

# TBJ – Transistor Bipolar de Junção



*Símbolo do transistor em calçada na Universidade de Aveiro – Fonte: Wikipédia*

# Conteúdo

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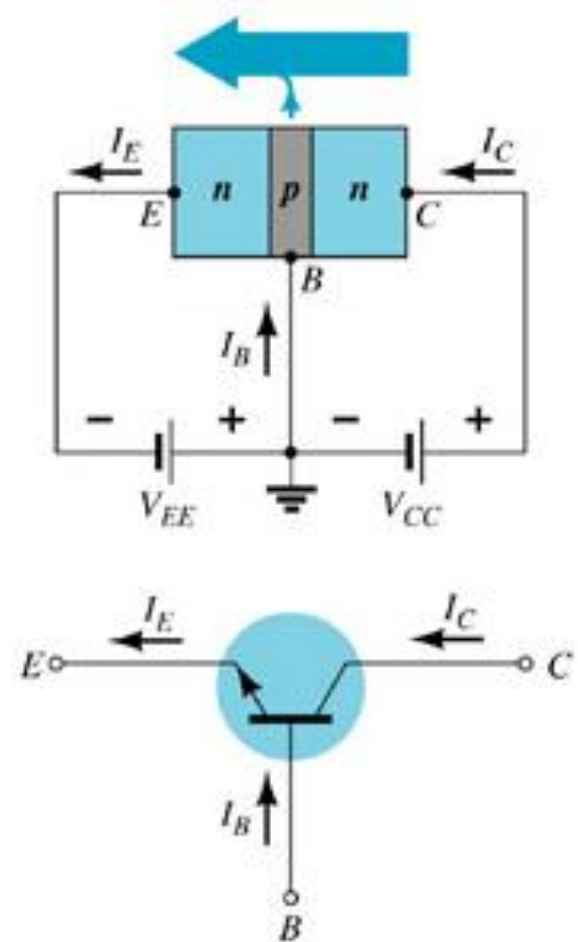
- Relações entre as correntes do TBJ
- Configuração Emissor Comum
- Configuração Coletor Comum
- Resumo de TBJ
- Exercícios de fixação

# Relações importantes

$$I_E = I_C + I_B$$

$$I_C = \alpha I_E$$

$$\alpha \approx 1$$



# Relações importantes

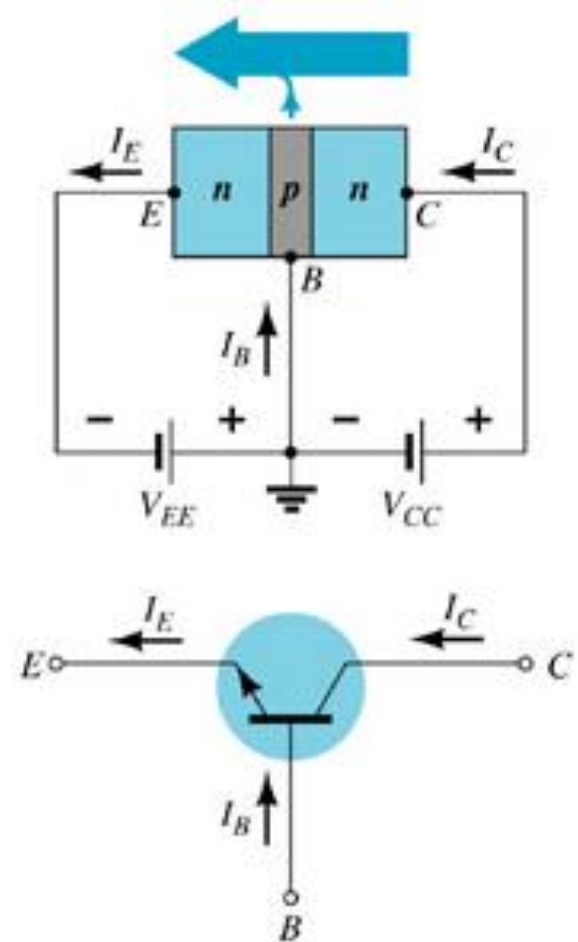
$$I_E = I_C + I_B$$

$$I_C = \alpha I_E$$

$$I_C = \beta I_B$$

$$\alpha \approx 1$$

$$\beta \approx 100 \text{ a } 1000$$



# Relações importantes

$$I_E = I_C + I_B$$

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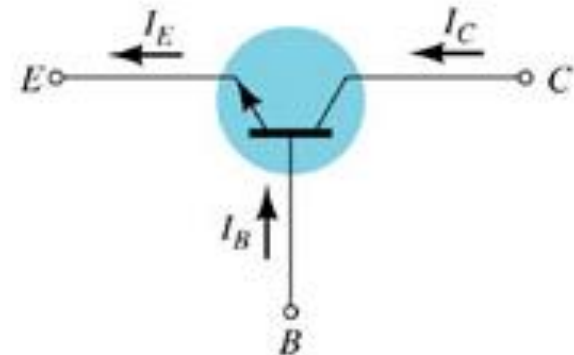
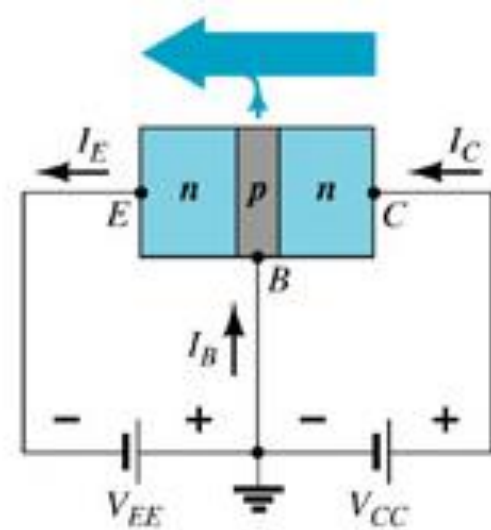
$$\alpha \approx 1$$

$$\beta \approx 100 \text{ a } 1000$$



$$\alpha = \beta / (\beta + 1)$$

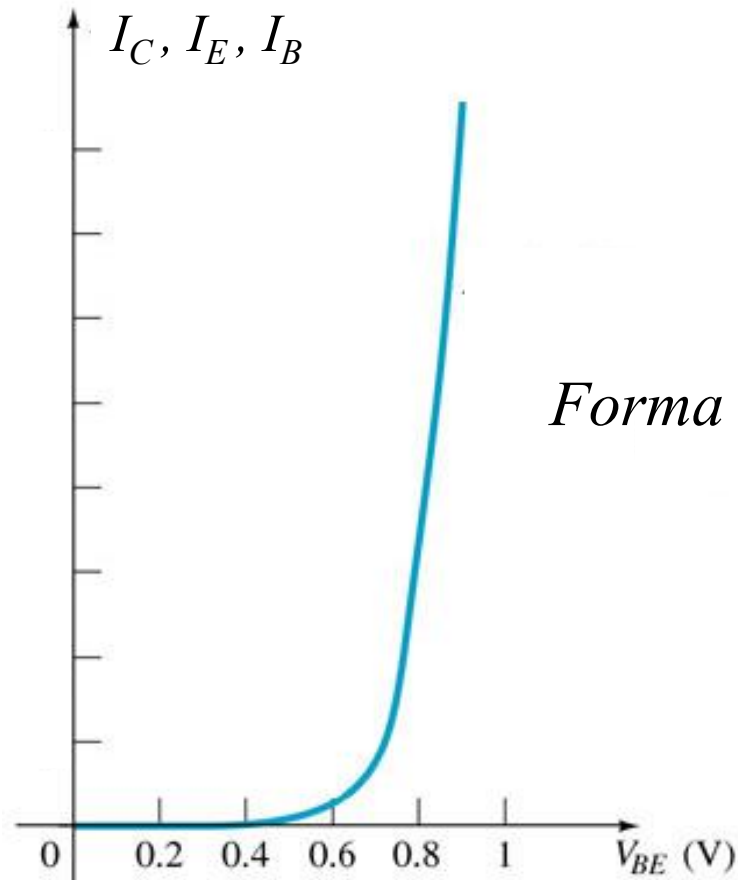
$$\beta = \alpha / (1 - \alpha)$$



# Relações importantes

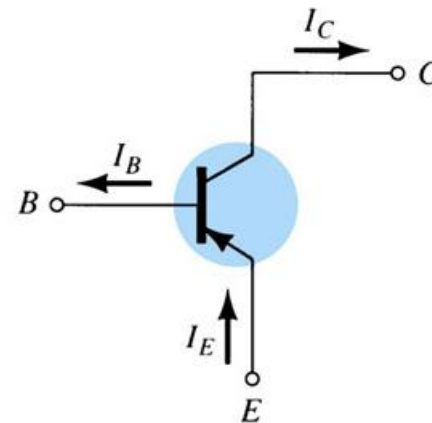
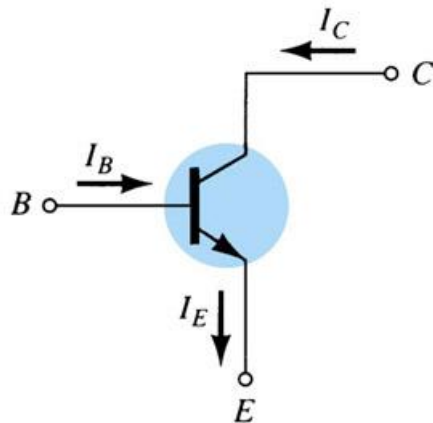
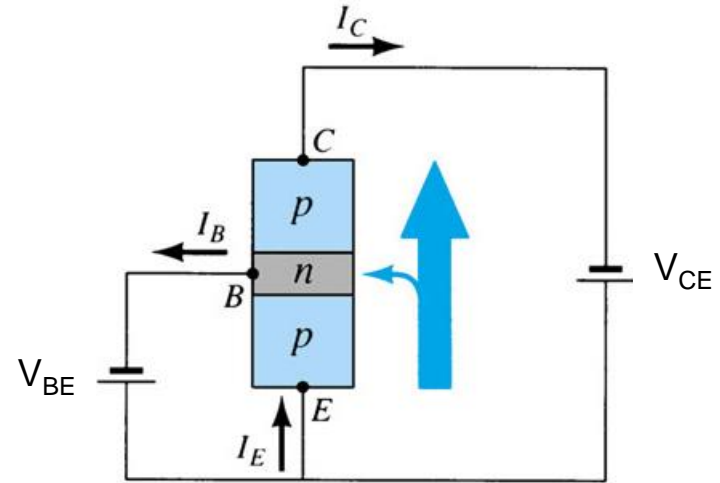
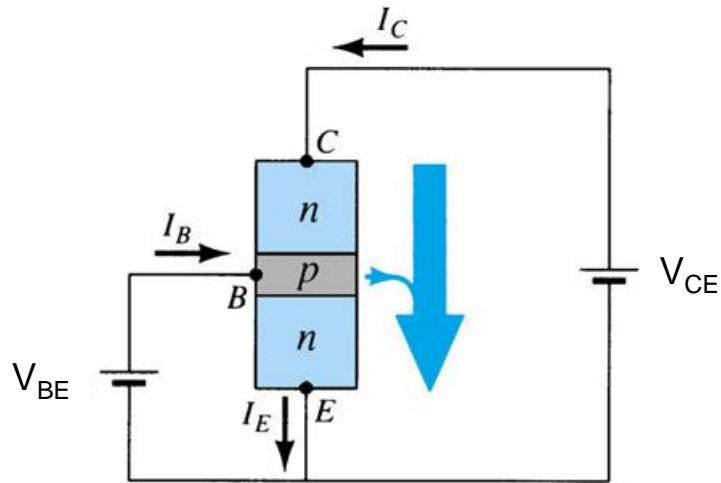
$$I_C = \alpha I_E$$

$$I_C = \beta I_B$$

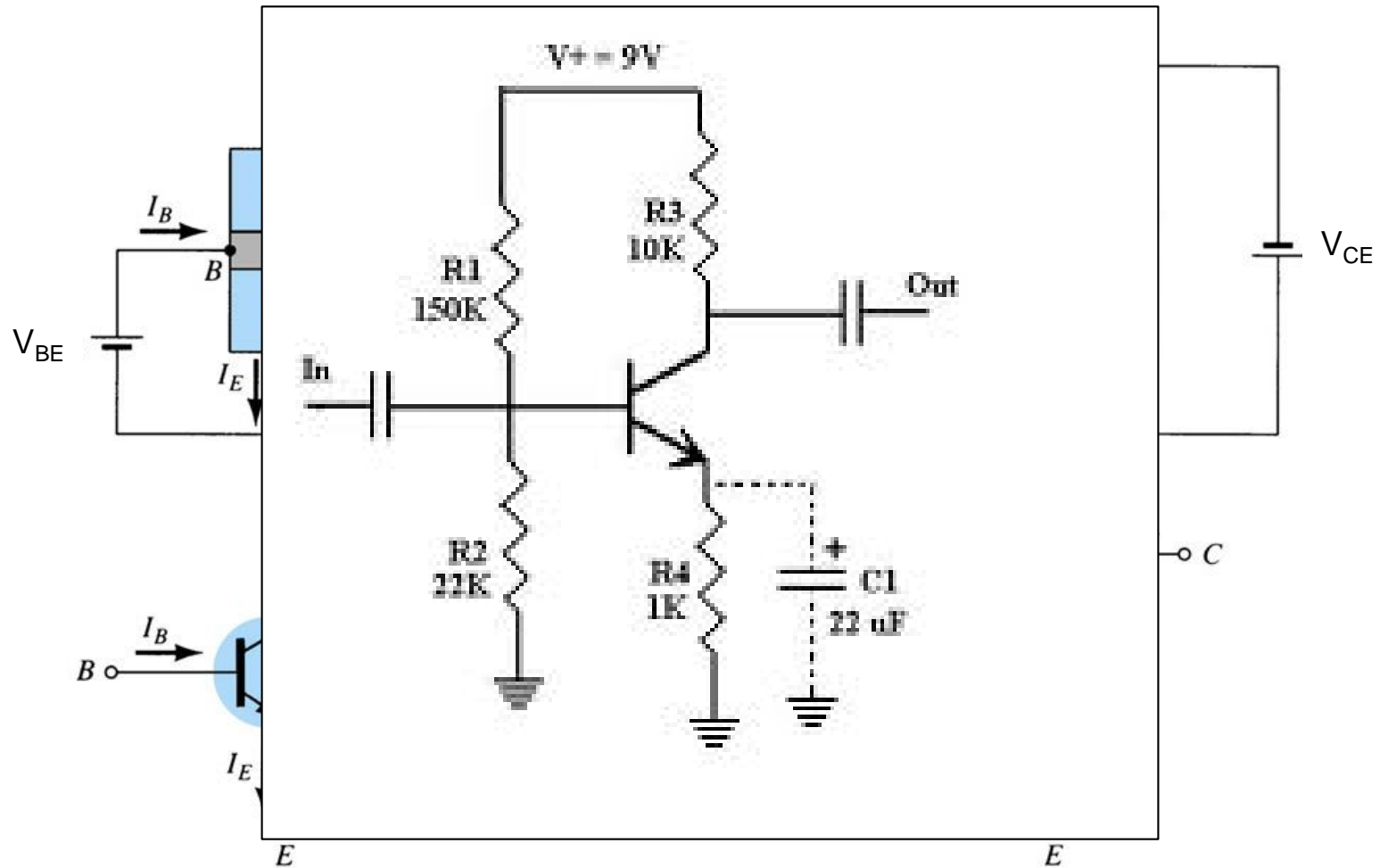


*Forma da curva é a mesma!*

# Configuração Emissor Comum



# Configuração Emissor Comum





# Configuração Emissor Comum

- Configuração mais utilizada
- Chave digital
- Fonte de corrente
- Amplificação de:
  - Tensão
  - Corrente
  - Potência

