Lab 2: Capacitors

Reading:	Chapter 1.12 – 1.21, pp. 20-40; omit "Power in reactive circuits", pp. 33-35. Appendix B (if you need it). **Warning:** This is by far the most mathematical portion of the course. Don't panic. Even if you don't understand the math, you'll be able to understand the rest of the book. Student Manual note on reading capacitor values (Manual, pp. 51-53)
Problems:	Problems in text. Additional Exercises 3-6.

ASAP2016 :
These are readings from Horowitz and Hill, "Art of Electronics", 2nd ed. Don't worry about them.

2-1 *RC* Circuit

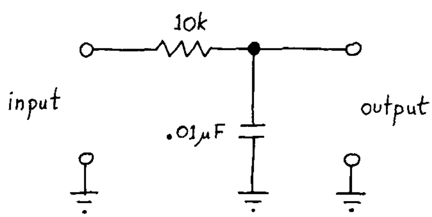


Figure L2.1: *RC* Circuit: step response

Verify that the *RC* circuit behaves in the time domain as described in Text sec. 1.13. In particular, construct the circuit above. Use a mylar capacitor (yellow tubular package, with one lead sticking out each end: "axial leads"). Drive the circuit with a 500Hz square wave, and look at the output. Be sure to use the scope's *DC* input setting. (Remember the warning about the AC setting, last time?)

Measure the time constant by determining the time for the output to drop to 37%. Does it equal the product ***RC***?

> *Suggestion:* The *percent* markings over at the left edge of the scope screen are made-to-order for this task: put the foot of the square wave on 0%, the top on 100%. Then crank up the sweep rate so that you use most of the screen for the fall from 100% to around 37%.

Measure the time to climb from 0% to 63%. Is it the same as the time to fall to 37%? (If not, something is amiss in your way of taking these readings!)

Try varying the frequency of the square wave.

2-2 Differentiator

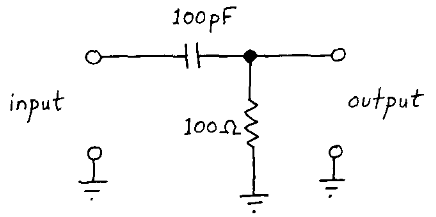


Figure L2.2: *RC* differentiator

Construct the *RC* differentiator shown above. Drive it with a square wave at 100kHz, using the function generator with its attenuator set to 20dB. Does the output make sense? Try a 100kHz triangle wave. Try a sine.

Input Impedance

Here's your first chance to try getting used to quick *worst-case* impedance calculations, rather than exact and frequency-dependent calculations (which often are almost useless).

- What is the impedance presented to the signal generator by the circuit (assume no load at the circuit's output) at f = 0?
- At infinite frequency?

Questions like this become important when the signal source is less ideal than the function generators you are using.

2-3 Integrator

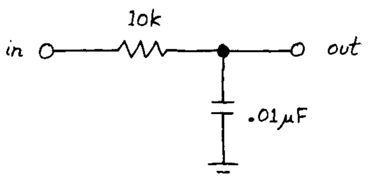


Figure L2.3: *RC* integrator

Construct the integrator shown above. Drive it with a 100kHz square wave at maximum output level (attenuator set at 0dB).

What is the input impedance at dc? At infinite frequency? Drive it with a triangle wave; what is the output waveform called? (Doesn't this circuit seem clever? Doesn't it remember its elementary calculus better than you do—or at least faster?)

To expose this as only an *approximate* or conditional integrator, try dropping the input frequency. Are we violating the stated condition (sec. 1.15):

$$v_{out} \ll v_{in}?$$

The differentiator is similarly approximate, and fails unless (sec. 1.14):

$$dV_{out}/dt \ll dV_{in}/dt$$

In a differentiator, *RC* too large tends to violate this restriction. If you are extra zealous you may want to look again at the differentiator of experiment 2-2, but this time increasing *RC* by a factor of, say, 1000. The "derivative" of the square wave gets ugly, and this will not surprise you; the derivative of the triangle looks odd in a less obvious way.

When we meet *operational amplifiers* in Chapter 3, we will see how to make "perfect" differentiators and integrators—those that let us lift the restrictions we have imposed on these *RC* versions.

2-4 Low-pass Filter

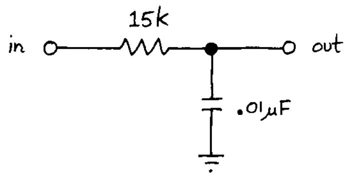


Figure L2.4: *RC* low-pass filter

Construct the low-pass filter shown above.

