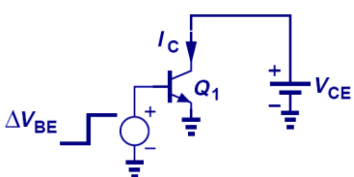
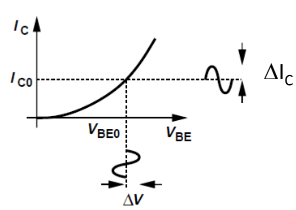
EE 530 Eletrônica Básica I

Transistores Bipolares de Junção

Prof. Pedro Xavier

Transcondutância



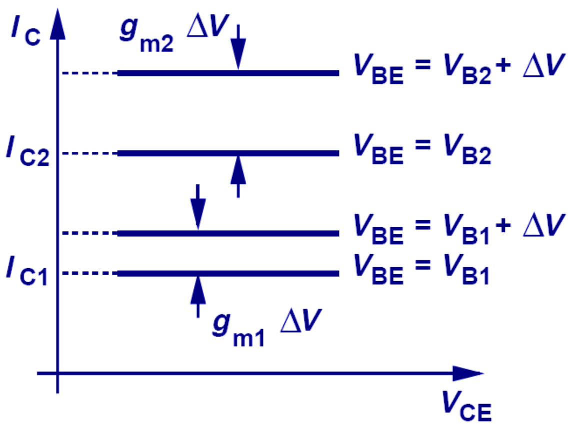


$g_m = \Delta I_C / \Delta V_{BE}$ → $$g_m = \frac{dI_C}{dV_{BE}}$$

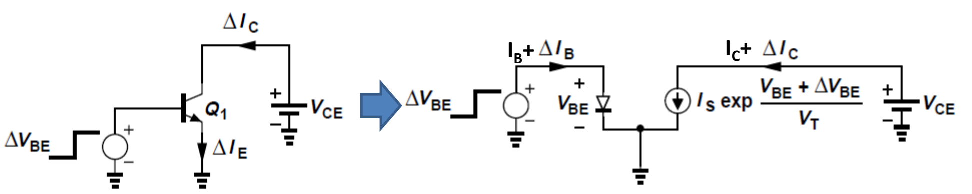
$$g_m = \frac{d}{dV_{BE}}\left(I_S \exp\frac{V_{BE}}{V_T}\right) = \frac{1}{V_T} I_S \exp\frac{V_{BE}}{V_T}$$

$$\boxed{g_m = \frac{I_C}{V_T}}$$

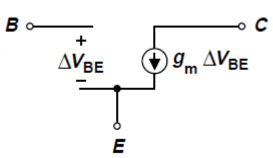
Transcondutância



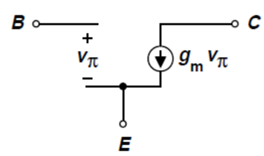
Modelo de pequenos sinais



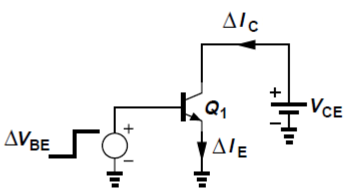
$\Delta I_C = g_m \Delta V_{BE}$

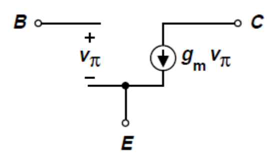


$v_\pi = \Delta V_{BE}$



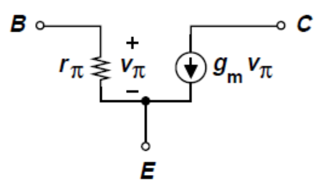
Modelo de pequenos sinais





$$\Delta I_B = \frac{\Delta I_C}{\beta} = \frac{g_m}{\beta}\Delta V_{BE}$$

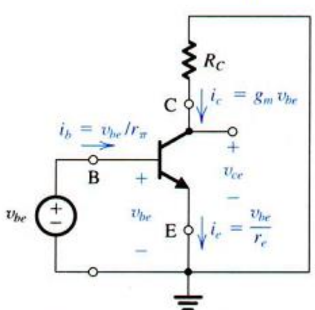
$$r_\pi = \frac{\Delta V_{BE}}{\Delta I_B} = \frac{\beta}{g_m}$$



