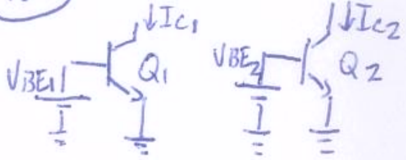
RAZAVI (4.5, 4.6, 4.10, 4.11, 4.16, 4.22 a), 4.25, 4.29, 4.36, 4.45, 4.53, 4.56)
CAP 4

(4.5)



$I_{C1} = I_{C2} = I_C$

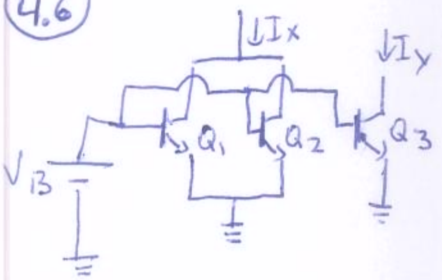
$V_{BE1} - V_{BE2} = 0{,}02$

$V_T \ln\left(\frac{I_C}{I_{S1}}\right) - V_T \ln\left(\frac{I_C}{I_{S2}}\right) = 0{,}02$

$V_T \ln\left(\frac{I_C}{I_{S1}} \frac{I_{S2}}{I_C}\right) = 0{,}02 \Rightarrow \frac{0{,}02}{V_T} = \ln \frac{I_{S2}}{I_{S1}} \Rightarrow \frac{I_{S2}}{I_{S1}} = \exp\left(\frac{0{,}02}{V_T}\right)$

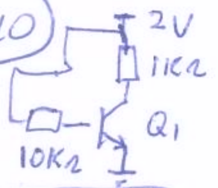
$I_S \propto A \Rightarrow$ $\boxed{\frac{A_2}{A_1} = \exp\left(\frac{0{,}02}{V_T}\right) = 2{,}1581}$ ($V_T \to 26\,mV$)

(4.6)



- $I_X = 1mA$; $I_{S1} = I_{S2} = 3 \cdot 10^{-16}$; $V_T = 26mV$; $I_{C3} = 2{,}5mA$
- $I_{C1} = I_{C2} = \frac{I_X}{2} = 0{,}5 \cdot 10^{-3} A$
- $V_{BE1} = V_{BE2} = V_{BE3} = V_T \ln\left(\frac{I_{C1}}{I_S}\right) \Rightarrow V_{BE} = 0{,}7317\,V$
- $I_{C3} = I_Y = 2{,}5mA \Rightarrow I_{C3} = I_{S3} \cdot \exp\left(\frac{V_{BE}}{V_T}\right) \Rightarrow$ $\boxed{I_{S3} = 1{,}5 \cdot 10^{-15} A}$

(4.10)



$I_S = 3 \cdot 10^{-16}$
$V_T = 26\,mV$

$\Rightarrow V_C = V_B \Rightarrow V_{CC} = R_C I_C + V_C \Rightarrow V_{CC} = R_C I_C + V_B$ ($V_B \to V_{BE}$)

$\begin{cases} V_{BE} = V_{CC} - R_C I_C \\ I_C = I_S \cdot \exp\left(\frac{V_{BE}}{V_T}\right) \end{cases} \Rightarrow V_{BE} = V_{CC} - R_C I_S \cdot \exp\left(\frac{V_{BE}}{V_T}\right)$

- $V_{CC} - R_C I_S \exp\left(\frac{V_{BE}}{V_T}\right) - V_{BE} = 0 \rightarrow$ Resolver por cálculo numérico ou

* Método Iterativo (Para $V_{CC} = 2V$)

① $V_{BE} = 0{,}7V$

$I_C = \underbrace{V_{CC} - V_{BE}}_{V_C} \cdot \underbrace{R_C}_{1k\Omega} = 1{,}3mA$

