Experiment 5

The Oscilloscope

5.1 Objectives

- Explain the operation or effect of each control on a simple oscilloscope.
- Display an unknown sinusoidal electrical signal on an oscilloscope and measure its amplitude and frequency.

5.2 Introduction

So far, we've been using a voltmeter to measure a voltage. That's all well and good if the voltage is steady or DC electricity. But what if the electrical voltage you want to measure is varying rapidly in time? The voltmeter display may oscillate rapidly preventing you from making a good reading, or it may display some average of the time-varying voltage. In this case, an oscilloscope can be used to observe and measure the entire time-varying voltage, or "signal".

The oscilloscope places an image of the time-varying signal on the screen of a cathode ray tube (CRT) allowing us to observe the shape of the signal and measure the voltage at different times. If the signal is periodic (it repeats itself over and over) we can also measure the frequency, the rate of repeating, of the signal.

5.3 Key Concepts

As always, you can find a summary online at Hyperphysics[1]. Look for keywords: waves, oscilloscope.

5.4 Theory

What the oscilloscope does

An oscilloscope plots voltage as a function of time.

There are two types of voltages: AC and DC. So far this semester we have been concerned with DC (or "direct current") that indicates a voltage whose magnitude is constant in time. In contrast, AC (short for "alternating current") indicates a voltage whose magnitude varies as a function of time. An example of an AC signal is shown in Fig. 5.1. The voltage is on the vertical (y) axis and the time is on the horizontal (x) axis. Notice that if we plotted a DC (or constant) voltage on this figure it would be a flat horizontal line.

In today's lab we will use an oscilloscope to look at some AC voltages. The oscilloscope has controls to make the x and y scales larger or smaller. These act like the controls for magnification on a microscope. They don't change the actual voltage any more than magnification makes a cell on the microscope slide bigger; they just let us see small details more easily. There are also controls to shift the center points of the voltage scales. These "offset" knobs are like the controls to move the stage of the microscope to look at different parts of a sample. You will learn about other adjustments in the course of the lab.

[1] http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html

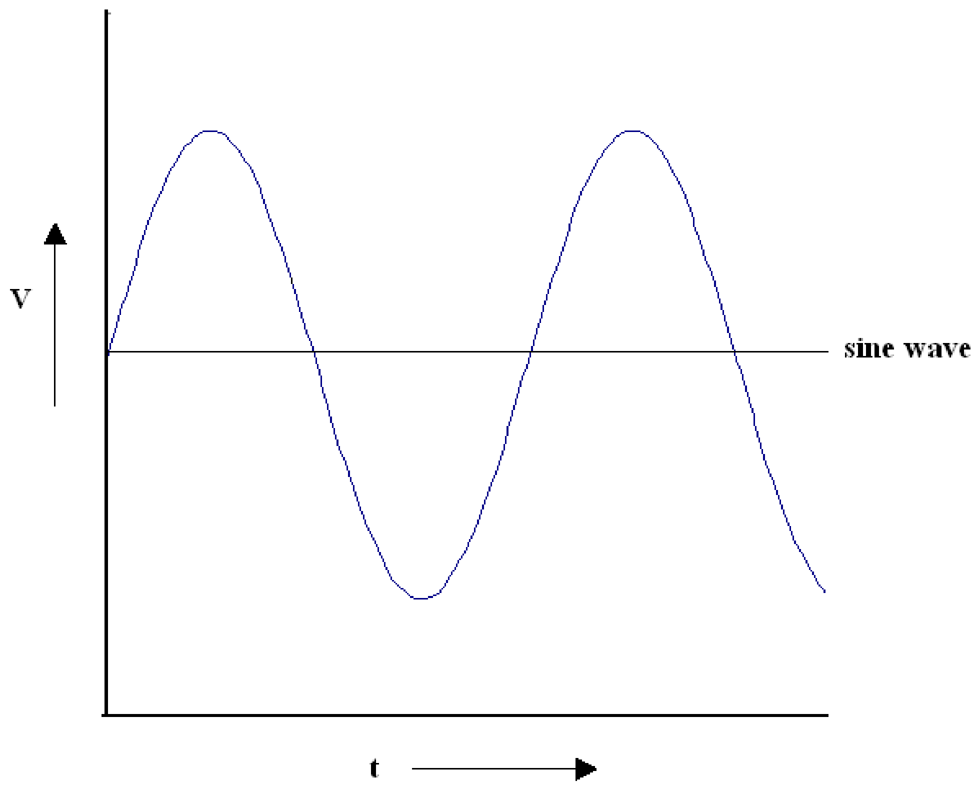


Figure 5.1: Graph of an oscillating voltage.

What the oscilloscope measures

There are two main quantities that characterize any periodic AC signal which can be measured with the aid of an oscilloscope. The first is the **peak-to-peak voltage** (V_{pp}), which is defined as the voltage difference between the time-varying signal's highest and lowest voltage (see the sine wave shown in Fig. 5.2). The second is the **frequency** of the time-varying signal (f), defined by

$$f = \frac{1}{T}, \tag{5.1}$$

where f is the frequency in hertz (Hz) and T is the period in seconds (s) (the period is also shown in Fig. 5.2).

