17 The Oscilloscope

OBJECTIVES:

After performing this experiment, you will be able to:

1. Explain the four major groups of controls on the oscilloscope.
2. Use an oscilloscope to measure ac and dc voltages.

READING:

Floyd and Buchla, *Principles of Electric Circuits,* Sections 11–1 through 11–4, 11–9, 11–10 and Application Activity

Oscilloscope Guide pp. 7–14

MATERIALS NEEDED:

None

SUMMARY OF THEORY:

The oscilloscope is an extremely versatile instrument that lets you see a picture of the voltage in a circuit as a function of time. There are two basic types of oscilloscopes—analog oscilloscopes and digital storage oscilloscopes (DSOs). DSOs are rapidly replacing older analog scopes because they offer significant advantages in measurement capabilities including waveform processing, automated measurements, waveform storage, and printing, as well as many other features. Operation of either type is similar; however, most digital scopes tend to have menus and typically provide the user with information on the display and may have automatic setup provisions.

There is not room in this Summary of Theory to describe all of the controls and features of oscilloscopes, so this is by necessity a limited description. You are encouraged to read the Oscilloscope Guide at the beginning of this manual, which describes the controls in some detail and highlights some of the key differences between analog scopes and digital scopes. You can obtain further information from the User Manual packaged with your scope and from manufacturers' web sites.

Both analog and digital oscilloscopes have a basic set of four functional groups of controls that you need to be completely familiar with, even if you are using a scope with automated measurements. In this experiment, a generic analog scope is described. Keep in mind, that if you are using a DSO, the controls referred to operate in much the same way but you may see some small operating differences.

Although the process for waveform display is very different between an analog oscilloscope and a DSO, the four main functional blocks and primary controls are equivalent. Figure 17–1 shows a basic analog oscilloscope block diagram which illustrates these four main functional blocks. These blocks are broken down further in the Oscilloscope Guide for both types of scope.

Controls for each of the functional blocks are usually grouped together. Frequently, there are color clues to help you identify groups of controls. Look for the controls for each functional group on your oscilloscope. The display controls include INTENSITY, FOCUS, and BEAM FINDER. The vertical controls include input COUPLING, VOLTS/DIV, vertical POSITION, and channel selection (CH1, CH2, DUAL, ALT, CHOP). The triggering controls include MODE, SOURCE, trigger COUPLING, trigger LEVEL, and others. The horizontal controls include the SEC/DIV, MAGNIFIER, and horizontal POSITION controls. Details of these controls are explained in the referenced reading and in the operator's manual for the oscilloscope.

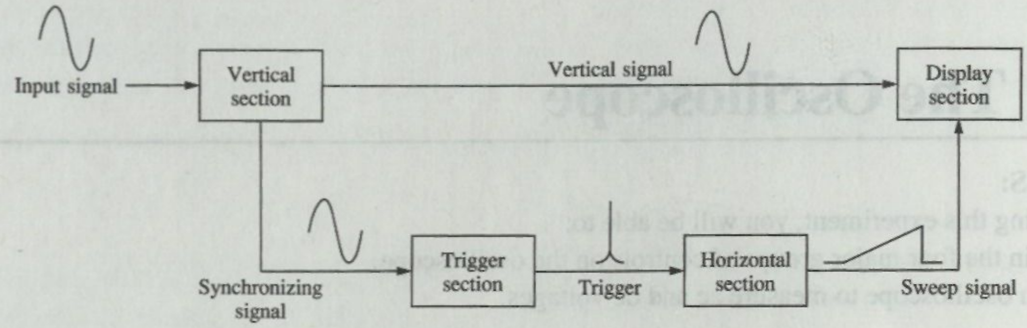

Figure 17–1 Block diagram of an analog oscilloscope

With all the controls to learn, you may experience difficulty obtaining a trace on an analog oscilloscope. If you do not see a trace, start by setting the SEC/DIV control to 0.1 ms/div, select AUTO triggering, select CH1, and press the BEAM FINDER. Keep the BEAM FINDER button depressed and use the vertical and horizontal POSITION controls to center the trace. If you still have trouble, check the INTENSITY control. Note that it's hard to lose the trace on a digital scope, so there is no BEAM FINDER.

