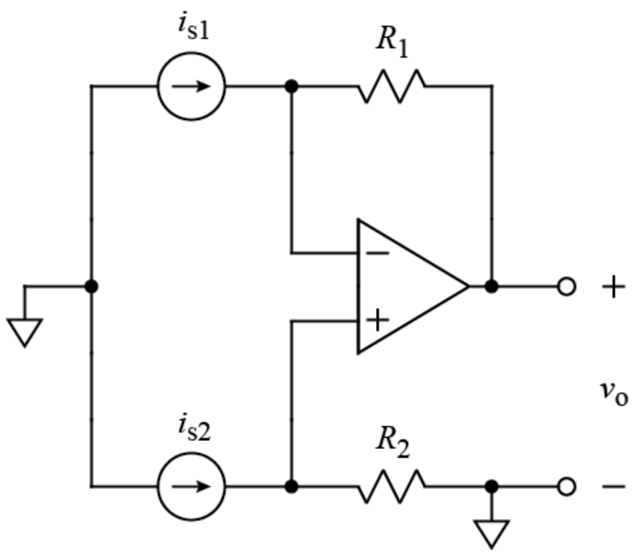
# FINAL EXAM prob 1 solution

Ex:




a) The above circuit operates in linear mode. Derive a symbolic expression for $v_o$. The expression must contain not more than the parameters $i_{s1}$, $i_{s2}$, $R_1$, and $R_2$.

b) Derive a symbolic expression for $v_o$ in terms of common mode and differential input currents:

$$i_{cm} \equiv \frac{(i_{s2} + i_{s1})}{2} \qquad \text{and} \qquad i_{dm} \equiv i_{s2} - i_{s1}$$

The expression must contain not more than the parameters $i_{cm}$, $i_{dm}$, $R_1$, and $R_2$. Write the expression as $i_{cm}$ times a term plus $i_{dm}$ times a term. Hint: start by writing $i_{s1}$ and $i_{s2}$ in terms of $i_{cm}$ and $i_{dm}$.

bonus) What condition must be satisfied in order for the above circuit to amplify only $i_{dm}$?

**SOL'N:** a) We first determine the voltage at the + input of the op-amp. No current flows into the op-amp, so $i_{s2}$ flows through $R_2$ to produce $v_+$.

$$v_+ = i_{s2}R_2$$

The negative feedback causes the voltage at the – input to be the same as the voltage at the + input.

$$v_- = v_+ = i_{s2}R_2$$

We equate the current flowing toward the – input from the left and right sides. (No current flows into the – input.)

$$i_{s1} = \frac{v_- - v_o}{R_1}$$

We solve the above equation for $v_o$.

$$v_o = v_- - i_{s1}R_1 = i_{s2}R_2 - i_{s1}R_1$$

b) We write the current sources in terms of the common mode and differential mode currents.

$$i_{s1} = i_{cm} - \frac{i_{dm}}{2} \quad \text{and} \qquad i_{s2} = i_{cm} + \frac{i_{dm}}{2}$$

We substitute these expressions into the expression for $v_o$.

$$v_o = \left(i_{cm} + \frac{i_{dm}}{2}\right)R_2 - \left(i_{cm} - \frac{i_{dm}}{2}\right)R_1$$

Rearranging terms yields the desired answer.

$$v_o = i_{cm}(R_2 - R_1) + \frac{i_{dm}}{2}(R_2 + R_1)$$

bonus) The common-mode term is eliminated by setting $R_1$ equal to $R_2$.

$$R_1 = R_2$$