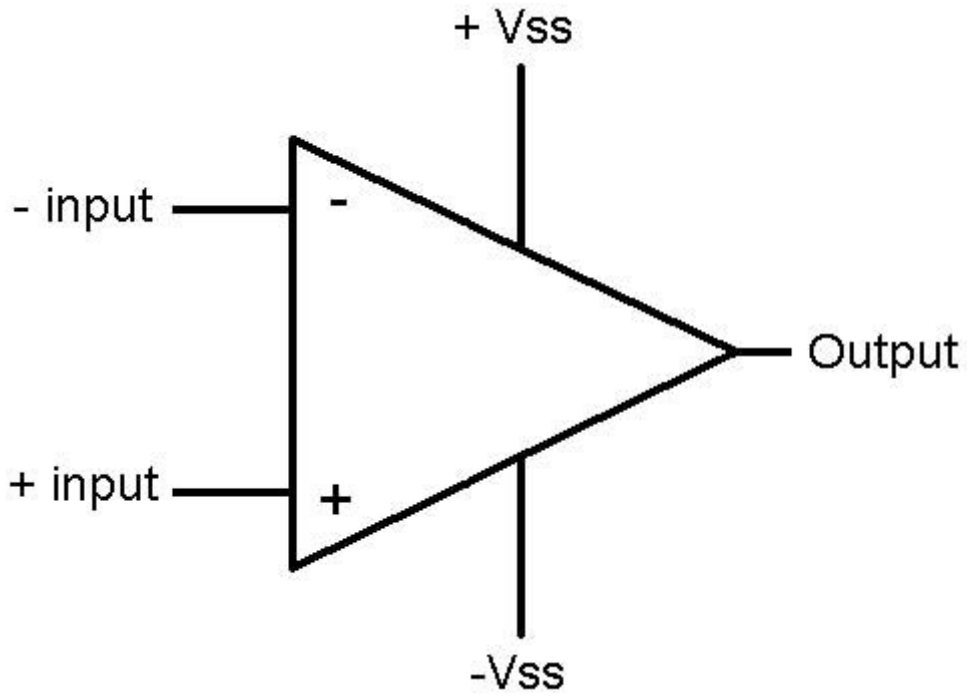
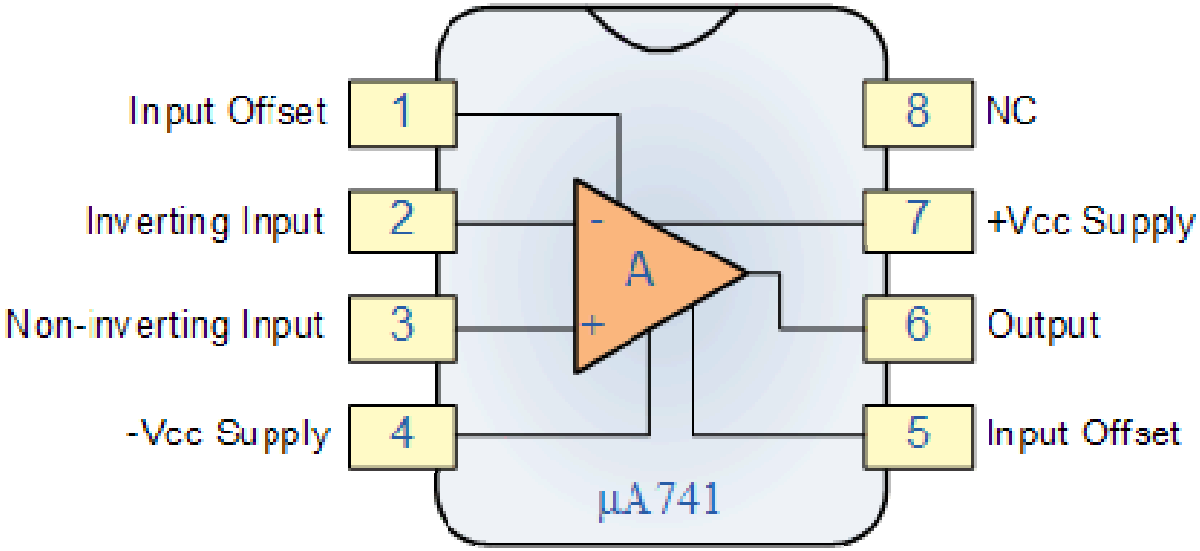
Amplificadores Operacionais – AMP OP

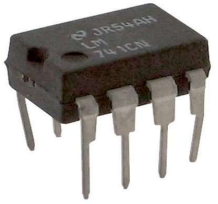


Objetivos

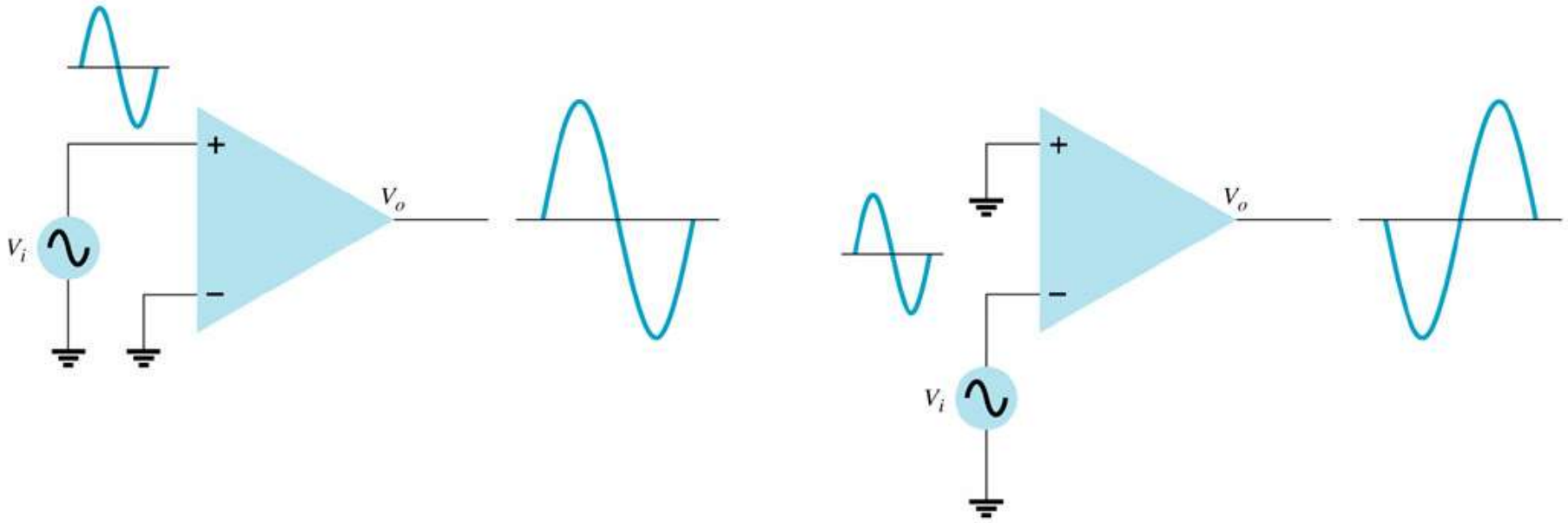
- Analisar o funcionamento do AMP OP
- Apresentar seus elementos internos
- Amplificador em malha aberta
- Amplificador com realimentação
- Conceito de terra virtual