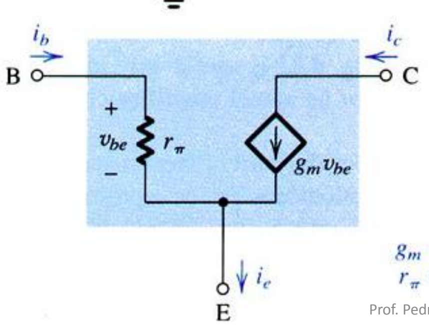
Modelo π-híbrido

Obs:Neste modelo se V_{CE} varia, I_C=cte.

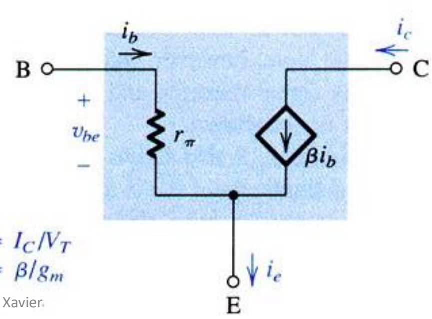
Modelos equivalentes para pequenos sinais



Modelo π-híbrido

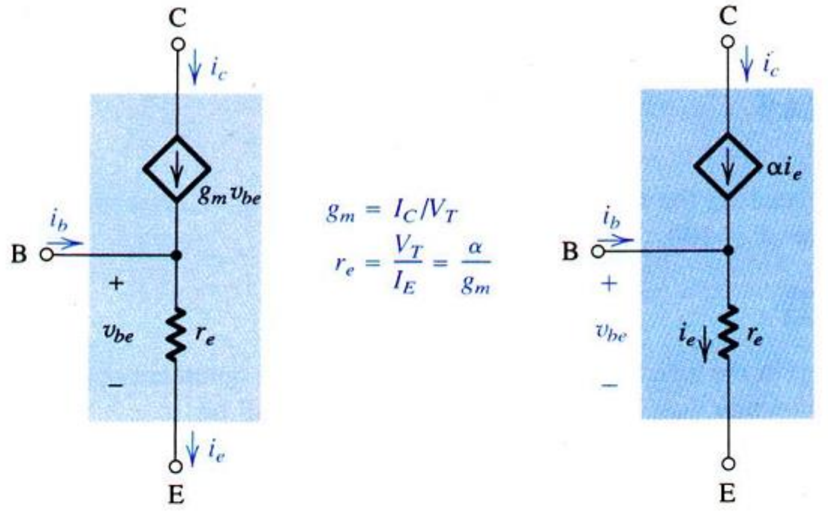


$g_m = I_C/V_T$
$r_\pi = \beta/g_m$



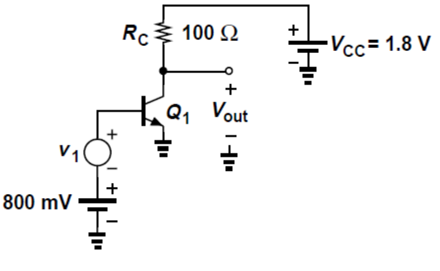
Modelos equivalentes para pequenos sinais

Modelo T



Exercício (Razavi)

