

University of Utah
Electrical & Computer Engineering Department
ECE 2210/2200 Lab 5
Capacitors

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Objectives

- 1.) Observe charging and discharging of a capacitor.
- 2.) Measure the time constant of an RC circuit.
- 3.) Observe and measure the frequency dependence of capacitor impedance.
- 4.) Observe the phase relationship of AC voltages and confirm KVL for these voltages.

Parts to be supplied by the student: (Parts in **bold** are new to this lab)

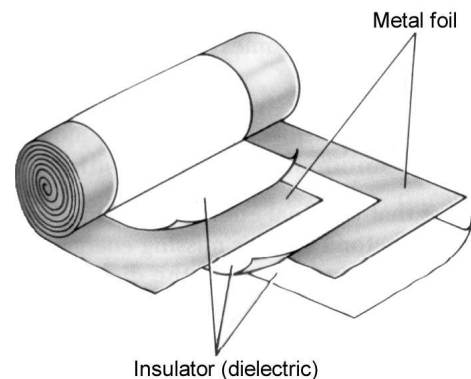
- 1 k Ω (brn,blk,red), and **100 k Ω** (brn,blk,yel) resistors
- **0.1 μ F** (usually marked 104) and two **47 μ F capacitors**

Equipment and materials to be checked out from stockroom:

- Analog BK precision multimeter or similar.

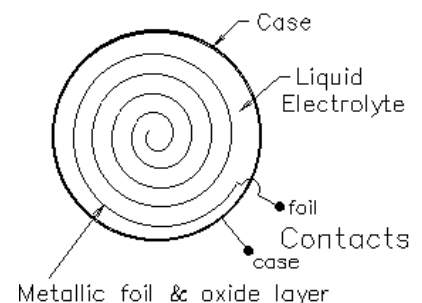
Capacitors (General background information)

Capacitors with values less than 1 μ F are usually constructed by layering sheets of metal foil and insulating material. Often these sandwiches are rolled into little cylinders or flattened cylinders. The metal foils are the plates of the capacitor and the insulator is the dielectric. The dielectric material determines the capacitor type (paper, ceramic, polyester, polypropylene, etc.) And its non-ideal characteristics (see Ch 3 of your textbook). The value of a capacitor is proportional to the area of the plates and inversely proportional to the thickness of the dielectric material between them. In general, a capacitor with a larger capacitance value will have to be physically larger as well. Capacitors come in many shapes and a huge range of sizes.



Many small capacitors are marked with numbers like 104K or 471M. The numbers are read like the bands on a resistor— two digits and a multiplier that indicate pico-farads (104 is 10×10^4 pF = 0.1 μ F or 471M is 47×10^1 pF). Pico-farads are 10^{-12} farads or 10^{-6} μ F. The letter indicates the part tolerance (how close should the actual value be to the marking), F = $\pm 1\%$, G = $\pm 2\%$, J = $\pm 5\%$, K = $\pm 10\%$, M = $\pm 20\%$. See Ch 3 of your textbook for more information.

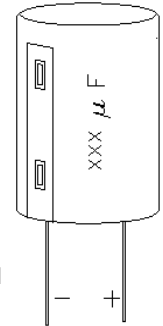
Capacitors with values greater than 1 μ F are usually constructed by immersing a roll of metal foil in a conducting liquid (see drawing, at right). A conducting liquid is called an electrolyte and these type of capacitors are called electrolytic capacitors. The foil is one plate and the liquid is the other. The dielectric is a very thin layer of oxide formed on the foil. Because the oxide layer is so thin, electrolytic capacitors can have very large values in relatively small packages. Unfortunately, the oxide dielectric



also gives them some other, less desirable, characteristics. Most electrolytic capacitors can only be charged with one polarity. Voltage of the wrong polarity can damage the oxide layer and sometimes even cause the capacitor to blow up. (I can personally vouch for this.) They are difficult to manufacture accurately and their actual value may differ from their claimed value by as much as a factor of two (-50%, +100%). The oxide is not the best of insulators so they can have significant leakage current. Finally, the oxide layer so thin that electrolytic capacitors have relatively low voltage ratings.

