Introduction to the Oscilloscope

I. INTRODUCTION

The cathode-ray oscilloscope is one of the most versatile laboratory instruments for studying ac circuits. Having long been quite common in the physics laboratory, the oscilloscope is finding increasing uses and applications in biology and medical fields. In its most basic application, the oscilloscope is used to display a graph of voltage versus time on its screen. The signal may be the voltage across a component in an electrical circuit or that generated by a nerve impulse or a heartbeat.

In this experiment, an introduction to the basic principles of the oscilloscope is presented, and you will operate an oscilloscope so as to become familiar with its controls and characteristics.

II. EQUIPMENT NEEDED

- Cathode-ray oscilloscope (student model)
- Audio-signal function generator (sine and square waves)
- (60-Hz sine wave source, or second generator if oscilloscope does not have internal line input)
- Connecting wires

III. THEORY

The basic component of an oscilloscope (or "scope") is a cathode-ray tube (CRT) or electron-beam tube (Fig. 38-1). The name "cathode-ray tube" comes from early experiments with gas discharge tubes in which "rays" coming from the cathode or negative electrode were observed. The beam of electrons (cathode rays) in a CRT is formed by an "electron gun," in which electrons thermally emitted from a cathode filament are accelerated through a potential difference of several thousand volts and focused into a beam. The electron beam strikes a fluorescent screen coated with a phosphor that emits visible light and a spot of light is seen on the screen.

The CRT is also equipped with sets of vertical and horizontal deflection plates. If no voltage signals are applied to the deflection plates, the beam is undeflected and strikes the center of the screen. However, if a voltage signal is applied to the horizontal deflection plates, the electron beam will experience a force and be deflected horizontally.

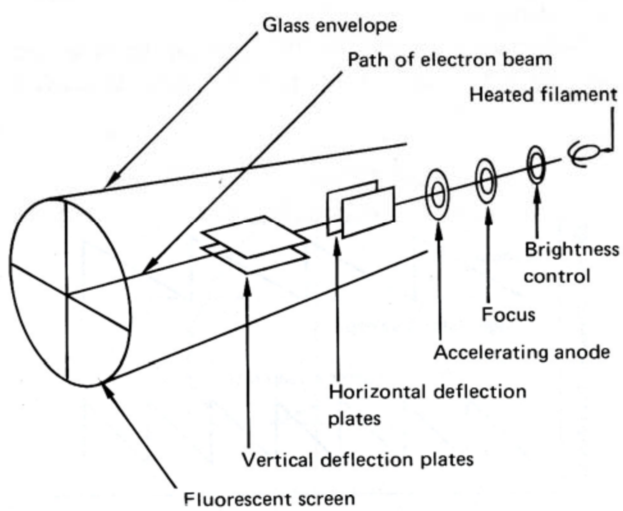


Fig. 38-1 The basic components of an oscilloscope cathode ray tube (CRT).

A constant dc voltage will deflect the beam spot on the screen a fixed distance. An ac voltage, on the other hand, will deflect the beam back and forth, since the polarity is continually changing. If the frequency of the ac voltage signal is large enough, the beam spot traces out an observable continuous horizontal line. This is due to the relatively slow decay of the brightness of the fluorescent screen after each excitation and the persistence of vision in the human eye.

Similarly, a voltage signal applied to the vertical deflection plates causes the beam to move vertically. In either case, the magnitude of the deflection of the beam spot from the center of the screen is proportional to the magnitude of the voltage applied to the deflection plates. As such, the cathode-ray oscilloscope is an extremely fast X-Y plotter that is capable of plotting an input signal versus time or another signal.

In ac voltage applications, it is usually desired to display the voltage on the screen as a function of time (i.e., a graph of voltage versus time). The signal to be studied is applied to the vertical deflection plates. The oscilloscope has an internal vertical amplifier or gain to amplify weak input signals. A horizontal linear time axis is obtained if the beam spot moves horizontally (left to right) with a constant speed.

