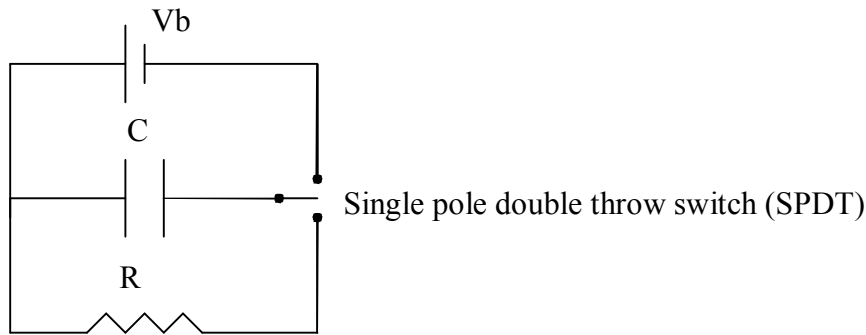


RC Circuits

In this lab you will be working with a variety of voltage sources each driving an RC circuit.

RC Circuits- Exponential decay by discharge

In this activity you will use the following circuit to quickly charge and then slowly discharge the capacitor through the resistor. You will measure the voltage across the capacitor at fixed time intervals as it discharges.



Circuit #1 $V_b=6V$, $C=0.47F$, and $R=R_1=100\Omega$.

When the switch is thrown to the up position, the battery is attached to the capacitor. The capacitor charges until the voltage across it equals that of the source (this happens nearly instantaneously). When the switch is thrown to the down position the battery is disconnected and the resistor is connected across the capacitor. This gives a path for the capacitor to discharge. Since the rate at which the charge leaves the capacitor is proportional to the amount of charge on the capacitor, this discharge is exponential. As discussed in class and chapter 28, the time constant for the decay is $\tau=RC$.

First observations of the phenomenon:

First charge and discharge the capacitor while watching the voltage across the capacitor, V_c with one of the multimeters you used last week. To do this assemble the circuit and connect a multimeter across the capacitor. Flip the switch to the power supply and observe the charging of the capacitor. Now that the capacitor is charged, flip the switch to the resistor and watch V_c decay.

Recording your data:

You may record your data (V_c every 5s until the capacitor has completely discharged) by hand from the multimeter, or if you find this tedious, you may use your computer to record the information using the Data Studio software. To use the computer to record your data:

- Turn on the interface box.
- Connect the leads of the “voltage probe” across the capacitor. (Leave the multimeter attached, too.)
- Start ‘Data Studio’. (It is on the desktop)
- Select Create Experiment.
- The voltage probe is plugged into the interface box but you must tell the computer that this is so. Click on port A and select “Voltage probe”.
- To create a graph of your data drag a graph from the “Displays” window up to the voltage probe in the “Data” window.

- g. Click on START and observe the voltage reading in the digital display on the screen as you flip the switch first to the power supply and then to the resistor and a graph of the voltage as a function of time. STOP taking data when the capacitor is discharged. The values on the screen should be about the same as those shown on the multimeter.
- h. Repeat if necessary.

Analyzing your data:

If you have not already done so graph your data.

- a. Fit the data to a “Natural Exponential Fit”. The fit equation is $y=A*\exp(-x*C)+B$ where A, B, and C are fit parameters. Note that the fit parameter “C” is *not* capacitance.
- b. Not all of your data corresponds to exponential decay. You will need to select only the data that corresponds to the time during which the voltage is decaying exponentially. Do this by high lighting the relevant data.
- c. Write the fit equation below in terms of your physical variables, V and t:

- d. How do you interpret the fit parameters A and C physically? Use the results of your fit to determine the time constant τ .

- e. Graphing your data so that it looks like a straight line is useful. We expect that the data should be an exponential curve, but as a final check graph the natural log of your data. To do this click the “Calculate” button near the start button. In the definition box enter “ $y=\ln(x)$ ” and define the x variable as “Data Measurement”. Graph the results of this calculation and fit it with a straight line (over the same period of time as in the last fit). How do you interpret the slope and what is the value you find?

