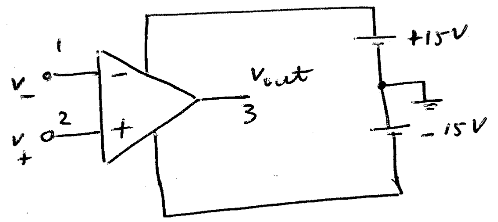
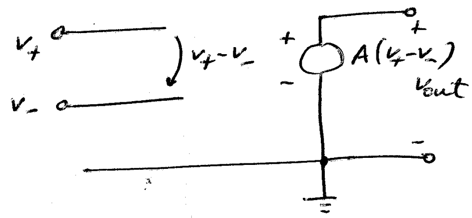
ELECTRÓNICA 1

AULA 2 – OP. AMPS

OP. AMP. IDEAL



modelo pequeno sinal



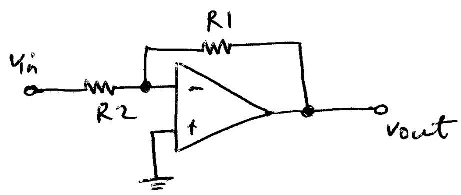
$$i_+ = i_- = 0 \Rightarrow R_{in} = \infty$$

$$R_{out} = 0$$

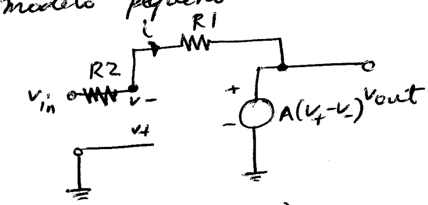
$$A \to \infty \Rightarrow (v_+ - v_-) \to 0$$

OP. AMP – amplificador com entrada diferencial e saída single-ended (referenciada à linha de referência), resistência de entrada infinita, resistência de saída zero, ganho (A) diferencial infinito

configuração inversora



modelo pequeno sinal



(teorema de Miller)

$$i = \frac{v_{in} - v_-}{R2} = \frac{v_- - V_{out}}{R1}$$

Mas $V_{out} = -A\,v_-$

logo $v_- = -\frac{V_{out}}{A}$

$$\frac{v_{in} + \frac{V_{out}}{A}}{R2} = \frac{-\frac{V_{out}}{A} - V_{out}}{R1}$$

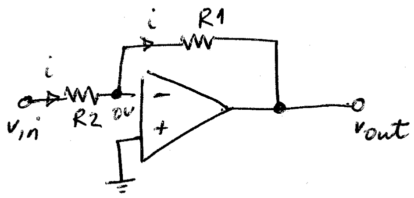
$$R1\ V_{in} + R1\frac{V_{out}}{A} = -\frac{R2\ V_{out}}{A} - R2\ V_{out}$$

$$R1\ V_{in} = -R2\left(1 + \frac{1}{A} + \frac{R1}{R2A}\right) V_{out}$$

logo

$$\frac{V_{out}}{V_{in}} = -\frac{R1}{R2}\ \frac{1}{1 + (1+\frac{R1}{R2})/A} \underset{A\to\infty}{\simeq} -\frac{R1}{R2} \quad //$$

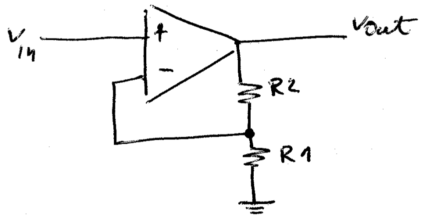
Assumindo agora que $A = \infty \rightarrow V_+ = V_-$

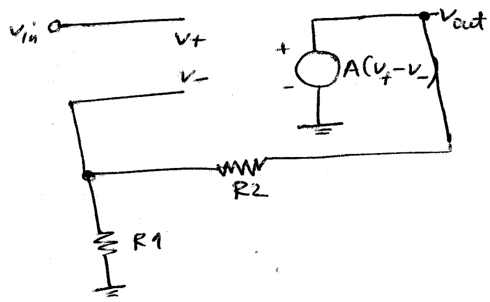


$$i = \frac{V_{in}}{R2} = -\frac{V_{out}}{R1}$$

logo $\frac{V_{out}}{V_{in}} = -\frac{R2}{R1}$ //

Configuração não inversora





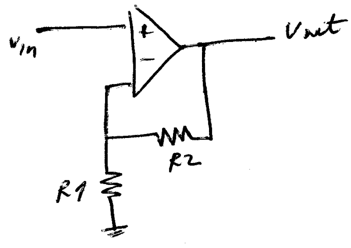
$$V_+ = V_{in}$$

$$V_- = \frac{R1}{R1+R2} V_{out} = \frac{R1}{R1+R2} A\left(V_{in} - \frac{R1}{R1+R2} V_{out}\right)$$