② $V_{BE} = V_T \log \frac{I_C}{I_S} = 0{,}7565V$

$I_C = 1{,}2435mA$

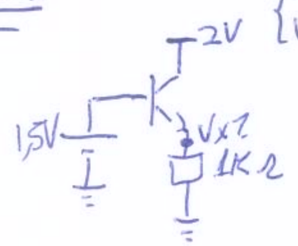
③ $V_{BE} = 0{,}7554$

$I_C = 1{,}2446mA$

④ $V_{BE} = 0{,}7554 \Rightarrow OK$ ~ $V_{CC} = 2V$

obs: O enuncido do Livro está errado. O correto é determine I_C e V_{BE}, para saturação fraca.
Não tem como resolver se não der o β, como enunciado do Livro

4.11



$\begin{cases} V_B < V_C \Rightarrow \text{modo Ativo} \\ V_B > V_E \end{cases}$

$I_S = 6 \cdot 10^{-16} A$

$V_T = 26mV$

$\Rightarrow \quad I_E = \frac{1{,}5 - V_{BE}}{1 \cdot 10^3} \overset{\beta \gg 1,\ I_C \sim I_E}{\Rightarrow} I_C \cong \frac{1{,}5 - V_{BE}}{1000}$ ①

$\Rightarrow \quad I_C = I_S \cdot \exp\frac{V_{BE}}{V_T}$ ②

$\overset{①}{\Rightarrow} \quad V_{BE} = 1{,}5 - 1000 I_C \overset{②}{\Rightarrow} \quad V_{BE} - 1{,}5 + 1000 \cdot I_S \exp\left(\frac{V_{BE}}{V_T}\right) =$

cálculo numérico ⇒ Matlab: fsolve

$V_{BE} = 0{,}7251V$
$I_C = 7{,}7494 \cdot 10^{-4} A$

ou

* Método iterativo

① $V_{BE} = 0{,}7V$

$I_C = \frac{1{,}5 - V_{BE}}{1000} = 8 \cdot 10^{-4} A$

② $V_{BE} = V_T \log \frac{I_C}{I_S} = 0{,}7259V$

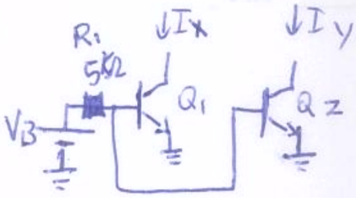
$I_C = 7{,}7411 \cdot 10^{-4} A$

③ $V_{BE} = 0{,}7250$

$I_C = 7{,}7497 \cdot 10^{-4} A$

④ $V_{BE} = 0{,}7251V$
$I_C = 7{,}7494 A$

4.16

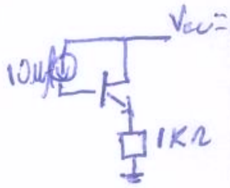


$I_{S1} = 2 I_{S2} = 4 \cdot 10^{-16}$
$\beta_1 = \beta_2 = 100$
$R_1 = 5k\Omega$
$V_B ?$ $I_x = 1mA$

$I_B = I_C/\beta$

- $\frac{I_x}{I_y} = \frac{I_{S1}}{I_{S2}} = (2) \Rightarrow I_{C1} = 2 I_{C2} \Rightarrow I_{B1} = 2 \cdot I_{B2}$
- $V_{BE1} = V_{BE2} = V_{BE} = V_T \log \frac{I_x}{I_{S1}} \Rightarrow V_{BE} = 0{,}7422$
- $I_{B1} = \frac{I_x}{\beta} \Rightarrow I_{B1} = 1 \cdot 10^{-5} A$
- $I_{B2} = \frac{I_{B1}}{2} \Rightarrow I_{B2} = 0{,}5 \cdot 10^{-5} A$
- $V_B = V_{R1} + V_{BE} = (I_{B1} + I_{B2}) R_1 + V_{BE} \Rightarrow \boxed{V_B = 0{,}8172 V}$

4.22 a)



