LAB 7: THE OSCILLOSCOPE

Equipment List:

Dual Trace Oscilloscope
HP function generator
HP-DMM
2 BNC-to-BNC[1] cables (one long, one short)
1 BNC-to-banana
1 BNC-probe
Hand-held DMM (freq mode)

Purpose: To acquaint the student with the fundamentals of the oscilloscope and gain confidence in measuring voltage signals with the oscilloscope.

What there is to learn:

1. How to calibrate the o-scope.
2. Vertical and horizontal control of the beam.
3. How to find the ground position (zero volts reference)
4. How to remove DC offset from a signal (filtering).
5. Triggering and auto-triggering.
6. How to measure the peak-to-peak voltage and the frequency of an AC signal.

Introduction: The oscilloscope is an instrument for measuring voltage as a function of time. The o-scope displays a graph, called a trace, of voltage (on the vertical axis) as a function of time (on the horizontal axis), and measurements are read from this graph using a grid of lines called "divisions" or centimeters. All the dials and switches on the scope exist to make measuring signals easy and accurate. Although the scope can do other things besides measuring voltage as a function of time, this is the instrument's primary purpose.

The following exercises should allow you to deepen your understanding of the oscilloscope. Follow them purposefully and do not rush through them, and you will come to use the oscilloscope with confidence rather than frustration. First complete the oscilloscope exercise sheets found at the end of this write-up; this will prime you for what lies ahead.

While following these procedures, bear in mind that the o-scope does not change an input signal but merely displays the same signal in different forms, large or small, compressed or extended, to aid your taking measurements. Changing a setting on the scope does not mean your measured value for the period or peak-to-peak voltage should change. The only exception to this occurs if the calibration dials have been re-set (see below, in the Calibration

[1]BNC stands for Bayonet Neill-Concelman and is a quick-connect coaxial cable connector.

section). The input signal changes when an adjustment on the function generator is made or the test circuit is changed. Adjusting the scope never changes the input signal.

What to put in your lab book when using an O-scope: Draw a rough picture of the trace and record all the dial settings for the measurement of a given trace; recording dial settings can help future attempts to reproduce the same trace. Also, record definitions, explanations and insights so you can gain easy access to them in future crises.

Calibration: You should follow this procedure at the beginning of every lab where the scope is to be used. You will notice a small, delicate knob at the center tip of both your volts/cm dial and your time-base dial. These knobs move independently from the larger knobs on which they sit. Note these "calibration" knobs change the shape (and the value of the measurement!) of the trace but again, not of the input signal. Gently turn the calibration knobs for the voltage scaling and the time-base clockwise until they stop with a quiet click you can feel but hardly hear.

Start up settings:

1. Auto trigger should be on.
2. Trigger source should be on int (internal) not ext (external).
3. AC-GND-DC switch should be on DC.
4. Mode switch should be on channel A (not dual).
5. Calibration knobs set all the way clockwise.

Procedure:

Connect the BNC-probe cable from your scope's channel A to a small metal tab located somewhere on the front of your o-scope. This small tab (the output terminal) is your calibration signal's output. The terminal is connected to a square signal oscillator inside the scope, therefore the terminal provides an output signal just like the function generator except that you cannot alter its values. The terminal provides an easy-to-use test signal so you can find out if your scope is measuring accurately. The peak-to-peak voltage is specified near the terminal and is accurate to plus or minus six percent. The small slide switch on the probe should be set to 1X. If the frequency is not specified then it is the "line" frequency of 60 Hz or perhaps 1000 Hz; you should be able to tell which value for the frequency by measuring the period on the scope and taking the reciprocal.

Practice measuring the test signal with the scope and see if you get the correct values for the peak-to-peak voltage and frequency. Is there DC offset in this signal? See the DC offset section below.

Whenever you start to use an unfamiliar scope, make sure the calibration knobs are turned all the way clockwise until they click to a stop.

