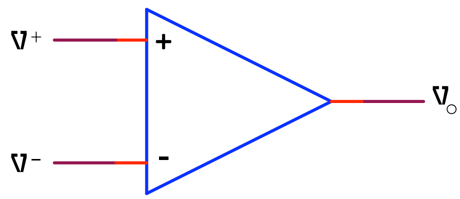
Analog Electronics Lecture 1 – Operational Amplifiers

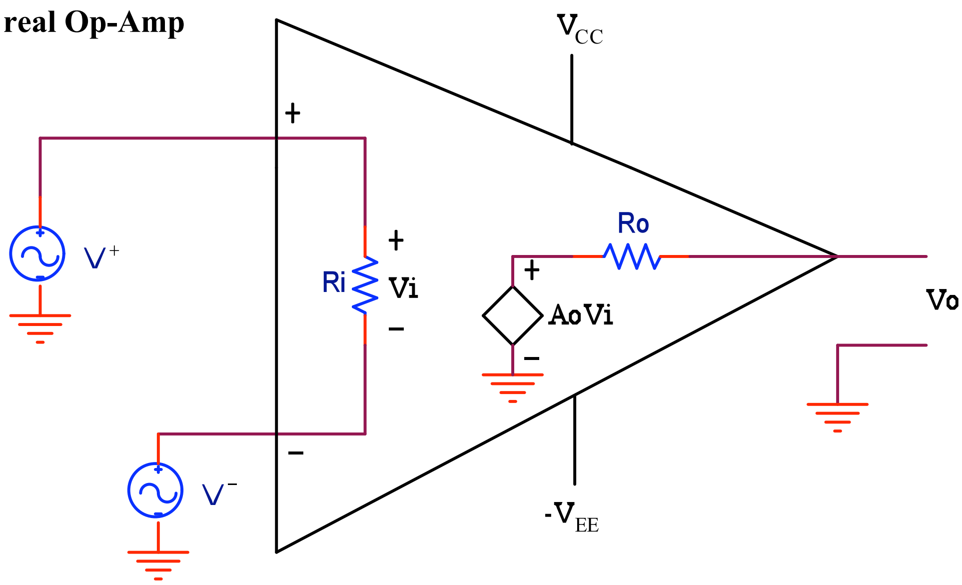
An Ideal Operational Amplifier – Op-Amp:



$V_O = -A_O V_d = -A_O(V^+ - V^-)$

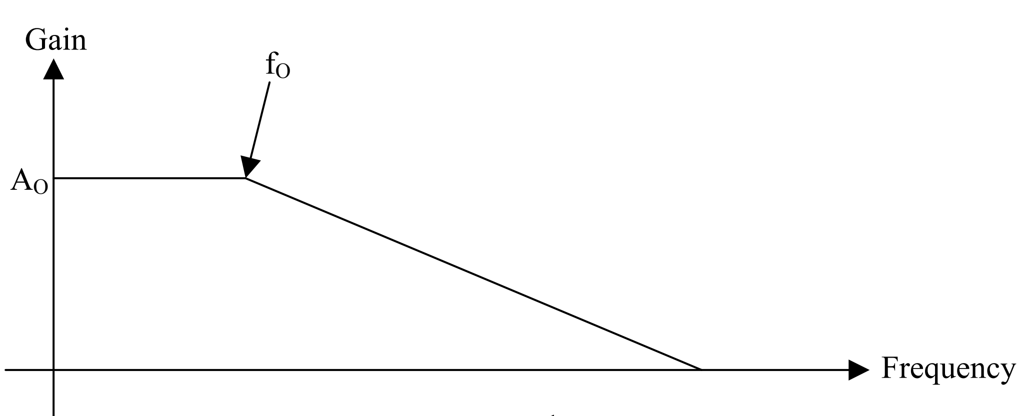
V_d is the differential input voltage or the mathematical difference between the voltage at V^+ and V^-. A_O is the gain.

