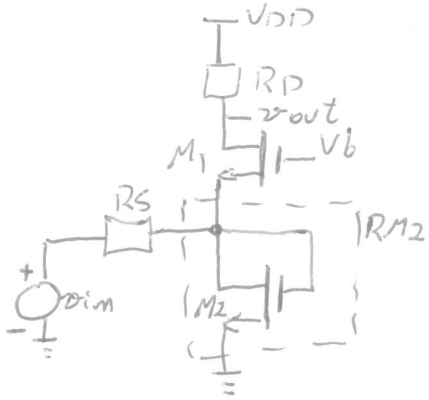
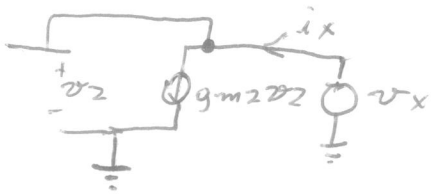
※ Exemplo 7.13



※ R_{M2} ($\lambda = 0$)

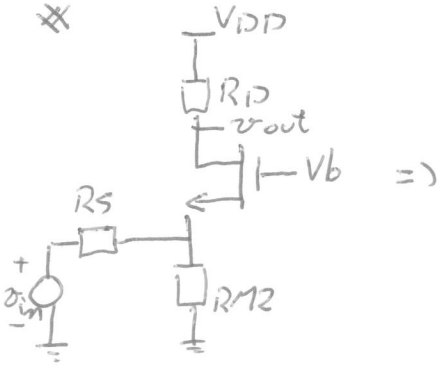


$v_x = v_2$

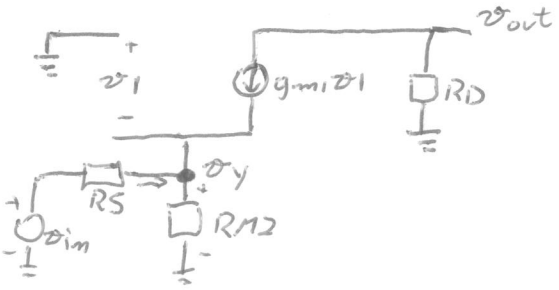
$i_x = g_{m2} v_2$

$$R_{M2} = \frac{v_x}{i_x} = \frac{1}{g_{m2}}$$

※



⇒



- $v_{out} = -g_{m1} v_1 R_D$
- $v_1 = -v_y$
- $\frac{v_{out}}{v_y} = g_{m1} R_D$

- $v_{in} = v_{RS} + v_y = R_S \left(\frac{v_y}{R_{M2}} - g_{m1} v_1 \right) + v_y$

$$v_{in} = R_S \left(\frac{v_y}{R_{M2}} + g_{m1} v_y \right) + v_y \Rightarrow v_{in} = R_S v_y \left(\underbrace{\frac{1}{R_{M2}}}_{\to g_{m2}} + g_{m1} \right) + v_y$$

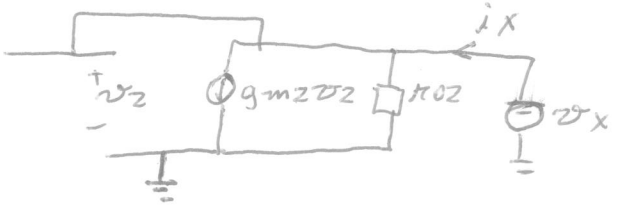
$$v_{in} = v_y \cdot \left[R_S \left(g_{m2} + g_{m1} \right) + 1 \right]$$

$$\frac{v_y}{v_{in}} = \frac{1}{R_S (g_{m2} + g_{m1}) + 1}$$

$$\therefore A_v = \frac{v_{out}}{v_y} \cdot \frac{v_y}{v_{in}} = \frac{g_{m1} R_D}{R_S (g_{m2} + g_{m1}) + 1}$$

