.00 V)**. Then press the **DISPLAY** button and change the **Format** option from **YT** to **XY**, which will turn your line into a dot (you will not be able to see it unless you adjust one of the **VERTICAL POSITION** knobs). In this mode, the oscilloscope is capable of plotting two-dimensional graphs representing a function  $y = f(x)$ . The plot here is achieved by eliminating the variable time  $t$  between the two functions  $f(x)$  and  $y(t)$ , where  $x(t)$  is the **CH 1** input signal and  $y(t)$  is the **CH 2** input signal. The physical meaning of this operation is the vector summation (or interference) of the two perpendicular signals. When both signals are periodic, the resulting graph is known as a “Lissajoux” figure. Press the **Format** button once again to return to the previous mode of operation **YT**.



Unlike **Ground**, when the **Coupling** button is in the **AC** position, only the DC (constant) component of the signal will be filtered from the input, which means that the AC (changing) component of the signal will still be displayed. And finally, it is only when the button is in the **DC** position that the oscilloscope will display the actual waveform input into the device—which includes *both* both the DC and AC components of the signal. The advantage of using AC coupling over DC coupling occurs when you are trying to measure small variations of a signal that contain a large DC bias. As an example, consider the relatively small “ripple” (5 mV) on the output of a typical DC power supply (say 5 V). With DC coupling, increasing the input sensitivity in an attempt to see the small variation will send the trace off the top of the screen. However, with AC coupling, the 5 V level will be suppressed and the sensitivity can be greatly increased while retaining the trace on the center of the display.

Use the 5 V DC power supply to confirm this behavior (turn ON the power to the Mastech DC Power Supply HY3005D-3). Use a BNC-banana adapter in conjunction with a BNC cable to hook up the +5 V@3A voltage supply on the Mastech Power Supply to the oscilloscope. Make sure the tab marked **GND** on the banana plug adapter is plugged into the ground plug of the voltage supply. However, before you attach the output of the power supply to the scope, first verify that you have a 5 V signal by connecting the output to the leads of the GW Instek Digital Multimeter (DMM). Note that you must plug the leads for the DMM into the appropriate plugs (and have selected the DC voltage button) to measure the voltage of the power supply. Once this has been done, using **DC** coupling on the oscilloscope, re-verify that the output voltage of the power supply is correct. If you then try to examine the ripple more closely by increasing the sensitivity (turning the **VOLTS/DIV** knob to the right), the trace will soon driven off the edge of the display. With **AC** coupling, the DC level is suppressed and the ripple can be observed in detail; measure its amplitude and compare it to the DC level. What happens if you gently wiggle the cable? Why?

### Trigger Controls

The triggering circuitry is the means by which the oscilloscope is able to provide repeated “snapshots” of a repetitive signal. By controlling the threshold voltage of triggering and slope polarity, the user is provided with great flexibility in the appearance of the display and the utility of the scope for capturing elusive signals. Some further details of scope operation are required to understand the concept of triggering.

As mentioned previously, the horizontal sweep of the electron beam is controlled by the timebase circuitry (the **SEC/DIV** knob). The beam sweep is driven by the application of a ramp voltage to the horizontal deflection plates, which serves to move the beam across the face a distance proportional to the elapsed time from a trigger event. The occurrence of the trigger event marks the start of the linear ramp. By slowing the timebase to about 1 s/div, the actual deflection of the beam can be slowed to the point where the resulting luminous waveform can be observed crossing the display from left to right.

