University of Utah
Electrical & Computer Engineering Department
ECE 2210/2200
Oscilloscope

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rev, 9/20/05

Name: ___________________________,

NOTE: This is a fill-in-the-blanks lab. No notebook is required. You are encouraged to use your notebook for personal notes and comments, but it will not be collected or graded. Instead you will hand in this completed lab handout at the end of your lab period. Read it and do the preliminary problems ***before*** coming to lab.

Objectives

This lab is an introduction to the oscilloscope, one of the most common, important, and useful electrical measuring devices. An oscilloscope (scope) is basically a fancy voltmeter that displays voltage as a function of time. You will learn how to use it to take both voltage and time measurements.

Check out from stockroom:

- *The XYZs of Using A Scope*, Tektronix booklet
- Analog voltmeter
- ECE 2210 kit, optional, if available
- Servo

Parts to be supplied by the student:

This item should be given to you with the ECE 2210 kit.

- Small speaker or microphone

Theory

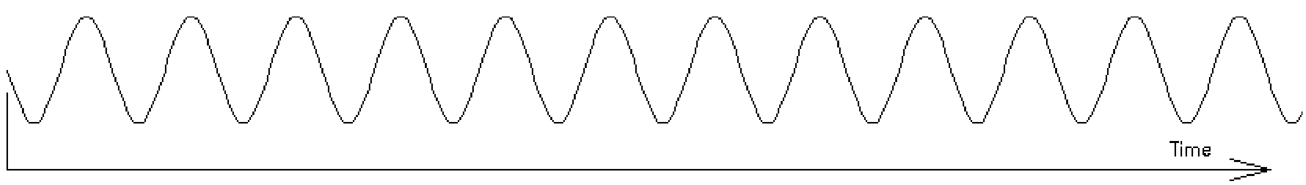
Voltage in an electrical circuit is the "electrical pressure" which makes the current flow. A DC voltmeter can be used to measure this "pressure" between two points in a circuit as long as it doesn't change, or at most, very slowly. An AC voltmeter can give you an average or an RMS (a type of average) reading of a changing voltage but won't give you any indication of how it changes. This means that the majority of important voltages in most circuits cannot be measured with a simple voltmeter. A voltmeter cannot show you the changing voltages (signals) which are often used to convey information like audio, video, or digital data.

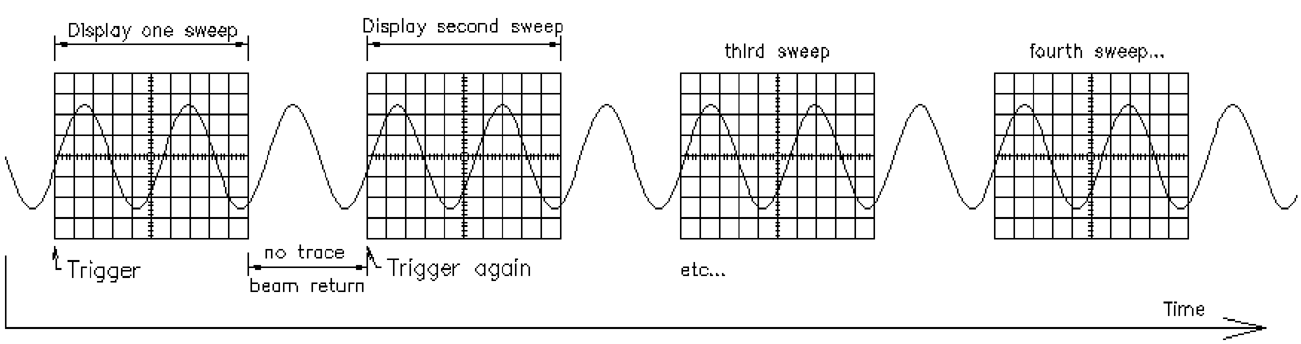
What we need is a type of voltmeter that can show, literally show, rapidly changing voltages. No mechanical pointer or pen could possibly move quickly enough to follow the signals that are regularly found in circuits so, a cathode ray tube is used.

A cathode ray tube uses a "beam" of electrons which is generated at the back of the tube and produces a spot of light on the tube' s phosphorus screen. It is bent by magnetic or electrostatic means so that the spot of light can be made to move across the face of the screen. A TV picture tube is a cathode ray tube (CRT). Its beam (3 beams in a color tube) is bent by a magnetic field. A picture is made by "scanning" the spot(s) across the entire screen 30 times each second and modulating the intensity of the electron beam(s). This is called a *raster* scan. Most computer terminals work the same way. In an oscilloscope the electron beam is bent, or deflected, by electric fields and it doesn't scan the whole screen. It simply traces a single spot on the screen. This spot moves up and down in response to an input voltage and left to right at a constant rate. The scope draws on its screen much like you do on a piece of paper-- in continuous lines. A TV draws its picture more like your computer printer does—one horizontal band at a time.