- f. Print both of your graphs.

RC Circuits- voltage during charging

In circuit #1 the capacitor charged quickly because of the very low resistance of the wires, battery, and capacitor itself. We analyzed in class the charging of a capacitor in series with a resistor. Rearrange your circuit elements to **make circuit #2**, a circuit with a single loop that contains the capacitor, resistor, battery and switch (you will only use one of the throws).

Prediction:

Based on the results we found in class, what equation do you expect to describe the voltage across the capacitor as a function of time, $V_c(t)$, as it is charging?

What is the value you expect theoretically for the time constant given the nominal values of the capacitor and resistor?

Recording your data:

Using the same method as above, record the value of V_c every 5s (or more frequently if your data collection is automated).

Analyzing your data:

Graph V_c vs time. Fit the data using an "Inverse Exponent Fit". Double click on the window with the fit parameter values to see their role in the fit the equation.

Use the results of your fit to determine the time constant based on your charging experiment.

Comment on the level of similarity between the values of the time constant based on the discharge experiment, charging experiment, and theoretical predictions

Print your graph.

RC Circuits- sinusoidal voltage source

In addition to storing energy from a steady power source (DC) they can be used in a circuit powered by an alternating current power source (AC). To create and observe such a circuit you will need to use a **function generator** (a controllable AC power source) to power your circuit and an **oscilloscope** to measure it. You will need to spend some time getting accustomed to these pieces of equipment before you can use them in the circuit we are interested in.

MEASUREMENTS OF VARYING VOLTAGES INTERLUDE

Measurements of varying voltages are commonly done with an oscilloscope. The oscilloscope displays a plot (graph) of voltage versus time. This is done by deflecting a stream of electrons (which has been accelerated from the back of the instrument to the front) both horizontally and vertically before it strikes a fluorescent screen. The amount of vertical deflection is determined by the voltage under study; the horizontal deflection is proportional to the time elapsed since the sweep began. The oscilloscope always responds to voltage, but these voltages are often characteristic of other phenomena. For example, a microphone changes the variations in air pressure associated with the sound to changes in voltage that can then be observed with the oscilloscope.

The oscilloscopes you will use in this lab all have common features. Each is a triggered dual-trace D.C. coupled scope. Dual trace means that two traces, or beams, can be viewed simultaneously. Each input voltage goes into its own amplifier and is displayed on the screen independently of the other. Triggered means that the electrons sweeping across the screen begin their journey from the left side only when "told to" or "triggered." There are several ways to trigger the beam. For many, but not all, of our uses, the beam will be triggered by the input voltage. If the triggering adjustment is not set correctly, the pattern will drift across the screen and will not be "locked in." (You will probably find this adjustment a bit of a mystery. Don't worry--ask your instructor if adjustments are needed.) D.C. coupled means that any input voltage, including a constant voltage, causes a deflection. (In A.C. coupling, only variations cause a deflection; the average of the display is zero).

About the only thing you can do to hurt a scope is to leave a bright dot at one place on the screen for a long time. Also, avoid putting a sharp pencil or pen on the screen as this scratches the surface.

1. Spend some time studying the front panel of the scope. There is a myriad of switches and knobs. Locate the following important ones:
 - a) On-Off (or A.C. on)
 - b) Intensity or brightness
 - c) Focus
 - d) Vertical Gain, in volts/div (one for each channel)
 - e) Horizontal Sweep rate, in time/div
 - f) D.C. - A.C. input switch

Be sure you understand the marking on the vertical and horizontal controls. Each must be set to the CAL position before the marked values will be accurate.

