6
First-Order RC and RL Circuits

OBJECTIVES:

To explore the concept of time constant and rise/fall times in simple RC and RL circuits, how to use the oscilloscope to make such measurements, and introduce the idea of differentiator, integrator, and frequency filtering circuits.

PROCEDURE:

Parts List:

(1) 0.01 μF capacitor
(1) 10mH inductor
(1) Resistor decade box
plus cables and clip leads for circuit construction.

1. RC Circuit

Build the RC circuit shown below, using the decade box for the resistor, R, and a 0.01μF capacitor. Note that the 50Ω resistor is just shown for reference - it is actually inside the function generator. You can verify the capacitor value using the impedance meter in the lab. Drive the circuit with a function generator, initially set to a 1kHz square wave, with an amplitude of 2 Volts peak-to-peak. Be sure that the DC offset switch on the function generator is off (pushed in) and that the vertical scope inputs are DC coupled (not AC coupled). It will be convenient to view the input and output signals simultaneously on the oscilloscope screen, which is accomplished by the connections shown below. Set the vertical positions so that the 0 volt (ground) level is the center of the screen for both channels.

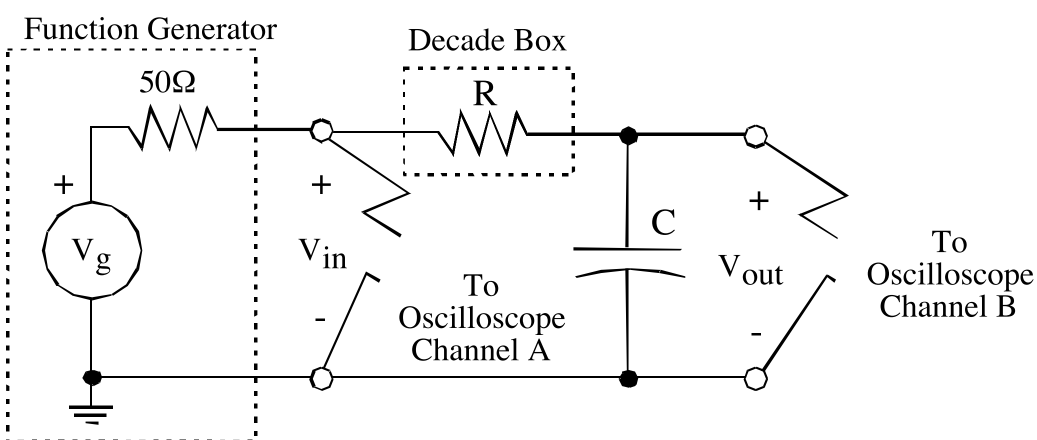


Fig 1: First-order RC circuit for time-constant experiments

(a) **RC Time Constant and Rise/Fall Time**

Starting with R=1kΩ, observe and record the input and output waveforms. They should be similar. Increase the resistance to 5kΩ, and record the resulting waveforms in your notebook. Calculate the time constant from this waveform, and compare with the theoretical prediction. Physically, the voltage across the capacitor rises more slowly as the resistance is increased because the flow of charge (ie. current) is reduced.

Another figure of merit commonly used in such cases is the rise-time (τ_r) or fall-time (τ_f) , defined as the time it takes for the signal to progress from 10% to 90% of its final value. From the expression for the output voltage as a function of time, show that the rise time can be expressed as

$$\tau_{10\text{ - }90\%} = \tau_r = \tau_f = 2.2 \text{ RC}.$$

And verify this experimentally. The rise time can be conveniently measured by adjusting the vertical sensitivity so that the waveform fills the screen, as there are two dotted horizontal lines which mark the 10% and 90% levels.

(b) **The Circuit as an Integrator**

Now increase the resistor to 20kΩ. The time constant is now longer than the duration of the square pulse, so the output waveform does not quite reach its previous peak value. Increase the resistance again to 100kΩ, and record the resulting waveform in your notebook. You will probably have to adjust the vertical scale, since the peak amplitude will continue to shrink. Can you see what is happening? The output is now approximately a triangular wave, which is the integral of the input signal. Verify that the circuit is acting as an integrator by changing the input waveform to triangular and sine waves, making plots of both in your notebook.

Change the scope from YT mode to XY mode (using the Display menu) and sketch the resulting figure. Can you explain the shape of this figure? Return to YT mode.

Note that we have chosen to adjust the value of the resistance to observe the integrator behavior. We could alternatively keep the resistor fixed and change the frequency. At approximately what frequency will the circuit behave as an integrator for a resistor value of 10kΩ instead of 100kΩ? Verify your answer experimentally.

(c) **The Circuit as a Low-Pass Filter**

Although we will not discuss filters at length in ECE 2A, you can see that the simple RC circuit of figure 1 is a type of filter called a *low-pass.* It is so called because low frequency signals will pass through, but high frequency signals get strongly attenuated. This kind of circuit is used in stereo speakers to direct low frequency audio to the big "woofers". Plot the output voltage as a function of input frequency for a sine wave excitation over the range 100Hz to 100kHz, for R=5kΩ. Plot the result on a log scale in frequency.

(d) **An RC Differentiator Circuit**
By simply switching the placement of the capacitor and resistor as shown in figure 2, the operation of the circuit can be changed significantly. Build this circuit, and drive it with a 1kHz square wave using a 5kΩ resistor. Make plots of the resulting waveforms. Can you see that the circuit is acting as a differentiator? Prove this by changing the excitation to triangular and sine waves, making plots for both cases. Using the square wave signal, zoom in on one of the transitions by adjusting the time base. Can you identify any characteristic property of the network from the shape of this signal?

