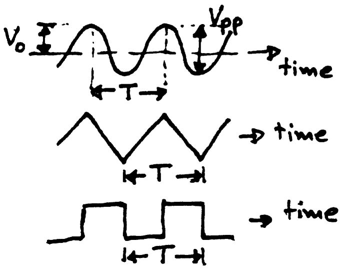
Physics 334
Notes for Lab 2 – Capacitors

January 19, 2009

Do the Lab Manual sections in the following order **2-1, 2-3, 2-4, 2-2, 2-5, 2-6, 2-8** *(Skip 2-7 and 2-9)* .

First, here's a review of some important points, courtesy of Professor Vilches:

Signals



Sine wave $V(t) = V_0 \sin \omega t = V_0 \sin 2\pi f t = V_0 \sin 2\pi \frac{t}{T}$

Triangular wave

Square wave

t = time ; T = period

V_0 = amplitude ; V_{pp} = peak to peak

f = frequency

The ratio between two periodic signals in decibels (dB) is given by

$$\text{Ratio (in dB)} = 10 \log_{10} \frac{P_1}{P_2} = \text{(for resistive loads)}\ 20 \log_{10} \frac{V_1}{V_2} ,$$

where V_1 and V_2 are the amplitudes of the signals 1 and 2, and P_1 and P_2 are the powers (energy/time) delivered by signals 1 and 2. For example, when we say that an output signal is 3dB attenuated with respect to the input signal, it means

$$-3\text{dB} = 20 \log_{10} \frac{V_{\text{out}}}{V_{\text{in}}} \quad \Longrightarrow \quad V_{\text{out}} = \frac{1}{\sqrt{2}} V_{\text{in}} \,\text{and}\, P_{\text{out}} = \frac{1}{2} P_{\text{in}}$$

Capacitors

As you'll remember in class, a capacitor is just a gizmo designed to hold a charge. Real capacitors come in a bewildering array of sizes, shapes, colors and electrical characteristics. Look on your computer motherboard or for that matter inside any electronic device, and you'll find capacitors spattered all over the place. The Splung website showed a nice sample of the variety with the following picture of some of the sizes and shapes available. Each has it's own application.

Typically, large cylindrical capacitors are used to store charge for power supplies and similar applications. These are often big rolled sheets of conductor separated electrically from each other in various ways including electrolytes, plastics and non conducting materials. Large capacitors tend to be of the variety called "Eletrolytic" capacitors. Use some caution when dealing with these "in the wild" – They can store a large, even deadly, charge. They should always be well and carefully discharged before working with them. You should encounter no such hazards this quarter in the lab, though. The smaller capacitors you'll use in lab, which typically take the shape of small discs, wafers, or even appear like shiny little chicklet candies, are usually ceramic or Tantalum capacitors.

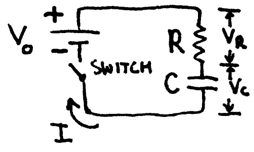
As with resistors, always be sure you have the right value of capacitor before constructing a circuit. The easiest way to do this is to read the value off the side. Most of the ones in the lab follow a simple numbering system.

Value in picoFarads = first two numbers * 10 ^(3rd number). So a capacitor labeled 104 would be 10 * 10,000 pF or 0.1 microFarad (A 1 Farad capacitor is a HUGE capacitor – A picoFarad is $10^{-12}F$) We'll usually use capacitors in the pico to micro Farad range. A reminder of the appropriate label for the capacitor you'll be using is included on the parts cabinets in many cases.

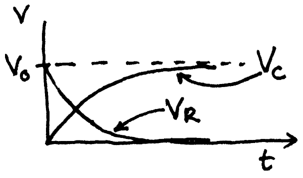
There are other ways that capacitors are labeled, but this is a common one you'll see in lab. See the Horowitz and Hayes lab manual if you're curious.

RC circuits

In the first circuit, when the capacitor is not charged and the switch is closed, the capacitor will charge.

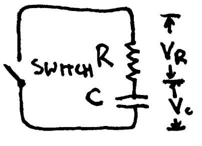


$$V_R = V_0 e^{-t/RC}$$
$$V_C = V_0(1 - e^{-t/RC})$$

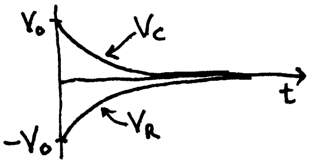


RC is the "time constant" of this circuit.

