

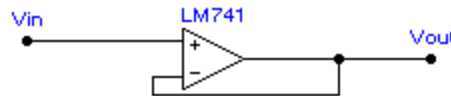
## Laboratory Exercise #1, Analog Electronics, Part B: Operational Amplifiers, Active Lead / Lag Controllers, and Active Filters

### Introduction:

This lab is an introduction to the most versatile linear integrated circuit (IC) used: the operational amplifier. You will also become familiar in this lab with active controllers and active filters. In part A you built and tested a low-pass RC filter. In this lab, you will place two RC low-pass filters in series and observe the loading effect. You will then place a buffer op-amp (high input impedance, low output impedance, unity gain) between the two RC filters and observe the loading effect disappear. You will construct active lead and lag controllers and compare their performance to the passive lead and lag controllers you built and analyzed in part A. You will construct active high-pass and low-pass filters and compare their performance to the passive versions. You will then construct a two-pole Butterworth active low-pass filter and compare the performance to the two RC low-pass filters in series with the buffer amplifier.

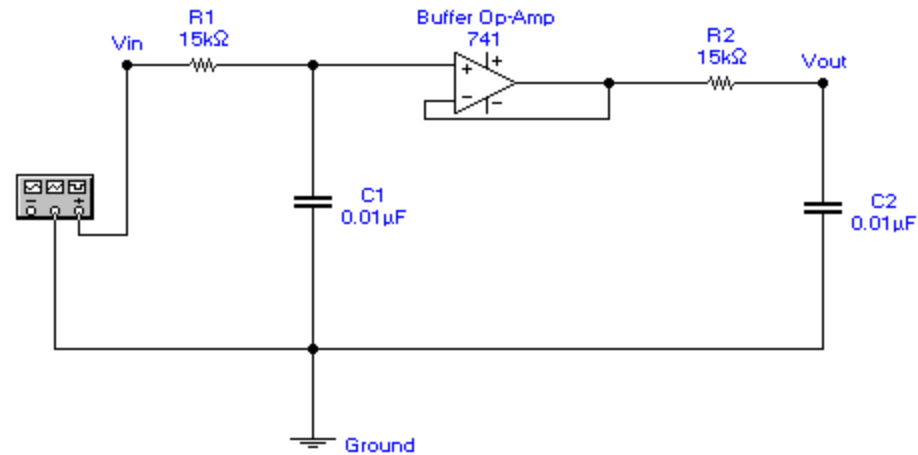
### Laboratory Procedure:

- **Buffer Op-Amp**



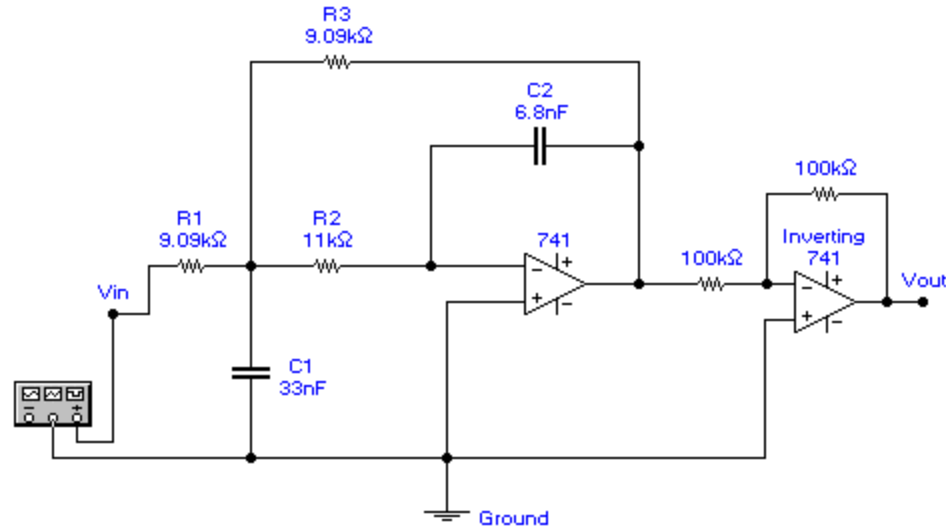
- ⇒ Build in hardware the buffer op-amp circuit and use the function generator and digital oscilloscope to measure the frequency response and step response.
- ⇒ Note: Slewing rate limitation vs. frequency response limitation. At very small amplitudes, the frequency response of the op-amp limits the high frequency behavior, while at larger amplitudes, the slewing rate limits its response.
- ⇒ Question: How would you measure the input impedance (very large) and output impedance (very small) of this circuit?

- RC - Buffer Op-Amp - RC Circuit



- ⇒ The transfer function for this circuit is given by:  $\frac{V_{out}}{V_{in}} = \frac{1}{(RCs+1)^2}$  because of the absence of loading effects as a result of the presence of the buffer op-amp.
- ⇒ Perform MatLab simulations: plot the step response and frequency response.
- ⇒ Build this circuit in hardware and use the function generator and digital oscilloscope to validate your step response and frequency response predictions in the MatLab simulations.

