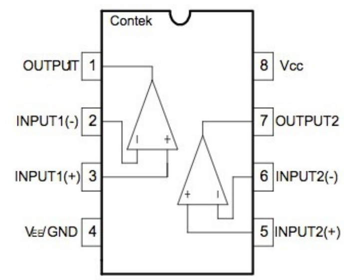
Differential Amplifier and Instrumentation Amplifier Characteristics Experiment

EET-210L Digital & Linear Circuits

Objective:

To investigate the basic construction and operation of integrated circuit based differential amplifiers (D.A.'s) and instrumentation amplifiers (I.A.'s). Investigative emphasis will be placed on the operating characteristics of differential-mode gain (A_{DM}), common-mode gain (A_{CM}) and the determination of the common-mode rejection ratio (CMRR).

LM358 Pin Out

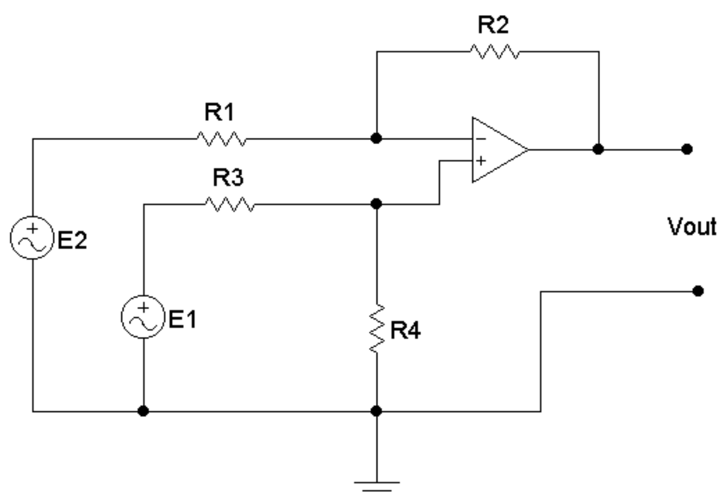


Equipment: LM358 op-amps
Various 5% tolerance ½ Watt resistors
Potentiometer(s) (as necessary for trim)
Variable Regulated Power Supply
Dual-trace oscilloscope
Signal Generator

Theory:

The standard op-amp based differential amplifier shown below has a gain expression given by:

$$\mathbf{V_{out} = E_1(R_4/(R_3+R_4))(1+R_2/R_1) - E_2(R_2/R_1)}$$



The differential-mode gain, A_{DM}, is the circuit gain measured with respect to the difference in potential between E_1 and E_2.

$A_{DM} = V_{out}/(E_1-E_2)$ $\quad$ $A_{DM}(dB) = 20*\log(V_{out}/(E_1-E_2))$

The common-mode gain, A_{CM}, is the circuit gain measured with respect to the common or "same" potential placed at the inputs to the circuit, E_{CM}.