# Configuração Emissor Comum

A junção B-C do TBJ é reversamente polarizada, enquanto a junção B-E é diretamente polarizada

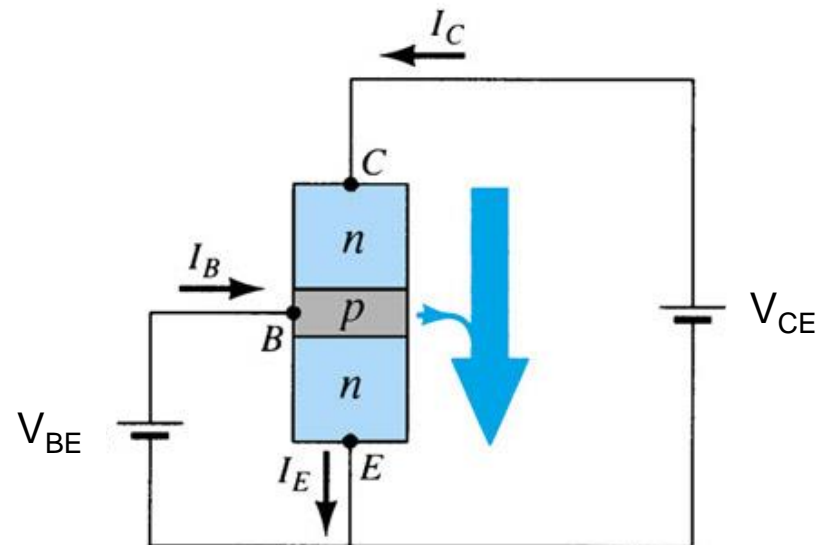
# Configuração Emissor Comum

A junção B-C do TBJ é reversamente polarizada, enquanto a junção B-E é diretamente polarizada

= Configuração Base Comum

# Configuração Emissor Comum

A junção B-C do TBJ é **reversamente** polarizada, enquanto a junção B-E é **diretamente** polarizada



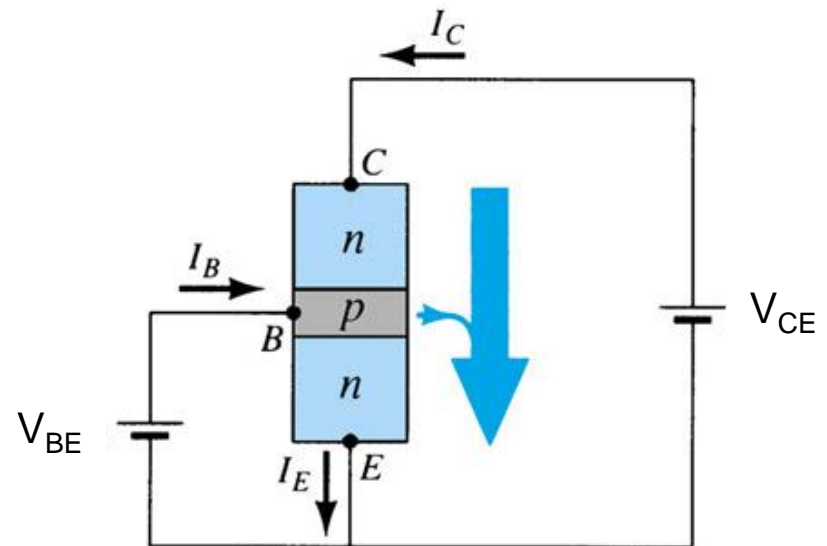
# Portanto...

Para 1) a junção B-C do TBJ ser **reversamente** polarizada e 2) a junção B-E ser **diretamente** polarizada:

$$1) V_{BC} = V_{BE} - V_{CE} < 0$$

$$\Rightarrow V_{BE} < V_{CE}$$

$$2) V_{BE} \cong 0,7 \text{ V}$$



# Configuração Emissor Comum

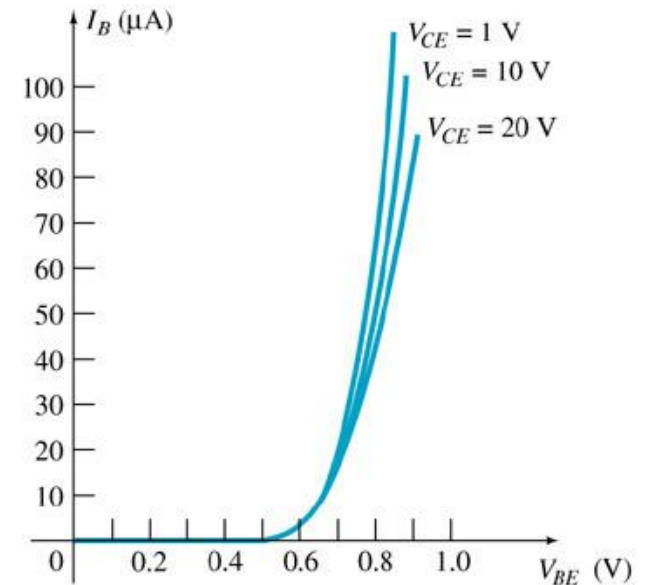
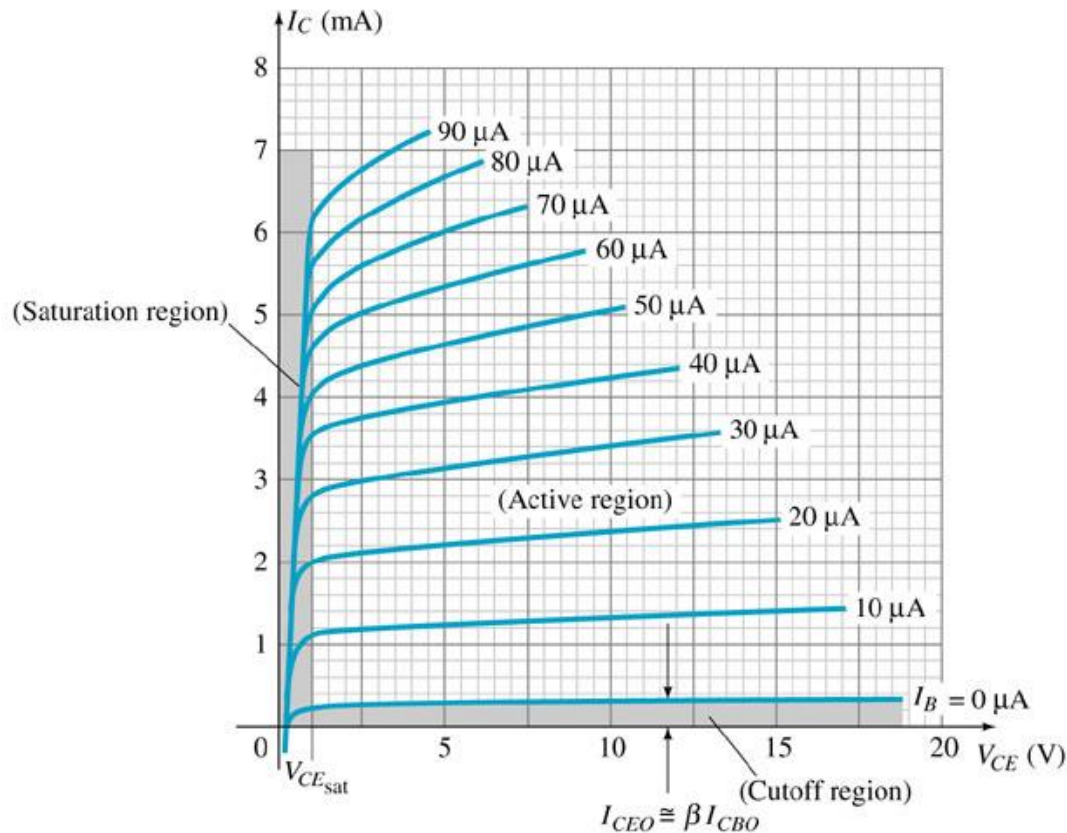
## Caracterização

DOIS conjuntos:

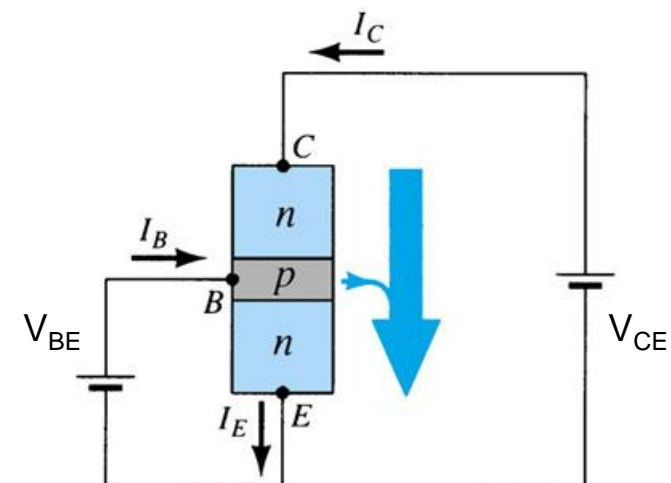
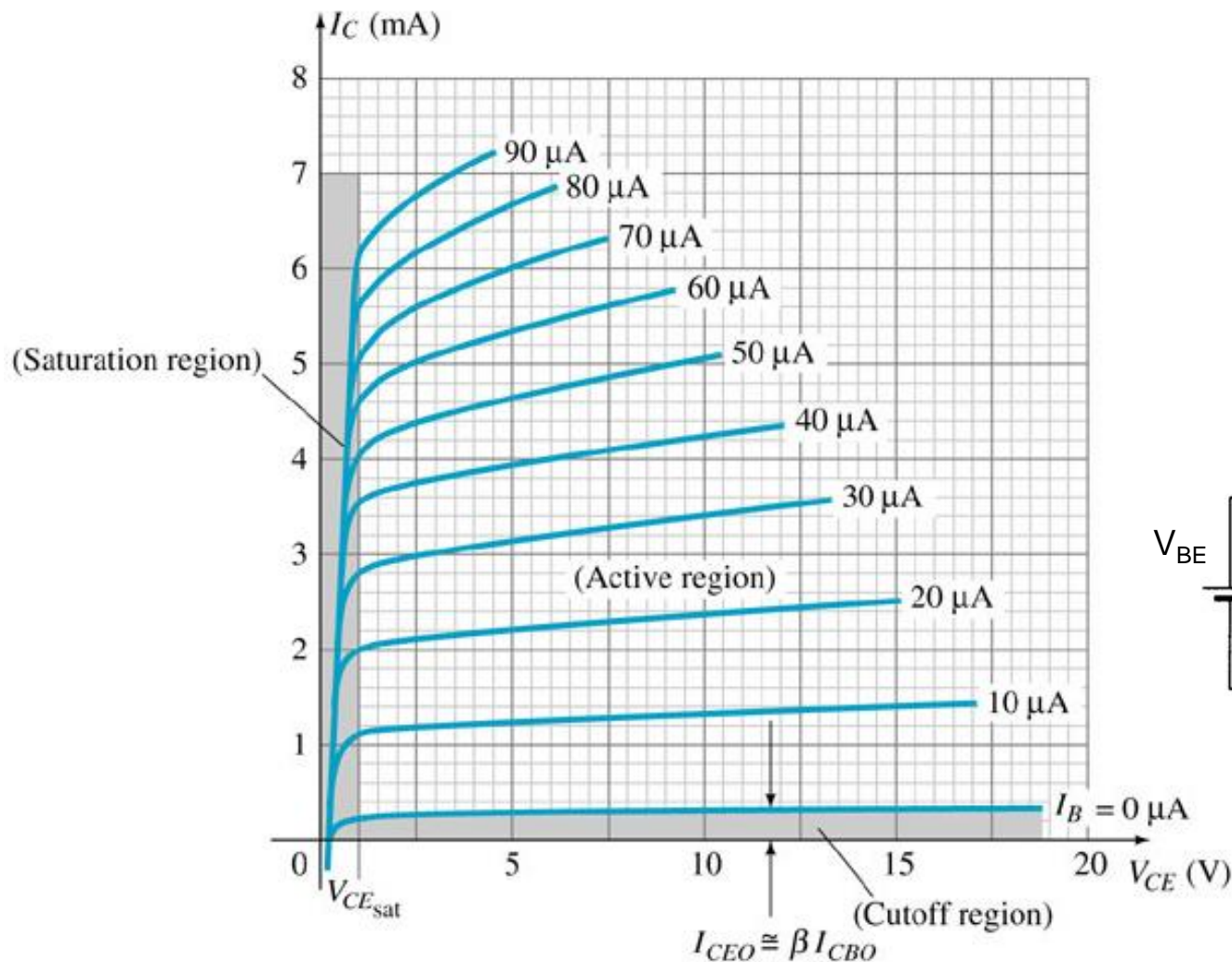
- Parâmetros de SAÍDA
- Parâmetros de ENTRADA