AMP OP – Circuito Integrado



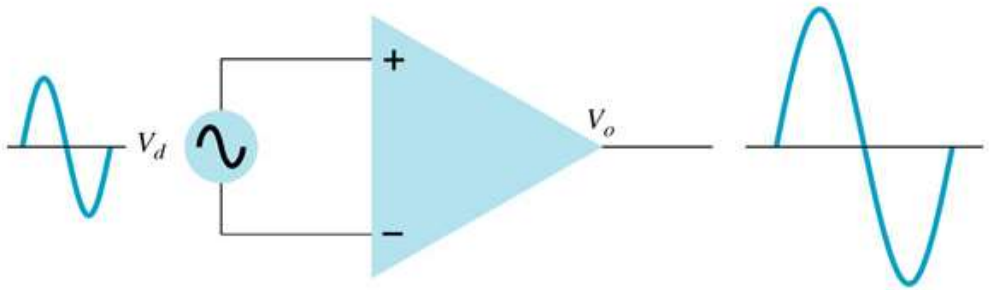


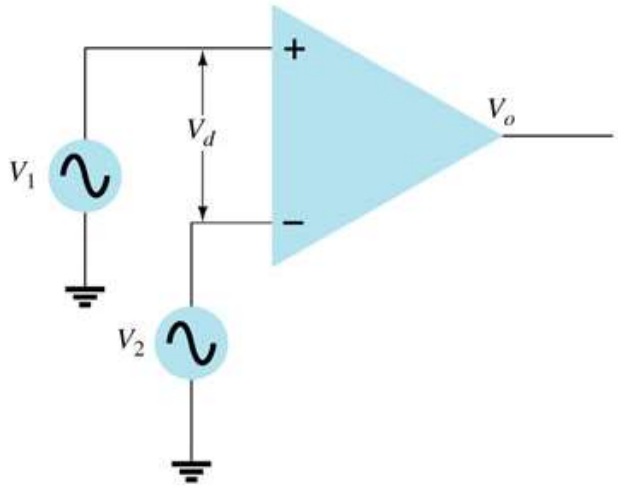
AMP OP – Operação



Entrada única

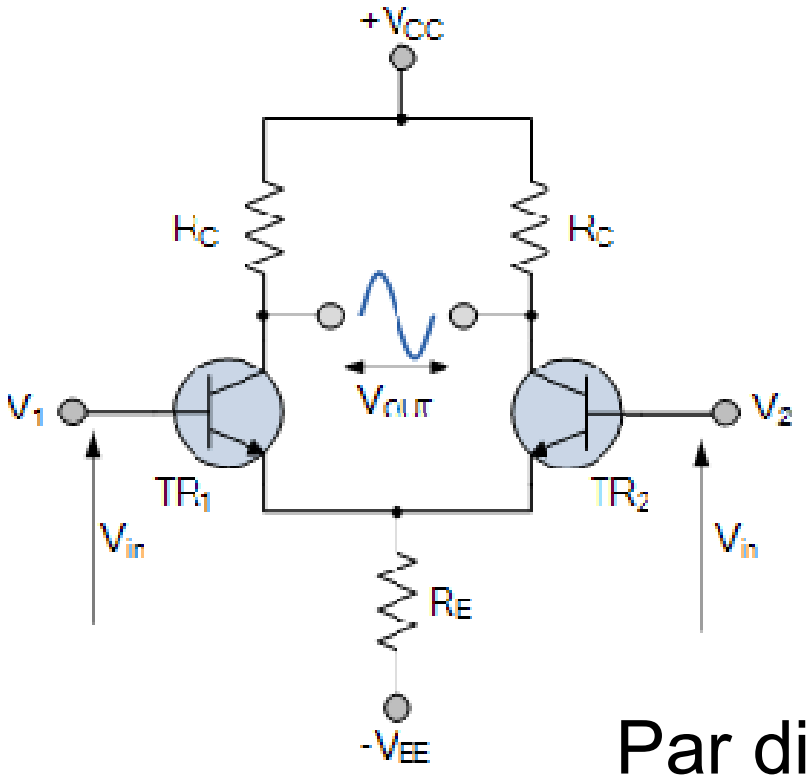
AMP OP – Operação





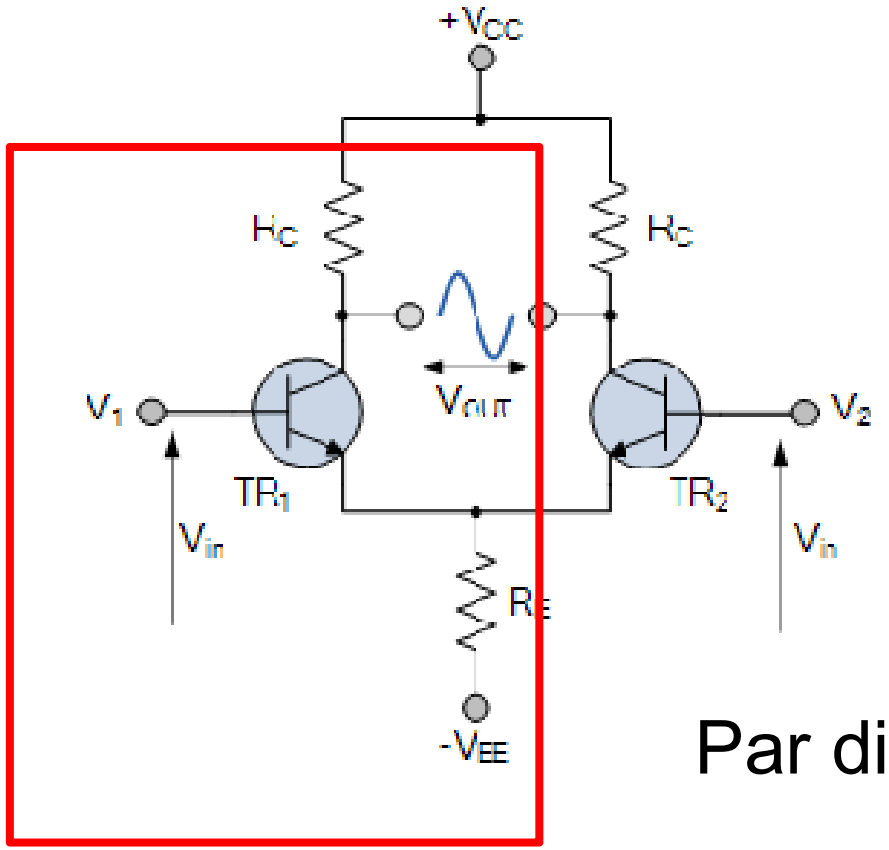
Entrada diferencial

AMP OP – Amplificação



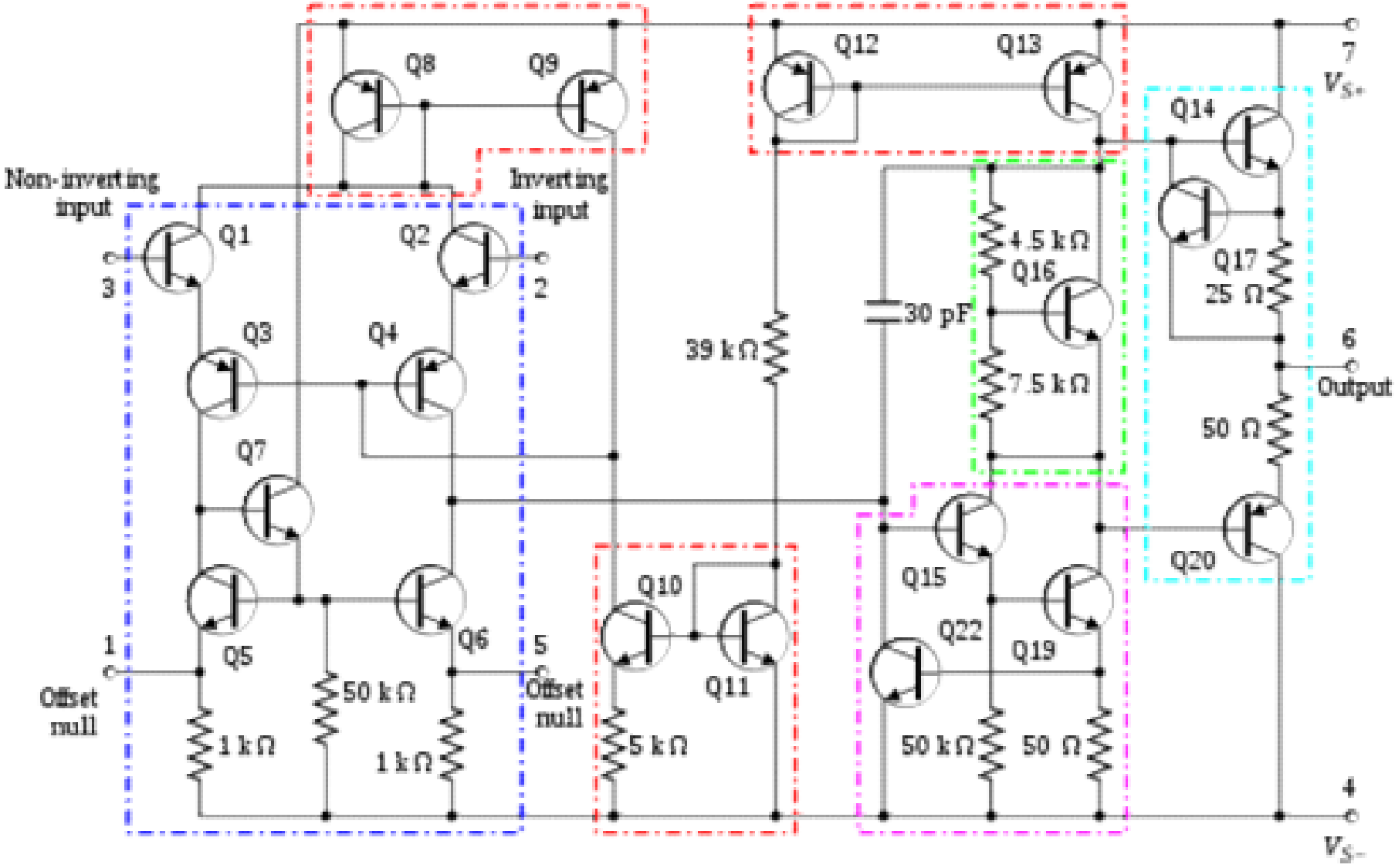
Par diferencial

AMP OP – Amplificação

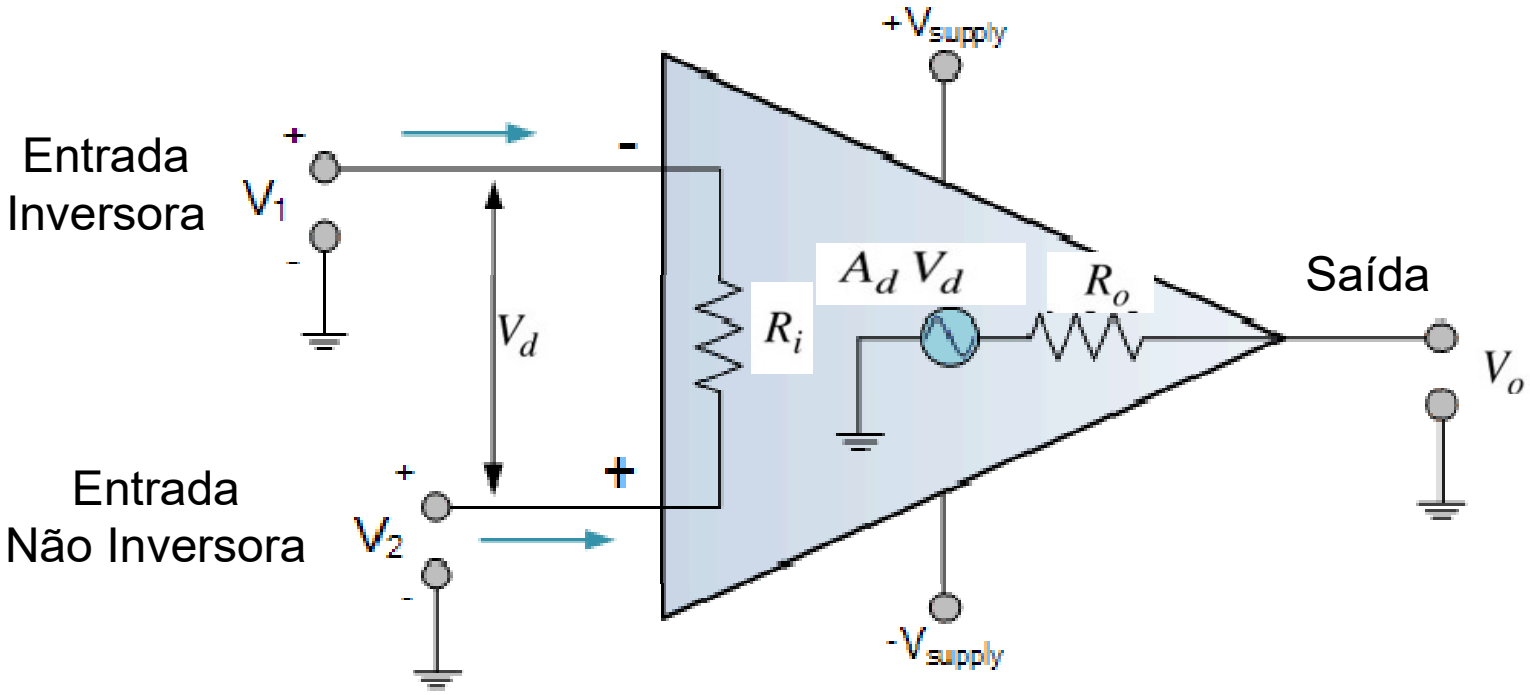


Par diferencial

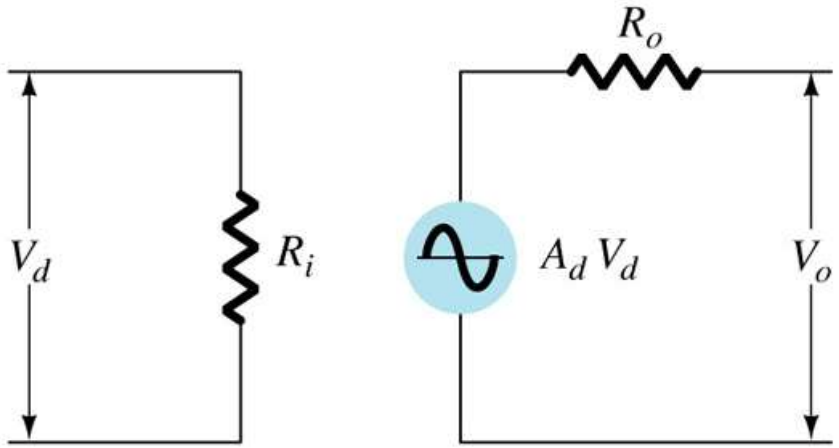
AMP OP – Diagrama Elétrico



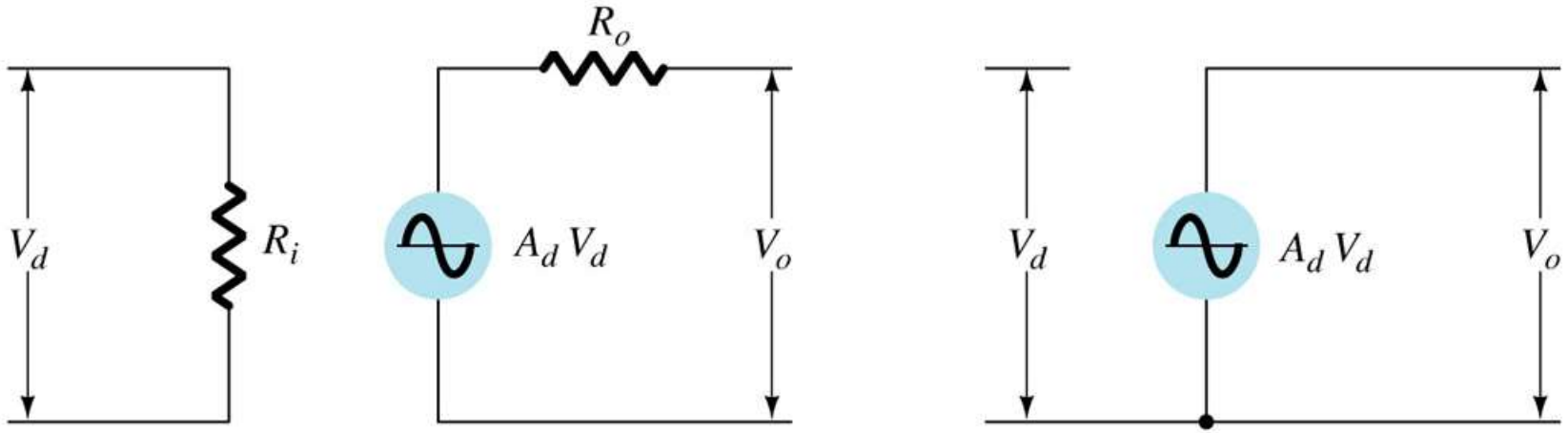
AMP OP – Modelo



AMP OP – Circuito equivalente



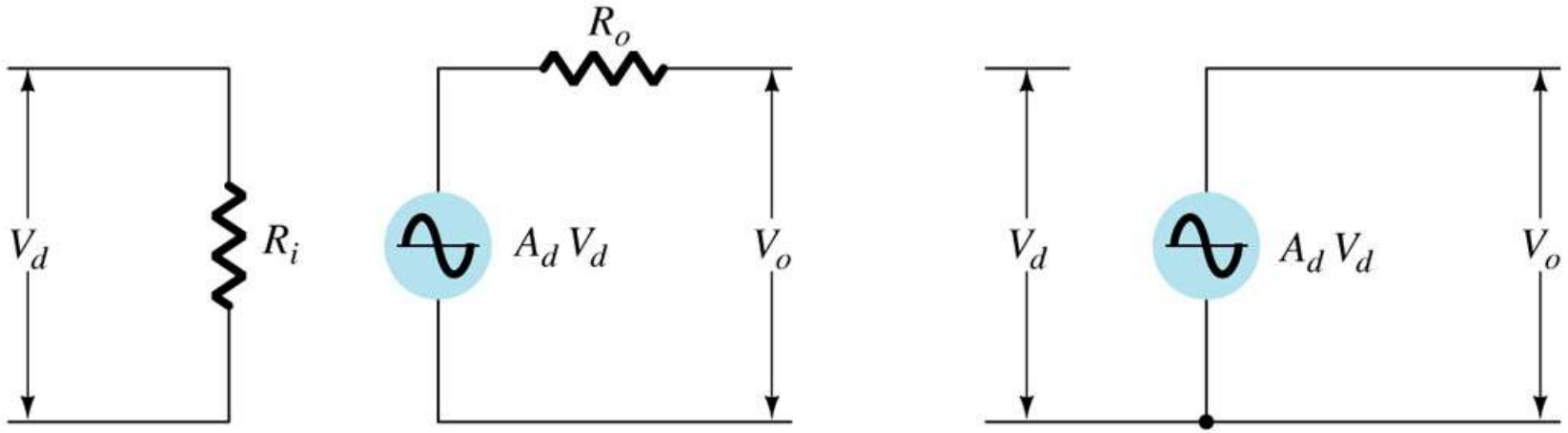
AMP OP – Circuito equivalente



AMP OP ideal $\Rightarrow$

$R_i = \infty$; $R_o = 0$; $A_d = \infty$

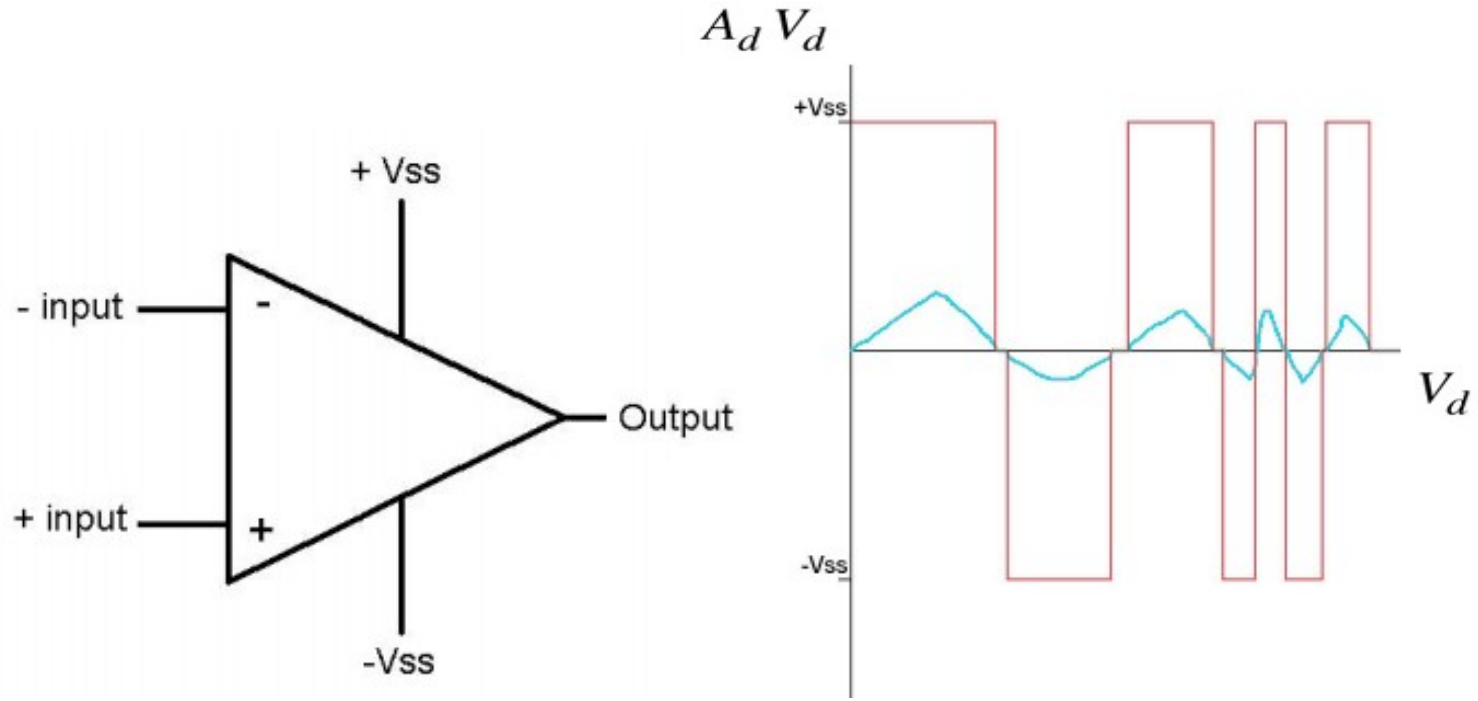
AMP OP – Circuito equivalente



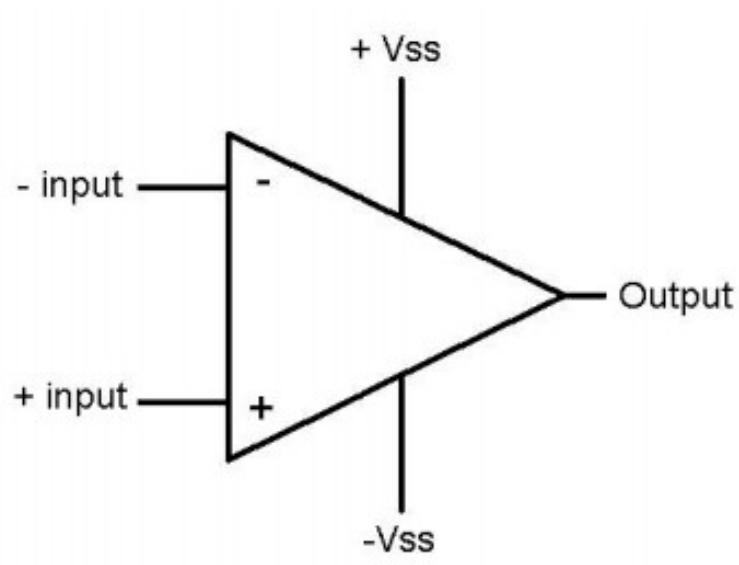
$R_i = \infty$; $R_o = 0$; $\boxed{A_d = \infty}$

