Physics 364, Fall 2014, Lab #3 **Name:** ______________________

(oscilloscope, function generator, and a bit more on voltage dividers)

Monday, September 8 (section 401); Tuesday, September 9 (section 402)

Course materials and schedule are at `positron.hep.upenn.edu/p364`

Don't waste time making your work look polished. Just write clearly enough that we can follow your reasoning. Most importantly, your written work should convince us that you thought about the questions asked in the lab assignment. Turn in your work at the end of class. If you need extra lab time to finish a given assignment, just let us know.

Part 1 **Start Time:** ____________

voltage divider as load for voltage divider

This is actually a repeat of Lab2/part4, because we ran out of time at the end of Lab 2.

1.1 Re-build the original (1 kΩ):(2 kΩ) voltage divider from part 3.1 of Lab 2. Remember that you designed it so that it would produce an output (when no load is attached) that is $\frac{2}{3}$ of whatever voltage is provided by the lab power supply. Now attach to the output of this first voltage divider a second voltage divider formed using much larger resistors, like (100 kΩ):(200 kΩ). Use V_{out1} from the first divider to supply V_{in2} for the second divider. Use $V_{\text{in1}} = +9$ V from the power supply. Draw the circuit (both dividers together).

1.2 Remember that in Lab 2 you found R_{thevenin} (a.k.a. the “source resistance,” a.k.a. the “output resistance”) for the first divider. To keep this R_{thev} value in your mind, work it out again and write it down.

What is the *input resistance* of the second divider? (In other words, what does the first divider “see” as the resistance of its load?) You can work this out just by looking at your schematic diagram.

What do you expect for V_{out1} and V_{out2}? (You can do this in your head, since in this course we’re usually not interested in effects that are smaller than a few percent.) Now measure V_{out1} and V_{out2} to check your prediction.

1.3 Now replace the 100 kΩ:200 kΩ divider with a second 1 kΩ:2 kΩ voltage divider. Draw and build the circuit. You should have two identical voltage dividers, with V_{out1} from the first feeding V_{in2} for the second. What is the input resistance of the second divider? Now what do you expect for V_{out1} and V_{out2}? (Unlike part 1.2, you probably need a pencil for this one.) Measure them and compare with the results you expect.

1.4 Let's see how Thevenin's model lets us calculate the expected values of V_{out1} in parts 1.2 and 1.3 above. First draw the Thevenin equivalent circuit for the "upstream" voltage divider — the one that didn't change from part 1.1 to part 1.3. It should consist of one ideal voltage source, one resistor, and two open terminals.

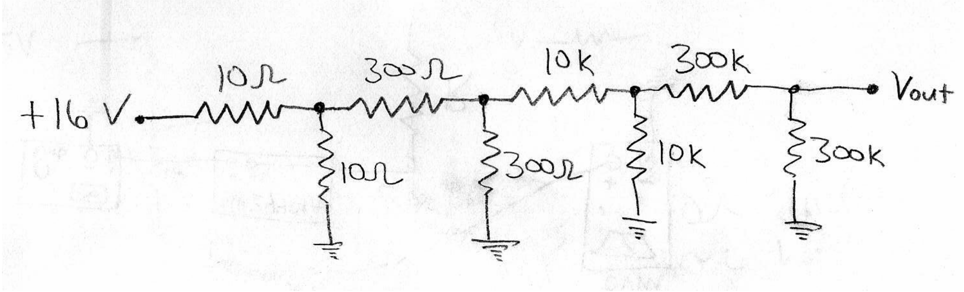
Now draw (don't build) a load resistor, $R = 300\ \text{k}\Omega$, attached across the two output terminals of your Thevenin model, and use the voltage-divider equation, $V_{\text{out}} = \frac{R_2}{R_1+R_2} V_{\text{in}}$, to calculate V_{out1}. Since the Thevenin model of a given two-terminal network has the same I-V curve as the original network, this calculated V_{out1} should agree with what you calculated in part 1.2. Does it?