✱ Rout

- R_{M2}



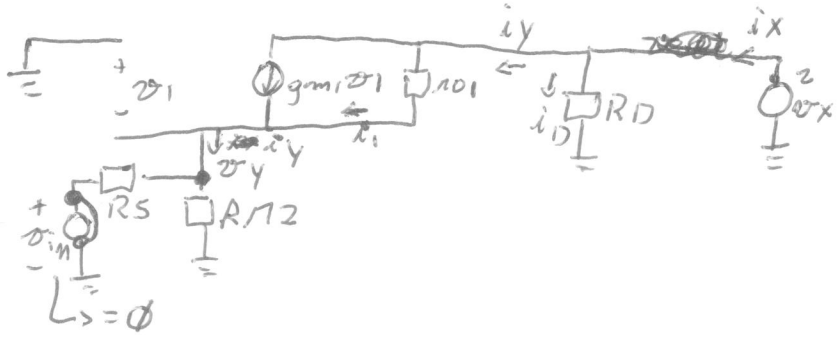
$v_X = v_2$

$i_X = g_{m2}v_2 + \frac{v_X}{r_{O2}}$ ($v_X \to v_2$)

$i_X = v_2\left(g_{m2} + \frac{1}{r_{O2}}\right)$

$R_{M2} = \frac{1}{g_{m2} + \frac{1}{r_{O2}}} \Rightarrow \boxed{R_{M2} = 1/g_{m2} \,//\, r_{O2}}$

-



- $v_Y = -v_1$

$i_Y = \frac{v_Y}{R_{M2}//R_S} = \frac{-v_1}{R_{M2}//R_S}$

- $v_X = v_Y + v_{r_{O1}} = v_Y + r_{O1}i_1 = v_Y + (i_Y - g_{m1}v_1)r_{O1}$

- $v_X = \underbrace{v_Y}_{-v_1} + \left(\frac{-v_1}{R_{M2}//R_S} - g_{m1}v_1\right)r_{O1}$

- $v_X = -v_1 \cdot \left[1 + r_{O1}\left(\frac{1}{R_{M2}//R_S} + g_{m1}\right)\right]$

- $i_X = i_Y + i_D = \frac{-v_1}{R_{M2}//R_S} + \frac{v_X}{R_D}$ ($v_X \to -v_1$) $= -v_1 \cdot \left(\frac{1}{R_{M2}//R_S} + \frac{1}{R_D}\right)$

$\Rightarrow i_X = -v_1 (R_{M2}//R_D)^{-1}$

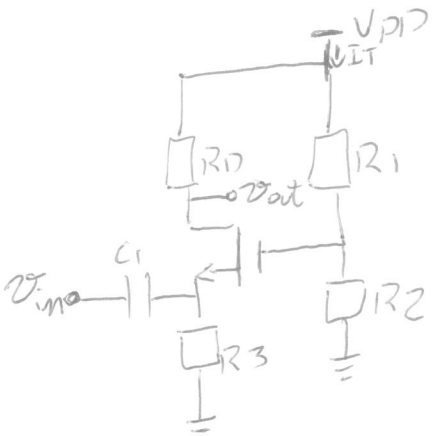
- $\frac{v_X}{i_X}$ ($v_X \to R_{out}$) $= \frac{1 + r_{O1}\left(\frac{1}{R_{M2}//R_S} + g_{m1}\right)}{(R_{M2}//R_D)^{-1}} = \left[1 + r_{O1}\left(\frac{1}{R_{M2}//R_S} - g_{m1}\right)\right] \cdot (R_{M2}//R_D)$

$$\boxed{R_{out} = \left[1 + r_{O1}\left(\frac{1}{\frac{1}{g_{m2}}//r_{O2}//R_S} + g_{m1}\right)\right] \cdot \left(\frac{1}{g_{m2}}//r_{O2}//R_D\right)}$$

$R_{out} \geq \left(\frac{1}{g_{m2}}//r_{O2}//R_S\right)$

Exemplo 7.14 modificado

(Serra do Livro)



$V_{DD} = 1{,}8\,V$
$P = 2\,mW$
$A_v = 50$
$R_3 = 500\,\Omega$
$g_m = \frac{1}{136{,}4}\,S$
$\mu_n C_{ox} = 100\,\mu A/V^2$
$V_{TH} = 0{,}5\,V$
$\lambda = 0$
$\frac{W}{L} = 244$ *

Projete.

