Laboratory Experiment #2: OpAmp Differential Amplifier

I. OBJECTIVES

An OpAmp differential amplifier with specified gain requirements will be designed. Performance characteristics of this amplifier including: common-mode and differential-mode gain and common mode rejection ratio (CMRR) will be investigated.

II. INTRODUCTION

A differential amplifier is any tow-input amplifier that has an output proportional to the difference of the inputs. The defining equation for a differential amplifier is then:

$$y_o = A(x_{i1} - x_{i2})$$

where the output, y_o, and the inputs $\{x_i\}$ could be either voltages or currents. For the differential amplifier shown in Figure 2-1, the output expression is:

$$v_o = \frac{R_B}{R_A}(v_{i1} - v_{i2})$$

if the resistor values are chosen so that

$$\frac{R_A}{R_B} = \frac{R_C}{R_D}$$

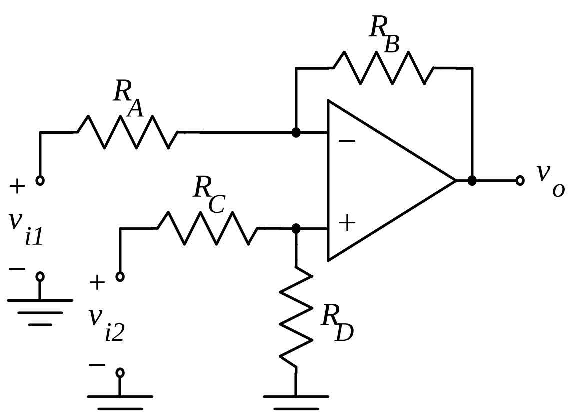

Figure 2-1 - A Differential Amplifier

Ideally this amplifier (or any differential amplifier) is sensitive only to the difference in the two input signals, and is completely insensitive to any common component of the tow signals. That is, if the difference in inputs remains constant, the output should not vary if the average value of the two inputs changes. Unfortunately, a differential amplifier rarely meets this goal completely, and the output has a slight dependence on the average of the input signals. The output for this type of imperfect differential amplifier is given by:

$$v_o = A_{DM}\left(v_{i2} - v_{i1}\right) + A_{CM}\left(\frac{v_{i2} + v_{i1}}{2}\right)$$

where

A_{DM} = the amplification of the input signal difference, v_{i2} - v_{i1}

and

A_{CM} = the amplification of the input signal average, $\frac{v_{i2} + v_{i1}}{2}$.

The *quality* of a differential amplifier is displayed in its ability to amplify the differential signal while suppressing the common signal. A measure of this quality is the ration of the differential gain to the amplification of the average (or common) part of the input signals. The measure of quality is named *Common-Mode Rejection Ratio* (CMRR) and is usually expressed in decibels (dB). The defining equation for CMRR is:

$$CMRR = 20\,log_{10}\left|\frac{A_{DM}}{A_{CM}}\right|$$

Unfortunately, usual analysis procedures do not produce an expression in this form: the differential-mode gain, A_{DM}, and the common-mode gain, A_{CM}, are not the usual results of analysis. A more typical result of analysis procedures is:

$$v_o = A_1 v_{i1} + A_2 v_{i2}$$

A conversion between the two output expressions can be obtained as:

$$A_{DM} = \frac{A_2 - A_1}{2} \qquad \text{and} \qquad A_{CM} = A_1 + A_2$$

III. PROCEDURE

A. Amplifier design

Design a differential amplifier with the circuit topology of Figure 1 with the following performance requirements and restrictions:

- Magnitude of the voltage gain ≈ 5 or 10 (your choice)
- Input resistance seen by each source ≈ 2 kΩ
- the DC power supplies will be seat at ± 15 V.

B. Design Verification

Construct the above designed amplifier. Measure the individual input AC voltage gains at any frequency less than 1 kHz (set the other source to zero). Compare results with theory and PSpice simulation. Calculate the common-mode and differential-mode gains and the CMRR from the experimental results.

C. Measurement of the Common-mode and Differential-mode Gains Directly

Common-mode gain can be most easily measured with an input that has only a common component: that is, inputs that are exactly the same. Connect the two input nodes together and apply the AC signal of part B. Measure the gain: this is a measurement of the common-mode gain.

In order to measure the differential-mode gain, the inputs must be exact inverses: they will then have only differential components as their average will be zero. Build an inverting amplifier of unity magnitude gain (it is suggested that a decade box be used as one of the resistors and the gain be "tuned" so it is as close to negative one as possible – use the difference function on the input of the oscilloscope). Since a function generator typically has an output impedance of approximately 50 Ω, the output impedance of the inverting amplifier should also be approximately 50 Ω. Connect this amplifier between the two inputs so that v_{i2} is the inverse of v_{i1}. Measure the gain: this is a measurement of the differential mode gain. Notice that the magnitude of the total input voltage across the differential input is twice that at either single input. Calculate the CMRR from these results and compare with the results of Part B.

D. A high-input resistance differential amplifier for future use in this lab.

In future labs, it will be useful to have a high input impedance differential amplifier with good CMRR. Modify the amplifier of part C so that unity-gain buffer amplifiers are placed on each input: these buffer amplifiers will increase the input impedance to that of the OpAmp. Test the CMRR of the amplifier.