DSO
Digital-Storage-Oscilloscope

revised August, 2021

(You will do two experiments; this one and the Charge-to-Mass Ratio of the Electron experiment. Sections will switch rooms and experiments half-way through the lab.)

Learning Objectives:

During this lab, you will

1. learn how to measure time-varying electronic signals with an oscilloscope (DSO).
2. estimate the uncertainty in measurements made with a DSO and estimate the uncertainty in quantities that are calculated from quantities that are uncertain.

A. Introduction

The oscilloscope, DSO or simply scope, is used in many fields of basic and applied research and in electronics development and repair. It is generally the tool of choice for examining signals that change with time on a scale of 1 second to 1 nanosecond. The sketch of the scope in Figure 1 includes a triangular wave signal, a voltage that, as a function of time, continually (*and linearly*) ramps up and down between two limiting voltages. The **operation of the DSO is described in detail in Appendix IX. You should read that appendix before attempting this lab**.

In this lab, you will learn how to use the DSO to investigate various types of time-dependent phenomena that you will encounter in your studies of electricity and magnetism. You should also become more comfortable with certain aspects of sine waves, such as phase differences and the relation of frequency to period, that are critical to understanding interference effects and electromagnetic radiation.

This experiment requires that you **complete the worksheet worth 30 points that can be found in Appendix XI. Attach the worksheet and graphs from Lab #3A to the paper from Lab #3B and use one cover sheet for both.**

B. Apparatus

You will be using a dual-trace oscilloscope, a special scope probe designed to mate with the scope, a ‘doorbell’ transformer, function generator, microphone and tuning forks.

Figure 1 is a diagram of the front panel

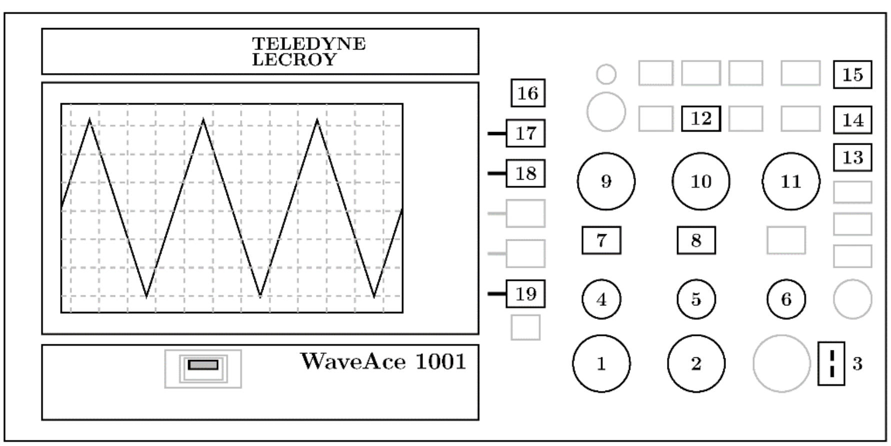

Figure 1: Oscilloscope Controls

of the scope, with labels for the important controls. A photograph of the scope is posted on the lab web site and in Canvas.

The **scope probe** is a cable with an end that resembles a pen with an alligator clip attached to it by a short wire. The alligator clip is for the ground connection and is not needed when the scope probe is connected to "ground-referenced" electronics but is used to establish the ground of other objects you may be measuring. (***DO NOT connect this alligator clip to a signal output; it will cause a short circuit!***)

The signal connection of the scope probe is a spring loaded hook located inside the tip of the probe. This hook is exposed by retracting its cover (*do not unscrew or remove the cover*). Some but not all probes let you switch between 1X and 10X where the 10X divides the signal by a factor of 10. If your probe has this option, be certain to use the 1X setting.

C. Familiarization and Use

Turn the oscilloscope POWER switch on. It is located on the top left of the device. This is a dual-trace oscilloscope (*it has two quasi-independent inputs*), so you must **select channel 1 [CH 1 (7)] for the following measurements**. (*The numbers in parentheses refer to the control locations shown in Figure 1 and are described in Appendix IX.*)

The scope is usually used to plot a changing voltage as a function of time, with the instantaneous voltage read along the vertical or y-axis while time is measured along the horizontal or x-axis of the display. The grid lines are referred to as divisions or DIV and one division is 1cm by 1 cm in size.

