Name ______________________ Section ____________ Date ____________

Laboratory 38

Oscilloscope Measurements

PRELABORATORY ASSIGNMENT

Read carefully the entire description of the laboratory and answer the following questions based on the material contained in the reading assignment. Turn in the completed prelaboratory assignment at the beginning of the laboratory period prior to the performance of the laboratory.

1. Describe the components that make up the electron gun in a cathode-ray tube.

2. Describe the voltage waveform that produces a linear time scale when applied to the horizontal plates of a cathode-ray tube.

3. When the electron beam strikes the fluorescent screen the phospor glow that results has a persistence. Approximately how long does the glow persist?

4. A function generator outputs a sine wave of f = 200 Hz. It is input to an oscilloscope set at 1 ms/DIV. How many complete cycles of the sine wave are displayed on the oscilloscope? (*Hint:* The period of the sine wave T is related to the frequency f of the wave by $T = 1/f$, and there are 10 divisions on the time display of the oscilloscope.)

5. A typical student oscilloscope on its least sensitive calibrated scale can display a voltage up to a maximum of approximately (a) 1 V, (b) 5 V, (c) 20 V, or (d) 200V.

6. A typical student oscilloscope on its most sensitive calibrated scale can display a voltage up to a minimum of approximately (a) 1 mV, (b) 5 μV, (c) 20 V, or (d) 200 mV.

7. Which statement best describes the function of the trigger level and trigger slope settings of an oscilloscope? (a) The trigger level sets a slope that must be exceeded to start the sweep. (b) The trigger level sets a voltage above which the sweep is started if the slope is positive, and below which the sweep is started if the slope is negative. (c) The trigger slope sets a voltage above which the sweep is triggered. (d) The trigger slope sets a voltage above which the sweep is started for positive level, and below which the sweep is started for negative level.

8. A sawtooth wave whose period is 100 ms is applied to an oscilloscope whose screen is 10 cm wide. What time is represented by 1 cm on the screen?

Laboratory 38

Oscilloscope Measurements

OBJECTIVES

In this laboratory signals from a function generator will be observed on an oscilloscope to accomplish the following objectives:

1. Introduction of students to the fundamental principles and practical operation of the oscilloscope
2. Measurement of sine and other waveform signals of varying voltage and frequency
3. Comparison of voltage measurements with the oscilloscope to voltage measurements using an AC voltmeter

EQUIPMENT LIST

1. Oscilloscope (typically, bandwidth DC to 20 Mhz)
2. Function generator (sine wave plus additional waveform such as a square wave or triangular wave)
3. AC voltmeter (capable of measuring high frequency)
4. Appropriate connecting wires (probably BNC to banana plug)

THEORY

The fundamental working part of an oscilloscope is a cathode-ray tube (CRT). Its components include: (1) a heated filament to emit a beam of electrons, (2) a series of electrodes to accelerate, focus, and control the intensity of the emitted electrons, (3) two pairs of deflection plates that deflect the electron beam when there is a voltage between the plates (one pair for deflection in the horizontal direction and one pair for deflection in the vertical direction), (4) a fluorescent screen that emits a visible spot of light at the point where the beam of electrons strikes the screen. Together the heated filament and series of electrodes in (1) and (2) above are called an "electron gun." The electron gun and deflecting plates are arranged linearly inside an evacuated glass tube, and the fluorescent screen coats the glass tube at the opposite end of the tube from the electron gun as shown in Figure 38.1.

When there is no voltage between either pair of deflection plates, the electron beam will travel straight down the evacuated tube and strike the center of the fluorescent screen. If a constant voltage is applied between either the horizontal or vertical deflection plates the beam will be displaced a constant amount on the fluorescent screen in either the horizontal (x) or vertical (y) direction. The direction of the displacement depends on the sign of the voltage, and the magnitude of the displacement is proportional to the voltage. If a time-varying voltage is applied to either set of deflecting plates, the displacement of the beam will vary with time as the applied voltage varies with time, and the electron beam spot will move on the screen as a function of time. When the beam strikes the screen the phosphor glow persists for approximately 0.1 s.