# Configuração Emissor Comum

## Caracterização



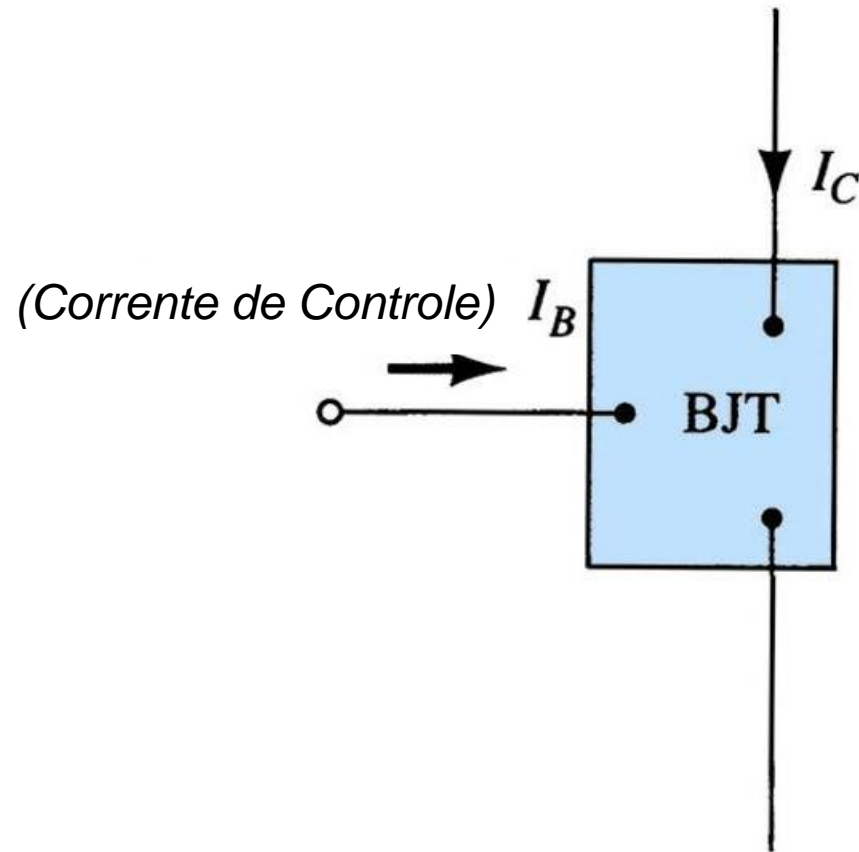
# Regiões de Operação do TBJ



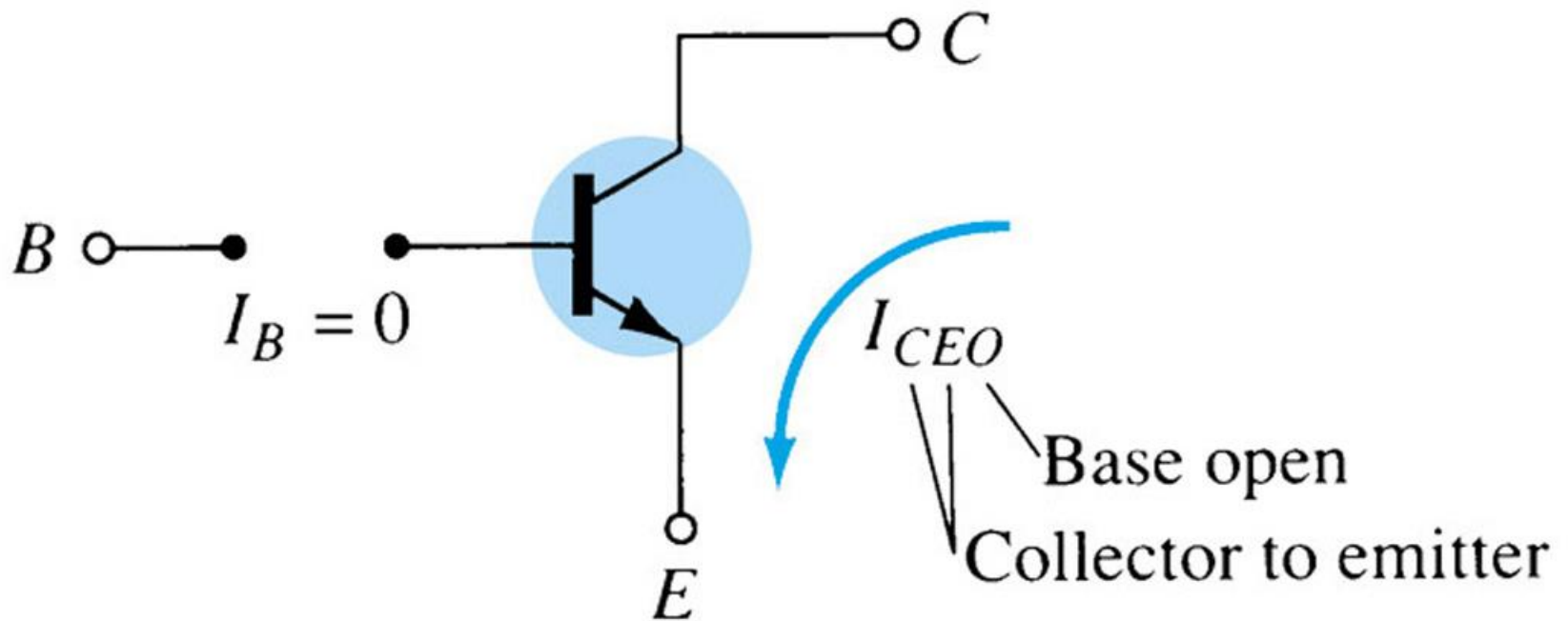


**Operação:**

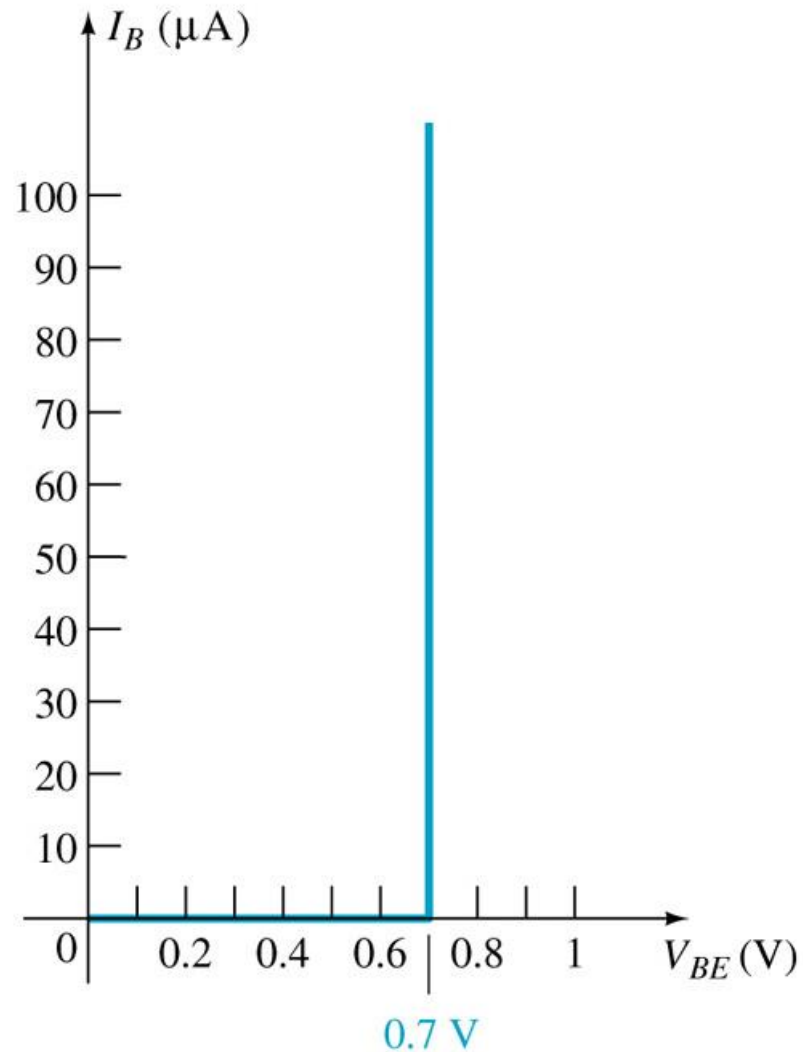
***TBJ – Fonte de corrente controlada por Corrente***



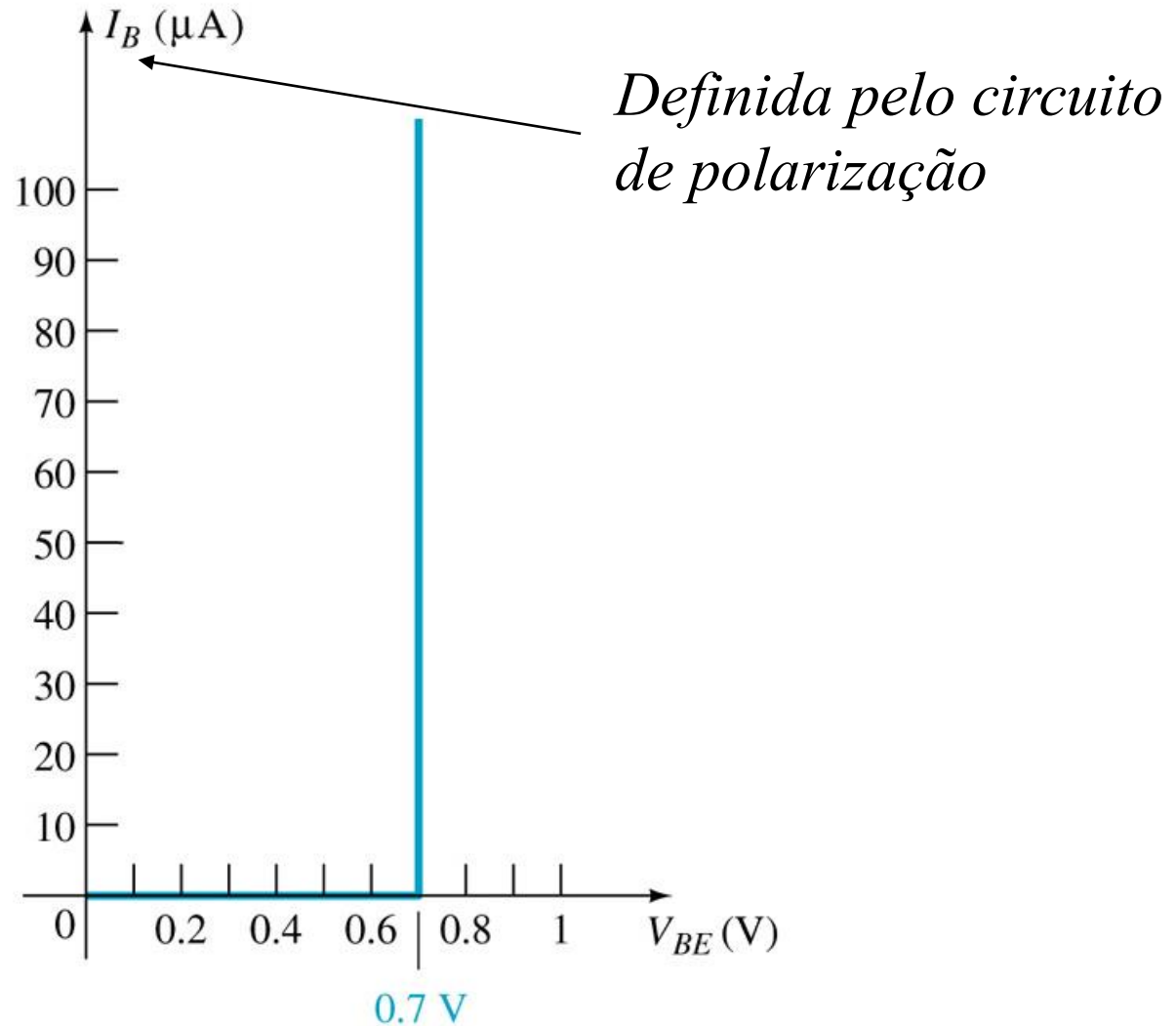
# Região de Corte



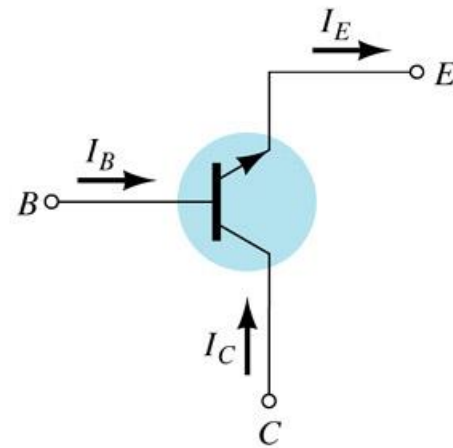
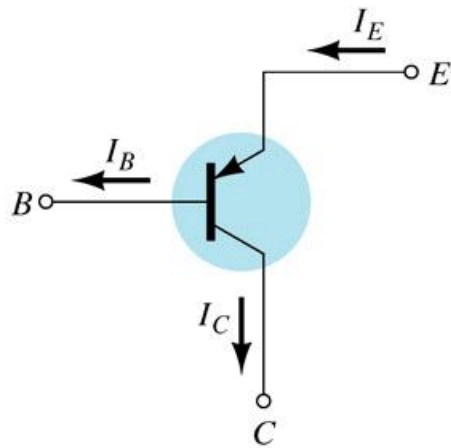
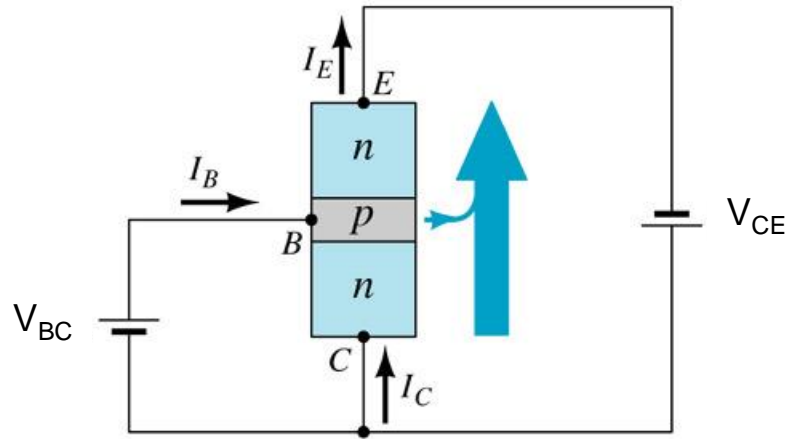
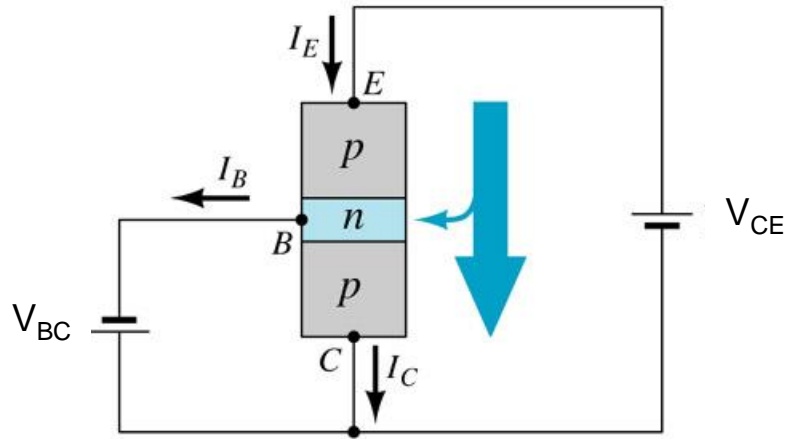
# Aproximações