In the second circuit, if the capacitor is initially charged to potential V_0, then when the switch is closed, the capacitor will discharge.

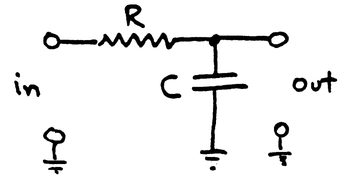


$$V_R = -V_0 e^{-t/RC}$$
$$V_c = V_0 e^{-t/RC}$$



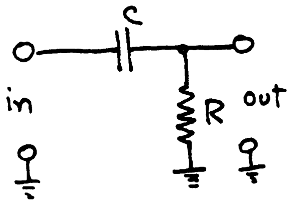
Instead of batteries and switches one can connect the RC circuit to a function generator with a square-wave output and study the figures above as a function of frequency. One can do the same with sine and triangle waves. This leads to the study of the two configurations below:

Integrator - Low pass filter



(one looks at V_c)

Differentiator- High Pass filter



(one looks at V_R)

For a sinusoidal input

The output (V_c) and input (V_{in}) signals are related by

$$V_c = \frac{1}{\left[1 + (\omega RC)^2\right]^{1/2}} V_{in}$$

The output (V_R) and input (V_{in}) signals are related by

$$V_R = \frac{\omega RC}{\left[1 + (\omega RC)^2\right]^{1/2}} V_{in}$$

So for both circuits $\omega_{3db} \cong \frac{1}{RC} = \frac{1}{\tau}$

But this circuit will let {Low Frequencies} through. (lower than $\frac{1}{\tau}$)

But this circuit will let {High Frequencies} through (higher than $\frac{1}{\tau}$)

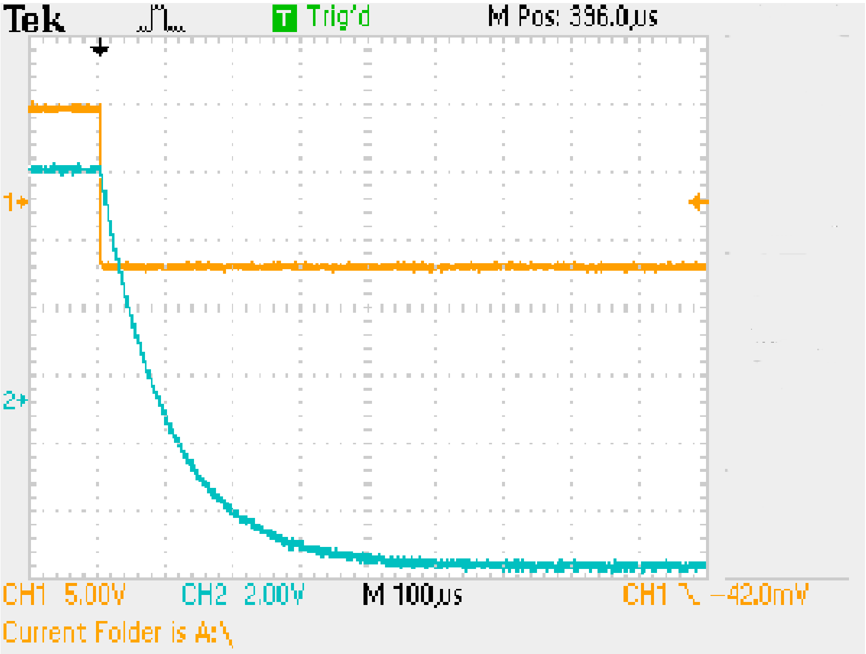
Lab Exercises

Before making measurements, if you are using a 10x scope probe, *make sure they have their compensation correctly set!* See pp. 62, 63 in the manual for a discussion of this. If you don't have the probe set right, your numbers will be off. Small screwdrivers to adjust your probe compensation can be found on the front desk if you need to make an adjustment. Please bring them back up to the front when you're done.

2-1. Use the same circuit for sections 2-1, 2-3, and 2-4. You may or may not have a yellow "mylar" cap. It's probabaly a brownish-orange or green ceramic one and labeled "103". You are supposed to both measure and calculate RC.

NOTE: **Our digital scopes do not have percent markings** that are present on most analog scopes, so ignore the information in the box. There is an easier way to find the drop to 37% with a digital scope.