- $I_T = \frac{P}{V_{DD}} \Rightarrow I_T = 1{,}111\,mA$
- Como $I_D \gg I_{R_1}$
  Escolho $I_D = 1{,}1\,mA$
  $I_{R_1} = 0{,}011\,mA$

- $I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2 \Rightarrow (V_{GS}-0{,}5)^2 = 0{,}0902 \Rightarrow V_{GS} = 0{,}8003\,V$
  ($I_D = 1{,}1\cdot10^{-3}$; $\mu_n C_{ox} = 100\cdot10^{-6}$; $\frac{W}{L} = 244$; $V_{TH} = 0{,}5$)
  $L > V_{TH} \Rightarrow$ OK

- R_D? $\Rightarrow A_V = 5 = \frac{R_3 \| \frac{1}{g_m}}{R_3 \| \frac{1}{g_m} + \emptyset} \cdot g_m R_D \Rightarrow g_m R_D = 5 \Rightarrow \frac{1}{136{,}4} R_D = 5 \Rightarrow R_D = 682\,\Omega$

- $V_S = V_{R_3} = R_3 I_D \Rightarrow V_S = 0{,}55\,V$
- $V_D = V_{DD} - R_D I_D \Rightarrow V_D = 1{,}0498\,V$
- $V_{DS} = V_D - V_S \Rightarrow V_{DS} = 0{,}4998$
- $V_{DS} \geq V_{GS} - V_{TH} \Rightarrow 0{,}4998 \geq 0{,}8003 - 0{,}5 \Rightarrow 0{,}4998 \geq 0{,}3003$
  saturação
  $\rightarrow$ OK $\rightarrow$ Saturado

- $I_R = \frac{V_{DD}}{R_1+R_2} \Rightarrow 0{,}011\cdot10^{-3} = \frac{1{,}8}{R_1+R_2} \Rightarrow R_1 + R_2 = 1{,}62\cdot10^5\,\Omega$

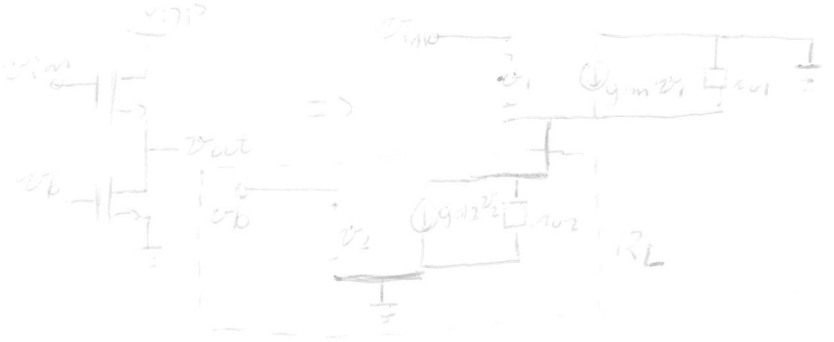
- $V_{GS} = V_{R_2} = R_2 I_R \Rightarrow R_2 = \frac{0{,}8003}{0{,}011\cdot10^{-3}} \Rightarrow R_2 = 7{,}2025\cdot10^4\,\Omega$

- $R_1 = 1{,}62\cdot10^5 - R_2 \Rightarrow R_1 = 8{,}9475\cdot10^4\,\Omega$

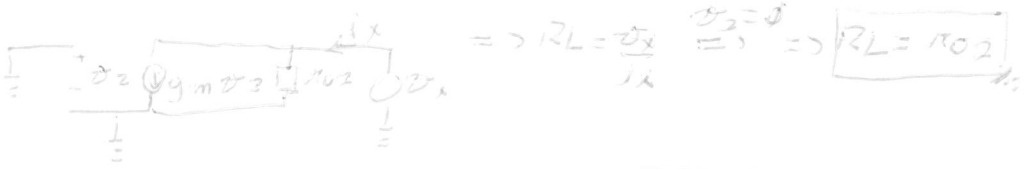
VG=VR2=R2xIR=>R2=VG/IR=(VGS-VS)/IR=(0.8003-0.55)/0.0111mA=> R2=22,527Kohm
R1=1,62x10^5-R2=> R1=139,47 kohm

* Example 7.16

Av ?

