October 19, 2009 | Due October 26, 2009, at the start of lab, 1pm

EGR 220: Engineering Circuit Theory
Lab 4: RC Circuits

Objective

The objective of this lab is to become familiar with the behavior of capacitors, and of first order circuits consisting of one capacitor and one resistor. The natural, forced and step responses will be observed and analyzed.

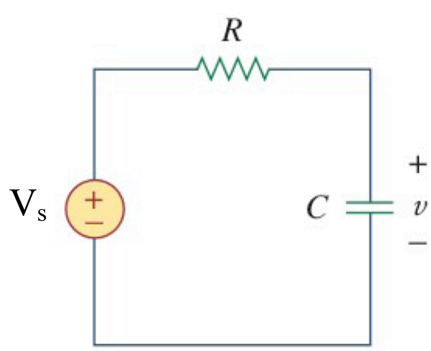
First Order Circuit Overview

The RC circuits below are your introduction to time dependent, or "dynamic," electrical systems. During this lab you will observe the capacitor's effect on circuit performance by observing the voltage across a capacitor as a function of time, as the source voltage changes. Both constant and time-varying voltage sources will be considered.

Observing the Behavior of RC Circuits

1.0 Transient Response of an RC Circuit

Build the circuit below using a 10MΩ resistor and a 10 μF capacitor. Set the dc power supply to 10V, and use the *output on/off* switch to toggle between supplying energy to the circuit an allowing the circuit to discharge *"source free"* (*i.e.,* toggling between having a 'closed' and 'open' circuit at the power supply). Connect the digital multi-meter to measure the voltage across the capacitor $v_c(t)$ (labeled simply 'v' in the circuit below).



1.1 Charging the Capacitor – Forced response

- With the circuit open, measure the voltage across the capacitor, $v_c(t)$, using the digital multimeter.
    - Verify that the voltage across the capacitor is zero when no voltage is supplied to the circuit. If the value is not zero, discharge the capacitor by momentarily shorting it with a piece of wire.
- Turn the voltage source on and record the capacitor voltage as a function of time.
    - ***prelab***: What is the system's theoretical time constant?
        - Recall that the digital multimeter has an internal resistance of 10MΩ.

- *prelab*: Use this τ to determine a reasonable duration for your test (the expectation of how long your measurements will take).
- ***prelab***: How do you know when you are done? *i.e.,* How do you know when you can stop taking measurements of $v_c(t)$ and time?
  - Let t=0 correspond to the time the voltage was applied to the circuit.
  - It might help to look at page 256, table 7.1, and think about how close to zero or V_{max} you want to get before you consider the experiment to be "done."
- If you make a mistake and need to start over, be sure to discharge the capacitor so $v_c(t)$ is zero at the start of your experiment.

1.2 Discharging the Capacitor – Natural, or "Source Free Response"

- Turn the voltage source off and repeat the steps above to record the capacitor voltage as a function of time.
  - ***prelab:*** Answer the same three questions as above, which might have the same answers (note that the time "t=0" is now the moment you removed V_s).

1.3 Results

- Plot the results of V_c as a function of time for parts 1.1 and 1.2.
- Estimate the time constant from the plots, label the time constant on the plots, and compare the estimates to your (theoretical) calculated, or predicted, values.
- In part 1.1, is the final value of V_c equal to V_s? Why or why not?

2.0 Step Response of an RC Circuit

Reduce the time constant of your circuit by changing to a resistor with R = 10kΩ. With the small time constant, the voltage across the capacitor will be changing too quickly to observe with the digital multi-meter – therefore, you will use the oscilloscope to observe the results for this experiment. Use a square wave from the function generator for $V_s(t)$. Using channels 1 and 2 on the scope, connect one to observe $V_s(t)$ and the other to observe $v_c(t)$. (Note that this experiment also addresses the transient response of an RC circuit, as did part 1 above, with emphasis on the step response for part 2.)

- ***prelab***: Calculate the predicted time constant for this circuit.
- ***prelab***: Sketch the expected output waveform (*i.e.,* $v_c(t)$) along with the square wave input waveform ($V_s(t)$) when the input frequency is 10Hz and when it is 0.5Hz (see below), and be ready to discuss why these are the waveforms you expect.
  - This does not need to be 'correct,' but does need to be **completed** for the prelab.
  - Simply draw your expectation, and be ready to discuss why these are your expectations. One of the best ways to learn is to identify any misconceptions you may have, and then learn from them.
- For the voltage source, use a square wave from the function generator of amplitude 1.0V.
- Begin with a frequency of 10Hz, and observe both the input and output voltages on the scope. …*Before* focusing too much on this display, play with other frequencies as outlined next…
  - Be patient. This is an opportunity to become more familiar with using the scope.

- … Repeat this experiment with frequencies of 8Hz, 6Hz, 4Hz, 2Hz, 1Hz and finally 0.5Hz.
    - You should set the x-axis on the scope (time axis) so that 2 to 4 (or so) periods of the input square wave are displayed on the scope.
    - Note that you will need to change the scale for the x-axis on the scope as you change the frequency.
- Now go back to 10Hz and gradually decrease the frequency again, watching the change in the waveform of $v_c(t)$ as you change the frequency for $V_s(t)$.
- Explain the waveforms you observe for $v_c(t)$ and the relationship between them for the different $V_s(t)$ frequencies.

Results
- Sketch the waveforms for $v_c(t)$ when V_s is 10Hz, 0.5Hz, and a frequency or two in between
- Why does the output waveform ($v_c(t)$) not look like input waveform ($V_s(t)$)?
- How could the values of R and C be changed to make the output look more like the input?

NOT TO HAND IN:
Only if you want to play more: Response of an RC Circuit to a Sinusoidal Input

For this part, use a 1kΩ resistor and a 1 μF capacitor.

- Use the function generator to create a sinusoidal V_s with amplitude of 1.0 V.
- Use values of frequency ranging from 50 to 300Hz in increments of 50Hz, as well as 500Hz and 1kHz.
- Using the oscilloscope, observe the amplitude of the output, along with the 1.0 V amplitude input.
- Also observe the phase shift between the input and output signals

Results to think about
- Think about the ratio of the output amplitude (capacitor voltage) to the input amplitude vs. the input frequency.
- What happens to low frequency sine waves when they pass through the system (the RC circuit)?
- What happens to the higher frequency sinusoids?
- This circuit is a first-order filter. What kind of filter is it (high-pass, low-pass or band-pass)?
- For the phase between the input and output signals, does the phase difference increase or decrease as the input frequency increases?