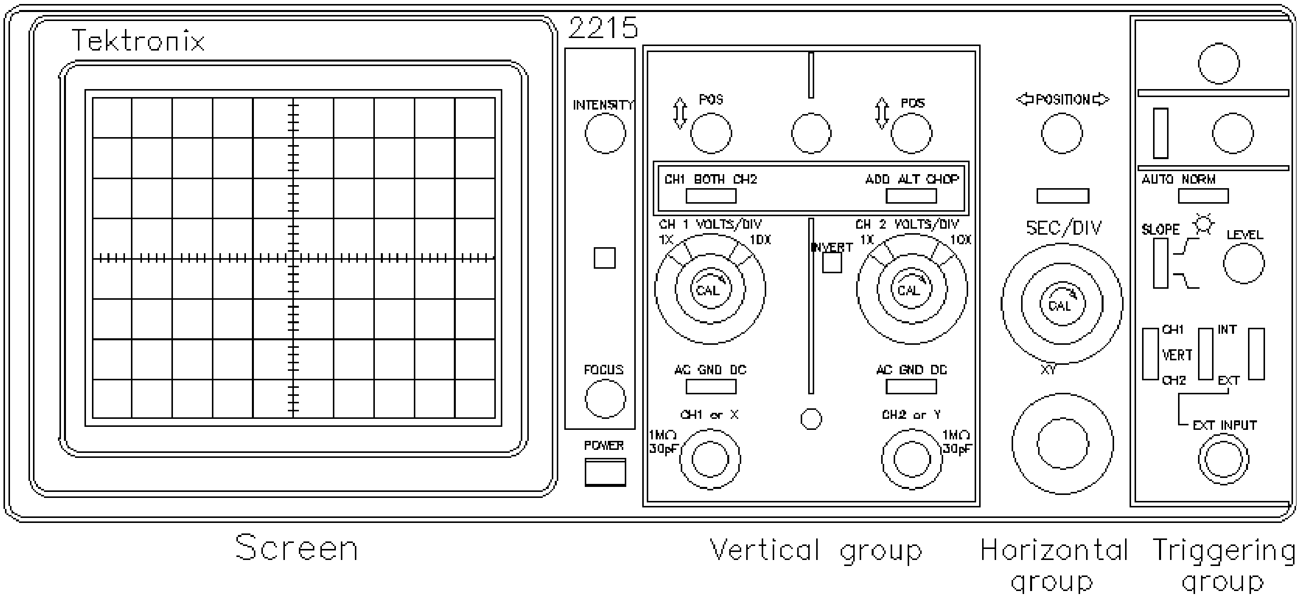
Beam movement: The most common way to move the beam of the oscilloscope (scope for short), is to move it from the left side of the screen to the right side at a constant rate. The voltage we are interested in "seeing" or measuring is then used to move the beam up and down on the screen. In this way the screen shows a plot of the voltage as a function of time. When the beam gets to the right side of the screen, it is turned off and then moved back to the left side.

Triggering: Before starting a new *sweep* from the left side to the right side of the screen, the scope waits to be "triggered". If the input signal is periodic and the scope triggers on the same point of the waveform each time, then the beam will draw a similar part of the waveform each time and the trace will appear stable. Look at the figures below. The first shows a continuous periodic waveform.





The second shows the pieces that will be seen on the scope screen.



Control groups: The profusion of controls on a scope allow you to control the beam movement and triggering as well as some other things we won' t cover in this lab.

These controls may be separated into four groups. One group controls the vertical (up and down) movement of the beam. The second group controls the horizontal (side to side) movement of the beam. The third controls the triggering. The remaining group controls everything else—power, beam intensity, beam focus, etc.

Screen divisions: The screen of the scope has a grid pattern printed on it, usually about 1 cm by 1 cm. These are called divisions, and the controls refer to these divisions in ways that let you take measurements from the screen.