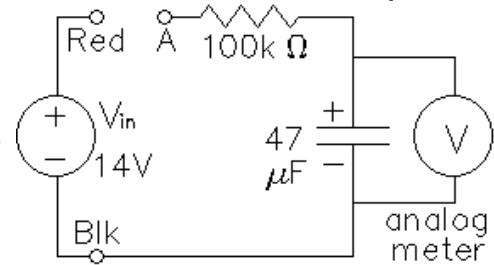
Experiment

Look at your two capacitors. Note that the 47 μF capacitor is larger than the 0.1 μF capacitor, but not 470 times larger. Also notice that the electrolytic capacitor has a voltage rating marked on the package and that one side has a whitish band that indicates polarity. Look for the polarity band, not the lead lengths. If you apply a voltage larger than the rating, or in the wrong polarity, you risk damaging the capacitor, quite possibly making it blow up. **DON'T DO THIS!**



Charge and Discharge

Set the bench power supply's output to about 14 V. Wire the circuit shown at right using an analog multimeter (switched to 10 V DC range). Note that point A is NOT yet connected to the power supply. If the reading on the voltmeter isn't 0 V, short the capacitor leads together for a second and measure again. Now, while watching the voltmeter, connect point A to the power supply. Notice the rising voltage across the capacitor. Does the voltage seem to follow the expected charging curve for an RC circuit?



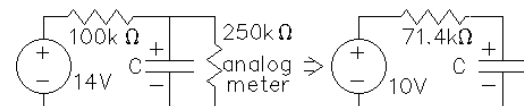
Look at the curve on the next page. It changes quickly at first and ever more slowly as the capacitor approaches its final charge (voltage). Draw a rough sketch of the curve in your lab notebook and comment. Notice that the voltage only rises to about 10 V, not 14 V as you might expect. That's because the meter affects the circuit (see box at right).

Allow the capacitor to charge until the voltage across it changes very slowly and nearly equals 10 V. We'll call this fully charged, although in reality it will never quite reach 10 V. No exponential curve ever really reaches its final value.

While watching the voltmeter, disconnect point A from the red connection of the power supply, allowing the capacitor to discharge through the meter. (Note: because the 100 k Ω is no longer part of this circuit, the discharge time will be longer than the charge time). Does the voltage seem to follow the expected discharge curve? Sketch the curve in your lab

Meter Effects

When switched to the 10 V DC setting, the BK meter is equivalent to 250 k Ω resistor hooked to the circuit. It is rated at 25 k Ω /V, to find its equivalent resistance you multiply the voltage setting by 25



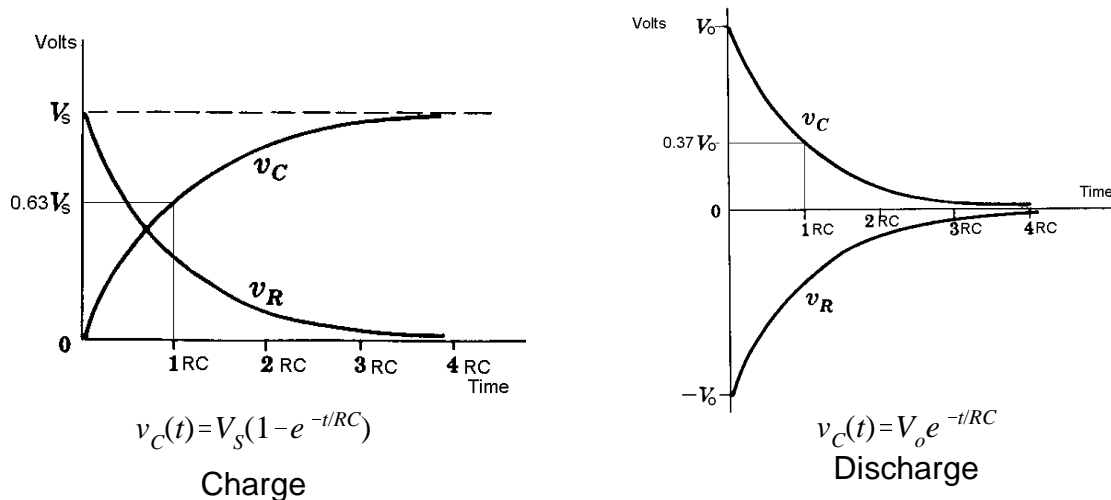
$$k\Omega/V \quad (10V \times 25 \text{ k}\Omega/V = 250 \text{ k}\Omega).$$

If you were to make a Thévenin equivalent circuit of the power supply, the 100 k Ω resistor, and the 250 k Ω internal resistance of the meter, it would look like a 10 V supply with a 71 k Ω resistor. Hence, the capacitor only charges to 10 V. If you change the range of the meter it will no longer look like a 250 k Ω resistor and the final capacitor voltage will be different.

notebook and comment. You just made current flow through the meter, even though it was not connected to any power supply or battery. Where did the required energy come from?

Measure time constant

The charge and discharge equations and curves for an RC circuit are shown below.



Where $v_C(t)$ is the capacitor voltage as a function of time, V_S is the source voltage during charging (The Thévenin voltage for us), and V_o is the initial voltage across the capacitor at the time that discharge begins.