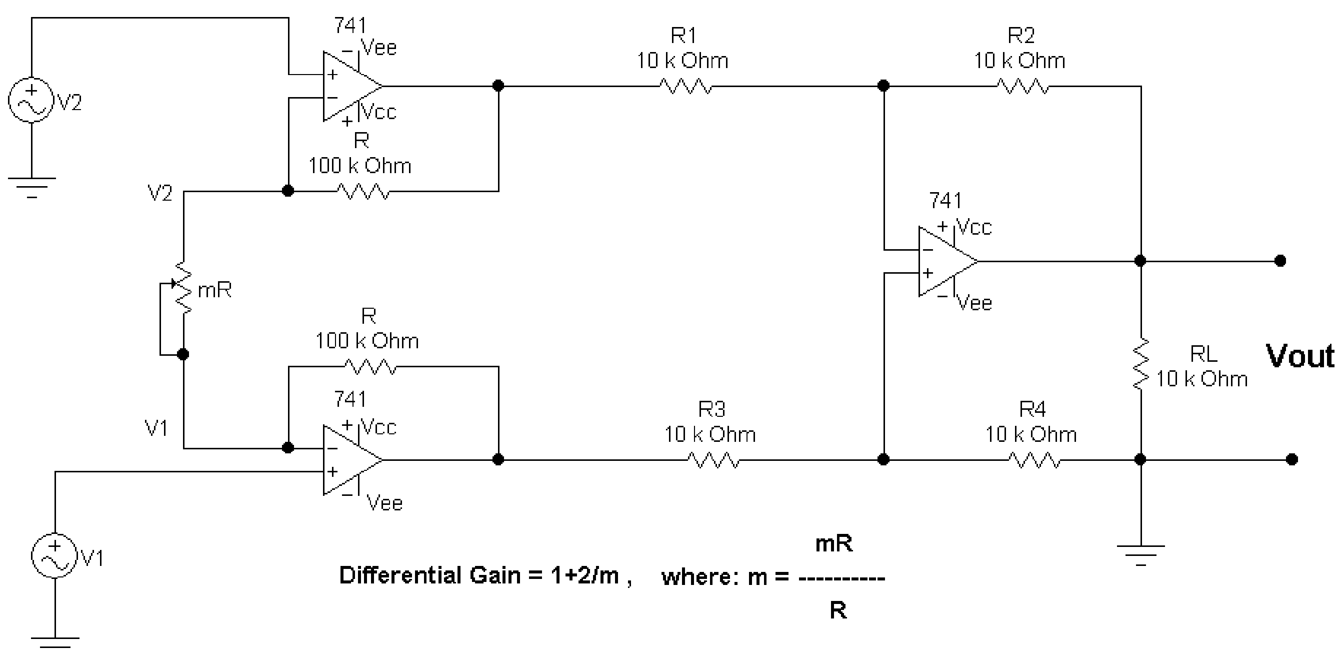
$$A_{CM} = V_{out}/E_{CM} \qquad A_{CM}(dB) = 20*\log(V_{out}/E_{CM})$$

Together, these two gains constitute the figure of merit for differential amplifiers known as the common mode rejection ration, CMRR. The CMRR is given by:

$$CMRR = A_{DM}/A_{CM} \qquad CMRR(dB) = 20*\log(A_{DM}/A_{CM})$$

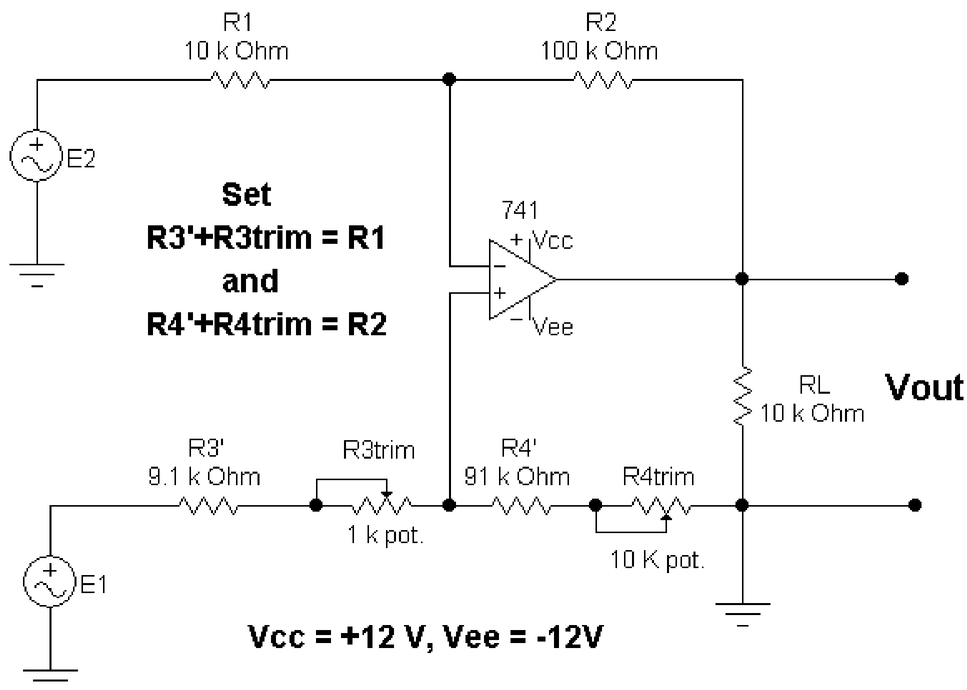
For an ideal differential amplifier, the common mode gain is zero. However, practical limitations in construction of the circuits will prevent this number from being exactly zero. As we will see in subsequent work, high quality integrated circuit differential amplifiers are available with a very small common-mode gain and hence a large common-mode rejection ratio.

