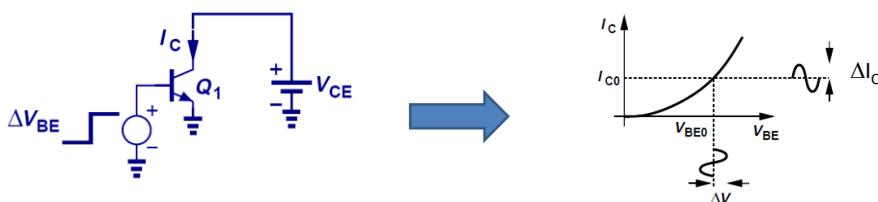


EE 530 Eletrônica Básica I

Transistores Bipolares de Junção

1

Transcondutância

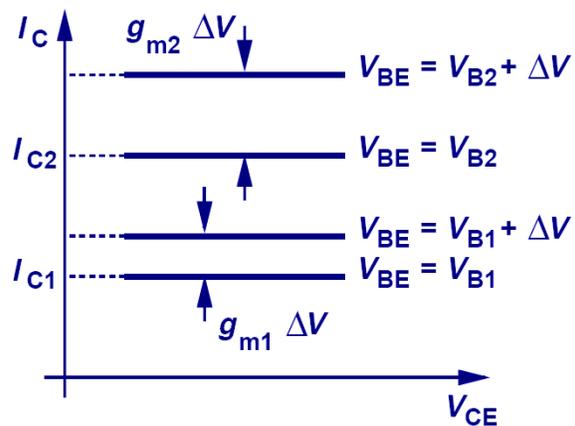


$$g_m = \Delta I_C / \Delta V_{BE} \quad \longrightarrow \quad g_m = \frac{dI_C}{dV_{BE}}$$