- Determine V_{out}



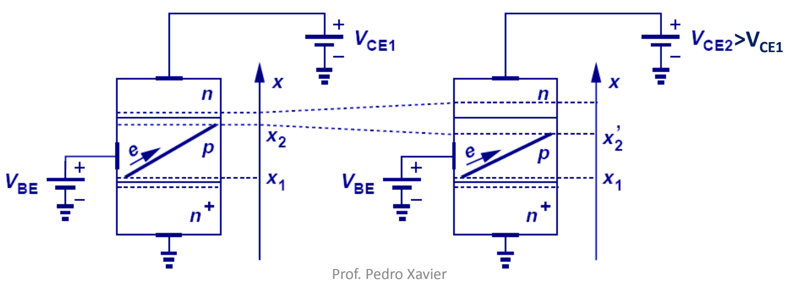
v_{1pp}= 1mV

$I_S = 3 \times 10^{-16}$ A

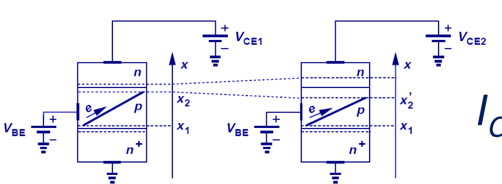
$\beta = 100$

Efeito Early – Modulação da Largura de Base

- A largura da junção BC aumenta com V_{BC} e/ou V_{CE}, diminuindo a largura efetiva da base
- O perfil de n_p muda, fica mais inclinado, mudando a corrente de difusão de e^- e I_C.

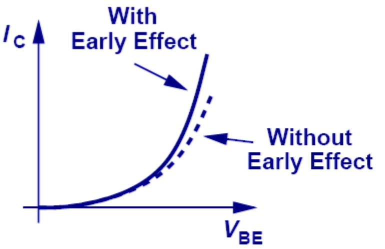


Efeito Early – Modulação da Largura de Base

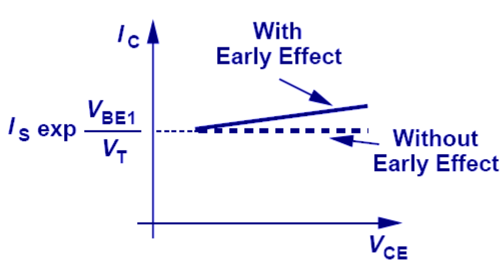


$$I_C = \left(I_S \exp \frac{V_{BE}}{V_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

Tensão Early

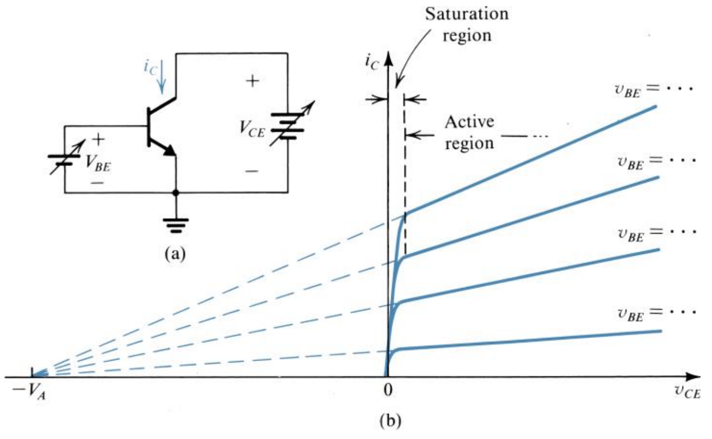


(a)

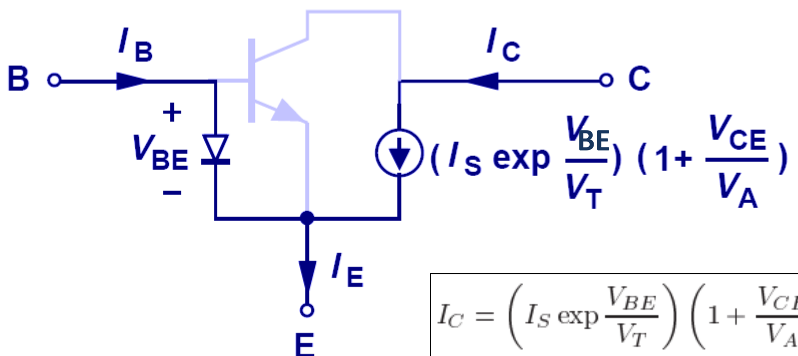


(b)

Efeito Early – Modulação da Largura de Base



Modelo de grandes sinais (região ativa)