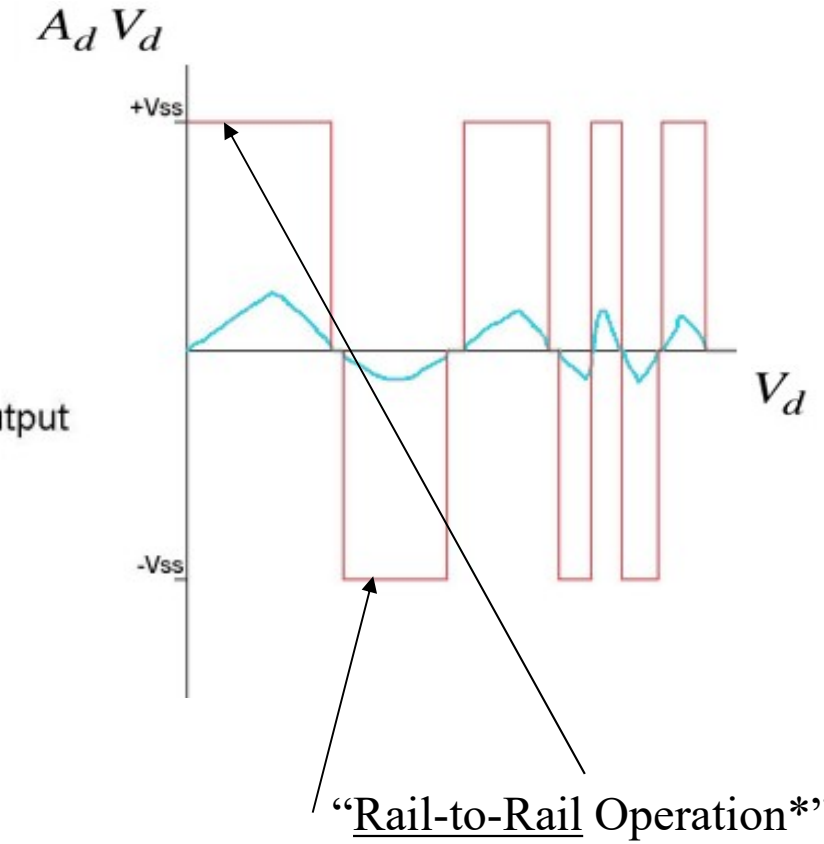
→ Se $V_d \neq 0$ ⇒ $V_o = \infty$!!!

AMP OP – Limites da tensão de saída



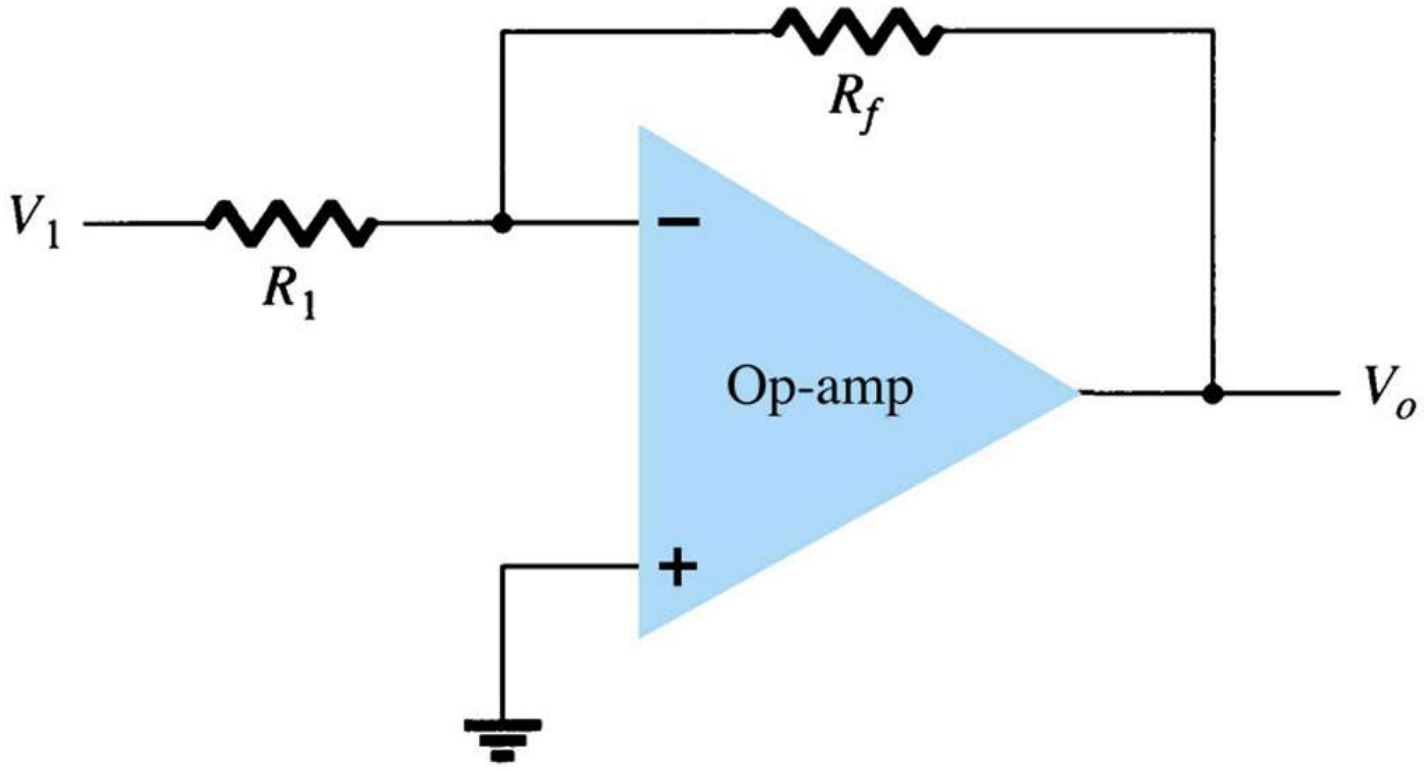
AMP OP – Limites da tensão de saída



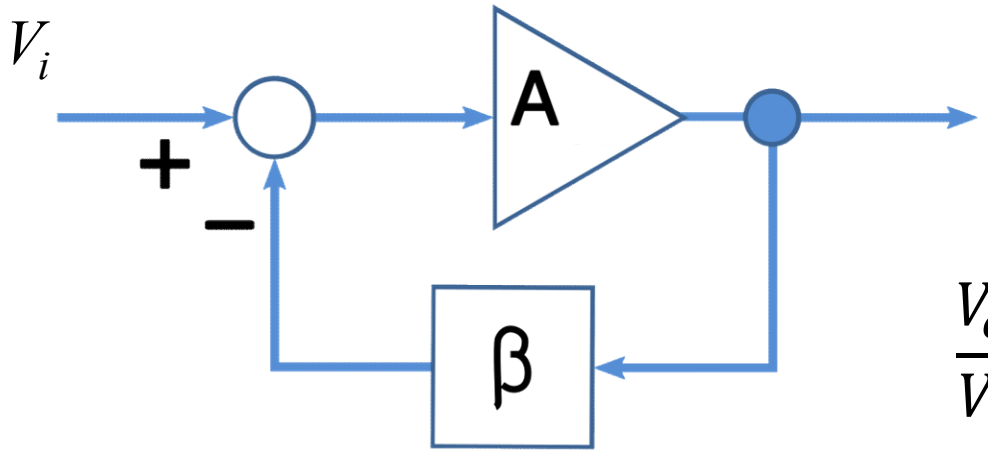


* Apenas alguns modelos operam dessa forma

AMP OP – Circuito com realimentação NEGATIVA

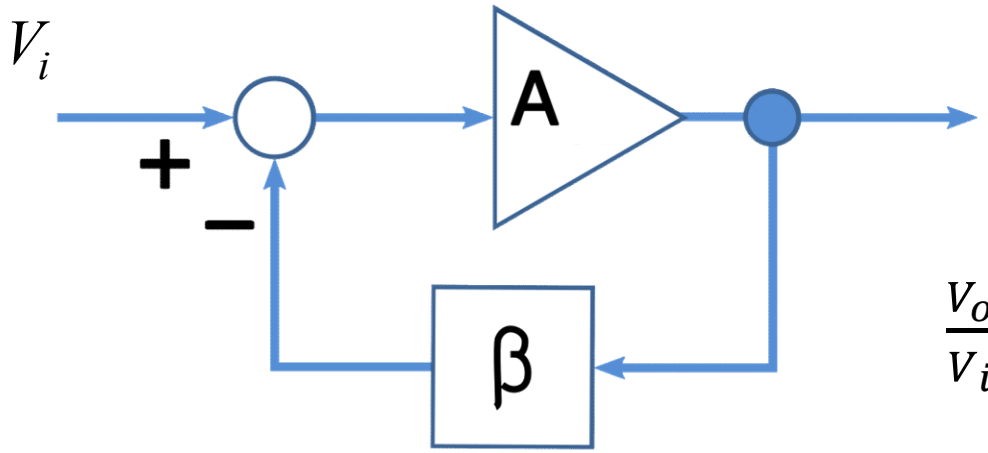


AMP OP – Circuito com realimentação NEGATIVA



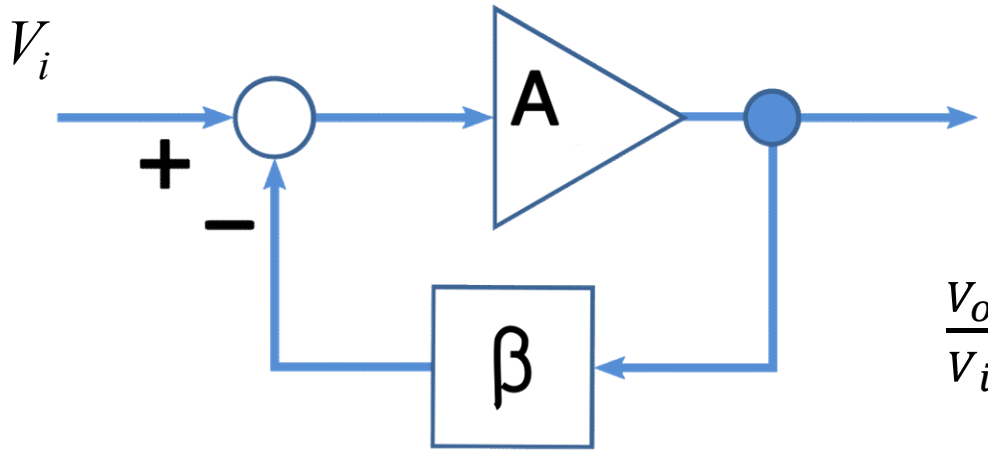
$$\frac{V_o}{V_i} = \frac{A}{1 + \beta A}$$

AMP OP – Circuito com realimentação NEGATIVA



$$\frac{V_o}{V_i} = \frac{A}{1+\beta A} \cong \frac{1}{\beta}$$

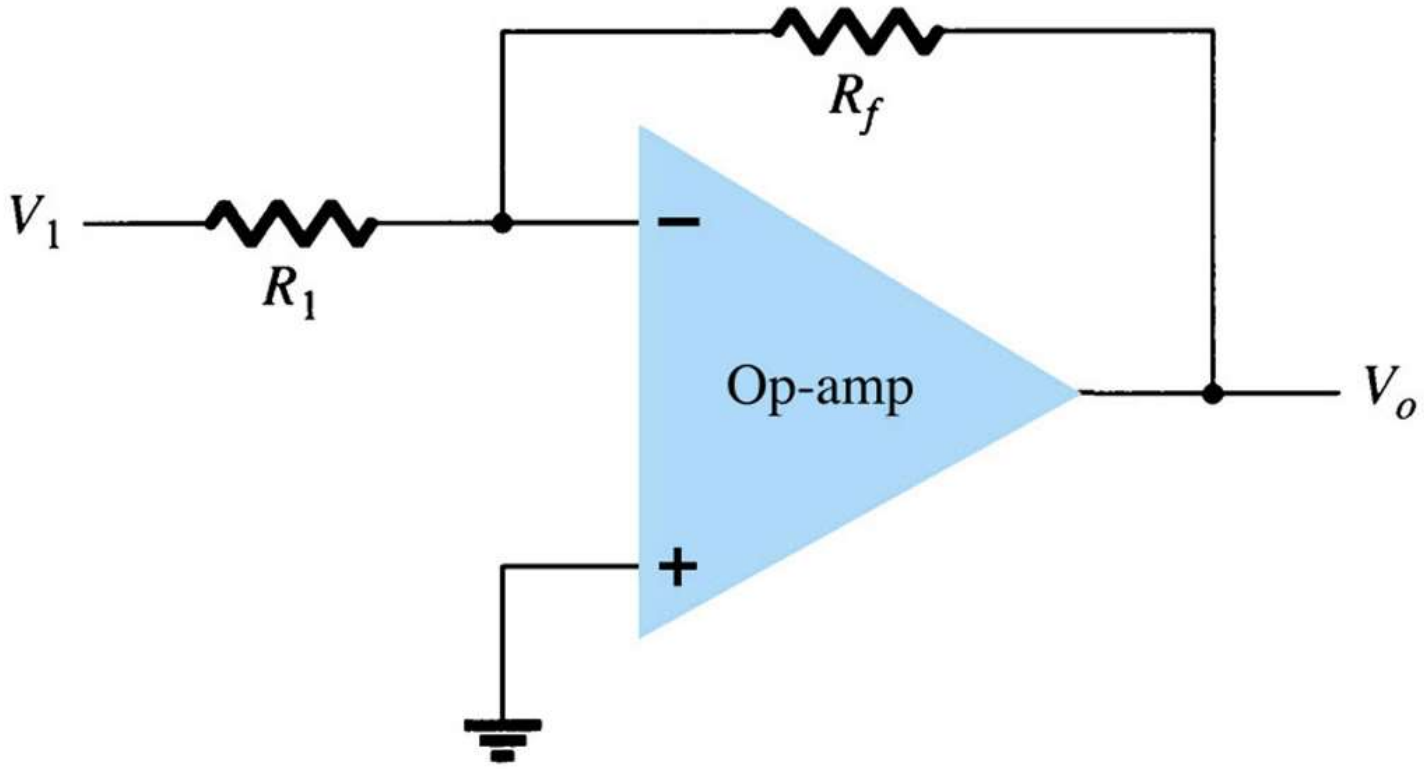
AMP OP – Circuito com realimentação NEGATIVA



