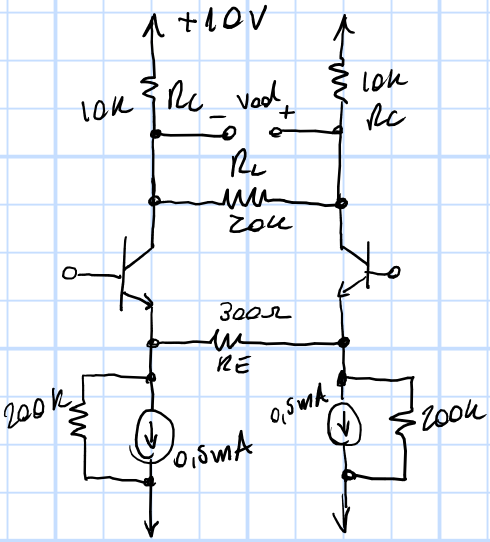
Exercício 9.62 → Sedra 7ª ed

↳ Para o circuito abaixo:

a) Esboce os meio-circuitos diferencial e de modo-comum

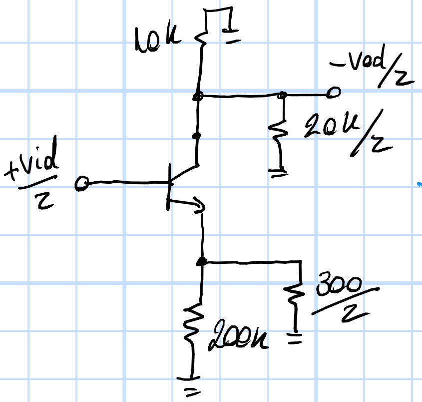
b) Encontrar Ad, Rid, Acm e Ricm, assumindo que Rc possuem 1% de tolerância → isso p/ o modo-comum!

→ Considerar $\beta = 100$ e $V_A = 100V$.

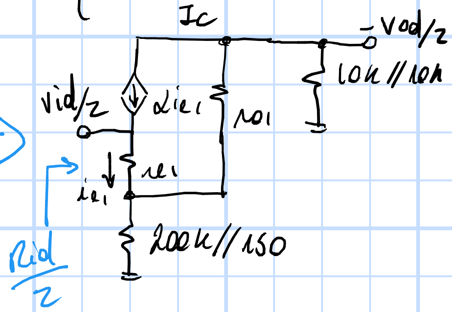


a) Note que o circuito é perfeitamente simétrico, assim

• ½ circuito diferencial



$$\begin{cases} r_{e1} = \dfrac{V_T}{0{,}5mA} = 50\Omega \\ r_o = \dfrac{V_A}{I_C} = 202k\Omega \end{cases}$$

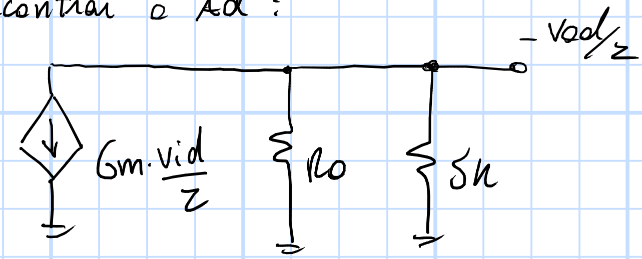


→ Modelo de pequenos sinais:

↳ Sabemos que: $\frac{R_{id}}{2} \cong (\beta+1)\left(r_{e1} + 200k//150\right)$

$$\boxed{R_{id} = 40{,}4\,k\Omega}$$

• Podemos usar o modelo Norton de um CE com degeneração para ajudar a encontrar o Ad:



• onde $G_m \cong \dfrac{1}{r_{e1} + 200k//150} = 5\,mA/V$

$R_o = 200k//150 + r_{o1} + g_{m1} r_{o1} (200k//150) = 801{,}65\,k\Omega$

$* \; g_{m1} = \dfrac{\alpha}{r_{e1}} = 19{,}8\,mA/V$

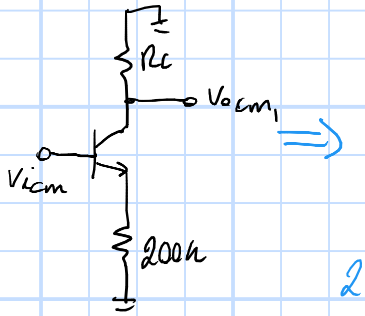
• Assim:

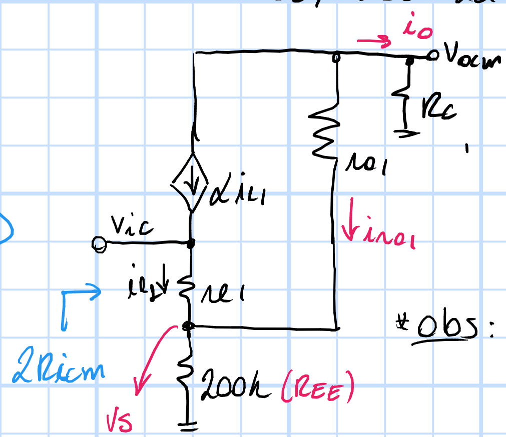
$$-\frac{v_{od}}{2} = -G_m \frac{v_{id}}{2} \cdot (R_o // 5k)$$

$$\boxed{A_d = \frac{v_{od}}{v_{id}} = 24{,}8\,V/V}$$

• 1/2 Circuito de modo-comum

↳ Como o circuito é simétrico, não há corrente em R_E e R_L, logo

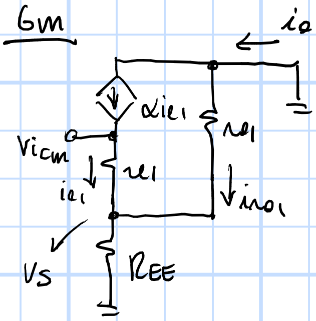




*obs: Como R_{EE} e r_{o1} tem a mesma magnitude, temos que analisar R_{icm} de forma diferente de R_{id}!

→ Calculando A_{cm_1}, usando o modelo Norton

• G_m



$$\bullet\ V_S = V_{icm} \cdot \frac{R_{EE}//r_{o1}}{r_{e1} + R_{EE}//r_{o1}}$$

$$\bullet\ i_{e1} = \frac{V_{icm} - V_S}{r_{e1}} = \frac{V_{icm}}{r_{e1}}\left(1 - \frac{R_{EE}//r_{o1}}{r_{e1} + R_{EE}//r_{o1}}\right)$$

$$= \frac{V_{icm}}{\cancel{r_{e1}}}\left(\frac{\cancel{r_{e1}}}{r_{e1} + R_{EE}//r_{o1}}\right)$$

$$\bullet\ i_{ro1} = \frac{-V_S}{r_{o1}} = \frac{-V_{icm}}{r_{o1}}\left(\frac{R_{EE}//r_{o1}}{r_{e1} + R_{EE}//r_{o1}}\right)$$

$$i_o = \alpha i_{e1} + i_{ro1} = \frac{V_{icm}}{r_{e1} + R_{EE}//r_{o1}}\left(\alpha - \frac{R_{EE}//r_{o1}}{r_{o1}}\right)$$

$$i_o = \frac{V_{icm}}{r_{e1} + \frac{R_{EE} \cdot r_{o1}}{R_{EE} + r_{o1}}} \cdot \left(\frac{\alpha r_{o1}(R_{EE} + r_{o1}) - R_{EE} r_{o1}}{r_{o1}(R_{EE} + r_{o1})}\right)$$

$$i_o = V_{icm}\left(\frac{\alpha \cancel{r_{o1}}(R_{EE} + r_{o1}) - R_{EE}\cancel{r_{o1}}}{\cancel{r_{o1}} r_{e1}(R_{EE} + r_{o1}) + R_{EE} r_{o1}^{\cancel{2}}}\right)$$

$$i_o = V_{icm}\left(\frac{R_{EE}(\alpha - 1) + \alpha r_{o1}}{R_{EE} r_{o1} + R_{EE} r_{e1} + r_{e1} r_{o1}}\right) \times \frac{\beta + 1}{\beta + 1}$$

$$i_o = V_{icm}\left(\frac{-R_{EE} + \beta r_{o1}}{(\beta + 1) R_{EE} r_{o1} + r_{\pi 1}(R_{EE} + r_{o1})}\right)$$

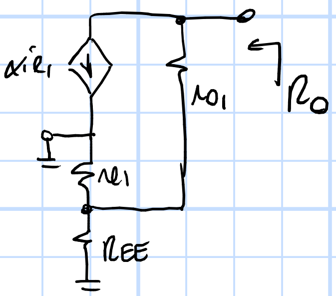
* Simplificando

↳ $\beta >> 1$ e $r_\pi << r_o, R_{EE}$

• Assim

$$i_o \cong V_{icm} \cdot \frac{\beta \cancel{r_{o1}}}{(\beta + 1)(R_{EE}\cancel{r_{o1}})} \cong \frac{\alpha V_{icm}}{R_{EE}} \Rightarrow \boxed{G_m \cong \frac{\alpha}{R_{EE}}}$$

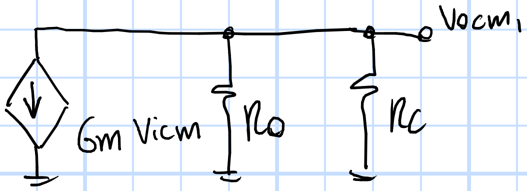
- Calculando R_o



→ Esse parâmetro já foi calculado em outros momentos:

$$R_o = R_{EE} // r_{\pi 1} + r_{o1} + g_{m1} r_{o1} R_{EE} // r_{\pi 1}$$

→ Calculando $\frac{V_{ocm1}}{V_{icm}}$



$$V_{ocm1} = -G_m \cdot (R_o // R_c)$$

$$\frac{V_{ocm1}}{V_{icm}} = -\frac{\alpha}{R_{EE}} \left(\frac{R_o R_c}{R_o + R_c} \right)$$