Now instead draw a load resistor $R = 3\ \text{k}\Omega$ across the terminals of your Thevenin model, and again calculate V_{out1} with the voltage-divider equation. Does it agree with what you measured in part 1.3? And did your V_{out2} from part 1.3 just equal $\frac{2}{3}$ of V_{out1}?

What you should be grasping (though this idea takes a while to assimilate) is that when you connect the output of circuit 1 to the input of circuit 2, the voltage seen by circuit 2 is the output of a voltage divider formed between R_{thev} of circuit 1 and R_{in} of circuit 2. If you don't follow this, ask one of us now to help talk you through it.

1.5 In making your voltage measurements in parts 1.1–1.3, you probably neglected the finite $R_{\text{in}} = 10\ \text{M}\Omega$ of the voltmeter. Explain why it made sense, in these measurements, to treat the meter as if its R_{in} were effectively infinite (i.e. to neglect it), as we normally do.

A rule of thumb for voltage sources (opposite for current sources) is that the *source resistance* (a.k.a. R_{thev}, a.k.a. "output resistance") of the driving circuit needs to be much smaller than the *input resistance* of the load, if you want the source voltage to be relatively unaffected by the presence of the load. The advantage of following this rule of thumb is that it allows you to consider the parts of a complicated circuit individually. Alternatively, keeping in mind R_{thev} for the driving circuit and R_{in} for the load allows you quickly to calculate or to approximate the interactions between two adjacent stages of a circuit. Does this exercise make the rule of thumb clear to you? If so, then you should find part 1.6 straightforward.



(You don't need to build this!)

1.6 Look at **(but don't build)** the circuit drawn above: what is V_{out}? (Do it in your head! If you can't, then you're not looking at it the right way yet.) Why would it be much more difficult to do this calculation in your head if every resistor were 1 kΩ?

Part 2 **Start Time:** ________________

oscilloscope / function generator tutorial

Now make your way through the attached “Tutorial on Oscilloscope and Function Generator,” which was written up by Jose Vithayathil and Joe Kroll. It will probably take you about 45 minutes.

The tutorial should be at the end of this handout and is also online at
`positron.hep.upenn.edu/wja/p364/2014/files/scope_tutorial.pdf`

(There is nothing that you need to write down here.)

Part 3 — Start Time: ______________

voltage divider with sinusoidal input

Put your venerable (1 kΩ):(2 kΩ) voltage divider back together. Drive it with an 0.5 Hz, 10 $\mathrm{V_{pp}}$ ("volts peak-to-peak") sine wave from the function generator. (The Rigol function generator's maximum amplitude is 20 $\mathrm{V_{pp}}$ for CH1 and 6 $\mathrm{V_{pp}}$ for CH2.) Connect the oscilloscope to graph V_{in} vs. time on channel 1 and V_{out} vs. time on channel 2. Make a rough sketch of $V_{\mathrm{in}}(t)$ and $V_{\mathrm{out}}(t)$. Does the voltage divider behave as you expect for time-varying input? Note: the amplitude displayed by the function generator may be half of the amplitude seen by the scope. If this happens, we can show you how to put the function generator into "high Z" mode, which is the mode it should normally be left in.[1] If the scope and the function generator disagree, trust the scope.