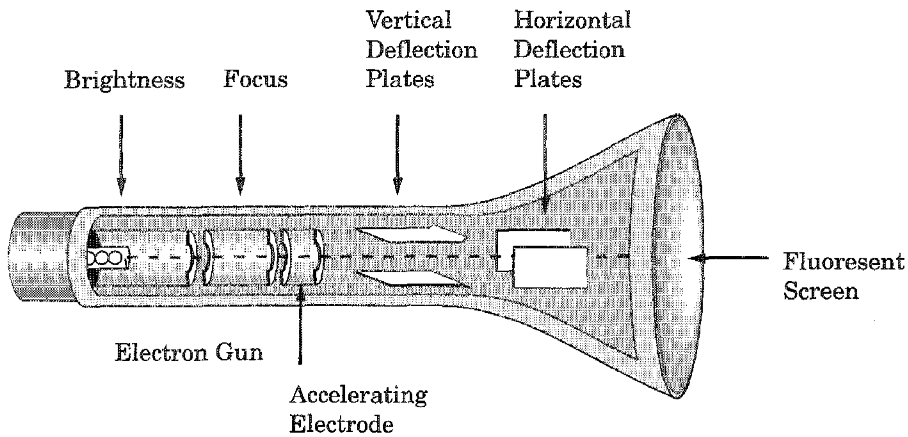

Figure 38.1 Cathode-ray tube.

Deflections of the electron beam in the horizontal (x) direction can be made to represent a time scale by applying a time-varying sawtooth voltage waveform as shown in Figure 38.2. When a voltage of that waveform and the appropriate maximum voltage is applied to the horizontal plates, the beam spot will sweep across the fluorescent screen once each time the voltage linearly increases from its minimum up to its maximum. At the end of sweep of the beam across the screen, the sawtooth voltage goes back to zero, which returns the beam back to the left of the screen. The time this takes will equal the period T of the sawtooth waveform. Since this sawtooth waveform sweeps the beam across the screen it is commonly called the "sweep generator." The finite time it takes to return the beam back to the left side of the screen could cause a visible trace. This is prevented by briefly applying a negative grid voltage in order to blank out the retrace.

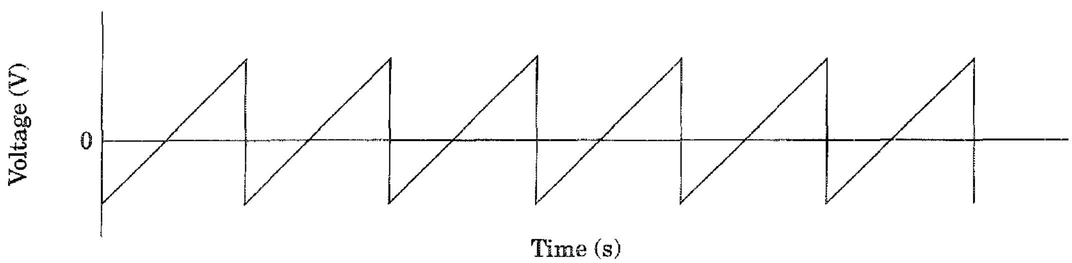

Fig 38.2 Sawtooth voltage waveform.

If the period T of the sweep generator is 1 s, the beam will clearly be recognizable as a spot that moves at constant speed across the tube face. If the period is as short as 0.1 s the beam is no longer recognizable as a spot, but instead appears to be a somewhat pulsating line. This is caused by the persistence of the phosphor, which causes the trace to still be glowing from one pass of the beam when another pass of the beam begins. For periods T of 0.02 s or less the beam is moving across the screen so often that the persistence of the phosphor makes the trace appear as a steady line.

The oscilloscope is designed so that a series of specific sweep generator periods can be applied to the horizontal plates by the selection of the position of a multi-position switch. The width of oscilloscope screen is fixed, usually 10 cm. Each different choice of period T therefore represents a specific time per length of scale division in the horizontal direction. Typically these are chosen to decrease in a series of scales that are in the ratio 2:1:0.5. For a typical student-type oscilloscope the times scales would be 19 settings ranging from 0.2 s/cm to 0.2 μs/cm. Note that since the screen is 10 cm wide there is a factor of 10 difference between the period T and the time scale. If the period of the sweep generator is 10 ms, that represents a time scale of 1 ms/cm. Also note that $t = 0$ is assumed to occur at the left of screen, and time is assumed to increase to the right.