The Horizontal sweep control (11) sets the time it takes the scope beam to scan across the screen horizontally. On the display, the value for Time/Div can be read off the bottom center, and it is labeled "M" for no apparent reason.

The Vertical gain control [(9) for Ch1 and (10) for Ch 2] controls the amplification of the signal or how large a given signal appears relative to the vertical or y-axis. It corresponds to the Volts/Div label on the right side of the display. Note that there are two Vertical controls (one for each channel) but only one Horizontal control. The value for Volts/Div can be read off the bottom left corner of the display.

Each of these Vertical or Horizontal controls can either be turned or pushed in. If the Vertical knob is pushed in, it switches between a fine and coarse signal. If the Horizontal knob is pushed in, it splits the display into two windows. You will want to push it in again so it returns to the single window.

C.1. Square Wave - Time and Voltage Measurement

The scope has a calibration output CAL(3) at the bottom right corner of the DSO which supplies a 3 $V_{\text{peak-to-peak}}$ (V_{pp}), 1 kHz square wave signal. The term *peak-to-peak* means that the signal is measured from its absolute maximum to its absolute minimum, or top to bottom. This CAL signal can be used to check the calibration of the scope settings, but we will actually be using it to check whether you know how to make proper measurements with the scope. If the measurements you are instructed to make below do not agree with the expected values, ask for help.

Use the scope probe to connect the CAL tab to the CH1(1) input of the oscilloscope. *DON'T USE THE ALLIGATOR CLIP on the probe to connect to this tab! This shorts it out. Use the hook inside the retractable tip to connect to the top, 1kHz contact. The alligator clip should be connected to the ground, which is the*

bottom contact below the 1kHz contact. **Connect the BNC plug on the other end of the scope probe to the scope's Channel 1 (1) input**. This input is a BNC jack, a common form of coaxial connector. To plug the BNC cable into the oscilloscope, align the slots of the BNC plug of the scope probe to the pins of the BNC jack on the scope. Push the plug into place and rotate it 90° to lock it in position.

There should be a menu displayed on the right side of the DSO screen. If it is not there, press the Menu ON/OFF button.

If your image of the square wave is not stationary, press the $\frac{RUN}{STOP}$ button. Once you have a stable image, **adjust the Horizontal dial until you see a sequence of a few cycles of a square wave on the screen. Adjust the vertical gain (9) and vertical position (4) so that the signal almost fills the screen vertically**. Read the VOLTS/DIV off the bottom left of the screen ("CH1= ____ mV") and the TIME/DIV from roughly the middle of the screen ("M _____ µs") and record them in your notebook.

You will have to estimate the accuracy of many of your measurements. You may assume that any errors in the scope electronics are negligible and that the only errors are due to your ability to judge the position of a signal on the screen. **For some arbitrary signal, how well do you think you can determine its position, in terms of either mm, cm, or DIV** (*your choice of units*)? **Later, when you need to convert your estimate of this error into an error in time or voltage, just multiply by the setting of the TIME/DIV or VOLTS/DIV, respectively.**

C.1.1. Time Measurement

The period of the square wave, as for any repetitive wave, is the time it takes to repeat itself. **Measure the period of the calibration square wave by multiplying the length, in cm or DIV, of one or more periods times the setting of the TIME/DIV.** (*Measure as large an image as possible to obtain the highest possible precision in your time measurements. If there are 7 full periods on the screen, measure the time for all 7 and divide by 7 to get the period; in this case you will also have to divide your error estimate by 7. Alternately, change the TIME/DIV so that 1-2 periods fill your screen.*) You can shift the signal horizontally using the *x*-position control (6) to start or end the sweep at some convenient mark on the display. Use the period you measured to **calculate the frequency (*and estimated error*) of the calibration signal.** Remember that frequency is just one over the period. (Pay attention to units!) To find the error in the frequency, you should use the 'derivative' method, $\delta(1/T) = (\delta T)/T^2$.

C.1.2. Voltage Measurement

Determine the peak-to-peak voltage of the square wave by multiplying the measured height of the square wave by the setting of the VOLTS/DIV. *Remember too that more careful measurements can be made if you adjust the calibrated VOLTS/DIV (9) knob so that the signal almost fills the screen vertically.* Compare this result with the expected value of 3 V_{pp}.