To examine the effects of the trigger settings on the triggering of the display, use the output available on the SFG-1013 function generator to generate a 600 Hz triangle wave (use the **WAVE** button) as the input signal for **CH 1**. Hook up the input to **CH 1** on the scope and increase the sensitivity to 5 V/div. Adjust the amplitude on the function generator so that the amplitude of your triangle wave is exactly 5 V (peak to peak), and select a 500  $\mu$ s/div sweep speed on the oscilloscope. With the trigger **Source** set for **CH1** (note there are 5 options—**CH1** for Channel 1, **CH2** for Channel 2, and **Ext** for an external trigger, **Ext/5** which divides the external trigger by 5, and **AC Line** which expects an AC signal), the **TRIGGER LEVEL** knob rotated to be just above 0 V, and the **Slope** option set to detect on the rising edge of a pulse, a stable trace showing the triangle wave should appear. Adjust the horizontal position of the trace until its starting position is seen on the display. Next, adjust the **TRIGGER LEVEL** by adjusting the knob to the left and right. Notice that as the threshold for the trigger is increased (moving the trigger toward the right), the starting point of the trace changes (in this case toward the left). Likewise, adjusting the threshold for the trigger toward a negative voltage (moving the trigger increasingly toward the left), the starting point of the trace moves in the opposite direction. Refer to Figure 3 for a pictorial representation of the various triggering combinations. Switch the trigger **SLOPE** and observe the changes to the displayed waveform. The **SLOPE** selector chooses whether the trigger event will occur when moving through the threshold from a high voltage to a low voltage (falling edge/negative slope) or from a low to high voltage (rising edge/positive slope). Refer again to Figure 3.

Finally, setting the trigger level too low or too high (outside the bounds of the signal amplitude) results in loss of triggering and an unstable “running” waveform. You can observe this if you decrease the input amplitude of the signal

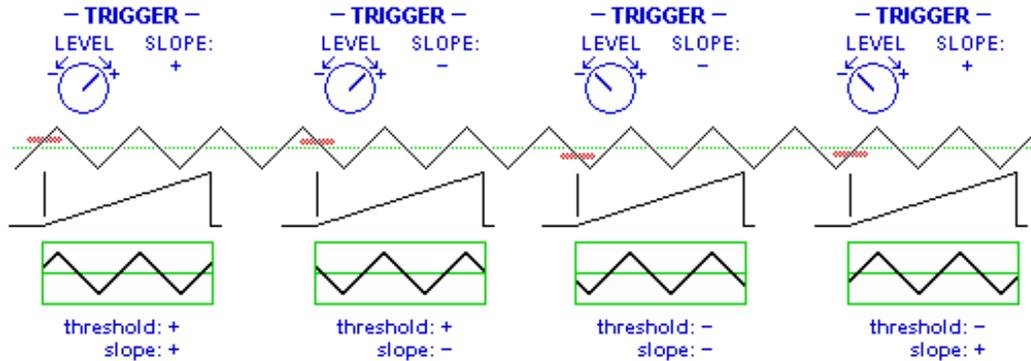


Figure 3: Effects of slope and the threshold on triggering.

by using the **AMPLITUDE** knob on the function generator. Decreasing the **TRIGGER LEVEL** down toward the voltage level of waveform will restore a stable trace. Notice also what happens if you switch the trigger **Source** to **CH2**. Explain your results for both cases.

Next, examine of the effects of the external trigger selection **EXT**. It is with this setting that an additional, better-conditioned signal can be used to trigger the scope while observing a relatively weak signal—one that is too weak when using internal triggering, as discussed above. For example, you may again observe the ripple on the DC power supply or the stray signal picked up by a loose lead, using the 600 Hz, AC signal to trigger the scope externally. External triggering is accomplished by connecting the signal to be used for triggering to the external trigger input **EXT TRIG** of the scope and selecting **Ext** on the trigger **Source** button.

When you are finished, display a 600 Hz, 5 V peak-to-peak sinewave using **CH 1** on the scope. Make whatever adjustments are necessary to display a stable waveform. Then start from 500  $\mu\text{s}/\text{div}$  and increase the timebase to larger settings (slower sweeps), which is simply a longer “snapshot” of the signal being displayed, but with less detail. Remember that the 600 Hz signal has not changed; the beam sweeps more slowly, so only more transitions are displayed. Moving to much smaller timebase settings (faster sweeps), more detail can be seen at the expense of the “big picture”. However, notice the decrease in intensity of the trace as the electron beam moves more swiftly over the screen at faster time base settings. Finally, adjust the frequency of the sinewave from 6 Hz all the way to 6 MHz by powers of 10 and adjust the time base setting as necessary to continue to provide a “clean” display. Comment on your results.