# Aproximações



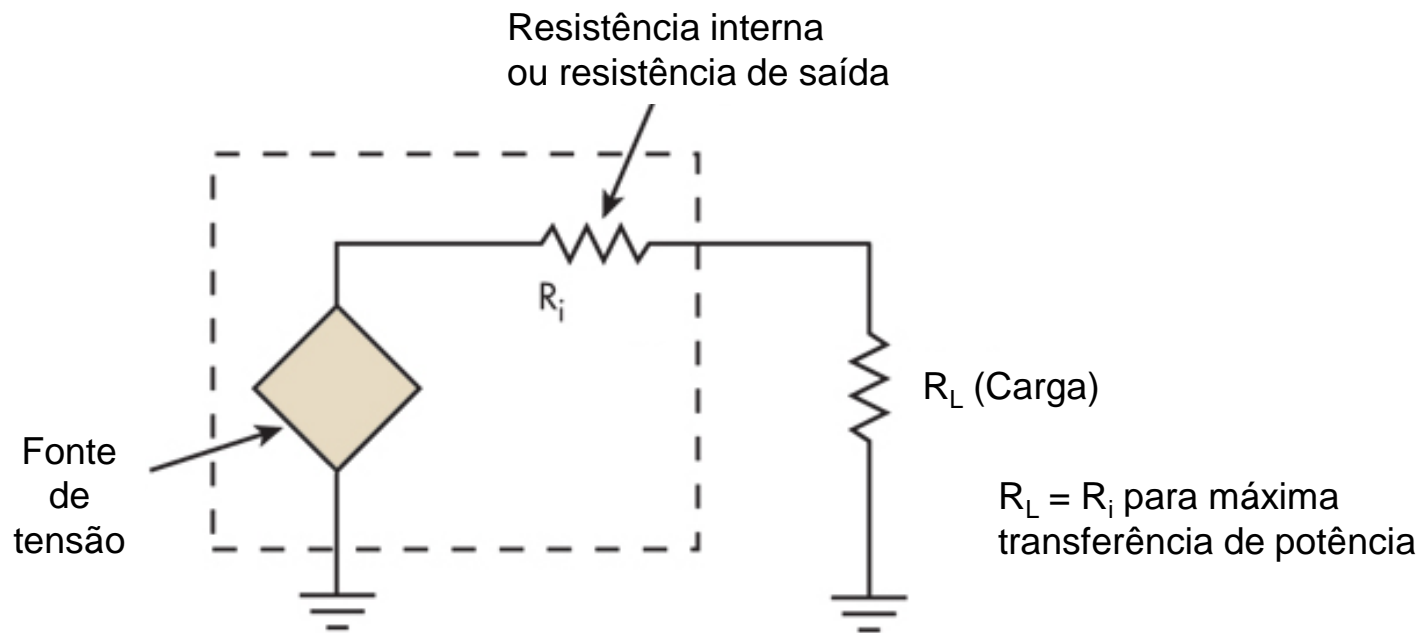
# Configuração Coletor Comum



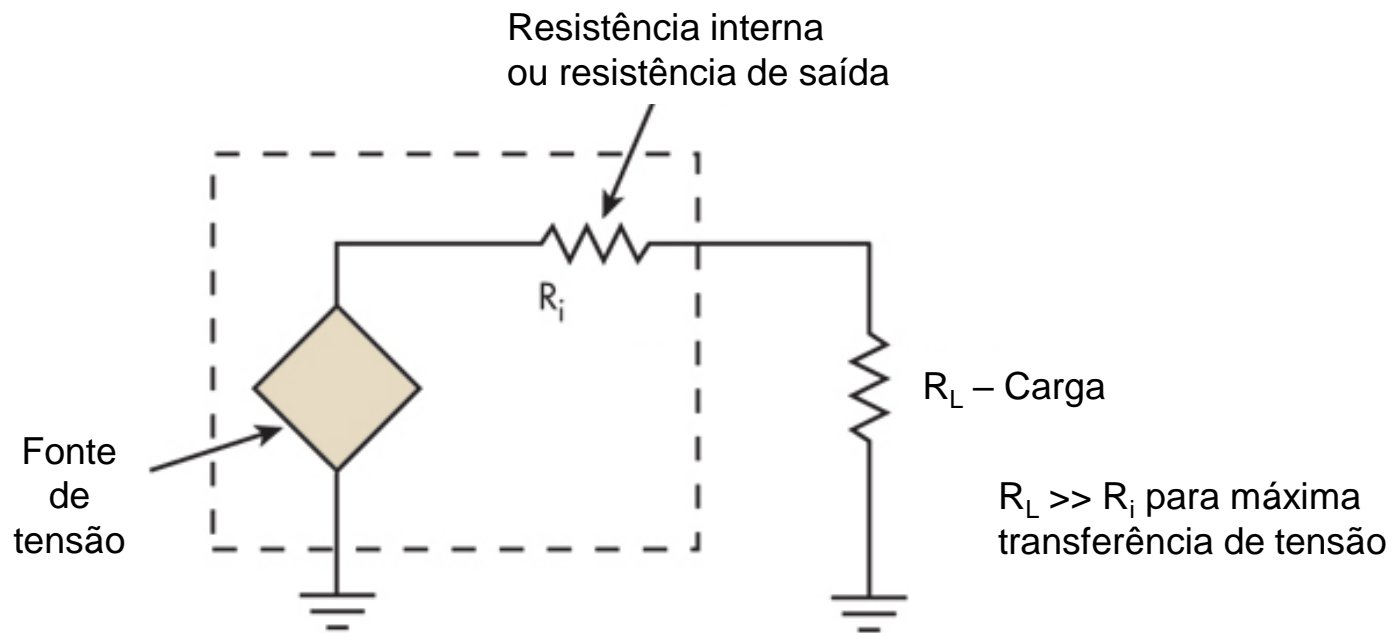
# Configuração Coletor Comum

- Ganho de tensão unitário
- Utilizada como “casador de impedâncias”
  - Para amplificadores de tensão
- Impedância de entrada:
  - ALTA
- Impedância de saída:
  - BAIXA

# Máxima transferência de potência



# Máxima transferência de tensão

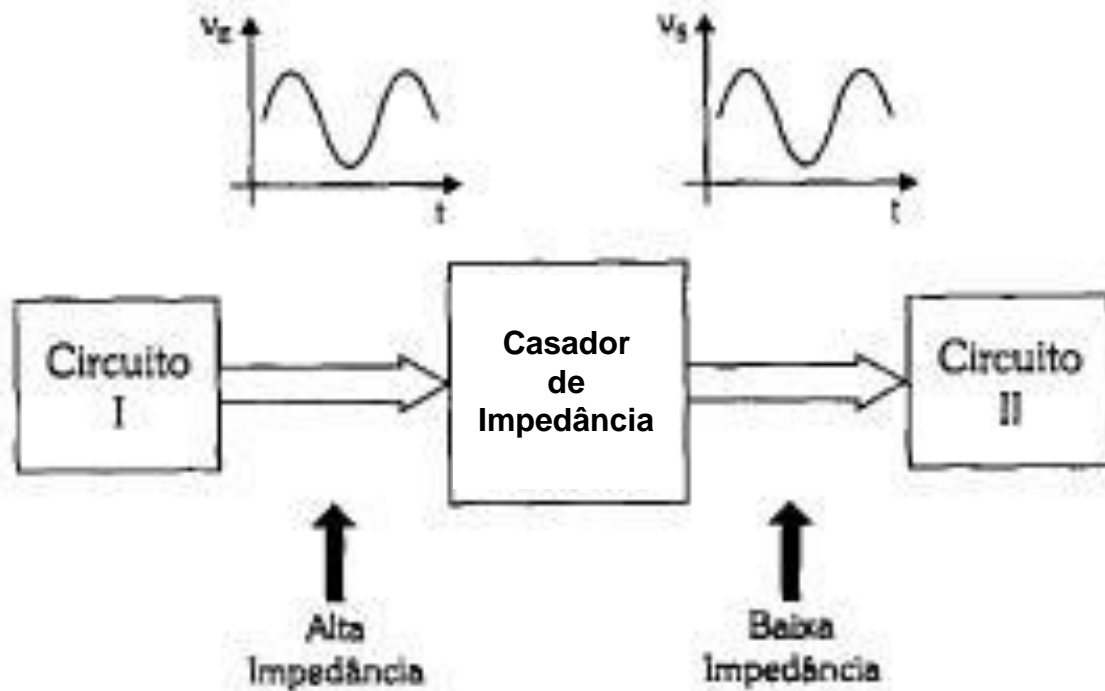


Divisor de tensão:

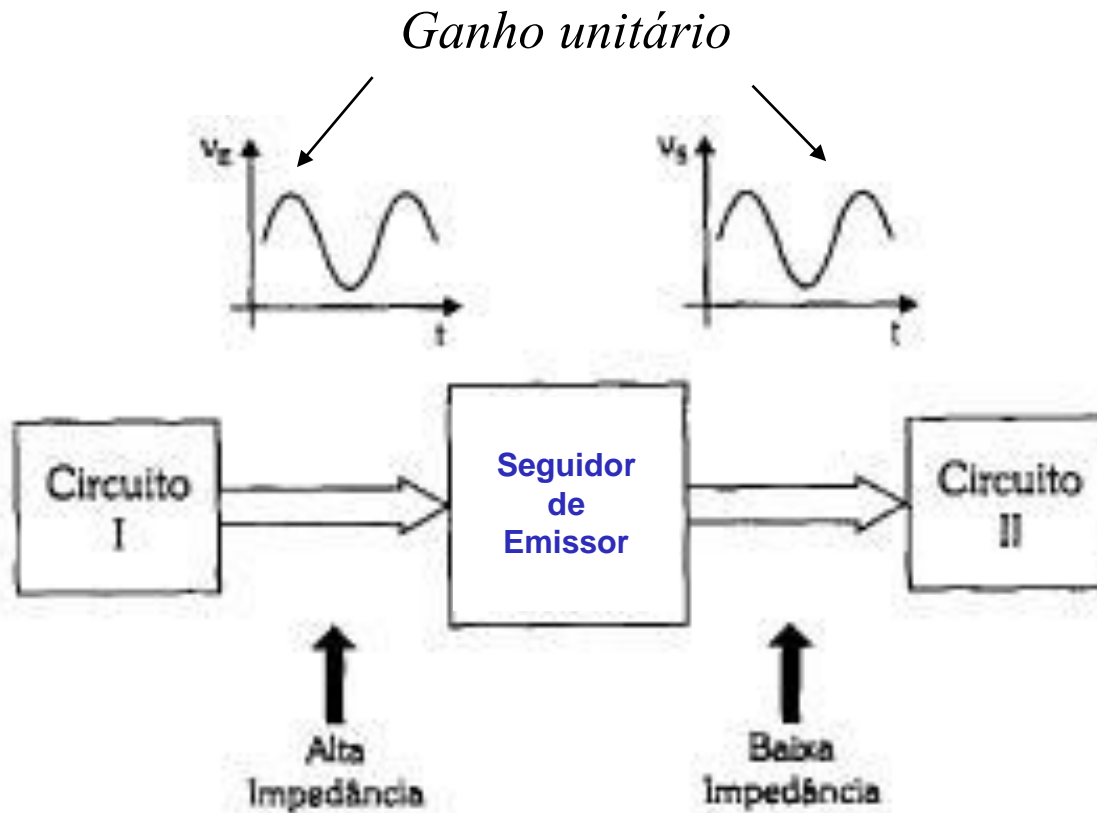
$$V_L = V_F \frac{R_L}{R_L + R_i}$$



# Casador de Impedâncias

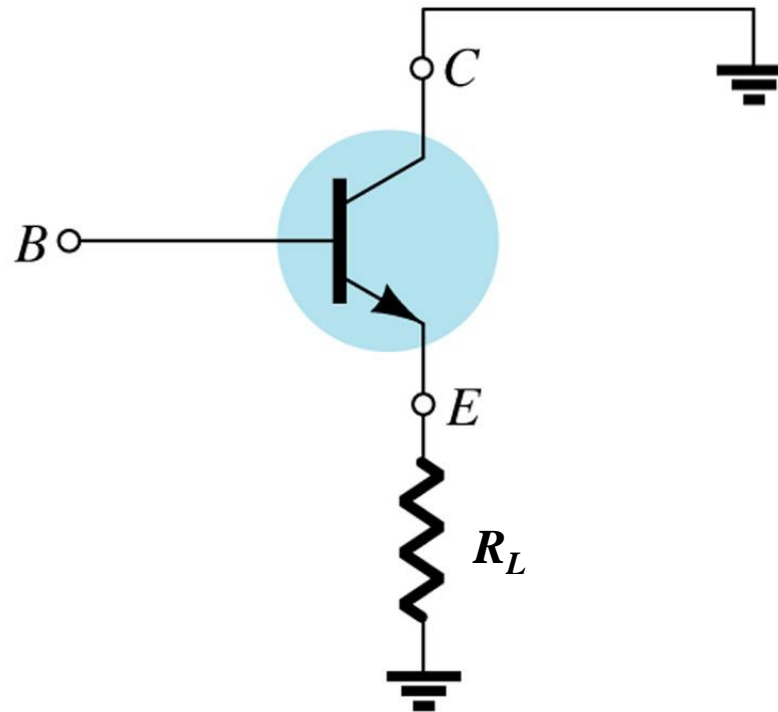


# Casador de Impedâncias

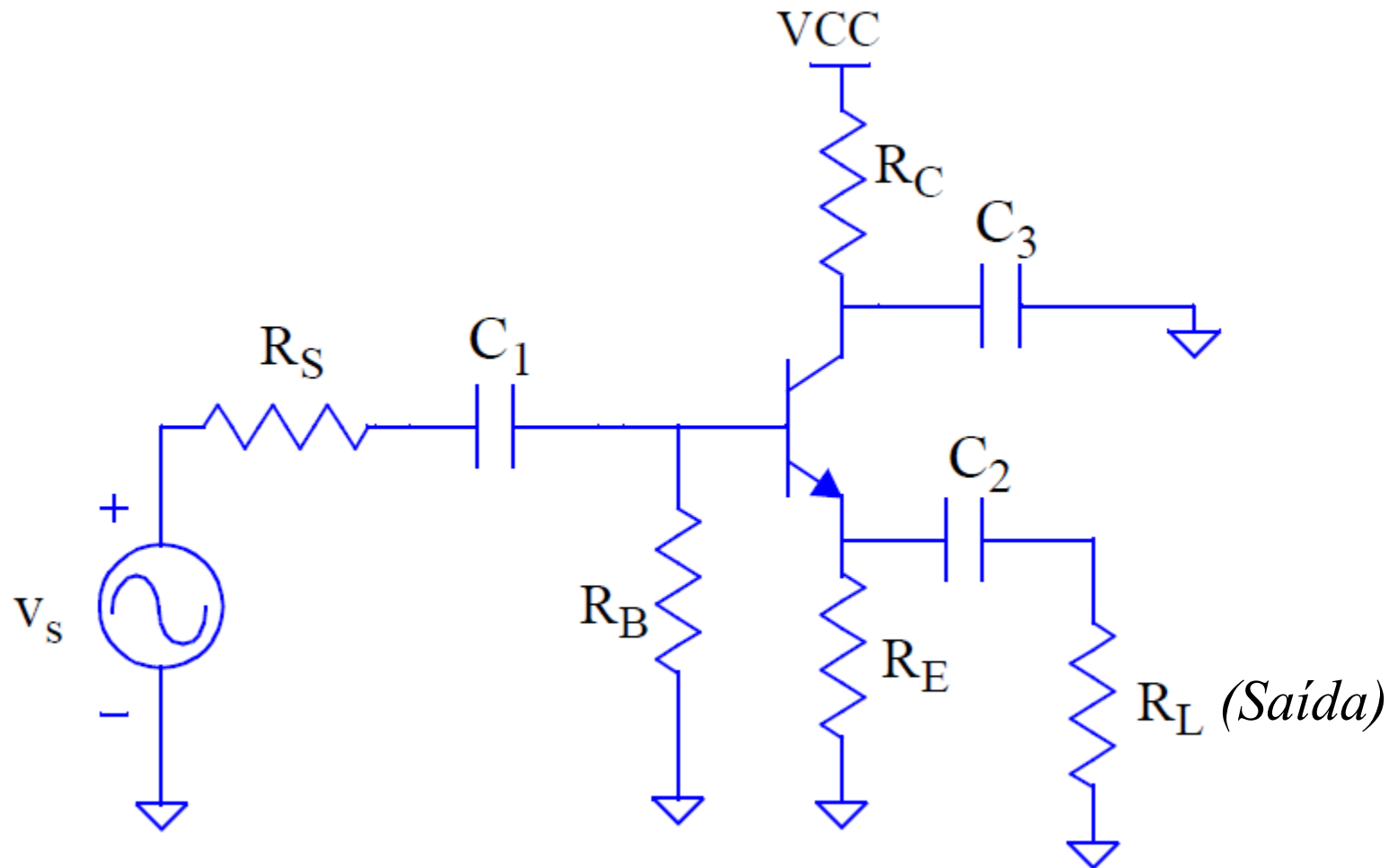


# Ex.: Configuração Coletor Comum

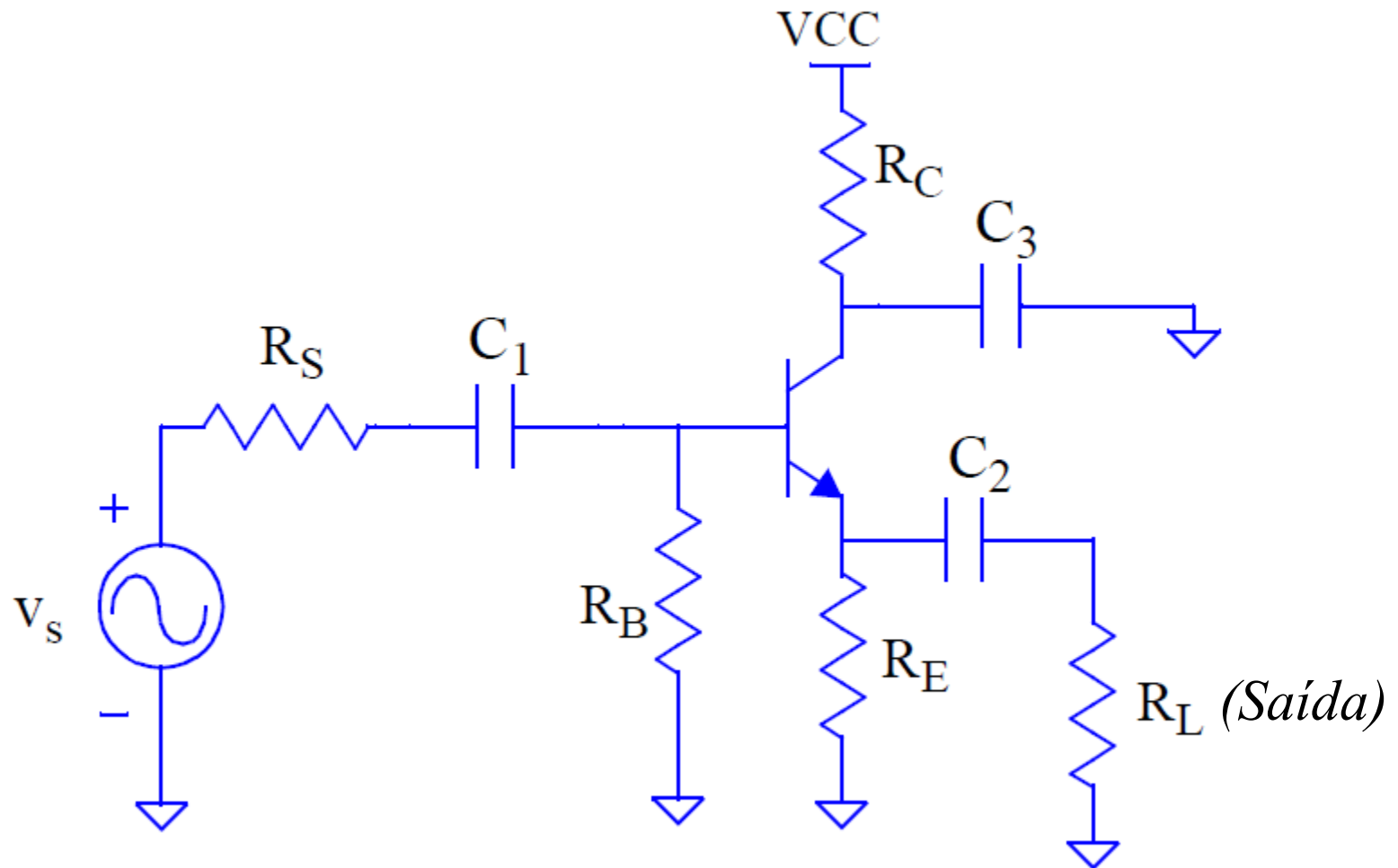
...como "casador de impedâncias"



# Qual a configuração do circuito?



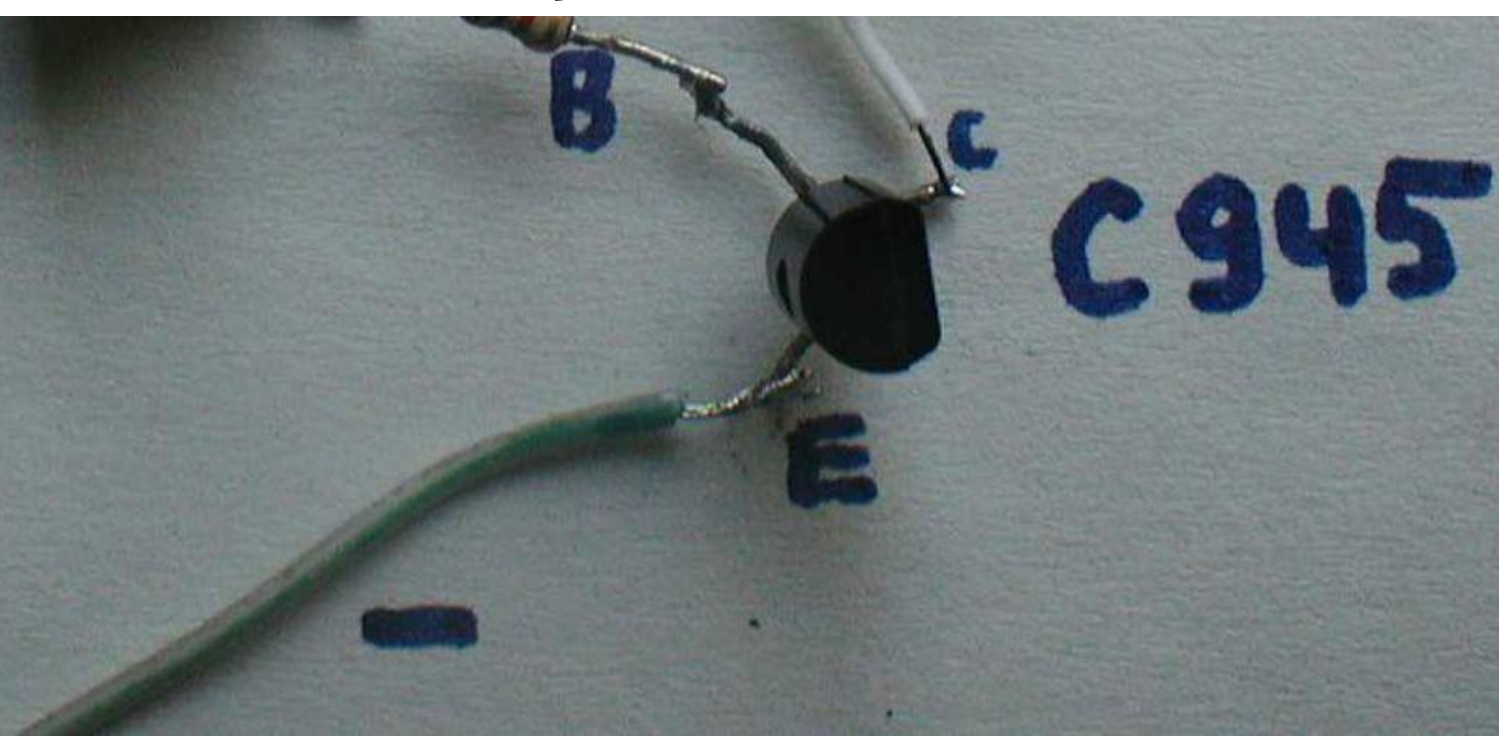
# Resp. Configuração Coletor Comum



+6V

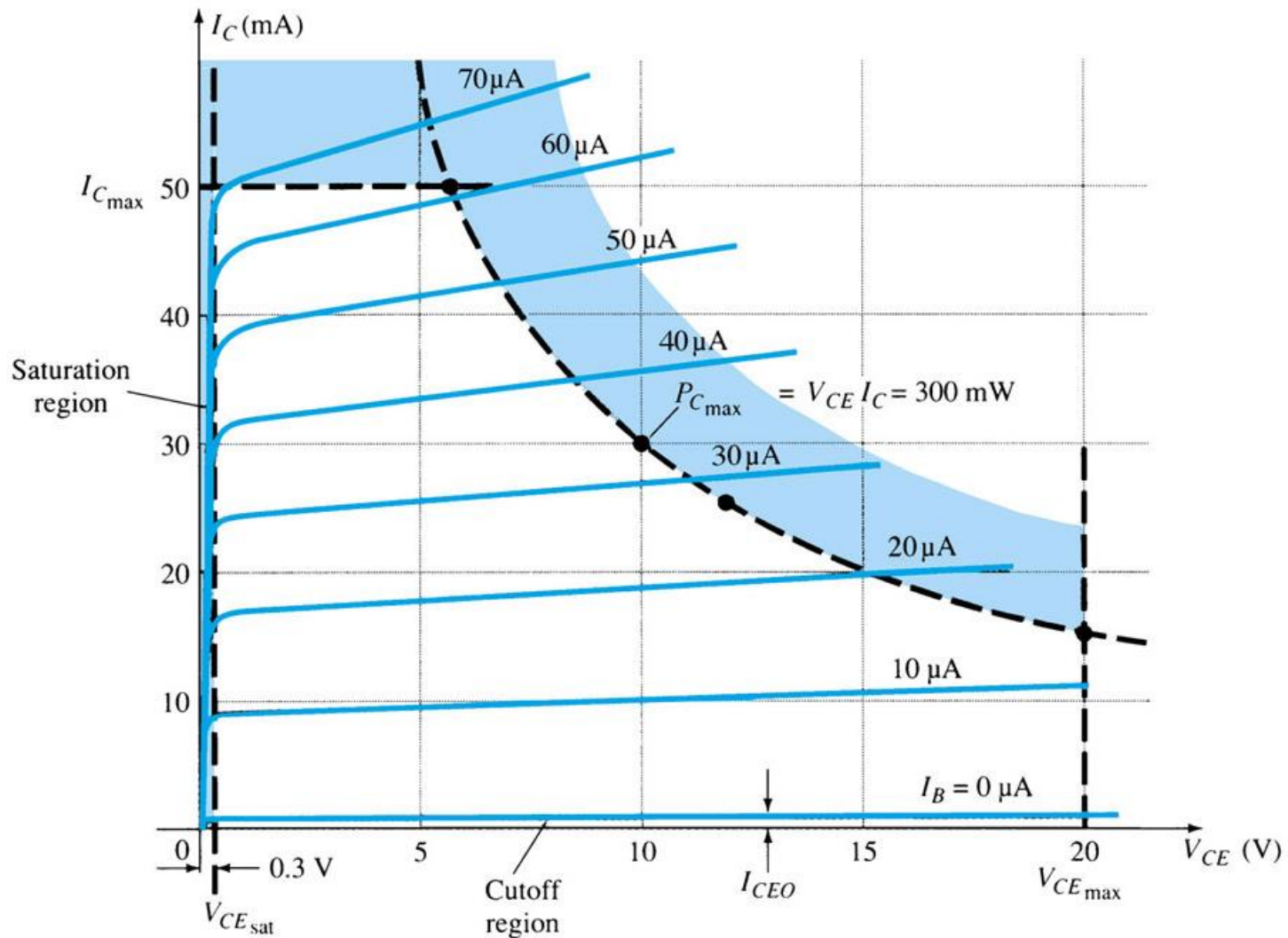


## Considerações Práticas



# Limites de Operação:

## Potência de saída **Máxima**





# Folha de dados

## MAXIMUM RATINGS

Rating	Symbol	2N4123	Unit
Collector-Emitter Voltage	$V_{CE0}$	30	Vdc
Collector-Base Voltage	$V_{CB0}$	40	Vdc
Emitter-Base Voltage	$V_{EB0}$	5.0	Vdc
Collector Current – Continuous	$I_C$	200	mAdc
Total Device Dissipation @ $T_A = 25^\circ\text{C}$ Derate above $25^\circ\text{C}$	$P_D$	625 5.0	mW mW/°C
Operating and Storage Junction Temperature Range	$T_j, T_{stg}$	-55 to +150	°C

## THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	83.3	°C/W
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	200	°C/W

## ELECTRICAL CHARACTERISTICS ( $T_A = 25^\circ\text{C}$ unless otherwise noted)

Characteristic	Symbol	Min	Max	Unit
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### OFF CHARACTERISTICS

Collector-Emitter Breakdown Voltage (1) ( $I_C = 1.0\text{ mAdc}$ , $I_E = 0$ )	$V_{(BR)CEO}$	30		Vdc
Collector-Base Breakdown Voltage ( $I_C = 10\text{ }\mu\text{Adc}$ , $I_E = 0$ )	$V_{(BR)CBO}$	40		Vdc
Emitter-Base Breakdown Voltage ( $I_E = 10\text{ }\mu\text{Adc}$ , $I_C = 0$ )	$V_{(BR)EBO}$	5.0	–	Vdc
Collector Cutoff Current ( $V_{CE} = 20\text{ Vdc}$ , $I_E = 0$ )	$I_{CBO}$	–	50	nAdc
Emitter Cutoff Current ( $V_{BE} = 3.0\text{ Vdc}$ , $I_C = 0$ )	$I_{EBO}$	–	50	nAdc

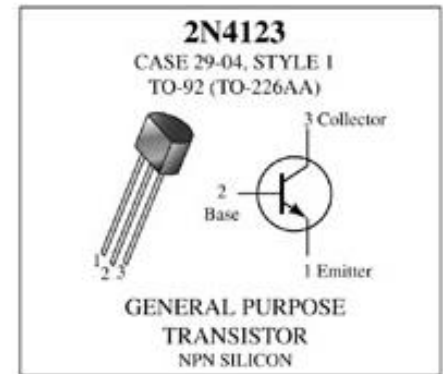
### ON CHARACTERISTICS

DC Current Gain(1) ( $I_C = 2.0\text{ mAdc}$ , $V_{CE} = 1.0\text{ Vdc}$ ) ( $I_C = 50\text{ mAdc}$ , $V_{CE} = 1.0\text{ Vdc}$ )	$h_{FE}$	50 25	150 –	–
Collector-Emitter Saturation Voltage(1) ( $I_C = 50\text{ mAdc}$ , $I_E = 5.0\text{ mAdc}$ )	$V_{CE(sat)}$	–	0.3	Vdc
Base-Emitter Saturation Voltage(1) ( $I_C = 50\text{ mAdc}$ , $I_E = 5.0\text{ mAdc}$ )	$V_{BE(sat)}$	–	0.95	Vdc

### SMALL-SIGNAL CHARACTERISTICS

Current-Gain – Bandwidth Product ( $I_C = 10\text{ mAdc}$ , $V_{CE} = 20\text{ Vdc}$ , $f = 100\text{ MHz}$ )	$f_T$	250		MHz
Output Capacitance ( $V_{CE} = 5.0\text{ Vdc}$ , $I_E = 0$ , $f = 100\text{ MHz}$ )	$C_{ibo}$	–	4.0	pF
Input Capacitance ( $V_{BE} = 0.5\text{ Vdc}$ , $I_C = 0$ , $f = 100\text{ kHz}$ )	$C_{iso}$	–	8.0	pF
Collector-Base Capacitance ( $I_E = 0$ , $V_{CB} = 5.0\text{ V}$ , $f = 100\text{ kHz}$ )	$C_{cb}$	–	4.0	pF
Small-Signal Current Gain ( $I_C = 2.0\text{ mAdc}$ , $V_{CE} = 10\text{ Vdc}$ , $f = 1.0\text{ kHz}$ )	$h_{fe}$	50	200	–
Current Gain – High Frequency ( $I_C = 10\text{ mAdc}$ , $V_{CE} = 20\text{ Vdc}$ , $f = 100\text{ MHz}$ ) ( $I_C = 2.0\text{ mAdc}$ , $V_{CE} = 10\text{ V}$ , $f = 1.0\text{ kHz}$ )	$h_{fe}$	2.5 50	– 200	–
Noise Figure ( $I_C = 100\text{ }\mu\text{Adc}$ , $V_{CE} = 5.0\text{ Vdc}$ , $R_S = 1.0\text{ k ohm}$ , $f = 1.0\text{ kHz}$ )	NF	–	6.0	dB

(1) Pulse Test: Pulse Width = 300  $\mu\text{s}$ . Duty Cycle = 2.0%





**NPN General Purpose Amplifier**

(continued)

**Electrical Characteristics**

TA = 25°C unless otherwise noted

Symbol	Parameter	Test Conditions	Min	Max	Units
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**OFF CHARACTERISTICS**

$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage*	$I_C = 1.0 \text{ mA}, I_B = 0$	30		V
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage	$I_C = 10 \text{ } \mu\text{A}, I_E = 0$	40		V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	$I_E = 10 \text{ } \mu\text{A}, I_C = 0$	5.0		V
$I_{CBO}$	Collector Cutoff Current	$V_{CB} = 20 \text{ V}, I_E = 0$		50	nA
$I_{EBO}$	Emitter Cutoff Current	$V_{EB} = 3.0 \text{ V}, I_C = 0$		50	nA

**ON CHARACTERISTICS\***

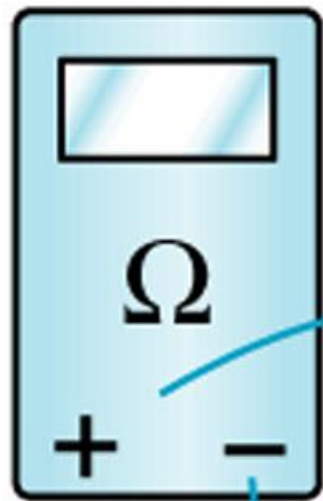
$h_{FE}$	DC Current Gain	$V_{CE} = 1.0 \text{ V}, I_C = 2.0 \text{ mA}$ $V_{CE} = 1.0 \text{ V}, I_C = 50 \text{ mA}$	50 25	150	
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	$I_C = 50 \text{ mA}, I_B = 5.0 \text{ mA}$		0.3	V
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	$I_C = 50 \text{ mA}, I_B = 5.0 \text{ mA}$		0.95	V

**SMALL SIGNAL CHARACTERISTICS**

$C_{ob}$	Output Capacitance	$V_{CB} = 5.0 \text{ V}, f = 100 \text{ kHz}$		4.0	pF
$C_{ib}$	Input Capacitance	$V_{EB} = 0.5 \text{ V}, f = 0.1 \text{ MHz}$		8.0	pF
$h_{fe}$	Small-Signal Current Gain	$I_C = 2.0 \text{ mA}, V_{CE} = 10 \text{ V},$ $f = 1.0 \text{ kHz}$ $I_C = 10 \text{ mA}, V_{CE} = 20 \text{ V},$ $f = 100 \text{ MHz}$	50 2.5	200	
$f_T$	Current Gain - Bandwidth Product	$I_C = 10 \text{ mA}, V_{CE} = 20 \text{ V}$ $f = 100 \text{ MHz}$	250		MHz
NF	Noise Figure	$V_{CE} = 5.0 \text{ V}, I_C = 100 \text{ } \mu\text{A},$ $R_s = 1.0 \text{ k}\Omega$		6.0	dB