Because the oscilloscope can show a voltage-versus-time presentation, it is easy to make ac voltage measurements with a scope. However, care must be taken to equate these measurements with meter readings. Typical digital multimeters show the *rms* (root-mean-square) value of a sinusoidal waveform. This value represents the effective value of an ac waveform when compared to a dc voltage when both produce the same heat in a given load. Usually the *peak-to-peak* value is easiest to read on an oscilloscope. The relationship between the ac waveform as viewed on the oscilloscope and the equivalent rms reading that a DMM will give is illustrated in Figure 17–2.

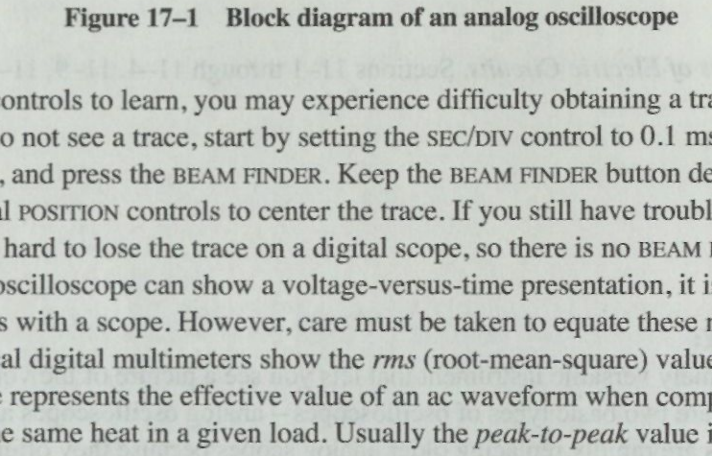

Figure 17–2

Many automated oscilloscopes can measure peak-to-peak or even rms readings of waveforms directly on the screen. They may include horizontal and vertical cursors. Be careful using an automated rms measurement of a sine wave. It may include any dc offset present. If you want to avoid including the dc component, ac couple the signal.

Waveforms that are not sinusoidal cannot be directly compared with an oscilloscope and DMM except for the dc component. (See Application Problem.) The dc level of any waveform can be represented by a horizontal line which splits the waveform into equal areas above and below the line. For a sinusoidal wave, the dc level is always halfway between the maximum and minimum excursions. The dc component can be correctly read by a DMM no matter what the shape of the wave when it is in the DC volts mode.

The amplitude of any periodic waveform can be expressed in one of four ways: the peak-to-peak, the peak, the rms, or the average value. The peak-to-peak value of any waveform is the total magnitude of the change and is *independent* of the zero position. The peak value is the maximum excursion of the wave and is usually referenced to the dc level of the wave. If you want to indicate that the reported value includes a dc offset, you need to make this clear by stating both the maximum and minimum excursions of the waveform.

An important part of any oscilloscope measurement is the oscilloscope probe. The type of probe that is generally furnished with an oscilloscope by the manufacturer is called an *attenuator probe* because it attenuates the input by a known factor. The most common attenuator probe is the $\times$ 10 probe, because it reduces the input signal by a factor of 10. It is a good idea, before making any measurement, to check that the probe is properly compensated, meaning that the frequency response of the probe/scope system is flat. Probes have a small variable capacitor either in the probe tip or a small box that is part of the input connector. This capacitor is adjusted while observing a square wave to ensure that the displayed waveform has vertical sides and square corners. Most oscilloscopes have the square-wave generator built in for the purpose of compensating the probe.

PROCEDURE:

1. Review the front panel controls in each of the major groups. Then turn on the oscilloscope, select CH1, set the SEC/DIV to 0.1 ms/div, select AUTO triggering, and obtain a line across the face of the CRT. Although many of the measurements described in this experiment are automated in newer scopes, it is useful to learn to make these measurements manually.