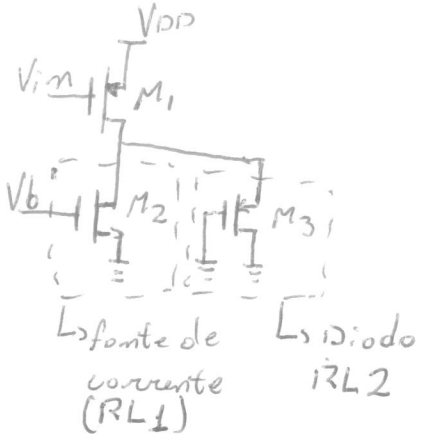


- RL



- Com $A_v = \frac{R_o \| R_L}{\frac{1}{g_m} + R_o \| R_L} \Rightarrow$ $A_v = \frac{r_o \| r_{o2}}{\frac{1}{g_{m1}} + r_o \| r_{o2}}$

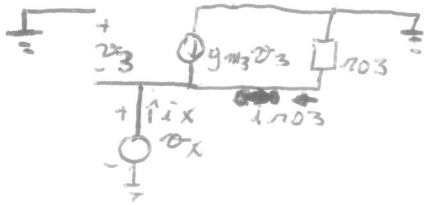
✱ Exemplo 7.19



- R_{L1}

$$\Rightarrow R_{L1} = \frac{v_x}{i_x} \Rightarrow \boxed{R_{L1} = r_{o2}}$$

- R_{L2}



$v_x = -v_3$

$$i_x + g_{m_3} v_3 + i_x r_{o3} = 0$$

$$i_x + g_{m_3} v_3 + \left(-\frac{v_x}{r_{o3}}\right) = 0$$

$$i_x = -g_{m_3} v_3 + \frac{v_x}{r_{o3}}$$

$$i_x = -g_{m_3} v_3 - \frac{v_3}{r_{o3}}$$

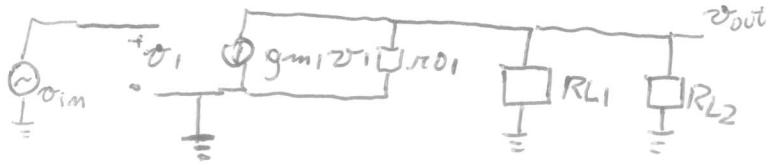
$$i_x = -v_{03}\left(g_{m_3} + \frac{1}{r_{o3}}\right) \Rightarrow i_x = -v_3 \left(r_{o3} \| \frac{1}{g_{m_3}}\right)^{-1}$$

$$\boxed{R_{L2} = \frac{v_x}{i_x} = r_{o3} \| \frac{1}{g_{m3}}}$$

✱ Modelo de pequenos sinais

$$v_{out} = -g_{m_1} v_i (r_{o1} \| R_{L1} \| R_{L2})$$

$v_i = v_{in}$

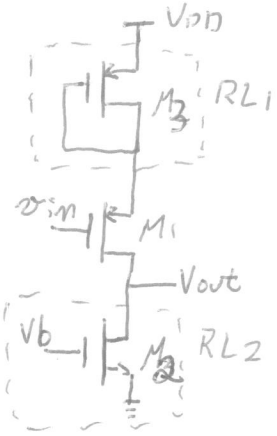


$$\frac{v_{out}}{v_{in}} = \boxed{A_v = -g_{m1} \cdot \left(r_{o1} \| r_{o2} \| r_{o3} \| \frac{1}{g_{m3}}\right)}$$

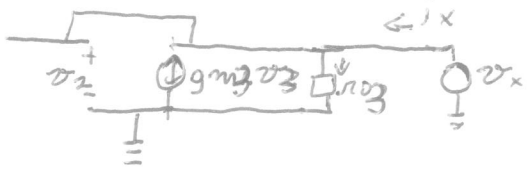
- R_{out}

$v_{in} = 0 \Rightarrow v_i = 0 \Rightarrow R_{out} = r_{o1} \| R_{L1} \| R_{L2} = \boxed{r_{o1} \| r_{o2} \| r_{o3} \| \frac{1}{g_{m3}}}$ R_{out}