The time axis is generated by applying a deflecting voltage to the horizontal plates, which increases linearly with time (e.g., a voltage signal with a "sawtooth" wave form, as illustrated in Fig. 38-2). As the voltage increases uniformly, the spot sweeps uniformly (with constant speed) across the screen from left to right. When the voltage suddenly drops to zero, the beam flies back to its initial position and begins another horizontal sweep with the "triggering" of the next sawtooth.

With a slow sweep rate, the spot can be observed moving periodically from left to right. However, with a fast sweep rate, a continuous trace is observed, as the eye cannot follow the motion. The oscilloscope is equipped with an internal variable sawtooth generator to supply such horizontal signals with no signal on the horizontal plates.

Suppose that a sinusoidal voltage having the form $V = V_0 \sin 2\pi ft$ is applied to the vertical plates. As discussed previously, the beam would move up and down and trace out a vertical line on the screen. However, if a sawtooth voltage signal is applied to the horizontal plates with the same sweep-rate frequency as the frequency f of the vertical sinusoidal voltage signal, the beam will sweep from left to right while it moves vertically up and down (Fig. 38-3). The combined motions of the beam spot then trace out a graph of the voltage of the applied vertical signal with time, and a sine wave is seen on the screen.

A. *Frequency Measurements*

If the sine-wave pattern retraces itself and appears to stand still, we say that the signals are synchronized. In this case, the frequency of the sinusoidal voltage input is equal to the sweep rate, which is the number of horizontal repetitions (cycles) of the beam spot per second. That is, there is one vertical oscillation for each horizontal sweep.

It follows that if the sinusoidal voltage frequency is twice that of the sweep rate, then two sine-wave cycles would appear on the screen, and so on. For example, if the sweep rate frequency is 100 Hz (cycles per second) and two cycles of a sine wave appear on the screen, the frequency input is 200 Hz. In general, a stationary pattern results when the ratio

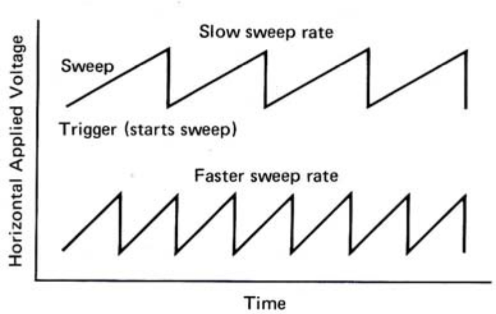


Fig. 38-2 Sawtooth voltage functions that supply different oscilloscope sweep rates.

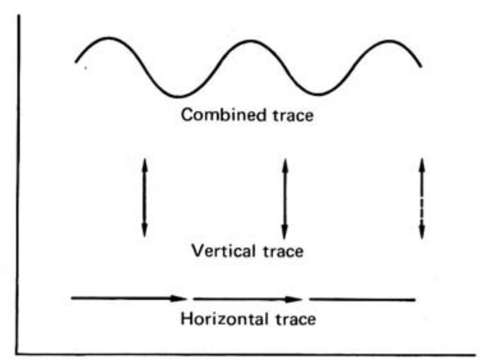


Fig. 38-3 The combination of a horizontal sweep signal and a vertical sinusoidal signal produces a sine-wave trace on an oscilloscope screen.

of the sweep-rate frequency and the frequency of the input-voltage signal is an integral or half-integral.

The sweep time of the trace across the screen is the reciprocal of the sweep rate frequency. For example, if the sweep-rate frequency is 100 Hz, the sweep time is $\frac{1}{100} = 0.01$ s. Knowing the sweep time, the frequency of a vertical input voltage can be determined by dividing the number of stationary-wave cycles observed on the screen by the sweep time.

Applied to the previous example with a sweep-rate frequency of 100 Hz and 2 cycles observed on the screen, the frequency of the input voltage is $f = \frac{2}{0.01} = 200$ Hz.

The frequency of a sinusoidal voltage can also be determined by comparing it with another calibrated sinusoidal signal. The simplest oscilloscope pattern results when the two sinusoidal signals have the same frequency and are in phase, for example, have the form

$$x = A \sin 2\pi ft$$

and

$$y = A \sin 2\pi ft \qquad \textbf{(38-1)}$$

A diagonal line is observed on the screen (Fig. 38-4). The pattern observed when the frequency of the y signal is three times that of the x signal is also shown in Fig. 38-4. Such patterns are called *Lissajous figures.* As before, a stationary pattern results when the frequency of the X-axis signal and the frequency of the Y-axis signal are integral or half-integral.