Returning to a timebase around 500  $\mu\text{s}/\text{div}$  and a frequency of 600 Hz, confirm with the oscilloscope that the period of the 5 V AC signal is 600 Hz. Adjust the trigger level if necessary to achieve a stable display. Measure the horizontal distance between the two closest points where the waveform crosses the baseline (0 V level) with the same slope. (Note that there are two zero crossings per cycle, each with different slope.) Multiply this number of divisions by the timebase setting (time/div); the resulting time T is known as the period.

How short a time can be read by this oscilloscope? This can be estimated by the smallest timebase setting. In practice, this setting may result in a trace too weak to be seen—thus the so-called writing speed of the oscilloscope may also limit the shortest time that can be accurately determined, as will the bandwidth of the input amplifiers.

### Dual Trace Operation

The availability of two independent input channels greatly facilitates comparison of two signals. To do this, turn on both Channels. While displaying the 5 V, 600 Hz sinusoidal signal on **CH 1**, using it as a trigger source, observe the signal from a loose BNC cable on **CH 2**. You will probably observe “spikes” and other types of electrical noise, depending on the sensitivity level. You should attempt to explain why this noise is “locked” to the signal on **CH 1**. For a more dramatic effect, touch your finger to the **CH 2** input conductor from the BNC cable. The noise probably has much higher amplitude and is still locked to the calibration signal. Finally, while holding the bare lead in one hand, touch the metal frame of the table and observe the noise signal on **CH 2**. Attempt to explain your observations.

Next, apply the 0 - 20 V input from the Mastech power supply to **CH 2** on the oscilloscope using the red and black banana plugs, making sure that the plug with the **GND** tab is attached to the common, black output from the power supply. While displaying both Channels on the oscilloscope, adjust the Coupling control to **DC** for both channels, and observe your results when using the **MATH MENU** options. As you do so, adjust the amplitude of the DC signal using the + **VOLTS** knob on the dual power supply. What happens, and why? Finally, try various combinations of **AC**, **GND**, and **DC**, and observe your results. When the knobs are in the **AC** position and you vary the amplitude of the DC voltage from the dual power supply, what happens? Why?

### **X-Y Mode**

Once you are comfortable with the dual trace operation of the oscilloscope, set the amplitude of the DC signal into **CH 2** to 5 V and select **XY** operation of the scope using the **Format** option after hitting the **DISPLAY** button. Now, the voltages into **CH 1** and **CH 2** are functions of each other. Can you justify which channel is a function of the second channel, based upon what you see on the screen? Next, switch the inputs, so that the sinusoid is input into **CH 2** and the DC voltage into **CH 1**. What changed, and why?

### **Additional Display Options**

Next press the **MEASURE** button and note that there are various measurements about the waveforms that can be displayed for both Channels 1 and 2. Experiment with the various measurement options and explain as many as you can in your laboratory notebook. Next press the **CURSOR** button and choose **Time** under the **Type** option. You can then move the two **VERTICAL POSITION** knobs to give you a measurement of the time difference between the two vertical lines. This can be used to help you make measurements in time. Similarly, if you choose **Voltage** under the **Type** option, you can make similar measurements with respect to voltage. Once finished, turn the **CURSOR Type** to **Off**.

Finally, press the **ACQUIRE** button and note that you can continually sample the voltage versus time plot by selecting **Sample**, choose to display the peak voltages by selecting **Peak detect**, or display an average of a number of voltages by selecting **Average** and then adjusting the **Averages** button. Explain the difference between the waveforms for each case, and describe what the oscilloscope is doing.

### **Conclusion**

Provide a brief conclusion based upon what you have learned today and both partners will turn in the lab book at the beginning of the next laboratory session. No group report is necessary for this laboratory.

### **Acknowledgments**

In addition to my own work, several people have allowed me to adapt portions of their lab manuals into this laboratory procedure. I would like to gratefully acknowledge the following people for giving me permission to use their materials:

*Dr. Larry Owens, Professor, Electrical and Computer Engineering Department, California State University, Fresno.*

*Dr. George Watson, Associate Dean, College of Arts & Sciences, University of Delaware.*

*Dr. Jeffrey Urbach, Associate Professor and Chair, Department of Physics, Georgetown University.*