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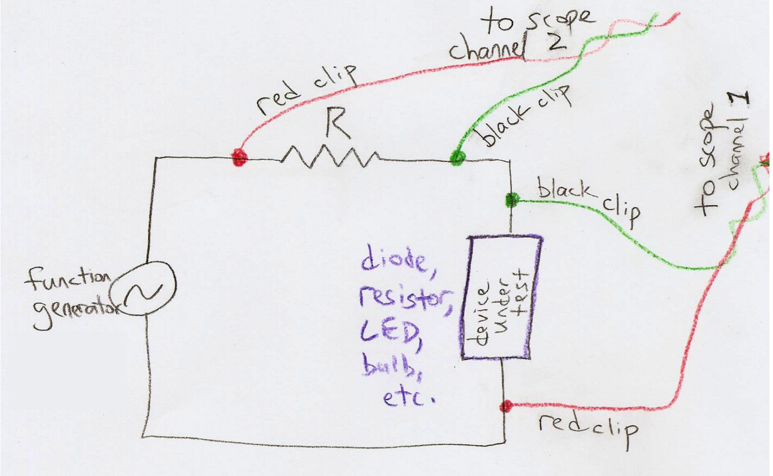
[1] The function generator's own output resistance (a.k.a. Thevenin resistance) is 50 Ω. Many lab instruments have 50 Ω input resistance, to match the characteristic impedance of long coaxial cables that one often uses as transmission lines in a lab. In that case, the downstream instrument's R_{in} equals the FG's R_{thev}, so the voltage seen by the downstream instrument (if its R_{in} is 50 Ω) is only $\frac{1}{2}$ of the FG's open-circuit output voltage (V_{thev}). If instead you connect the FG output to a device having $R_{\mathrm{in}} \gg 50\ \Omega$ (as we normally will), that device will see the full V_{thev}. The FG adjusts its voltage display to account for the assumed R_{in} of the load you attach. If the FG is connected to a "high-impedance" load having $R_{\mathrm{in}} \gg 50\ \Omega$, you need to inform it of this fact by putting the FG into "high-Z" mode, so that the voltage displayed on the FG's front panel is the same as the voltage observed by your circuit. The scope's R_{in} is normally 1 MΩ, though (confusingly) there is an option to set the scope's R_{in} to 50 Ω, in case the scope is at the end of a transmission line.

Part 4 **Start Time:** ______________

much faster way to make I-V curves

4.1 Now replace the 2 kΩ resistor from part 3 with a 1N4148 (or similar) diode. Sketch $V_{\text{in}}(t)$ and $V_{\text{out}}(t)$. You should see the diode *clamp* V_{out} at about 0.7 V. This feature is often used to protect sensitive circuits from excessive input voltage. We'll see this and other diode circuits again next week.

We haven't really discussed diodes yet, except to mention them in passing, so you're entitled to find them mysterious. For the moment, we'll look at a diode simply as a device with an interesting (and non-linear) I-V curve: for $V < 0$ (called "reverse"), the current is negligible, and for $V > 0$ (called "forward" voltage for a diode), the current increases exponentially with voltage. Typically the current reaches an "appreciable" value (many milliamps) around the point where $V \approx 0.7$ V, so we very loosely say that the diode behaves like a very small resistance for $V > 0.7$ V, like an open circuit for $V < 0$, and somewhere in-between for $0 < V < 0.7$ V. Light-emitting diodes glow, usually monochromatically, as electrons and holes recombine—making the on/off transition more tangible. We'll use the scope and function generator below to trace out the I-V curves of several devices, including a diode and some LEDs.



4.2 The most common use of an oscilloscope is to graph one or more voltages as a function of time: $V_1(t)$, $V_2(t)$, etc. — normally the horizontal axis represents time. But we're now going to put the scope into XY mode, so that we see V_2 vs. V_1 — the horizontal axis will be V_1, and the vertical axis will be V_2. Using this feature will let the scope and function generator trace out several I-V curves for us, far less tediously than measuring them point-by-point. Your set-up should look like the above diagram. We want to measure I vs. V for the *device under test*, which initially will be the diode from part 4.1. Scope channel 2 will show the voltage drop across resistor R (initially use 1 kΩ). Since the current through R equals the current through the diode (the scope's input resistance is 1 MΩ, so it will draw negligible current), we can look at channel 2 and infer the diode current $I = V_2/R$. Scope channel 1 will show (minus) the voltage drop across the diode.[2] Remarkably, you can fix this sign annoyance by telling the scope to "invert" the channel 1 signal! If all goes well (ask for help!), you should see the scope trace out $R \times I_{\text{diode}}$ vs. V_{diode} on the screen, with zero current for $V_{\text{diode}} < 0$ and an exponentially increasing current for $V_{\text{diode}} > 0$. Make a rough sketch of the curve.

