The Oscilloscope

Objective

After the meter sticks, rulers, and tapes, the oscilloscope is one of the tools frequently used by physicists. It is to a physicist what a crescent wrench is to an auto mechanic—it is the old standby that is always there ready for any purpose. The general objective of this lab[1] is to acquaint you with the oscilloscope. A specific objective is for you to learn how to make voltage and time readings from the scales on the oscilloscope. In addition, an optional step in the lab exercise is available to introduce you to Lissajous figures.

Equipment

Oscilloscope	ac signal generator	dc low voltage source
loudspeaker	Hookup wires	

Introduction

Operation

General use

The basic use of an oscilloscope is to make a graph on the screen. The y-axis plots a voltage of interest and the x-axis plots time, resulting in a graph of voltage versus time. A voltage source of interest (usually because the voltage changes with time) is connected to the vertical deflection plates. An internal circuit sweeps the beam horizontally in time by applying another voltage (that changes linearly with time) to the horizontal deflection plates. The y-axis is calibrated in volts. The x-axis is calibrated in seconds.

The electron gun

This section would be best understood by referring to figure 1 as you read. The heater filament, similar to the filament found in a light bulb, literally boils off electrons. A large accelerating voltage is applied with the negative side on the filament, also called the *cathode*, and with the positive side connected to a plate, which is called the *anode*. The electrons (negative, of course) that are boiled off of the filament are thus attracted toward the positive anode and they typically reach speeds of 10^5 $\mathrm{m \cdot s^{-1}}$, or more. Most electrons hit the anode but some others go zooming through a hole in the anode and their momentum carries them toward the fluorescent screen. A fluorescent powder coats that thin sheet of glass and the powder absorbs those electrons, releasing their energy in the form of light. This results in the glow that we see.

[1] This lab exercise is based on an exercise, “The Oscilloscope”, in the General Physics, Laboratory Manual, Fall 2002-Spring 2003, eighth edition by Laney Mills (College of Charleston, Fall 2002). Used by kind permission of Dr. Mills.

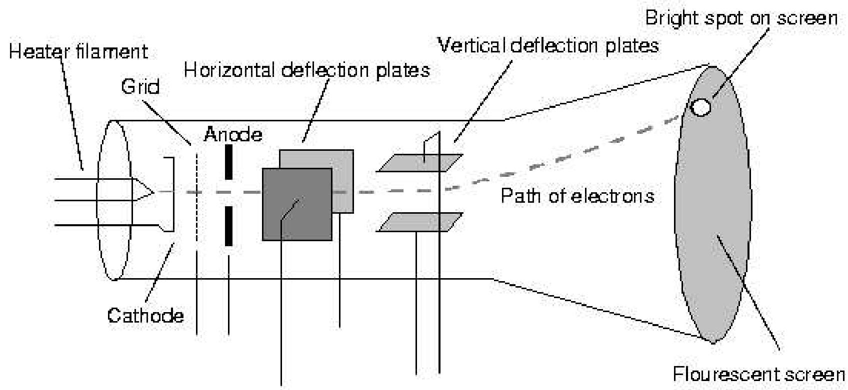

Figure 1: A cathode ray tube (CRT), similar to those found in oscilloscopes.

The grid is a tiny wire screen. When the grid is made negative, fewer electrons reach the region of the anode. Accordingly the voltage on the grid can be used to control the brightness of the dot on the screen. Together the filament, the grid, and the anode constitute a gun which shoots a beam of electrons down the length of the tube. Before scientists knew what it was that was coming off the cathode, they referred to the emitted things as “cathode rays”. To this day, the tube, with all of its parts, is called a cathode ray tube (CRT). Incidentally, it is not unusual to hear the "cool" term "o-scope" for oscilloscope ... very fashionable, though a bit informal!