C.2 Measurements of a Sine Wave

You have been looking at a square wave. Another common signal is a sine wave [$V = V_0\sin(\omega t + \varphi)$] such as the 110-volt AC power line. You will use a doorbell transformer to reduce the signal to a safer level.

Connect the center and either one of the two outer terminals of the transformer to the CH 1 input of the oscilloscope. Press the blue "Auto" button (13) to find the signal. (*It probably won't be a very good sine wave, but that's what you often have at* *an outlet.*) **<u>Sketch the waveform</u>** (*don't forget to label the scales on your sketch*). **<u>Measure and record the period and calculate the frequency</u>. <u>Measure and record the peak-to-peak voltage of the signal.</u>** You will have to do this in two ways, first by reading the values off the DSO display, and then by doing the calculations the way you did them with the square wave, by counting horizontal and vertical divisions and multiplying them by TIME/DIV or VOLTS/DIV.

<u>Use a DMM set to measure AC voltages to check the voltage output of the transformer</u>. Are your DSO measurements of the transformer voltage consistent with the DMM measurements? This probably won't appear to be the case at first, the meter should read less than half of your scope measurement. One reason for this is that your oscilloscope measurement was a *peak-to-peak* voltage. This is twice the *amplitude* of the sine wave, the V_0 term in the equation $V_0\sin(\omega t + \varphi)$. Another reason is that the DMM measures the RMS (*root mean square*) voltage, given by

$$V_{RMS} = \sqrt{<V^2>} = \sqrt{\frac{\int\left[V_0\cos(\omega t)\right]^2 dt}{\int dt}} \quad (1)$$

where the integrals are over one period. V_{RMS} is more closely related to the strength of a signal than is V_0; although the two are the same for a DC signal, they vary significantly for various types of AC signals. The integral of $\cos^2(\omega t)dt$ divided by the integral of time, over any number of whole periods, is just ½. V_{rms} is proportional to the square root of this factor or the square root of ½. Taken all together, $V_{pp} = 2\sqrt{2}\,V_{rms}$. Knowing this, <u>are your scope and DMM measurements consistent</u>?

You can view a cleaner sine wave using a function generator. **Connect the CH2 output of your function generator to channel 2 of your scope, leaving the transformer connected to channel 1. Turn on the function generator. Press the Output button above the Ch2 output. Press the CH2 button on the DSO to display Channel 2, and the blue AUTO button (13) to see both signals well.** The top of the display will be the channel 1 signal and the bottom of the display the channel 2 signal.

On the function generator, make sure that Channel 2 is selected (**CH1/2** to the top right of the display). Press it until you can read "CH2 Waveform" in the middle left of the display. **Set the frequency to 60 Hz by using the dial or keypad.** (You will first have to make sure that "Freq" on the top right of the display is highlighted. If it isn't, press the button to the right of it. If you use the keypad to set the value of the frequency, you set the units by pressing the button to the right of the unit you want to select.) Set the Amplitude to the same value as the V_{pp} of the doorbell transformer (value that you read off the DSO – you should have it in your notes, as well). To do that select "Ampl" by pressing the button to the right of it. Then use the keypad or dial to set the value and select the unit.

Note that on the DSO, the VOLTS/DIV for the two channels may not be the same, so the amplitude of the sign waves could be different. You can fix that by using the Vertical dials.

Now, switch the scope to XY mode. To do that, press the Display button (12) go to "Next Page" by pressing the knob next to the words (19), and press the button next to the YT display (and under the "Menu ON/OFF" button (17). The display next to it should now read "XY.") That will display the amplitudes (voltages) of the two signals with respect to one another.

C.3. Lissajous Figures

An alternate method for comparing two signals is to **plot one on the horizontal (X) axis and the other on the vertical (Y) axis.** This will produce Lissajous figures which allow for very quick visual comparison of the relative frequency and phase of two signals (*but which are rarely used except as special effects in science fiction movies*).

On the DSO, you should now see a circle and a diagonal straight line at an angle of roughly 45º with the horizontal alternately appear on the screen.