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[2] Unfortunately, the black clip for each scope input is wired to Earth ground, so we are forced to connect channel 1 upside-down, as shown in the diagram. The function generator doesn't have this problem — the outer shield on its signal cable is "floating" (not held at any fixed potential w.r.t. Earth ground).

4.3 Now replace the 1N4148 diode with a red LED. The curve should look similar, though perhaps shifted to the right a bit w.r.t. the ordinary diode. Next try a blue LED. The curve should shift farther to the right. Expressed in electron-volts, what are the energies of red and blue photons? (Hint: $\lambda_{\rm red} \approx 630$ nm, $\lambda_{\rm blue} \approx 470$ nm, Planck's constant is $h = 6.626 \times 10^{-34}$ J $\cdot$ s, the proton charge is $e = 1.602 \times 10^{-19}$ C, and the speed of light is (exactly!) 2.99792458×10^{8} m/s.) The forward voltages (the "knee" of the I-V curve) for the red and blue diodes should roughly equal the corresponding photon energies (in eV).

4.4 Now replace the LED with a flashlight bulb, and replace the 1 kΩ resistor with approximately 10 Ω, so that you get enough current flowing to see the bulb light up. (It's a 1 W bulb, roughly.) Watch the bulb turn on and off as the scope traces out the $I(V)$ curve. Note that the bulb doesn't care about the sign of V, unlike the diode. Note also that the bulb is non-linear. Can you see that the resistance of the tungsten filament increases as the bulb heats up? (This is why old incandescent bulbs usually burn out when you first turn them on.) There is also an interesting hysteresis that you might see, depending on the frequency that you set with the function generator: the bulb takes a while to heat up or cool down as the applied voltage changes. Comment here on what you see.

4.5 Finally, replace the flashlight bulb with a boring resistor (around 1 kΩ), and check that you get the straight-line $V(I)$ curve that you expect from Ohm's law.

4.6 (completely optional) Try this only if you have extra time. Leave the scope in XY mode. Connect a BNC cable from the CH1 output of the function generator to CH1 of the scope. Connect a second BNC cable from the CH2 output of the function generator to CH2 of the scope. Set the two channels of the function generator to output sine waves of the same frequency, the same amplitude, and press the "Phase Align" button to get them in phase with one another. Set the voltage scales for both channels of the scope so that the trace fills most of the screen. You should now be sending the same signal to both the horizontal and vertical channels, so you should see a straight line.

Try reducing the frequency of the function generator to just 1–2 Hz so that you can see where the trace has been recently updated.

Try making the two sine waves out of phase by 0°, 45°, 90°, etc., and see if you can make sense of the resulting graphs.

Now to back to 0° and try making the two sine waves have frequencies that are different, but are related by a ratio of small integers. Use the "Phase Align" button after each frequency adjustment so that the two sine waves are (initially) back in phase with one another. See if by doing this you can get the scope to graph out Lissajous figures.

Ask for help if you need it. Getting the scope to graph this mathematical curiosity gives you a bit more practice with the function generator and the oscilloscope.

Tutorial on Oscilloscope and Function Generator

Jose Vithayathil and Joseph Kroll (9 September 2013, v1.0)

Both the Oscilloscope (scope) and the Function Generator (FG) are general purpose instruments that are used in a range of fields. Understanding and being adept at using them correctly will help you make proper measurements efficiently.

In this laboratory, the scope is the Tektronix DPO 3014 Digital Phosphor Oscilloscope and the FG is the Rigol DG 1022 Dual-Channel Arbitrary/Waveform Generator.

The FG provides various types of voltages to your device under test (DUT). The scope samples the voltages at the test points in your DUT (ideally with minimal disturbance of the DUT) and displays the voltage samples as a function of time.

Getting Started

Turn on the power of the FG and the scope. Connect a coaxial cable (coax) from CH1 of the FG to CH1 of the scope.

