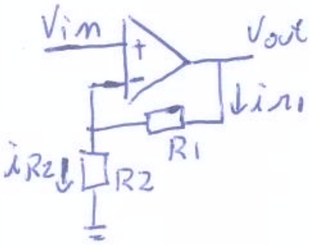
Aula 11

Amplificador não inversor ($A_0 \to \infty$)



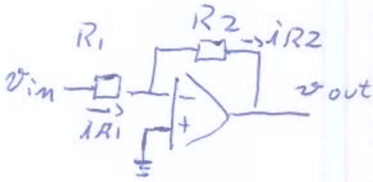
$A_0 \to \infty \Rightarrow v_+ = v_- = V_{in}$

Como $Z_{i\,AMPOP} \to \infty \Rightarrow i_{R1} = i_{R2} = \dfrac{v_{out}}{R_1+R_2} = \dfrac{v_-}{R_2}$ (com $v_- = V_{in}$)

$$\frac{V_{out}}{v_{in}} = \frac{R_1+R_2}{R_2} \Rightarrow \boxed{\frac{V_{out}}{v_{in}} = A_V = 1 + \frac{R_1}{R_2}}$$

- $R_{in} = \infty$
- $R_{out} = \emptyset$

Amplificador inversor ($A_0 \to \infty$)

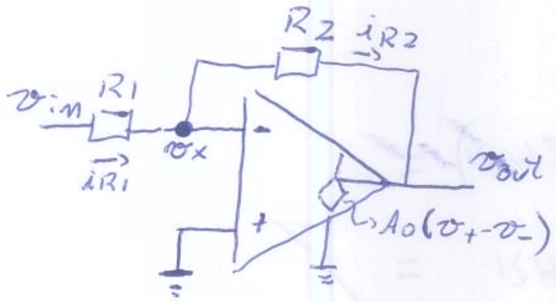


- $v^- = v^+ = \emptyset \Rightarrow i_{R1} = i_{R2}$

$$\frac{v_{in}}{R_1} = -\frac{v_{out}}{R_2} \Rightarrow \boxed{\frac{v_{out}}{v_{in}} = \frac{-R_2}{R_1}}$$

- $R_{in} = \dfrac{v_{in}}{i_{R1}} \Rightarrow \boxed{R_{in} = R_1}$ $\quad \boxed{R_{out} = 0}$

Amplificador inversor ($A_0 < \infty$)



- $v_{out} = A_0(v_+ - v_-)$

$v_{out} = A_0 \cdot (0 - v_x) \Rightarrow \boxed{v_{out} = -A_0 \cdot (v_x)}$

- $i_{R1} = i_{R2}$

$$\frac{v_{in} - v_x}{R_1} = \frac{-(v_{out} - v_x)}{R_2} \quad (v_x - v_{out})$$

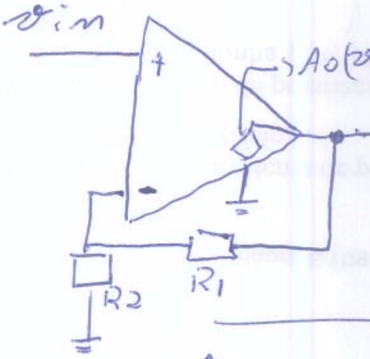
$$\frac{v_{in} - \left(-\frac{v_{out}}{A_0}\right)}{R_1} = \frac{-\frac{v_{out}}{A_0} - v_{out}}{R_2} \Rightarrow R_2 \cdot \left(v_{in} + \frac{v_{out}}{A_0}\right) = -R_1 v_{out}\left(1 + \frac{1}{A_0}\right)$$

$$R_2 v_{in} + R_2 \frac{v_{out}}{A_0} = -R_1 v_{out}\left(1 + \frac{1}{A_0}\right) \Rightarrow R_2 v_{in} = -R_1 v_{out}\left(1 + \frac{1}{A_0}\right) - R_2 \frac{v_{out}}{A_0}$$

$$R_2 v_{in} = -v_{out} \cdot \left[R_1\left(1 + \frac{1}{A_0}\right) + \frac{R_2}{A_0}\right]$$

$$\frac{v_{out}}{v_{in}} = \frac{R_2 \cdot R_1^{-1}}{R_1\left(1 + \frac{1}{A_0}\right) + \frac{R_2}{A_0} \cdot R_1^{-1}} \Rightarrow \frac{v_{out}}{v_{in}} = \frac{R_2/R_1}{1 + \frac{1}{A_0} + \frac{R_2/R_1}{A_0}} \Rightarrow \boxed{\frac{v_{out}}{v_{in}} = \frac{R_2/R_1}{1 + \frac{1}{A_0}\left(1 + R_2/R_1\right)}}$$

