**Science 14**

**Lab 2: The Oscilloscope**

**Introduction**

**General Construction & Operation of Oscilloscopes**

An oscilloscope is a widely used device which uses a beam of high speed electrons (on the order of $10^7$ m/sec) to create a visual display of the waveforms of periodically changing voltages. It not only allows us to see the shape of the waveform, but also to obtain such quantitative data as the waveform's frequency, period and amplitude. Oscilloscopes are powerful research tools and are used extensively in both the physical and biological sciences. It is the intent of this laboratory exercise to familiarize you with the general construction and operation of oscilloscopes and to introduce you to the particular scope you will be using in the laboratory.

The display mechanism of an oscilloscope is a highly evacuated tube called a cathode-ray tube (abbreviated CRT), the principal of which are shown in figure 1. The heater heats the cathode to a temperature high enough to boil electrons off its surface. As the electrons are boiled off the cathode, they are accelerated down the CRT by the focusing anode which is kept at a high positive voltage with respect to the cathode. This focusing anode has a small hole in its center. Only those electrons that are traveling down the center of the tube will pass through this anode thereby creating a narrow beam. The electrons emerging from the focusing anode are further accelerated by the accelerating anode; and if the deflecting plates do not have a potential difference between them, the

![Diagram of Oscilloscope](image_url)
electrons will travel in a straight line to the far end of the tube where they will strike the center of a phosphor-coated screen creating a small bright spot. The control grid can be made more or less negative thereby controlling the intensity of the spot by controlling the number of electrons reaching the screen. The heater, cathode, control arid, and anodes constitute the part of the CRT called the electron gun (which will be studied in a later laboratory).

The electron beam can be deflected by two sets of deflecting plates oriented at right angles to each other. If a potential difference is placed across either set of plates an electric field will be created transverse to the direction of the beam resulting in a force on the electrons that will deflect them so they hit off the center of the screen. If the plates are properly designed, the amount of deflection will be proportional to the potential difference. The two sets of plates are oriented so that one set deflects the beam in the horizontal direction and the other deflects the beam in the vertical direction. The x, and y coordinates of the spot at any instant are then proportional to the voltages on the respective deflection plates. The electron path between each pair of plates is approximately 2 cm and the total beam path is on the order of 30 cm. An electron spends approximately $2 \times 10^{-9}$ seconds between each set of deflection plates and has a total time of flight on the order of $30 \times 10^{-9}$ seconds (30 nanoseconds). Thus, the beam is capable of extremely rapid response to varying voltages. The two sets of deflection plates are generally used simultaneously to produce either a display of $V(t)$ vs. $t$ or a display of $V_1(t)$ vs. $V_2(t)$.

To obtain a display of $V(t)$ vs. $t$, the voltage to be observed is applied to the vertical deflection plates and a voltage which increases uniformly with time is applied to the horizontal plates. The horizontal deflecting voltage (sweep voltage) is supplied by a voltage generator built into the oscilloscope; and it has the shape shown in figure 2. At $t = 0$, the sweep voltage is

![figure 2](image-url)
negative enough to cause the beam to be at the far left of the screen. As \( t \) progresses, the voltage becomes more positive at a uniform rate causing the beam to be swept across the screen from left to right at a constant rate. At \( t = T \), the beam reaches the far right side of the screen and the voltage immediately jumps back to negative thereby putting the beam back to the far left of the screen. The pattern then repeats itself. At the same time as the sweep voltage is sweeping the beam horizontally from left to right across the screen, the voltage to be observed is deflecting the beam vertically. In this way the vertical deflection is proportional to \( V(t) \), the horizontal to time, and the spot traces out a graph of \( V \) as a function of time. The frequency of the sweep voltage is variable and it can be synchronized with the frequency of the vertical deflecting voltage to obtain a stable display. The sweep voltage is sometimes called the linear time base. Figure 3 shows the voltage patterns for the deflection plates and their respective screen displays for an observed sine wave voltage.

With this type of display, the amplitude and frequency (or period) of the observed voltage can be measured.

To obtain a display of \( V_1(t) \) vs. \( V_2(t) \), the sweep voltage is disconnected from the horizontal deflection plates and is replaced by \( V_2(t) \). In this way the vertical position of the beam is proportional to \( V_1(t) \) while the horizontal position is proportional to \( V_2(t) \). The resulting displays are called lissajous figures when \( V_1(t) \) and \( V_2(t) \) are described by sine waves; the lissajous figures can be used to determine the phase difference between the two waves. A complete discussion of how this is done is found later in this write-up.
In addition to the CRT and sweep generator, an oscilloscope contains the following functional units:

1. **Power supply.** The power supply supplies the potentials for the electrodes of the electron gun, the current to heat the cathode, the potential to run the sweep generator, and any other power needed by the scope.