Controls

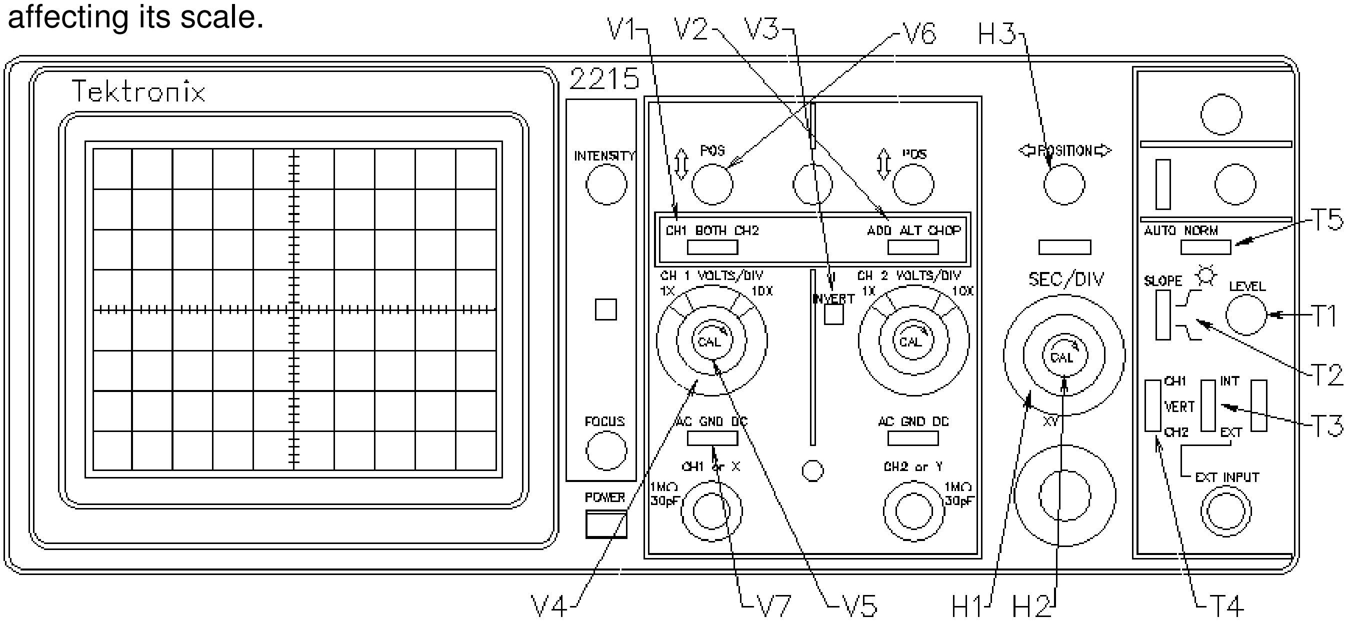
The next page shows the most common oscilloscope used in this lab. We'll take a look at the controls one at a time and see what they do. The horizontal controls are numbered on the figure as H1, H2, ..., the triggering controls are numbered as T1, T2, ..., and the vertical controls are numbered as V1, V2, ... If the scope on your bench is not the 2215 model then some of the control locations will be different, particularly the triggering controls.

I won't describe all the controls, because you won't need them all in this class. You may want to read about them in the booklet you checked out, or simply play with them sometime to see what they do.

H1, SEC/DIV: This is the most important control in the horizontal group. It controls the how fast the beam moves (or sweeps) across the screen from left to right. It is calibrated in seconds, ms (10^{-3} seconds), or µs (10^{-6} seconds) per horizontal division on the scope screen. By knowing how much time it takes the beam to move across one horizontal division, you can get all sorts of timing information from the scope screen.

H2, Sweep rate fine adjust: With this little center knob you can adjust the beam' s horizontal speed more finely. This can be handy when you are interested in relative time measurements, but can also cause problems. You should always check this knob to make sure that it' s in its "CAL" (calibrated) position before taking time measurements with the scope. If it isn’t, the number from SEC/DIV knob won' t be right.

H3, < POSITION >: Horizontal position. Moves the screen display left and right without affecting its scale.



T1, LEVEL: Remember the earlier discussion of triggering? The scope is usually used to view a periodic waveform over and over. To make the *trace* (line on the screen) appear stable, the horizontal movement of the beam should start at the same point on the waveform for each sweep. That point is defined by a voltage level and a slope (+ slope means the is voltage increasing). The scope waits for a certain input voltage level and slope before starting the next left-to-right sweep. The LEVEL knob control sets the trigger voltage level.

T2, SLOPE: If the input waveform is periodic, then the input voltage will pass though any level at least twice, once going up and once going down. The SLOPE switch tells the scope which of these two occurrences you wish to trigger on.

T3 & T4, INT and/or SOURCE: These switches select which voltage signal the scope will use for triggering. The scope has three inputs on the front panel, CH1, CH2 and EXT, any of which can be used to trigger the trace. CH1, CH2 are considered “internal” (INT) sources, since they are input to the scope for display, so they are available “internally”. The “external” (EXT) input is specifically for triggering. (If the scope refers to “Z” at this input, then it can also be used to control the brightness of the trace, a feature we won’t use) Leave on CH1 (INT) for now.