2. Turn on your power supply and use the DMM to set the output for 1.0 V. Now we will use the oscilloscope to measure this dc voltage from the power supply. The following steps will guide you:
   (a) Place the vertical COUPLING (AC-GND-DC) in the GND position. This disconnects the input to the oscilloscope. Use the vertical POSITION control to set the ground reference level on a convenient graticule line near the bottom of the screen.
   (b) Set the CH1 VOLTS/DIV control to 0.2 V/div. Check that the vernier control is in the CAL position or your measurement will not be accurate. Note that digital scopes do not have a vernier control. For fine adjustments, the VOLTS/DIV control can be changed to a more sensitive setting that remains calibrated.
   (c) Place the oscilloscope probe on the positive side of the power supply. Place the oscilloscope ground on the power supply common. Move the vertical coupling to the DC position. The line should jump up on the screen by 5 divisions. *Note that* 5 *divisions times* 0.2 V *per division is equal to* 1.0 V *(the supply voltage).* Multiplication of the number of divisions of deflection times volts per division is equal to the voltage measurement.

3. Set the power supply to each voltage listed in Table 17–2. Measure each voltage using the above steps as a guide. The first line of the table has been completed as an example. To obtain accurate readings with the oscilloscope, it is necessary to select the VOLTS/DIV that gives several divisions of change between the ground reference and the voltage to be measured. The readings on the oscilloscope and meter should agree with each other within approximately 3%.

4. Before viewing ac signals, it is a good idea to check the probe compensation for your oscilloscope. To check the probe compensation, set the VOLT/DIV control to 0.1 V/div, the AC-GND-DC coupling control to DC, and the SEC/DIV control to 2 ms/div. Touch the probe tip to the PROBE COMP connector. You should observe a square wave with a flat top and square corners. If necessary, adjust the compensation to achieve a good square wave.

5. Set the function generator for an ac waveform with a frequency of 1.0 kHz. Adjust the amplitude of the function generator for 1.0 V_{rms} as read on your DMM. Set the SEC/DIV control to 0.2 ms/div and the VOLTS/DIV to 0.5 V/div. Connect the scope probe and its ground to the function generator. Adjust the vertical POSITION control and the trigger LEVEL control for a stable display near the center of the screen. You should observe approximately two cycles of an ac waveform with a peak-to-peak amplitude of 2.8 V. This represents 1.0 V_{rms}, as shown in Figure 17–2.

6. Use the DMM to set the function generator amplitude to each value listed in Table 17–3. Repeat the ac voltage measurement as outlined in step 4. The first line of the table has been completed as an example. Remember, to obtain accurate readings with the oscilloscope, you should select a VOLTS/DIV setting that gives several divisions of deflection on the screen.

FOR FURTHER INVESTIGATION:

Most function generators have a control that allows you to add or subtract a dc offset voltage to the signal. Set up the function generator for a 1.0 kHz sine-wave signal, as shown in Figure 17–3. To do this, the AC-GND-DC coupling switch oscilloscope should be in the DC position and the offset control should be adjusted on the function generator. When you have the signal displayed on the oscilloscope face, switch the AC-GND-DC coupling switch into the AC position. Explain what this control does. Then measure the signal with your DMM. First measure it in the AC VOLTAGE position; then measure in the DC VOLTAGE position. How does this control differ from the AC-GND-DC coupling switch on the oscilloscope? Summarize your findings.

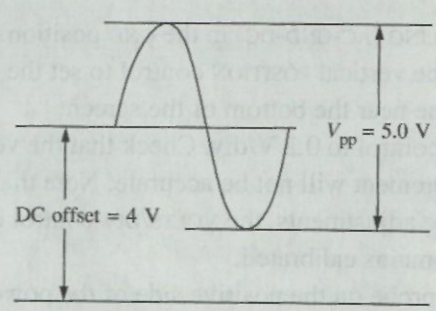

Figure 17–3

APPLICATION PROBLEM:

Suppose you want to compare the reading of an oscilloscope to that of a DMM or a VOM when the waveform is not sinusoidal. Most meters do not read the true rms value of a waveform. Instead, they read the absolute average value and convert the reading to an equivalent rms value *based on a sinusoidal input signal.* When the input waveform is not sinusoidal, the meter reading is in error. The meter can correctly read the dc offset of any waveform, but in the ac position it is calibrated only for a sinusoidal input. All average reading meters (including most DMMs and VOMs) apply a form factor (FF) to the *absolute magnitude* of the average value of a sine wave to obtain the value shown on the display. By knowing the FF, you can compute the expected reading of a nonsinusoidal waveform on the DMM or VOM and compare it with the oscilloscope.