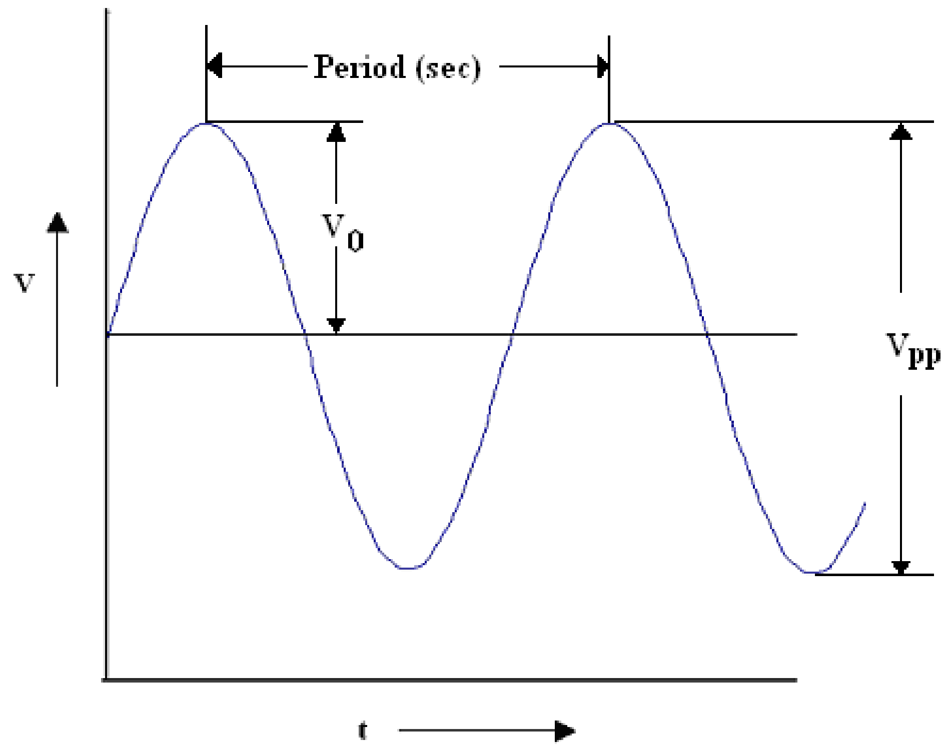


Figure 5.2: Graph of voltage vs. time, illustrating the period (T), peak-to-peak voltage (V_{pp}) and amplitude (V_0) of a sine wave.

Sometimes the angular frequency ω in rad/s is used instead of the frequency f in Hz.[2] They are related by

$$\omega = 2\pi f \tag{5.2}$$

The form of the voltage as a function of time for a standard AC signal is

$$V(t) = V_0 \sin(2\pi f t) + V_{\mathrm{DC}}, \tag{5.3}$$

[2]Radian is a unit of angular distance. You are probably more familiar with degrees. While there are 360 degrees in a full circle, there are 2π radians.

where V_{DC} is an optional constant DC offset that shifts the sine wave up or down and V_0 is the amplitude and is related to the peak-to-peak voltage V_{pp} of the signal by

$$V_{pp} = 2V_0. \quad (5.4)$$

Notice that the 2π in Eq. 5.3 makes it so that if the frequency f is 1 Hz, then the sine wave travels a full cycle in 1 s, which is what we would expect from that frequency.

5.5 In today's lab

In this experiment you will familiarize yourself with the use of an oscilloscope. Using a signal generator you will produce various time-varying voltages (signals) which you will input into the oscilloscope for analysis.

5.6 Equipment

- Oscilloscope.
- Signal generator.
- BNC-to-banana wire.

Safety Tips

- When plugging or unplugging wires, first **turn off all electronics that are connected**, or will become connected, to the circuit.

The oscilloscope.

An oscilloscope contains a cathode ray tube (CRT), in which the deflection of an electron beam that falls onto a phosphor screen is directly proportional to the voltage applied across a pair of parallel deflection plates. A measurement of this deflection yields a measurement of the applied voltage. The oscilloscope can be used to display and measure rapidly varying electrical phenomena. The internal subsystems of the oscilloscope are shown in Fig. 5.3 and the front panel of the oscilloscope is shown in Fig. 5.4. Because

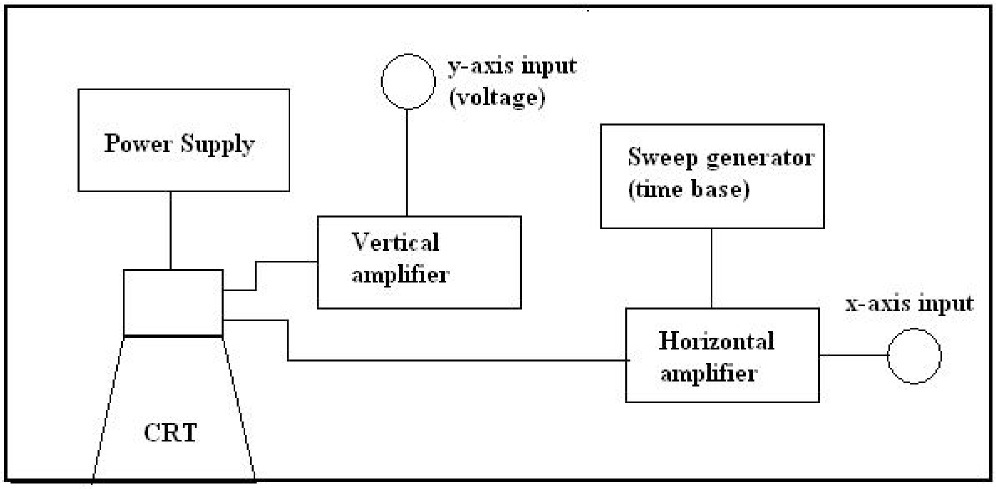


Figure 5.3: Diagram of subsystems in an oscilloscope.