$$\left(1 + \frac{R1}{R1+R2} A\right) V_{out} = A\ V_{in}$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{\frac{1}{A} + \frac{R1}{R1+R2}} \underset{A\to\infty}{\simeq} 1 + \frac{R2}{R1} \quad //$$

assumindo agora que $A = \infty \rightarrow v_+ = v_-$



$$v_- = v_+ = \frac{R1}{R1+R2} V_{out}$$

mas $v_{in} = v_+$

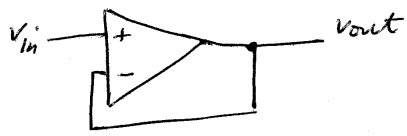
logo

$$V_{in} = \frac{R1}{R1+R2} V_{out}$$

logo

$$\frac{V_{out}}{V_{in}} = \frac{R1+R2}{R1} = 1 + \frac{R2}{R1} \,//$$

amplificador de ganho unitário (buffer)



$V_{out} = v_-$

mas $v_+ = v_- = v_{in}$

logo

$v_{out} = v_{in}$

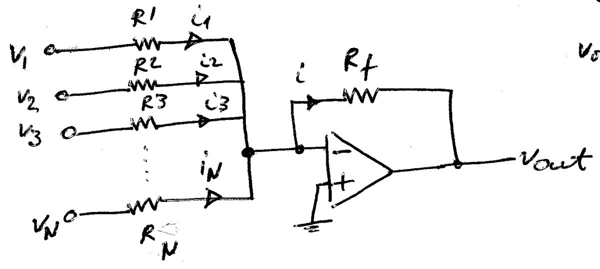
$$\frac{V_{out}}{V_{in}} = 1 \,//$$

Buffer ideal

$R_{in} = \infty$

$R_{out} = 0$

amplificador somador

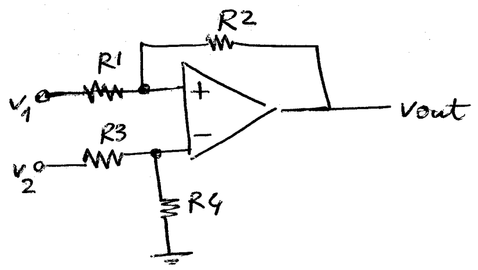


$V_{out} = -i \, R_f$

$i = i_1 + i_2 + i_3 + \cdots + i_n$

$$V_{out} = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \cdots + \frac{V_N}{R_N} \right)$$

amplificador diferença



(pelo princípio da sobreposição)

- $V2 = 0$

$$V'_{out} = -\frac{R2}{R1} V_1$$

- $V_1 = 0$

$$V_- = \frac{R4}{R3+R4} V2$$

$$V_+ = \frac{R1}{R1+R2} V_{out}''$$

logo $$V_{out}'' = \frac{R1+R2}{R1} \frac{R4}{R3+R4} V2$$

$$V_{out} = V'_{out} + V''_{out} = \left(\frac{R1+R2}{R1}\right)\left(\frac{R4}{R3+R4}\right) V2 - \frac{R2}{R1} V_1 \;//$$

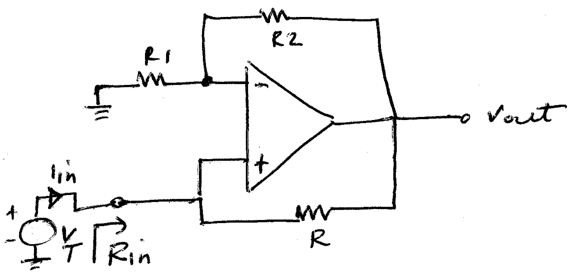
$$V_{out} = \frac{1+R2/R1}{1+\frac{R3}{R4}} V2 - \frac{R2}{R1} V1$$

impondo $$\frac{1+\frac{R2}{R1}}{1+\frac{R3}{R4}} = \frac{R2}{R1} \iff 1 + \cancel{\frac{R2}{R1}} = \cancel{\frac{R2}{R1}} + \frac{R2}{R1}\frac{R3}{R4}$$

vem $$\frac{R2}{R1} = \frac{R4}{R3} \;//$$

nestas condições $$V_{out} = \frac{R2}{R1}(V2 - V1)$$

Negative impedance converter (NIC) – circuito com resistência de entrada negativa



$$R_{in} = \frac{V_T}{i_{in}}$$

$$i_{in} = \frac{v_T - v_{out}}{R}$$

mas $v_T = \frac{R1}{R1+R2} v_{out}$ logo $v_{out} = \left(1 + \frac{R2}{R1}\right) v_T$