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

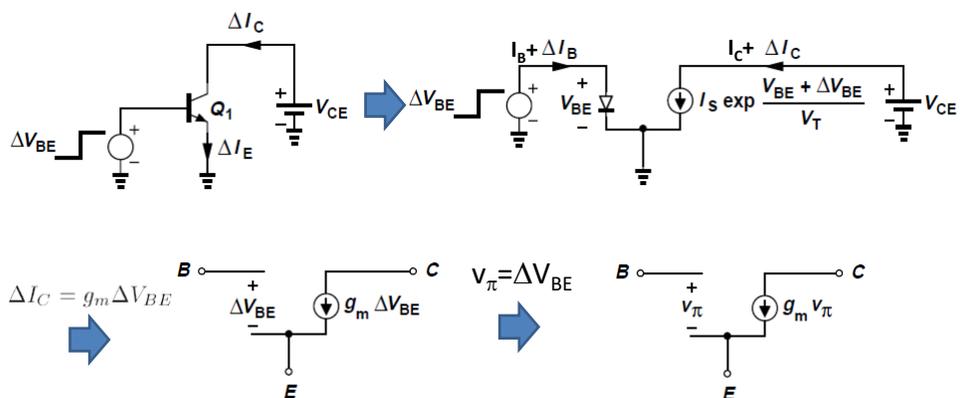
$$g_m = \frac{I_C}{V_T}$$

Transcondutância



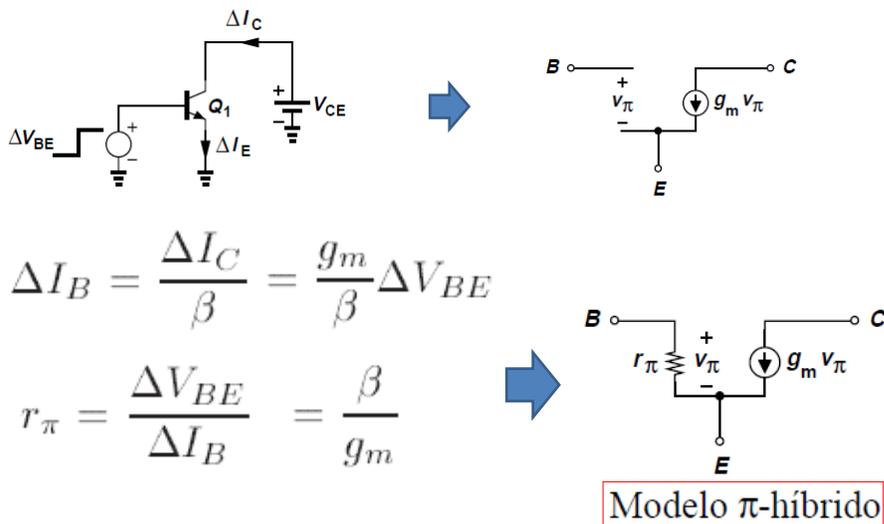
3

Modelo de pequenos sinais



4

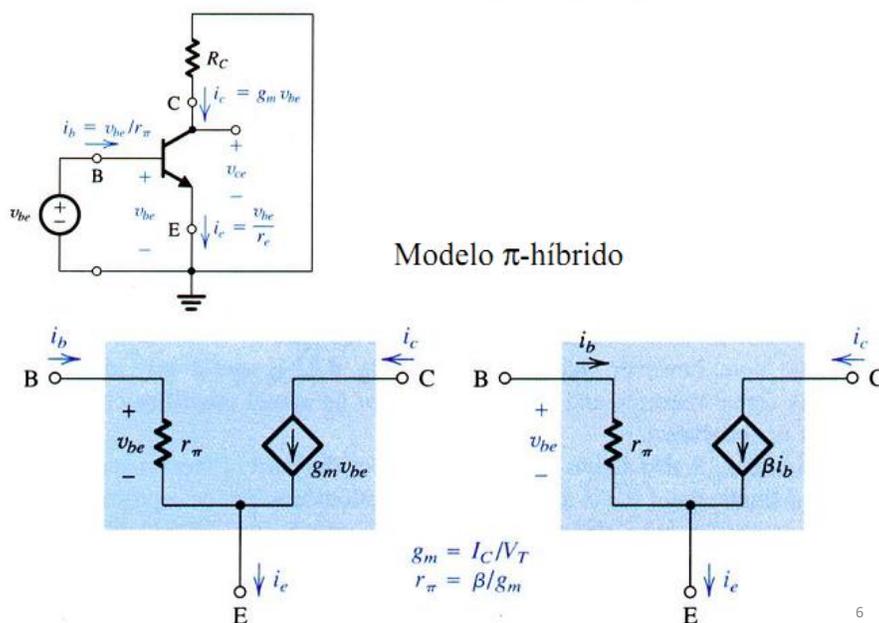
Modelo de pequenos sinais



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

5

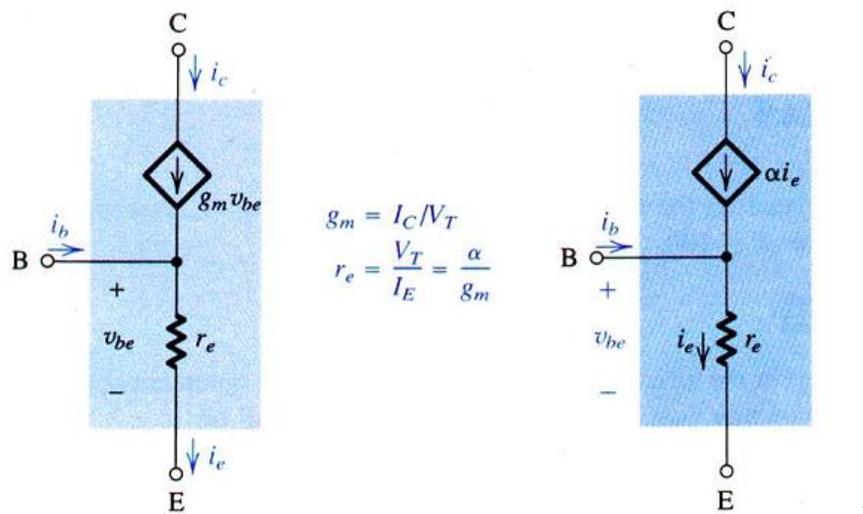
Modelos equivalentes para pequenos sinais