T5, AUTO NORM etc: Tells the scope how long to wait for the next trigger. AUTO = wait for a little while, then sweep even without a trigger. NORM = wait as long as it takes. AUTO will display a trace even if it never triggers. Most people find that less disconcerting then the totally blank screen you'd get in the NORM mode. Auto also limits the effect of the level control. Leave on AUTO for now.

T6, HOLDOFF: Tells the scope to wait, or "holdoff" before looking for the next trigger.

V1, CH1 BOTH CH2: There are two complete sets of the vertical controls. That is because you can display two different voltages on the scope at the same time. The first is called channel 1 (CH1), and the second is called channel 2 (CH2). You can display either one by itself or both at the same time.

V2, ADD ALT CHOP: If you choose to display both traces, you have some more choices. You can ADD them together, making one trace, or you can display them separately by two methods, ALT or CHOP. Leave in CHOP for now.

V3, INVERT: If you push this switch in, the channel 2 voltage will be displayed upside-down. This is sometimes used in conjunction with the ADD switch to subtract two traces.

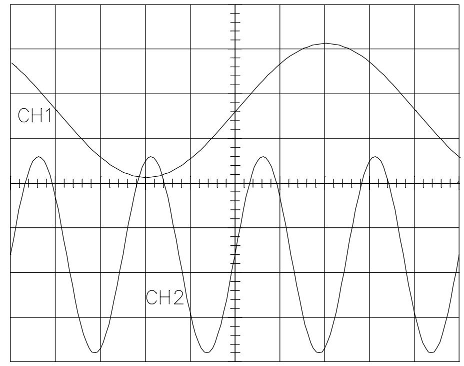
V4, VOLTS/DIV CH1: This is the most important control in the vertical group. It controls how far the beam moves up or down on the screen for a given input voltage. It is calibrated in volts and mV (10^{-3} volts) per vertical division on the scope screen. By knowing how many volts it takes to get the beam to move up or down one vertical division, you can take all sorts of voltage measurements from your scope screen. You can read the volts/div in two places. Upper left if you're using a 1X probe (a probe is the connection to the voltage you want to measure), upper right if you're using a 10X probe. For now, our simple BNC-to-clip probes are 1X.

V5, Vertical gain fine adjust: With this little knob you can adjust the beam' s vertical response to input voltage more finely. This can be handy when you are interested in relative voltage measurements, but can also cause problems. You should always check this knob to make sure that it' s in its "CAL" (calibrated) position before taking voltage measurements with the scope. If it isn't, the number from VOLTS/DIV knob won' t be right.

V6, ⇕POSITION: Vertical position. Moves the trace up and down. The left knob is for CH1, and the right knob is for CH2.

V7, AC-GND-DC Switch: In the AC position, the voltage displayed on the scope is only the changing part of the input voltage, with no average or DC voltage shown. The DC component is filtered out with a capacitor. In the DC position, the voltage displayed on the scope is the input voltage, with no parts missing. In the GND position, there will only be a zero voltage line displayed on the scope. You can use this to set up the zero baseline on the scope with the POSITION knob. When you switch back to the AC or DC position, voltages can be measured relative to the known zero baseline.

Ok, that pretty well covers what you need to know about the controls. If you didn't commit all that to memory, then keep this lab as a reference. Next, let' s see how to take some measurements from the screen of the scope. This can best be shown by example.



EXAMPLE: The drawing at right shows the screen of an oscilloscope. The zero baseline (ground) for channel 1 is the center line of the screen and the zero baseline for channel 2 is the bottom of the screen. The scope is set as follows:

CH1 VOLTS/DIV:	0.5V/div
CH2 VOLTS/DIV:	2v/div
SEC/DIV:	0.2mS/div
INT trig:	CH1.

a) Find the amplitude of the channel 1 waveform.

(3.1div - 0.1 div) x 0.5V/div = 1.5Vpp, 0.75V amplitude

b) Find the maximum of the channel 2 voltage. 4.6div x 2V/div = 9.2V

c) Find the minimum of the channel 2 voltage. 0.2div x 2V/div = 0.4V

d) Find the average, or DC value of the each voltage.

CH1: (3.1div + 0.1div)/2 x 0.5V/div = 0.8Vpp, CH2: (9.2V + 0.4V)/2 = 4.8V

e) Find the period and the frequency of the channel 1 waveform.

T = 8div x 0.2ms/div = 1.6ms, f = 1/T = 1/1.6ms = 625Hz

f) Find the period and the frequency of the channel 2 waveform.