The deflection plates

There are two pairs of deflection plates, for horizontal and vertical deflections. The principle behind their operation is simple. The trivial case is when no voltage difference is applied to either pair. In that case, the beam of negatively charged electrons lands smack dab in the center of the screen because it experienced no deflection. Now let’s consider the pair of plates for horizontal deflection. Let’s start with the right plate in that pair being given a negative charge and the left plate being given a positive charge. (You will see later on that this represents a voltage difference between the plates and it is actually easier to talk about voltages.) The charges on the plates cause the electrons to be deflected to the left side of the screen and we say that the voltage difference across these two plates is negative. Now, let’s gradually make that voltage difference zero (by reducing the amount of charge on each plate to zero) and then make it increasingly positive (by increasing the charge on each plate, but opposite in charge to what we started with). As the voltage goes to zero, the beam sweeps back to the center of the screen. As the voltage goes positive, the beam sweeps towards the right side of the screen. Aha! We call what we apply to the plates a *sweep signal*. The principle of operation for the vertical deflection plates is identical, but of course in the vertical direction; up represents a positive voltage and down represents a negative voltage.

BONUS! FREE! We are so close now to describing the way TVs and CRT computer

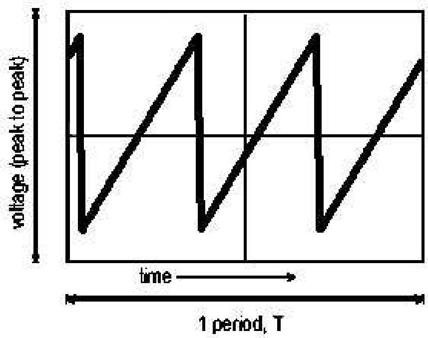

Figure 2: A sweep signal, also known as a ramping waveform. This is what is applied to the horizontal deflection plates when we want the horizontal axis to represent time.

monitors work that it would be a shame not to mention the rest of the story on these gadgets. Essentially, TVs and CRT monitors are oscilloscopes. Instead of applying a signal voltage on the vertical deflection plates, another sweep circuit applies a ramping voltage that represents time; this one is about 500 times slower than the horizontal deflection voltage in completing its sweep. The signal voltage (which is derived from the TV signal supplied by the antenna, cable, VCR, etc.) is then applied to the intensity circuit. This signal voltage represents the intensities of the red, blue, and green colors for any given area and the signal very quickly cycles through this sequence repeatedly. Complicated circuitry then ensures that the beam hits a bit of red fluorescent powder when its intensity is representing the intensity of the red color component, a bit of blue powder when it represents the intensity of blue, and similarly for green. These bits of powder are located so close together that our eyes combine their output and we see the desired color. Meanwhile, the two sweep circuits continue on the the next patch of red, blue, and green bits of powder to make the next picture element—called a *pixel*.

The horizontal sweep signal

There is an internal, adjustable oscillator that sweeps the beam across the screen by applying a ramping voltage, such as that shown in figure 2, to the horizontal deflection plates. The positively sloped portion of the sweep signal that rises relatively slowly to the right causes the beam to sweep slowly from the left side of the screen to the right side. The relatively steep portion of the sweep signal going down and to the right, very rapidly returns the beam from the right side of the screen to the left side, getting it ready for the next trace across the screen. This negatively sloped "return sweep" is so rapid that our eyes cannot follow it. The user can adjust the sweep speed (that is, the magnitude of the positive slope) over a very wide range, representing a very wide range of times.

It is also possible to disconnect the horizontal plates from the internal sweeping oscillator and allow the user to supply a custom sweep. This custom sweep waveform may also be a ramp or it could be any other waveform that is desired.

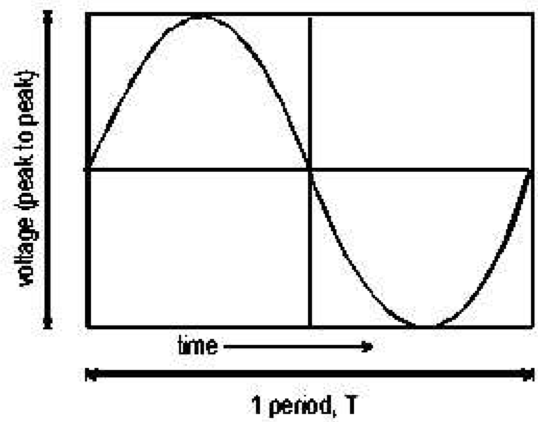

Figure 3: The trace of a sinusoidal voltage oscillation on the screen of an oscilloscope.