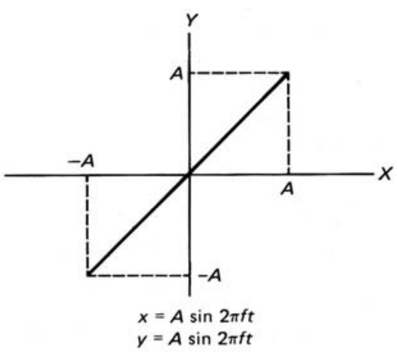
Suppose that two sinusoidal signals have the same frequency but different phases, for example of the form

$$x = A \sin 2\pi ft$$

and

$$y = A \sin (2\pi ft - \delta) \qquad \textbf{(38-2)}$$

where δ is the phase angle or the phase difference. The phase angle of the x signal is equal to zero. Then an ellipse will be traced out on the screen (Fig. 38-5). If the phase difference is 90°, the pattern is a circle.



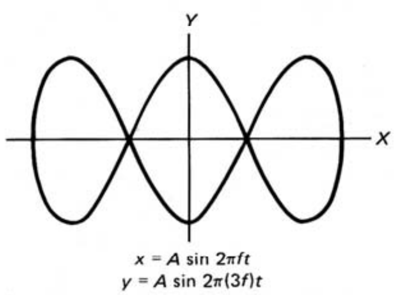


Fig. 38-4 Lissajous figures for different x and y signals.

B. Voltage Measurements

In addition to frequency measurements, the oscilloscope can be used as a voltmeter to read the peak-to-peak voltages of ac signals as well as dc voltages. The voltage readings are read directly from a plastic screen or grid attached to the face of the oscilloscope tube. Recall that the vertical deflection of the beam is proportional to the voltage of the signal applied to the vertical deflection plates.

To calibrate the oscilloscope screen, a voltage signal of known magnitude is used. For ac measurements, an internal or external reference voltage is applied to the vertical input of the scope with the horizontal sweep turned off. The resulting vertical line represents the peak-to-peak voltage of the input

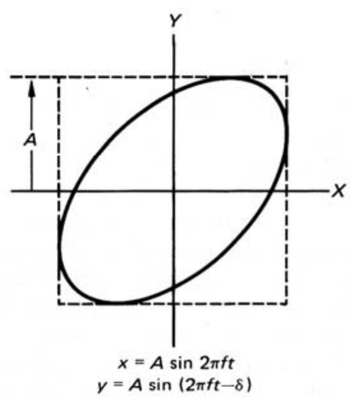


Fig. 38-5 The Lissajous figure for signals having the same frequency but different phases is an ellipse.

signal. For example, suppose the reference voltage is 5 volts peak-to-peak. By adjusting the vertical height control or gain so the vertical trace line corresponds to 5 scale divisions, the calibration is 5 volts/5 divisions or 1 volt/div. The vertical height control is left in this position after calibration. (Why?) Most scopes have internal voltage calibrations in several voltage steps or values.

The peak-to-peak height of the trace of an ac input signal is then measured and the peak-to-peak voltage computed from the calibration. Dividing by two gives the peak voltage, and multiplying by $1/\sqrt{2} = 0.707$ gives the root-mean-square (rms) value of the voltage.

There is a large variety of oscilloscopes and the controls of each model and make cannot be discussed here. All oscilloscopes have some operating controls in common, however, some have controls that others lack, depending on the purpose and sophistication of the scope. Also, controls and connectors are not always found in the same location or in the same form on all oscilloscopes. A typical type oscilloscope (B+K, Model 1466A) found in an introductory physics lab is shown in Fig. 38-6(a).