Press '*Sine*' on FG. Read across the top of the FG display. You should see (from left to right): "Sine," "High Z" and "CH1." High-Z means that the display of the FG is set to report parameters of the waveforms assuming that the FG is connected to a DUT with large impedance.

Read the frequency and amplitude of the sine wave by pressing the blue buttons under the display. The amplitude is reported as the peak-to-peak voltage, that is, twice the amplitude that you usually associate with a sine wave: A*sin(omega*t) has a peak-to-peak amplitude of Vpp=2*A.

Change the frequency to f=2.8 kHz. Do this by directly entering the frequency from the number pad. Then change the frequency to 1.5 kHz using the knob and the arrow keys. The frequency is f=omega/2*pi.

Output the signal from the FG. To do this press 'Output' for Ch1. On the scope press the black autoset button. The FG signal should be displayed on the scope screen. Read the scope vertical (voltage) scale and the horizontal (time) scale. Estimate the signal amplitude and the period and thus the frequency from the screen display. Do they agree with the FG values?

On the FG press '*Square*' to output rectangular pulses. Observe the change in the waveform. Did the frequency or amplitude change? Then press 'Ramp'. Press the blue button under the '*Symm*' label on the FG display and vary it from 0-100. What do you observe?

Connect a coax from CH2 of the FG to CH2 of the scope. Press '*CH1/Ch2*' on the FG and highlight CH2. Take note of the default waveform, frequency and amplitude. Change CH2 to output a sine wave.

Press '*View*' on FG to toggle between different views of the active channel and to display both channels together.

Output CH2 by pressing '*Output*' on the FG. In the '*Vertical*' block on the scope panel, press the '*blue*' button to display CH2. Turn the knob under the '*blue*' button to 1V/div to observe the full signal.

Vertical Block of the Oscilloscope

Now study the following info tabs for the vertical setting on the bottom of the scope screen.

'*Coupling*': *DC* coupling is used most often. The full input signal is input to the scope.

When *AC* coupled the scope only sees the AC signal. You will use this setting when you are trying to measure the details of a small AC signal superimposed on a much larger DC signal.

In 'GND', the scope input is set to the scope Ground. The button below the coupling info tab toggles between DC, AC, and GND. Try it and reset to DC. The channel indicator label on the display is the location of the scope ground. Its location can be shifted vertically by varying the knob above the corresponding channel button in the 'Horizontal' block.

We will study the effects of input couplings later on in the tutorial.

'*Termination*': The scope can be set to 3 different input impedances. 1M sets the scope impedance to 1 megaOhm and is the setting most used. 50 sets the scope to 50 Ohm input impedance. This is needed when observing signals with frequencies > ~1 MHZ. Distortions due to signal reflection from unmatched impedances are avoided in the 50 Ohms setting for common lab instruments. The coax cable used in the lab has a characteristic impedance for signal transmission of 50 Ohm (to understand what this means, refer to the textbook by Millman among the lab reference books). If the scope input impedance is not the same as the coax characteristic impedance, the signal will be partly reflected by the scope. Common lab instruments have an output source impedance of 50 Ohms. 75 sets the scope input impedance to 75 Ohms and is a standard for video equipment but is not normally used in a lab.

You will notice that when the scope input termination is set to 50 Ohms, that the signal amplitude is reduced by a factor of 2. The FG source output impedance is 50 Ohms. The scope with an input impedance at 50 Ohms sees the voltage divided signal. Try it.

Would the signal amplitude be reduced measurably with the scope set to have 1 megaOhm input impedance?

'*Invert*': Turning on '*Invert*' inverts the signal. Try it.

Press the *Yellow* button above Ch1. This toggles (turns on and off the display for CH1). Similarly the *blue* button toggles the Ch2 display. Toggle both channels on and off and then leave both CH1 and CH2 on.

Horizontal Block of the Oscilloscope

On the '*Horizontal*' block of the scope turn the knob to vary the horizontal time scale and observe the change on the display.

Press the 'Acquire' button

Press the button under the '*Mode*' info tab on the screen.

On the right hand side (RHS) select '*Sample*' by pressing the button next to it. '*Sample*' makes the scope display traces in sequence.