Figure 5.4: Front panel of an oscilloscope.

Figure 5.5: The left side of the scope front panel.

you'll need to be able to read the dials and markings, blowups of the left and right halves of the front panel are shown in Fig. 5.5 and Fig. 5.6.

A vertical amplifier is connected to the y-axis deflection plates. It serves to amplify the input signal to the y-plates so that the CRT can show an appreciable vertical displacement for a small signal. The horizontal amplifier serves the same purpose for the x-axis plates and the horizontal display. Although an external input signal can be applied to the x-axis input, this function of the oscilloscope is not used in this course. Instead, a sweep generator, which is internal to the oscilloscope, is used to control the horizontal display. The sweep generator makes a beam move in the x-direction at a constant, but adjustable, speed. The beam's speed is adjusted using the time base (TB) control knob. This allows the oscilloscope to display the external y-input signal as a function of time.

The sweep generator functions in the following way. A saw-tooth voltage is applied to the horizontal deflection plates. A saw-tooth voltage is a time-varying periodic voltage and is shown in Fig. 5.7(a). The voltage

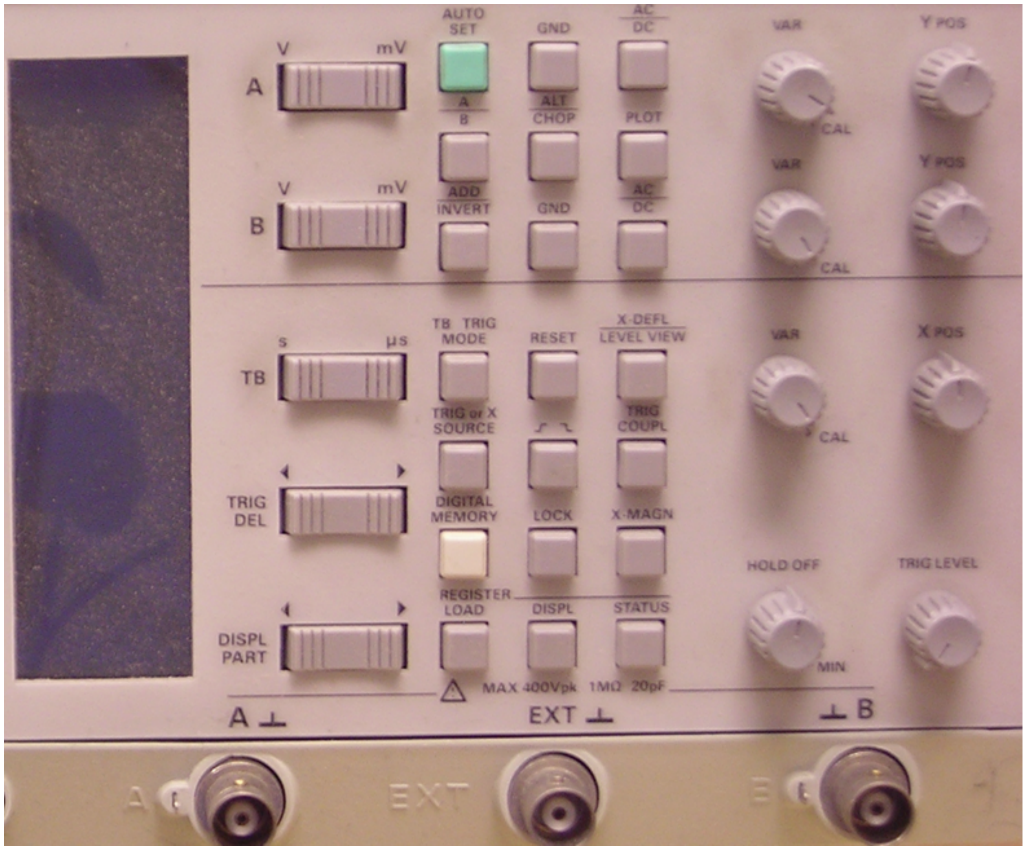
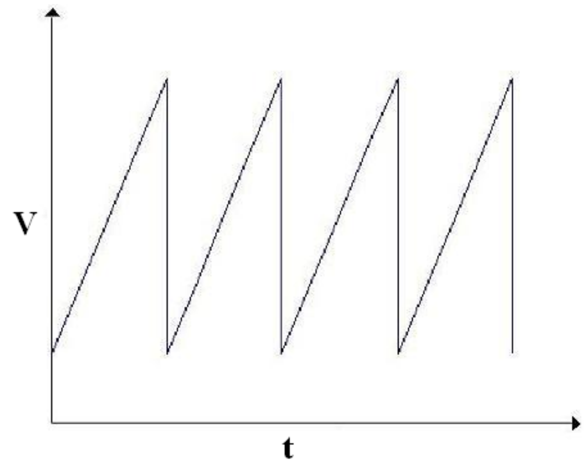
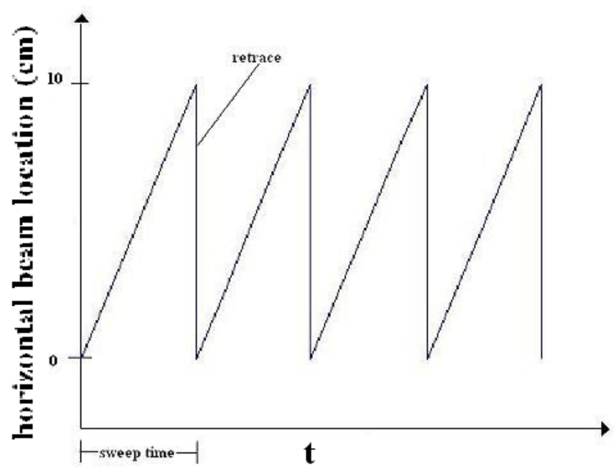