⁂ Exemplo 7.20



- $RL1$



$v_3 = v_x$

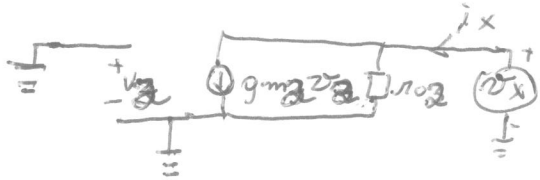
$i_x = g_{m3} v_3 + i_{ro2}$

$= g_{m3} v_3 + \frac{v_3}{r_{o3}}$

$i_x = v_x \left(g_{m3} + \frac{1}{r_{o3}}\right)$

$$RL1 = \frac{v_x}{i_x} = r_{o3} \,//\, \frac{1}{g_{m3}}$$

- RL_2



$$\Rightarrow RL_2 = r_{o2}$$

- Modelo de pequenos sinais

$v_{out} = -g_m v_1 \cdot RL_2$

$v_{in} = v_1 + v_{RL1}$

$v_{in} = v_1 + RL_1 \cdot g_{m1} v_1$

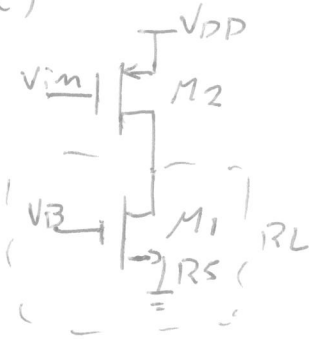
$v_{in} = v_1 \cdot (RL_1 g_{m1} + 1)$

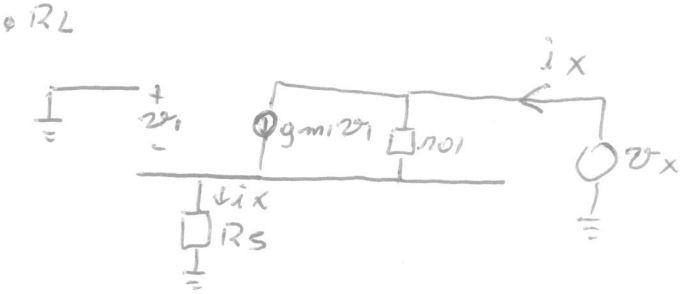
$$A_V = \frac{v_{out}}{v_{in}} = \frac{-g_{m1} RL_2}{RL_1 g_{m1} + 1} = \frac{-g_{m1} \cdot r_{o2}}{\left(r_{o3} \,//\, \frac{1}{g_{m3}}\right) g_{m1} + 1} \quad \begin{matrix} \div g_{m1} \\ \div g_{m1} \end{matrix}$$

$$\Rightarrow \boxed{A_v = \frac{-r_{o2}}{\frac{1}{g_{m1}} + r_{o3} \,//\, \frac{1}{g_{m3}}}}$$

Exemplo 7.21

a)





- $v_{RS} = -v_1$
- $i_x = \frac{v_{RS}}{R_S} = -\frac{v_1}{R_S}$

$v_x = v_{ro1} + v_{RS}$

$v_x = r_{o1}.(i_x - g_{m1}v_1) + v_1$

$v_x = r_{o1} i_x - r_{o1} g_{m1} v_1 - v_1$

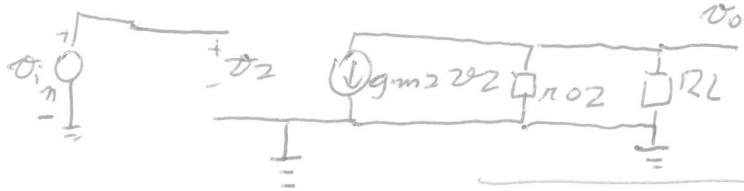
$v_x = -r_{o1}\frac{v_1}{R_S} - r_{o1} g_{m1} v_1 - v_1$

$v_x = -v_1\left(\frac{r_{o1}}{R_S} + g_{m1} r_{o1} + 1\right)$

~~$v_x = -v_1[r_{o1}(1+g_{m1})+1] \Rightarrow \frac{v_x}{i_x} = R_L = r_{o1}(1+g_{m1}) + 1 \cdot \frac{1}{R_S}$~~