6

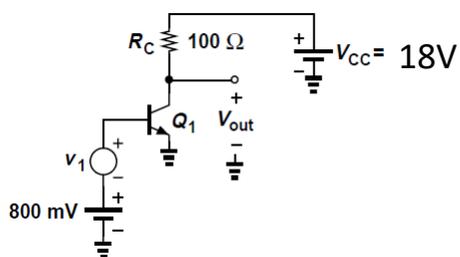
Modelos equivalentes para pequenos sinais

Modelo T



Exercício (Razavi)

- Determine V_{out}



$$v_{1pp} = 1\text{mV}$$

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

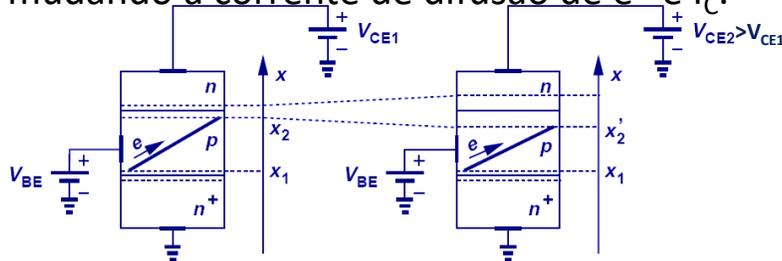
$$\beta = 100$$

$$V_T = 25\text{ mV}$$

8

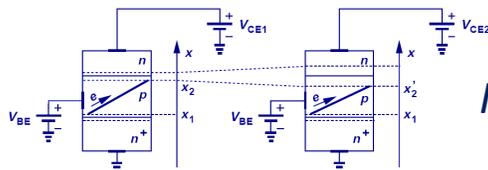
Efeito Early – Modulação da Largura de Base

- A largura da camada de depleção 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 .



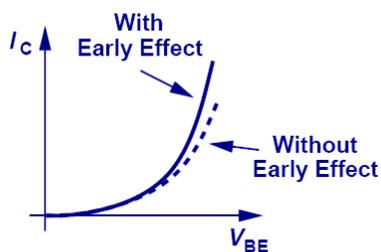
9

Efeito Early – Modulação da Largura de Base

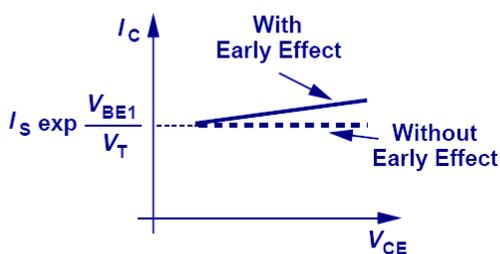


$$I_C = I_S \exp \frac{V_{BE}}{V_T} \left(1 + \frac{V_{CE}}{V_A} \right)$$

Tensão Early



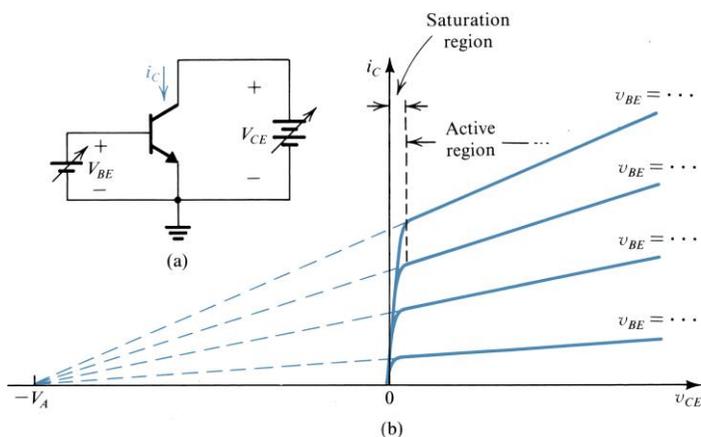
(a)



(b)