substituindo

$$i_{in} = \frac{v_T}{R} - \frac{1}{R}\left(1 + \frac{R2}{R1}\right) v_T$$

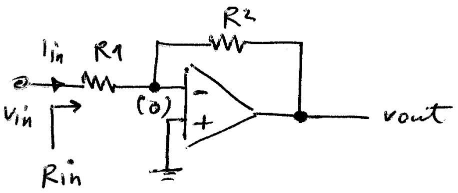
$$i_{in} = -\frac{1}{R}\frac{R2}{R1} v_T$$

logo

$$R_{in} = \frac{v_T}{i_{in}} = -R\frac{R1}{R2}$$

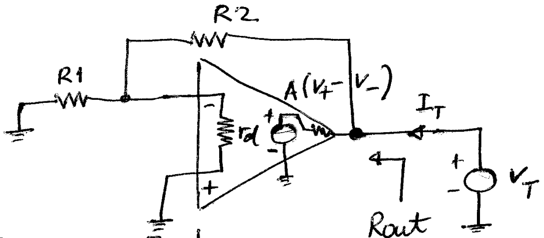
notar que R_{in} é negativo!

Resistência de entrada da configuração inversora



$$R_{in} = \frac{V_{in}}{I_{in}} \approx R1$$

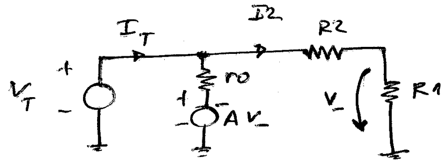
Resistência de saída da configuração inversora



$$R_{out} = \frac{V_T}{I_T}$$

NOTA: SÓ EM SIMULAÇÃO!
SÓ EM ANÁLISE DE PAPEL E LÁPIS

Assumindo que $r_d >> R1$



$$\begin{cases} V_T = r_o\,(I_T - I_2) - A V_- \\ V_T = I2\,(R2 + R1) \end{cases}$$

mas $V_- = R1\, I2$

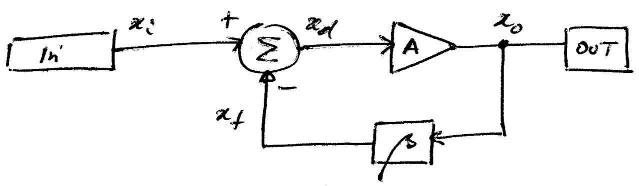
$$V_T = r_o I_T - I2\,(r_o + A R1)$$

$$V_T = r_o I_T - \frac{r_o + A R1}{R2 + R1} V_T$$

$$\left(1 + \frac{r_o + A R1}{R2 + R1}\right) V_T = r_o I_T$$

$$\text{Logo} \quad R_{out} = \frac{r_o}{1 + \dfrac{r_o + A R1}{R2 + R1}} \simeq \frac{r_o}{1 + \dfrac{A R1}{R2 + R1}}$$

O que é que está a acontecer? (Introdução à teoria da realimentação)



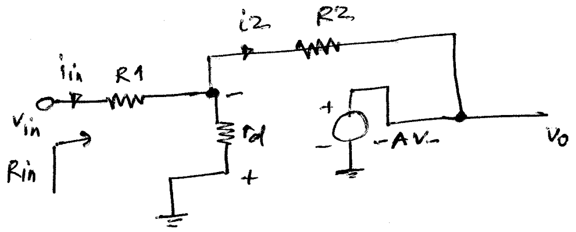
$$\left.\begin{aligned} x_o &= A\, x_d \\ x_d &= x_i - x_f \\ &= x_i - \beta x_o \end{aligned}\right\} \qquad \begin{aligned} x_o &= A\, x_i - A\beta\, x_o \\ A_V &= \frac{x_o}{x_i} = \frac{A}{1 + A\beta} \underset{A \to \infty}{\simeq} \frac{1}{\beta} \end{aligned}$$

A - ganho em malha aberta

β - factor de realimentação

$A\beta \,(= T)$ - ganho da malha

Resistência de entrada da configuração inversora <u>revisited</u>



(Miller effect)

$$v_{in} = R1\, i_{in} + r_d\,(i_{in} - i_2)$$

$$v_- + A v_- = R2\, i_2$$

Logo $$i_2 = \frac{(1+A)}{R2} v_- = \frac{(1+A)}{R2} (v_{in} - i_{in} R1)$$

$$v_{in} = (R1 + r_d)\, i_{in} - \frac{r_d\,(1+A)}{R2} v_{in} + \frac{R1}{R2} r_d (1+A)\, i_{in}$$

$$\left(1 + \frac{r_d\,(1+A)}{R2}\right) v_{in} = \left[R1 + \left(1 + \frac{R1}{R2}(1+A)\right) r_d\right] i_{in}$$

Logo $$R_{in} = \frac{v_{in}}{i_{in}} = \frac{R1 + \left(1 + \frac{R1}{R2}(1+A)\right) r_d}{r_d\,(1+A)/R2} \simeq R1$$