The vertical signal

This is usually what we wish to observe. Let's say we have a voltage that oscillates smoothly between positive and negative, much like a mass bouncing up and down on a spring oscillates in vertical position. As the voltage passes through zero it is changing most rapidly, just as the mass's vertical velocity is greatest as it passes through the equilibrium point. At the extremity of oscillation (for either the voltage or the mass), the rate of change is zero and the direction of change reverses. You may recall from last semester that we called this simple harmonic motion. Now, if we were to mount the mass and spring apparatus on a cart moving at a constant speed across the room, its position at any time could be described as a sine wave. Here, instead of a vertically oscillating mass, we have an oscillating voltage. And instead of a cart moving at a constant speed (rate of position change is constant) across the room, we have a sweep signal, whose rate of voltage change is constant and which moves the beam at a constant rate across the screen. This results in something that looks like figure 3 for sinusoidal voltages applied to the vertical deflection plates.

So, we now have a way to scope out the pattern of oscillating signals. Do you see now why this gadget is called an oscilloscope? Sometimes there is a small oscillation in voltage on top of a constant voltage component. Imagine our bouncing mass being placed on top of a skyscraper while we are required to view it from the street. But if we can "block out" the height of the skyscraper from our observation by subtracting it from all the instantaneous mass positions, which is much like going up to the top of the building to more clearly see the mass bouncing up and down.

We can do the analogous thing on an oscilloscope by selecting "AC" for our input filter, which blocks out all "DC" components. (Later on you will learn what is meant by those terms.)

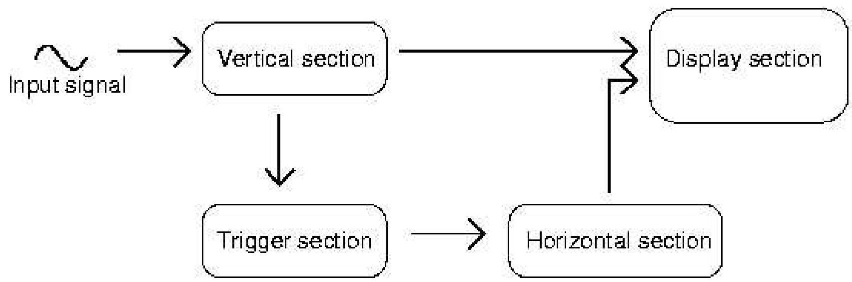

Figure 4: Figure #: Functional schematic of an oscilloscope.

Triggering

We've got a practical problem to consider here. Out of habit, we expect things to start at position zero at time zero. No need for that, but it sure makes the math easier! Oscilloscopes don't do this for us automatically though.

Let's say you want to look at a sine wave voltage. You would like to adjust the oscilloscope so that one cycle fills the screen. In order to do that, there is a special circuit, called the triggering circuit, that will synchronize the beginning of the sweep with the beginning of the sine wave. It is possible to set the sensitivity of the trigger (trigger level) and to set whether the sweep triggers when the voltage starts positive or when it starts negative.

Controls

The various functions we mentioned above can be grouped according to the functional diagram in figure 4.