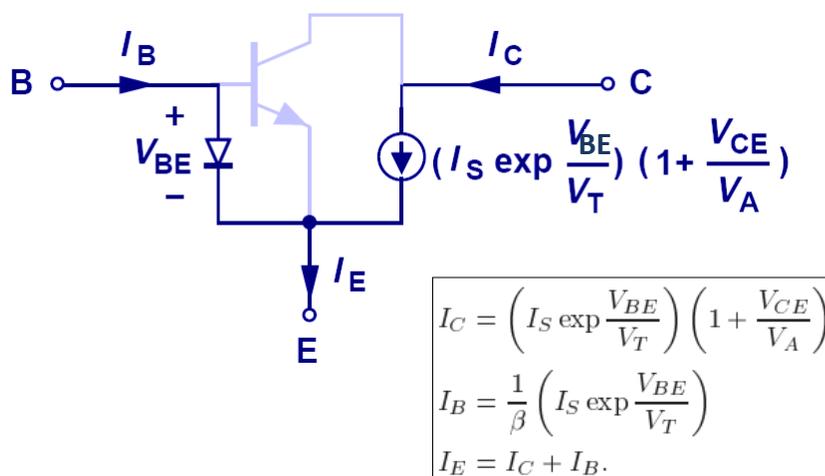
10

Efeito Early – Modulação da Largura de Base



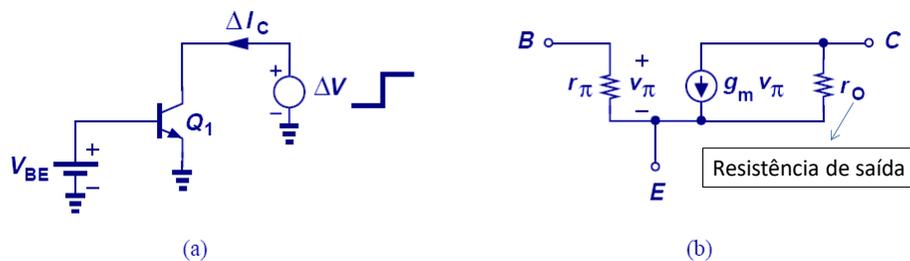
11

Modelo de grandes sinais (região ativa)



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Modelo de pequenos sinais

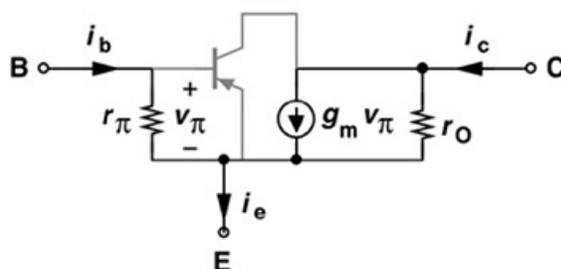


$$I_C + \Delta I_C = \left(I_S \exp \frac{V_{BE}}{V_T} \right) \left(1 + \frac{V_{CE} + \Delta V_{CE}}{V_A} \right) \Rightarrow \Delta I_C = \left(I_S \exp \frac{V_{BE}}{V_T} \right) \frac{\Delta V_{CE}}{V_A}$$

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

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



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Parâmetros do Modelo em Termos das Correntes de Polarização cc :

$$g_m = \frac{I_C}{V_T} \quad r_e = \frac{V_T}{I_E} = \alpha \left(\frac{V_T}{I_C} \right)$$

$$r_\pi = \frac{V_T}{I_B} = \beta \left(\frac{V_T}{I_C} \right) \quad r_o = \frac{V_A}{I_C}$$

Em termos de g_m :

$$r_e = \frac{\alpha}{g_m} \quad r_\pi = \frac{\beta}{g_m}$$

Em termos de r_e :

$$g_m = \frac{\alpha}{r_e} \quad r_\pi = (\beta + 1)r_e \quad g_m + \frac{1}{r_\pi} = \frac{1}{r_e}$$