In the vertical direction the screen is typically smaller, usually about 8 cm total. The vertical input is calibrated directly in volts. The input voltage scale is also variable by the choice of a multiposition switch that selects the appropriate amplification of the input voltage over some chosen voltage range. Typical ranges of possible voltage scales are from 5 V/cm to 5 mV/cm, again chosen in the ratio 2:1:0.5. This choice of voltage scales allows a range of input voltages to be displayed with deflections on the oscilloscope screen that are large enough to be easily visible. Since the voltage can be of either positive or negative polarity, the vertical scale has its zero in the center of the screen in order to be able to display both positive and negative voltages. Note that for the voltage scales given, input voltages must be equal to or less than 20 V either positive or negative from zero since a 20-V signal would deflect the beam 4 cm from the center of the screen even if the scale chosen were the maximum 5 V/cm.

The most common use of the oscilloscope is to use the time scale provided by the sweep generator to display the time variation of a voltage signal that is applied to the vertical plates. Usually this is some specific waveform that is repeated with a fixed frequency. For example, if a simple sine-wave voltage is applied to the vertical plates, a display of the voltage versus time will be directly displayed on the oscilloscope screen as a sine-wave trace of the beam whose maximum amplitude is proportional to the maximum voltage of the signal and whose period on the time scale of the oscilloscope is equal to the period of the signal. If the voltage waveform applied to the vertical plates is a more complex waveform, the resulting trace on the screen will represent the shape of that complex waveform.

The discussion so far has ignored one important point, which involves the means to coordinate the starting time of the sweep generator with the starting point of the voltage signal that is to be displayed. This is accomplished by using some waveform as a "trigger" to start the sweep generator. The triggering waveform can be the same signal that is input to the vertical plates for analysis, a secondary external signal, or the 60-Hz line voltage. When the signal itself is used as the trigger for the sweep generator, the signal is observed on the oscilloscope as a steady display that is constant in time because the sweep generator is initiated at the same point on the repetitive vertical signal for each pass of the sweep generator. On most oscilloscopes this is referred to as internal triggering and is the mode to be used in this laboratory. The trigger function of the oscilloscope has both a level and slope control. The level control sets a voltage level at which the trigger pulse is initiated, and the slope control refers to whether the trigger pulse will be generated as the signal goes above the set level or when it goes below that level. For example, if the level control is set at 1 V and the slope set at (+), the sweep will be triggered when the signal goes above 1 V. With the same level setting and the slope set on (−), the sweep will be trigger when the signal goes below 1 V.

TYPICAL OSCILLOSCOPE CONTROLS

A description is given below of the controls for a particular oscilloscope, the Hitachi model V-212 shown in Figure 38.3. It is a typical student-type oscilloscope. Although the description given is for that specific instrument, it is intended to show what will be available in the instruction manual of essentially any oscilloscope that is being used. Using the instruction manual for the oscilloscope, familiarize yourself with the operation of the controls that are the same as or similar to those described below.