Knobology

It's all well and good to understand the theory behind the operation of an oscilloscope. But theoretical farmers starve to death unless provided for by someone else. We need to go over the location of the various knobs and switches on an oscilloscope so that you know where to go and what to do to affect one of the functions in the previous section. Learning how to use a complex-appearing arrangement of controls is sometimes known affectionately as *knobology.*

All those knobs

How do the myriad of knobs and switches on the front of a oscilloscope translate to these various functions we have been discussing? Of course that varies from oscilloscope to oscilloscope, but the most frequently used knobs are pretty much labeled the same way regardless of manufacturer or model. More importantly, all oscilloscopes containing work on the same principles; LCD oscilloscopes emulate those controls for the most part. In what follows, we

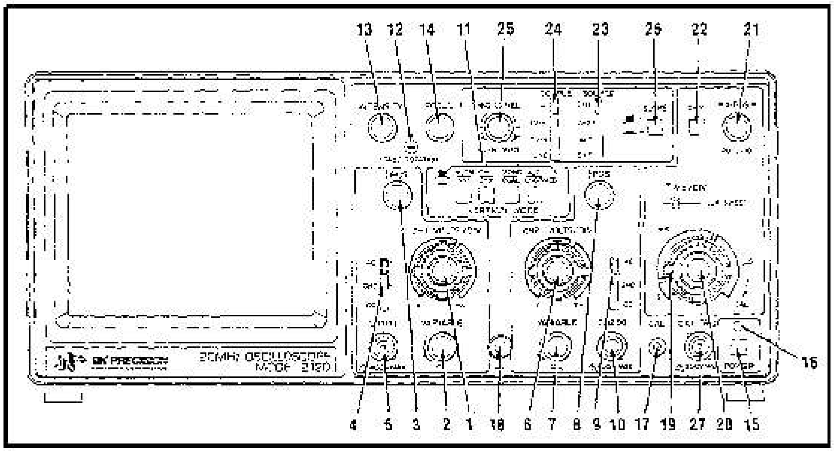

Figure 5: Front panel of a BK 2160 oscilloscope, made by the BK Precision Company.

give one of our oscilloscopes: BK model 21601. A picture[2] is shown in figure 5, including key numbers to help you locate these knobs. The numbers are shown in the descriptions below.

On the left side... Here we see the section for vertical (y) controls:

INTENSITY—13 brightens or dims the spot. (Recall from above how it does this.) Don't leave this knob turned up all the way as it may damage the screen.

FOCUS—14 focuses the spot or display.

Y-POS—3 moves the display vertically.

AC-ground-DC switch—4 tells the oscilloscope what sort of voltage to expect. When set on ground, the oscilloscope grounds the voltage applied to it. This setting allows you to center the spot. When in the AC position, a large capacitor (you will learn about these later) is inserted into the circuit within the oscilloscope to block the constant (dc) portion of the signal and to pass only the oscillating (ac) portion of the signal.

CH1(Y)—5 inputs the connected signal to the vertical deflection plates. (CH means "channel.")

TRIG LEVEL—25 This knob adjusts how far the y axis signal (the one you are displaying on the oscilloscope) moves from zero before the time (horizontal) axis sweep starts horizontally across. Experiment with this knob. You will use it a lot.

SLOPE—26 selects whether the "trigger" is made when the signal being displayed moves plus or minus. Experiment with this knob.

[2]The sketch here is from the manual of the BK model 2160 by the BK Precision company.

VOLTS/DIV—1 allows you to adjust the scale of the grid vertically. "DIV" means divisions (the lines spaced 1 cm apart on the screen not the little lines spaced about 2 mm apart). For the knob scale values to have any real meaning, the internal CAL knob is completely clockwise.

VARIABLE—2 a calibration knob. This should be turned fully counterclockwise to the CAL setting during this lab.

On the right side... Here we see the section for horizontal (x or time) controls:

X-POS—21 moves the display horizontally.

TIME/DIV—19 and 20 allows you to adjust the horizontal scale of the screen if it is being used to represent time. It does this be changing the positive slope of the horizontal sweep signal. For the knob scale values to have any real meaning, the internal VAR Sweep Control knob is completely clockwise (the CAL position).

POWER—15 this one should be obvious.

CH2(X)—10 is a jack for a second input voltage. This second source may be examined separately from the source in the first channel, or the two may be viewed simultaneously. In either of these two cases, the signal entering this jack goes to the vertical deflection plates. The oscilloscope is also capable of plotting the two inputs against each other (channel 1 on the y-axis and channel 2 on the x-axis as they vary in time). The resulting pattern is called a Lissajous figure, and if you are bold enough to figure out the rest of the controls on this oscilloscope, you just might be able to create such a figure.