The instrumentation amplifier (I.A.) builds upon the basic differential amplifier structure. It improves upon the D.A. in two principle ways. First, it provides a mechanism for an easily adjustable differential-mode gain. (The basic D.A. require's precision matched resistors, and changing the gain requires that a pair of matched resistors be changed. This is not easy to do, as you will see.) Second, the I.A. creates a very high and equal input resistance seen by each source. This is done by the presence of the voltage follower (a.k.a. buffer) amplifiers placed at each input.



PROCEDURE

1.) Measure all of your components accurately. Make and record each measurement as accurately as possible. Construct the circuit shown below. One of the goals of these experiments is to derive the highest CMRR possible. This will require that resistors be selected and trimmed as accurately as possible. (The student/lab group who consistently documents the highest CMRR's for each experiment in this lab report will receive a bonus.) You can use D.C. sources for the differential and common mode gain measurements. When measuring the common-mode gain, connect the same potential to points E_1 and E_2 on the circuit. (***NOTE:*** *USE AN LM358 Op-Amp instead of the LM741 shown.*)



Calculate the expected A_{DM} for this circuit. A_{DM} = _______________

Measured A_{DM} = ___________ Measured A_{DM} (dB) = ___________

Measured A_{CM} = ___________ Measured A_{CM} (dB) = ___________

Measured CMRR = ____________ Measured CMRR (dB) = ____________

2.) With your equipment connected to measure the common-mode output gain, move **one** of the trim pots from its correct setting and observe the effect on A_{CM}. Try to restore this pot back to its proper setting by observing and finding the minimum common-mode output voltage. Then move the other trim pot and observe the effect on A_{CM}. Try to restore this pot back to its proper setting by observing and finding the minimum common-mode output voltage.

3.) Replace the combinations of [R3'+ R3trim] and [R4' + R4trim] with fixed resistors of the appropriate values. Measure and record the following:

Measured A_{DM} = __________ Measured A_{DM} (dB) = __________

Measured A_{CM} = __________ Measured A_{CM} (dB) = __________

Measured CMRR = ___________ Measured CMRR (dB) = ___________

Are these CMRR values better or worse than the measurements obtained in step #1? ______________

4.) Perform the modifications necessary on the circuit above to get a differential-mode gain of approximately 100. Remember the goal is to get the highest CMRR possible, so carefully select components and use the trim pots as necessary.

Repeat the measurements made in step #1.

Expected A_{DM} = _____________

Measured A_{DM} = __________ Measured A_{DM} (dB) = __________

Measured A_{CM} = __________ Measured A_{CM} (dB) = __________

Measured CMRR = ___________ Measured CMRR (dB) = ___________

5.) Repeat step #2 on this new circuit. Do you observe the same effects as in the first circuit? Do you notice any differences?

6.) Repeat step #2 on this new circuit. Record your measurements below.