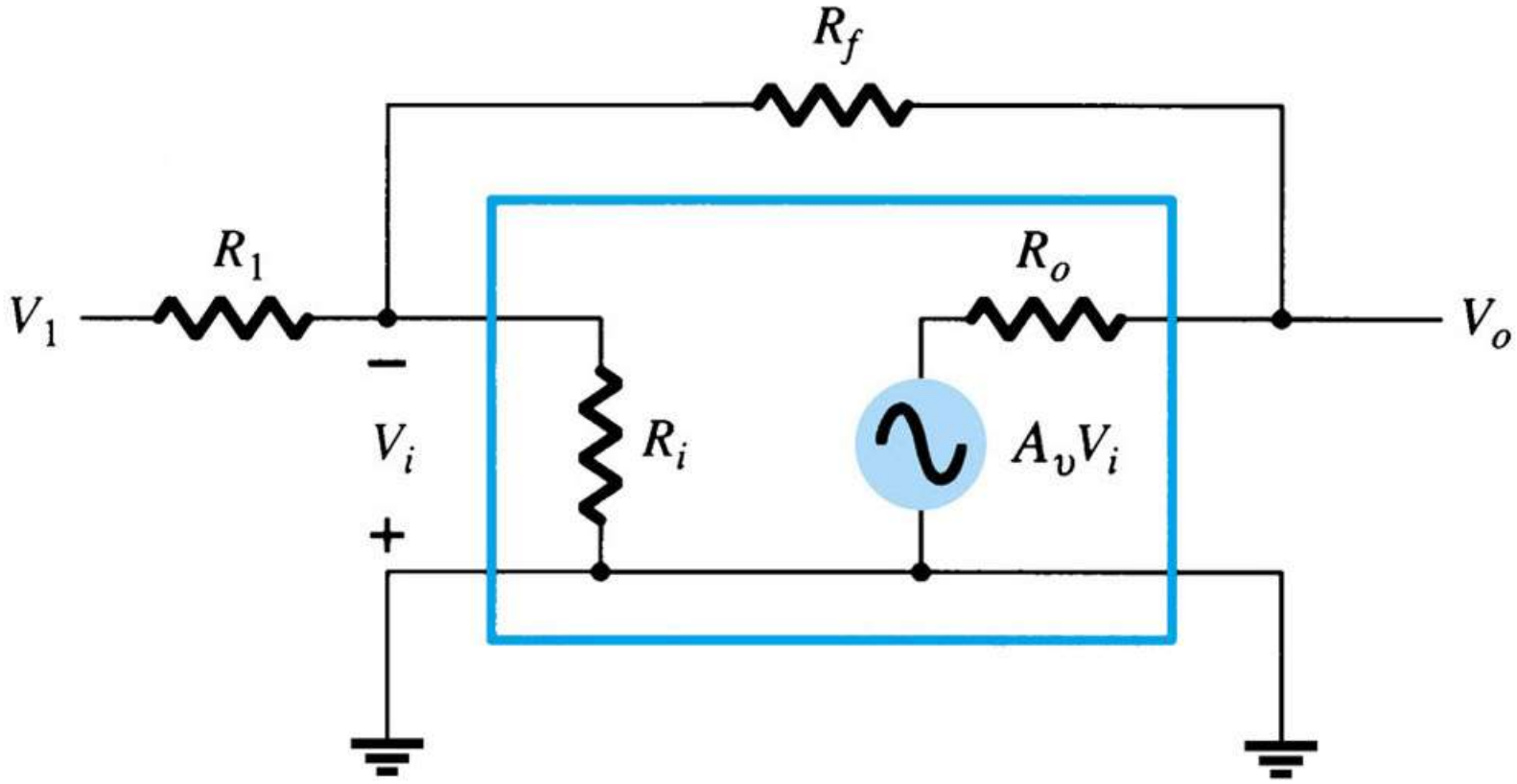
$$\frac{V_o}{V_i} = \frac{A}{1+\beta A} \cong \frac{1}{\beta}$$