Controlling the beam horizontally and vertically:

1. Getting started. Remove the BNC-probe cable and connect the HP function generator's output with a BNC-to-BNC cable to Channel A of the scope. The function generator should be set for a sinusoidal output; a small green light indicates the generator is

turned on. Turn the function generator's frequency dial to read a very low frequency of about 2 Hz. To achieve this, you may also need to push the correct power of ten button.

2. The time-base setting. Adjust the scope so you can see the beam moving up and down slowly, with no right and left motion. To do this, turn the time-base setting to channel B or select the x-y plot feature found nearby; which one of these options you have (i.e., the channel B or x-y plot) depends on the scope that you have, either way this feature will stop the beam from any left or right motion. If the time-base is set to channel B or the x-y plot feature is selected, then the scope is waiting for you to control the horizontal sweep of the beam by connecting a signal to channel B. In this part you want the beam to not move horizontally, so leave channel B without an input. It is interesting to note that the reciprocal of your time-base setting (in sec/cm) is the horizontal speed of the beam (in cm/sec).

3. The voltage scaling setting. Turn the voltage scale to a value that allows the vertical displacement of the beam to traverse at least four divisions. The amplitude dial on the function generator changes the vertical displacement of the beam on the scope face because the actual signal's amplitude is changed. Changing the volts/div value on the scope does not change the amplitude of the input signal, it changes the appearance or scaling of the signal on the screen. Typically, you adjust the voltage scaling to make the function easier to measure.

   If the function generator's output is sinusoidal and the frequency dial and order of magnitude setting for the frequency are low enough, then the motion of the beam undergoes simple harmonic motion. It could describe the undamped sinusoidal motion of a mass on a spring. See the effect on the motion of the beam when you push different output signals, square and triangle.

4. About the beam. At any instant, the electron beam only produces a dot on the CRT screen of the scope but to your eye the beam may appear to be a curve or straight line if moving fast enough. It is not always easy to find the beam. To find the beam, use the horizontal and vertical position knobs and don't forget to have the intensity dial set about half way to full position. When you find the beam, you don't want it to be too bright or the phosphors on the screen may become permanently damaged. If the beam has a "halo" around it, turn the intensity down! When you are not using the scope don't turn it off, this shocks the circuitry, instead leave the scope on and turn the intensity to a low level so the screen is not damaged.

   Avoid turning dials aimlessly and especially quickly as if you were spinning a roulette wheel in a casino. When you make an adjustment to the voltage scale or the time-base, always consider what would happen and why before you actually make the adjustment. Predict the result before you turn the dial and if you are wrong, find out why and correct it. Ask this question before changing a scale setting: "Do I want more or less volts/div?". Answer the question, then turn the dial and see if you were right.

5. Sweeping the beam: Slowly increase the frequency of the signal with the function generator's dial. Observe the consequences. Increase the frequency until the moving

[1]Cathod ray tube. TVs used to have these.

beam turns into a solid straight vertical line. Of course the beam is still moving but so fast that it blends into a solid line. The next step demonstrates the usefulness of an oscilloscope.

Turn the time-base dial from the channel B or x-y setting to a setting of 0.5 sec/div (seconds per division). Remember, the value 0.5 seconds per division means it takes the beam half a second to move one division to the right (that is a horizontal beam speed of $1/0.5 = 2$ div/sec). Gradually turn the time-base setting to smaller amounts of time per division. You should observe the beam going from a vertical line to a "trace" that is spread over the screen in the pattern of a sinusoid. See that changing a time-base setting to a smaller time per division increases the horizontal speed of the beam. Don't call the trace a "sine wave" because it is not a wave; call the trace "the trace" or as is common, a "sinusoidal waveform".

The optimal trace contains 2 to 3 cycles on the scope face.

6. Taking Measurements. (See the pictures in the slides for the set-up to this part.) The two basic measurements taken with an oscilloscope are the peak-to-peak voltage ($V_{\text{p-p}}$) and the period (T) of the input signal. The frequency (f) of your input signal is calculated from the period ($f = 1/T$). In the following exercises you are to take these measurements ($V_{\text{p-p}}$ and T) and confirm your values with the HP-DMM (for $V_{\text{p-p}}$) and the Pasco frequency counter (for f and T).