$\beta = 100$
$I_S = 8 \cdot 10^{-16} A$
$V_A = \infty$

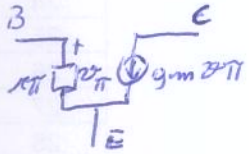
$I_B = 10 \mu A$
$I_C = \beta I_B = 1mA$
$I_E = I_C + I_B = 1{,}01 mA \Rightarrow V_E = 1000 I_E = 1{,}01 V \Rightarrow V_{CE} = V_{CC} - V_E$
$V_{CE} = 0{,}99V$
$V_{BE} = V_T \log \frac{I_C}{I_S} = 0{,}7242 V$
~~V...~~
$V_{CE} > V_{BE}$
↳ modo ativo

$g_m = \frac{I_C}{V_T} = 0{,}0385 S$

$r_\pi = \frac{\beta}{g_m} = 2.600 \Omega$

$r_o = \infty$

$\Rightarrow$



4.25 $\Delta V_{CE} = 1 \text{ a } 3V$

V_{BE} cte

V_A ? $\Delta I_C < 5\% I_C$

$$\Rightarrow I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \cdot \left[1 + \frac{V_{CE}}{V_A}\right]$$

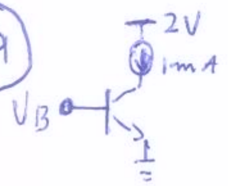
$$\Delta I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \cdot \frac{\Delta V_{CE}}{V_A}$$

$$\frac{\Delta I_C}{I_C} < 5\% \Rightarrow \frac{\Delta I_C}{I_C} = \frac{I_S \exp\frac{V_{BE}}{V_T}\left[\frac{\Delta V_{CE}}{V_A}\right]}{I_S \cdot \exp\frac{V_{BE}}{V_T} \cdot \left[1 + \frac{V_{CE}}{V_A}\right]}$$

$$\frac{\frac{\Delta V_{CE}}{V_A}}{1 + \frac{V_{CE}}{V_A}} < 0{,}05 \Rightarrow \frac{\frac{\Delta V_{CE}}{V_A}}{\frac{V_A + V_{CE}}{V_A}} < 0{,}05 \Rightarrow \frac{\Delta V_{CE}}{V_A + V_{CE}} < 0{,}05$$

$$\frac{\Delta V_{CE}}{0{,}05} < V_A + V_{CE} \Rightarrow \frac{(3-1)}{0{,}05} < V_A + 1 \Rightarrow \boxed{V_A > 39V}$$

4.29



$I_S = 3 \cdot 10^{-17} A$

a) $V_A = \infty$: V_B?

$$V_B = V_{BE} = V_T \ln \frac{I_C}{I_S} \Rightarrow V_B = 0{,}8096 V$$

($I_C \sim 1mA$)

b) $V_A = 5V$; $I_C = 1mA$; $V_{CE} = 1{,}5V$

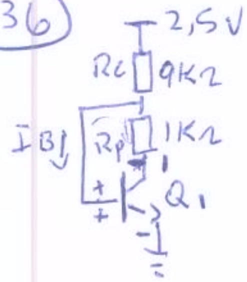
$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \cdot \left(1 + \frac{V_{CE}}{V_A}\right) \Rightarrow \exp\left(\frac{V_{BE}}{V_T}\right) = \frac{I_C}{\left(1 + \frac{V_{CE}}{V_A}\right) \cdot I_S}$$

$$V_{BE} = V_T \ln\left(\frac{I_C}{I_S \cdot \left(1 + \frac{V_{CE}}{V_A}\right)}\right)$$

$$\boxed{V_{BE} = 0{,}8028V}$$

(4)

4.36



$\beta = 100$
$V_{CB} = 200mV$
I_S ?
$V_A = \infty$

$R_p \cdot I_C = 0,2V$

$I_C = 0,2\,mA$

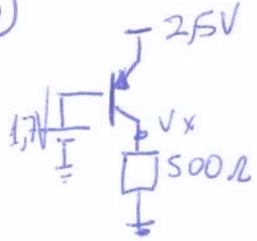
$\bullet\; V_{cc} = 9 \cdot I_{RC} + V_{BE}$