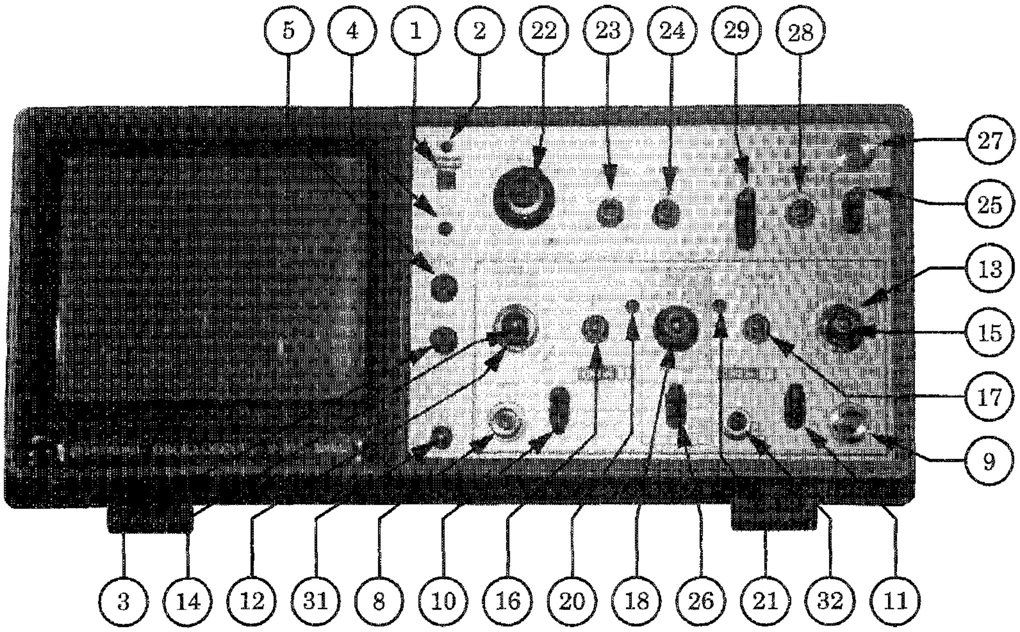

Figure 38.3 The Hitachi model V-212 Oscilloscope.

Power Supply and CRT

1. POWER switch—The power is on at the pushed-in position and off at the released position.
2. POWER LAMP—The lamp glows red when the power switch is on.
3. FOCUS—After obtaining an appropriate brightness by operating the intensity control, adjust the focus until the display is sharpest.
4. TRACE ROTATION—Used to align the trace of the CRT with horizontal scale.
5. INTENSITY—This knob adjusts the brightness. Brightness increases as the intensity is rotated clockwise. Perform all measurements at the lowest intensity level that is comfortable to the eyes. Avoid leaving the intensity set to a high level for extended time periods to prevent permanent damage to the phosphor.
6. VOLTAGE SELECTOR—This control is on the back of the instrument. It is used to select the power source, either 110 V or 220 V. (not pictured)
7. AC inlet—This is an inlet for the detachable AC power cord. (not pictured)

Controls of the Vertical Deflection System

8. CH1 INPUT—BNC connector for the vertical axis input. The signal input to this terminal becomes the x-axis signal when the oscilloscope is used as an x-y oscilloscope.

9. CH2 INPUT—BNC connector for a second vertical axis input. This input becomes the y-axis signal when the oscilloscope is used as an x-y oscilloscope.

10 & 11. (AC-GND-DC)—These input coupling switches are used to select the coupling system between the input signal and the vertical axis amplifier. (a) AC—At this setting the signal is connected through a capacitor that blocks any DC component of the input signal and displays only the AC component. (b) GND—At this setting the input to the vertical axis amplifier is grounded. (c) DC—At this setting the input signal is directly connected to the vertical axis amplifier and displayed unchanged, including any DC component.

12 & 13. VOLTS/DIV—A step attenuator that selects the vertical deflection factor. Set it to an easily observable range corresponding to the amplitude of the input signal. Ranges available from 5 V/DIV to 5 mV/DIV.

14 & 15. VAR (PULL x 5 GAIN)—When this control is fully rotated clockwise the vertical scale is calibrated to the ranges described above in 12 & 13. When rotated counterclockwise a continuously variable vertical attenuation up to a factor of 2.5 is introduced. When the knob is pulled out a fixed gain of 5 is introduced.

16 & 17. VERTICAL POSITION—This knob is used to adjust the position of the vertical axis. The display rises with clockwise rotation of this knob and falls with counterclockwise rotation.

18. MODE—This switch is used to select the operation mode of the vertical deflection. (a) CH1—Only the signal that has been applied to CH1 appears on the screen (b) CH2—Only the signal that has been applied to CH2 appears on the screen (c) Alt—Signals applied to CH1 and CH2 appear on the screen alternately at each sweep. This is used when the sweep time is short in two-channel observation. (d) Chop—At this setting the input signals applied to CH1 and CH2 are switched at about 250 kHz independent of the sweep and at the same time appear on the screen. This setting is used when the sweep time is long in two-channel observation. (e) Add—The algebraic sum of the input signals applied respectively to CH1 and CH2 appears on the screen.