A real Op-Amp

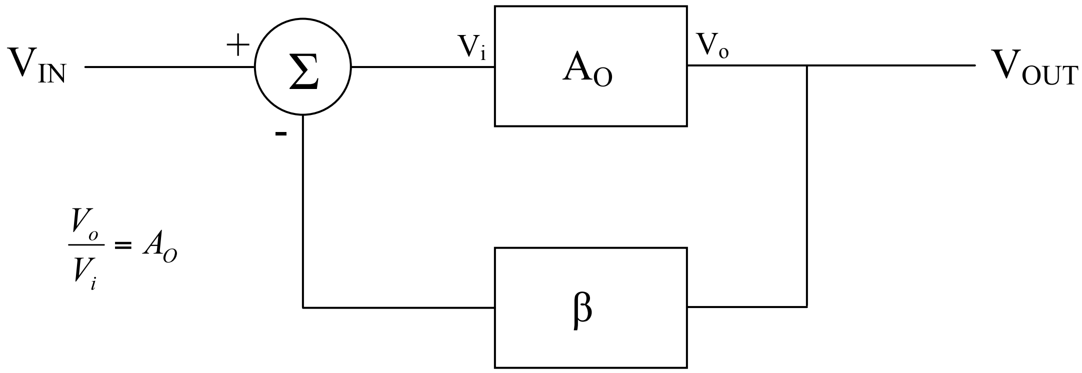


Ideally:
$A_O \rightarrow \infty$
$R_i \rightarrow \infty$
$R_O \rightarrow 0$

Reality:
A_O is less than ∞ and is dependant on frequency.
R_i ranges from 2MΩ to 1TΩ ($1 \times 10^{12}\Omega$).
R_O ranges from 10Ω to 100Ω, typically 75Ω.



Control Theory

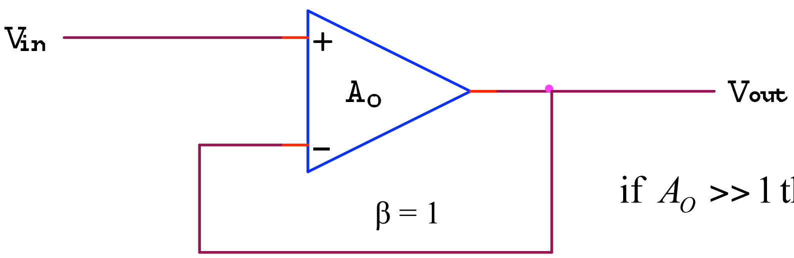


$$\frac{V_o}{V_i} = A_O$$

$$\text{System Gain} = \frac{V_{OUT}}{V_{IN}} = \frac{A_O}{1 + A_O\beta}$$

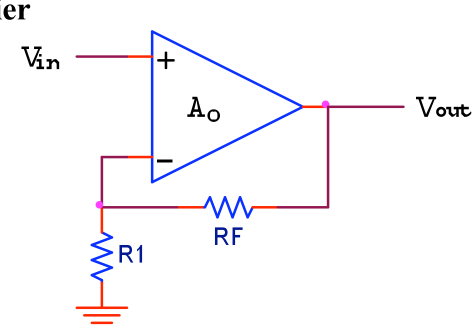
Applications of the Op-amp

- **The Voltage Follower**



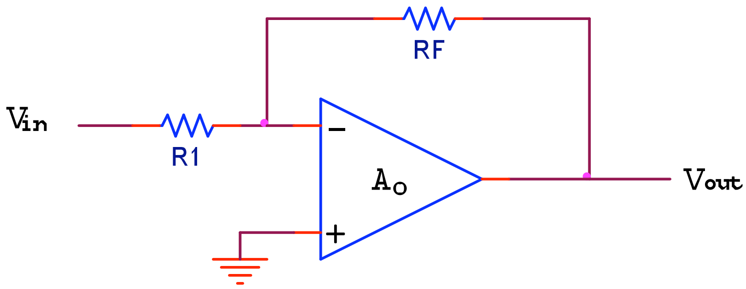
$$\text{if } A_O >> 1 \text{ then } \frac{V_{out}}{V_{in}} = \frac{A_O}{1 + A_O} \cong 1$$

- **The Non-Inverting Amplifier**



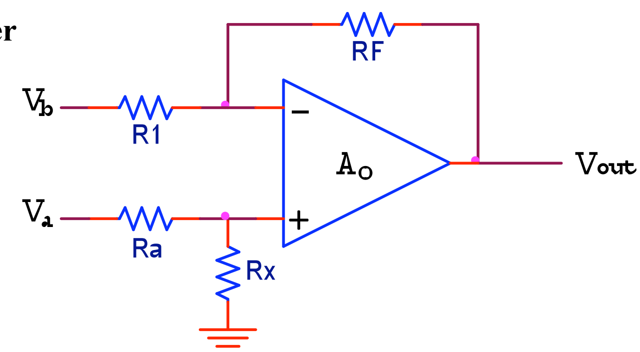
$$\text{Here } \beta = \frac{R_1}{R_1 + R_F} \text{ Therefore, } A = \frac{A_O}{1 + A_O \frac{R_1}{R_1 + R_F}} = \frac{R_1 + R_F}{\frac{1}{A_O}(R_1 + R_F) + R_1} \cong \frac{R_1 + R_F}{R_1} = \frac{1}{\beta}$$