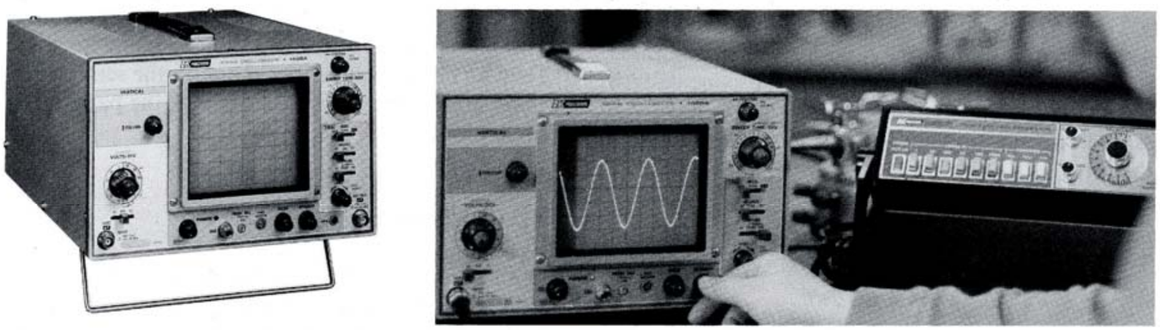


Fig. 38-6 (a) A typical student model oscilloscope. (b) A sine wave on oscilloscope from a function generator input. (Photo in (a) courtesy of B+K Precision, Dynascan Corporation.)

EXPERIMENTAL PROCEDURE

1. Locate and familiarize yourself with the following general controls and connections on your oscilloscope. The operating manual of your instrument should be consulted for specific and detailed explanations of the operating controls and for initial control settings.

DISPLAY CONTROLS

(a) INTENSITY—adjusts the rate of electron emission of the cathode, and hence the brightness of the spot.
(b) FOCUS—adjusts the sharpness of the spot.
(c) ASTIG (astigmatism)—adjusts vertical and horizontal positions of trace to same position. If a well-defined trace cannot be obtained with focus control, it may be necessary to adjust the astigmatism control.
(d) SCALE LIGHT (optional)—adjusts a lamp that lights the edges of the screen scale.
(e) POWER SWITCH (OFF-ON)—turns the oscilloscope on and off. This switch is often on the same shaft as one of the preceding controls.

POSITION CONTROLS

(a) HORIZONTAL POSITION (H-POS)—adjusts the horizontal position of the spot or trace on the screen.
(b) VERTICAL POSITION (V-POS)—adjusts the vertical position of the spot or trace on the screen.
(c) HORIZONTAL GAIN—provides continuous adjustment of the gain of the horizontal amplifier (i.e., amplifies or "magnifies" the trace).
(d) VERTICAL GAIN—provides continuous adjustment of the gain of the vertical amplifier (i.e., amplifies or "magnifies" the trace).
(e) VOLTS/DIV or VERTICAL ATTENUATOR—provides step adjustment of vertical sensitivity in calibrations of volts per grid division or volts/cm. [On uncalibrated scopes, at the "1" position the amplitude of the signal

voltage is unchanged (no attenuation). At the "10" or "10:1" position, the amplitude is attenuated by a factor of 10, and so on.]

(f) VARIABLE VOLTS/DIV (VERTICAL GAIN)—provides fine control of vertical sensitivity. In CAL (calibrated) position, the VERTICAL ATTENUATOR is calibrated. May also serve as vertical gain in some operations. (On uncalibrated scopes, the VERTICAL GAIN provides fine control of vertical sensitivity between steps of VERTICAL ATTENUATOR settings, usually in steps of 10.)

SWEEP TIME AND TRIGGERING MODE

(a) SWEEP TIME/DIV or SWEEP (HOR) SELECTOR—selects calibrated horizontal sweep rates in terms of time per grid division. On instruments with sweep selector frequency controls, the switch positions are calibrated in terms of frequency rather than time. For example, set on the 100- to 1000-Hz range, the sweep time is between $\frac{1}{100}$ and $\frac{1}{1000}$ of a second ($t = 1/f$). Consult instrument Instruction Manual for operation of any additional sweep selections.