$R_L = \frac{v_x}{i_x} = \frac{\frac{R_{o1}}{R_S} + g_{m1} r_{o1} + 1}{\frac{1}{R_S}} \Rightarrow \boxed{R_L = r_{o1} + (g_{m1} r_{o1} + 1) \cdot R_S}$

- Modelo de pequenos sinais equivalente

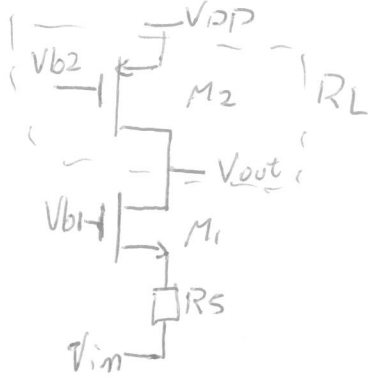


- $v_{out} = -g_{m2} v_2 \cdot r_{o2} \| R_L$
- $v_{in} = v_2$
- ~~$A_v = \frac{v_{out}}{v_{in}} = -g_{m2} \cdot r_{o2} \| [r_{o1}(g_{m1}$~~

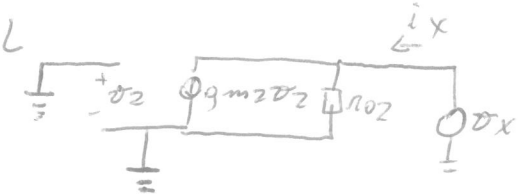
$A_v = \frac{v_{out}}{v_{in}} = -g_{m2} \cdot r_{o2} \| R_L = \boxed{-g_{m2}\{r_{o2} \| [r_{o1} + (g_{m1} r_{o1} + 1) \cdot R_S]\}}$

* Exemplo 7.21 b

$r_{o1} = \infty$

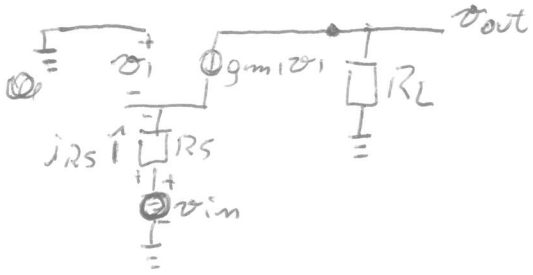


• RL



$R_L = r_{o2}$

• Modelo equivalente de pequenos sinais



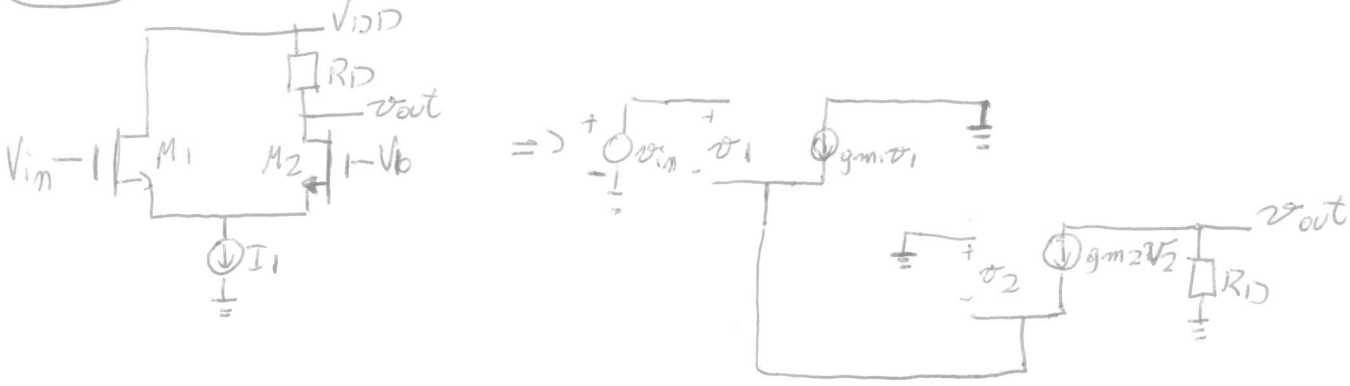
• $v_{out} = -g_{m1} v_1 \cdot R_L$

• $v_{in} \rightarrow v_{RS} + v_1 = 0 \Rightarrow v_{in} = v_{RS} - v_1 \Rightarrow v_{in} = i_{RS} \cdot R_S - v_1 \Rightarrow$ ($i_{RS} = -g_{m1} v_1$)

