PART C: Pre-Lab

C.1 What is the gain of an entire amplifier circuit in closed, negative, loop and how is it different from the open loop gain of Op Amp?

The closed loop gain is the negative ratio of the feedback resistor and the source resistor. The open loop gain of an ideal Op Amp would be infinite, but in real life it is just a very high value.

C.2 For the circuit of Figure 3:

a. Calculate the gain $\boldsymbol{K}$ for the inverting amplifier if $\boldsymbol{R_s = 10k\Omega}$; $\boldsymbol{R_f = 20k\Omega}$; $\boldsymbol{+V_{CC} = 15V}$; $\boldsymbol{-V_{CC} = -15V}$. Assume that the Op Amp is ideal.

K = -2

b. Calculate the theoretical linear operating range of the input voltage for the circuit (before the output reaches saturation): for which values of $\boldsymbol{V_s}$ will the output $\boldsymbol{v_o}$ stays within the linear range.

-7.5 <= Vs <= 7.5

C.3 For the circuit of Figure 4:

a. Calculate the gain $\boldsymbol{K}$ for the non-inverting amplifier if $\boldsymbol{R_s = 10k\Omega}$; $\boldsymbol{R_f = 20k\Omega}$; $\boldsymbol{+V_{CC} = 15V}$; $\boldsymbol{-V_{CC} = -15V}$. Assume that the Op Amp is ideal.

K = 3

b. Calculate the theoretical linear operating range of the input voltage for the circuit (before the output reaches saturation): for which values of $\boldsymbol{V_g}$ will the output $\boldsymbol{v_o}$ stays within the linear range.

-5 <= Vs <= 5

C.4 Derive Equation 5 for the voltage output of a Inverting Summing Amplifier with three inputs Va, Vb, and Vc.

Vo = -Rf(Va/Ra + Vb/Rb + Vc/Rc)

PART D: In Lab Experiments

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Lab Experiment #3

Date of lab experiment: ____________________

Lab section: __________ GROUP (A/B): ______

Team members: ____

Laboratory instruments:

- Power supply: Keithley 2231-30-3
- Digital Multimeter (DMM): Keysight (Agilent) 34461A
- Breadboard/Arduino set
- 1 kΩ or higher resistors by design
- Op-amps (741)
- Variable 10kΩ resistor

Experiment # 3.1: Inverting Amplifier

Design:

a. Use the following circuit for this experiment:

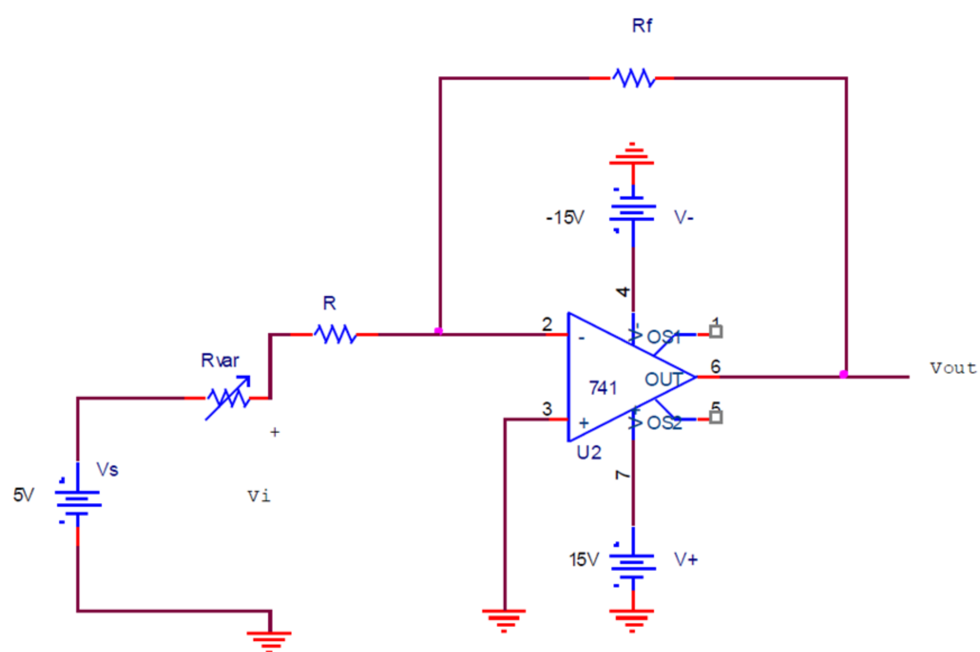
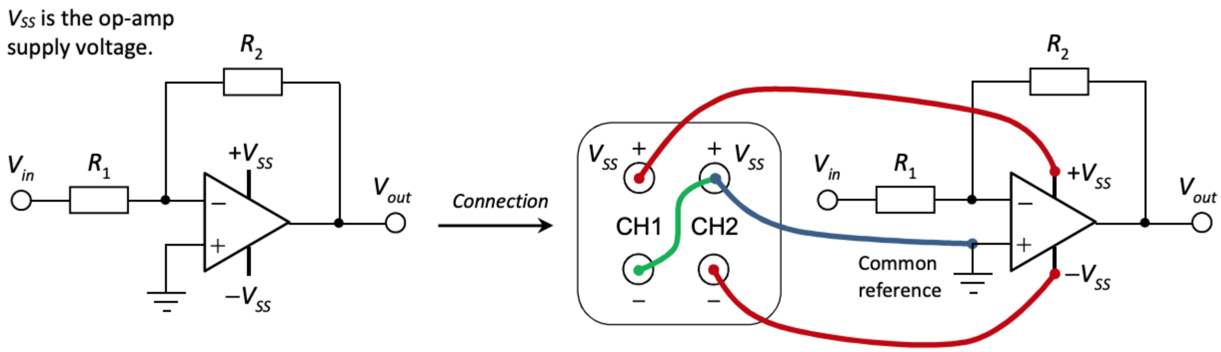