Procedure

Set up the oscilloscope

To prepare the oscilloscope for use, set

- INTENSITY and FOCUS controls centered (arrows pointing up)
- TRIG LEVEL knob centered
- COUPLING set to AC
- SOURCE set to CH1
- SLOPE set to +
- All four mode buttons below the above controls should be out
- CH1 and CH2 AC/GND/DC switches set to GND
- Both VOLTS/DIV set to AC, 50 mV
- Both VAR knobs (for CH1 and CH2) fully clockwise (CAL) and pushed in

Figure 6: Square waveform of the signal used for calibration of the vertical scale.

- TIME/DIV set to 0.5 ms/div
- VAR SWEEP knob (time section) fully clockwise (CAL)
- All POSition controls centered (arrows pointing up)

(Less time per division means that the beam sweeps across more quickly!)

Turn the oscilloscope on by pushing in the POWER button. You should see a green line on the screen (It may take a few seconds to warm up). If you don't see a line, check to make sure that the intensity knob is not turned all the way to the left and gradually turn it to the right.

Turn the INTENSITY knob and FOCUS knob to see the effect. Do not use any more intensity than needed. That merely wears out the fluorescent powder more quickly. It is possible to damage the screen if the intensity is extremely large.

One at a time, turn the POS knob for CH1 and the POS knob in the time section to see the effect each one has.

Calibrate the oscilloscope

Check again to make sure the CH1 variable knob is on CAL (fully clockwise). It is only in this position that the CH1 VOLTS/DIV scale values are meaningful. Attach the red CH1 (Y) terminal to the CAL terminal (lower right of oscilloscope)—the black CH1 terminal is ground, which is connected to the case, and the CAL terminal's ground is also connected to the case. This little terminal supplies a square wave voltage that is 0.2 V peak-to-peak, similar to figure 6. Let's set the CH1 VOLTS/DIV knob to 50 mV/div. Then the 0.2 V (which is 0.2×1000 mV = 200 mV) would occupy 200 mV/(50 mV/div) = 4 divisions. (Remember, a division is 1 cm in size (not the tiny 2 mm or so divisions)).

Disconnect the CAL lead. You were just checking the calibration. (If you don't get four divisions here, advise your instructor.

Make a practice measurement of a dc (i. e. constant in time) voltage on the vertical scale

Change the position of the CH1 AC/GND/DC switch to DC. Only after this is done, connect a dc power supply or some other source whose dc voltage you know to the CH1 (Y) input.. Using the same idea as for the calibration, compute the voltage by counting the number of divisions between zero volts (power supply disconnected or turned off) and the full voltage. What you will see is a trace moving from left to right above or below the horizontal center line when the voltage source is connected and on; when it is off, or the switch is in the GND position the trace should be on the horizontal line. (Remember this voltage is constant in time, which is the reason that the trace is horizontal.) Incidentally, if you wish, you can set the power supply to an ac (sin wave alternating in time) voltage and measurement the peak to peak voltage.

Do not apply an excess of 25 V to the oscilloscope. If you are uncertain about the use of the power supply, get your instructor's assistance before beginning work.

Determine the voltage of an unknown dc source

Connect the source to the oscilloscope's CH1 (Y) jack.

Set the CH1 AC/GND/DC switch to GND. (Your instructor will tell you the reason for making this setting.) Adjust vertical position of the line to midscreen. Set the switch (previously on ground) to DC. If the signal leaves the screen adjust the VOLTS/DIV switch until it returns. Read the dc voltage directly from the screen and record your answer.

Studying sound

Observation of your entire range of hearing

One of the most interesting uses of the oscilloscope is to study sound. We will use an audio oscillator (which makes electrical waves) to produce waves and detect them by two methods. We will hear the sound (loudspeaker). And we will "see" the waves (oscilloscope).