$v_{in} = -g_{m1} v_1 R_S - v_1 \Rightarrow v_{in} = -v_1 (g_{m1} R_S + 1)$

• $A_v = \frac{v_{out}}{v_{in}} = \frac{g_{m1} R_L}{g_{m1} R_S + 1} \div g_{m1} \Rightarrow A_v = \frac{R_L}{R_S + \frac{1}{g_{m1}}} \Rightarrow \boxed{A_v = \frac{r_{o2}}{R_S + \frac{1}{g_{m1}}}}$

7.22



- $v_{in} = v_1 + v_2 = 0$

  $v_{in} = -v_2 + v_1$ (1)

- $v_{out} = -g_{m_2} v_2 R_D$ (2)

- $g_{m1} v_1 = -g_{m2} v_2$ (3)

  $v_2 = \frac{-g_{m1} v_1}{g_{m2}}$

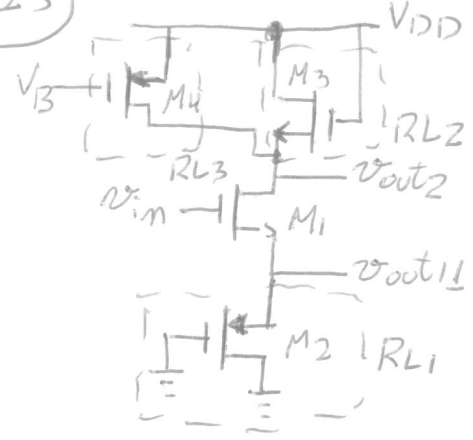
(3) -> (1) $v_{in} = +\frac{g_{m1} v_1}{g_{m2}} + v_1 \Rightarrow$ $\boxed{v_{in} = +v_1\left(\frac{g_{m1}}{g_{m2}} + 1\right)}$

(3) -> 2 $v_{out} = -g_{m2}\left(\frac{-g_{m1}}{g_{m2}}\right) \cdot v_1 R_D \Rightarrow v_{out} = g_{m1} v_1 \cdot R_D$

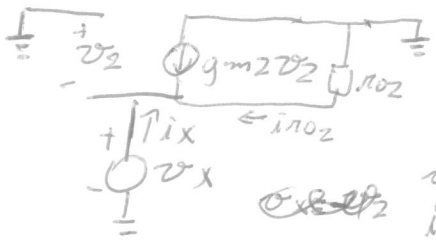
$A_v = \frac{v_{out}}{v_{in}} = \frac{g_{m1} R_D}{\frac{g_{m1}}{g_{m2}} + 1} \div g_{m1} \Rightarrow$ $\boxed{A_v = \frac{R_D}{\frac{1}{g_{m2}} + \frac{1}{g_{m1}}}}$

7.23

$\lambda_1 = 0$



- R_{L1}



$v_x = -v_2$

$i_x + g_{m2} v_2 + \frac{v_x}{r_{o2}} = 0$

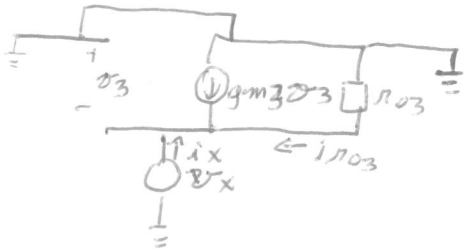
$i_x = -g_{m2} v_2 - \frac{v_x}{r_{o2}}$

$i_x = -g_{m2} v_2 - \frac{v_2}{r_{o2}}$

$i_x = -v_2 \left(g_{m2} + \frac{1}{r_{o2}}\right)$

$\Rightarrow \boxed{R_{L1} = \frac{v_x}{i_x} = r_{o2} \parallel \frac{1}{g_{m2}}}$