(b) VARIABLE TIME/DIV (*X* or HORIZONTAL GAIN or SWEEP VERNIER)—provides fine sweep time adjustment. In CAL (calibrated) position, the sweep time is calibrated in time/div steps. (On uncalibrated scopes, horizontal gain adjustment is provided by a HORIZONTAL GAIN control.)

(c) TRIG MODE—three-position switch that selects triggering mode.

AUTO—triggered sweep operation when trigger signal is present and automatically generates sweep in absence of trigger signal.

NORM—normal triggered sweep operation. No trace unless proper trigger signal is applied.

X-*Y*—vertical input signal produces vertical (*Y*-axis) deflection, EXT input signal produces horizontal (*X*-axis) deflection.

(d) SOURCE or SYNC (HOR) SELECTOR—selects the triggering source (i.e., source that determines *when* spot is triggered or starts sweeping across screen).

INT—wave form being observed is used as sync trigger.

LINE—sweep is triggered by line voltage or in step with (60 Hz) line frequency.

EXT—sweep is triggered by signal applied to EXT jack.

EXTERNAL CONNECTIONS

(a) VERTICAL INPUT—applies an external signal to the vertical amplifier. The lower terminal is usually grounded (GND) to the instrument case. (Sometimes there are two terminals above ground for balanced inputs. The lower terminal must be grounded for grounded-side input and is usually gauged to the ground terminal by a connector. See the Instruction Manual for the instrument.

(b) HORIZONTAL INPUT and/or EXT TRIG —applies an external signal to the horizontal amplifier. May also be input terminal for external trigger signal.

2. Consult the instrument Instruction Manual for initial starting procedure and control settings. Make the appropriate control adjustments. Turn on oscilloscope. A trace should appear on the screen.

Adjust the INTENSITY and FOCUS. *Never advance the intensity control to the point where an excessively bright spot or trace appears on the screen. A bright spot can burn the screen and decrease its useful life.* Adjust the HORIZONTAL POSITION and VERTICAL POSITION controls so that the spot is in the center of the screen. If you have trouble obtaining a spot, ask the instructor for assistance.

3. Calibrated Scopes: With a low SWEEP TIME/DIV setting, adjust the VARIABLE TIME control and note the effect.

Uncalibrated Scopes: Advance the HORIZONTAL GAIN and note the trace. (The horizontal trace may have an unavoidable stray sinusoidal "ripple.") Return the gain to zero.

The following general procedures are divided into Calibrated Scope and Uncalibrated Scope sections, with the latter being assumed to have an internal voltage calibration signal and an internal 60-Hz line horizontal input.

A. *Time and Frequency Measurements*

CALIBRATED SCOPES

1. Set the TRIG MODE to NORM, the SOURCE SWITCH to INT, and the SWEEP TIME variable control to CAL. Connect the function generator sine-wave output to the VERTICAL (*X*) INPUT of the scope. Turn on the function generator and set the generator frequency at 90 Hz. Adjust the function generator amplitude control

so that the sine-wave pattern is almost full-scale on the screen. (Switch the TRIG MODE momentarily to X-Y. What do you observe and why?)

2. Adjust the SWEEP TIME/DIV control so that a wave pattern with two peaks appears on the screen. Read the number of divisions for one full sine-wave cycle and record in the Laboratory Report.

3. (a) Compute the time period (T) of one cycle of the wave pattern using the calibrated SWEEP TIME/DIV setting and record.
   (b) Compute the sine-wave frequency ($f = 1/T$) and compare with the function generator setting by computing the percent difference.

4. Repeat the preceding procedures for a function generator output of 300 Hz.

5. With the generator output still at 300 Hz, adjust the SWEEP TIME/DIV control in various steps and note the relationship of the number of wave cycles to the sweep time/div. Can you explain? (See Question 1 at the end of the experiment.)

6. Set the SOURCE SWITCH to LINE. Adjust the function generator frequency to 60 Hz so a stationary pattern appears on the screen. This matches the generator frequency to the relatively stable 60-Hz line frequency, which is more accurate than the calibration markings on the function generator. Compare the generator frequency setting to the line frequency by finding the percent error.