* Amplificador não inversor ($A_o < \infty$)



$$\bullet\ v_{out} = A_o(v_+ - v_-)$$

$$v_{out} = A_o\left(v_{in} - \frac{v_{out}}{R_1+R_2} R_2\right)$$

$$v_{out} = A_o v_{in} - \frac{v_{out}}{R_1+R_2} R_2 \cdot A_o$$

$$v_{out} \cdot \left(1 + \frac{R_2 A_o}{R_1+R_2}\right) = A_o v_{in}$$

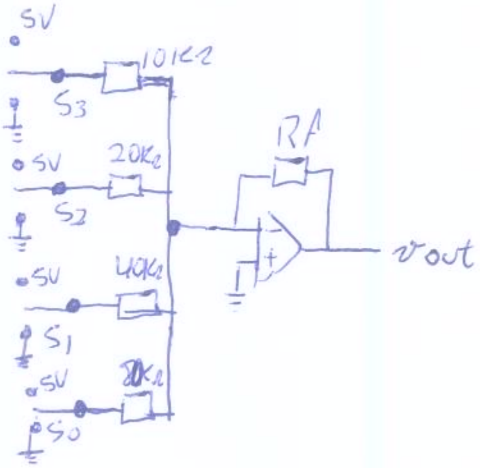
$$\boxed{\frac{v_{in}}{v_{out}} = \frac{A_o}{1 + \frac{R_2}{R_1+R_2} A_o}}$$

obs

$$\frac{v_{in}}{v_{out}} = \frac{A_o}{\frac{R_1+R_2+R_2A_o}{R_1+R_2}} = \frac{A_o \cdot (R_1+R_2) \cdot A_o^{-1}}{R_1+R_2+R_2A_o \cdot A_o^{-1}}$$

$$\frac{v_{in}}{v_{out}} = \frac{R_1+R_2}{R_2 + \frac{(R_1+R_2)}{A_o}} \xrightarrow{A_o \to \infty} \boxed{\frac{v_{in}}{v_{out}} = 1 + \frac{R_1}{R_2}}$$

※ Conversor D/A



$$v_{o_t} = \frac{Rf}{80} \cdot v_0 + \frac{Rf}{40} v_1 + \frac{Rf}{20} v_2 + \frac{Rf}{10} \cdot v_3$$

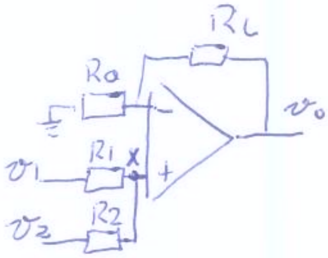
$$v_{out} = Rf \cdot \left[\frac{v_0 + 2v_1 + 4v_2 + 8v_3}{80} \right]$$

$$v_{out} = \frac{Rf}{5 \cdot 4^4} \cdot \left[2^0 v_0 + 2^1 v_1 + 2^2 v_2 + 2^3 v_3 \right]$$

$$v_{out} = \frac{Rf}{5 \cdot 4^4} \cdot 5 \cdot \left[2^0 a_0 + 2^1 a_1 + 2^2 a_2 + 2^3 a_3 \right]; a_i = 0 \text{ a}$$

$$\boxed{v_{out} = \frac{Rf}{16} \cdot 2^0 a_0 + 2^1 a_1 + 2^2 a_2 + 2^3 a_3}$$

※ Somador não inversor



=> Como o circuito é linear, podemos utilizar a superposição

$$v'_x = \frac{v_1}{R_1+R_2} \cdot R_2 \quad (v_2 = \emptyset)$$

$$v''_x = \frac{v_2}{R_1+R_2} \cdot R_1 \quad (v_1 = \emptyset)$$

$$\Rightarrow v_x = v'_x + v''_x$$

$$v_x = \frac{v_1 R_2 + v_2 R_2}{R_1 + R_2} \cdot \frac{R_1 R_2}{R_1 R_2}$$

$$v_x = \frac{R_1 R_2}{R_1 + R_2} \cdot \left(\frac{v_1}{R_1} + \frac{v_2}{R_2} \right) \Rightarrow \boxed{v_x = R_1 /\!/ R_2 \left(\frac{v_1}{R_1} + \frac{v_2}{R_2} \right)}$$