Ganho em malha fechada

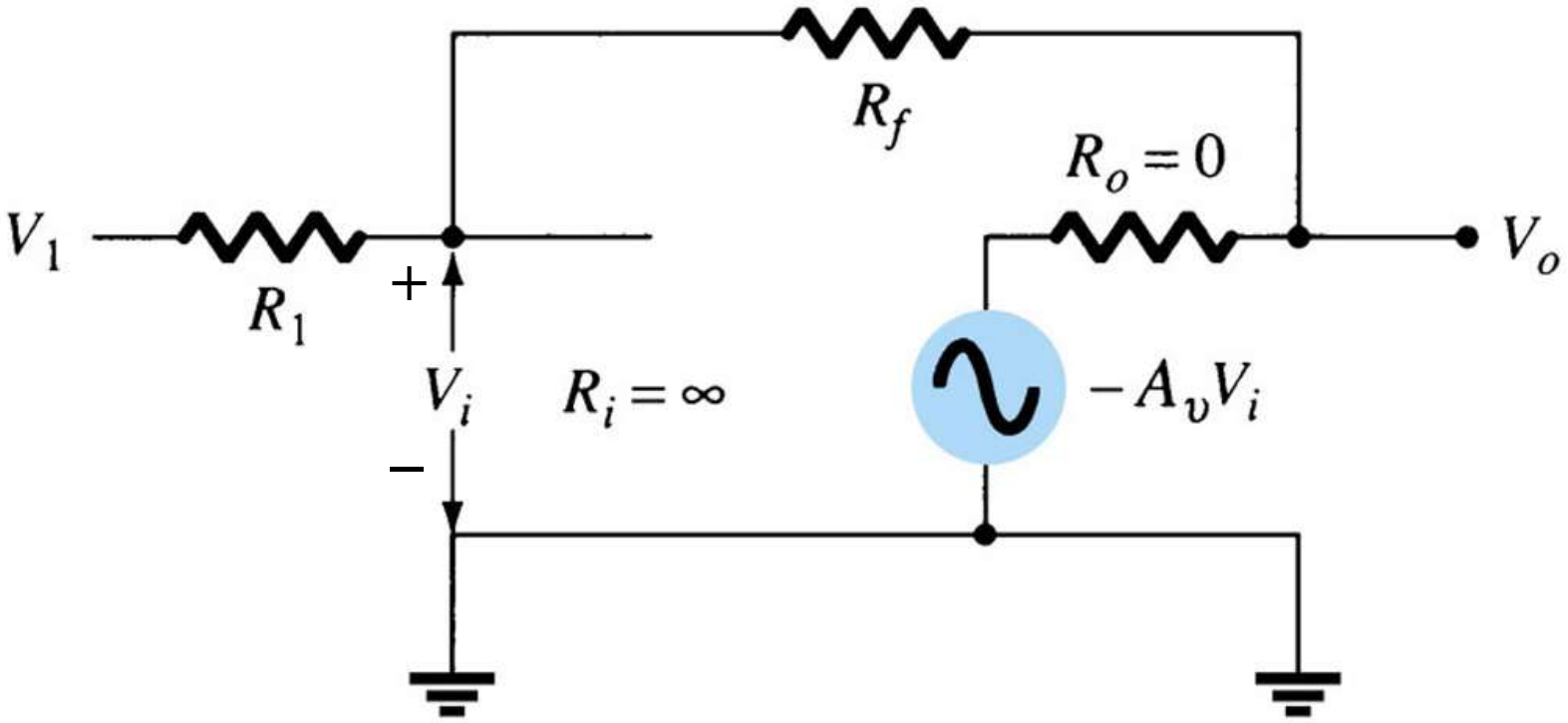
AMP OP – Amplificador Inversor



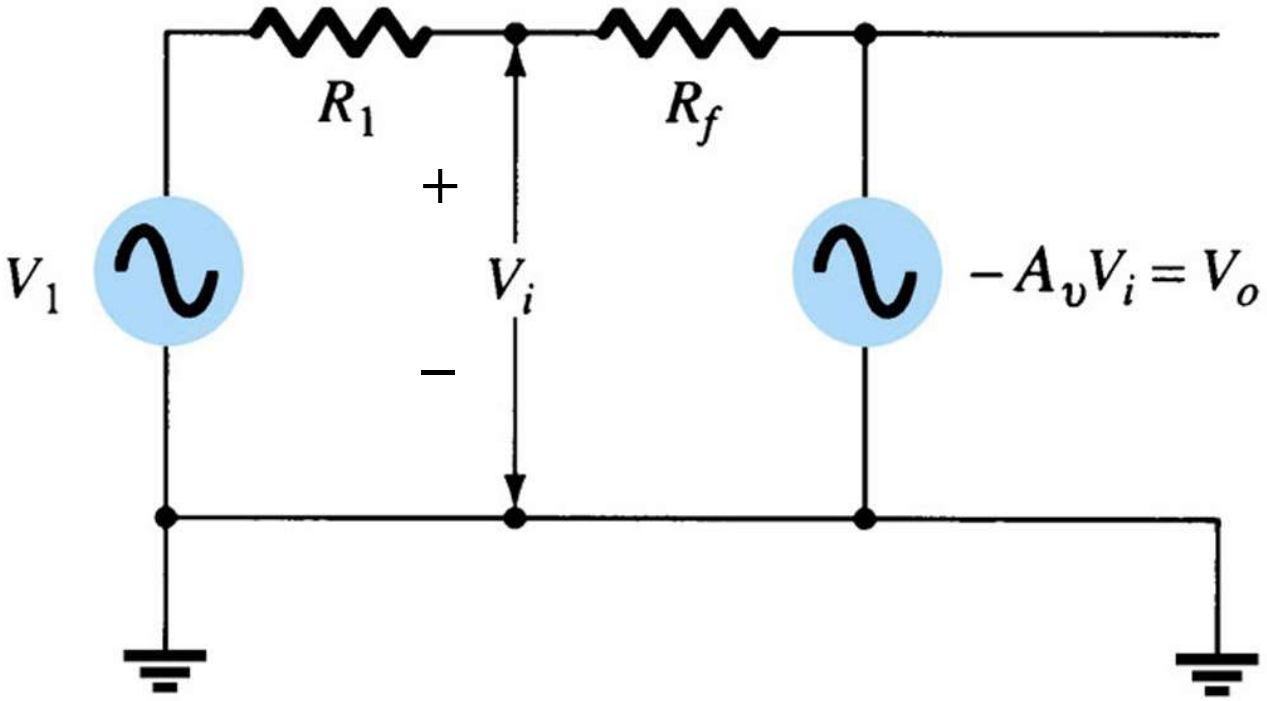
AMP OP – Amplificador Inversor



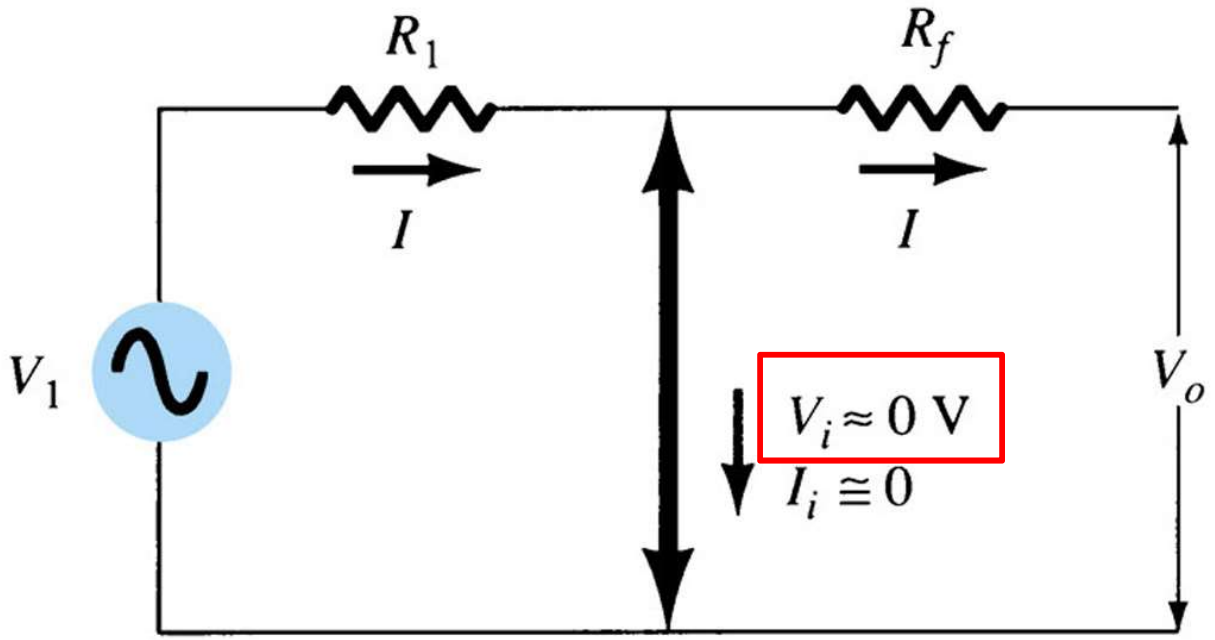
AMP OP – Amplificador Inversor



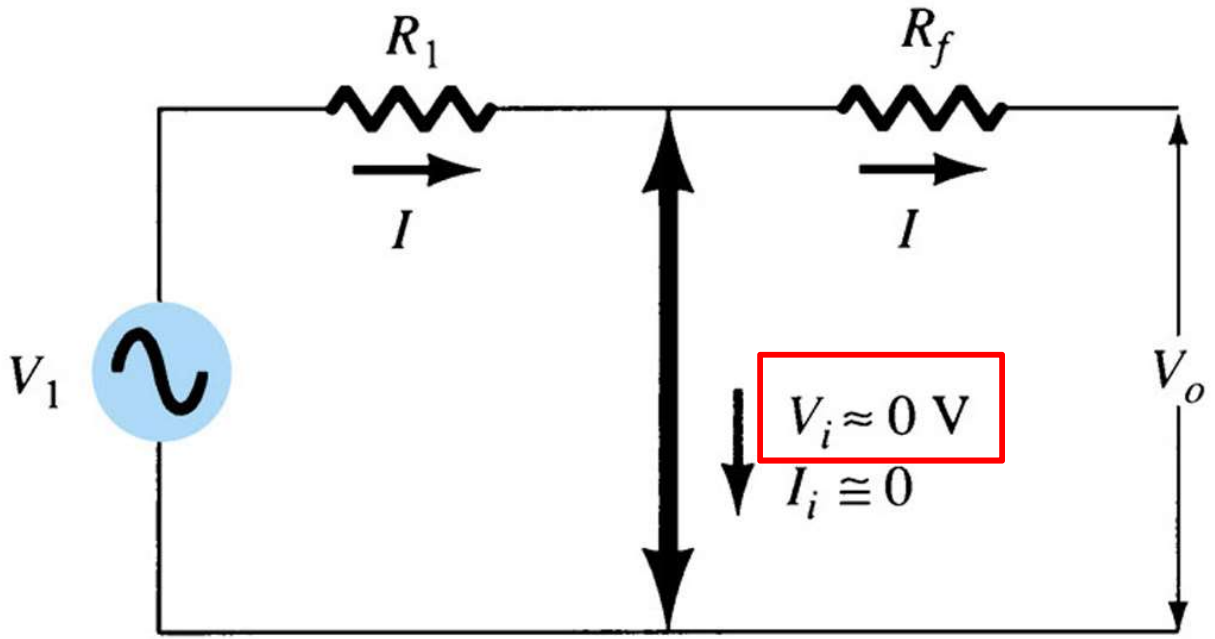
AMP OP – Amplificador Inversor



AMP OP – Amplificador Inversor

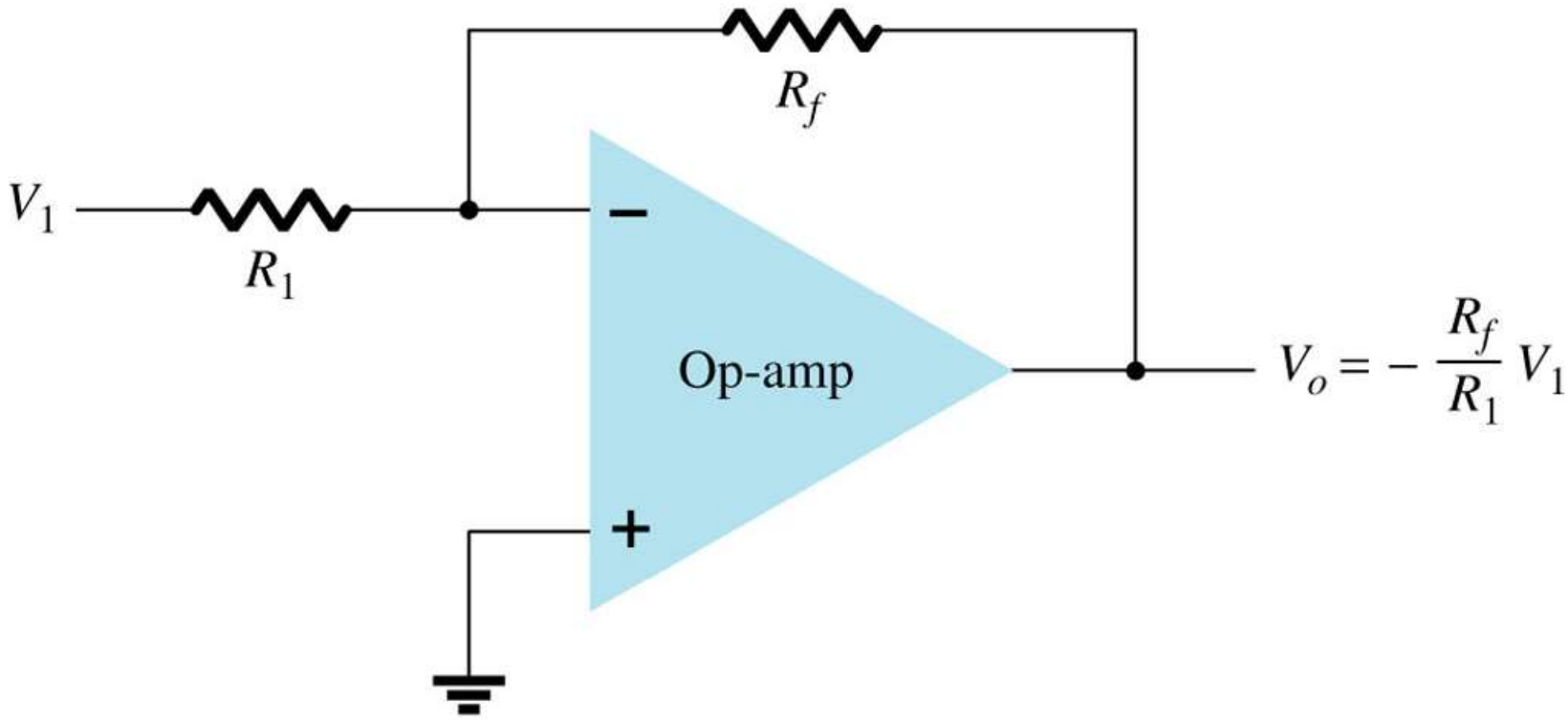


AMP OP – Amplificador Inversor

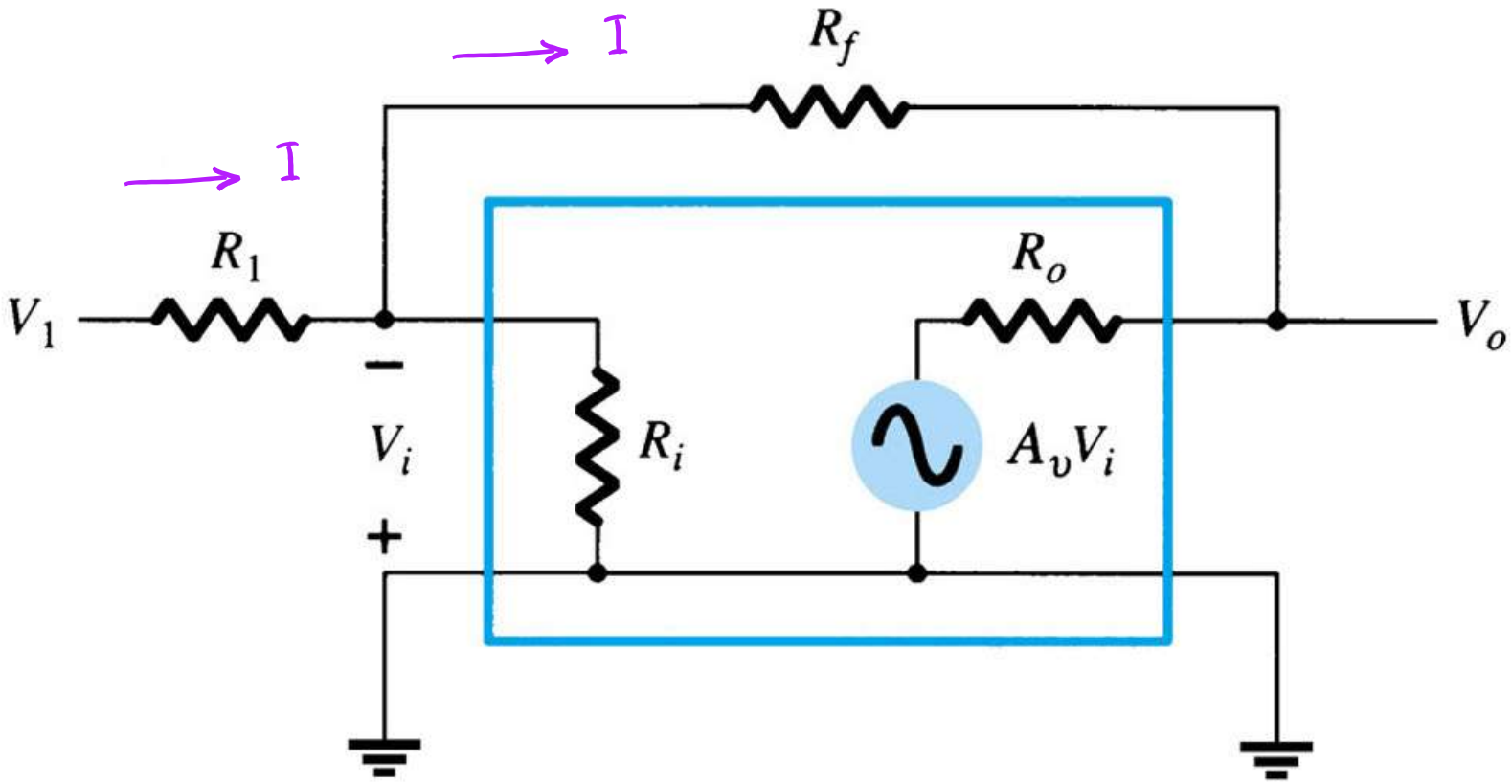


Mas $A_v = \infty$

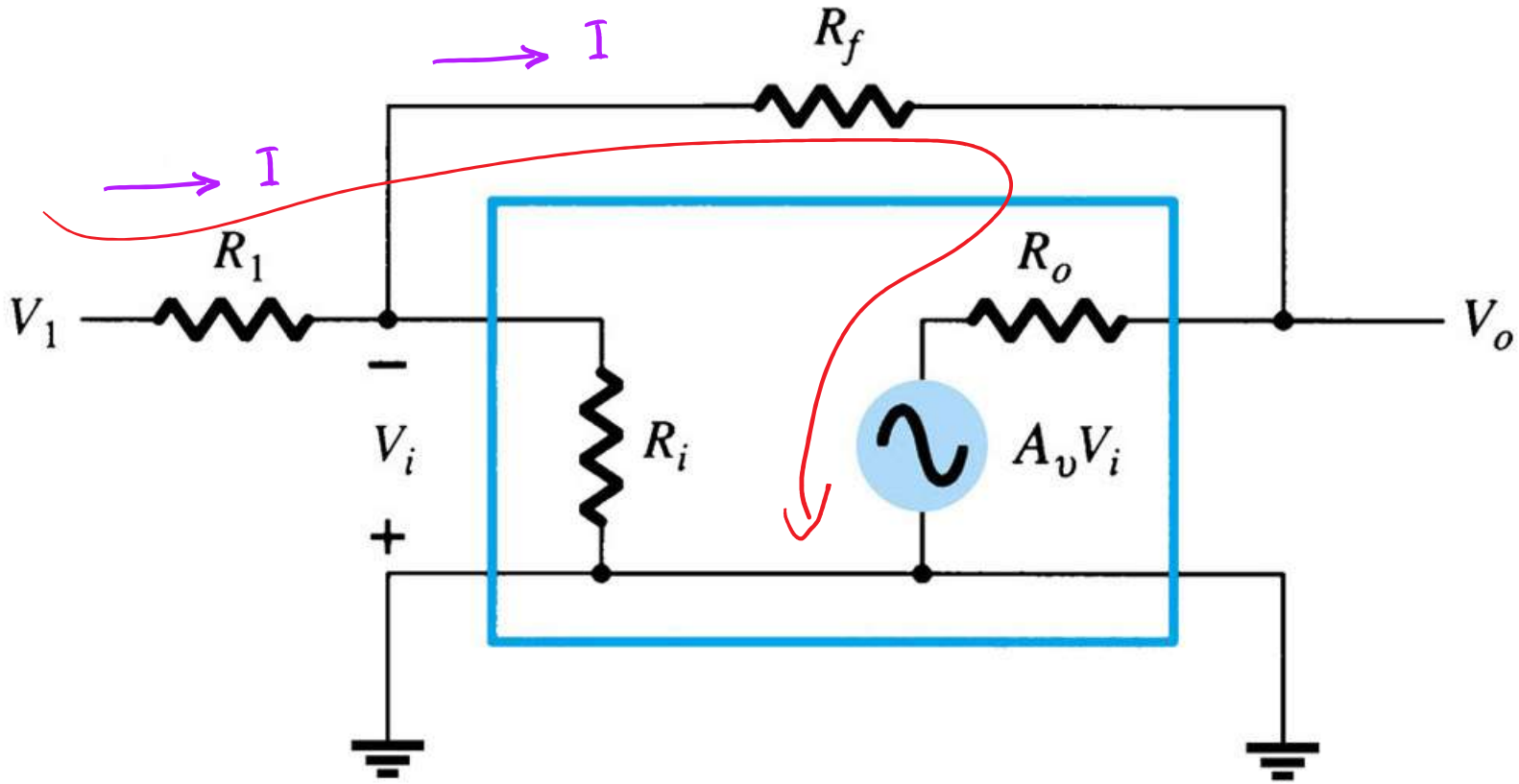
AMP OP – Amplificador Inversor



AMP OP – Amplificador Inversor

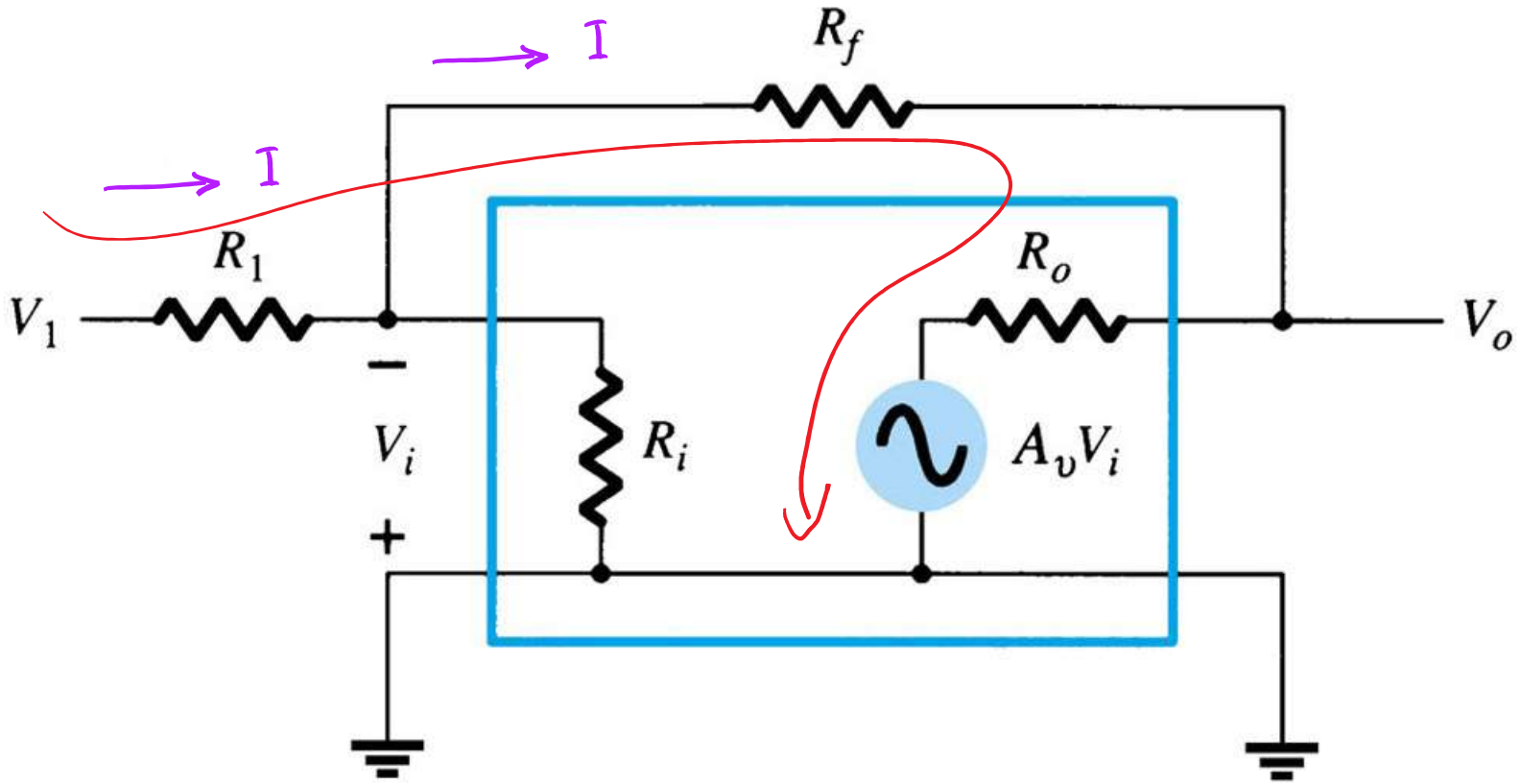


AMP OP – Amplificador Inversor



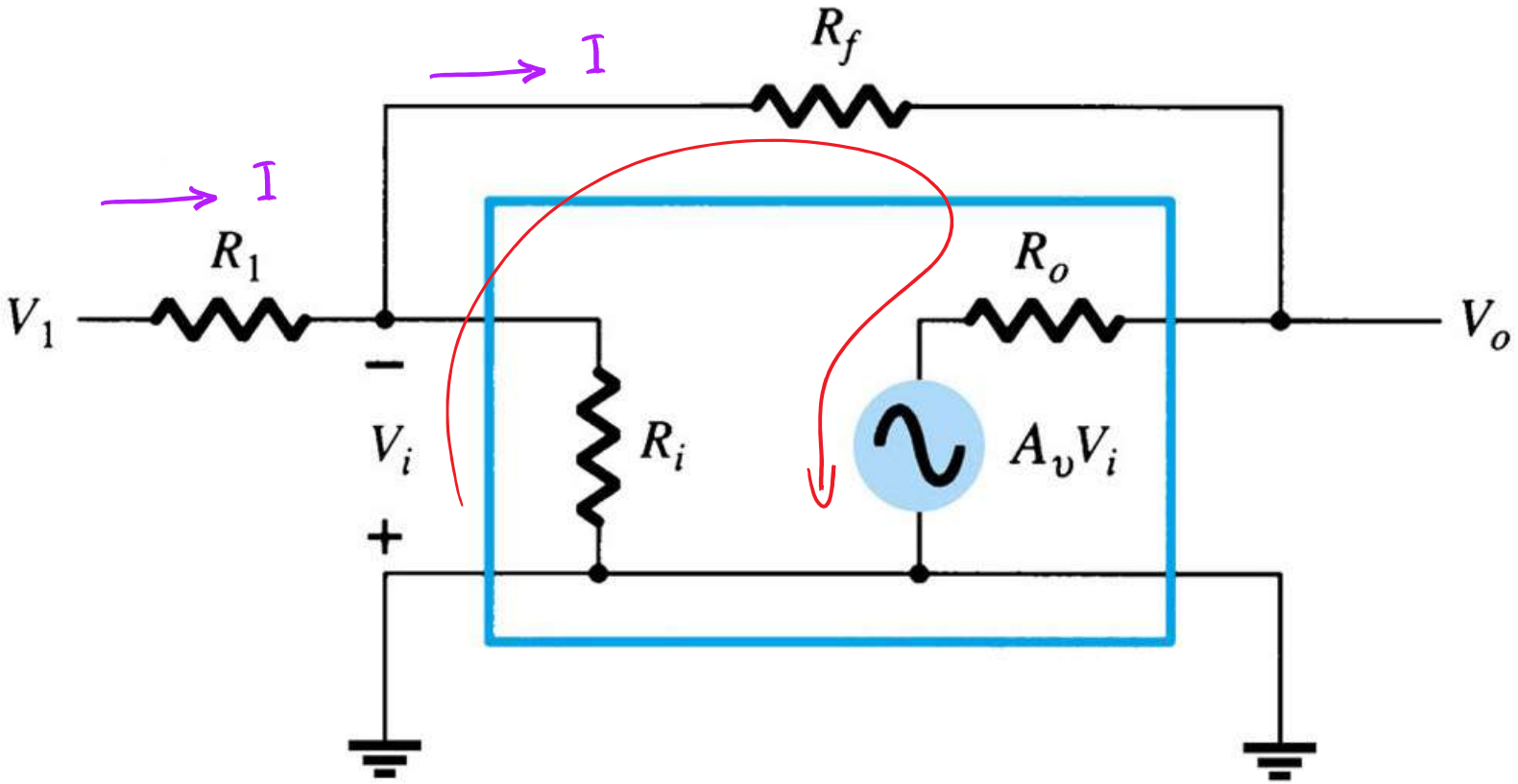
$$V_1 - R_1 \cdot I - R_f \cdot I - A_v \cdot V_i = 0$$

AMP OP – Amplificador Inversor



$$V_1 - I(R_1 + R_f) - A_v \cdot v_i = 0 \quad (1)$$

AMP OP – Amplificador Inversor



$$v_i + R_f \cdot I + A_v \cdot v_i = 0 \qquad (2)$$

AMP OP – Amplificador Inversor

$$V_1 - I(R_1 + R_f) - A_v \cdot v_i = 0 \quad (1)$$

$$v_i + R_f \cdot I + A_v \cdot v_i = 0 \quad (2)$$

AMP OP – Amplificador Inversor

$$V_1 - I(R_1 + R_f) - A_v \cdot v_i = 0 \quad (1)$$

$$v_i + R_f \cdot I + A_v \cdot v_i = 0 \quad (2)$$

De (1): $$I = \frac{V_1 - A_v \cdot v_i}{R_1 + R_f}$$