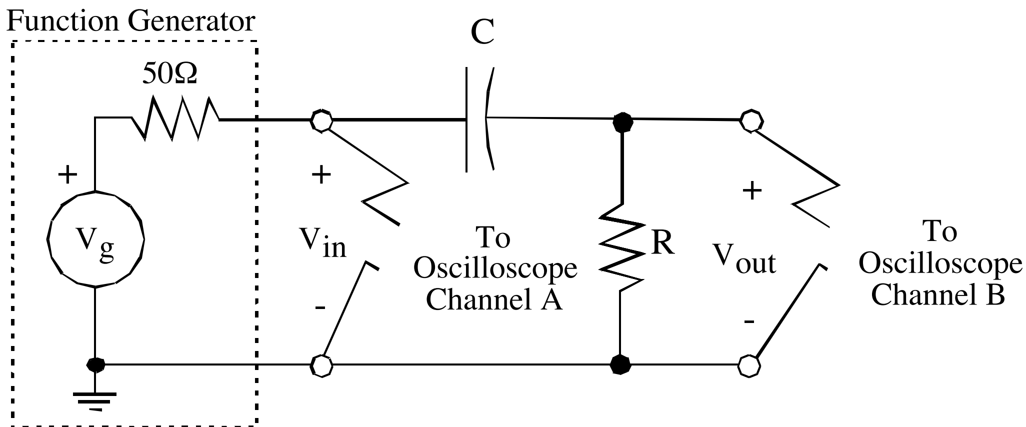


Fig 2: Differentiator circuit

2. RL Circuits

The RL circuit is very similar to the RC circuit in terms of the mathematical form of the response, despite the different physical mechanisms involved. Therefore, we will not examine this case quite as thoroughly.

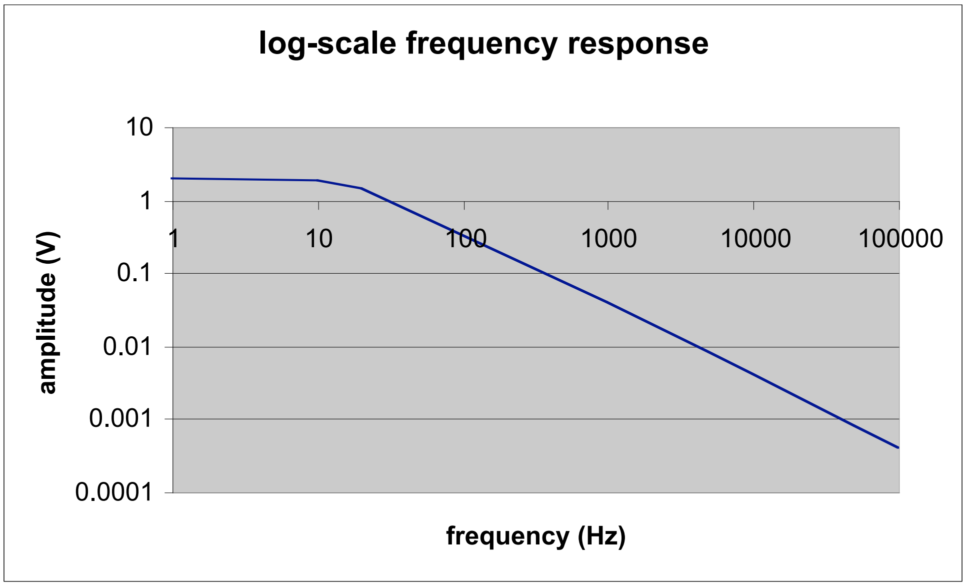
(a) **RL time constant**
Build the circuit of figure 2, but replace the capacitor with a 10mH inductor. Drive the circuit with a 1kHz square wave, using a 100Ω resistor, and measure the time constant. Compare with the theoretical prediction. Can you observe the influence of the 50Ω internal generator resistance? Is there evidence of additional resistance? Make plots of your waveforms.

(b) **An RL differentiator/High-Pass Filter**
Build the circuit of figure 1, but replace the capacitor with a 10mH inductor. Drive the circuit with a 1kHz square wave, using a 1kΩ resistor, and verify the action of this circuit as in part 1d. This circuit also functions as a *high-pass* filter, because only high frequency signals go through without attenuation. Show that this is true by making a frequency response plot for sine-wave excitation as in part 1c.

3. Notes on the Report

It is important that you derive the mathematics used in this lab yourself, and therefore you should include these derivations in your report. These include the relationship between rise-time and time constant, plus the basic relationship between input and output signals for the circuit of figure 1. In your report, you should (wherever possible) compare the theory and experiment, and explain why the circuits behave as they do for different combinations of resistance (time constant) and frequency.

If you don't have a more powerful math program, a convenient way to plot data on a log scale is to create an X-Y plot with Excel, using frequency as the X axis variable. After you've created the plot, use the "format axis" function, and under "scale" select logarithmic scale. A sample is shown here:



(Note that there is a great *Plotting with Excel* tutorial on the course website)

4. Discussion Question

The time constant you found in Part 2, step (a) should have differed noticeably from what you would predict based on the resistance shown in the schematic. Explain a possible source of this difference.