T = (6.9div x 0.2ms/div) / 3cycles = 0.46ms, f = 1/T = 1/0.46ms = 2174Hz

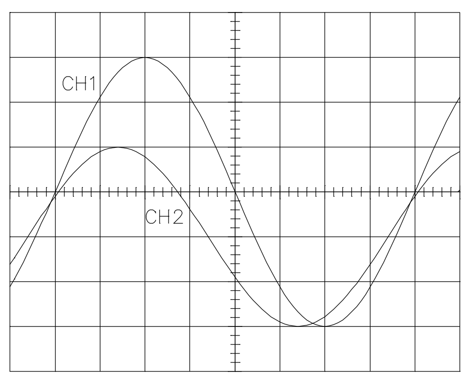
g) What is the scope' s trigger LEVEL set to?

Triggering on CH1, CH1 starts at about 2.6div x 0.5V/div = 1.3V

h) What is the setting of the SLOPE switch? CH1 starts on downward (-) slope

Note: While the drawing above is a OK for this example, it would be almost impossible to actually get this these traces stable in real life unless f_{CH2} were an integer multiple of f_{CH1}. Can you see why?

Preliminary Problem



Refer to the screen at right. The zero baseline for channel 1 is the center line of the screen and the zero baseline for channel 2 is the bottom of the screen. The knobs are set as follows:

CH1 VOLTS/DIV:	50mV/div
CH2 VOLTS/DIV:	0.2V/div
SEC/DIV:	0.5ms/div
INT trig:	CH1

a) Find the amplitude of the channel 1 waveform.

b) Find the peak-to-peak voltage of the channel 2 waveform.

c) Find the maximum of the channel 2 voltage.

d) Find the minimum of the channel 2 voltage.

e) Find the average, or DC value of the each voltage.

f) Find the period and frequency of the channel 1 waveform.

g) Find the period and frequency of the channel 2 waveform.

h) What is the scope' s trigger LEVEL set to?

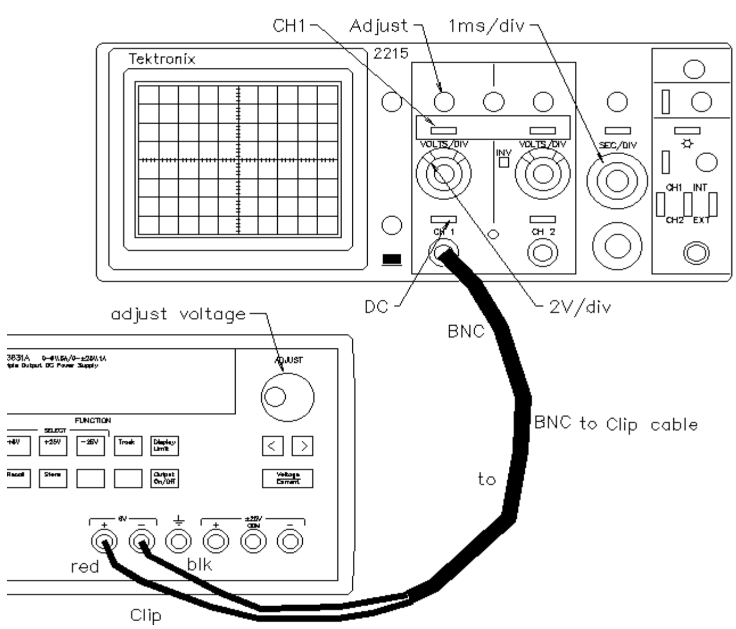
i) What is the setting of the SLOPE switch?

Booklet: I've asked you to check out a Tektronix booklet on the scope. Look it over now if you still have questions that my earlier explanations did not answer or if you were confused by those explanations. Keep the booklet handy as a reference during this lab.

Experiment

Much of this lab does not lend itself well to the standard lab notebook format, so no notebook will be required. Simply fill in the blanks in this handout and hand it in. To make up for not keeping a notebook, <u>everyone will have to work somewhat individually!</u> There are not enough scopes to truly work individually, so take turns with the same equipment. It is important that everyone turns the knobs and takes their own measurements from the screen. The point is to get <u>everyone</u> familiar with the scope.

Initial control settings: Set up the oscilloscope as shown on the drawing taped to the top of your scope. Each drawing is specific to the scope it's attached to, and will help you disable unused features and set the scope in a common base setting. You should do this before you begin using the scope in all future labs. It will save you and the TA a lot of trouble in the long run. Try to commit this base setup to memory, because this drawing may not remain on the scope for the entire semester and, of course, other scopes you will use in other classes or on the job won't come with such a drawing.



DC measurements: Set up the oscilloscope as shown. Adjust the CH1 vertical position knob so that the horizontal line is centered (half-way up the screen). If you have any trouble getting a trace across the center of your screen, call your TA over for help. Turn the AUTO INTENSITY (or simply INTENSITY) knob so that your trace is not too bright. A trace that is too bright will not be sharp and can burn the phosphor of the CRT. Turn the FOCUS knob to focus the beam.

