# LABORATORY 6
RC Circuits, Time Constants, and Oscilloscopes

Capacitor Circuits

In this lab, we will learn about time constants of RC circuits. We will also learn how to measure time constants using the oscilloscopes in the lab.

-
-

We will work with the circuit shown below. The purpose of the R_s resistor is to prevent a surge of current into the capacitor when the switch is closed. We will use $C = 1\mu F$ and $V_s = 12$ volts.
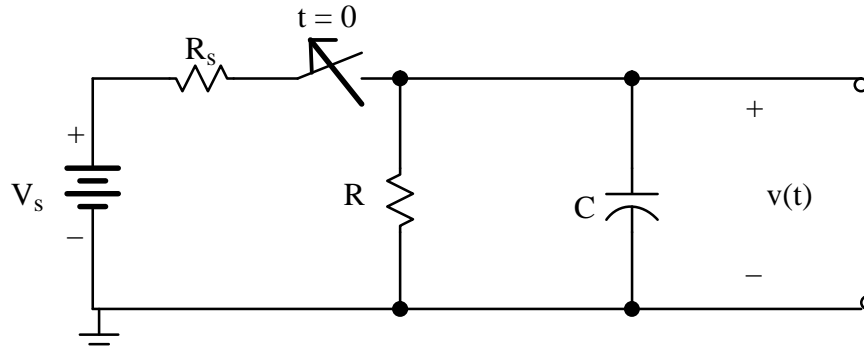
Questions: Please answer the following questions (you will work out the details for homework).

1. If the switch has been closed for a long time so that the capacitor is fully charged, what is the voltage v(t) across the capacitor? (Hint: No current flows into the capacitor when it is charged, so does the rest of the circuit look familiar?)

2. Suppose that the switch opens at time t = 0 seconds. Analyze the circuit and find an equation describing the voltage v(t). (I'll help you with this in lab.)

3. What is the *time constant* for this circuit, in terms of R_s, R, and C? Make a sketch of v(t), indicating the value of v(t) after 1, 2, 3, 4, and 5 time constants.

4. You should be able to see from your plot where the following two facts and "rules of thumb" about time constants come from:

- The response decays to 36.8% of its original value after one time constant.

- The response has decayed to "zero" after 5 time constants, since the amplitude is less than 1% of the original value.

5. What value of R should be used to obtain a time constant of 1 msec?

More Questions: (We'll work out the details for homework next week.)
(Hint: This is a first–order circuit!)

1. Suppose that the switch has been opened for a long time, so that the capacitor is fully discharged. What is the voltage v(t)?

2. Now suppose that the switch is *closed* at time t = 0. How do you think v(t) will change with time? (Make an educated guess!)

3. What is the time constant for the charging capacitor? Is it different from the time constant of the discharging capacitor considered above? (Hint: Thevenin.)

4. What value does v(t) approach after a long time? Your answer should agree with question 1 above!

Measurements

Please choose R to achieve a time constant of approximately 1 msec, and choose R_s so that most of the 12 volts appears across the R–C parallel combination when the switch is closed. Consider the case of *opening* the switch at time t = 0. We will use the oscilloscope to *measure* the time constant of the circuit.

Please set up the circuit from page 1 on your protoboard. The lab assistant and I will help you to use the scopes in order to measure the time constant. Record notes in your lab notebook so you can refer to them in the future when we use the scopes.

An outline of the procedure that you can use to measure the time constant is as follows. The scopes are *digital* instruments, so they can be programmed to perform a lot of useful functions. The steps below allow a single "trace" of the capacitor discharge to be displayed on the oscilloscope. Measurements can then be performed on the trace.

1. Adjust the horizontal (time) axis scaling and the vertical (voltage) scaling to values that are appropriate for the value of V_s and the time constant.

2. Open and close the switch a few times. Make sure the v(t) you observe on the scope matches the sketch you made earlier.

3. Use the MODE key on the scope to set it to record a *single* trace when you open the switch. Also set the scope to *trigger* at a level just below v(0), and set the scope to trigger on a negative slope.

4. Use the STOP, RUN, and ERASE keys to record a trace of v(t) after you open the switch.

5. Use the *cursors* on the oscilloscope screen to measure and compute the time constant. If you use the "%" option in a clever way, then you can get the scope to do all the computations for you in checking the time constant.