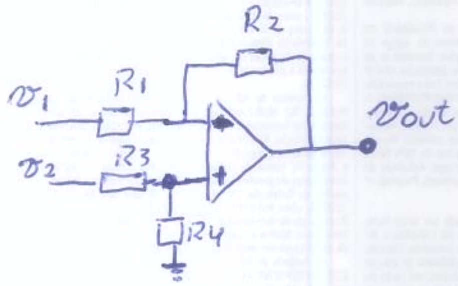
$$\Rightarrow v_0 = \left(1 + \frac{R_L}{R_a} \right) v_x \Rightarrow \boxed{v_0 = R_1 /\!/ R_2 \left(\frac{v_1}{R_1} + \frac{v_2}{R_2} \right) \cdot \left(1 + \frac{R_L}{R_a} \right)}$$

(ganho do amplificador não inversor)

- $R_{in1} \Rightarrow v_2 = \emptyset \Rightarrow \boxed{R_{in1} = R_1 + R_2}$
- $R_{in2} \Rightarrow v_1 = \emptyset \Rightarrow \boxed{R_{in2} = R_2 + R_1}$

* Amplificador de diferenças (Subtrator)

→ combinação do amplificador inversor ($A_v = -\frac{R_2}{R_1}$) como não inversor ($A'_{v_n} = 1 + \frac{R_2}{R_1}$)



→ Tem que usar o divisor resistivo (R_3; R_4), pois $|A'_{v_n}| > |A_v|$

→ Os ganhos tem que ser iguais em módulo

$$|A_{v_i}| = |A_{v_n}|$$

$$\frac{R_2}{R_1} = \frac{R_4}{R_3+R_4}\cdot\left(1+\frac{R_2}{R_1}\right) \Rightarrow \frac{R_2}{R_1} = \frac{R_4}{R_3+R_4}\left(\frac{R_1+R_2}{R_1}\right) \Rightarrow \frac{R_1 R_2}{R_1(R_1+R_2)} = \frac{R_4}{R_3+R_4}$$

~~$\frac{R_2}{R_1} = \frac{R_4}{R_3+R_4} + \frac{R_4}{R_3+R_4}\frac{R_2}{R_1} \Rightarrow \frac{R_2}{R_1}$~~ $\Rightarrow$ $\boxed{\frac{R_2}{R_1+R_2} = \frac{R_4}{R_3+R_4}}$ (1)

$$\Rightarrow \boxed{\frac{R_2}{R_1} = \frac{R_4}{R_3}} \quad (2)$$

→ Superposição

$$v_{out}' \overset{v_2=0}{=} -\frac{R_2}{R_1}v_1$$

$$v_{out}'' \overset{v_1=0}{=} \frac{R_4}{R_3+R_4}\cdot\left(1+\frac{R_2}{R_1}\right)v_2$$

$v_{out} = v_{out}' + v_{out}''$

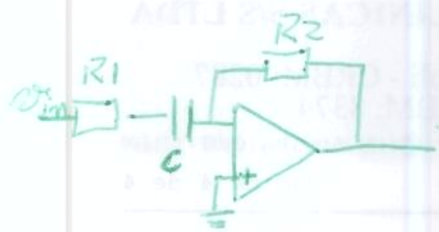
~~$v_{out} = -\frac{R_2}{R_1}v_1 + \frac{R_4}{R_3+R_4}\left(1+\frac{R_2}{R_1}\right)v_2$~~

(1)

$$v_{out}'' = \frac{R_2}{R_1+R_2}\cdot\frac{R_1+R_2}{R_1}v_2 \Rightarrow v_{out}'' = \frac{R_2}{R_1}\cdot v_2$$

$$v_{out} = -\frac{R_2}{R_1}v_1 + \frac{R_2}{R_1}\cdot v_2 \Rightarrow \boxed{v_{out} = \frac{R_2}{R_1}(v_2 - v_1)}$$