$\Rightarrow V_{cc} = 9 \cdot (I_B + I_C) + V_{BE} \Rightarrow V_{BE} = V_{cc} - 9 \cdot \left(\frac{I_C}{\beta} + I_C\right)$

$V_{BE} = V_{cc} - 9 \cdot \frac{\beta+1}{\beta} \cdot I_C \Rightarrow V_{BE} = 0,6820$

$I_C = I_S \exp \frac{V_{BE}}{V_T} \Rightarrow I_S = I_C / \exp \frac{V_{BE}}{V_T} \Rightarrow I_S = 8,1124 \cdot 10^{-16}\,A$

4.45



a) $I_S = 5 \cdot 10^{-17} A$; $V_T = 26mV$
$V_A = \infty$

$V_{EB} = 2,5 - 1,7 = 0,8V$

$I_C = I_S \exp \frac{V_{EB}}{V_T} = 1,1531\,mA$

$V_X = I_C \cdot 500 \Rightarrow V_X = 0,5766V$

$\begin{cases} V_B > V_C \\ V_B < V_E \end{cases} \Rightarrow$ transistor PNP no modo ativo

b) $V_A = 6V$ $\quad V_{EC} = V_{cc} - 500 I_C$

$I_C = I_S \exp \frac{V_{EB}}{V_T} \left(1 + \frac{V_{EC}}{V_A}\right)$

$I_C = I_S \exp \frac{V_{EB}}{V_T} \left(1 + \frac{V_{cc} - 500 I_C}{V_A}\right) = I_S \exp \frac{V_{EB}}{V_T} + I_S \exp \frac{V_{EB}}{V_T} \left(\frac{V_{cc} - 500 I_C}{V_A}\right)$

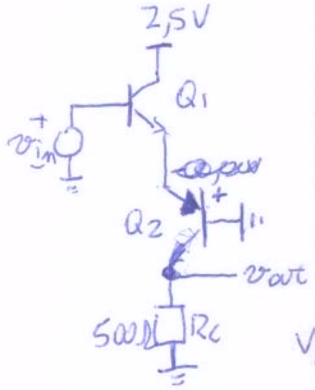
$I_C = I_S \exp \frac{V_{EB}}{V_T} + \frac{V_{cc}}{V_A} I_S \exp \frac{V_{EB}}{V_T} - \frac{500 I_C}{V_A} \cdot I_S \exp \frac{V_{EB}}{V_T}$

$I_C \cdot \left(1 + \frac{500}{V_A} I_S \exp \frac{V_{EB}}{V_T}\right) = I_S \exp \frac{V_{EB}}{V_T} \left(1 + \frac{V_{cc}}{V_A}\right)$

$$I_C = \frac{I_S \exp \frac{V_{EB}}{V_T} \left(1 + \frac{V_{cc}}{V_A}\right)}{1 + \frac{500}{V_A} I_S \exp \frac{V_{EB}}{V_T}} = 1,49\,mA$$

$V_X = 0,7452V \rightarrow$ modo ativo

4.53



$I_{S1} = 3 I_{S2} = 5 \cdot 10^{-16} A$

$\beta_1 = 100 ; \beta_2 = 50$

$V_A = \infty ; V_T = 26 mV$

• $V_{EB2} \leq 0,2 V$

$I_{C2} \cdot 500 \leq 0,2V$

$I_{C2} \leq 4 \cdot 10^{-4} A$

$V_{E2} = V_{EB2} \leq V_T \ln \frac{I_{C2}}{I_{S2}} \Rightarrow V_{E2} \leq 0,7412 V$

$I_{E1} = I_{E2} = \left(\frac{\beta_2 + 1}{\beta_2}\right) \cdot I_{C2} \Rightarrow I_{E1} = I_{E2} \leq 4.08 \cdot 10^{-4} A$