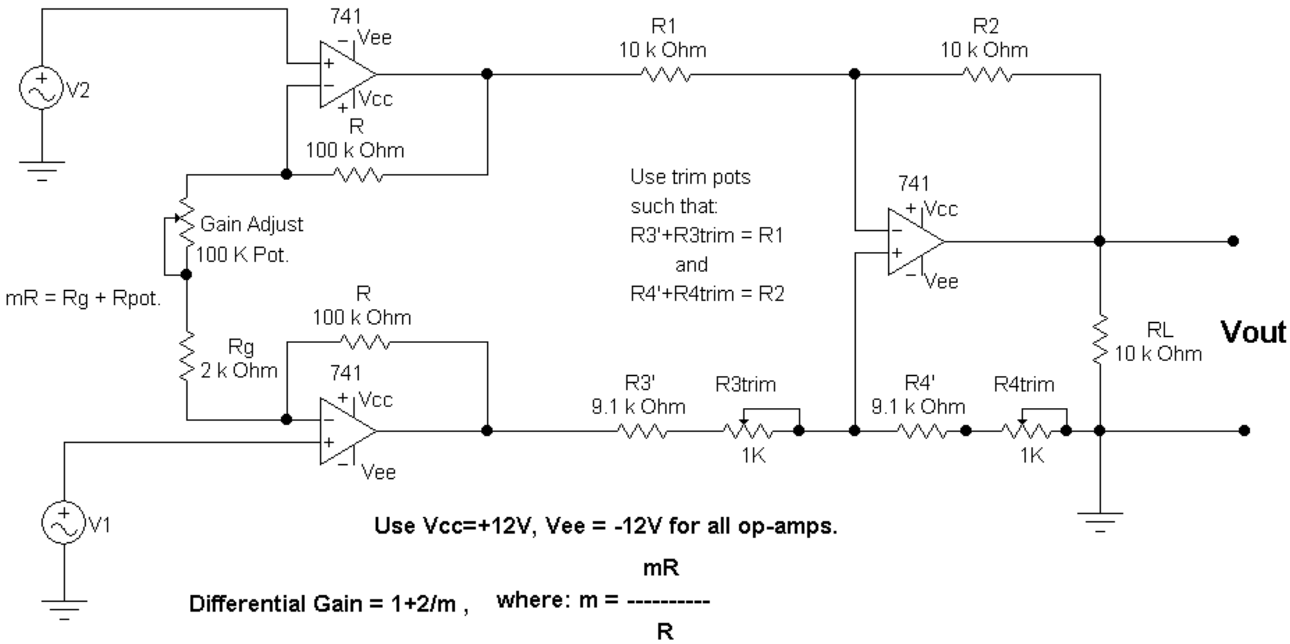
Measured A_{DM} = __________ Measured A_{DM} (dB) = __________

Measured A_{CM} = __________ Measured A_{CM} (dB) = __________

Measured CMRR = ___________ Measured CMRR (dB) = ___________

Are these CMRR values better or worse than the measurements obtained in step #4?

7.) Construct the Instrumentation amplifier circuit shown. You should recognize the right-hand portion of this circuit as the standard differential amplifier with ADM = 1. The two op-amps on the left-hand portion provide a buffered input and allow for an adjustable gain without having to "unbalance" the differential amplifier. (***NOTE:*** *USE LM358 Op-Amps instead of the LM741's shown.*)



8.) Set the ***Gain Adjust*** pot to its **maximum** resistance setting.
Calculate the expected A_{DM} for this circuit. A_{DM} = ______________
Perform the measurements necessary to determine each of the following:

Measured A_{DM} = __________ Measured A_{DM} (dB) = __________

Measured A_{CM} = __________ Measured A_{CM} (dB) = __________

Measured CMRR = ___________ Measured CMRR (dB) = ___________

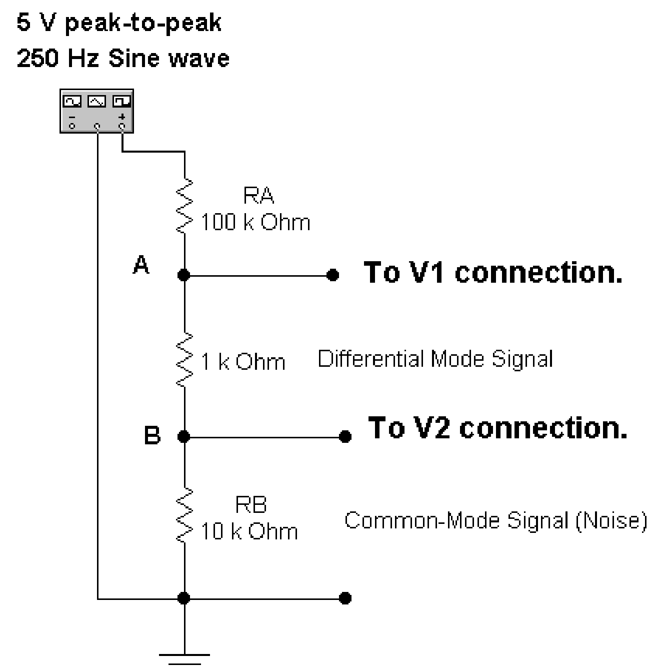
9.) Set the ***Gain Adjust*** pot to its **minimum** resistance setting.
Calculate the expected A_{DM} for this circuit. A_{DM} = ______________
Perform the measurements necessary to determine each of the following:

Measured A_{DM} = __________ Measured A_{DM} (dB) = __________

Measured A_{CM} = __________ Measured A_{CM} (dB) = __________

Measured CMRR = ___________ Measured CMRR (dB) = ___________

10.) **The challenging part.** Construct the voltage divider circuit below. This will synthesize the differential mode signal (the desired signal) and the common-mode (noise) signal (the undesired signal). Adjust the signal generator to the output specified and make the connections to the instrumentation amplifier constructed in step #7. (In this circuit, the potential at point B should be approximately 450 mVp-p. The voltage between points A and B should be approximately 45 mVp-p. The potential difference between A and B is the differential mode signal. The potential at point B is about 450 mVp-p, the voltage at point A is 450 mV plus 45 mV, or a total of about 495 mVp-p. Since both points A and B have the point B potential "in common", the voltage at that point is the common-mode signal. This creates an input signal-to-noise ratio (SNR) for our instrumentation amplifier of: 45 mV of signal/450mV of noise, or about 0.1. (The noise signal is ten times stronger than the desired signal.) Expressed in decibels, the SNR is equal to about –20 dB. (If you look at the signal present at point A using an oscilloscope, you will see the "single" composite 495 mV signal. Remember that just 45 mV of this is due to our desired signal.) Once this signal is applied to the instrumentation amplifier, we will measure the SNR present at the output. We would expect the SNR to improve by the value of the CMRR determined for this amplifier.



Once you have made the connections to your I.A., measure the output voltage of the I.A. using the oscilloscope. What do you observe?

V_{out}p-p = ____________ Differential-mode output. Capture a screen-shot. (*Screen shots should have your initials/name and any relevant measurements.*)

To see how much of this output signal is due to the "noise" component, connect the signal from point B to both V1 and V2 connections of the I.A. The output of the I.A. at this time is due only to the noise. Are you able to make a reliable measurement of this output? Remember, your "noise" is only the 250 Hz signal present in the output.

V_{out}p-p = ___________ Common-mode output. Capture a screen-shot.

Calculate the SNR at the output but dividing the differential-mode output by the common-mode output:

$$SNR = \frac{\text{Differential-mode output}}{\text{Common-mode output}}$$

Express this result in decibels by: SNR (dB) = 20*log(SNR).

Look at the CMRR of this circuit expressed in dB's and the SNR present at the input of the circuit. Has the signal to noise ratio at the output improved by approximately the CMRR of the I.A.? Try to explain any discrepancies that might exist.

11.) When you have completed this lab exercise, make a post on the Forums and post your two screen-shots.

QUESTIONS.

1.) Did each of your circuits perform as expected? If not, try to explain any sources of error.

2.) Use Electronics Workbench/Multi-Sim/etc. to simulate each of your circuits used in steps 1 through 6 of this exercise. Be sure to put your **measured resistance values** into your simulation circuits. Using the results of the simulations, calculate the CMRR for each circuit as a ratio and in dB's. For each circuit, do you feel the simulation accurately reflects the the circuit operation you observed? If so, why? If not, why not?

3.) Did your instrumentation amplifier work as expected? What was the range of gains possible with your I.A.? Was it easy to adjust the gain of this circuit? Did adjusting the gain effect the CMRR figure at all? If so, how?

4.) Were the measurements performed to observe the effects of the CMRR on the signal-to-noise ratio accurate enough to verify the theory? Why or why not?

5.) Assemble the all of your work for this experiment and neatly organize it and keep it in your lab notebook.