Below are some specific activities and measurements to make.

1. Measure the time constant of the circuit using the oscilloscope. Compare the measured value with the expected value based on the R and C component values.

2. Modify the circuit to achieve a time constant on the order of one second. Use the oscilloscope to verify that the time constant is indeed about one second.

3. Consider the case in which the switch is initially opened and then closed to charge the capacitor. Use the oscilloscope to capture one trace of the charging capacitor. Note that the procedure needs to be modified slightly to capture this trace. Compare the measured time constant with the expected value that you determined in the "More Questions" section abov.e Be sure to record your measured time constant.

LABORATORY 6a

Op Amp Clock Circuit (If you have time)

In this lab we will understand and build an "astable multivibrator" or clock circuit using a 741 op amp. The circuit output will be a square wave, and the period of the square wave can be adjusted by changing the resistor and capacitor values in the circuit.

Think about how circuit (b) will operate. Please be sure that you understand why the op amp output will oscillate between values of approximately +10 volts and –10 volts. Note that the "three zeros" of ideal op amp operation (with feedback) are *not* valid for this circuit!
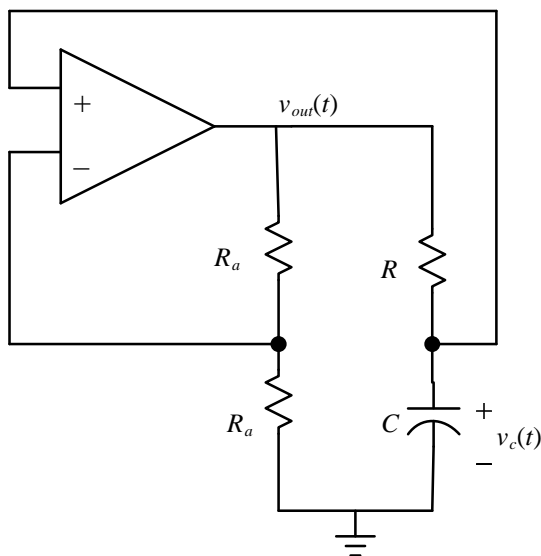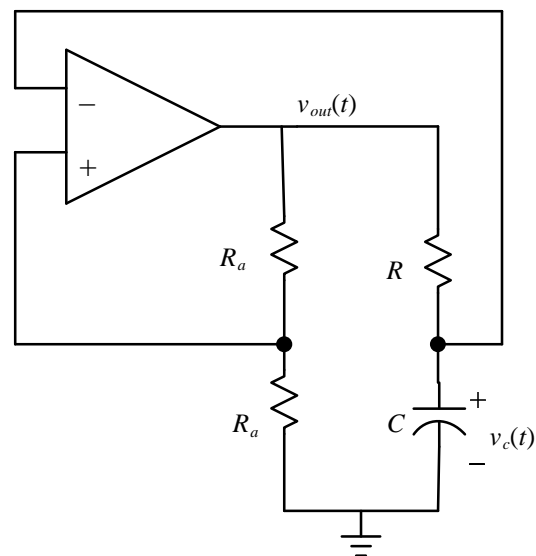
(a)   (b)

Question: What does circuit (a) do? Will it oscillate? Does it operate differently than circuit (b)?

Lab Activities:

Please sketch on a single plot the capacitor voltage $v_c(t)$ and the op amp output voltage $v_{out}(t)$ versus time for circuit (b). How is the period of the wave related to the values of R and C? (Do analysis!!)

What value should you choose for the resistor R_a? Hint: Keep the op amp output current < 10 mA.

If R is a potentiometer that varies from 0 ohms to 100 k ohms, what value of C should you use to produce a clock frequency as low as 1000 hertz? How can you modify the circuit to produce clock frequencies in the range from 100 to 1000 hertz?

Set up and test your circuit. Demonstrate how the frequency of your clock circuit varies as you change the potentiometer. Observe both $v_c(t)$ and $v_{out}(t)$ on the oscilloscope, and compare with analysis.

Another question: What if the pair of resistors with value R_a are replaced by resistors with values that are *not* identical? Can you make a *triangle wave* generation circuit? Try it!!