Aside: "Integrator" versus "Low-pass Filter"

'Wait a minute!,' you may be protesting, 'Didn't I just build this circuit?' Yes, you did. Then why do it again? We expect that you will gradually divine the answer to that question as you work your way through this experiment. One of the two experiments might be called a special case of the other. When you finish, try to determine which is which.)

What do you calculate to be the filter's –3dB frequency? Drive the circuit with a sine wave, sweeping over a large frequency range, to observe its low-pass property; the 1kHz and 10kHz ranges should be most useful.

Find f_{-3dB} *experimentally*: measure the frequency at which the filter attenuates by 3dB (v_{out} down to 70.7% of full amplitude).

Note: henceforth we will refer to "the 3dB point" and "f_{3dB}," henceforth, not to the *minus* 3dB point, or f_{-3dB}. This usage is confusing but conventional; you might as well start getting used to it.

What is the limiting phase shift, both at very low frequencies and at very high frequencies?

Suggestion:

As you measure phase shift, use the function generator's SYNC or TTL output to drive the scope's External Trigger. That will define the input phase cleanly. Then use the scope's *variable* sweep rate so as to make a full period of the input waveform use exactly 8 divisions (or centimeters). The output signal, viewed at the same time, should reveal its phase shift readily.

Check to see if the low-pass filter attenuates 6dB/octave for frequencies well above the –3dB point; in particular, measure the output at 10 and 20 times f_{3dB}. While you're at it, look at phase shift vs frequency: What is the phase shift for

$f \ll f_{3dB}$,
$f = f_{3dB}$,
$f \gg f_{3dB}$?

Finally, measure the attenuation at $f = 2f_{3dB}$ and write down the attenuation figures at $f = 2f_{3dB}$, $f = 4f_{3dB}$ and $f = 10f_{3dB}$ for later use: in section 2-9, below, we will compare this filter against one that shows a steeper *rolloff*.

> *Sweeping Frequencies*
>
> This circuit is a good one to look at with the function generator's ***sweep*** feature. This will let your scope draw you a plot of amplitude versus *frequency* instead of amplitude versus *time* as usual. If you have a little extra time, we recommend this exercise. If you feel pressed for time, save this task for next time, when the LC resonant circuit offers you another good target for sweeping.
>
> To generate such a display of v_{out} versus frequency, let the generator's *ramp* output drive the scope's horizontal deflection, with the scope in "*X-Y*" mode: in *X-Y*, the scope ignores its internal horizontal deflection ramp (or "timebase") and instead lets the input labeled "X" determine the spot's horizontal position.
>
> The function generator's **ramp** time control now will determine sweep rate. Keep the ramp *slow*: a slow ramp produces a scope image that is annoyingly intermittent, but gives the truest, prettiest picture, since the slow ramp allows more cycles in a given frequency range than are permitted by a faster ramp.

2-5 High-pass Filter

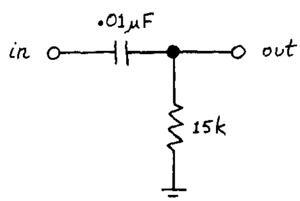


Figure L2.5: *RC* high-pass filter

Construct a high-pass filter with the components that you used for the low-pass. Where is this circuit's 3dB point? Check out how the circuit treats sine waves: Check to see if the output amplitude at low frequencies (well below the –3dB point) is proportional to frequency. What is the limiting phase shift, both at very low frequencies and at very high frequencies?

2-6 Filter Application I: Garbage Detector

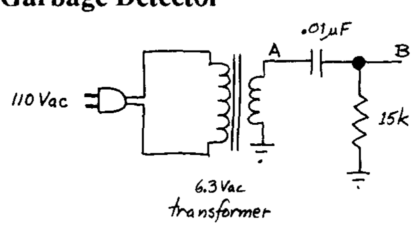


Figure L2.6: High-pass filter applied to the 60Hz ac power

The circuit above will let you see the "garbage" on the 110-volt power line. First look at the output of the transformer, at **A**. It should look more or less like a classical sine wave. (The transformer, incidentally, serves two purposes — it reduces the 110Vac to a more