2. **Signal amplifiers.** Full scale deflections require about 200 V. To display small signals (as small as 1 mV), both the vertical and horizontal deflections are amplified using variable gain amplifiers. The amplifiers also permit adjustment of the size of the picture on the screen.

3. **Triggering.** In the "free run" mode, the horizontal sweep runs at a set rate. This rate is unlikely to be synchronized with the input signal, so the pattern will not be steady on the screen. To keep the pattern steady, a "trigger" is used to determine when the horizontal sweep will begin. The horizontal sweep - starts when the trigger signal reaches some value, which is adjustable with the trigger level control. The displayed signal may be used for triggering, or another signal may be supplied to the scope as an external trigger. For our purposes, it will not be necessary to know the actual trigger level, but it will only be necessary to adjust the trigger level until a steady display is obtained.

Additional controls permit moving the entire picture up and down or sideways, magnifying a small portion of the display, synchronizing the sweep frequency exactly with the frequency of the vertical deflecting voltage, and triggering the trace at various levels.

Figure 4 is a picture of the scope, you will be using in this and future labs. The function of each control is explained below.

1. **POWER switch:** When in the up position, the oscilloscope is on.

2. **INDICATOR LIGHT:** Lights when power is on.

3. **TRACE ALIGN:** When only the horizontal deflection plates are functioning, turning this screw aligns the trace with the horizontal axis.

4. **FIND BEAM:** When pressed, returns the off set beam to the display screen.

5. **INTENSITY:** Adjusts the brightness of the display.

6. **FOCUS:** Adjusts sharpness of display.
7. CAL: When a wire is run from this jack to one of the channels, a 1 V square wave is fed into that channel. In this way, the calibrated values on the vertical gain dials can be checked.

8. HORIZONTAL POSITION: Turning of this control moves the display horizontally on the screen.

9. SWEEP/EXT HORIZ.: In the SWEEP position, the sweep generator is activated. is the normal operating position. If in the MAG position, the horizontal time scale is magnified by 10. The EXT HORIZ. position determines the deflection factor of external signals applied to TRIG & HORIZ INPUT jack.

10. TIME/DIV: Selects the speed at which the beam is to be swept horizontally across the screen. The time it takes to move 1 division (1 cm) on the screen is given by numbers around this dial. Note, however, that for those numbers to accurately represent the sweep speed, the VAR SWEEP (11), control must be turned full clockwise.

11. VAR SWEEP: Allows selection of a sweep not given on the TIME/DIV dial.

12. SOURCE: Selects the origin of trigger signal that starts sweep. The normal operating position is INT.

13. COUPLING: Determines whether the input signal is joined to the deflection plates through a capacitor (if AC button is depressed) or directly (if DC button is depressed). Use of AC screens out unwanted DC signals.


15. TRIGGER LEVEL: This determines the amplitude of the signal needed to start a horizontal sweep. If on automatic (full counterclockwise), the scope will trigger on any incoming signal. If turned clockwise off automatic, the scope will trigger only for incoming signals above a certain amplitude. The exact amplitude is determined by how far clockwise the control is turned.

16. SLOPE: If this switch is in the + position, the trace will start on a portion of the signal which has a positive slope. If the switch is in the - position, the trace will start on a portion of the signal with a negative slope.

17. RESET: In SINGLE mode, pressing this push button resets sweep to zero and releasing it arms the circuit preparatory to receipt of trigger signal. Indicator lamp glows when circuit is armed.
18. **MODE:** In NORM, the sweep is periodically started by incoming signal. In SINGLE, sweep is triggered only once then must be manually reset. In FREE RUN, sweep cycles continuously and is not affected by trigger signals.

19. **VERTICAL COUPLING:** Selects capacitive (AC) or direct (DC) coupling of vertical input signals. In OFF, vertical amplifier input circuit is grounded and INPUT jacks are disconnected.

20. **INPUT:** Jacks for channel A and channel B inputs. If + jack is used with the black ground jack, voltage is measured with respect to ground. If red + and - jacks are used the voltage measured is the potential difference between the two jacks.

21. **BW LIMIT:** When pressed, reduces bandpass to about 50 KHz to attenuate noise level. Press again to restore bandpass.

22. **BAL.** Turning these screws minimizes the trace shifts when changing VOLTS/DIV ranges.

23. **VAR SENS:** Allows for a vertical calibration not given on the VOLTS/DIV (24) dial.

24. **VOLTS/DIV:** Selects the vertical deflection amplifier factor. The voltage value of each division on the screen is given by numbers around the outside of the dial. As with the TIME/DIV (10), the numbers are accurate only if the VAR Sens (23) controls are full clockwise.