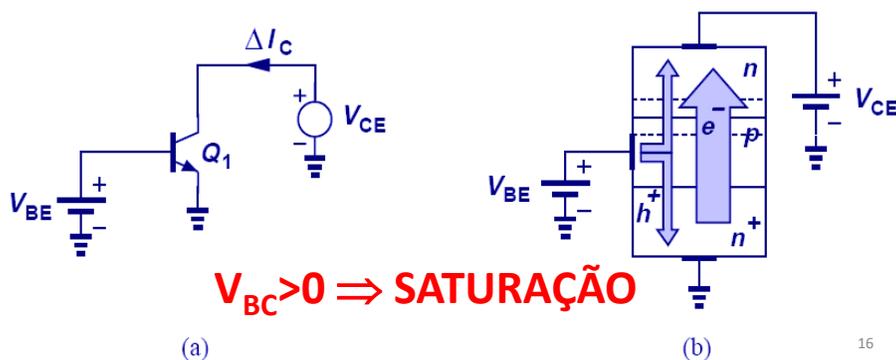
Relações entre α e β :

$$\beta = \frac{\alpha}{1 - \alpha} \quad \alpha = \frac{\beta}{\beta + 1} \quad \beta + 1 = \frac{1}{1 - \alpha}$$

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Saturação

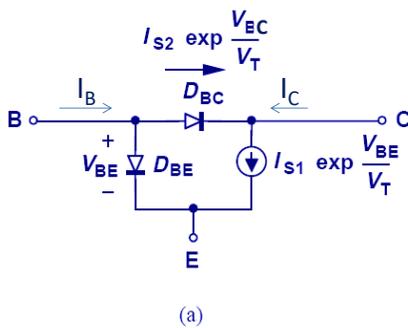
- As duas junções estão polarizadas diretamente
- $V_{BC} > 0,4$ V: Saturação forte
- $V_{BC} < 0,4$ V: Saturação fraca (despreza a corrente do diodo coletor- base)



16

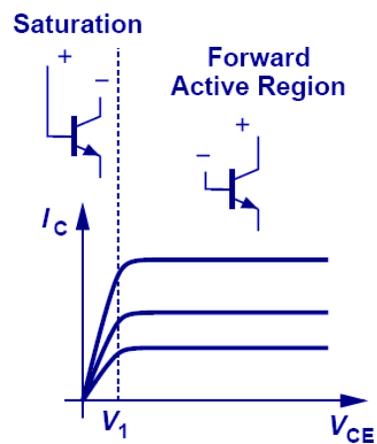
Saturação

- $I_C = I_{S1} \exp(V_{BE}/V_T) - I_{S2} \exp(V_{BC}/V_T)$
- I_B aumenta e I_C diminui $\rightarrow \beta$ diminui



Saturação

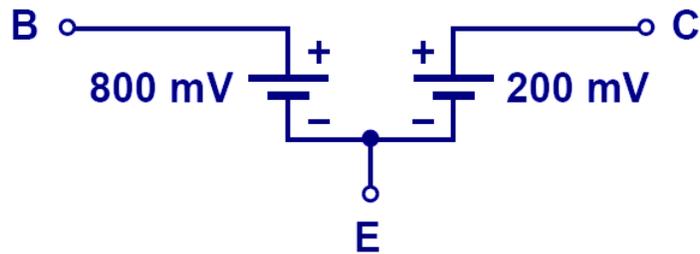
- V_{CE} diminui
- Para saturação:
 $V_{CEsat} = 200\text{mV}$



Saturação

- Modelo para saturação forte:

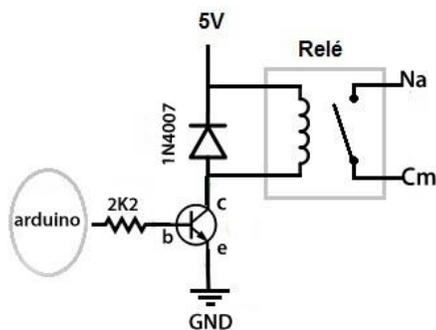
$$V_{CEsat} = 200\text{mV}$$



Obs: Menor resposta em frequência.