Figure 5.6: The right side of the scope front panel.

first increases linearly with time and then abruptly drops to zero. As the voltage increases the beam is deflected more and more to the right of the CRT screen. When the voltage reaches its maximum value, the beam trace will be at the far right hand side of the screen ($x = 10$ cm). The voltage then abruptly retraces back to zero — during this phase the signal is not displayed on the scope. The result is that the beam spot sweeps across the screen with the same frequency as the saw-tooth signal. The horizontal position of the beam spot is shown in Fig. 5.7(b). Note that the time it takes the beam spot to move across the screen (sweep time) is equal to the period of the saw-tooth signal. The rate at which the beam spot sweeps across the screen is selected by using the time base (TB) selector knob and is calibrated in time/cm. Because both the phosphor screen and the human



(a) Voltage supplied to horizontal plates of oscillator.



(b) Deflection of beam on CRT of oscilloscope. The sweep time is one period of the saw-tooth wave.

Figure 5.7: Saw-toot input to oscilloscope.

eye have some finite retention time, the beam spot looks like a continuous curve at frequencies higher than about 15 Hz.

Figure 5.8: The signal generator.

The signal generator

To investigate how the oscilloscope works in this first experiment, we will need to give it a test input signal. To accomplish this, we will be using a signal generator like the one pictured in Fig. 5.8.

It is important to understand the function of all of the dials and switches on the signal generator that are described below:

- The digital read out (upper left) displays the frequency that the signal generator is currently set to. This readout is in hertz (Hz).
- The RANGE buttons (to the right of the display) will move the decimal in the read out left or right. This means that by pressing the button once, we can change the frequency by a factor of ten. In the example pictured, one press of the button would change the frequency from 999.99 Hz to either 99.999 Hz or 9 999.9 Hz, depending on which direction we move the decimal. This will allow us to generate a large number of different frequencies quickly and easily. This only moves the decimal; it does not change the numbers that are displayed.
- If we wish to make a different numerical value, we need to turn the knob immediately below the range buttons, marked ADJUST. This

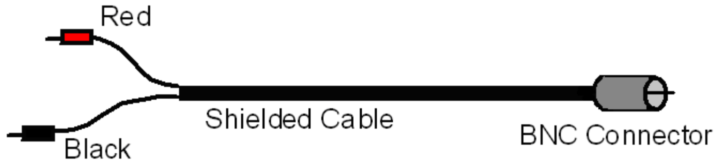


Figure 5.9: Cartoon of BNC-to-banana connector.

adjustment works in a rather unique way. If the knob is turned quickly the numbers change quickly. If we turn the knob slowly, the digits change slowly. So, with our frequency set at 999.99 Hz, as in the example above, if we wish to set it to 999.48 Hz, we would turn the knob slowly. If we wanted to set it to 188.34 Hz, we could turn the knob the same amount, but turn it faster so the digits change faster. It may seem a little bit awkward at first, but it gives us quick access to a large range of frequencies.

- At the top is a setting labeled WAVEFORM. By changing this setting, we can create smooth sine curves, square waves or triangular waves. The LED will light up next to the type of wave selected.

- Below the waveform setting is a knob labeled AMPLITUDE. By rotating this knob, we can change the amplitude or height of our wave. This amplitude will be measured using the oscilloscope.

- The far right hand side is the OUTPUT of the signal generator. This is where we connect the cables to take the signal to an oscilloscope or an external circuit. We will use the two banana jacks at the bottom (the red and black ones) to connect banana plugs to a cable that has a BNC connector on the other end. The BNC connector is the round metal one that will connect to the "input" on the oscilloscope. The cable with the banana plugs and a BNC connector is shown in Fig. 5.9.

5.7 Procedure

It is extremely important that you learn how to operate the oscilloscope since it will be used extensively in several other exper-

iments this semester.