To understand what is happening, think back to your high school trigonometry course. If someone told you to make an *xy* plot as a function of time of a signal given by $x = A\cos\omega t$ and $y = A\cos\omega t$, where A is some arbitrary amplitude, ω is an angular frequency and t is time, hopefully you can see that you would just trace out a 45º line, since $x = y$ at every instant of time. What changes if $x = A\cos\omega t$ and $y = A\sin\omega t$? Now you would sketch out a circle. What's the difference? It's just the phase difference between the x and y signals, since the *sin* function is just the *cos* function shifted by 90º. What happens if the phase difference between x and y slowly changes with time? The pattern slowly drifts from a line to a circle and back. **Sketch the pattern you observe on the scope at a few representative times as it changes.**

Switch the oscilloscope back to YT mode and note the gradual phase change of the oscillator signal relative to the transformer signal. The signal on which the scope is triggered should remain steady while the other sine wave gradually drifts to the left or right. The speed of this drift corresponds to the rate at which your Lissajous pattern changes shape. Try adjusting the frequency on the function generator to make the drift larger or smaller, and switching the DSO back and forth between XY mode and YT mode to observe the corresponding effect on the Lissajous pattern.

Next, slowly increase the frequency of the signal from the function generator until it is approximately doubled, then fine-tune it to produce a fairly stable Lissajous pattern. Measure the frequency with the scope, (go back to YT mode so you can see a sine wave and can figure out the period and frequency that way) **confirm that it is roughly 120 Hz and sketch this Lissajous pattern.** (*It's a lot harder to explain the shape of a Lissajous pattern when the frequencies of the two signals are different but the drift in the pattern is still related to a drift in their relative phases.*)

Vary the frequency between 60 - 120 Hz and locate the simplest, nearly stable pattern in this range. Measure this frequency and sketch the Lissajous pattern. (*In principle, there are an infinite number of patterns in this range of frequencies but one should stand out as simpler than any others.*)

Try to analyze the experiment and/or the theory to determine what conditions on the frequencies are necessary for a relatively simple, stable pattern to appear, ignoring the drifts caused by slowly varying phases.

C.4. Sound Waves

Disconnect all of the input leads from the scope. Attach a microphone to the channel 1 input. Find the frequency of a tuning fork struck with the rubber end of the mallet supplied to you. (*Press the blue AUTO button after you strike the tuning fork so that the signal gets displayed as a sine wave. Then press the "SINGLE" button in the top right of the DSO to freeze the frame on one signal.*) Note that the loudest sound comes from the opening in the sounding box, not directly from the vibrating

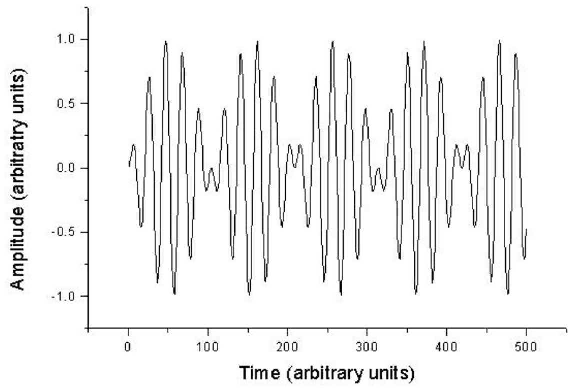

Figure 2: Example of beats.

metal tines. Read the frequency off the screen and record it.

Beats are the phenomenon that two sine waves of similar frequencies add to produce a signal that looks like a sine wave whose frequency is the average of the original sine waves with an overall modulation at a frequency given by half the difference in the original signals (Fig. 2). For example, if you add a 1000 Hz tone to a 1060 Hz tone, you will produce a 1030 Hz tone that increases and decreases in magnitude at 30 Hz. The 30 Hz is sometimes called an *envelope* that *modulates* the amplitude of the 1030 Hz signal. (*The AM in AM radio refers to a similar modulation.*)

Borrow another fork from a neighbor, strike both simultaneously and try to hear beats and see them on the scope. Since the beats will be at a lower frequency than the signal from a single tuning fork, you will have to **press AUTO again followed by Single (15) to freeze the frame.** Use the Horizontal control (11) to adjust the signal so as to see an image similar to that in Figure 2. (*There are a few pairs of tuning forks that produce particularly clear beat patterns. These are marked with matching colored squares or circles.*)

If you have time, you may wish to investigate the sound of your own voice using the microphone and scope, although this is not required for the worksheet. What is the frequency of your speaking voice? What are the highest and lowest frequency tones you can vocalize by singing, humming, etc.? Can you match the tone of your tuning fork? Can you and your lab partner(s) sing in harmony and produce beats? (*Only the BEST lab partners can do this!*)