# Teste rápido

Low R

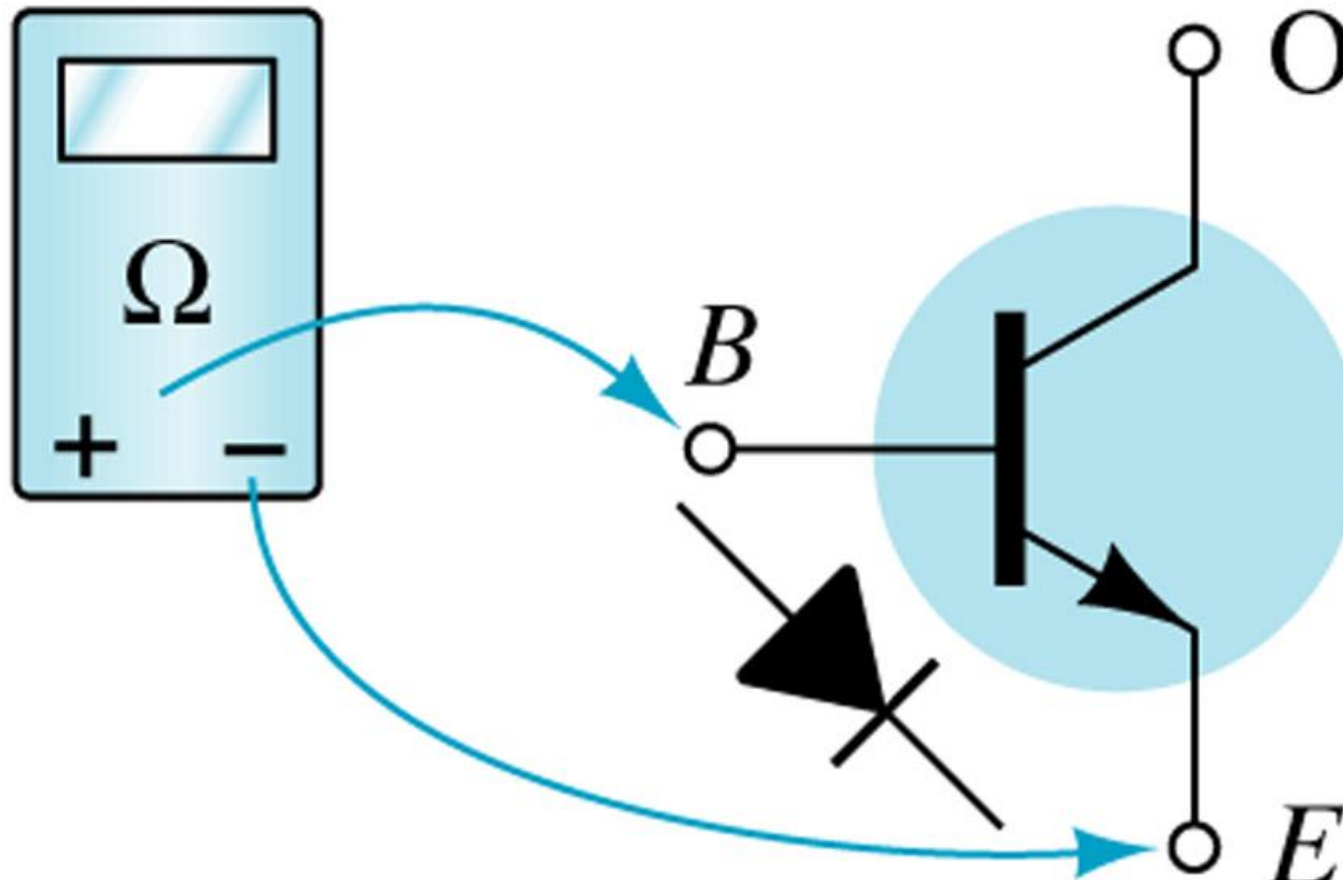


Open

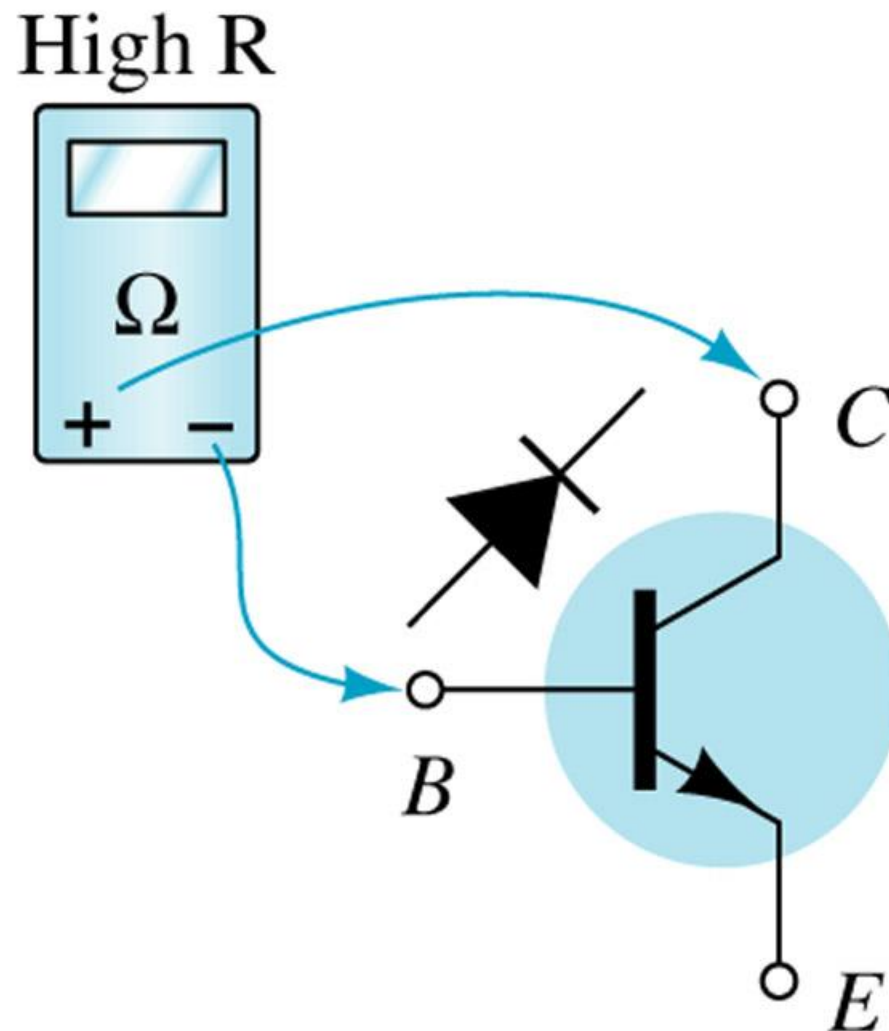
*B*



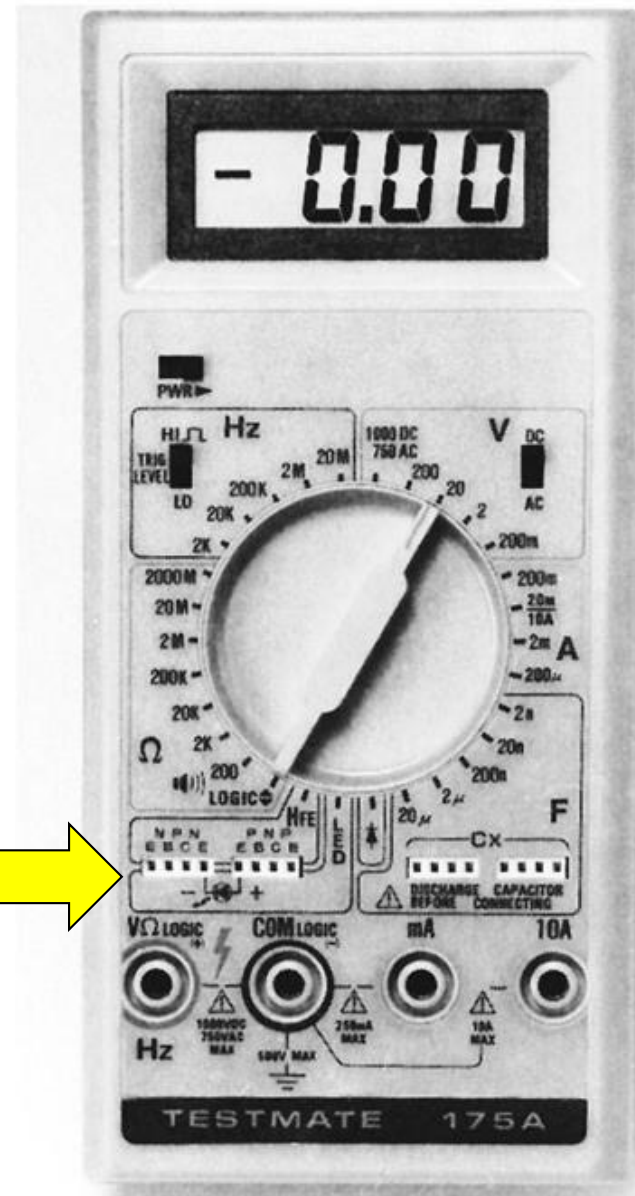
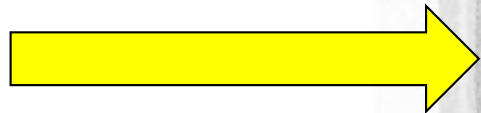
*E*



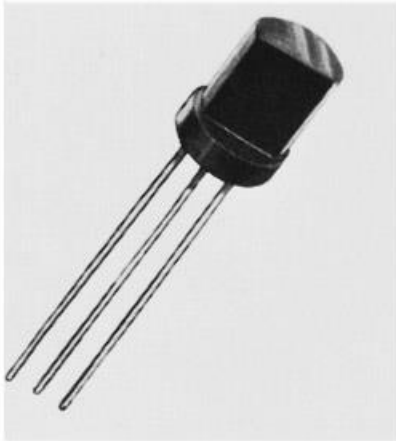
# Teste rápido



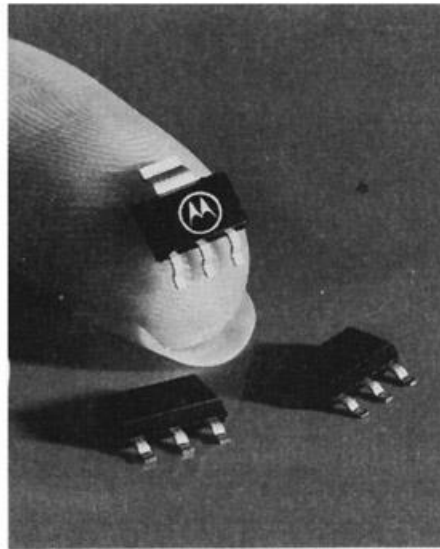
# Teste rápido



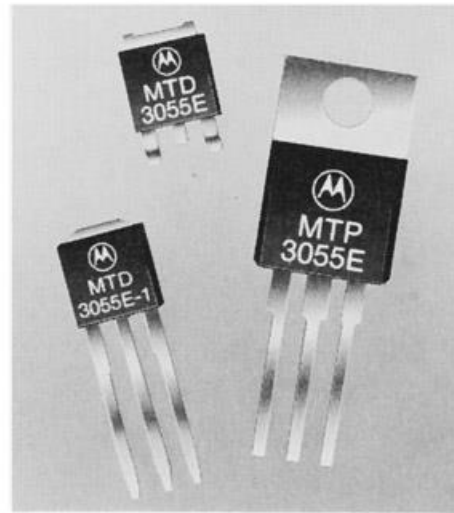
# Formas



(a)



(b)

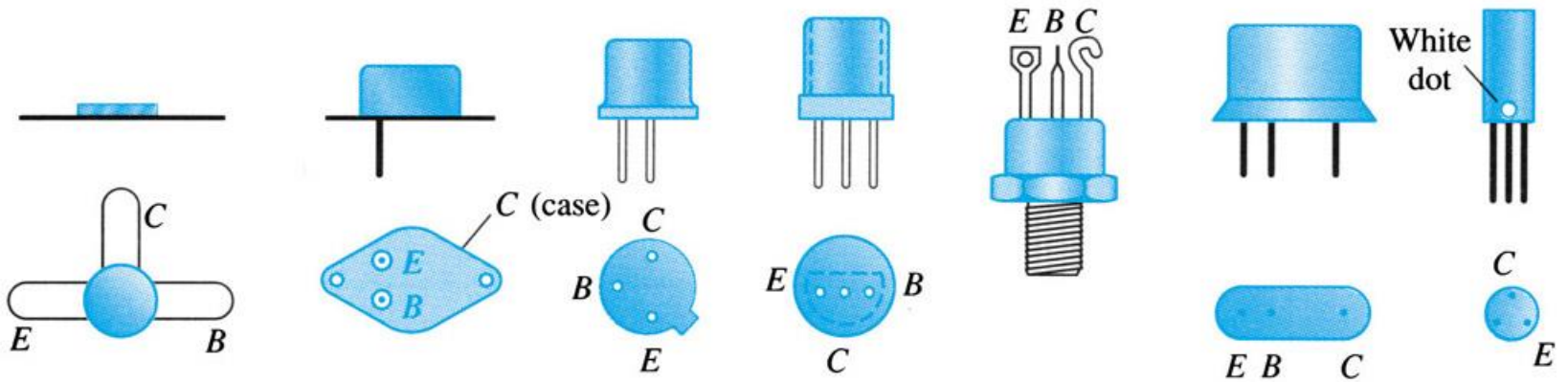


(c)

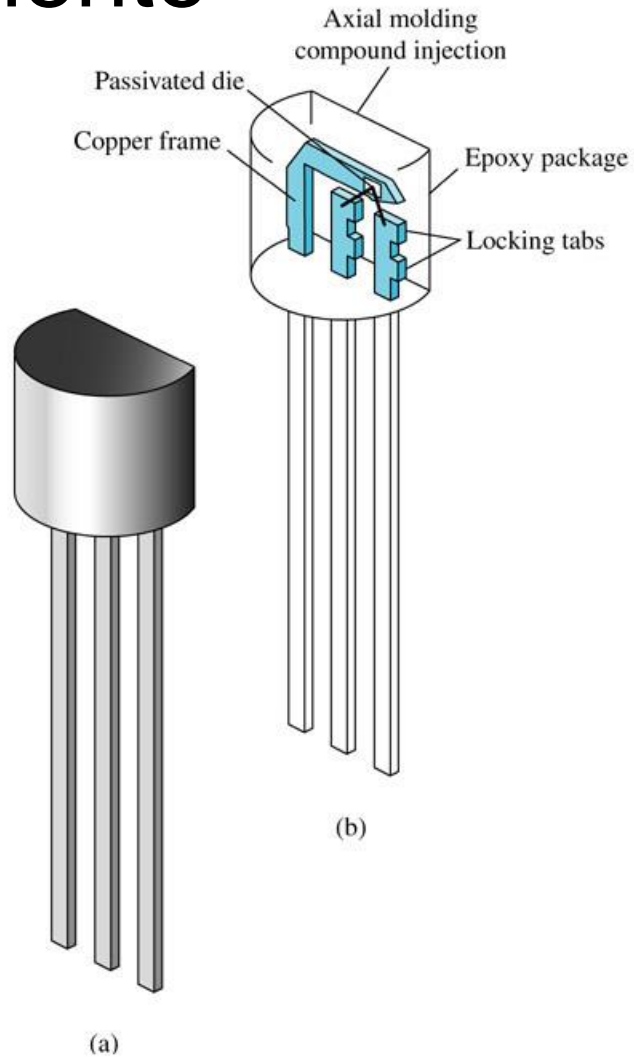


(d)

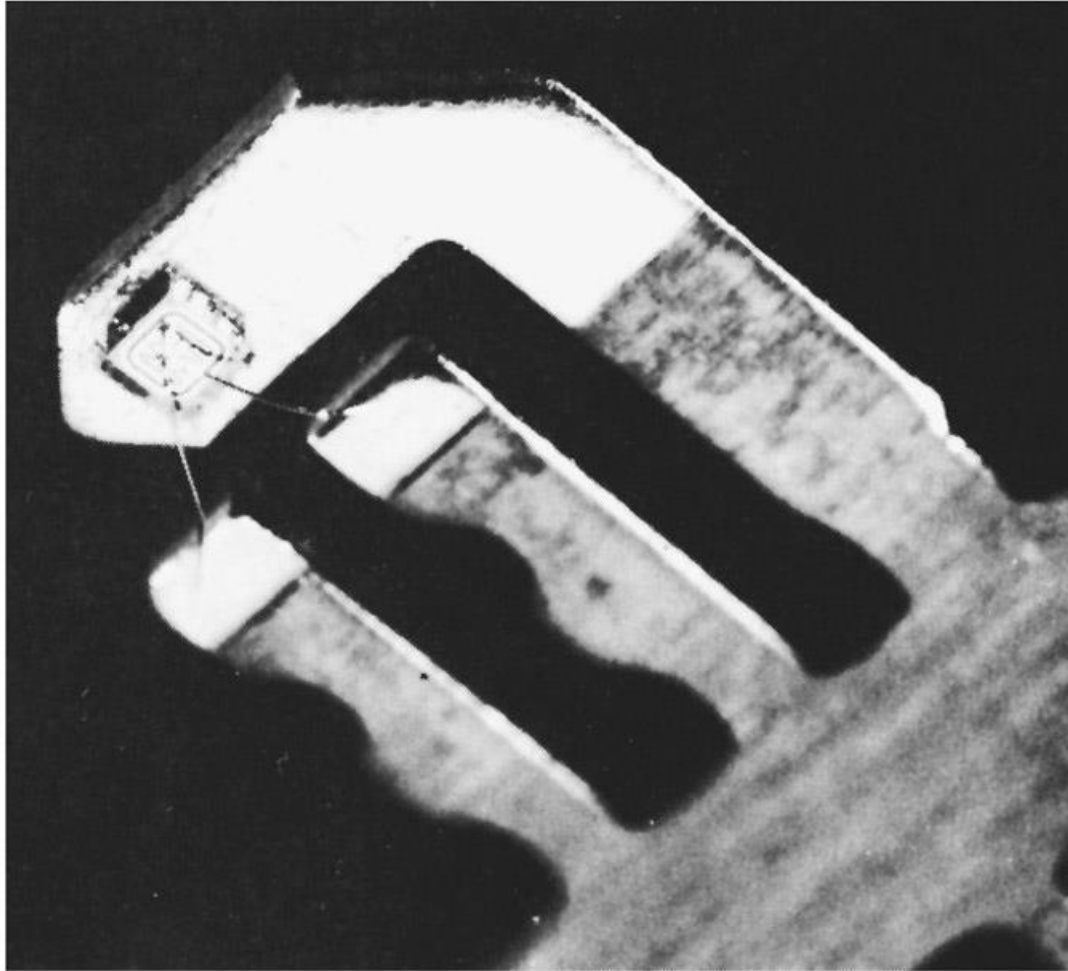
# Formas



# Encapsulamento



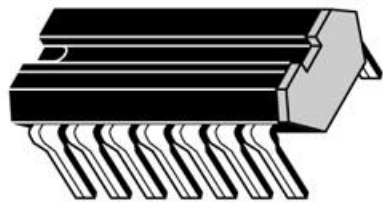
# Encapsulamento



(c)

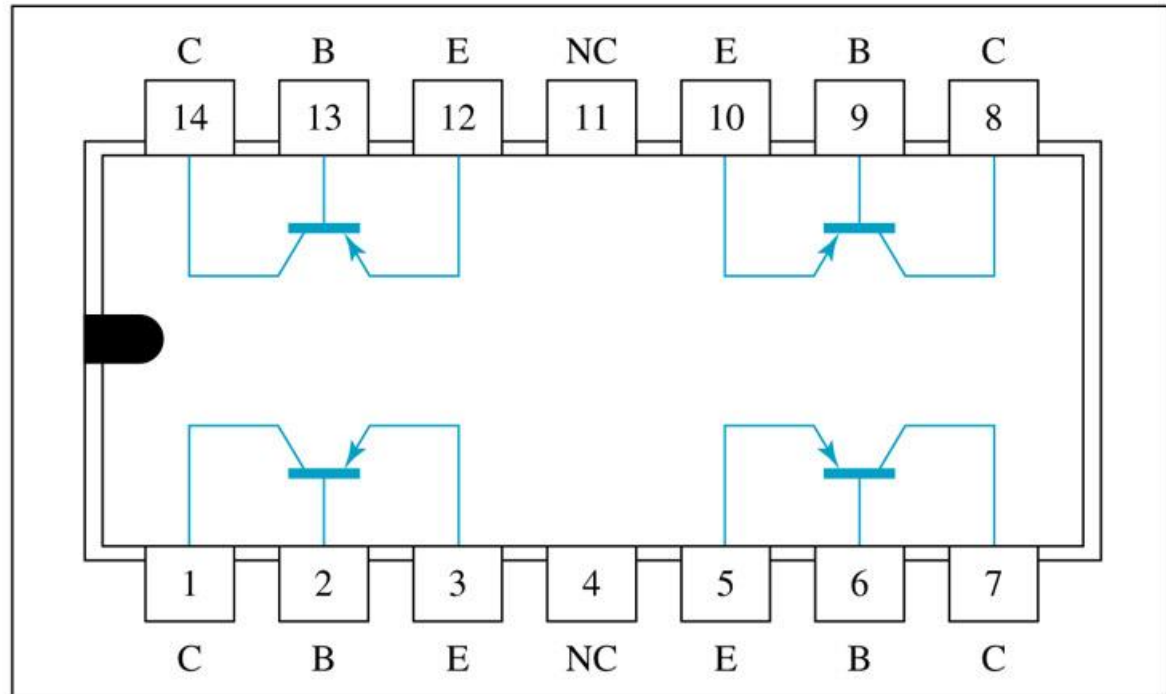


# Encapsulamento



(a)

