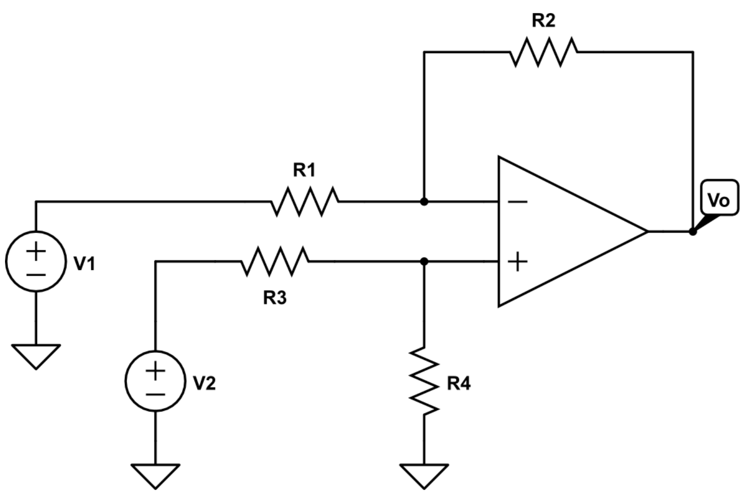
This handout expands on "Experiment 41: Differential Amplifiers" in the *Experiments Manual for Contemporary Electronics: Fundamentals, Devices, Circuits, and Systems* by Louis E. Frenzel.

Instructions: Be sure to review the introduction section to Experiment 41 in the Manual. Then, complete this handout and complete the experiment (by making notes in your notebook). **Submit handout and notebook images as a *.PDF** to the D2L dropbox (Assignments > *CMRR and Op Amp Limitations – Simulated Investigation*).

Objectives: Approximate the gain the common-mode rejection ratio (CMRR) of a differential amplifier, and determine which set-up conditions or design related choices can influence CMRR values.

Differential Amplifier Review (Alexander & Sadiku Chapter 5.7):



When $R_1 \neq R_2 \neq R_3 \neq R_4$:

$$v_0 = \frac{R_2(1 + R_1/R_2)}{R_1(1 + R_3/R_4)} v_2 - \frac{R_2}{R_1} v_1$$

When $R_1/R_2 = R_3/R_4$:

$$v_0 = \frac{R_2}{R_1}(v_2 - v_1)$$

When $R_1 = R_2 = R_3 = R_4$:

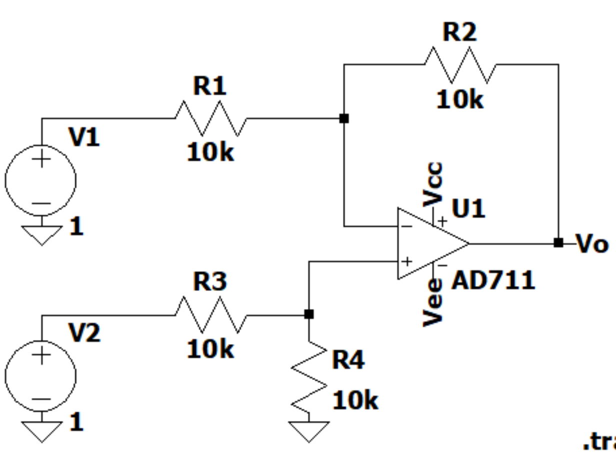
$$v_0 = v_2 - v_1$$

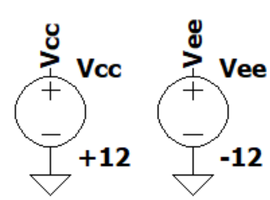
Datasheet Comparison: Compare the AD711(c) datasheet and the LT1037 datasheet. *Hint: you may need to estimate some of these parameters from plots.*

AD711(c) *Typical* Specifications from Datasheet:	**LT1037 *Typical* Specifications from Datasheet:**
Z_{IN} (Ω):________________________________	R_{IN} (Ω):________________________________
Z_{OUT} (Ω):________________________________	R_{OUT} (Ω):________________________________
V_{OS} (µV):________________________________	V_{OS} (µV):________________________________
CMRR (dB):________________________________	CMRR (dB):________________________________
Slew Rate (V/µs): ________________________	Slew Rate (V/µs): ________________________
Unity Gain Bandwidth (Hz): ________________	GBP or GBW (Hz): ________________________
Best uses and/or Other key features:	Best uses and/or Other key features:

Procedure:

1. Let's begin the analysis with the AD711. Construct the following Circuit in LT Spice. Run a transient analysis.





.tran 0 0.5 0.01 0.0001

2. Hover the red probe over Vo to get an accurate reading of the output voltage. If the op amp were ideal, it should read 0V. However, with v1 = 1.0V and v2 = 1.0V, you should get a value in the nV range. Now, calculate CMRR using units of V/V and in dB. Recall:
   $CMRR = \left|\frac{A}{A_{cm}}\right|$ and $v_0 = A(v_2 - v_1) + A_{cm}(v_{ic})$, where v_{ic} is the average of the input signals.