7. Adjust the calibrated SWEEP TIME/DIV control until one or more full sine-wave cycles appear on the screen. Then, compute the frequency of the sine wave appearing on the scope as before.

UNCALIBRATED SCOPES

1. Set the VERTICAL ATTENUATOR (or CALIBRATION control) to calibration. (This introduces a 60-Hz sinusoidal calibrated voltage signal to the vertical amplifier by which the vertical voltage scale may be calibrated—so many volts per centimeter on the screen scale.) Adjust VERTICAL GAIN and note effect. With the SWEEP SELECTOR set on the 10- to 100-Hz range, advance the HORIZONTAL GAIN and note the trace.

2. Adjust the SWEEP VERNIER to 60 Hz and note the trace. The sweep-rate frequency is now equal to the vertical voltage frequency. What should be observed, and why? Adjust the SWEEP VERNIER so that exactly one sine-wave cycle appears on the screen. This matches the sweep-rate frequency to the line frequency (60 Hz). The sweep-knob setting may be slightly off.

3. Set the HORIZONTAL SELECTOR to 60 Hz (or LINE) and note the pattern. Can you explain what appears? Adjust the HORIZONTAL and VERTICAL GAINS and note the pattern. Are the input voltages exactly in phase?

4. Leave the SWEEP VERNIER set at the matched 60-Hz setting, set the HOR SELECTOR to + or −, and the VERTICAL GAIN and VERTICAL ATTENUATOR at their lowest settings. Connect the function generator sine-wave output to the V-INPUT terminals. Turn on the function generator and set the generator frequency at 60 Hz. Adjust the generator amplifier (wave amplitude) so that the sine wave is almost full scale on the oscilloscope screen. Advance the VERTICAL ATTENUATOR to the 10 (or 0.1) setting (or the VOLTS/DIV control) and note the attenuation. Advance the VERTICAL GAIN until the pattern is about half-scale on the screen.

5. Finely adjust the frequency of the function generator so that the pattern is as stationary as possible. Record the generator frequency setting in the Laboratory Report. The sweep frequency, which has been matched to the relatively stable 60-Hz line frequency, is much more accurate than the calibration markings on the function generator and may be used to calibrate the function generator.

   Compare the generator frequency to the line-matched 60-Hz sweep frequency by finding the percent error.

6. Set the function generator frequency to 30 Hz. (Make a fine adjustment of the generator frequency to obtain a stationary pattern.) Note and record the number of whole and one-half fractional parts of complete sine-wave cycles. Also make a sketch of the pattern.

   Advance the generator frequency and find several frequencies that produce stationary patterns. Record the generator frequency and the number of sine-wave cycles for each stationary pattern. Round off the generator frequencies to the nearest whole-10 Hz (e.g., 30 Hz, etc.) to take into account the error in the generator frequency calibration markings. Advance the HORIZONTAL GAIN to spread out the pattern if necessary.

Compute the ratio of the generator frequency and the line frequency (60 Hz) for each case.

7. Set the function generator for a frequency of 200 Hz and adjust the oscilloscope controls until a stationary pattern of one sine-wave cycle is obtained on the screen. Note the sweep rate or frequency of the signal indicated by the oscilloscope controls. Set the function generator to 2 kHz. How many cycles are there now? Adjust for one cycle. Do you see how the sweep rate can be calibrated from a generator?

B. *Voltage Measurement*

CALIBRATED SCOPES

1. (a) With the full sine-wave cycles on the screen (procedure 7), record the VOLTS/DIV control setting (with variable control at CAL).
   (b) Read the number of peak-to-peak divisions for the height of the wave pattern on the screen.
   (c) Compute the rms voltage of the wave.

UNCALIBRATED SCOPES

1. Set the VERTICAL ATTENUATOR (or CALIBRATION control) to calibration. This introduces a 60-Hz sinusoidal calibrated voltage signal to the vertical amplifier by which the vertical voltage scale may be calibrated—so many volts per centimeter on the screen scale. Consult the Instruction Manual or the instructor for the magnitude of the internal calibration signal.
   (a) Using the VERT GAIN, adjust the voltage signal so as to extend over several vertical scale divisions and compute the volts per division calibration. (Leave the VERTICAL GAIN set at this position throughout the rest of this procedure.)
   (b) With a 60-Hz input from the function generator, obtain a stationary wave pattern on the screen.
   (c) Read the number of peak-to-peak divisions for the height of the wave pattern.
   (d) Compute the rms voltage of the wave.