25. **DISPLAY:** If set on A, the display is $V_A(t)$ vs. $t$ with $V_A(t)$ being the signal input to channel A. If set on B, the display is $V_B(t)$ vs. $t$ with $V_B(t)$ being the signal input to channel B. If set on alternate or chop, $V_A(t)$ vs. $t$ and $V_B(t)$ vs. $t$ will be displayed simultaneously. If set on A vs B, the display will be $V(t)$ vs $V(t)$ where channel A gives the y-deflection and channel B gives the x-deflection.

26. **VERTICAL POSTION:** Adjusts vertical position of display.

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**Lissajous Figures and the Measurement of Phase**

Suppose you are feeding into the two channels of an oscilloscope two voltages that are varying sinusodially with the same frequency. This can be expressed as

$$V_1(t) = A \sin \omega t$$
\[ V_2(t) = B \sin (\omega t + \delta) \]

where \( A \) and \( B \) are the maximum amplitudes of the voltages and \( \delta \) is the phase difference between the voltages. \( A, B \) and \( \delta \) are constant. What would a plot of \( V_1 \) vs \( V_2 \) look like? To answer this we will look at a few special cases.

1. \( \delta = 0 \). In this case \( V_1(t) = A \sin \omega t \)
   \[ V_2(t) = B \sin \omega t. \]
   Dividing the bottom equation into the top and solving for \( V_1(t) \) yields
   \[ V_1(t) = \frac{A}{B} V_2(t) \]
   This is the general form of a linear equation, \( y = ax + b \), where \( a = A/B \) and \( b = 0 \). Therefore, a plot of \( V_1 \) vs. \( V_2 \) would be a straight line through the origin with slope \( A/B \). (see figure 5) If \( A = B \) the line would be at a 45\(^\circ\) angle with the \( V_2 \) axis.

![Figure 5](image)

2. \( \delta = \pm (\pi/2) \). This gives
   \[ V_1(t) = A \sin \omega t \]
   \[ V_2(t) = B \sin(\omega t \pm \frac{\pi}{2}) = B \cos \omega t \]
If we divide by \( A \) and \( B \), square both equations, and then add, we get

\[
\frac{V_1(t)^2}{A^2} + \frac{V_2(t)^2}{B^2} = 1
\]

This is the general form of an ellipse. Therefore, a plot of \( V_1(t) \) vs \( V_2(t) \) would be elliptical with its major axis coinciding with one of the axes of the coordinate system. If \( A = B \), then the plot is a circle. (see figure 6)

3. \( \delta = \pi \). This gives

\[
V_1(t) = A \sin \omega t
\]
\[
V_2 = B \sin (\omega t + \pi) = -B \sin \omega t
\]

Dividing the bottom equation into the top and solving for \( V(t) \) yields

\[
V_1(t) = -\frac{A}{B} V_2(t)
\]

Again we have a linear equation. A plot of \( V_1(t) \) vs. \( V_2(t) \) would be a straight line with a slope of \(-A/B\). (see figure 7)
4. Cases other than those above are difficult to analyze, but it can be shown that they are ellipses with their axes tilted with respect to the $V_1$ and $V_2$ axes. (see figure 8)

At $t = 0$, our original equations become

\[
V_1(t) = A \sin \delta = 0
\]

\[
V_2(t) = B \sin \delta
\]

In figure 8, $V_2(t) = x_0$ when $t = 0$. Solving for $\sin \delta$ yields

\[
B \sin \delta = x_0
\]
or

\[ \delta = \sin^{-1} \frac{x_0}{B} \]

Note that the pattern must be centered on the horizontal and vertical axes for this to work. To minimize this centering error, it is better to calculate \( x_0 \) and \( B \) by measuring \( 2x_0 \) and \( 2B \) (as shown in figure 9) and then dividing by 2.

A more direct method of measuring phase difference is possible with the dual-mode scope by displaying both signals simultaneously, as shown in figure 10. If \( V_1(t) = A \sin \omega t \) and \( V_2(t) = B \sin (\omega t + \delta) \) then the phase difference, \( \delta \), is given (in radians) by \( \delta = 2\pi \left( \frac{d}{P} \right) \), where \( P \) is the period of either signal \( V_1 \) or \( V_2 \).
References

The following sections in Halliday and Resnick are pertinent to the lab

1. Chapter 27 section 27-5 (examples 8 and 9)
2. Chapter 15 section 15-7

Purpose

The purpose of this lab is to familiarize you with the general construction and operation of oscilloscopes and to introduce you to the particular scope you will be using in future labs.