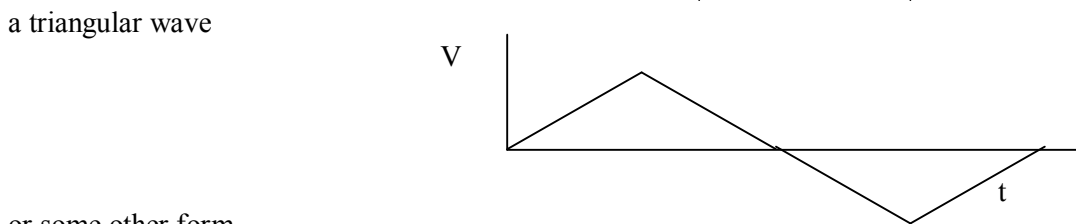
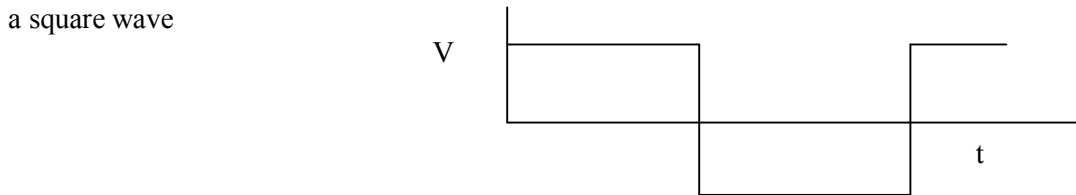
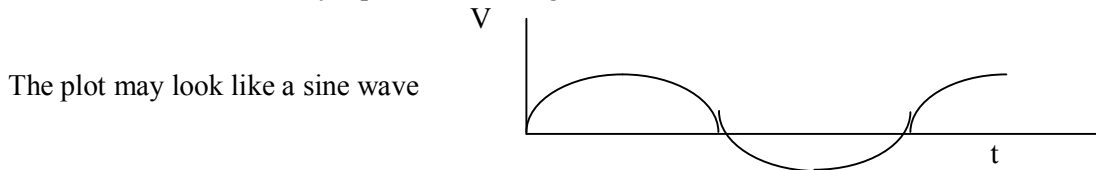
2. Turn on the scope. After a minute or so, you should have a focused line centered on the screen. Turn the sweep rate to its slowest value. Watch the dot move across the screen. Now step-by-step, increase the speed of the electron beam's travel across the screen. The spot will develop a comet-like tail which finally seems to turn into a continuous line. Remember that this line is an illusion caused by the persistent glowing of the phosphor after being hit by the electrons. There is still a dot of electrons moving across, now very rapidly. Continue to increase the sweep rate.

The line will get very dim at the highest rates because the time spent at any place on the screen decreases.

- Set the vertical gain to $.5V/Div$ and the input to D.C. Read the voltage of a 1.5 volt battery on the oscilloscope. Try it with the opposite polarity of the battery by reversing the leads. What would happen if the gain were changed to $1V/Div$? Try it and find out if what you expect indeed happens. Now set the INPUT to AC and try to measure the battery. What happens?

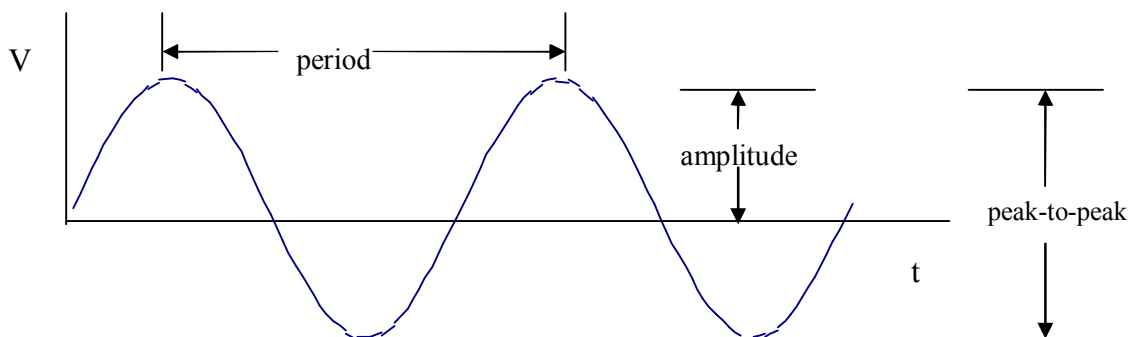


- A function generator (AKA signal generator) produces a voltage which varies with time. The type of variation is characterized by a plot of the voltage versus times.



or some other form.