Diode Response to AC

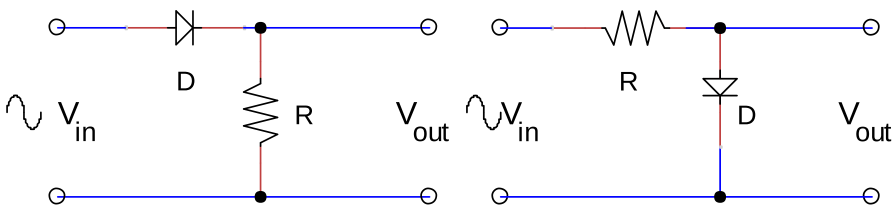


FIGURE 1A FIGURE 1B

Part 1.1: Half-wave Rectifier

Drive the circuits of Figure 1A and 1B with a 10V peak (= $20V_{pp}$,or peak-to-peak), 1 kHz sine wave. Use a BNC tee at the function generator to split the signal so that one coaxial cable provides input to the circuit while the other cable allows you to view that signal on the first channel of the scope.

Use a 1N914 or 1N4148 diode and R = 1kΩ (what is the function of R?). Look at both the voltage V_r across the resistor (Fig 1A) and the voltage V_d across the diode (Figure 1B) using the oscilloscope. Acquire these waveforms into the computer.

Note that one side of an oscilloscope is ALWAYS connected to ground, so you can't measure a ΔV directly unless one side of the component is already at ground, as with the resistor in Fig 1A ($V_R = V_{out}$). For V_d swap the location of the two components, resistor and diode, and then read V_d directly with the scope.

a. Submit: Show one period of each of $V_d(t)$ and $V_R(t)$ on the same plot. Note important voltages in detail: the peak voltages and the behavior around the points where the diode turns on and off.
b. Confirm that Kirchhoff's voltage law is always satisfied by adding the two waveforms. You may need to align the waveforms, as the scope might trigger differently for each measurement.
c. From your V_R waveform determine the peak current in the circuit. Compare with Prelab calculation.

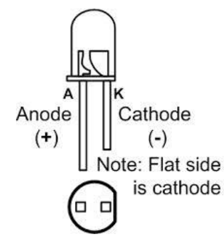
Now replace the diode with a 1N4733 zener diode, with a V_z = 5.1V, and acquire a waveform of the diode voltage.

d. Submit your waveform. On this plot, show the zener voltage V_z and confirm that it meets the spec of V_z = 5.1V . Also confirm that the forward voltage drop, V_d = 0.6

Part 1.2: LEDs

Repeat the circuit of Fig 1B using a clear Really Bright Red LED. .

Care and feeding of LEDs: As with other diodes, you should never connect and LED directly across a voltage source. They should always be used in series with a current-limiting resistor, or more generally, powered by a current source. The sketch to the right shows how to identify the anode(+) and cathode(-) of an LED. The leads usually, but not always, are different lengths. If you can't figure out which end is which, use the diode function on your DMM to determine this.



www.smex.net.au/reference/leds01.php

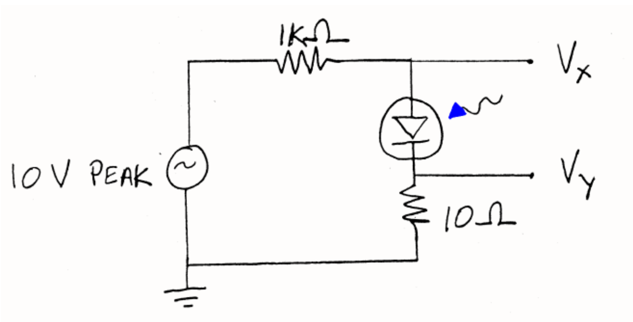
a. Acquire one cycle of the waveform, and indicate V_d, the forward voltage drop.
b. What is the peak current seen by the LED (measured from your plot)?
c. To get the LED to turn on even brighter, calculate the value of R (instead of 1k) to get approximately 60 mA peak through the LED using the 10V peak ($20V_{pp}$) sine wave input. The LED housing is a lens so you need to look down the axis of the housing.

d. Use this value of R in the circuit and repeat steps a and b.

e. Estimate the "true" wavelength of your red LED by comparing your V_d to the diode drops of a set of calibrated colored LEDs (plot of diode drops and wavelengths is on Coursework.

Test your scopesmanship by building this circuit:

Use an LED for the diode.



I
View on the cope in x-y mode using the voltages shown. You will get a diode i-V curve