Connect a BNC-to-Clip cable to the CH1 input of the scope (use a push and twist motion), and the alligator clips to the power supply as shown. Turn on the power supply and set it to 3V (push the +6V button and turn the knob).

How many vertical divisions did the trace move up? ______________________________

Determine the voltage from the scope trace. ____________________________________

Change the VOLTS/DIV knob to 1V/div, what happened to the trace? ________________

____

Determine the voltage again. ____

Which of these two voltage measurements was easiest and/or the most accurate, the first (Made with the scope set to 2V/div) or the second (1V/div)? ________________________

Reverse the leads at the power supply. How did the trace change? _________________

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Switch the scope's AC GND DC switch to AC. What happened to the trace?

____

The scope now filters out the DC component of the input, which is all there is in this case.

Reverse the leads again (to the red-red, blk-blk configuration), switch the AC GND DC switch back to DC, and the VOLTS/DIV knob to 2V/div. Play with the knob (adjust the voltage) on the power supply while you watch the scope screen. Adjust the VOLTS/DIV and ⇕ POSITION knobs as needed to keep the trace on the screen. The point I want you to get here is that the scope is just a voltmeter and it can show DC as well as AC.

Horizontal beam movement: Disconnect the input from the power supply and adjust the ⇕ POSITION if necessary to get a trace. Turn the SEC/DIV knob to 0.2s/div. Does the spot of light move across the screen at a constant speed? ________________________

Does it take about two seconds to cross the entire screen? _________________________

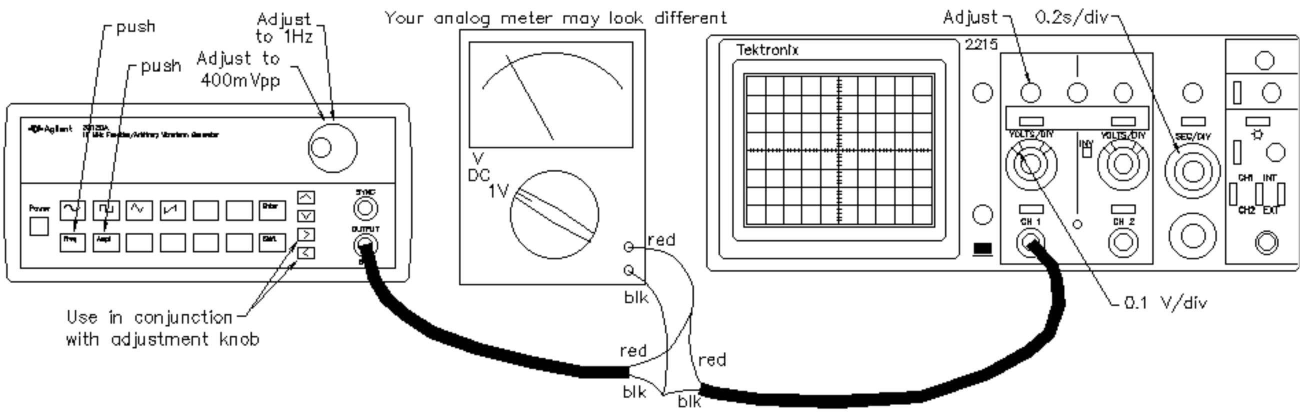
Turn the SEC/DIV knob to 0.1s/div. Does the spot of light now move twice as fast? ______

Does it take about one second to cross the entire screen? __________________________

Turn the SEC/DIV knob further CW until the display looks more like a solid line than a moving spot. What is it set at? ____

So, if the beam moves fast enough it looks like a line instead of a moving spot. Most of the time the beam will be moving fast enough that you won't see the moving spot.

AC low frequency: Set up the Agilent or HP 33120A function generator, the analog voltmeter, and the oscilloscope as shown. Before you turn on the function generator, adjust the CH1 vertical position knob so that the horizontal line is centered (half-way up the screen).



Turn on the function generator and hit the “Freq” button. Adjust the frequency to 1 Hz (use the < and > buttons to select a digit and the round knob to adjust that digit). Hit the Ampl button. Adjust the amplitude to 400 mVpp (use the < and > buttons to select a digit and the round knob to adjust that digit). For reasons I can only describe as “ding-a-ling design”, the function generator actually outputs twice the amplitude it shows, hence, 400 mVpp is actually 0.8 Vpp. (The ding-a-lings made the idiotic assumption that you would always hook their function generator to a 50 Ω load. Since their output resistance is also 50 Ω that would result halving the output. Given that you almost never *actually* hook the function generator to a 50 Ω load, that was an incredibly stupid assumption on their part.)