* Diferenciador

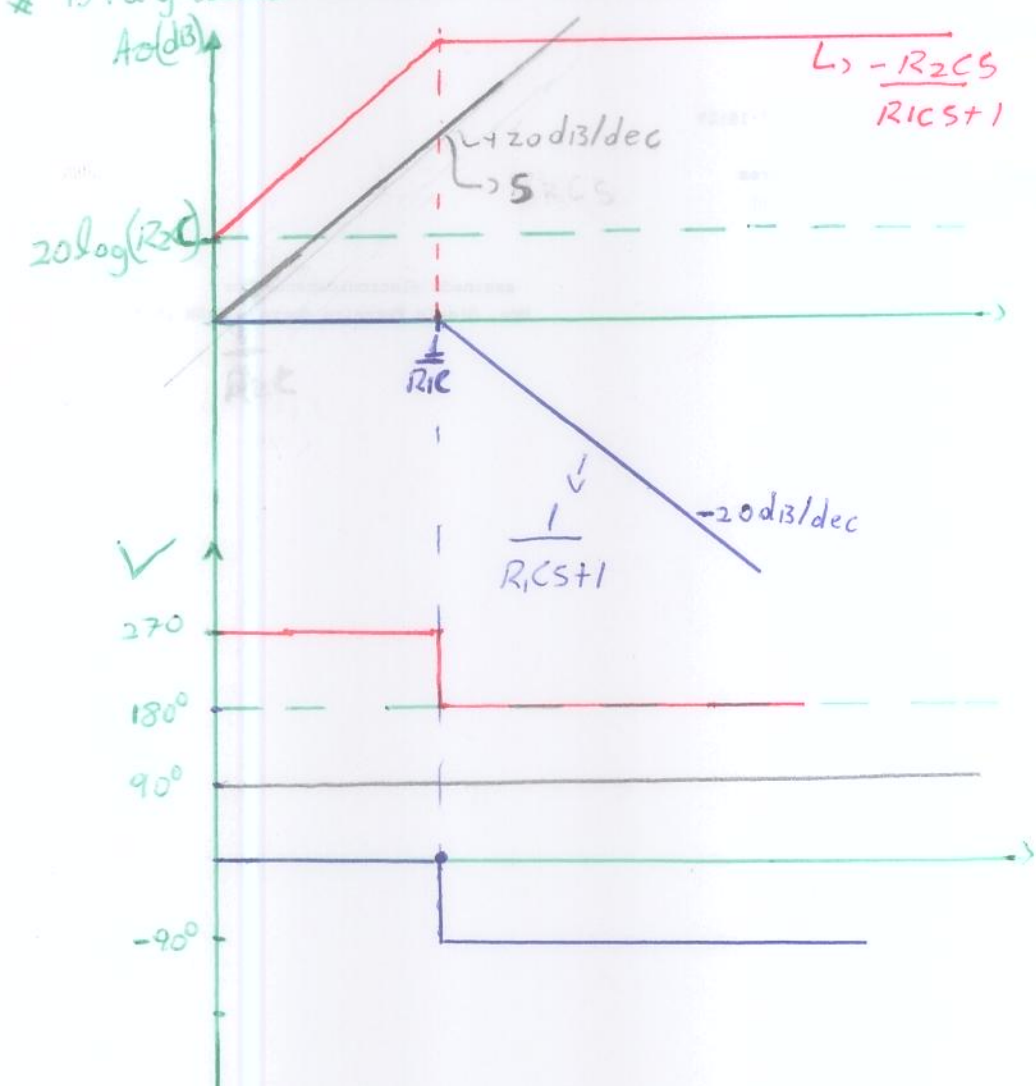


$$\frac{v_{out}}{v_{in}} = \frac{-R_2}{R_1 + \frac{1}{sC}} = \frac{-R_2}{\frac{R_1 sC + 1}{sC}}$$

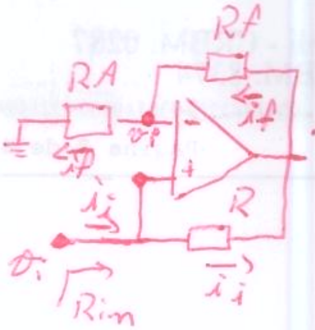
$$\frac{v_{out}}{v_{in}} = -\frac{R_2 sC}{R_1 sC + 1} \Rightarrow$$

$$\boxed{\frac{v_{out}}{v_{in}} = -\frac{R_2 C s}{R_1 C s + 1}} \Rightarrow \text{Função Transferência}$$

