Oscilloscope Measurements

OBJECTIVES

- ❑ Investigate the fundamental principles and practical operation of the oscilloscope using signals from a function generator.
- ❑ Measure sine and other waveform signals of varying voltage and frequency.
- ❑ Compare voltage measurements with the oscilloscope to voltage measurements using an alternating current voltmeter.

EQUIPMENT LIST

- Oscilloscope (typical direct current to 20 Mhz), alternating current voltmeter (high frequency capability)
- Function generator (sine wave plus additional wave form such as a square wave or triangular wave), appropriate connecting wires (BNC to banana plug)

THEORY

The fundamental working part of an **oscilloscope** is a device called a **cathode-ray tube** (CRT). Its components include a heated filament to emit a beam of electrons, a series of electrodes to accelerate, focus, and control the intensity of the emitted electrons, 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), and 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 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. When a constant voltage is applied between either the horizontal or vertical deflection plates, the beam will be displaced by a constant amount on the fluorescent screen in either the horizontal (x) or vertical (y) direction. The direction of the displacement depends upon 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.

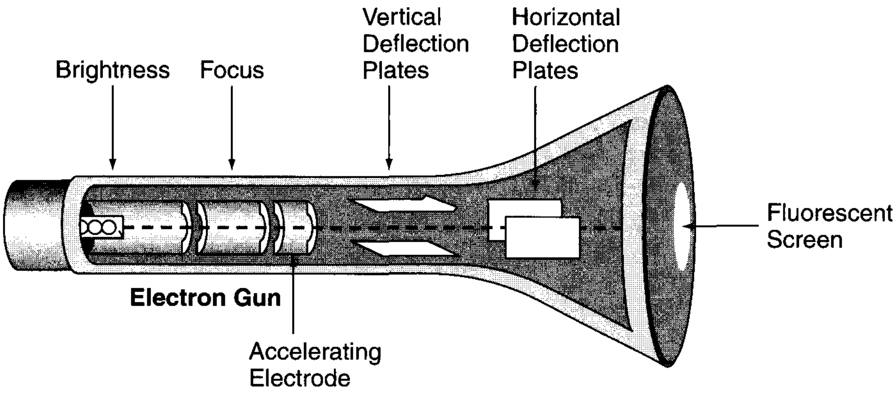


Figure 38-1 Cathode-ray tube.

We can deflect the electron beam in the horizontal (x) direction 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 of 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 the sweep of the beam across the screen, the beam returns to the left of the screen. The time this takes will equal the period T of the sawtooth waveform. Because this waveform sweeps the beam across the screen, it is commonly called the **sweep generator.**

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 because of 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 0.01 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 selecting the position of a multiposition switch. The width of oscilloscope screen is fixed, usually 10 cm. Each different choice of period T 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 time scales would be 19 settings ranging from 0.2 s/cm to 0.2 ms/cm. Because the screen is 10 cm wide, there is a factor of 10 between the period T and the time scale. If the period of the sweep generator is 10 ms, the time scale is 1 ms/cm. Time $t = 0$ is assumed to occur at the left of the 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. The typical range of possible voltage scales is from 5 V/cm to 5 mV/cm. 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. For the choices stated, the maximum voltage that can be displayed on the screen is 20 V. The voltage can be either positive or negative polarity, so the vertical scale has its zero in the center of the screen to display both positive and negative voltages.

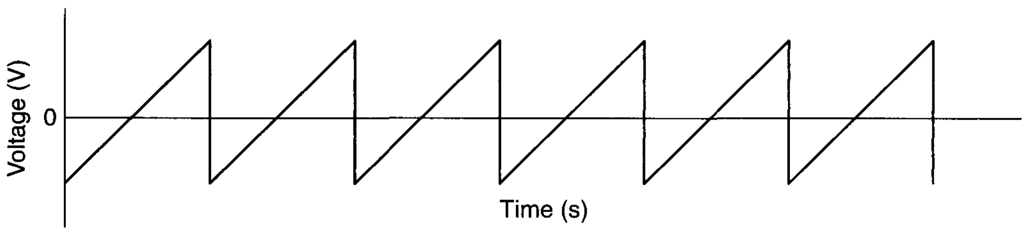


Figure 38-2 Sawtooth voltage waveform.

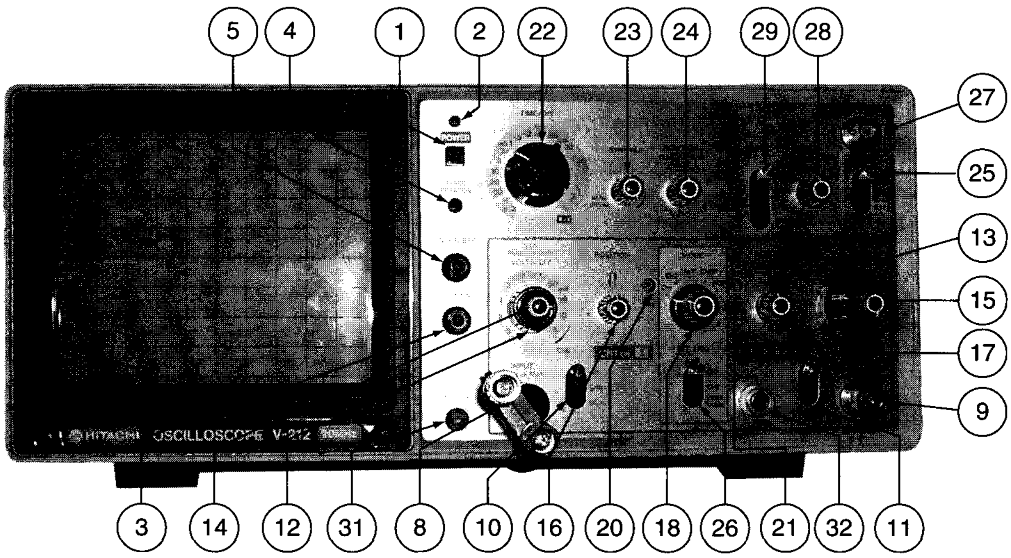


Figure 38-3 The Hitachi model V-212 oscilloscope.