Fasten the loudspeaker to the audio generator and run through the whole range of audible frequencies. Determine and record the highest and lowest frequency each member of the group can hear (do each member separately). You can read the frequency right off the audio generator..

Turn the CH1 AC/GND/DC switch to AC.Now connect the audio generator to CH1. Run through the same frequency range and see what the signals look like on oscilloscope. You should experiment with the TIME/DIV knob settings and see what that does. Disconnect the audio generator.

Measurement of a known frequency

Now we are ready to address the other skill we have set forth for ourselves. We will use the oscilloscope to measure the period of the sound being put out by a tuning fork. To do that make sure that the VAR SWEEP knob is set to "CAL" (fully clockwise). Otherwise the all important "TIME/DIV" setting on the sweep dial will be meaningless.

Strike a tuning fork of known frequency with the provided mallet and hold it in front of the loudspeaker, which will also act as a microphone. Adjust the TRIG LEVEL knob until you see just one trace of a wave (regardless of the number of cycles seen) and the trace is holding fairly steady. (Random room noise may occasionally upset this display's stability.) By varying the TRIG LEVEL knob, you can control which part of the wave's positive slope starts the trace. Notice that this knob triggers on the portion of the wave below 0 V when turned to the left (−) and on the portion above 0 V when turned to the right (+).

Adjust that horizontal sweep setting until you have a bit more than one full cycle filling the screen. Using the horizontal position knob, put the beginning point on the cycle on one of the vertical lines. Set the VOLTS/DIV setting until the cycle pretty much fills the screen vertically. Use the vertical position to center the cycle pattern on the center horizontal line as shown in figure 3.

Now for the period. Count the number of time divisions occupied by one complete signal, for example 7.6 divisions. The multiply the sweep setting (let's say 5 ms/div) to get the period: Here we would get: 1 period = 7.6 div $\times$ 5 ms/div = 38 ms. The corresponding frequency (the reciprical of the period, you may recall) is 1/38 ms = 26.3 Hz.

How well does the oscilloscope match the frequency of the tuning fork? Sketch the screen, record the horizontal sweep setting, show your calculations.

Measurement of an unknown frequency

Once you are convinced you understood how periods and frequencies are measured with some confidence, determine the frequency of one of the unknown tuning forks on the instructor's table. Sketch the screen, record the horizontal sweep setting, show your calculations.

Seeing your song

Try whistling, humming, talking, or...? Can you whistle a perfect sine wave? Which comes closest to looking like a sine wave—a note that you whistle or a note that you hum? (You may need to turn the VOLTS/DIV knob until you observe the effects).

Lissajous Patterns (optional, but a heck of a lot of fun!)

Lissajous patterns are formed by tampering with the sweep on the x-axis. Say you put a sine wave on the x-axis and also put a sine wave on the y-axis.

If you put these two in phase, the screen will show a line slanting upwards to the right. If you put them 90° out of phase (the phase angle of one is already 90° when the phase angle of the other is at zero just starting out), you will form a circle on the screen. (You can see that these effects occur by holding hands with a friend and you move both yours and your friend's hands horizontally while your friend takes care of the vertical motion.

Effect of having integer frequency ratios: If your friend sweeps vertically twice while you sweep horizontally once, you will get a figure eight pattern. The eight will be lying on its side. If you sweep horizontally twice while your friend sweeps vertically once, the eight will sit upright.

Sketch what would happen if the frequency ratios were made 3 (on the y-axis)/1 (on the x-axis), $4y/1x$, $1y/3x$, $1y/4x$, etc.?

To make the figures, connect signal into the CH1 (vertical) input and signal into the CH2 vertical input and choose "X-Y" in the TIME/DIV block. The effect of "X-Y" is to take the signal applied to CH2 and not to use it as a vertical signal for the second trace, but instead to make it the horizontal beam sweeping signal, replacing the unidirectional internally generated regular sweep signal.

Hold the frequency of V_1 constant and vary the frequency of V_2. Sketch the patterns as you observe them and label them with the x and y frequencies.