Helpful unit prefixes

- 1 millisecond = 1 ms = 1×10^{-3} seconds
- 1 microsecond = 1 μs = 1×10^{-6} seconds
- 1 millivolt = 1 mV = 1×10^{-3} volts
- 1 microvolt = 1 μV = 1×10^{-6} volts

1. **Set the Phillips PM3335 Oscilloscope to Mid-Range or "Nominal" Conditions.**

   a) First disconnect all input cables to your oscilloscope except the rear power cable.

   b) Find the controls listed in Table 5.1 and set their nominal values (see Fig. 5.4). (In the following, LCD refers to the Liquid Crystal Display screen to the right of the main screen.)

   c) Now press the AUTO SET button. This will automatically reset the internal electronics of the oscilloscope to reasonable nominal settings. Your oscilloscope should now display a horizontal line across the screen. If not, go back and recheck that each control is in the nominal position. If the horizontal line still does not appear ask your instructor for help. If you ever get lost later in the lab, you can return to the nominal settings. (The AUTO SET button does not necessarily give you the *best* configuration for your particular measurement; it gives *nominal* settings which are a good starting point. You will then use manual adjustments to customize the setup.)

2. **Adjustments.**

   a) Adjust the FOCUS and INTENSITY controls for a sharp and moderately bright line.

   b) Rotate the Y POS knob associated with the A-Channel (top knob) and move the horizontal line up and down on the screen. Set the line near the middle of the screen.

Control	**Setting**	**Notes**
inputs	disconnected	
POWER	on	(switch in, LCD light on)
INTENS(ity)	mid-range	
FOCUS	mid-range	
ILLUM(ination)	off	(knob fully counterclockwise)
DIGITAL MEMORY	on	(check LCD for “Digital Memory”)
Y-POS(ition)	mid-range	(both knobs: A and B channels)
X-POS(ition	mid-range	
VAR(iable)	**CAL**	**(fully clockwise, all three knobs)**
HOLD OFF	MIN(imum)	(fully clockwise)
TRIG(ger) LEVEL	mid-range	
LOCK	off	(button, check LCD for no “Locked”)

Table 5.1: Nominal settings for the oscilloscope

c) Set the display to Channel B: keep pressing the A/B button until you see ”B” (and no ”A”) indicated on the LCD. You can now adjust the Y POS knob of the B-Channel. Set the line near the middle of the screen.

d) Set the display to both Channel A and B simultaneously: “A” and “B” indicated on the LCD.

e) Rotate the Y POS knobs for both channels A and B. Notice that the signal moves up and down on the screen and note the independence of the two controls. Reset both to the center of the screen and then set the display for Channel A only.

3. **Digital and analog.** The oscilloscope can be operated in either digital or analog mode. Although you will use the digital side of the oscilloscope in all of the subsequent labs, we will first use the analog side of the oscilloscope to help you understand how a signal is displayed on the oscilloscope. You can switch between the digital and analog modes by pressing the DIGITAL MEMORY button. In analog

mode the trace comes on the screen directly from the input (after some amplification or attenuation). The voltage of the input signal is given by the vertical displacement of the trace on the screen. To measure the voltage in analog mode, you need to know the sensitivity setting of the scope. The sensitivity V/mV is changed using the switch labeled A for signals on channel A and the switch labeled B for signals on channel B. The sensitivity setting is displayed on the LCD screen. The voltage and its uncertainty are then calculated by

$$V(\text{volts}) = \text{sensitivity (volts/cm)} \times \text{height (cm)} \tag{5.5}$$

with the uncertainty

$$\delta V = V\frac{\delta(\text{height})}{\text{height}} \tag{5.6}$$

The height is measured using the grid on the CRT's screen. Each of the 80 squares which make up the grid is 1.0 cm on a side. You should make a reasonable estimate of the uncertainty in the height when making a measurement in analog mode.

In digital mode, the oscilloscope automatically digitizes the input voltage. It quickly (up to forty million times per second) reads the input signal and stores its value in Volts in its electronic memory. The contents of the memory are then displayed on the screen (at 100,000 times per second or less). You can then calculate the voltage using the same method as you would in analog mode, or you can use the screen cursors to help you to read the voltage directly off of the screen. You will use both methods in this experiment.

4. **View the oscilloscope without an input signal in analog mode.** Turn on the oscilloscope and make sure it is in analog mode. Use the switch labeled TB to set the time base to its largest possible value. The time base setting is displayed on the LCD screen. You should now see the beam move across the CRT screen. Using the time base, calculate how long it takes the beam to move across the screen. Also, estimate the uncertainty in the distance the beam travels (δ distance) across the screen and use it to calculate the uncertainty in your calculated time. In addition, directly measure the time the beam takes to move across the screen using a clock, watch or timer. Estimate the

uncertainty in this time. Record this data and show your calculations in Question 1 and answer Question 2.

$$t = \text{time base (s/cm)} \times \text{distance (cm)} \tag{5.7}$$

$$\delta t = t\,\frac{\delta(\text{distance})}{\text{distance}} \tag{5.8}$$

5. **View the input signal from the signal generator.**

   The signal generator produces a signal which is simply an electric voltage which varies with time. We will be using sine-wave signals in this lab. Here, the voltage varies in time like a sine wave oscillating between a positive and negative voltage at a particular frequency. Attach the output of the signal generator to the channel A input of the oscilloscope using a cable with banana jacks at one end and a BNC connector at the other.