Procedure

1. Follow this initial turn on procedure.
   a. Turn the POWER switch to the ON position and allow a few minutes to warm up.
   b. Set INTENSITY to midrange.
   c. Set DISPLAY to CH A.
   d. Set VAR SENS and VAR SWEEP full clockwise.
   e. Set VOLTS/DIV to 0.5 volts/div.
   f. Set TIME/DIV to 5 ms/div.
   g. Set the BW LIMIT to the OUT position.
   h. Set VERTICAL and HORIZONTAL POSITIONS to mid range.
   i. Set MODE to NORM.
   j. Set SOURCE to INT.
   k. Connect a wire from the positive terminal on channel A to the CAL jack. Set coupling to AC.
   l. Adjust the FOCUS and INTENSITY to obtain a sharp display. At this point you should see a square wave with an amplitude of 2 divisions and a period of approximately 3.4 divisions.
2. With the scope set as above, do the following.

   a. Sketch the observed trace.

   b. Measure the peak-to-peak amplitude of the square wave.

   c. Measure the period of the square wave.

   d. Change the vertical gain to 1 volt/div. Has the amplitude of the square wave changed? Explain.

   e. Change the sweep speed to 10 msec/div. Has the period of the square wave changed? Explain.

   f. Input a sine wave from your oscillator into channel A and turn the sine wave amplitude knob clockwise to its maximum value. Measure the peak-to-peak amplitude of the sine wave. Turn the sine wave amplitude knob full counterclockwise to its minimum value. Measure the peak-to-peak amplitude of the sine wave. What is the range of sine wave voltages your oscillator can put out?

   g. Repeat step 2f with the square-wave output of your oscillator.

   h. Change the sweep dial to MAG. Determine the power of magnification.

   i. Return the VOLTS/DIV & TIME/DIV to their original settings and set the MODE to LINE. Describe what you see and explain what is happening. What could you do to make the trace stable?

   j. Set the MODE to FREE RUN. Describe what you see and explain what is happening.

3. Connect the output from the sine wave terminals of your oscillator to either channel A or B.

   a. Set the oscillator dial to 1 kilohertz (1000 Hz). Measure the period of the sine wave. Compute the frequency from the period. Compare with the oscillator dial.

   b. Repeat step 3a using the square wave output of the oscillator.

   c. Reconnect the sine wave output to the scope. Turn the HORIZONTAL POSITION until you can see the left hand edge of the trace. Set the SLOPE to +. Turn the TRIGGER LEVEL off automatic. Continue turning until a trace can be seen. Turn the TRIGGER LEVEL clockwise. Describe what
happens to the trace. In particular, pay attention to the left hand edge of the trace. Now turn the trigger level counterclockwise. Again describe what happens to the trace. Explain. How does the SLOPE switch effect the trigger mechanism? Turn the TRIGGER LEVEL until a trace is again observed. Turn down the amplitude of the wave by using the sine wave amplitude control on the oscillator. Describe what happens to the trace. Explain.

d. Turn the TRIGGER LEVEL back to midrange and increase the amplitude of the sine wave until it has a peak-to-peak amplitude of 8 volts. Turn the VAR SENS control counterclockwise. Describe what happens to the trace. Is the amplitude of the wave changing? Calibrate your scope to a value not given on the VOLTS/DIV scale. Turn down the amplitude of the sine wave approximately 1/8 turn. Measure the new sine wave’s amplitude using your calibration. Put the scope back on automatic calibration (by turning the VAR SENS fully clockwise until a click is heard. Again measure the amplitude of the new sine wave. Compare the two values.

4. The phase-shifter boxes on each bench have two pairs of output terminals. Input the signal from one pair of terminals into channel A and input the signal from the other pair into channel B. Display both signals simultaneously by setting DISPLAY to ALTERNATE. Note that the internal sweep triggers on channel A, but that the oscillator connected to B can also be connected to the external trigger and then the scope will trigger on channel B. Now switch the DISPLAY to A vs B and observe the differences when the horizontal sweep is sinusodial rather than sawtooth. When the frequencies are integral multiples of each other, one finds the so-called lissajous figures, which can be used to measure the relative phase and frequency of the two signals. The frequency of the signal from the gray box is 6 KHz. Set the frequency of your oscillator to 6 KHz and use the fine tuning to obtain as stable a trace as possible (What must be true to get a stable trace?). Sketch and describe what you see. Repeat this procedure with frequencies of 12 KHz, 18 KHz, 3 KHz, and 2 KHz.

5. Leaving channel A connected to the red terminal of the gray box, connect the black terminal to channel B of your scope. Display A vs. B. At this point the lab instructor will tell you what to do. The vertical gains should be at the same setting for both channels.

6. Input the signal from the red terminal into channel A and input a signal from your function generator into channel B. Using lissajous figures determine the frequency of the signal from the red terminal.
Lab Report

Your lab report will be your lab notebook. Include in your report all the sketches and explanations asked for in the procedure and the answers to all questions asked in the procedure. Be neat and organized in your presentation.

There will be a laboratory quiz at the end of the period, in which you will be asked to make certain measurements using the oscilloscope.