Select '*Average*', '*Average*' makes the scope display a running average of consecutive traces. The number averaged can be varied by using the multipurpose 'a' knob. Signal averaging is very useful because random voltage noise accompanies any signal. Since the noise is not correlated with the signal, averaging the trace reduces the contribution due to the noise. Select 'Noise' output from CH2 on the FG. Select 'Average' and try different averages and observe how the noise averages out while increasing number of averages. Reset the FG back to 1.5 kHz 5 Vpp amplitude.

Select '*Hi Res*', '*Hi Res*' is a variation of sample. The scope acquires more sample points (in the time interval displayed on the screen) than the displayed points on the screen. '*Hi-Res*' averages a fixed number of neighboring points for each trace and displays the smoothed average of that trace.

Next turn on the *XY* display.

Press the blue button under '*AligPha*' on the FG. This sets the output of both channels of the FG to be in phase. Do you observe a line with a slope of 1 on the scope? In the *XY* mode, the horizontal axis is set by the CH1 input signal and the vertical axis by the CH2 input signal. Does the display make sense?

Now vary the phase on the FG from 0-180? Is the display what is expected? You may have heard of Lissajous figures. If you finish the lab early, you can have fun trying CH2 with different integer multiples of CH1 frequency and by varying the phase.

Trigger Block

Understanding the trigger functions is important in the proper use of the scope. The function of the trigger is to display a signal when it meets the conditions set by the trigger. A digital scope is capable is displaying signals a little before the trigger and also after the trigger. In the default setting of the scope the trigger event occurs when the trace is at the center of the screen.

Vary the '*level*' knob in the trigger block. This sets the threshold voltage to reach before the scope can display a trace. Notice as you increase or decrease the trigger level the trace shifts left or right so that signal at the trigger position (center of screen in the default mode) matches the trigger level set. Notice as you move the trigger level outside the signal range the display looks unstable in the '*Auto*' mode, which is the default setting. Also on the upper RHS corner of the screen the '*Trig'd*' label becomes '*Trig?*. '*Trig?*' indicates that the scope is not getting a trigger signal. There is still an unstable display because in the ‘*Auto*’ trigger mode, the scope decides after some fixed time without a trigger to display another trace. The length of time before the auto trigger activates varies with the horizontal time base set. The auto triggered trace is not going to start at the same time as the previous trace.

Next press the ‘*Menu*’ in the trigger block. Press the button under the ‘*Type*’ info tab on the screen. Many different trigger conditions suitable for various tests are shown. Throughout the course ‘*Edge*’ triggering is used. Make sure it is the ‘*Edge*’ triggering is the setting used when you use the scope.

‘Source’ info tab shows the channel used for the source. The signal for the trigger can come from a signal from any of the channels or the AC power line. Triggering on the ac power line is particularly useful when you are suspicious that the noise is correlated with the ac line. AC Line noise is a common source of noise that can couple into your DUT in many ways. It can require some effort to reduce its effect.

‘*Coupling*’ info tab displays trigger options. DC coupling is used most often. If the signal is noisy selecting ‘*HF Reject*’ or ‘*Noise Reject*’ minimizes the effect of noise and reduces jitter in the display. Try and observe the effect in the ‘DC’, ‘*HF Reject*’, and ‘*Noise Reject*’ modes. Since the function generator noise is quite clean you won’t see much of a difference, however some of the circuits you test will have a significant noise and then the ‘*HF Reject*’, and ‘*Noise Reject*’ trigger settings will be handy.

Selecting ‘Mode’ displays ‘*Auto*’, ‘*Normal*’, and ‘*Holdoff*’ on the RHS. ‘*Auto*’ trigger is useful for displaying a signal if you don’t know its voltage level. ‘*Normal*’ trigger forces the scope to wait for a trigger. While making measurements you usually want to be in the ‘*Normal*’ trigger mode. ‘*Holdoff*’ is the dead time between the acquisition of a trace and the next trigger. You normally want it set to ‘*Minimum*’. Observe the display while changing the trigger level from a value within the signal range to a value outside the signal range in the ‘Normal’ trigger mode.