   The signal generator produces voltage signals of different frequencies and peak-to-peak voltages. In order to use the signal generator effectively, we will have to learn something about its operation. Set the signal generator initially with frequency = 60.000 Hz, WAVEFORM being a smooth sine wave, and AMPLITUDE being approximately in the middle of the range.

   Change the oscilloscope to digital mode. Press the AUTO SET button on the oscilloscope. Adjust the sensitivity setting (A) so that the peak to peak signal fills most of the oscilloscope's screen, without extending above or below the grid. Also, adjust the time base so that one period of the signal fills most of the grid. NOTE: making these changes to the sensitivity and time base does not change the voltage or period of the signal; it only changes the scale the oscilloscope uses to display the signal.

   Sketch the signal displayed on the oscilloscope in Question 3.

6. **Using the cursors with the digital oscilloscope.** Inspect the CRT screen. If there is no writing at the bottom of the screen, press one of the blue keys just below the screen. If there is some writing and one of the soft keys has RETURN written above it, press the RETURN soft key and keep pressing it until RETURN is no longer

visible. This returns you to the highest menu level. You should now see:

CURSORS SETTINGS INTF TEXT_OFF

at the bottom of the CRT screen.

You can use these soft keys to help you measure voltages, times, periods and frequencies of input signals. Appendix E is an outline of the soft key structure.

a) **Measuring peak to peak voltage.**

   We will use the soft keys to move the screen cursors (reference lines) to read voltages and times from the CRT screen. Press the CURSORS soft key. Press the MODE soft key to set up the cursors you wish to use. Press the V-CURS ON/OFF soft key to toggle the two horizontal cursors on and off: **you want these on to measure voltage.** Press the RETURN soft key to return to the main cursors menu. Press the V-CTRL soft key to control the two voltage cursors. Use the ↑REF↓ soft keys to move the bottom cursor up and down. Use the ↓ Δ ↑ soft keys to move the top cursor up and down. These two cursors are used to measure the peak-to-peak voltage of the input signal. The displayed voltage is the voltage difference between these two cursors; you move these cursors to make a measurement. To estimate the uncertainty in this measurement, use two clicks, or if the trace is larger than two clicks use the width of the trace. Measure the peak to peak voltage of your signal and record it in Question 4.

   Using the sensitivity adjustment, you can change the height of the trace displayed on the screen without changing the actual input voltage. Change the sensitivity using the button labeled A on the oscilloscope. Re-adjust the cursors and measure the peak to peak voltage. Answer Question 5.

   Change the sensitivity back to its previous setting.

   The VAR knob varies the sensitivity in a continuous way, which cannot be interpreted by the electronics. Move the A VAR knob away from the full-right CAL position and observe what happens to the trace. Notice on the CRT a voltage is no longer displayed.

It should now only tell you how many divisions (cm) apart the cursors are placed. Also, on the LCD display next to the voltage sensitivity you should see a blinking ">" — this means the actual voltage sensitivity is something greater than the value indicated on the LCD screen. **When using the oscilloscope, it is very important that all three of the VAR knobs are set to the full-clockwise CAL position**. Return the knob to the CAL position.

b) **Frequency measurement.** The digital mode of the oscilloscope can be used to measure the period and frequency of a signal. As with the peak to peak voltage measurements you can use the soft keys to help you measure these values. Now, you will use the T-cursors. Go to the MODE menu and use the T-CURS/ON/OFF soft key to turn on the two vertical cursors. Then go to the T-CTRL menu to set the location of your cursors. Use the ←REF→ and ← Δ → soft keys to set the location of vertical cursors to correspond to one period of the input signal. At the top of the CRT screen you should see "$\Delta t =$" and "$1/\Delta t =$" corresponding to the period and the frequency of your signal. Record these in Question 6.

Change the time base and re-measure the frequency. Answer Question 7.

Return the time base to its previous setting.

7. **The features on the signal generator.**

a) **The ADJUST knob.**

Turn the ADJUST knob and observe what happens to the signal displayed on the oscilloscope. Sketch the trace before and after you turned the ADJUST knob. These need not be exact representations and you may change the scale (voltage sensitivity and time base) if you are unable to reasonably sketch the trace. Record these sketches (Question 8) and answer Questions 9–10.

b) **The RANGE setting.**

Push one of the two RANGE buttons and observe what happens to the signal displayed on the oscilloscope. Sketch the trace before and after you pushed the RANGE button (Question 11) and answer Questions 12–13.

c) **The AMPLITUDE setting.**

Turn the AMPLITUDE knob and observe what happens to the signal displayed on the oscilloscope. Sketch the trace before and after you turned the AMPLITUDE knob (Question 15) and answer Questions 15–16.

d) **The WAVEFORM setting.**

Push the WAVEFORM button and observe what happens to the signal displayed on the oscilloscope. Sketch the trace before and after you pushed the WAVEFORM button (Question 17) and answer Questions 18–19.