$I_{C1} = \alpha_1 I_{E1} = \frac{\beta_1}{\beta_1 + 1} \cdot I_{E1} \Rightarrow I_{C1} \leq 4,039 \cdot 10^{-4} A$

$V_{BE1} = V_T \cdot \ln \frac{I_{C1}}{I_{S1}} \Rightarrow V_{BE1} \leq 0,7129 V$

$V_{in} = V_{BE1} + V_{EB2} \Rightarrow V_{in} \leq 1,4540$

b) $I_{C1} = 4,039 \cdot 10^{-4}$

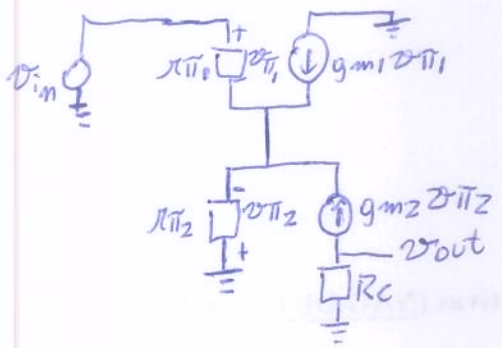
$I_{C2} = 4 \cdot 10^{-4} A$

$g_{m1} = \frac{I_{C1}}{V_T} = 0,0155 S$

$g_{m2} = \frac{I_{C2}}{V_T} = 0,01545$

$r_{\pi 1} = \frac{\beta_1}{g_{m1}} = 6,4363 \cdot 10^3 \Omega$

$r_{\pi 2} = \frac{\beta_2}{g_{m2}} = 3,25 \cdot 10^3 \Omega$



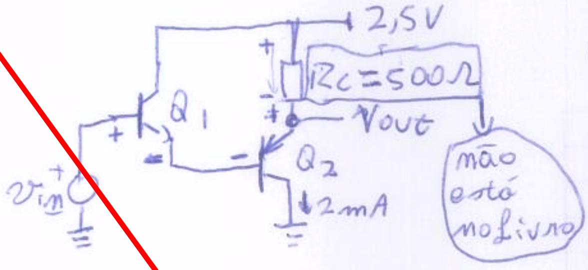
Não tem como resolver, pois IE1 não pode ser igual a IB2

4.56 $I_{S1} = 2I_{S2} = 6 \cdot 10^{-17} A$

$\beta_1 = 80$; $\beta_2 = 100$

a) V_{in}?

$I_{C2} = 2 mA$



$V_{EB2} = V_T \ln \frac{I_{C2}}{I_{S2}} = \underline{0,8276V}$

$I_{E2} = \frac{\beta_2 + 1}{\beta_2} \cdot I_{C2} = \underline{2,02 mA}$

$I_{B2} = \frac{I_{C2}}{\beta_2} = 2 \cdot 10^{-5} A$

~~$v_{out} = V_{CC} - R_C I_{E2}$~~

$I_{E1} = I_{B2} = \underline{2 \cdot 10^{-5} A}$

$I_{C1} = \alpha_1 I_{E1} = 1,9753 \cdot 10^{-5} A$

$\alpha_1 \to \frac{\beta}{\beta + 1}$

$V_{BE1} = V_T \ln \frac{I_{C1}}{I_{S1}} = 0,968951 V$

$V_{CC} - R_C I_{C2} - V_{EB2} + V_{BE1} - V_{in} = 0$

$V_{in} = V_{CC} - R_C I_{C2} - V_{EB2} + V_{BE1} = \boxed{1,3619V}$

b) $g_{m1} = \frac{I_{C1}}{\beta_1} = 7,5973 \cdot 10^{-4} S$ $\qquad V_A = \infty \Rightarrow R_O = \infty$

$g_{m2} = \frac{I_{C2}}{\beta_2} = 0,0769 S$

$r_{\pi 1} = 1,053 \cdot 10^{5} \Omega$

$r_{\pi 2} = 1300 \Omega$