* Diagrama de Bode



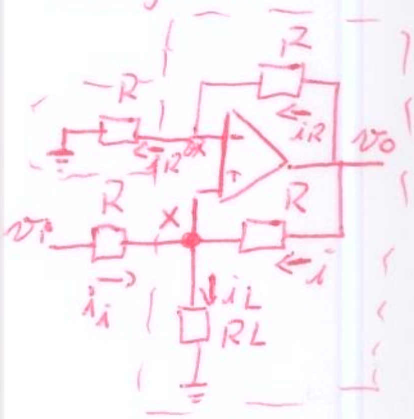
※ Circuito de impedância negativa



- $i_f = \dfrac{v_0 - v_i}{R_f} = \dfrac{v_i}{R_A} \Rightarrow \boxed{v_i = \dfrac{R_A(v_0 - v_i)}{R_f}}$

- $\boxed{i_{in} = \dfrac{v_0 - v_i}{R}} \Rightarrow \dfrac{v_i}{i_i} = \boxed{R_{in} = -\dfrac{R_A \cdot R}{R_f}}$

※ Fonte de Corrente controlada por tensão com carga aterrada



- $i_R = \dfrac{v_0 - v_x}{2R} = \dfrac{v_x}{R} \Rightarrow v_x = \dfrac{v_0}{2} \Rightarrow \boxed{v_0 = 2v_x}$

- $i = \dfrac{v_0 - v_x}{R}$ ($v_0 = 2v_x$) $\Rightarrow \boxed{i = \dfrac{v_x}{R}}$

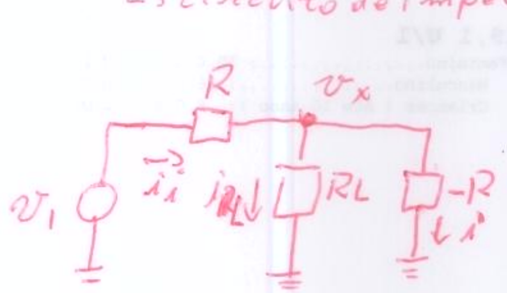
- $i_i = \dfrac{v_i - v_x}{R}$

- $i_L = i + i_i = \dfrac{v_x}{R} + \dfrac{v_i - v_x}{R} \Rightarrow \boxed{i_L = \dfrac{v_i}{R}}$

→ outra forma de resolver

$$R_x = -\frac{R \cdot R}{R} \Rightarrow R_x = -R$$

↳ circuito de impedância negativa



$$i_i = \frac{v_i - v_x}{R}$$

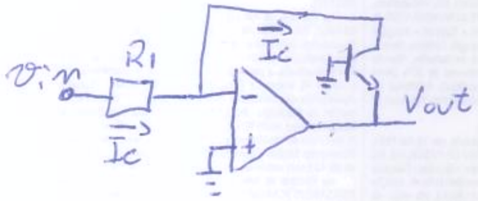
$$i = -\frac{v_x}{R}$$

$$i_L = i_i - i = \frac{v_i - v_x}{R} - \left(-\frac{v_x}{R}\right)$$

$$\Rightarrow \boxed{i_L = \frac{v_i}{R}}$$

Aula 10

* Amplificador Logarítimico

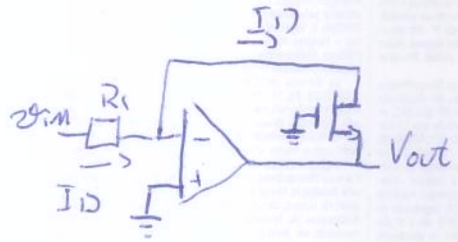


$\Rightarrow I_C = \frac{v_{in}}{R_1}$

$\rightarrow V_{BE} = V_T \ln \frac{I_C}{I_C} = V_T \ln \frac{v_{in}/R_1}{I_S}$

$\rightarrow V_{out} = -V_{BE} \Rightarrow \boxed{V_{out} = -V_T \cdot \ln \frac{v_{in}}{R_1 I_S}}$

* Amplificador de raiz quadrada



$\rightarrow I_D = \frac{v_{in}}{R_1}$

$\rightarrow I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2$

$\rightarrow V_{GS} = \sqrt{\frac{I_D \sim \frac{v_{in}}{R_1}}{\frac{1}{2} \mu_n C_{ox} \frac{W}{L}}} + V_{TH}$

$\rightarrow V_{out} = -V_{GS}$

$\rightarrow \boxed{v_{out} = -\sqrt{\frac{2 \cdot v_{in}}{R_1 \mu_n C_{ox} \frac{W}{L}}} - V_{TH}}$