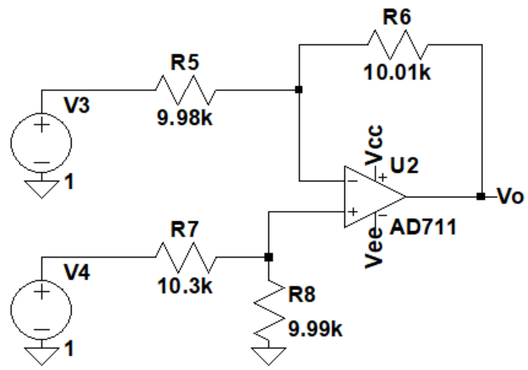
3. Does CMRR vary based on the voltage values of the DC signals v_1 and v_2? To investigate this, complete the following table.

Table 41-1. CMRR and A_{cm} Calculations using different v_1 and v_2 for the AD711 (c).

v_1 [V]	v_2 [V]	v_0 [nV]	v_{ic} [V]	A_{cm}	CMRR	CMRR [dB]
1.0	1.0					
2.0	2.0					
5.0	5.0					
8.0	8.0					

4. **Describe the behavior of CMRR.**

5. Steps 2-3 should tell you the best CMRR we could hope to achieve because all of the resistors are perfectly matched. In practice, how well an amplifier rejects common-mode signals also depends on how well matched the resistors are. Update your resistor values to match the following circuit diagram. These values were chosen to reflect 1% tolerance in 10 kΩ. Update v1 = 1.0V and v2 = 1.0V.



6. Determine CMRR in dB for the circuit in step 5. Do this 2 ways: (1) Assume A = 1 V/V (aka all resistors are really 10 kΩ), and (2) use the gain equation found on page 1 to calculate the gain more precisely.

7. Let's investigate the CMRR effects when AC signals of various frequencies are used. Change the resistor values to match their ideal settings used in step 1. Make $v_1 = 1\sin(2\pi 1000t)$V and $v_1 = v_2$. *Hint: record the peak-to-peak voltage. Click on the name in the plot to activate the cursors.*

Table 41-2. CMRR and A_{cm} Calculations at different frequencies for the AD711(c). Both v_1 and v_2 have magnitudes of 1 V.

Frequency [Hz]	v_0 **[μV$_{pk}$]**	v_{ic} **[V$_{pk}$]**	A_{cm}	**CMRR**	**CMRR [dB]**
1.0 k					
10.0 k					
100.0 k					
1.0 M					
10.0 M					

8. **Describe the behavior of CMRR as frequency is varied.**

9. Repeat steps 1, 2, 7, and 8 for the LT1037 op amp. Steps 2, 7, and 8 are repeated here (as Steps 10-12) for your convenience.

10. Hover the red probe over Vo to get an accurate reading of the output voltage. If the op amp were ideal, it should read 0V. However, with v1 = 1.0V and v2 = 1.0V, you should get a value in the nV range. Now, calculate CMRR using units of V/V and in dB. Recall:
$CMRR = \left|\frac{A}{A_{cm}}\right|$ and $v_0 = A(v_2 - v_1) + A_{cm}(v_{ic})$, where v_{ic} is the average of the input signals.

11. Let's investigate the CMRR effects when AC signals of various frequencies are used. Change the resistor values to match their ideal settings used in step 1. Make $v_1 = 1\sin(2\pi 1000t)$V and $v_1 = v_2$.

Table 41-3. CMRR and A_{cm} Calculations at different frequencies for the LT1037. Both v_1 and v_2 have magnitudes of 1 V.

Frequency [Hz]	v_0 **[μV$_{pk}$]**	v_{ic} **[V$_{pk}$]**	A_{cm}	**CMRR**	**CMRR [dB]**
1.0 k					
10.0 k					
100.0 k					
1.0 M					
10.0 M					

12. **Describe the behavior of CMRR as frequency is varied.**

13. Compare the performance between the AD711 and LT1037. Discuss CMRR and other features. When would 1 be a better choice over another?