AMP OP – Amplificador Inversor

$$V_1 - I(R_1 + R_f) - A_v \cdot v_i = 0 \quad (1)$$

$$v_i + R_f \cdot I + A_v \cdot v_i = 0 \quad (2)$$

De (1): $$I = \frac{V_1 - A_v \cdot v_i}{R_1 + R_f} \quad (3)$$

De (2): $$I = -\frac{V_i - A_v \cdot V_i}{R_f} \quad (4)$$

AMP OP – Amplificador Inversor

$$I = \frac{V_i - A_v \cdot V_i}{R_i + R_f} \quad (3)$$

$$I = -\frac{V_i - A_v \cdot V_i}{R_f} \quad (4)$$

$$(3) = (4)$$

AMP OP – Amplificador Inversor

$$I = \frac{V_1 - A_v \cdot v_i}{R_1 + R_f} \quad (3)$$

$$I = -\frac{V_1 - A_v \cdot V_i}{R_f} \quad (4)$$

$$\frac{V_1 - A_v \cdot v_i}{R_1 + R_f} = -\frac{V_i + A_v \cdot v_i}{R_f}$$

AMP OP – Amplificador Inversor

$$\frac{V_1 - A_v \cdot v_i}{R_1 + R_f} = -\frac{v_i + A_v \cdot v_i}{R_f}$$

Usando $A_v \cdot v_i = v_o$

AMP OP – Amplificador Inversor

$$\frac{V_1 - A_v \cdot v_i}{R_1 + R_f} = -\frac{v_i + A_v \cdot v_i}{R_f}$$

Usando $A_v \cdot v_i = v_o$

$$\Rightarrow \left[\frac{V_1}{v_o} - 1\right] \Big/ (R_1 + R_f) = \frac{-1/A_v - 1}{R_f}$$

AMP OP – Amplificador Inversor

$$\frac{V_1 - A_v \cdot v_i}{R_1 + R_f} = -\frac{v_i + A_v \cdot v_i}{R_f}$$

Usando $A_v \cdot v_i = v_o$

$$\Rightarrow \left[\frac{V_1}{v_o} - 1\right] \Big/ (R_1 + R_f) = \frac{1/A_v - 1}{R_f} \to 0$$

