Op-Amp : Operational Amplifier

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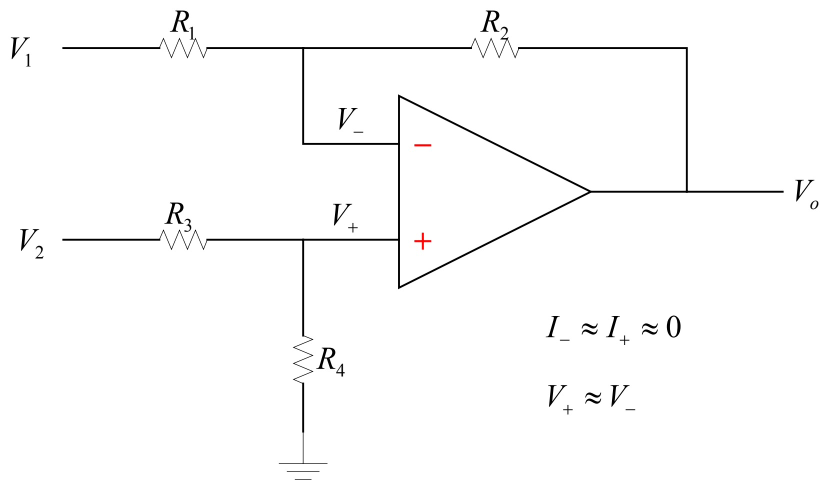
1. Basic Op-Amp



Op-Amp has very high input impedance, *ie* $I_- \approx I_+ \approx 0$, so

$$\frac{V_1 - V_-}{R_1} = \frac{V_- - V_o}{R_2} \Rightarrow V_- = \frac{G_1 V_1 + G_2 V_o}{G_1 + G_2}, \;\; G_i = \frac{1}{R_i} \tag{1}$$

and

$$\frac{V_2 - V_+}{R_3} = \frac{V_+}{R_4} \Rightarrow V_+ = \frac{G_3 V_2}{G_3 + G_4} \tag{2}$$

Very input impedance also gives

$$V_- = V_+ \tag{3}$$

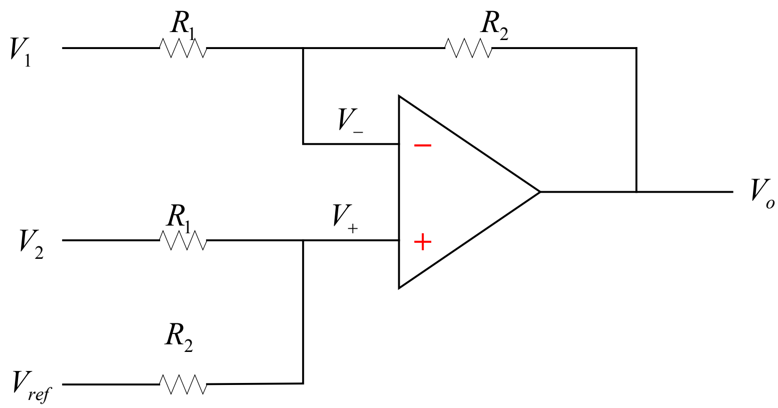
thus, equating Eq(1) & (2) gives

$$\frac{G_1 V_1 + G_2 V_o}{G_1 + G_2} = \frac{G_3 V_2}{G_3 + G_4} \tag{4}$$

Therefore

$$V_o = V_2 \frac{R_4}{R_3 + R_4}\left(1 + \frac{R_2}{R_1}\right) - V_1\left(\frac{R_2}{R_1}\right) \tag{5}$$

2. Op-Amp with Vref



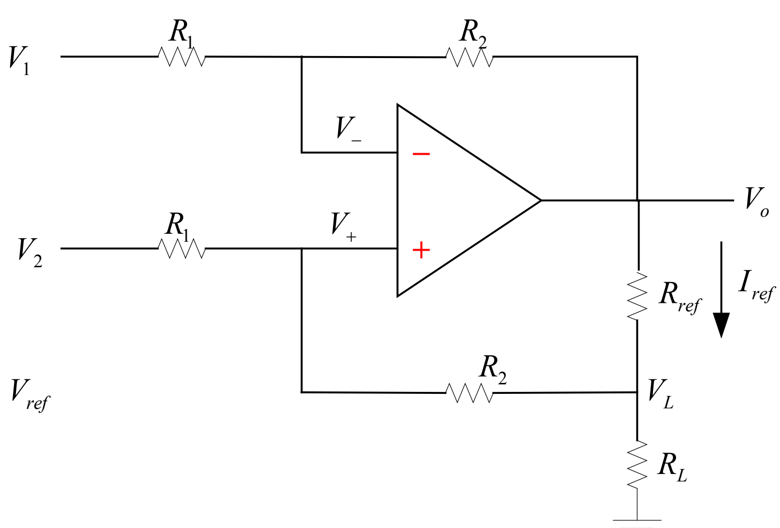
By superposition principle for linear devices, we have

$$V_o = V_2 \frac{R_2}{R_1 + R_2}\left(1 + \frac{R_2}{R_1}\right) + V_{ref}\frac{R_1}{R_1 + R_2}\left(1 + \frac{R_2}{R_1}\right) - V_1\left(\frac{R_2}{R_1}\right) = V_2\left(\frac{R_2}{R_1}\right) + V_{ref} - V_1\left(\frac{R_2}{R_1}\right)$$