Figure 6: Circuit for experiment 3.1

Note: this circuit is identical to the inverting amplifier circuit shown in Figure 3, except for the voltage divider at the inverting input terminal whose purpose is to decrease the input voltage and keep the Op Amp from saturating. The connections to the DC power supplies and the pins are labeled along with their pin numbers.

Power supply to the $\boldsymbol{V_+}$ **=15V**, and $\boldsymbol{V_-}$ **=15V** should be connected as follows:



b. Choose the resistors values to design a gain of a maximum gain of 2.5 (not accounting for the variable resistor R_{var}, i.e. assuming that R_{var}=0 **Ω** position):

R =____________

R_f =____________

$\boldsymbol{R_{\mathrm{var}}}$**=** Variable 10kΩ resistor

c. If R_{var}=0 **Ω**, Calculate the proportionality constants:

$$\boldsymbol{K = \frac{V_o}{V_S}} = \_\_\_\_\_\_\_\_\_\_\_\_$$

d. Given that $\boldsymbol{V_S}$ **=5V,** $\boldsymbol{V_+}$ **=15V**, and $\boldsymbol{V_-}$ **=15V**, If R_{var}=0 **Ω**, calculate the output voltage:

$\boldsymbol{V_{\mathrm{out}}}$ =____________

Wiring: wire the network in Figure 6 you designed on the breadboard. Make sure the voltage sources initial value is set to 0V.

TA Verification: ______________

Measurements:

Important: ***Do not connect your board to the source BEFORE the instructor has approved your connections!***

- Set the power supply to 5V for the source V_s. Measure V_i and record in Table 1. Change V_i in in steps of 0.25V by changing R_{var} between 0 Ω to 10 kΩ and record these values in Table 1

Table 1: Set values and measured values V_{out}

V_i (measured)	V_{out} (measured)	R_{var} (measured)	$K \cdot V_i$ (calculated)	% error

- For an input voltage of your choice that keeps the Op Amp in the linear region, place an ammeter in series with R_f. Record the value of the current I.

  $V_i =$ ____________________

  $I =$ _________________________

- Disconnect the ammeter. Keep the input voltage the same as before. Attach a load resistance between the output terminal of the Op Amp and ground. In so doing one can study the output resistance characteristics of the Op Amp.

  a. Place a 20 kΩ resistor between the output terminal of the Op Amp and ground and set the supply voltage V_S to 5V.

  b. Measure the output voltage V_{out} and compare with the results obtained for the same input voltage in the previous step.

     $V_i =$ ____________________

     $V_{out} =$ _________________________

     $K =$ ____________________

- This item involves the study of the relationship between the load resistance and output voltage (and thus voltage gain): Keeping the source voltage at 5V, measure I_L (the current through the load resistance R_L) for three values of R_L in the range of 4 kΩ to 20 kΩ. Record the resistor values and measured currents in Table 2.

Table 2: Data collected for load resistor

R_L	I_L

Experiment # 3.2: Non-Inverting Amplifier

Design:

a. Use the following circuit for this experiment:

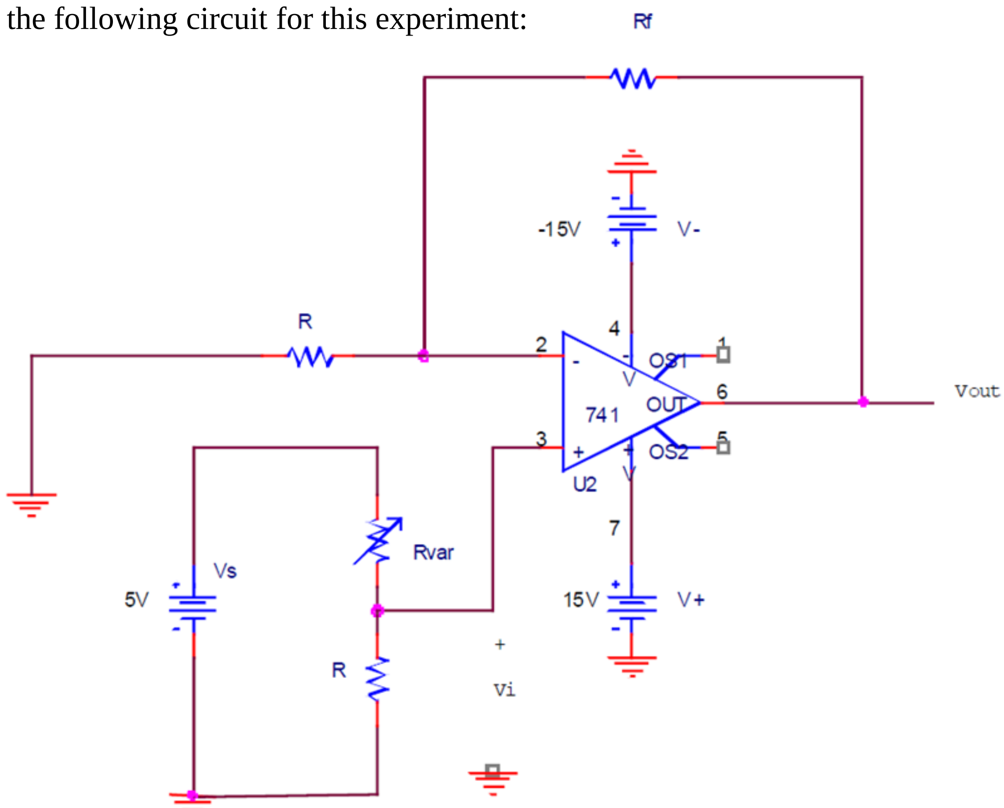


Figure 7: Circuit for experiment 3.2

Note: this circuit is identical to the non-inverting amplifier circuit shown in Figure 4, except for the voltage divider at the non-inverting input terminal whose purpose is to decrease the input voltage and keep the Op Amp from saturating. The connections to the DC power supplies and the pins are labeled along with their pin numbers.

b. Choose the resistors values to design a maximal gain of 2.5 (not accounting for the variable resistor R_{var}, i.e. assuming that R_{var}=0 **Ω** position):

R =____________

R_f =____________

$\boldsymbol{R_{var}}$**=** Variable 10kΩ resistor

c. If R_{var}=0 **Ω**, Calculate the proportionality constants:

$$\boldsymbol{K = \frac{V_o}{V_S}} = \_\_\_\_\_\_\_\_\_\_\_\_$$

d. Given that $\boldsymbol{V_S}$ **=5V,** $\boldsymbol{V_+}$ **=15V**, and $\boldsymbol{V_-}$ **=15V**, If R_{var}=0 **Ω**, calculate the output voltage:

$\boldsymbol{V_{out}}$ =____________

Wiring: wire the network in Figure 7 you designed on the breadboard. Make sure the voltage sources initial value is set to 0V.

TA Verification: ______________

Measurements:

Important: ***Do not connect your board to the source BEFORE the instructor has approved your connections!***

- Set the power supply to 5V for the source V_s. Measure V_i and record in Table 3. Change V_i in in steps of 0.25V by changing R_{var} between 0 Ω to 10 kΩ and record these values in Table 3

Table 3: Set values and measured values V_{out}

V_i (measured)	V_{out} (measured)	R_{var} (measured)	$K \cdot V_i$ (calculated)	% error

V_i (measured)	V_{out} (measured)	R_{var} (measured)	$K \cdot V_i$ (calculated)	% error

- For an input voltage of your choice that keeps the Op Amp in the linear region, place an ammeter in series with R_f. Record the value of the current I.

  $V_i =$ ____________________

  $I =$ _________________________

- Disconnect the ammeter. Keep the input voltage the same as before. Attach a load resistance between the output terminal of the Op Amp and ground. In so doing one can study the output resistance characteristics of the Op Amp.

  a. Place a 20 kΩ resistor between the output terminal of the Op Amp and ground and set the supply voltage V_S to 5V.

  b. Measure the output voltage V_{out} and compare with the results obtained for the same input voltage in the previous step.

     $V_i =$ ____________________

     $V_{out} =$ _________________________

     $K =$ ____________________

- This item involves the study of the relationship between the load resistance and output voltage (and thus voltage gain): Keeping the source voltage at 5V, measure I_L (the current through the load resistance R_L) for three values of R_L in the range of 4 kΩ to 20 kΩ. Record the resistor values and measured currents in Table 4.

Table 4: Data collected for load resistor

R_L	I_L