The FF used by meters is the ratio of the true rms value to the absolute average value of a sinusoidal wave. This ratio is 1.11 for full-wave meters.* Thus a 10 V_{rms} reading is sensed by a full-wave

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*If your meter is a half-wave meter, the form factor is 2.22.

reading meter as 9.00 V_{avg} and displayed as $1.11 \times 9.00 = 10.0\ V_{rms}$. For a nonsinusoidal waveform, the DMM will read the average value of the waveform and *incorrectly* multiply it by the sinusoidal FF. By dividing the displayed reading by the FF, you can obtain the correct *average* value for the waveform on the display. The rms or peak value can then be found by multiplying the computed average value by the appropriate conversion factor for that waveform. To compare the oscilloscope reading to that of the DMM, you will need to convert from peak-to-peak to average for that waveform and then multiply by the FF for your meter. The FF and ratios of peak, avg, and rms voltages for several waveforms are listed in Table 17–1.

Using the oscilloscope, set up a 1.0 V_p (2.0 V_{pp}) waveform at 100 Hz from your function generator for each waveform shown. Use AC coupling on your oscilloscope and on your DMM. From the conversion factors listed in Table 17–1, calculate the average ac voltage for the waveform you are viewing. Then compute the reading that you expect on your DMM by multiplying by the FF for your meter. Tabulate your results in Table 17–4 of your report. The last two columns of Table 17–4 should agree within experimental error.

Table 17–1

Waveform	$FF = \frac{V_{rms}}{V_{avg}}$	Peak, average, and rms values		
		V_p	V_{avg}	V_{rms}
Sine	1.11	1.00	0.637	0.707
Square	1.00	1.00	1.00	1.00
Triangle	1.15	1.00	0.500	0.576
Sawtooth	1.15	1.00	0.500	0.576

Report for Experiment 17

Name ______________
Date ______________
Class ______________

ABSTRACT:

DATA:

Table 17–2

Power Supply Setting	VOLTS/DIV Setting	Number of Divisions of Deflection	Oscilloscope (measured voltage)	DMM (measured voltage)
1.0 V	0.2 V/div	5.0 div	1.0 V	1.0 V
2.5 V				
4.5 V				
8.3 V				

Table 17–3

Function Generator Amplitude	VOLTS/DIV Setting	Number of Divisions (peak-to-peak)	Oscilloscope measured (peak-to-peak)	Oscilloscope measured (rms)
1.0 V_{rms}	0.5 V/div	5.6 div	2.8 V_{pp}	1.0 V_{rms}
2.2 V_{rms}				
3.7 V_{rms}				
4.8 V_{rms}				

RESULTS AND CONCLUSION:

FURTHER INVESTIGATION RESULTS:

APPLICATION PROBLEM RESULTS:

Table 17–4

	Oscilloscope Readings			
Waveform	V_p (Measured)	V_{avg} (Computed)	$V_{avg} \times FF =$	DMM Reading
Sine				
Square				
Triangle				
Sawtooth				

EVALUATION AND REVIEW QUESTIONS:

1. (a) Compute the percent difference between the DMM measurement and the oscilloscope measurement for each dc voltage measurement summarized in Table 17–2.

   (b) Which do you think is most accurate? _____________ Why?

2. Briefly, describe the four main functional groups of controls on the oscilloscope and the purpose of each group.

3. If you are having difficulty obtaining a stable display, which group of controls should you adjust?

4. (a) If an ac waveform has 3.4 divisions from peak-to-peak and the VOLTS/DIV control is set to 5.0 V/div, what is the peak-to-peak voltage?

   (b) What is the rms voltage?

5. If you want to view the amplitude of an ac waveform that is 20.0 V_{rms}, what setting of the VOLTS/DIV control is best?

6. The most accurate way to measure a waveform on an oscilloscope is to use a large portion of the display area. Why?