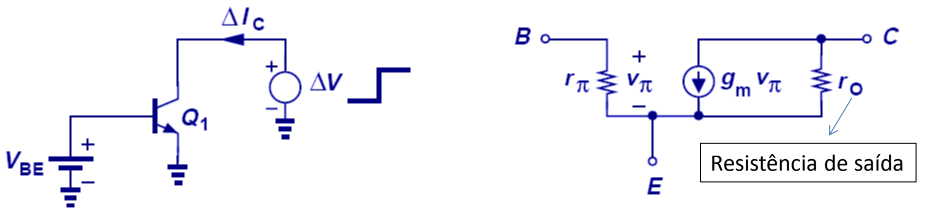


$$I_C = \left(I_S \exp \frac{V_{BE}}{V_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

$$I_B = \frac{1}{\beta}\left(I_S \exp \frac{V_{BE}}{V_T}\right)$$

$$I_E = I_C + I_B.$$

Modelo de pequenos sinais

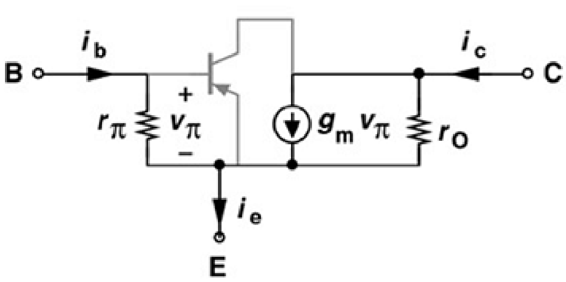


(a) (b)

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

$$r_O = \frac{\Delta V_{CE}}{\Delta I_C} = \frac{V_A}{I_S \exp\frac{V_{BE}}{V_T}} \Rightarrow \boxed{r_O \approx \frac{V_A}{I_C}}$$

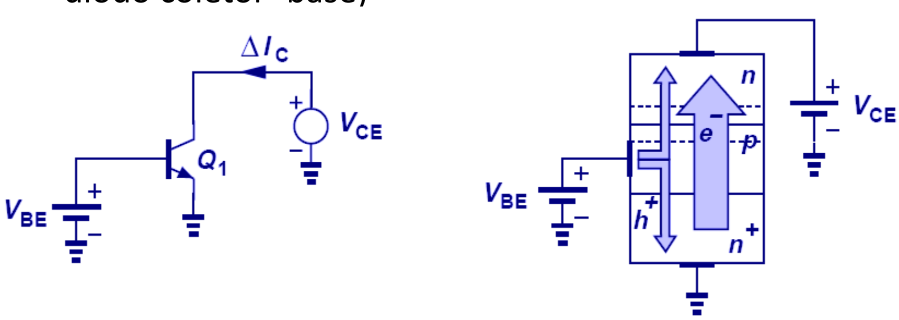
Observe que o modelo de pequenos sinais é o mesmo independente do TBJ ser NPN ou PNP



Parâmetros do Modelo em Termos das Correntes de Polarização *cc*:		
$g_m = \dfrac{I_C}{V_T}$	$r_e = \dfrac{V_T}{I_E} = \alpha\left(\dfrac{V_T}{I_C}\right)$	
$r_\pi = \dfrac{V_T}{I_B} = \beta\left(\dfrac{V_T}{I_C}\right)$	$r_o = \dfrac{V_A}{I_C}$	
Em termos de g_m:		
$r_e = \dfrac{\alpha}{g_m}$	$r_\pi = \dfrac{\beta}{g_m}$	
Em termos de r_e:		
$g_m = \dfrac{\alpha}{r_e}$	$r_\pi = (\beta + 1)r_e$	$g_m + \dfrac{1}{r_\pi} = \dfrac{1}{r_e}$
Relações entre α e β:		
$\beta = \dfrac{\alpha}{1 - \alpha}$	$\alpha = \dfrac{\beta}{\beta + 1}$	$\beta + 1 = \dfrac{1}{1 - \alpha}$

Saturação

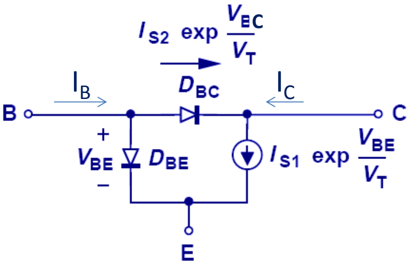
- As duas junções estão polarizadas diretamente
- V_{BC}>0,4 V: Saturação forte
- V_{BC}<0,4 V: Saturação fraca (despreza a corrente do diodo coletor- base)