Now investigate the effect of scope input coupling on the trigger level setting

Set the FG to output a 500 mVpp sine wave offset by a DC level of 4 Volts on CH1. Set the vertical scale to 2V/div. With the scope in ‘DC’ input coupling mode (press the yellow channel button to access input coupling), you may observe that the display is not stable and ‘Trig?’ is displayed. Set the scope trigger mode to ‘Normal’. Increase the trigger level; at around a trigger level of 4 V, you should see the scope begin to trigger. The trigger should become active and ‘Trig’d’ should be displayed. The trigger sensitivity depends on the AC signal displayed and if the AC signal displayed is small, the trigger sensitivity is not very good. Now change the CH1 input coupling to ‘AC’ (not the trigger coupling, the CH1 input coupling). Change the vertical scale to 100mV/div. You will observe that you have to now adjust the trigger level down towards zero to enable the scope to trigger. Also note, as expected, the DC offset has been removed from the signal

Reset the function generator to its previous (default) sine wave (5 Vpp, 1kHz) setting on CH1 and adjust CH1 input coupling to ‘DC’ coupling and if need be adjust the trigger level to trigger the signal.

Measurement

The traces can either be measured manually by using cursors or automatically by using the 'Measure' feature of the scope.

To use the cursors, press and hold the '*Cursors*' button until the cursors info tabs appear on the bottom of the screen. The cursor values are shown on the upper RHS box. The color of the text indicates the channel being displayed. Also make sure that the '*Fine*' button below the cursors is highlighted. From the bottom of the cursor info tabs select '*Screen*', source – CH1 or CH2, and horizontal or vertical cursors. Record the amplitude and the period and thus the frequency of the signal in CH1 by positioning the cursors.

Next press the '*Measure*' button. Press the button to 'Add measurement', on the RHS select the same channel used for the cursor measurement for the source and select '*Measurement Type*'. View the measurement types possible. Select '*Amplitude*' and then '*OK*' to add measurement and then do the same for '*Frequency*'. Press '*Menu Off*'. How do the values measured by the '*Measure*' function and manually by the '*Cursors*' compare?

Save

Connect a memory stick to the USB port. Press the '*Menu*' button below the screen and save the *'Screen Image*' in your favorite format. Display the screen image on your computer. The display can be printed on the lab printer. Instructions for enabling your computer to print can be found at:

http://www.sas.upenn.edu/computing/physics/printers/

Probe

Connect CH1 of the FG to your attenuator circuit. Connect the scope probe to the input of your circuit and to CH1. The alligator clip of the scope probe should be connected to Ground on the circuit. Connect the second probe to each of the stages of the attenuator and measure the attenuation of each of the stages. How does it compare with your DC measurements? The input of the scope has a resistance of 1 megaOhm and a capacitance of 20 picoFarad. The scope probe has an input impedance of 10 megaOhm. Probes reduce the load on the DUT compared to a straight coaxial connection to the scope. In addition the connecting coaxes have a capacitance which distort time varying signals coming from the DUT. A probe has an adjustment capacitor that will compensate for it. The details of how this is done will be understood later. Signals are attenuated by a factor of 10 by the probe. There is an identifying pin in the probe that lets the scope know that a probe is being used so that it can account for the attenuation and display the correct signal amplitude seen at the DUT.

Postscript

You have covered a lot of the features on both the FG and the scope that you will normally use in the course. However we haven't covered useful features of the FG that include modulating the signal or sweeping a range of frequencies. Useful features include 'Math' functions like derivative, integral, and

Fourier transform (FFT) of the signal. Some of the options you observed while pressing the buttons have not been discussed. In addition the scope can acquire 5 million points/ trace. There are functions to search for events meeting user specified conditions within the trace. This is done using the controls within the '*Wave Inspector*' block. To learn about the additional features and to get detailed specifications of the scope consult the scope manual in the lab.