For RC circuits the quantity $\tau = RC$ is defined as the “time constant”. When $t = \tau = RC$ during charging $v_C(\tau) = 0.63 V_{Th}$. When $t = \tau = RC$ during discharge $v_C(\tau) = 0.37 V_o$. Calculating τ for the charging circuit: $\tau = 71 \text{ k}\Omega \times 47 \mu\text{F} = 3.4\text{s}$. During discharge R is only the meter resistance. Calculating τ for the discharging circuit: $\tau = 250 \text{ k}\Omega \times 47 \mu\text{F} = 11.8\text{s}$.

Repeat the charge and discharge procedure above, only now use a clock, watch, or stopwatch to try and measure the time it takes for the capacitor to charge to 63% of 10 V. Yeah, I know this is tricky and not likely to produce an accurate measurement, but for now, it’s good enough. During discharge, measure the time it takes to discharge to 37% of the fully charged voltage. Compare your measured time constants to those calculated in the previous paragraph.

Quickly repeat this time constant measurement for two 47 μF capacitors in parallel and again for two 47 μF capacitors in series. Comment on series and parallel capacitors.

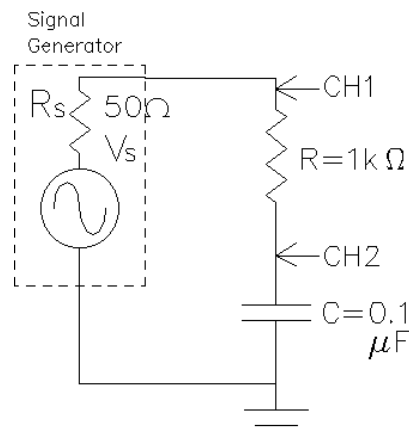
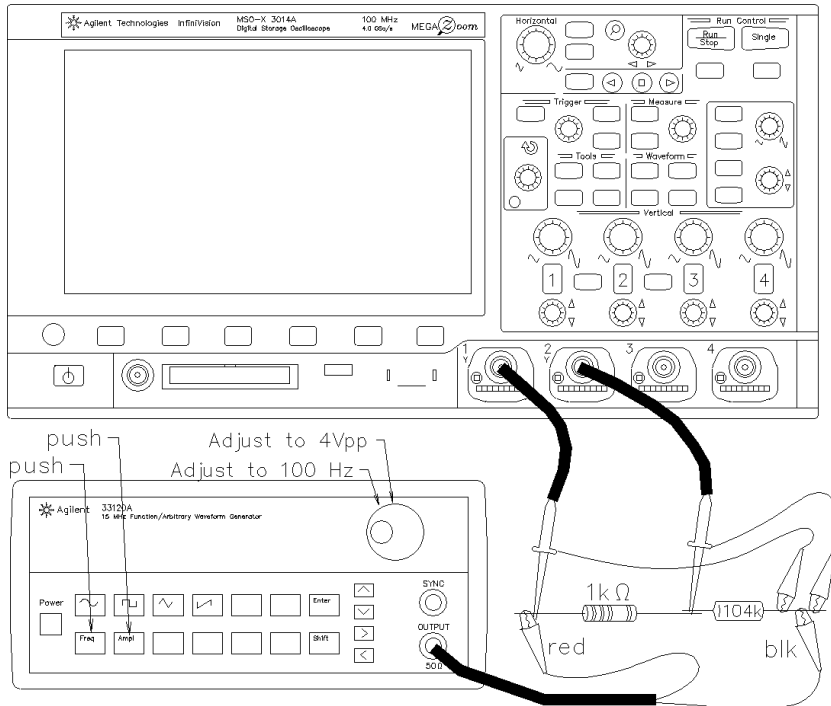
RC Filter

The previous sections you looked at the response of an RC circuit to a DC input voltage switched on and off. In this section you’ll see how this circuit behaves when the input voltage is steady-state AC rather than DC. It turns out that the response of the circuit depends on the frequency of the AC input voltage. This type of circuit is commonly called a *filter*. It *passes* some frequencies and *filters out* other frequencies.

Set up the scope and circuit as shown. This is a voltage divider for AC voltages. Use an Agilent or HP 33120A function generator as the signal generator. (It’s internal source

resistance R_s is shown on the schematic to remind you that it exists). Using the knob and arrow buttons, set the signal generator to $8 V_{pp}$ (Function generator may have to be set at half this, $4V_{pp}$) at about 100 Hz. (Because the scope screen is often 8 divisions high, a signal like $8V_{pp}$ that will fill the screen.)

Make sure that both scope channels are set to match the probe settings that you are using (1x or 10x). Measure the peak-to-peak voltage across the capacitor (CH2) at 100 Hz, 300 Hz, 1 kHz, 3 kHz, 10 kHz, 30 kHz, 100 kHz. Make a graph in your notebook to plot these V_{pp} measurements. If you divide your horizontal axis into 7 even divisions and label them with the 7 frequencies above, then you'll have a close approximation of a logarithmic scale for frequency. That's the way frequencies are normally plotted, on a log scale. Note: If you want to use log paper for your plot, or use a computer to make a log plot, that would be even better.