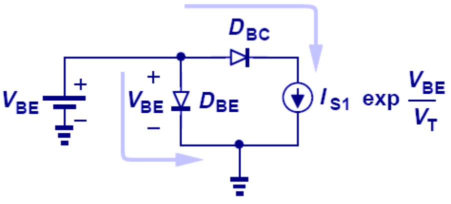
(a) (b)

Saturação

- Para $V_{BC}<0,4 \rightarrow I_C \cong I_{S1}\exp(V_{BE}/V_T)$
- Para $V_{BC}>0,4 \rightarrow I_C = I_{S1}\exp(V_{BE}/V_T) - I_{S2}\exp(V_{BC}/V_T)$
- I_B aumenta e I_C diminui $\rightarrow \beta$ diminui

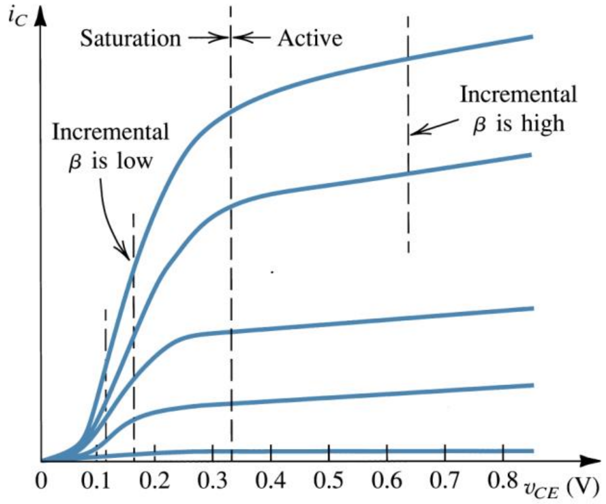


(a)



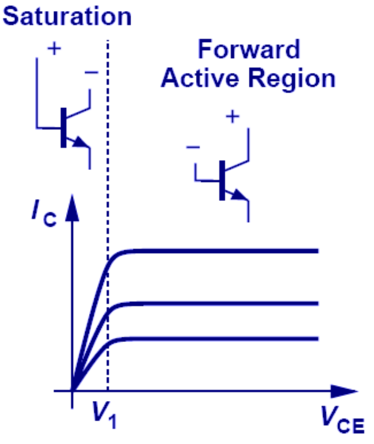
(b)

Saturação

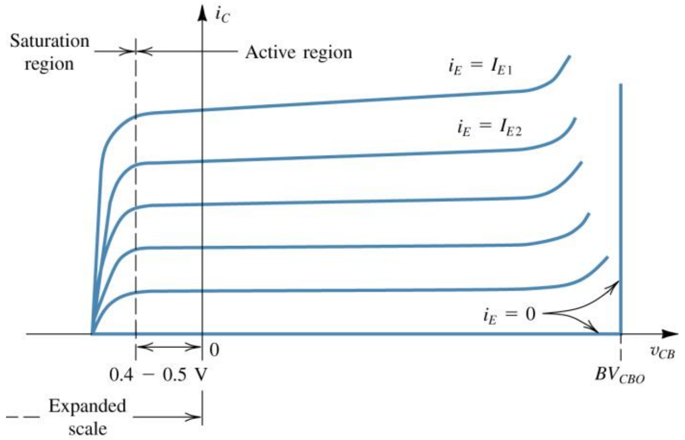


Saturação

- V_{CE} diminui
- Para saturação forte:
  V_{CEsat}=200mV



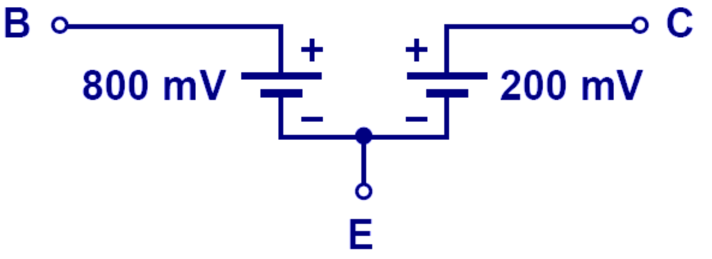
Saturação



Saturação

- Modelo para saturação forte:

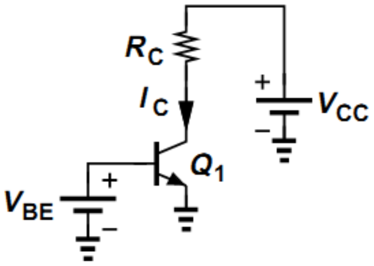
  V_{CEsat}=200mV

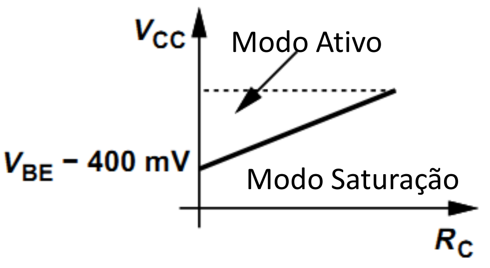


Obs: Menor resposta em frequência.

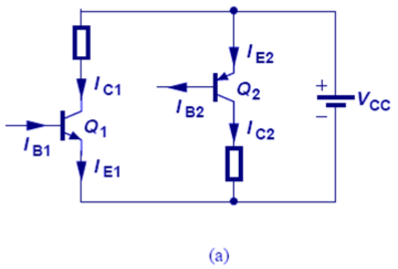
Limite Modo Saturação - Ativo

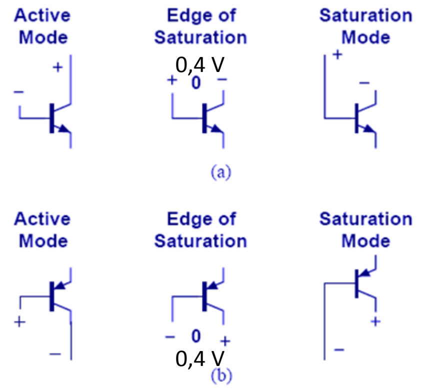
- Região Ativa: $V_{CC} \geq I_C R_C + (V_{BE} - 400\,\mathrm{mV})$