5.8 Questions

1. While viewing the oscilloscope without an input signal in analog mode, record the following values. Make sure to **include uncertainties** for all values, except the time base setting, and show your work.

   time base setting:

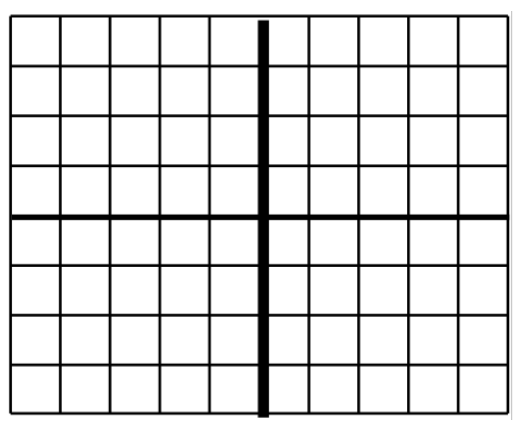
   distance traveled:

   time (calculated):

   time (measured):

2. Are the two times in Question 1 consistent? If they are not consistent, what would you conclude about your measured time?

3. After initially viewing the input signal, sketch the signal displayed on the oscilloscope on the grid below.



4. What is the peak-to-peak voltage V_{pp}? Don't forget to include the uncertainty.

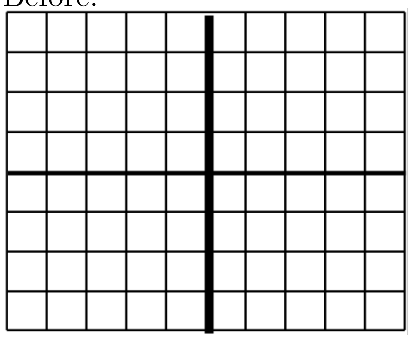
5. Did changing the voltage sensitivity on the oscilloscope change the peak-to-peak voltage? Explain.

6. What is the period and frequency of the wave? Use the Procedure Step 6b to find it. Don't forget uncertainties and units.

7. Did changing the time base change the frequency of the signal? Explain.

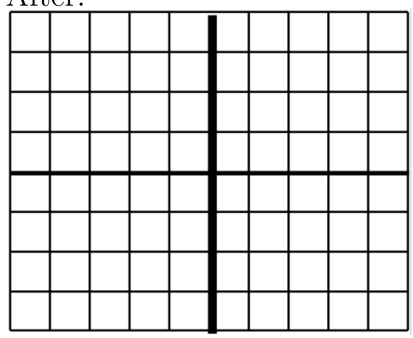
8. Sketch the trace before and after you turned the ADJUST knob. These need not be exact representations and you may change the scale (voltage sensitivity and time base) if you are unable to reasonably sketch the trace.

Before:



Volt/cm =
Time/cm =

After:



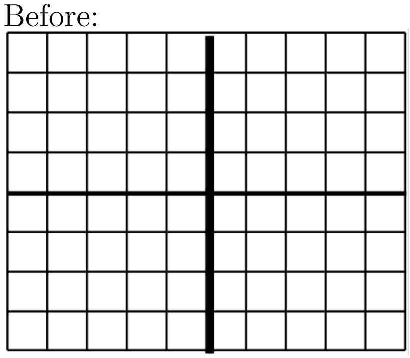
Volt/cm =
Time/cm =

9. After turning the ADJUST knob, use the cursors to measure V_{pp} and the frequency. What are they?

10. How did turning the ADJUST knob affect the signal?

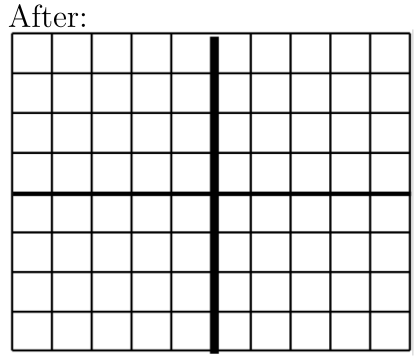
11. Sketch the trace before and after you pushed the RANGE button. These need not be exact representations and you may change the scale (voltage sensitivity and time base) if you are unable to reasonably sketch the trace.

Before:



Volt/cm =
Time/cm =

After:



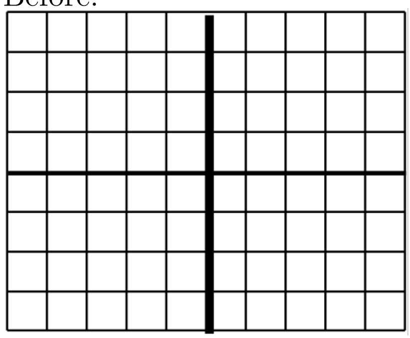
Volt/cm =
Time/cm =

12. After pushing the RANGE button, use the cursors to measure the peak-to-peak voltage and the frequency. What are they?