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 with a maximum amplitude proportional to the maximum voltage of the signal, and with a period on the time scale of the oscilloscope that 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. We accomplish this 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. That is the mode we will use in this laboratory.

EXPERIMENTAL PROCEDURE

The procedure refers to the Hitachi model V-212 in Figure 38-3. It is a typical student oscilloscope. If using another oscilloscope, refer to the instruction manual for the corresponding settings and controls.

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 that 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 1 ms/DIV, the SWP VAR control rotated fully clockwise to the CAL position, the VOLTS/DIV control to 1 V/DIV, and the VAR (PULL × 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 2 ms/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 that 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 that sets the trigger slope to (+), and the trigger level is still set at zero. Draw on the grid label 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 alternating current voltmeter to set the output of the function generator to 1.00 V as read on the voltmeter. Input this sine wave to the oscil-loscope 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 alternating current 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 instructed 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. Now simply experiment for yourself with the features of the oscilloscope. Input as many different frequencies and waveforms as time allows 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 horizontal axis and the voltage as read on the voltmeter as the vertical axis. Determine the slope, the intercept, and the correlation 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 horizontal axis and the voltage as read on the voltmeter as the vertical axis. Determine the slope, the intercept, and the correlation coefficient. Record those values in Calculations Table 2.

Name

Section

Date

LABORATORY 38 *Oscilloscope Measurements*

PRE-LABORATORY ASSIGNMENT

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 phosphor glow that results has 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 (d) 200 V.

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

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

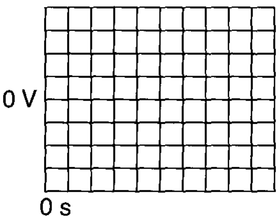
Name ____________________ Section __________ Date __________

Lab Partners ____________________

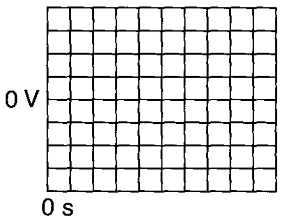
LABORATORY 38 *Oscilloscope Measurements*

LABORATORY REPORT

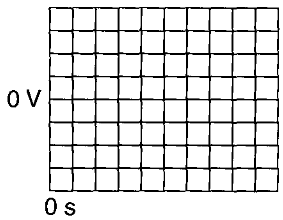
1A. TIME/DIV = ________
1A. VOLTS/DIV = ________



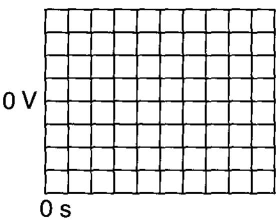
1B. TIME/DIV = ________
1B. VOLTS/DIV = ________



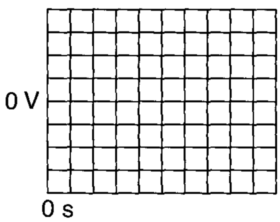
1C. TIME/DIV = ________
1C. VOLTS/DIV = ________



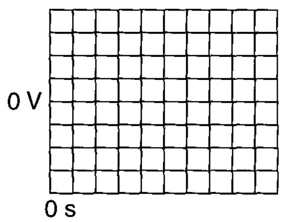
2A. TIME/DIV = ________
2A. VOLTS/DIV = ________



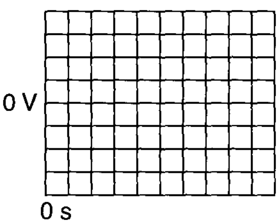
2B. TIME/DIV = ________
2B. VOLTS/DIV = ________



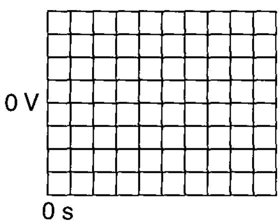
2C. TIME/DIV = ________
2C. VOLTS/DIV = ________



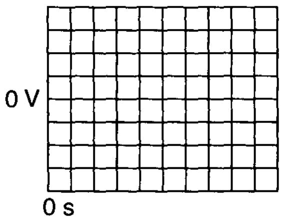
3A. TIME/DIV = ________
3A. VOLTS/DIV = ________



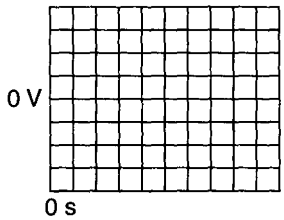
3B. TIME/DIV = ________
3B. VOLTS/DIV = ________



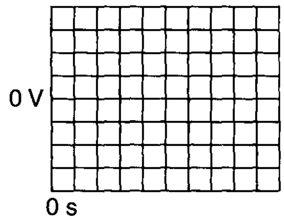
4A. TIME/DIV = ________
4A. VOLTS/DIV = ________



4B. TIME/DIV = ________
4B. VOLTS/DIV = ________



4C. TIME/DIV = ________
4C. VOLTS/DIV = ________



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

None

QUESTIONS

1. In the grid labeled 2A, how many complete cycles are sketched in your figure? From your sketch, what is the 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 these two sketches in 3A and 3B appear as 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 alternating current 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 your slope for these data and 1.414.

5. For a triangular wave, an alternating current 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 these data and 1.736.

6. An oscilloscope is set on a TIME/DIV setting of 50 ms. 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?