Notice that the voltmeter needle would like to swing both up and down but it’s physically unable to show the negative part of the waveform. The function generator should produce a sine wave of 1 Hz (cycle per second). Do you see the spot on the scope moving in sync with the meter needle? ________________ Both are responding to voltage. At very low frequencies the voltmeter can be used to see the relationship of the input voltage and time. Adjust the function generator) to higher and higher frequencies. At what frequency is the voltmeter no longer able to keep up (This is a very subjective judgement and the number is not important)? ____________ Adjust the SEC/DIV knob of the scope and make some astute observation about the capability of the scope as verses the voltmeter. ___________

____

AC measurements: Disconnect the voltmeter from your circuit, and connect the output of the function generator directly to the scope with a BNC-to-BNC cable. Hit the “Freq” button on the function generator and adjust the frequency to 15 MHz (hit “Enter Number” and enter 15000000 using the green numbers. This is the highest frequency that the function generator can supply. Turn the SEC/DIV and VOLT/DIV knobs on the scope until you get a good trace (a good trace shows about 1 to 2 periods of the waveform and isn’t too small vertically). Is this frequency too high for the scope to display? _____________

Adjust the function generator to 1000 Hz and get a good trace on the scope. Set the CH1 VOLTS/DIV knob to 0.5 Volts/div (at he 1x position)
Use the scope to find the amplitude of the voltage. ______________________________
Turn the VOLTS/DIV knob to 0.1 Volts/div. Find same the amplitude again.

____

Which amplitude measurement do you think is most accurate? ____________________
For the best accuracy, always get the biggest trace you can on the scope before taking measurements. Find the period of the waveform from your scope. __________________

What is the waveform' s frequency?_______________________________________

Get your lab partner (or someone else) to change the settings on the function generator to whatever he or she wants, hiding the display from you. Find the amplitude and frequency of the waveform. If your numbers aren't reasonably close to those displayed on the function generator (don't forget that the function generator actually outputs twice the amplitude it shows), try again. Repeat twice more at different amplitude and frequency settings each time.

Amplitude _______________________ Frequency _____________________________

Amplitude _______________________ Frequency _____________________________

Amplitude _______________________ Frequency _____________________________

Hit 2nd button on the first row of the function generator (the square-wave button). Make a crude sketch of what you see on the scope. ________________________________
Notice that you can't see the vertical lines of the square wave on the scope. The vertical transitions occur so quickly that the scope beam doesn't spend enough time on that part of the trace to even light up the phosphors on the screen.

Hit 3rd button on the first row of the function generator (the triangle-wave button). Make a crude sketch of what you see on the scope. ________________________________

Hit 4th button on the first row of the function generator (the saw-tooth button). Make a crude sketch of what you see on the scope. ________________________________

Dual Trace: Hit 1st button on the first row of the function generator (the sine-wave button). Hook another cable from the SYNC output of the function generator to the CH2 input of the scope. Switch the CH1 BOTH CH2 switch to BOTH. Get a good trace for channel two by adjusting the CH2 VOLTS/DIV and POSITION knobs. Describe what you see.

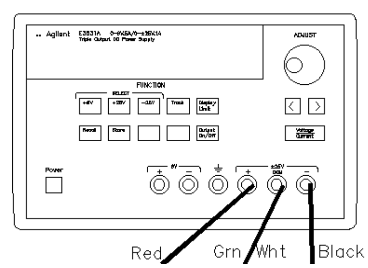
____
Switch the CH1 BOTH CH2 switch back to CH1.

Trigger adjustments: . Adjust the trigger LEVEL knob on the scope. What happens to the trace? ____

Why? (Think about triggering and what's happening at the left side of the screen ? ______
____
Change the position of the SLOPE switch on the scope. What happens to the trace?
____
Why? ____