   (a) Measure the time for one period of the oscillation you observe on the scope screen, take the reciprocal and compare with the frequency reading on the function generator; they should agree to within 5 or 10 percent.

   (b) Measure $V_{\text{p-p}}$ on your scope and compare this value to the value measured on the HP-DMM. The HP-DMM, like all DMM's or VOM's, is designed to display a non-changing number. Since an AC signal is continuously varying in value, measuring the AC signal with a DMM requires a special convention. The DMM will measure an average value to represent the varying AC signal, and this average value will of course be a constant one that can be displayed with a meter needle (VOM) or a digital readout (DMM). Your HP-DMM measures a common kind of average value called the "root-mean-square" (RMS) value. For a sinusoidal signal the $V_{\text{p-p}}$ and the V_{rms} values are related by the following equation:

$$V_{\text{rms}} = \frac{V_{\text{p-p}}}{2\sqrt{2}}$$

   The RMS value of other signals (e.g., square or triangle) have different relationships to $V_{\text{p-p}}$. Using this formula, compare your o-scope measured $V_{\text{p-p}}$ to the calculated $V_{\text{p-p}}$ from the HP-DMM's RMS readout. You must have the HP-DMM set for AC volts.

Practice measuring at least three different input signals from the function generator of varying frequency and amplitude.

Other things about the oscilloscope:

The "ground switch": From any given trace, you may be able to measure the difference between two potential values, however you cannot measure the electric potential of a single point in a circuit without knowing where the ground (V=0) value is on the scope face. By setting the scope switch to "GND" (ground reference), you will see the straight, solid, horizontal line representing the zero volts value. Using the vertical position knob, you may place this reference value on a convenient grid line. Now set the ground switch to DC, you will see the ground level line disappear and the sinusoidal trace reappear. As long as you don't re-adjust the vertical position knob, you now will know where the zero volt value is located and can measure the electric potential or "voltage" of any other point in a circuit with respect to that location.

DC offset: On your scope make sure the "DC" switch is selected so your scope displays AC and DC signals together. Every AC signal may or may not have a DC offset added to it. To observe this, connect a BNC-to-BNC cable between your generator and scope. Your HP function generator has a dial that controls the DC offset added to the AC signal. Find that dial on the generator and note that there is a blue toggle pin at the center of the dial. The blue toggle pin will immediately set your DC offset to zero when pushed in. Push the toggle pin so it is in the "out" position and your AC signal will have DC offset. Confirm this effect by seeing the entire AC signal on your scope move vertically as you adjust the DC offset on the function generator.

Next, experiment with manipulating the DC offset on your scope. Remember when you adjust your scope you aren't eliminating DC offset from the input signal, you are adjusting DC offset so you can see only the AC part of the input signal. This is accomplished by the "DC coupling" button. Find this switch on the scope. On De Anza scopes it is the same as the ground switch. There is a "DC" setting and an "AC" setting. When the switch is set to AC, the signal has the DC offset removed (filtered). When the switch is set to DC, the signal is displayed with DC offset.

Triggering: "Triggering" is specifying the voltage at which the beam will start sweeping across the scope's face, from left to right. Usually you should leave the trigger switch on "auto-trigger", but you should try adjusting the trigger level manually and see how it controls the beam's starting voltage. Try the procedure below.

Use the function generator as a source and a BNC-to-BNC cable to the scope. Create and display a sinusoid of frequency over 5000 Hz to reduce screen "flicker" and avoid eye strain. Now turn the "auto-trig" function off. Turn the trigger level dial until the trace disappears. Now turn on the auto-trig. Notice how the trace reappears but is now "moving" or "out of sync". When auto-trig is on, and your trace is moving out of sync, there is a good chance your trigger level setting is telling the beam to start at a voltage the signal never attains. Turn the trigger level until the trace stabilizes; now turn off auto-trig. The trace should now stay and not disappear. Continue turning the trigger level dial and see how it affects where the beam starts at the left side of the screen. If you know where the zero level is you should be able to measure the voltage of the trigger level.