The frequency of the signal is the repetition rate of the regular pattern (frequency is the inverse of the period, which is the time between adjacent peaks). The amplitude of the signal is the maximum voltage of the signal (half the peak-to-peak value). (See the figure below).



- A.C. Connect the oscilloscope cable to the output of the generator. You may have to vary the sweep speed (**horizontal on the scope**) to spread the pattern enough to make a frequency measurement and you may need to vary the **vertical gain on the scope** to make it fit nicely vertically on the screen. If you have trouble getting a stable pattern, see your instructor. As you are making these changes in gain and sweep speed, the pattern will change; are the characteristics of the input signal changing? Based on your measurements **with the scope**, what are the period, frequency, amplitude and p-p voltage of the signal you have?
- Now connect a small speaker to the output of the signal generator and leave the scope also connected to the output. Now the same signal that the oscilloscope looks at is driving the speaker, converting it to sound waves of the same frequency. Do you hear the tone?
 - Find the controls **on the signal generator** which would change the frequency of the signal. You should be able to observe on the oscilloscope when you have found the right control. Now find the control **on the signal generator** which would vary the amplitude of the signal. Again, you should be able to observe on the scope when you have the right control. Adjust these until you can hear a tone; large enough amplitude (loud enough) and a frequency you are sensitive to. Change the signal frequency and notice the effect it has on the display and the pitch of the tone. Make sure you understand how the display changes as you go from low to high frequency and vice versa. In going over the range of audible frequencies, you may have to change the sweep rate of the oscilloscope. When you do, make sure you understand that the display looks different because of a scale change and not necessarily a change in frequency of the signal. Find the highest and lowest frequencies you can hear.
 - Now try to use your speaker as a microphone. In (b) and (c) you supplied a varying voltage to the speaker and that caused the speaker to vibrate. Suppose you cause the speaker to vibrate (by tapping it or "hitting" it with sound waves). Would it output a voltage? **Disconnect** the speaker from the signal generator so that **only** the speaker is now connected to the input of the oscilloscope. See if you can detect any voltage output from the speaker as you tap it or talk into it. (You may need to increase the sensitive by changing the vertical gain of the scope.)

You can now make circuit #3 by placing the 220nF capacitor in series with the 100Ω resistor and the signal generator.

Recording your data:

Use the oscilloscope to measure the amplitude of the voltage across the capacitor as a function of frequency. Make your measurements at 10Hz, 30Hz, 100Hz, 300Hz, 1kHz, 3kHz, 10kHz, 30kHz, 100kHz, and 300kHz.

Use the oscilloscope to measure the amplitude of the voltage across the resistor as a function of frequency. Make your measurements at 10Hz, 30Hz, 100Hz, 300Hz, 1kHz, 3kHz, 10kHz, 30kHz, 100kHz, and 300kHz. **Note:** the capacitor and resistor measurement cannot be made at the same time because of the common ground on the oscilloscope and the function generator (the black connectors from both machines must be attached to the circuit in the same spot).

Analyzing your data:

Graph V_C and V_R vs time on the same graph. Print out your graph.

To see how this circuit is useful you could replace the power supply with a music source and hook your speaker up across the resistor and then across the capacitor and note the difference in sound quality.

Advanced: for those with the time, ability, and interest.

The function generator is creating a voltage that obeys

$$V_S = V_{S0} \cos(\omega t).$$

And the voltage across the resistor you have seen has the same functional form

$$V_R = V_{R0} \cos(\omega t)$$

Which according to Ohm's law tells us that the current flowing through the resistor is given by

$$i_R = V_R/R = (V_{R0}/R) \cos(\omega t).$$

But the current flowing through the resistor is the same current flowing through the function generator, is the same current flowing through the capacitor. Use this information to find a theoretical expression for the voltage across the capacitor and hence explain the behavior found in the graph above.