AMP OP – Amplificador Inversor

$$\left[\frac{V_1}{V_o} - 1\right] \Big/ (R_1 + R_f) = \frac{0 \quad -1}{R_f}$$

$$\frac{V_1}{V_o} - 1 = - \frac{R_1 + R_f}{R_f}$$

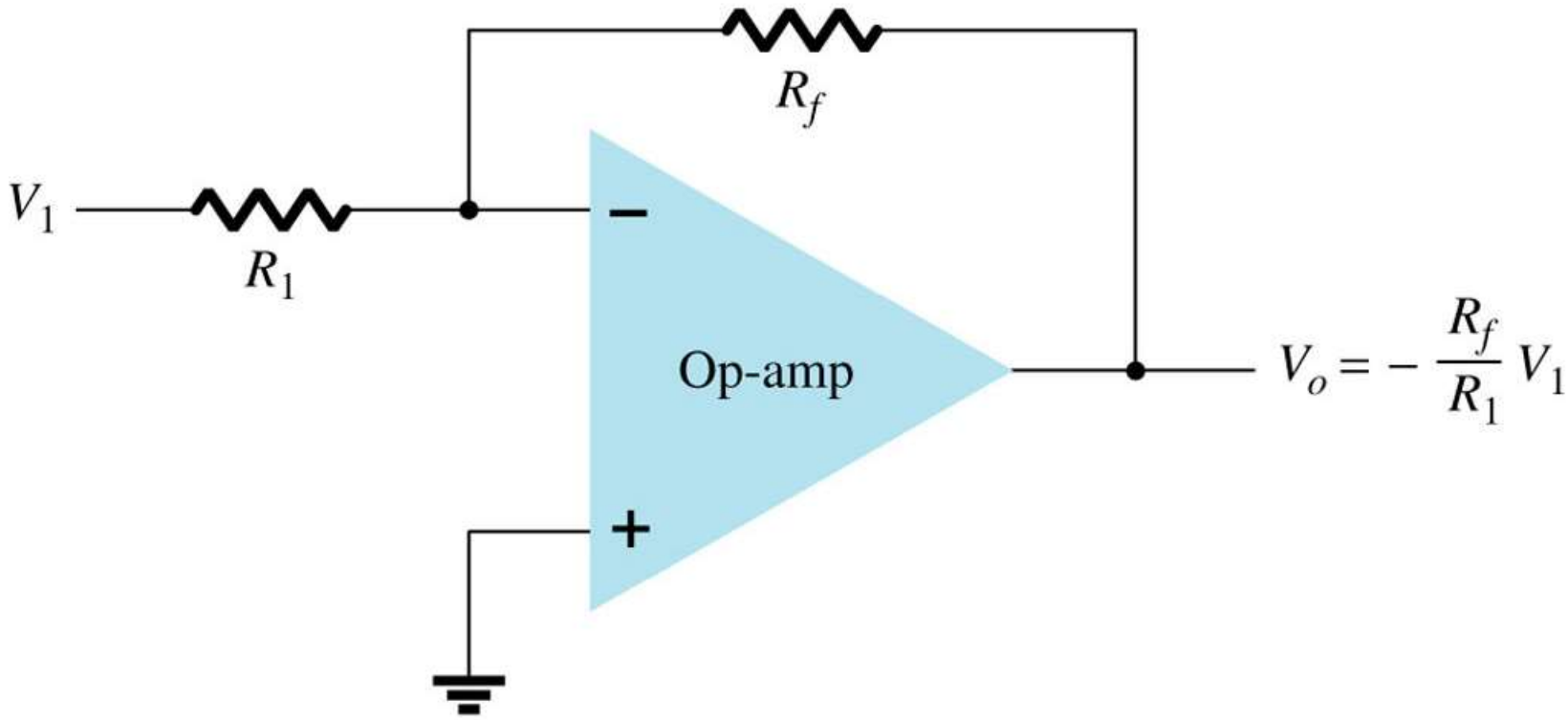
AMP OP – Amplificador Inversor

$$\left[\frac{V_1}{V_o} - 1\right] \Big/ (R_1 + R_f) = \frac{0 \quad - 1}{R_f}$$

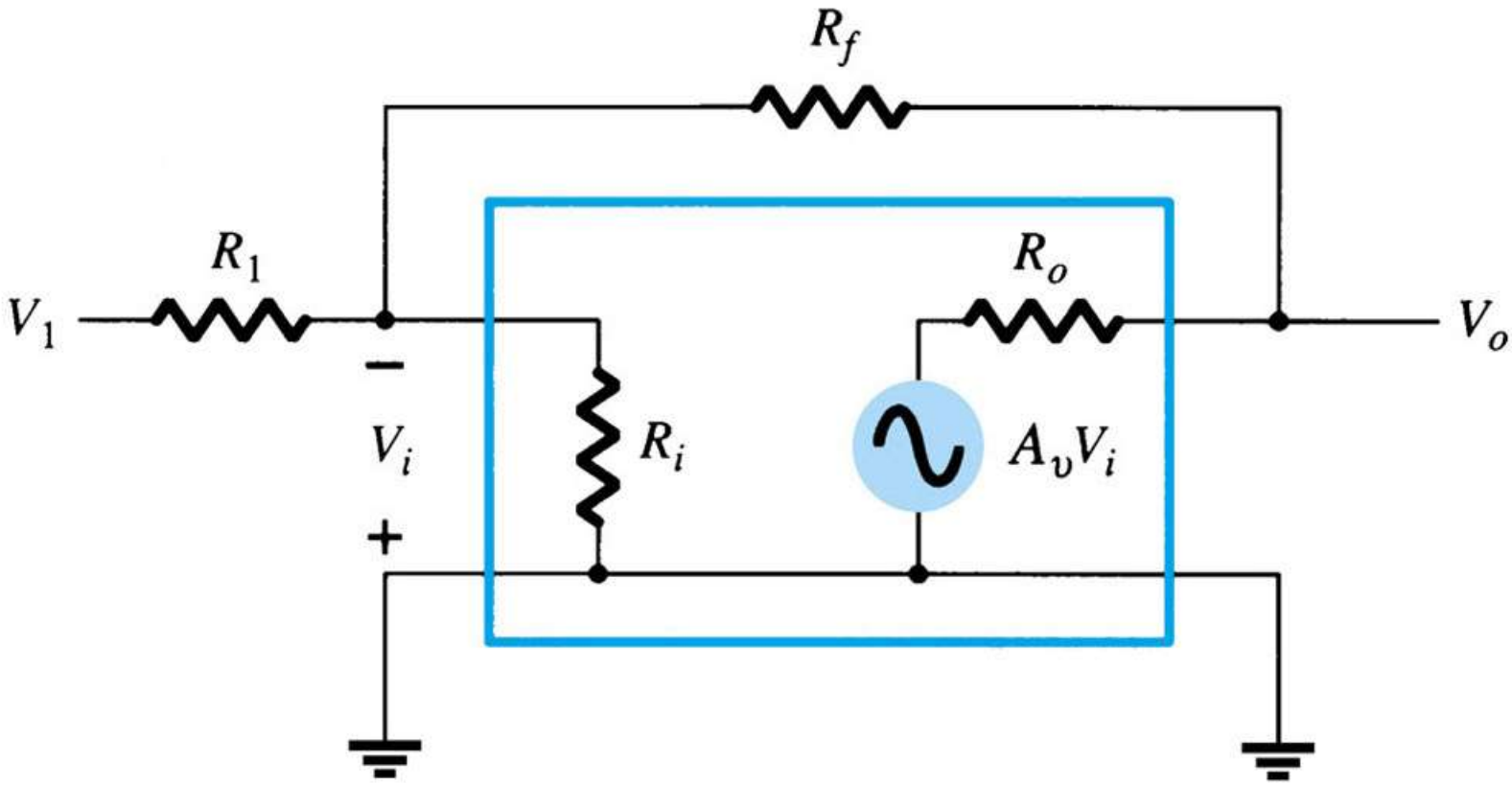
$$\frac{V_1}{V_o} - 1 = - \frac{R_1 + R_f}{R_f}$$