19. CH1 OUTPUT—An output connector providing a sample of the signal applied to the CH1 connector. It is on the back of the oscilloscope. (not pictured)

20 & 21. DC BAL—These adjustment controls are used for the attenuator balance adjustment.

Controls of the Horizontal Deflection System

22. TIME/DIV (x-y)—(a) Sweep time ranges are available in 19 steps from 0.2 μs/cm to 0.2 s/DIV (b) x-y—This position is used when using the instrument as an x-y oscilloscope. In the position the x (horizontal) signal is connected to the input of CH1 and the y (vertical) signal is applied to the input of CH2 and has a deflection range from less than 1 mV to 5 V/DIV at a reduced bandwidth of 500 khZ.

23. SWP VAR—When this control is rotated fully in the clockwise direction of the arrow, the CAL state is produce and the sweep time is calibrated to value indicated by the time/DIV. Counterclockwise rotation of the control produces a continuously variable delay of the sweep time up to a factor of 2.5.

24. HORIZONTAL POSITION (PULL × 10 MAG)—This knob is used to move the display in the horizontal directions. The display is moved right when the knob is rotated clockwise and moved left with counterclockwise rotation. The sweep is magnified 10 times by pulling out the POSITION knob. In this case the sweep time is 1/10 of the value indicated by the time/DIV.

Synchronization System

25. (INT-LINE-EXT)—This switch is used to select the triggering signal source. (a) INT—The input signal applied to CH1 or CH2 becomes the triggering signal (b) LINE—This setting is used when observing a signal with the power supply line frequency. (c) EXT—An external triggering signal applied to the TRIG INPUT becomes the triggering signal.

26. INT TRIG—This switch is used to select the internal triggering signal source. (a) CH1—The input signal applied to CH1 becomes the triggering signal (b) CH2—The input signal applied to CH2 becomes the triggering signal. (c) VERT MODE—For observing two waveforms, the sync signal changes alternately corresponding to the signals on CH1 and CH2 to trigger the signal.

27. EXT TRIG—Input terminal for use for external triggering signal.

28. LEVEL/PULL (−) SLOPE—This knob sets the voltage level at which the sweep generator is triggered. The zero level is with the knob at the 12 o'clock position. Turning clockwise from there sets a positive level and counterclockwise from there sets a negative level. The slope of the trigger is positive (normally set there) when the knob is pushed in and negative when the knob is pulled out.

29. TRIGGER MODE—(a) AUTO—In this mode a sweep is always conducted. In the presence of a triggered signal, normal triggered sweep is obtained and the waveform stands still. In the case of no signal or out of triggering the sweep line will appear automatically. This setting is convenient in most cases and used almost all the time. (b) NORM—Triggered sweep is obtained and sweep is conducted only when triggering is effected. No sweep line will appear in the case of no signal or out of synchronization. Use this mode when effecting synchronization to a very-low-frequency signal (25 Hz or less).

Experimental Procedure

In several of the instructions below you are asked to draw what is on the oscilloscope display on the grids provided. In each of those cases assume the VOLTS/DIV and TIME/DIV are properly calibrated, and fill in the blank given for the values of VOLTS/DIV and TIME/DIV for the exercise associated with each set of grids. On the vertical scale, 0 V is labeled. Label the full-scale voltage both positive and negative. The time scale is labeled with 0 s. Label the value of the full-scale time on the horizontal axis. Do this for each grid.

1. Turn on the power to the oscilloscope and let it come to thermal equilibrium for at least 10 minutes. Set the oscilloscope mode setting to CH1, the trigger source

to INT, the trigger level to zero (center of range), trigger SLOPE to + (level knob pushed in), trigger MODE to AUTO, the INT TRIG to CH1, and CH1 to AC.