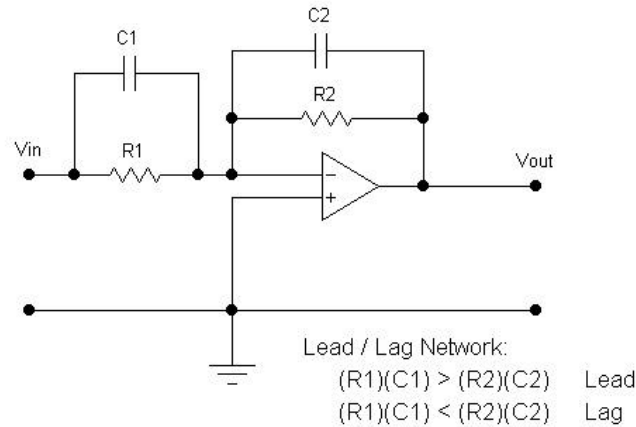
- **Two-Pole, Low-Pass, Active Filter with a 1061 Hz Cutoff Frequency**



⇒ The transfer function for this active filter is given by: 
$$\frac{V_{out}}{V_{in}} = \frac{1}{R_1 R_2 C_1 C_2} \frac{1}{s^2 + \left[ \frac{1}{R_2 C_1} + \frac{1}{R_1 C_1} + \frac{1}{R_3 C_1} \right] s + \frac{1}{R_2 R_3 C_1 C_2}}$$

⇒ Build this circuit in hardware. Using MatLab Simulations and experimental measurements, compare the predicted frequency response and step response with the measured responses. Also compare the frequency response of this filter with the frequency responses of the single RC filter and the RC-Buffer Op-Amp-RC filter circuit already studied.

- **Active Lead / Lag Controller**

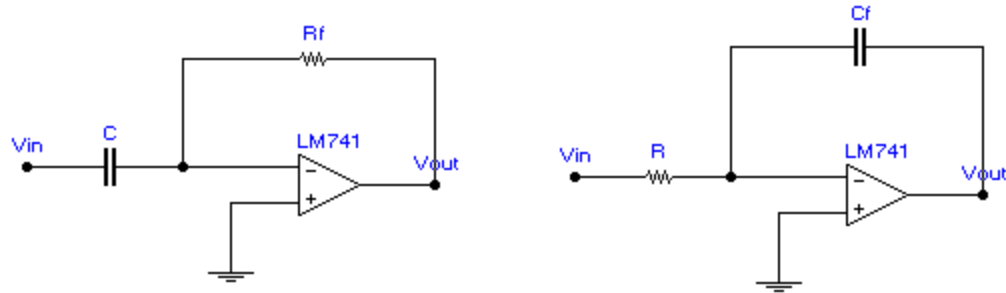


⇒ The transfer function for this circuit is:  $\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1} \frac{R_1 C_1 s + 1}{R_2 C_2 s + 1}$ . Pick parameter values to give you first lag behavior and then lead behavior.

⇒ Perform MatLab simulations: plot the step response and frequency response.

⇒ Build this circuit in hardware and use the function generator and digital oscilloscope to validate your step response and frequency response predictions in the MatLab simulations. Compare your results to the passive lag and lead controllers you have already studied.

- **Active Differentiator (High-Pass Filter) and Active Integrator (Low-Pass Filter)**

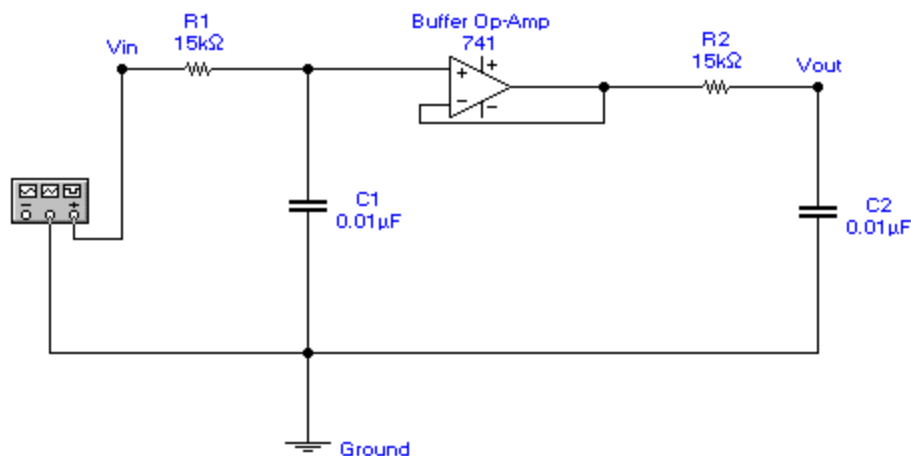


⇒ The transfer functions for these two circuits are:  $\frac{V_{out}}{V_{in}} = -R_f C s$  and  $\frac{V_{out}}{V_{in}} = \frac{-1}{R C_f s}$ , respectively.