13. How did pushing the RANGE button affect the signal?

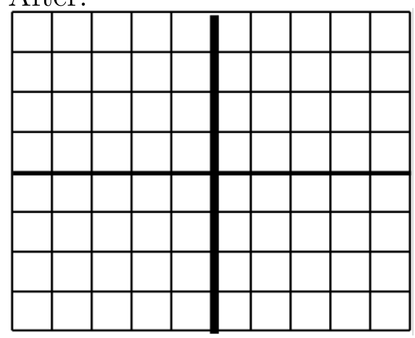
14. Sketch the trace before and after you turned the AMPLITUDE knob. These need not be exact representations and you may change the scale (voltage sensitivity and time base) if you are unable to reasonably sketch the trace.

Before:



Volt/cm =
Time/cm =

After:



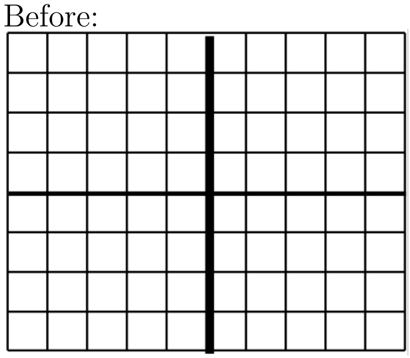
Volt/cm =
Time/cm =

15. After turning the AMPLITUDE knob, use the cursors to measure V_{pp} and the frequency. What are they?

16. How did turning the AMPLITUDE knob affect the signal?

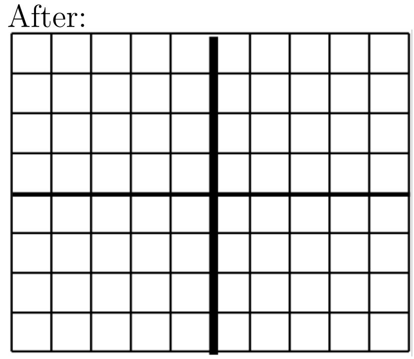
17. Sketch the trace before and after you pushed the WAVEFORM button. These need not be exact representations and you may change the scale (voltage sensitivity and time base) if you are unable to reasonably sketch the trace.

Before:



Volt/cm =
Time/cm =

After:



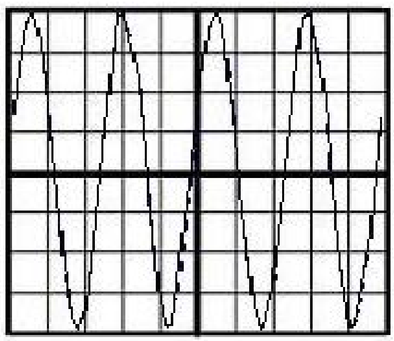
Volt/cm =
Time/cm =

18. After pushing the WAVEFORM button, use the cursors to measure V_{pp} and the frequency. What are they?

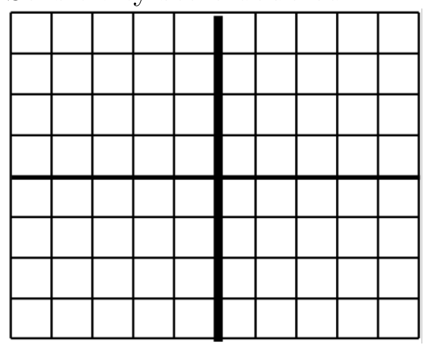
19. How did pushing the WAVEFORM button affect the signal?

20. The diagram below shows a signal on the CRT screen of an oscilloscope. Sketch the appearance of the trace if the voltage sensitivity scale setting on the oscilloscope is increased by a factor of 2.

Original display:

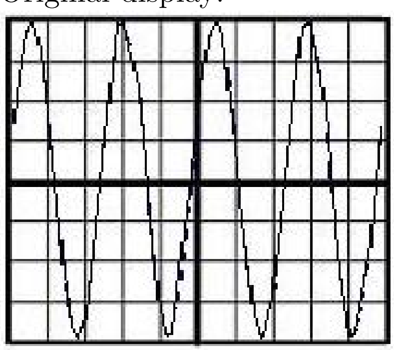


Sensitivity scale doubled:

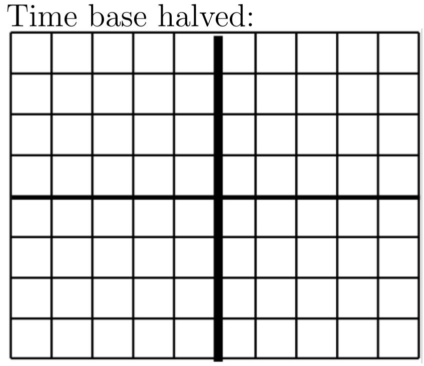


21. The voltage sensitivity is returned to its original setting, and then the time base is halved. Sketch the appearance of the trace after the time base has been decreased by a factor of 2.

Original display:



Time base halved:



22. If you wish to measure the frequency of the signal more accurately, which trace should you use (original or with the time base halved)? Why?

23. Suppose you have an unknown input signal. Briefly describe the steps you would take to view the signal appropriately and to make measurements of the frequency, period, and peak-to-peak voltage.

24. **Now do it:**
Measure the frequency and V_{pp} for the mystery signal from the white box. Here you will connect the output of an unknown box directly to the oscilloscope. You will not need the signal generator. Be sure to turn on the power supply connected to the unknown box. Remember to include uncertainties and units.

White box I.D. =

V_{pp} =

Frequency =