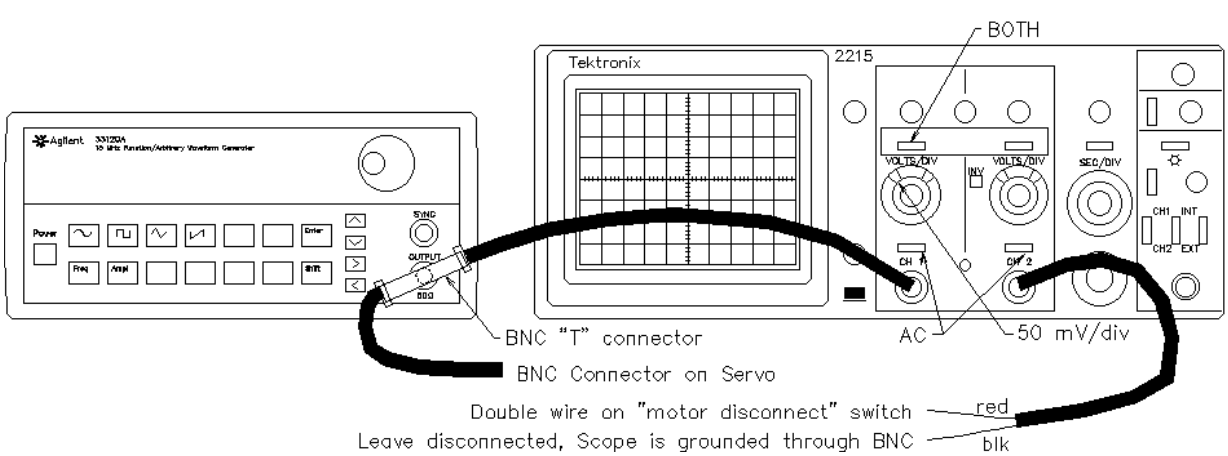
Audio signal: There should be a little speaker in the ECE 2210 kit. A speaker can also function as a microphone, and that is how we will use it here. Connect this speaker to the scope (CH1) in place of the function generator. Turn the VOLTS/DIV knob to the most sensitive position (fully clockwise). (Some scopes can be made more sensitive if you pull out the CAL, 10x PULL knob at the center of the VOLTS/DIV knob.) The trace may be a little fuzzy, this is caused by electrical noise and may be lessened if you don't hold the speaker in your hand, try to ignore the fuzz.

Speak into the speaker. Can you "see" your voice on the scope? ________ Try different settings of the SEC/DIV knob to see how the trace is affected. Notice that each sweep starts at the same level and slope, even though the waveform isn't periodic (each trace is different from the last one). The scope is triggering normally, it can't help it that the traces don't overlap nicely after the trigger.
What is the difference between high-pitched sounds and low-pitched sounds?
____
What is the difference between loud sounds and soft sounds?
____



Servo: Turn off the power switch on the servo and hook it up to the power supply. Adjust the power supply to provide $\pm$ 6V as you did in previous labs. Turn on the power switch on the servo. Turn the potentiometer marked "GAIN" to about center position and make sure the servo is functioning properly.

Turn off the function generator and then turn it back on again to reset it. Your wire kit should include a BNC "T" connector, connect it to the output of the function generator. Then wire the function generator, scope, and servo as shown below using two BNC-to-BNC cables and one BNC-to-Clip cable. The "Double wire" referred to at the "motor disconnect" switch is the bottom connection that has two wires rather than one. Trace one



of the wires down to the breadboard on the servo, push in an extra wire there and connect CH2 of the scope to that wire. This is the output of the servo circuitry, normally hooked directly to the motor.

Now let's look at the input. Notice that the yellow wire from the BNC connector hooks into the proto board at the same place as the center wire from the "INPUT POSITION" pot. That means that the function generator is now the input instead of that pot, in fact, try the pot and see that it no longer affects the output.

Observe the CH2 trace on the scope as you turn the GAIN pot back and forth. Switch down the motor disconnect switch for a cleaner output signal and no oscillations. (Make sure you don't switch it down *while* the servo is oscillating-- turn down the GAIN first to stabilize the position, *then* disconnect the motor.) What does the GAIN pot do?

____

If you turn up the gain far enough you may see the top and/or bottom of the output signal "clip", that's where they get chopped down flat. It is a form of distortion caused by limits of the servo circuitry, called "clipping".

Adjust the GAIN pot so that the output is twice as big as the input. The easiest way to do this is to set CH1 to 50 mV/div and CH2 to 0.1 V/div and adjust the GAIN until both traces are the same size. This is now a gain of 2, meaning, if you multiply the input by 2, you get the output. Which is exactly what the circuitry is doing.

Make sure that the motor disconnect switch is down. Find the brown, center, wire that comes from the motor position sensor (potentiometer) and trace it to where it's pushed into the proto board. Move the yellow wire from the BNC connector to this point
Observe the CH2 trace on the scope now. What is the gain from this circuit input? That is, what number is this input multiplied by to get the output? ________________________
When the output is inverted relative to the input, the gain is said to be negative.

Now add a jumper to connect both inputs together, so that both are connected to the yellow wire from the BNC. What happened to the output? __________________________
Why do yo suppose that happened? ____
The circuitry actually amplifies the difference between the two inputs, if they are both the same then the output should be zero. We say that the "common-mode gain" is zero.

Remove the jumper, restore the BNC connection to where it was originally (back to where the other yellow wire is), remove the output wire and the BNC connection to the function generator. Switch the motor disconnect switch up, and make sure the servo is functioning properly.

Conclusion

This should give you a quick overview of the most important features of the oscilloscope as well as give you some practical experience with the servo. The booklet will help you explore further if you want. Throughout the rest of this semester you will use the scope for many of your measurements and will become much handier with it.

The speaker should (hopefully) have been in a plastic bag when you got it. Please return it in that bag.