$$\Rightarrow \frac{V_o}{V_1} = - \frac{R_f}{R_1}$$

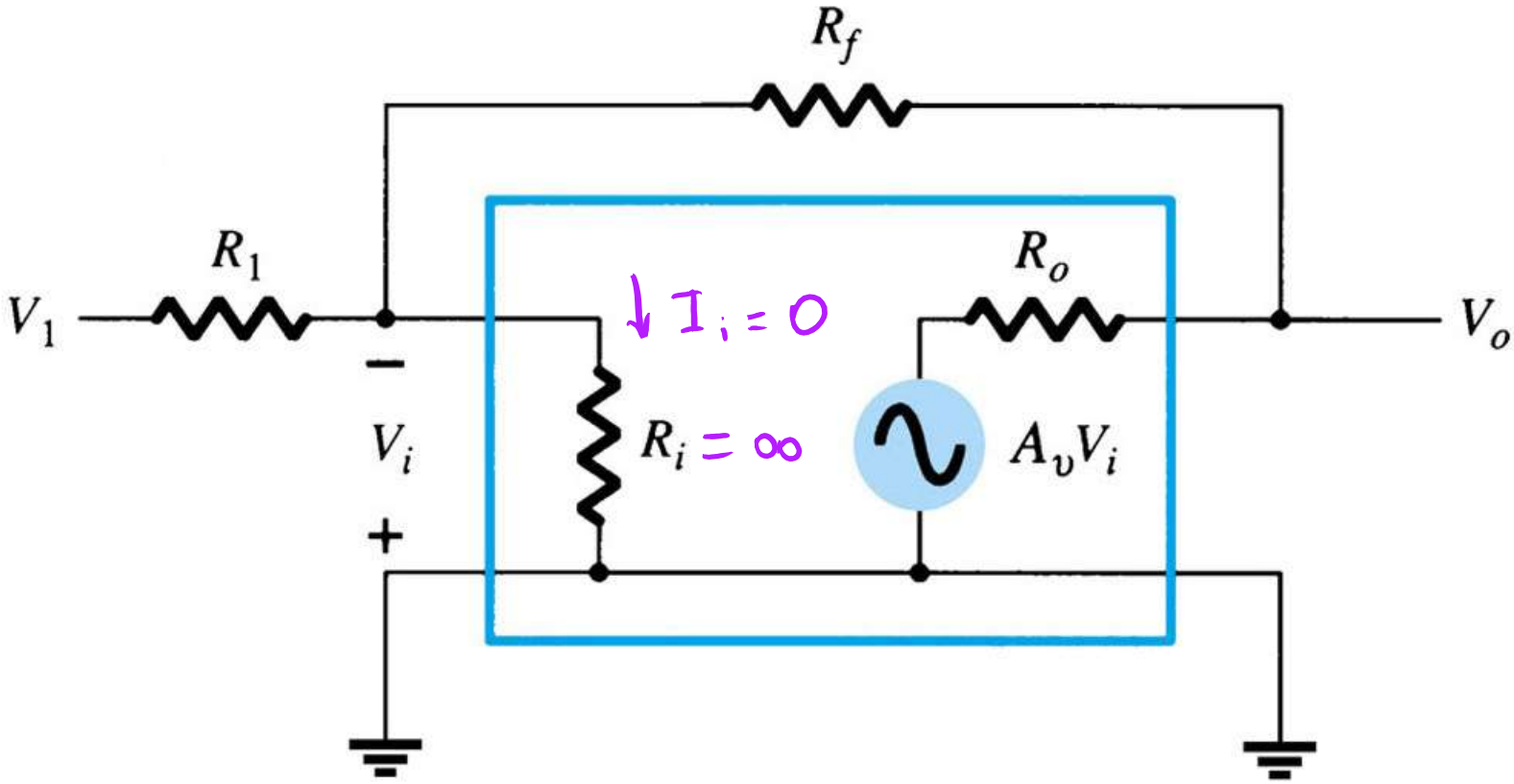
AMP OP – Amplificador Inversor



AMP OP – Terra Virtual

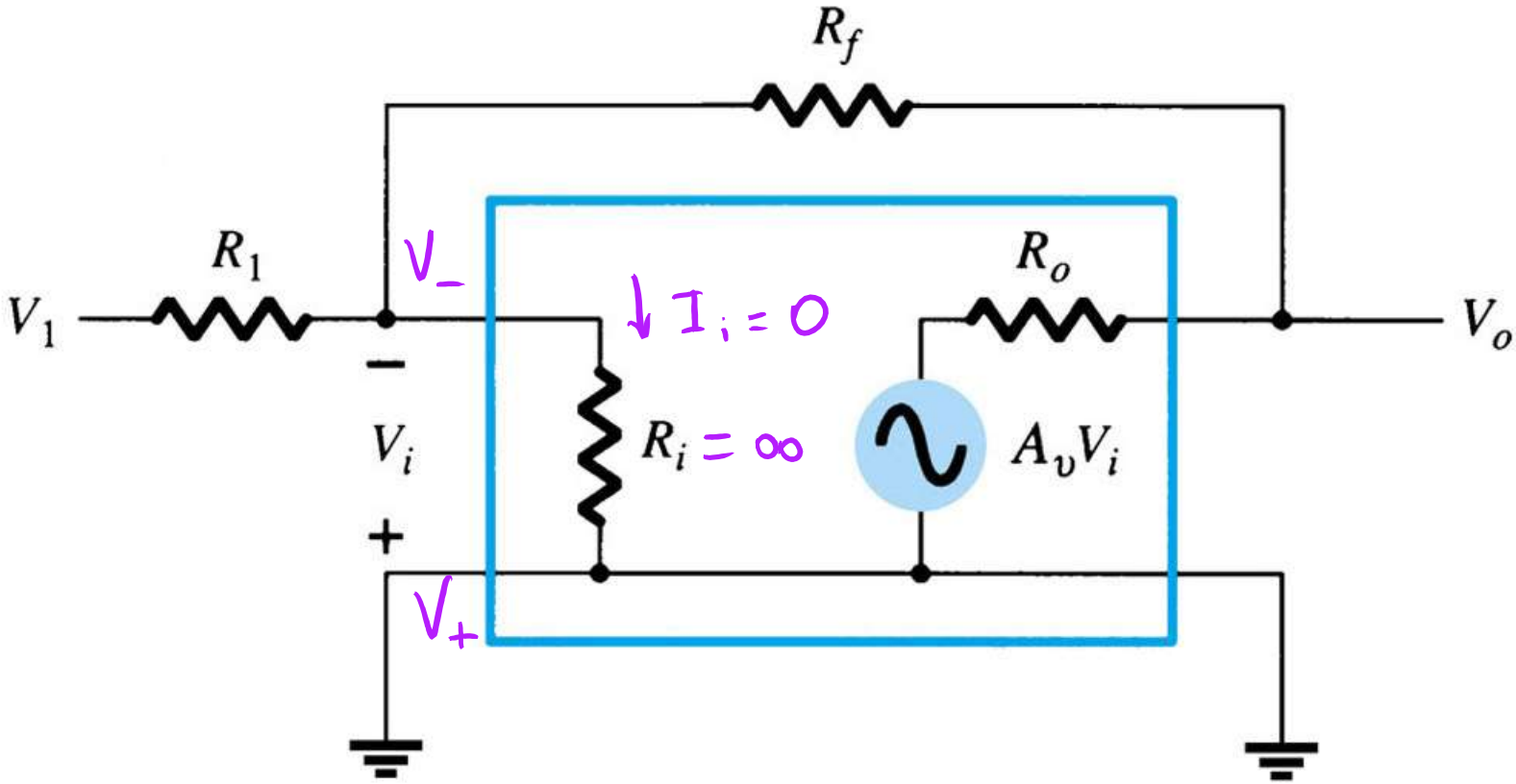


AMP OP – Terra Virtual



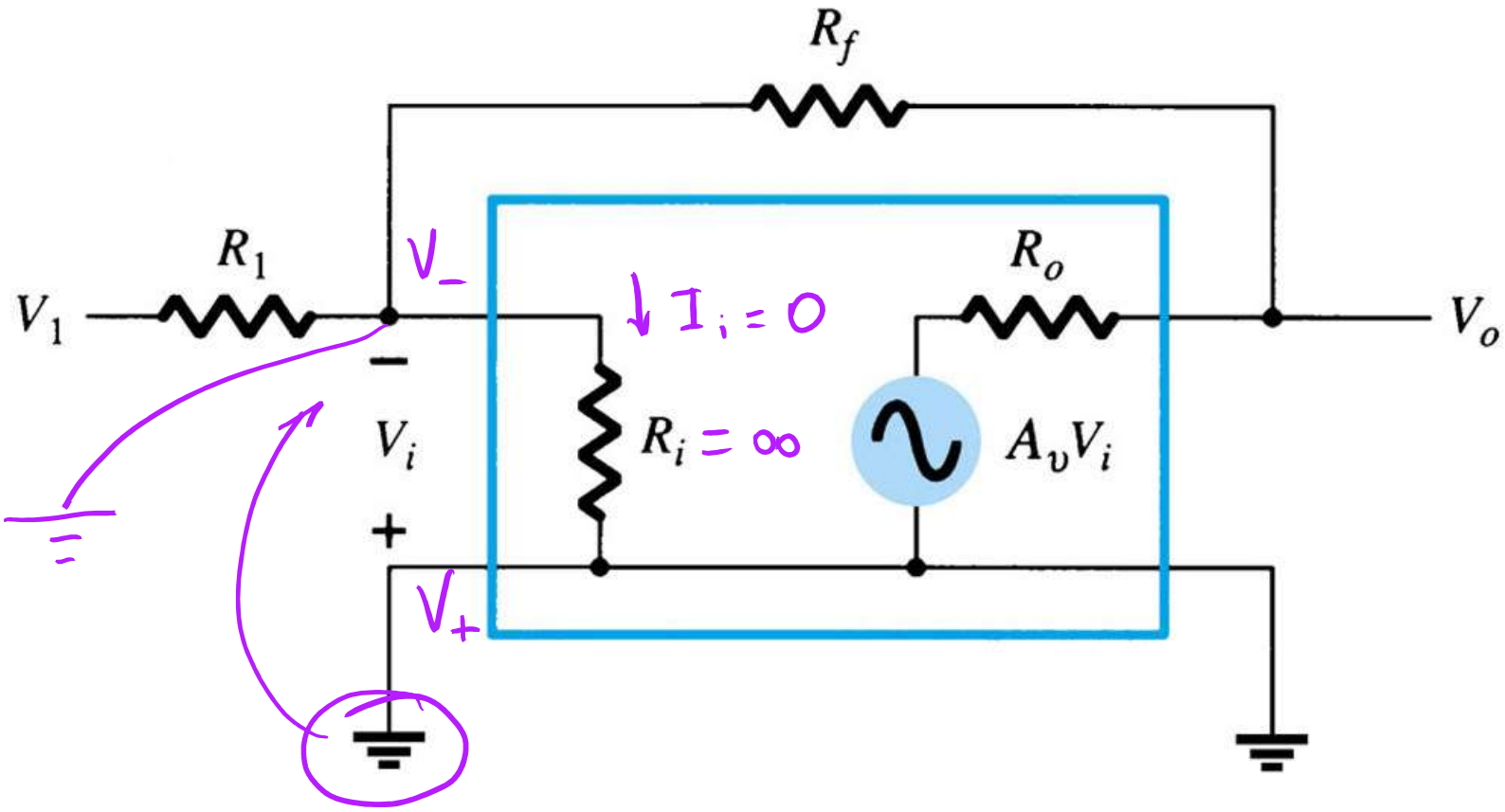
$\Rightarrow v_i = 0$

AMP OP – Terra Virtual

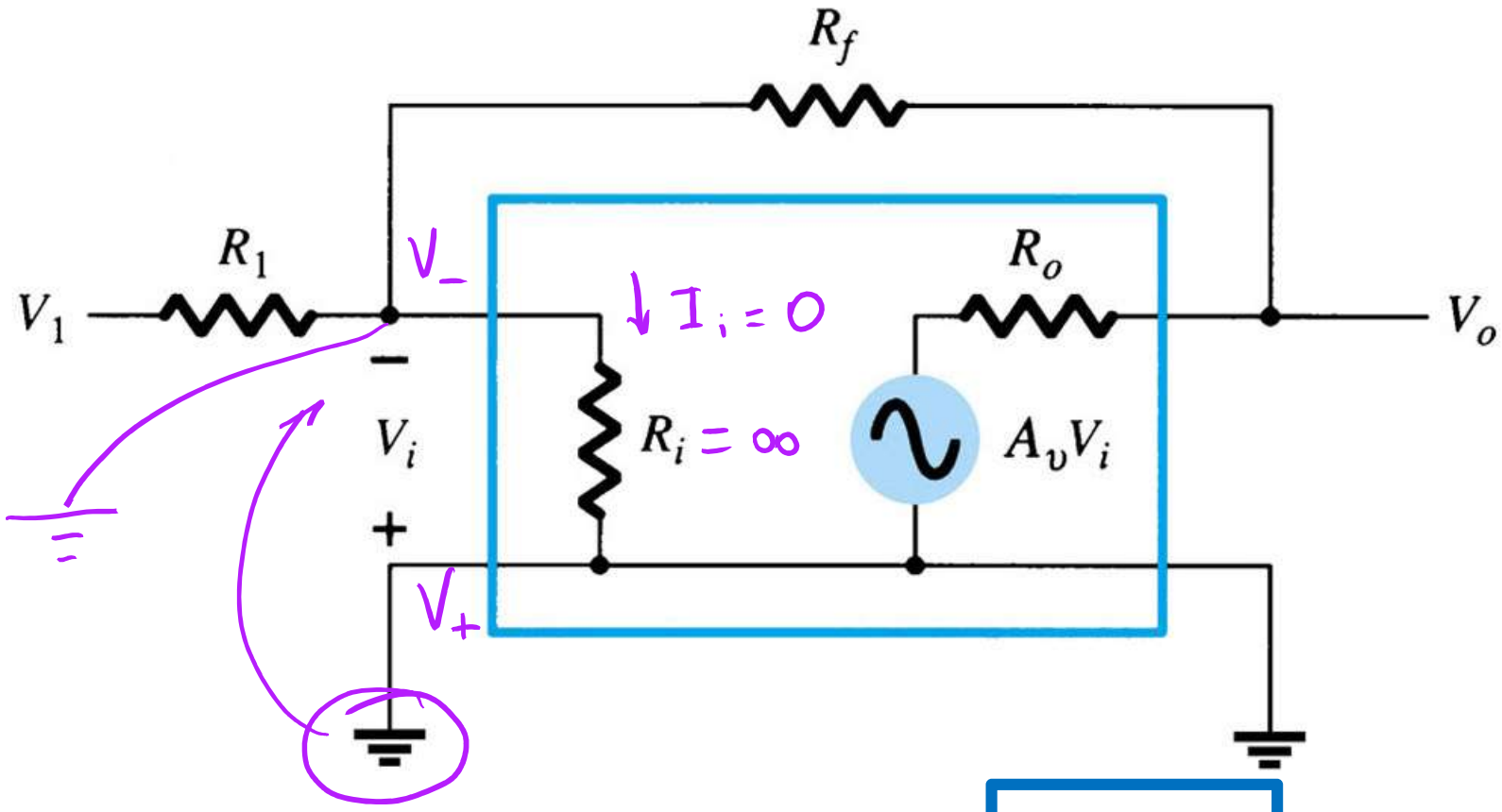


$\Rightarrow v_i = 0 \Rightarrow V_- = V_+$

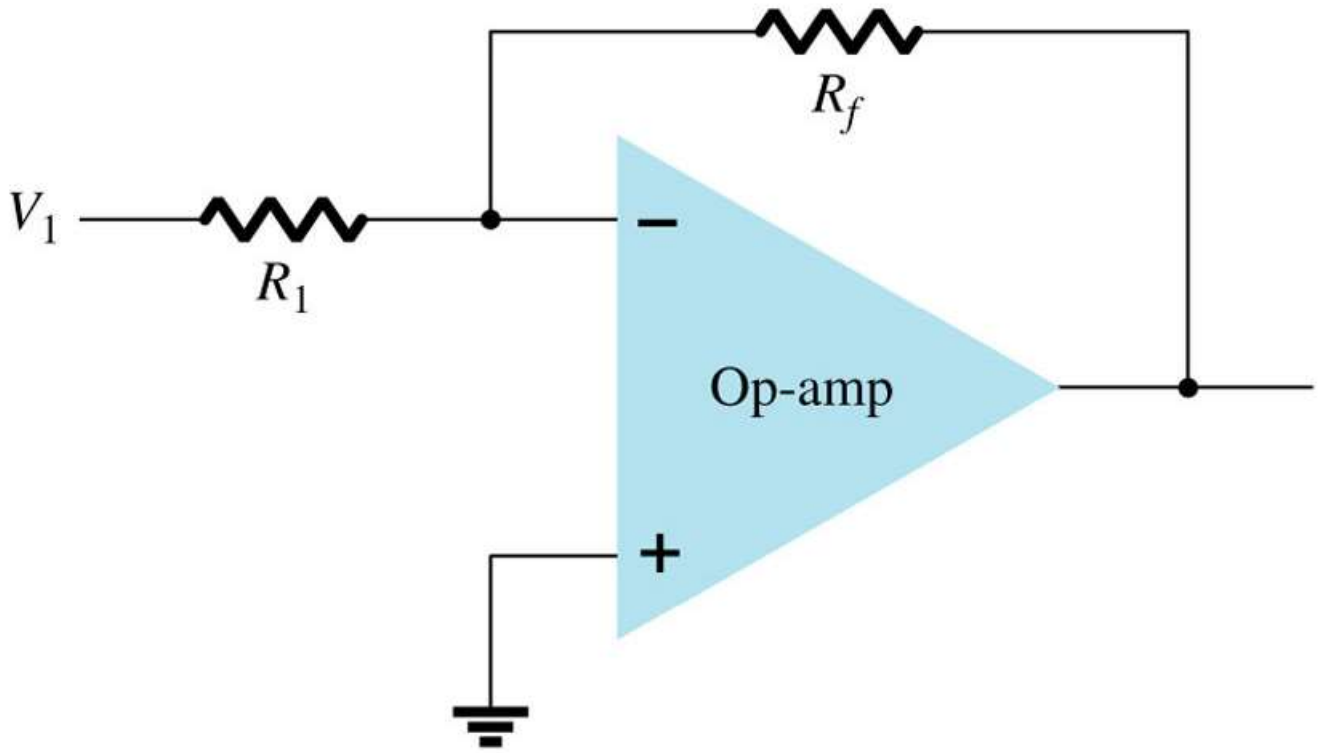
AMP OP – Terra Virtual



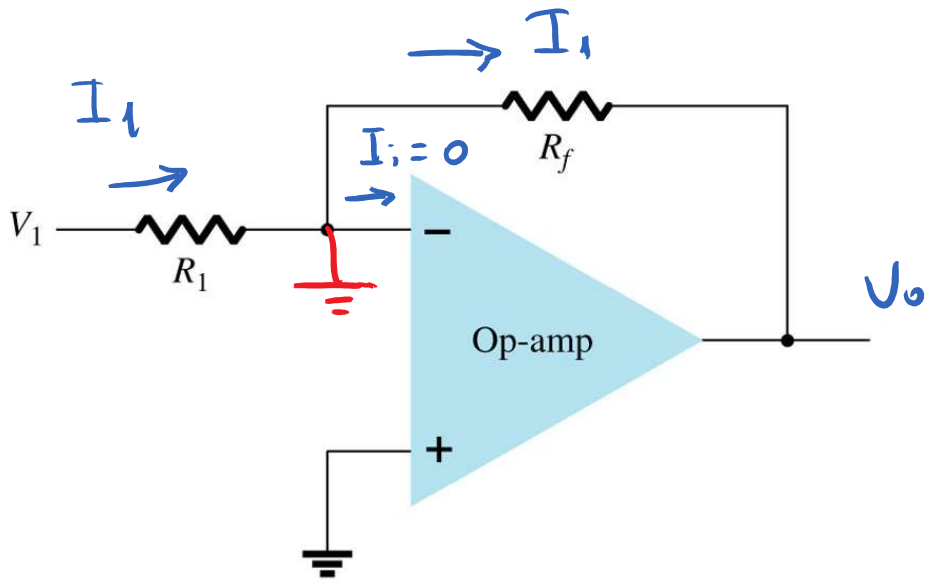
AMP OP – Terra Virtual



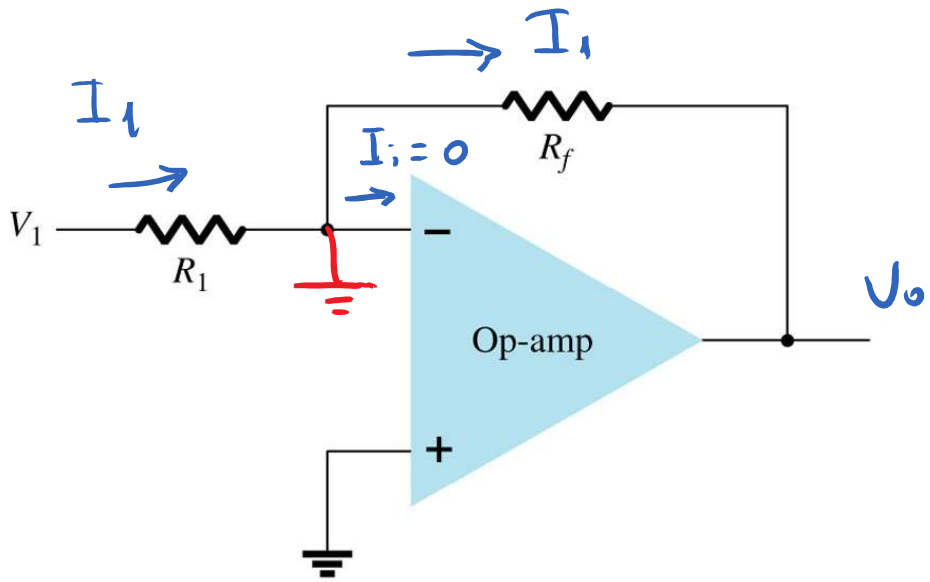
AMP OP – Terra Virtual



AMP OP – Terra Virtual



AMP OP – Terra Virtual

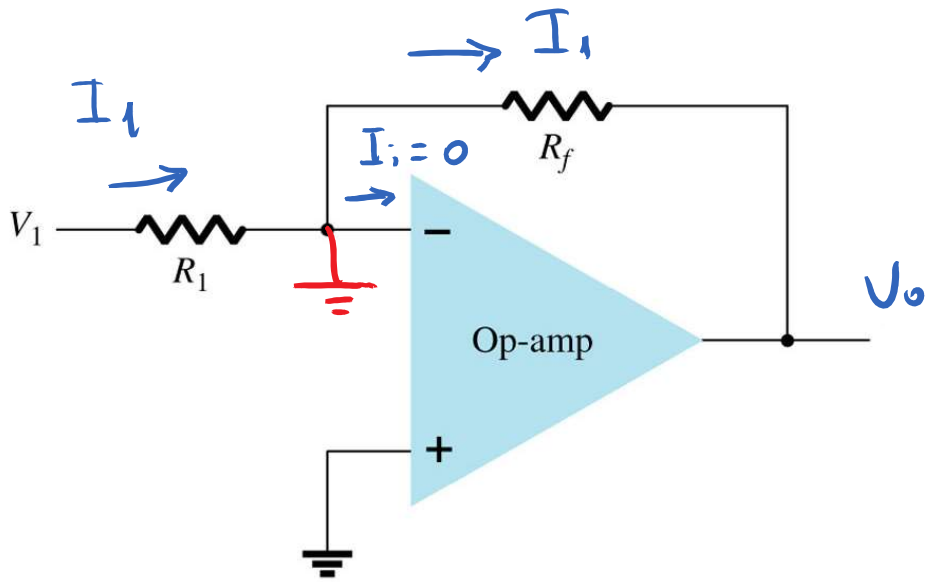


Considerando $V_- = V_+$

$\Rightarrow V_i = R_1 . I_1$

$V_o = - R_f . I_1$

AMP OP – Terra Virtual



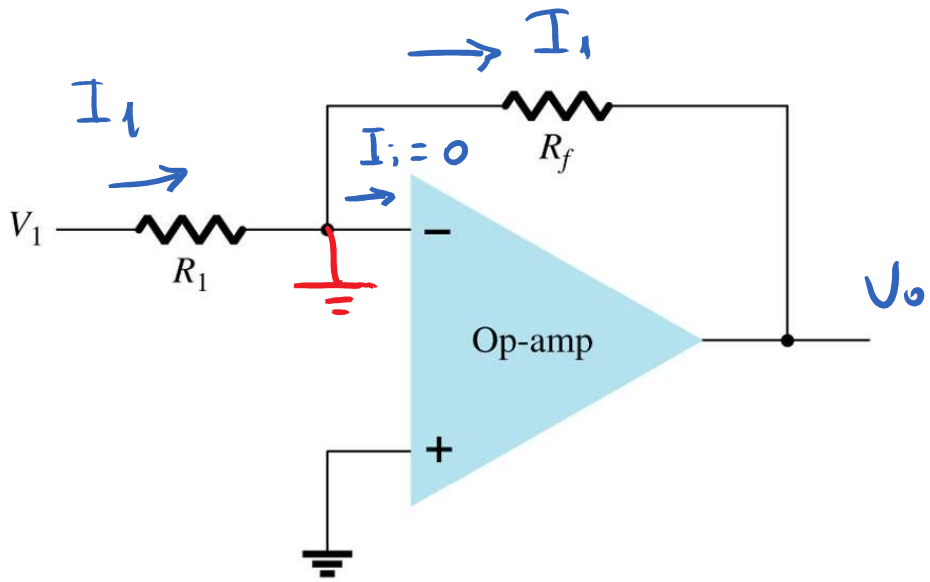
Considerando $V_- = V_+$

$$\Rightarrow V_i = R_1 . I_1$$

$$V_o = - R_f . I_1$$

$$\Rightarrow \frac{V_o}{V_i} = - \frac{R_f . I_1}{R_1 . I_1}$$

AMP OP – Terra Virtual



Considerando $V_- = V_+$

$$\Rightarrow V_i = R_1 . I_1$$

$$V_o = - R_f . I_1$$

$$\Rightarrow \frac{V_o}{V_i} = - \frac{R_f . I_1}{R_1 . I_1} = - \frac{R_f}{R_1}$$