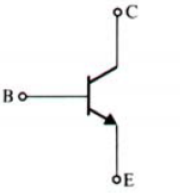


Resumo



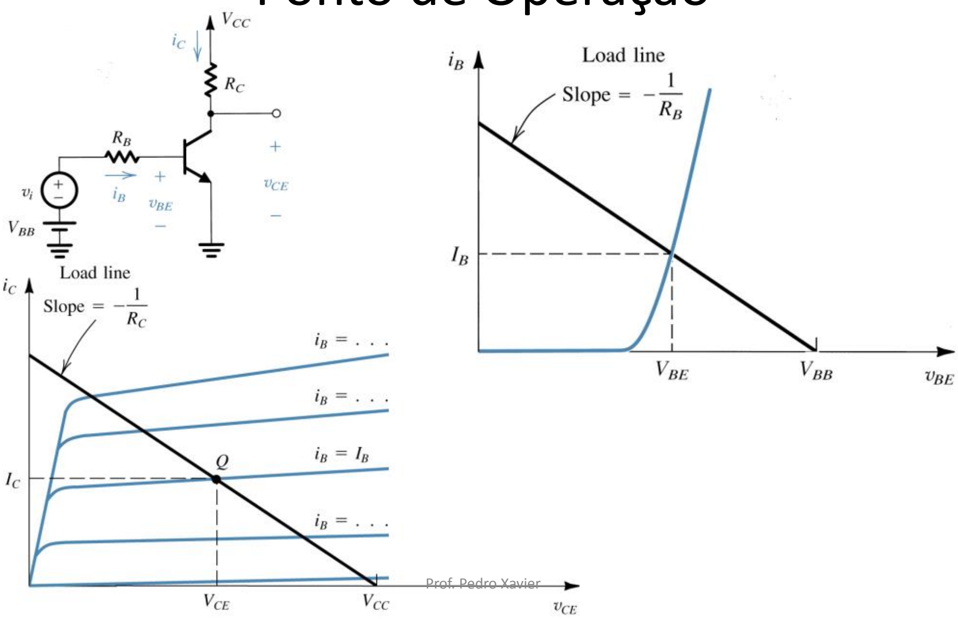


Modos de operação



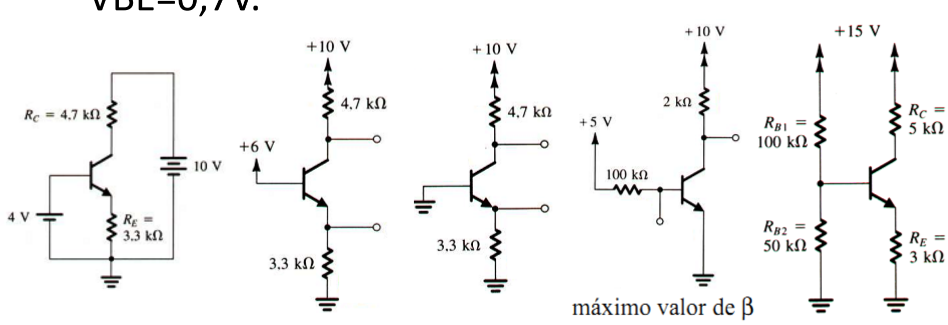
Modo	JBE	JBC
Corte	Reversa	Reversa
Ativo direto	Direta	Reversa
Saturação	Direta	Direta

Ponto de Operação



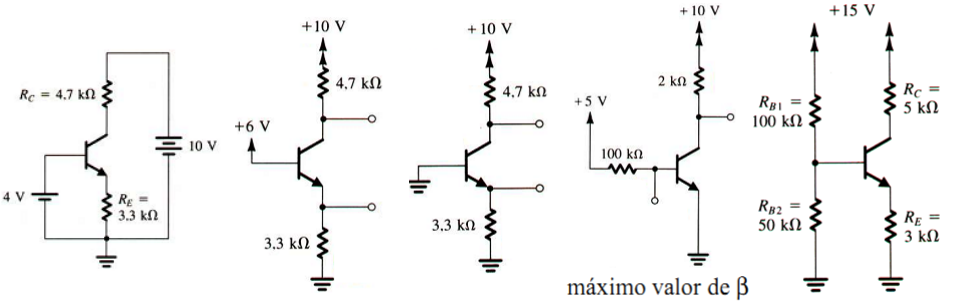
Análise cc

- Determine todas tensões e correntes dos circuitos a seguir (β=100). Considere VBE=0,7V.



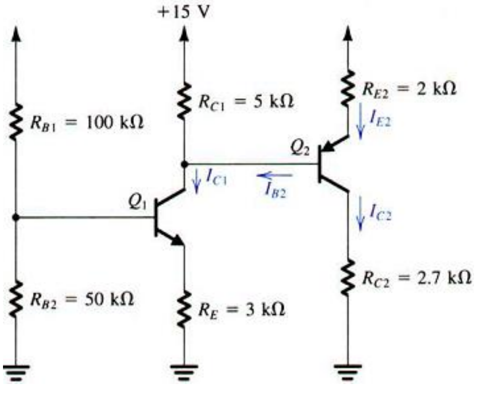
Análise cc

- Determine todas tensões e correntes dos circuitos a seguir (β=100).



Análise cc (V_{BE} = 0,7V)

- Determine todas tensões e correntes dos circuitos a seguir (β=100).



Fontes de figuras da aula

- Aula do prof. Fabiano Fruett
- Introdução à física dos semicondutores (H.A. Mello)
- Fundamentos da microeletrônica (Razavi)
- Microeletrônica (Sedra)

Sugestão de estudo

- Sedra/Smith cap. 4 seções 4.5 até 4.8
- Razavi cap. 4 a partir da seção 4.4.3

Para saber mais:

Paul R. Gray e Robert G. Meyer, Analysis and Design of Analog integrated Circuits, John Wiley & Sons