or

$$V_o - V_{ref} = (V_2 - V_1)\left(\frac{R_2}{R_1}\right) \quad (6)$$

3. Op-Amp with Iref



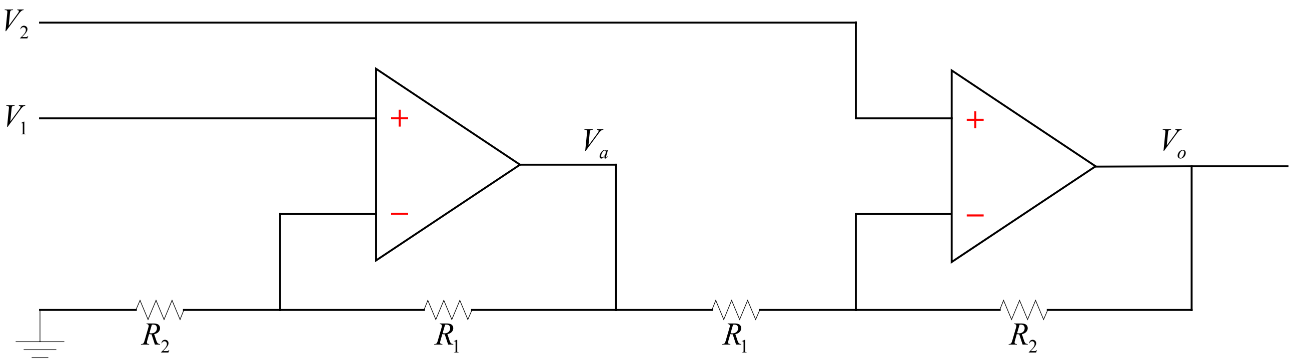
By Eq(6), we have

$$V_o - V_L = (V_2 - V_1)\left(\frac{R_2}{R_1}\right)$$

or

$$I_{ref} R_{ref} = (V_2 - V_1)\left(\frac{R_2}{R_1}\right) \quad (7)$$

4. Two Op-Amp



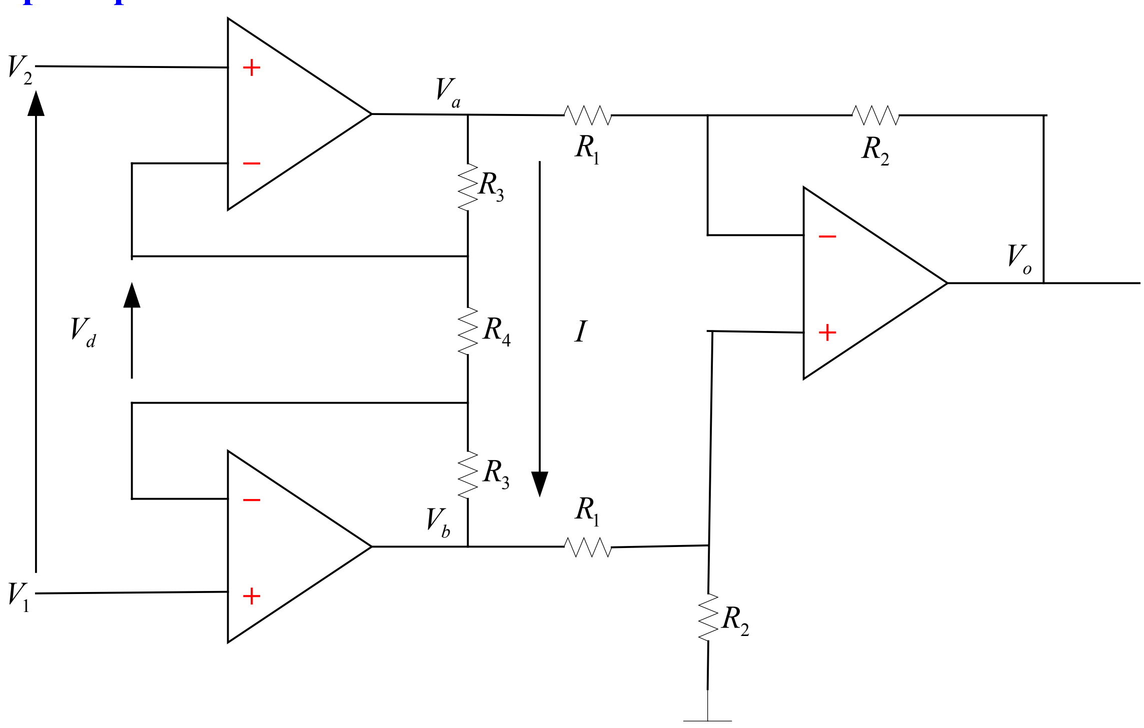
We have

$$V_o = V_2\left(1+\frac{R_2}{R_1}\right) - V_a\left(\frac{R_2}{R_1}\right) = V_2\left(1+\frac{R_2}{R_1}\right) - V_1\left(1+\frac{R_1}{R_2}\right)\left(\frac{R_2}{R_1}\right) = V_2\left(1+\frac{R_2}{R_1}\right) - V_1\left(1+\frac{R_2}{R_1}\right)$$

or

$$V_o = (V_2 - V_1)\left(1+\frac{R_2}{R_1}\right) \qquad (8)$$

5. Three Op-Amp



We have

$$V_o = V_b\frac{R_2}{R_1+R_2}\left(1+\frac{R_2}{R_1}\right) - V_a\left(\frac{R_2}{R_1}\right) = (V_b - V_a)\left(\frac{R_2}{R_1}\right) = -I(2R_3+R_4)\left(\frac{R_2}{R_1}\right) = -\frac{V_d}{R_4}(2R_3+R_4)\left(\frac{R_2}{R_1}\right)$$

or

$$V_o = -(V_2 - V_1)\left(\frac{R_2}{R_1}\right)\left(1+2\frac{R_3}{R_4}\right) \qquad (9)$$