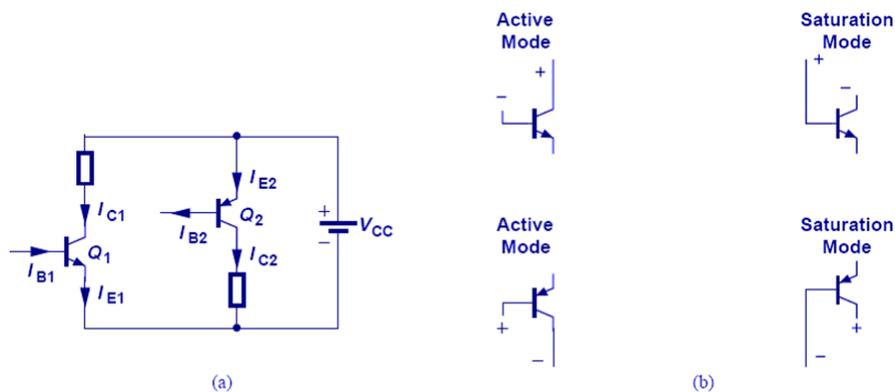
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Exemplo de aplicação



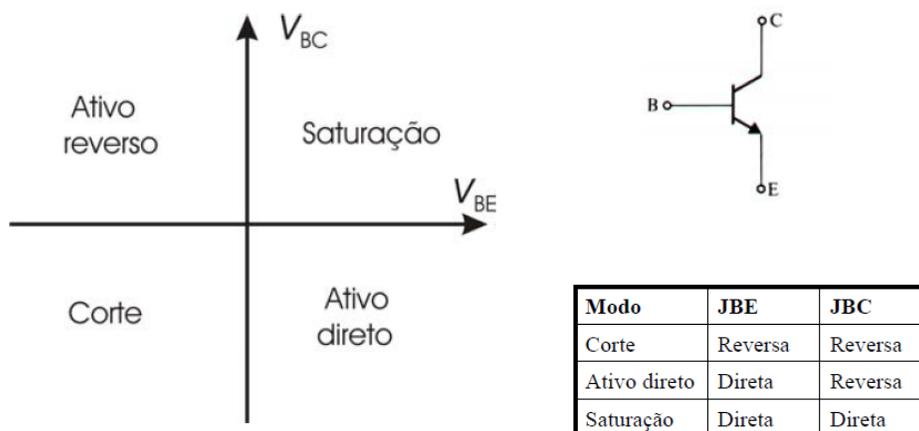
20

Resumo



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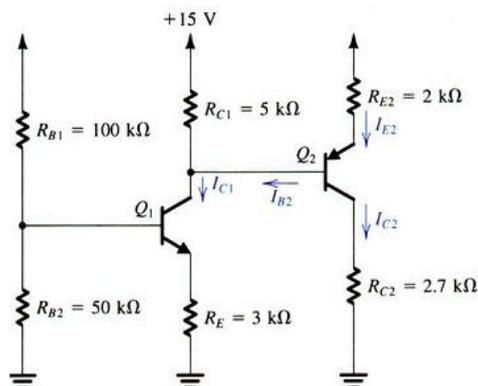
Modos de operação



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Análise cc ($V_{BE} = 0,7V$)

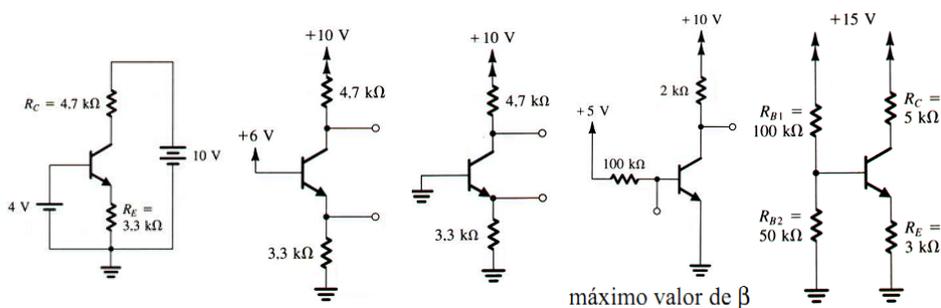
- Determine todas tensões e correntes dos circuitos a seguir ($\beta=100$). **PARA CASA**



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Análise cc

- Determine todas tensões e correntes dos circuitos a seguir ($\beta=100$). $I_S = 3 \times 10^{-16} A$



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Fontes de figuras da aula

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

27

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

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