→ Como $R_o >>> R_c$

$$\boxed{\frac{V_{ocm1}}{V_{icm}} = \frac{-\alpha R_c}{R_{EE}}}$$

- Calculando A_{cm}

$A_{cm} = -A_{cm1} + A_{cm2}$, assumindo $R_{c1} = R_c - \Delta R_c/2$, $R_{c2} = R_c + \Delta R_c/2$

$$A_{cm} = +\frac{\alpha(R_c - \frac{\Delta R_c}{2})}{R_{EE}} - \frac{\alpha(R_c + \Delta R_c/2)}{R_{EE}}$$

$$A_{cm} = \cancel{\frac{\alpha R_c}{R_{EE}}} - \frac{\alpha \Delta R_c}{2 R_{EE}} - \cancel{\frac{\alpha R_c}{R_{EE}}} - \frac{\alpha \Delta R_c}{2 R_{EE}}$$

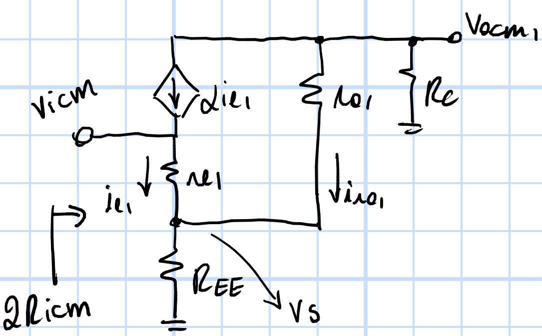
$$\boxed{A_{cm} = -\frac{\alpha \Delta R_c}{R_{EE}}}$$

→ Como $R_c = 10k\Omega$

$\Delta R_c = 1\%$ de R_c $= 100\Omega$

$$\boxed{A_{cm} = -\frac{0{,}99 \cdot 100}{200k} = -495 \ \mu V/V}$$

- Calculando R_{icm}



→ Sabemos que $2R_{icm} = \frac{V_{icm}}{i_{b1}} = \frac{(\beta+1) V_{icm}}{i_{e1}}$

↳ também: $i_{e1} + i_{ro1} = \frac{V_s}{R_{EE}}$

- $\frac{V_{icm} - V_s}{r_{e1}} + \frac{V_{ocm} - V_s}{r_{o1}} = \frac{V_s}{R_{EE}}$
- $V_{ocm} \cong \frac{-\alpha R_c}{R_{EE}} V_{icm}$

logo: $V_{icm} \left(\frac{1}{r_{e1}} - \frac{\alpha R_c}{r_{o1} R_{EE}} \right) = V_s \left(\frac{1}{R_{EE}} + \frac{1}{r_{o1}} + \frac{1}{r_{e1}} \right)$

• $$v_{icm}\left(\frac{r_{o1}R_{EE} - \alpha r_{e1} R_C}{\cancel{r_{e1} r_{o1} R_{EE}}}\right) = V_S \frac{r_{e1} r_{o1} + R_{EE} r_{e1} + R_{EE} r_{o1}}{\cancel{r_{e1} r_{o1} R_{EE}}}$$

$$V_S = v_{icm}\left(\frac{r_{o1} R_{EE} - \alpha r_{e1} R_C}{r_{e1} r_{o1} + R_{EE} r_{e1} + R_{EE} r_{o1}}\right)$$

• Assim:

$$i_{e1} = \frac{v_{icm} - V_S}{r_{e1}} = \frac{v_{icm}}{r_{e1}}\left[1 - \frac{r_{o1}R_{EE} - \alpha r_{e1}R_C}{R_{EE}(r_{e1}+r_{o1}) + r_{e1}r_{o1}}\right]$$

$$= \frac{v_{icm}}{\cancel{r_{e1}}}\left[\frac{R_{EE}\cancel{r_{e1}} + R_{EE}\cancel{r_{o1}} + \cancel{r_{e1}}r_{o1} - r_{o1}\cancel{R_{EE}} + \alpha \cancel{r_{e1}} R_C}{R_{EE}(r_{e1}+r_{o1}) + r_{e1}r_{o1}}\right]$$

$$i_{e1} = v_{icm}\left[\frac{R_{EE} + r_{o1} + \alpha R_C}{R_{EE}r_{e1} + R_{EE}r_{o1} + r_{e1}r_{o1}}\right]$$

$$2R_{icm} = \frac{v_{icm}}{i_{e1}}(\beta+1) = \frac{R_{EE}r_{e1} + R_{EE}r_{o1} + r_{e1}r_{o1}}{R_{EE}+r_{o1}+\alpha R_C}(\beta+1)$$

$$\boxed{R_{icm} = \frac{[R_{EE}r_{o1} + r_{e1}(R_{EE}+r_{o1})](\beta+1)}{2(R_{EE}+r_{o1}+\alpha R_C)} = 4{,}95\ M\Omega}$$