C. *Lissajous Figures*

CALIBRATED SCOPES

1. Set TRIG MODE to *X-Y* and apply a 60-Hz sine wave to the HORIZONTAL or *X* INPUT. A second function generator may be used. (Do not exceed the voltage limitation of the oscilloscope in any case.)

   With either the VERTICAL or HORIZONTAL INPUT set at 60 Hz, adjust the other input frequency to 30 Hz, making a fine adjustment of this generator frequency to obtain a stationary pattern. (If two generators are used, adjust the generator amplitude control(s) so the signals have equal amplitudes. This is done by alternately adjusting the signal amplitude with the other generator switched off.) Observe the pattern on the screen.

2. Adjust the generator frequency to 60 Hz and obtain a stationary wave pattern. Note that by slight adjustment you can vary the pattern between a straight line or a circle. Can you explain why?

3. Continue to increase the generator frequency and observe the various stationary and moving patterns. Record in the data table.

UNCALIBRATED SCOPES

1. Set the HORIZONTAL SELECTOR to 60 Hz (or LINE). Repeat the series of generator frequency settings as in the previous procedure 6 and observe the patterns, adjusting the frequency so a pattern is as stationary as possible. Record the frequencies and patterns in the data table. In particular, at the 60-Hz generator setting, notice that by slight adjustment of the frequency control that you can vary the pattern between a straight line and a circle. Can you explain this behavior and the Lissajous figures?

General: Calibrated and Uncalibrated Scopes

You should now be getting a feeling for the oscilloscope controls and operations. Adjust the various control knobs so as to better understand their functions. Also, connect the square-wave output of the function generator to the VERTICAL INPUT and investigate this wave form.

Name .... Section .... Date ....

Lab Partner(s) ....

EXPERIMENT 38 *Introduction to the Oscilloscope*

LABORATORY REPORT

Calibrated Scopes

A. *Time and Frequency Measurements*

Generator frequency 90 Hz

Calculations (show work)

No. divisions ....

Time Sweep/Div ....

Period ....

Frequency ....

Percent difference ....

Generator frequency 300 Hz

Calculations (show work)

No. divisions ....

Time Sweep/Div ....

Period ....

Frequency ....

Percent difference ....

Source—Line (60 Hz)

Generator frequency setting ....

Percent error ....

No. divisions ....

Time Sweep/Div ....

Period ....

Frequency ....

Calculations (show work)

Name .... Section .... Date ....

Lab Partner(s) ....

EXPERIMENT 38 *Introduction to the Oscilloscope*

B. *Voltage Measurement*

Calculations (show work)

Volts/div ....

No. of divisions (peak-to-peak) ....

Rms voltage ....

Uncalibrated Scopes

A. Time and Frequency Measurements

Function generator frequency ....

Line frequency ....

Percent error ....

Stationary Wave Patterns Generator frequency	Sine cycles (number and sketch)	Ratio of generator frequency and line frequency
30 Hz	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....

B. *Voltage Measurement*

Calculations (show work)

Volts/div ....

No. of divisions (peak-to-peak) ....

Rms voltage ....

Lissajous Figures

X-input frequency	*Y*-input frequency	Sketches of patterns
....	....	
....	....	
....	....	
....	....	
....	....	
....	....	

QUESTIONS

Calibrated Scopes

1. How does the number of wave cycles seen on a screen for a fixed input frequency vary with the SWEEP TIME/DIV control setting? Why?

2. Explain why the 60-Hz Lissajous figure could be varied between a straight line and a circle.

Uncalibrated Scopes

1. What is the sweep time of a trace with a sweep rate of 60 Hz?

2. In the stationary wave patterns procedure, compare the number of wave cycles and the frequency ratio. Explain any similarity.

3. Explain why the 60-Hz Lissajous figure could be varied between a straight line and a circle.