- Attach both the input signal (via a BNC tee and an extra cable from the output of the generator) and the output signal to the scope on channels 1 and 2 respectively. This is often a good way to view your circuits – See what's "going in" on channel 1 and what's "coming out" on channel 2 and make sure both are what you expect.
- Set the scope to trigger on the *input* square wave, then under the TRIGGER menu choose a falling slope.
- Use the horizontal position knob to set the trigger point to the left side of the screen, at exactly large division from the extreme left.
- Adjust the amplitude of the generator and channel sensitivity to show a signal that takes up most of the vertical extent of the screen. Adjust the time/div knob to show a clearly visible exponential fall on the output signal. You should have something akin to the below should be on your screen.



Tek Trig'd M Pos: 396.0µs

CH1 5.00V CH2 2.00V M 100µs CH1 ╲ −42.0mV

Current Folder is A:\

- Press the CURSORS menu button and select horizontal lines. Then position one cursor at the top, right at the beginning of the falling signal and the other at the bottom, where the signal reaches the other extreme.

- Read off the difference in voltage between the cursors: The "Delta".
- Calculate 37% of the delta and then move the upper cursor down so that it is at a value giving this 37% delta.
- Read off the horizontal coordinate where this cursor crosses the signal trace, and compare it to the horzontal point of the trigger. The difference should be equal to RC.

When you vary the frequency of the square wave, note how it looks as if you are simply "chopping" the charge/discharge curves off, not changing their shape.

2-3. You may need to use a lower frequency than 100kHz to see much. Answer the impedance question without a calculation, but with a brief discussion. Assume no load on the output. Hint on the triangle wave question: it is *not* a sine wave. What is the integral of a line ($y = ax + b$)?

2-4. Even though the diagram calls for a 15k resistor, you can use the 10k already there.

Hint on measuring the f_{3dB} point: Use the MEASURE menu to set up a voltage (peak-to-peak) measurements on both the input and output signal. The f_{3dB} frequency is the frequency when the ratio of the output voltage to the input voltage is 0.71. It is easiest to dial this in if you set the generator amplitude to give you 10V peak-to-peak input. You can also use the scope to measure the frequency of the input.

Don't spend too much time on measuring phase shifts; mainly look for the qualitative behavior. Ignore the "suggestion" box; Our scopes do not have a variable sweep rate. But again, the cursors are helpful here. If you use the vertical cursors, you can find the ratio of the time between the input and output peak voltages and compare that to the time for a full period of the input waveform. The ratio of these multiplied by 360 gives the phase shift in degrees.

Make a table of the attenuation figures, with a column for the frequencies, a column for the amplitude relative to that at f_{3dB} and then a column for the *dB attenuation* relative to that at f_{3dB}

Ignore the box on "Sweeping Frequencies" unless you have enough time.

2-2. If you use the x10 probe to measure the output, you may need to change the 100Ω resistor to something bigger, like 1k. The signal is pretty weak. "Does the output make sense" means "ask yourself what the derivative of a square wave should look like." You may see "glitches" on your sine wave derivative; that's because the generators you are using don't make particularly good sine waves.

Don't forget to answer the impedance questions.

2-5. See advice for exercise 2-4 on measuring f_{3dB} and phase shifts.

2-6. You may find it helpful to trigger the scope on "AC Line" (press the TRIG MENU button and then use the "Source" softkey) to make a stable trace.

To "count octaves" means to double the frequency, i.e., 60 Hz, 120 Hz, 240 Hz, etc., until you reach (approximately) the f_{3dB} point. Well below this point, the filter attenuates 6dB/octave.

2-8. Draw labeled pictures of the waveforms you see at the input of (A), the output of (A) and the output of (B), including the DC part. (Make sure you don't have your scope input set to "AC"! Why?)

To calculate the low-frequency limit of the blocking circuit, replace the resistor network in (A) with its Thévenin equivalent.

You can use any two plugs on the transformer to make this circuit. *But be sure that you ground or fix the voltage of ONLY ONE of them or you are inviting the wrath of a "smoke genie".* Remember, the transformer behaves just like a battery (that changes it's output voltage) or your power supply. What we mean by this is that the transformer is a floating supply, so you can attach ANY ONE of the points to a fixed voltage. After you have done so, the other plugs (transformer "taps") have a fixed relationship to the grounded point.