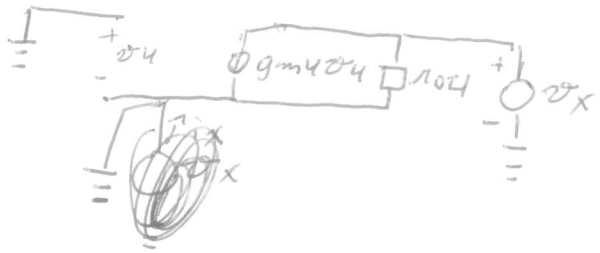
- R_{L2}



- Mesmo caso anterior

$\boxed{R_{L2} = r_{o3} \parallel \frac{1}{g_{m3}}}$

- R_{L3}

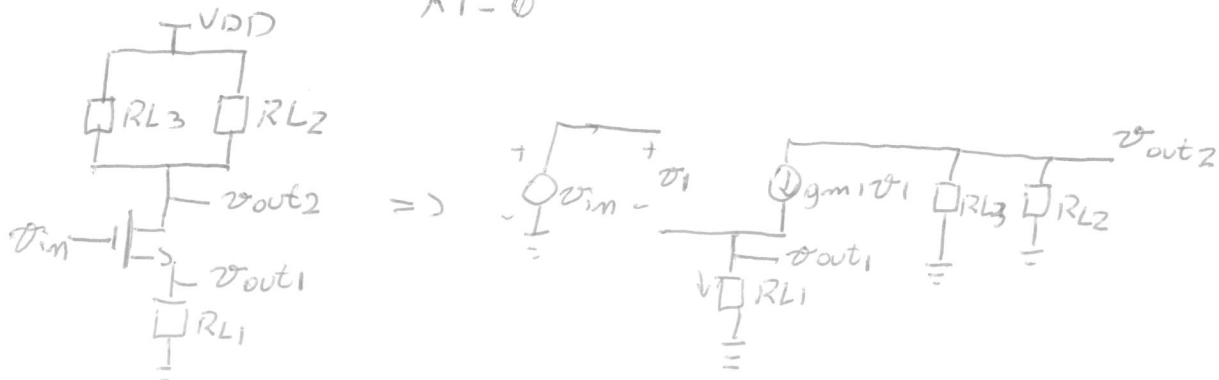


- $v_4 = 0$
- $g_{m4} v_4 = 0$

$\Rightarrow R_{L3} = r_{o4}$

- Circuito equivalente

$\lambda_1 = 0$



- $v_{in} = v_1 + v_{RL_1} \Rightarrow v_{in} = v_1 + g_{m1} v_1 R_{L1} \Rightarrow \boxed{v_{in} = v_1 (1 + g_{m1} R_{L1})}$
- $v_{out2} = -g_{m1} v_1 . (R_{L2} \parallel R_{L3})$
- $A_{V2} = \frac{-g_{m1} R_L}{R_{L2} \parallel R_{L3}} = g_{m1} \Rightarrow A_{V2} = \frac{1}{g_{m1} + R_L}$ $\quad A_{V2} \approx -g_{m1}$

$\frac{1}{g_{m1}} \cdot r_{o2} \parallel \frac{1}{g_{m3}}$

$$A_{v2} = \frac{v_{out2}}{v_{in}} = \frac{-g_{m1} v_1 \cdot (R_{L2} \parallel R_{L3})}{v_1 (1 + g_{m1} R_L} \div g_{m1} = \frac{-R_{L2} \parallel R_{L3}}{\frac{1}{g_{m1}} + R_{L1}}$$

$$\boxed{A_{v2} = -\frac{r_{o3} \parallel \frac{1}{g_{m3}} \parallel r_{o4}}{\frac{1}{g_{m1}} + r_{o2} \parallel \frac{1}{g_{m2}}}}$$

- $v_{out1} = g_{m1} v_1 . R_{L1}$

- $A_{v1} = \frac{v_{out1}}{v_{in}} = \frac{g_{m1} v_1 R_{L1}}{v_1 (1 + g_{m1} R_{L1})} \div g_{m1} = \frac{R_{L1}}{\frac{1}{g_{m1}} + R_{L1}}$

$$\boxed{A_{v1} = \frac{r_{o2} \parallel \frac{1}{g_{m2}}}{\frac{1}{g_{m1}} + r_{o2} \parallel \frac{1}{g_{m2}}}}$$