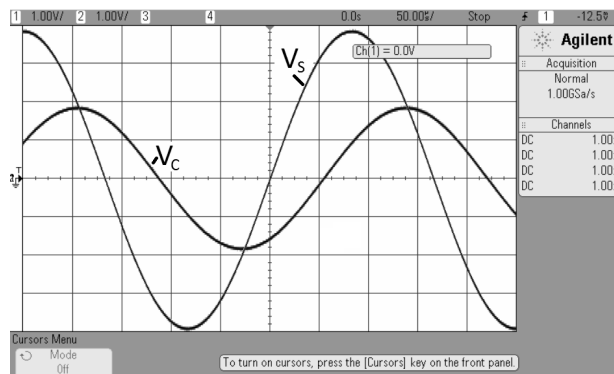


The calculations necessary to determine the theoretical capacitor and resistor voltages are shown in the appendix. Look at the resistor and capacitor peak-to-peak voltages at 3kHz. How can they add up to more than the peak-to-peak source voltage? Is this a violation of Kirchoff's voltage law? Plot the theoretical values (found in the appendix) on the plot you made above. Compare the two lines.

Observe the phase relationship of AC voltages and confirm KVL for these voltages

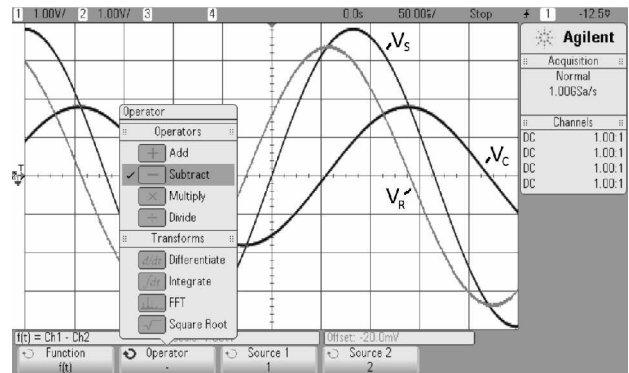
Set your signal generator back to 3 kHz. Turn on both scope channels and adjust both Volts/Div knobs to 1V/div (shown at the top of the scope screen).

Use the CH1 vertical position knob (right below the lighted "1" key) to move the tiny ground symbol on the left side of the screen to the center line of the screen. You can also use the little box in the upper-right part of the screen to help. Repeat for the CH2 position. Do the two

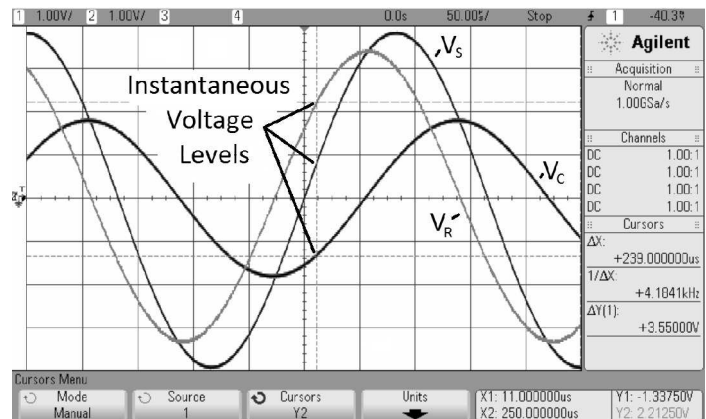


waveforms (V_S and V_C) peak at the same instant in time? If not, then you really can't add the peak-to-peak voltages. You *cannot* add the peaks if they don't happen at the same time! You can, however, add the instantaneous voltage levels and we will do that next.

Hit the "Math" key, then hit the "Operator" softkey and select "- Subtract". Now you should see a third, pink, trace on the screen. This trace shows the difference between the voltages of CH1 and CH2, which is the voltage across the resistor, V_R



Now you can measure the instantaneous level of all three voltages. I've shown that measurement at a cursor line just to the right of the center line of the scope. I'm using the cursors to help me make measurements (see the Y1 and Y2 at the bottom right of the screen. Make a set of three instantaneous voltage measurements at some time of your choice. Do the two instantaneous levels of V_C and V_R add up to the instantaneous level of V_S ? Check this on at least two other times on the scope. Does Kirchoff's voltage law still hold at each instant? Make a comment in your notebook about your findings.



Conclude Check-off as usual. Write a conclusion in your notebook. Make sure that you touch on each of the subjects in your objectives.