2. Set the TIME/DIV control to 1ms/DIV, the SWP VAR control rotated fully clockwise to the CAL position, the VOLTS/DIV control to 1 V/DIV, and the VAR (PULL $\times$ 5 GAIN) control rotated fully clockwise to the CAL position.

3. Turn on the power to the function generator and let it come to thermal equilibrium for at least 10 minutes. Select a sine-wave voltage, set the frequency $f = 100$ Hz, and connect the output of the function generator to the CH1 INPUT of the oscilloscope. Adjust the amplitude control of the function generator to zero. Adjust the VERTICAL POSITION control of the oscilloscope until the flat trace is exactly on the center line of the vertical display.

4. (a) Adjust the amplitude control of the function generator until the display on the oscilloscope is full-scale positive on the positive part of the cycle and full-scale negative on the negative part of the cycle. In the laboratory report section carefully draw on the grid labeled 1A what is displayed on the screen. (b) Leaving all other parameters fixed, set the VOLT/DIV control to 2 V/DIV, and draw on the grid labeled 1B what is now displayed on the screen. (c) Leaving all other parameters fixed, set the VOLT/DIV control to 5 V/DIV, and draw on the grid labeled 1C what is now displayed on the screen.

5. (a) Leaving all other parameters fixed, set the VOLT/DIV control to 1 V/DIV, and select $f = 200$ Hz from the function generator. Draw on the grid labeled 2A what is now displayed on the screen. (b) Leaving all other parameters fixed select $f = 400$ Hz from the function generator, and draw on the grid labeled 2B what is now displayed on the screen. (c) Leaving all other parameters fixed, select $f = 600$ Hz from the function generator and draw on the grid labeled 2C what is now displayed on the screen.

6. (a) Leaving all other parameters fixed, set the VOLT/DIV control to 1 V/DIV, the TIME/DIV control to 2ms/DIV, and select $f = 100$ Hz from the function generator. Note that the trigger slope control is still set at (+). Draw on the grid labeled 3A what is now displayed on the screen. (b) Leaving all other parameters fixed, pull out the trigger level control, which sets the trigger slope to (−). Draw on the grid labeled 3B what is now displayed on the screen.

7. (a) Leaving all other parameters fixed, push in the trigger level control, which sets the trigger slope to (+), leaving the trigger level still set at zero. Draw on the grid labeled 4A what is now displayed on the screen. (b) Leaving all other parameters fixed, slowly turn the trigger level control clockwise, increasing the trigger level. Increase it only so long as the display remains triggered. At the maximum level that the display is triggered, draw on the grid labeled 4B what is displayed on the screen. (c) Leaving all other parameters fixed, slowly turn the trigger level control counterclockwise, decreasing the trigger level. Decrease it only so long as the display remains triggered. At the minimum level that the display is triggered, draw on the grid labeled 4C what is displayed on the screen.

8. Push the trigger level control in for (+) slope and turn the level back to zero. Set the TIME/DIV to 2 ms/DIV and set the function generator to a sine wave of $f = 100$ Hz. Use the AC voltmeter to set the output of the function generator to 1.00 V as read on the voltmeter. Input this sine wave to the oscilloscope and measure the peak voltage of the sine wave. To measure the peak voltage of the sine wave you are free to adjust the VOLT/DIV control to give the most accurate measurement

possible. Generally this means adjusting the scale for as large a deflection as possible. Record the peak voltage of the sine wave as read from the oscilloscope in Data Table 1. Complete all the measurements in Data Table 1 from 1.00 V to 5.00 V. For each voltage, set the output from the generator using the voltmeter, and then read the voltage from the oscilloscope, each time choosing the VOLT/DIV that will allow the most accurate reading from the oscilloscope.

9. Set the function generator to output a triangular wave with f = 1000 Hz, and the TIME/DIV on the oscilloscope to 1 ms/DIV. Use the AC voltmeter to set the output of the function generator to 1.00 V as read on the voltmeter. Input this triangular wave to the oscilloscope and measure the peak voltage of the wave. Proceed as done for the sine wave above, this time measuring the voltages between 1.00 V and 5.00 V as read on the voltmeter. Record the results in Data Table 2.