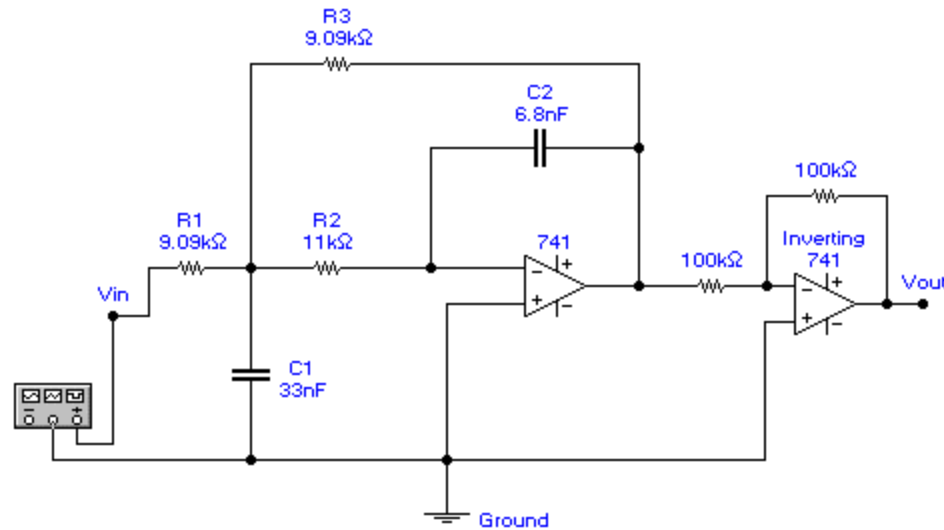
⇒ Using MatLab simulations and hardware implementation and measurement of these two circuits, explain the differentiating and integrating functions of these two circuits.

## Laboratory Exercise # 1, Analog Electronics, Part B: Operational Amplifiers, Active Lead / Lag Controllers, Active Filters Questions

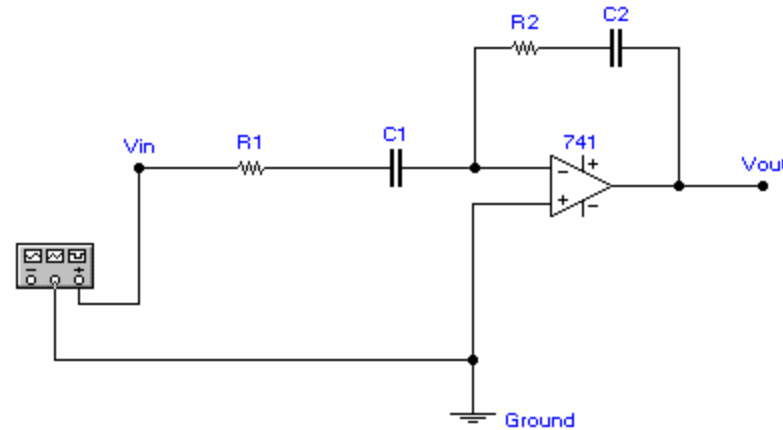
1. In laboratory exercise #1, Part A, you derived and measured the transfer function for two identical RC low-pass filters connected in series. It is given by:  $\frac{1}{(RCs+1)^2 + RCs} = \frac{1}{(RC)^2 s^2 + 3RCs + 1} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$  where  $\omega_n = 1/RC$  and  $\zeta = 1.5$ . Place an buffer operational amplifier between the RC low-pass filters, as shown below, and show that the overall transfer function is given by  $\frac{1}{(RCs+1)^2}$ , as predicted in the absence of loading effects .



2. A two-pole, low-pass active filter with a 1061 Hz cutoff frequency is shown below. Derive the transfer function  $V_{out} / V_{in}$  for this filter. Using MatLab, compare the frequency response of this filter with the frequency responses of a single RC low-pass filter (same cutoff frequency) and two identical RC low-pass filters cascaded and perfectly buffered (same cutoff frequency). What is the purpose of the second op-amp in the circuit?



3. An active electronic lead / lag controller is shown below. Derive the transfer function  $V_{out} / V_{in}$  and show how this circuit can be used as either a lag controller or a lead controller by the appropriate choice of parameter values.



4. For an inverting op-amp, derive the expression for the transfer function  $V_{out} / V_{in}$  in two ways: (a) carry out the analysis for a real op-amp and, at the end of the derivation, replace the parameters of the real op-amp with those of the ideal op-amp, and (b) make the ideal op-amp simplifying assumptions at the very start of the analysis.

5. For a non-inverting op-amp, calculate the input impedance and the output impedance of the circuit.

6. We have seen how a passive RC low-pass filter and a passive RC high-pass filter behave as an integrator and a differentiator, respectively. Construct a "perfect integrator" and a "perfect differentiator" using op-amps and derive the output / input transfer functions. Compare the passive integrator and differentiator with the active integrator and differentiator.