- **The Inverting Amplifier**



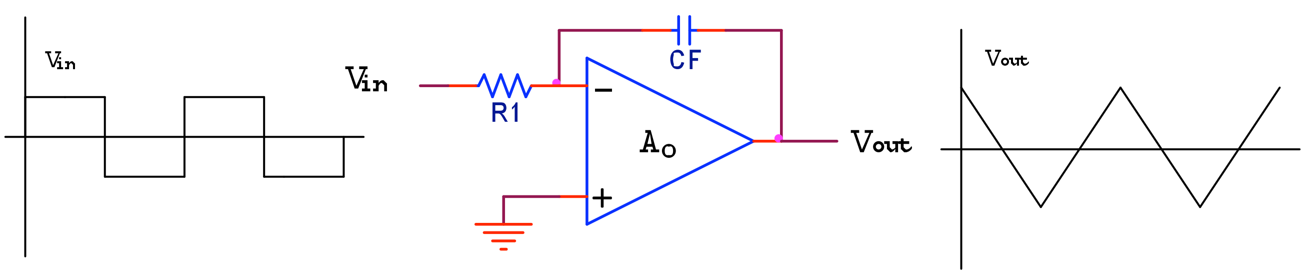
$$\text{Here } \beta = -\frac{R_1}{R_F} \text{ Therefore, } A = \frac{A_O}{1 - A_O \frac{R_1}{R_F}} = \frac{R_F}{\frac{1}{A_O} R_F - R_1} \cong -\frac{R_F}{R_1} = \frac{1}{\beta}$$

- **The Differential Amplifier**

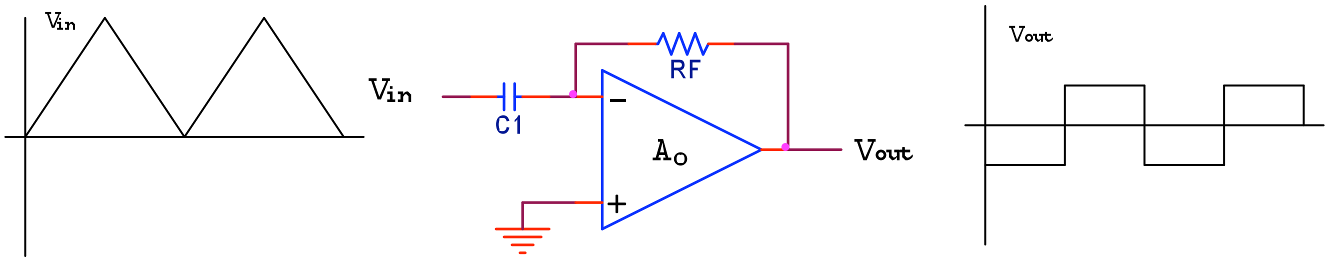


$$V_{out} = -\frac{R_F}{R_1} V_b + \left(1 + \frac{R_F}{R_1}\right)\left(\frac{R_x}{R_x + R_a}\right) V_a \text{ if } R_a = R_1 \text{ and } R_F = R_x \text{ then } V_{out} = \left(V_a - V_b\right)\frac{R_F}{R_1}$$

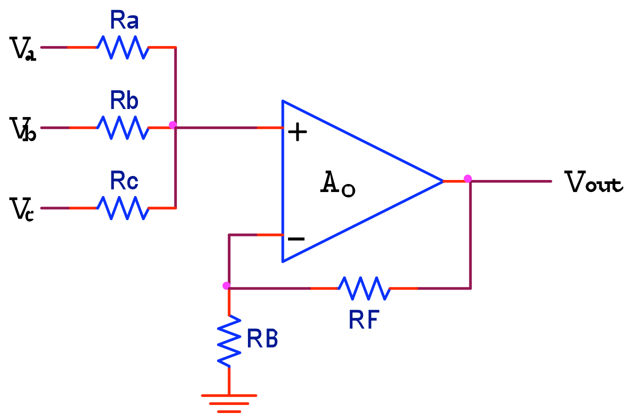
- **The Integrator**



- **The Differentiator**



- **The Non-Inverting Summing Amplifier**



$$V_{out} = \left(1 + \frac{R_F}{R_B}\right)\left(\frac{R_A}{R_a}V_a + \frac{R_A}{R_b}V_b + \frac{R_A}{R_c}V_c\right) \text{ where } R_A = \frac{1}{\frac{1}{R_a} + \frac{1}{R_b} + \frac{1}{R_c}}$$

$$\text{If } R_a = R_b = R_c \text{ then } V_{out} = \left(1 + \frac{R_F}{R_B}\right)\left(\frac{V_a + V_b + V_c}{3}\right)$$