10. The goal of this laboratory is to introduce students to the oscilloscope. At this time simply experiment for yourself with the features of the oscilloscope. Input as many different frequencies and waveforms as you have time for and attempt to learn everything you can about the operation of the oscilloscope by simply trying different settings of all of the oscilloscope controls.

CALCULATIONS

1. Perform a linear least squares fit to the data in Data Table 1 with the peak voltage read on the oscilloscope as the ordinate and voltage as read on the voltmeter as the abscissa. Determine the slope, intercept, and regression coefficient. Record those values in Calculations Table 1.

2. Perform a linear least squares fit to the data in Data Table 2 with the peak voltage read on the oscilloscope as the ordinate and voltage as read on the voltmeter as the abscissa. Determine the slope, intercept, and the regression coefficient. Record those values in Calculations Table 2.

Name ______________________ Section ____________ Date ____________

Laboratory 38

Oscilloscope Measurements

LABORATORY REPORT

1A. TIME/DIV = ________

1A. VOLTS/DIV = ________

0 V

0 s

1B. TIME/DIV = ________

1B. VOLTS/DIV = ________

0 V

0 s

1C. TIME/DIV = ________

1C. VOLTS/DIV = ________

0 V

0 s

2A. TIME/DIV = ________

2A. VOLTS/DIV = ________

0 V

0 s

2B. TIME/DIV = ________

2B. VOLTS/DIV = ________

0 V

0 s

2C. TIME/DIV = ________

2C. VOLTS/DIV = ________

0 V

0 s

3A. TIME/DIV = ________

3A. VOLTS/DIV = ________

0 V

0 s

3B. TIME/DIV = ________

3B. VOLTS/DIV = ________

0 V

0 s

4A. TIME/DIV = ________

4A. VOLTS/DIV = ________

0 V

0 s

4B. TIME/DIV = ________

4B. VOLTS/DIV = ________

0 V

0 s

4C. TIME/DIV = ________

4C. VOLTS/DIV = ________

0 V

0 s

Data Table 1

Voltmeter (V)	Oscilloscope (V)
1.00	
2.00	
3.00	
4.00	
5.00	

Data Table 2

Voltmeter (V)	Oscilloscope (V)
1.00	
2.00	
3.00	
4.00	
5.00	

Calculations Table 1

Intercept = ______________________

Slope = ______________________

r = ______________________

Calculations Table 2

Intercept = ______________________

Slope = ______________________

r = ______________________

SAMPLE CALCULATIONS

QUESTIONS

1. In the grid labeled 2A, how many complete cycles are sketched in your figure? From your sketch, what is period of the wave? Using this period, calculate the frequency of the wave for this sketch. Is it in agreement with the frequency used for this part of the experiment?

2. In your own words, explain why the two sketches in 3A and 3B look like they do. They both have the trigger level zero, but one has a positive trigger slope and the other has a negative trigger slope.

3. Explain the appearance of sketches 4A, 4B, and 4C. They all have a positive trigger slope, but the trigger level of 4A is zero, the trigger level of 4B is positive, and the trigger level of 4C is negative.

4. For a sine wave, an AC voltmeter measures a root-mean-square value that is 0.707 of the peak value of the sine wave. Therefore, the peak value measured on the oscilloscope should be 1/.707 or 1.414 times the voltmeter readings. The slope of the data in Data Table 1 that you calculated and recorded in Calculations Table 1 should be approximately 1.414. Calculate the percentage error between you slope for this data and 1.414.

5. For a triangular wave, an AC voltmeter measures a root-mean-square value that is 0.576 of the peak value of the triangular wave. Therefore, the peak value measured on the oscilloscope should be 1/.576 or 1.736 times the voltmeter readings. The slope of the data in Data Table 2 that you calculated and recorded in Calculations Table 2 should be approximately 1.736. Calculate the percentage error between your slope for this data and 1.736.

6. An oscilloscope is set on a TIME/DIV setting of 50 μs. There are 10 divisions on the time scale. A sine wave on the oscilloscope display has exactly three full cycles of the sine wave that fit on the 10 divisions. What is the frequency of the wave?