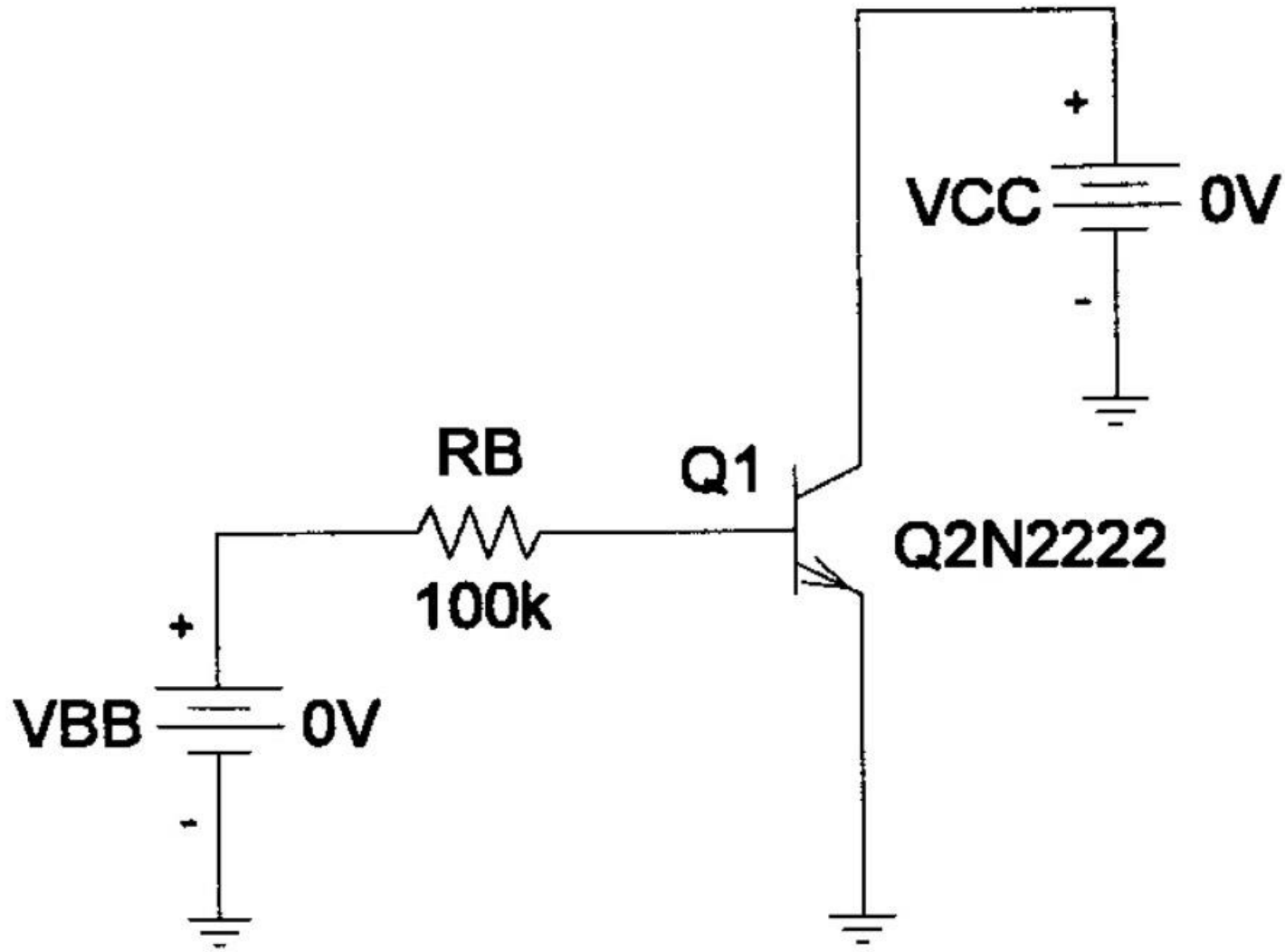
(Top View)



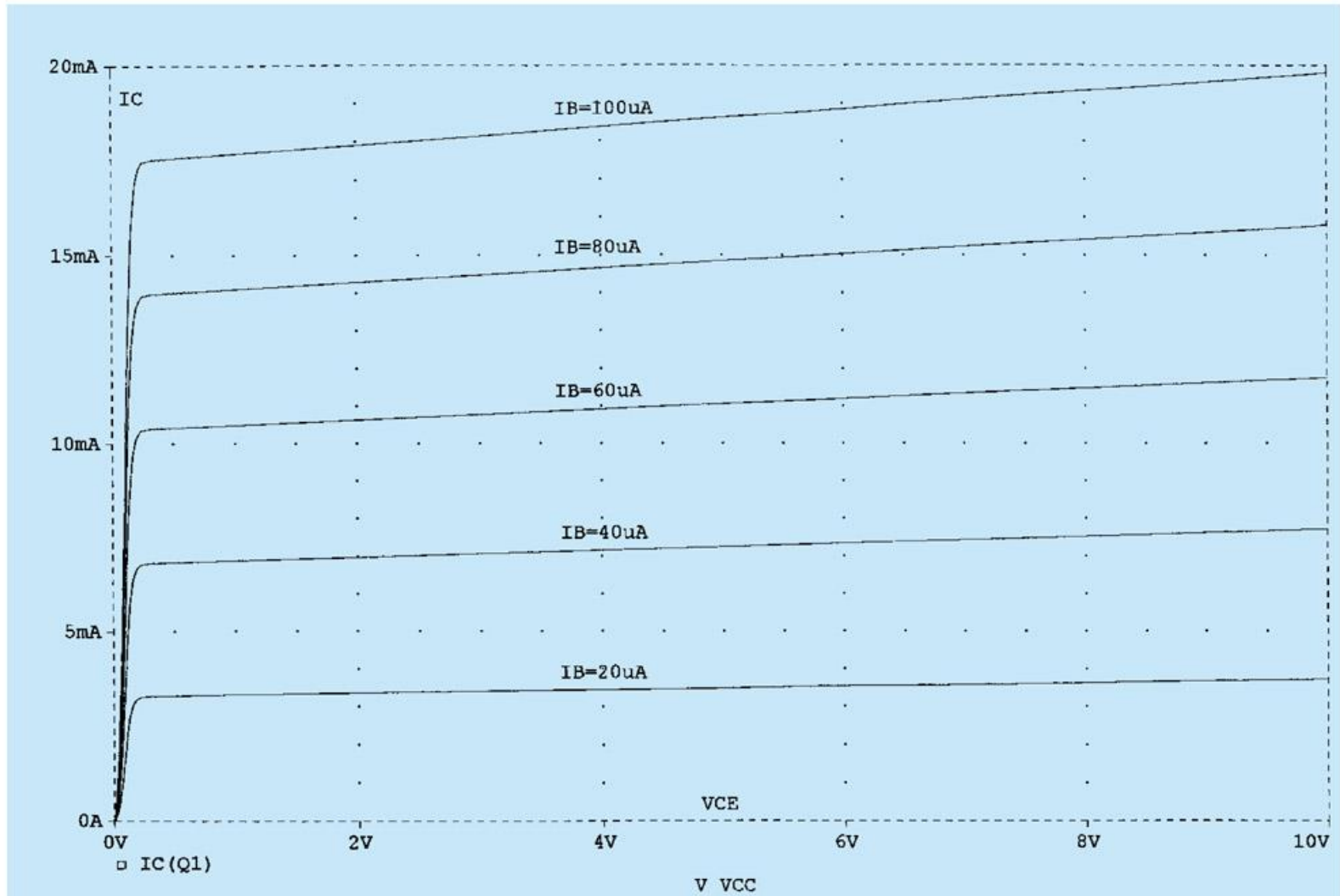
NC – No internal connection

(b)

# Caracterização Experimental



# Caracterização Experimental



# TBJ - Resumo

<b>JEB</b>	<b>JCB</b>	<b>MODO</b>
Reversa	Reversa	
Direta	Reversa	
Direta	Direta	

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# TBJ - Resumo

JEB	JCB	MODO
Reversa	Reversa	<i>CORTE</i>
Direta	Reversa	<i>ATIVO</i>
Direta	Direta	<i>SATURAÇÃO</i>

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# TBJ - Resumo

- A curva característica  $I_C (I_B) \times V_{BE}$  é uma exponencial e quase idêntica à característica  $I \times V$  do diodo de junção.
- Para  $V_{BE}$  menor que  $\sim 0,5$  a  $0,7V$ , a corrente  $I_C$  é desprezível (modo de corte).
- Em operação normal  $V_{BE}$  situa-se na faixa de  $0,6$  a  $0,8V$ .
- Para transistores de silício, a tensão  $V_{BE}$  diminui cerca de  $2mV$  para cada  $1^\circ C$  de aumento de temperatura.
- Para valores baixos de  $V_{CE}$ , a tensão de coletor é menor que a tensão de base e a junção coletor-base fica diretamente polarizada (modo de saturação).
- Na região ativa, as curvas características (de saída) são retas com uma inclinação finita (baixa).
- A inclinação diferente de zero das retas na característica  $I_C \times V_{CE}$  na região ativa é modelada por uma resistência de saída  $r_o$  finita e definida por:

$$r_o \equiv \left[ \frac{\partial i_C}{\partial v_{CE}} \right]^{-1}.$$

# Exercícios

Considere um transistor NPN com  $V_{BE} = 0,7 \text{ V}$  e com  $I_C = 1 \text{ mA}$ .  
Calcule  $V_{BE}$  para i)  $I_C = 0,1 \text{ mA}$  e ii)  $10 \text{ mA}$ .

# Exercícios

Considere um transistor NPN com  $V_{BE} = 0,7 \text{ V}$  e com  $I_C = 1 \text{ mA}$ .  
Calcule  $V_{BE}$  para i)  $I_C = 0,1 \text{ mA}$  e ii)  $10 \text{ mA}$ .

i) Solução: Usando a equação exponencial

$$I_C = I_S \cdot \exp[V_{BE}/(K_B T)] \Rightarrow V_{BE} = K_B T \ln(I_C/I_S)$$



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$V_{BE2} - V_{BE1} = K_B T \ln(I_{C2} / I_{C1})$ . Dessa forma, pode-se escrever (com  $K_B T = 26 \text{ mV}$ )

$$V_{BE2} - 0,7 = 0,026 \ln(0,1 / 1), \text{ que resulta em } V_{BE2} = 0,64 \text{ V}.$$

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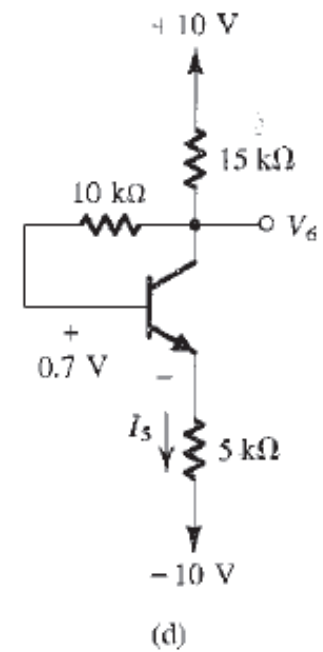
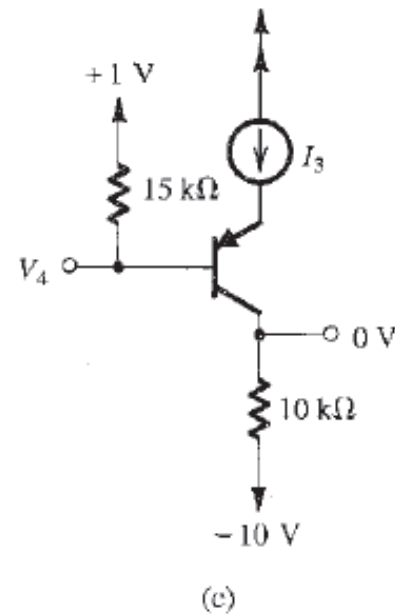
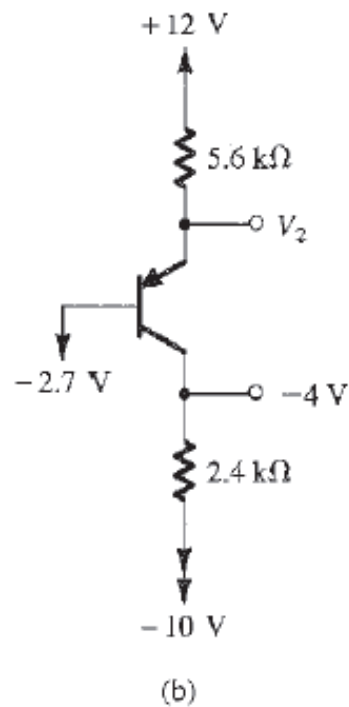
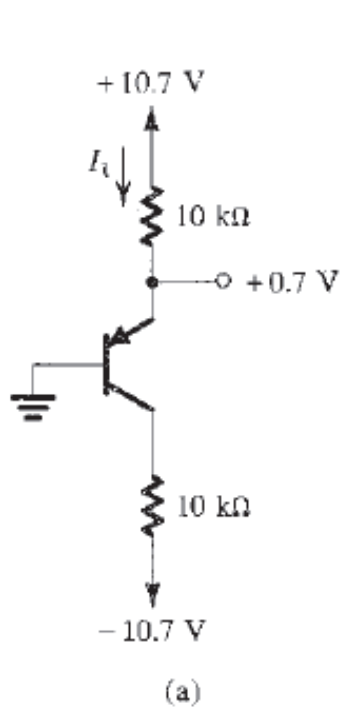
$$V_{BE2} - 0,7 = 0,026 \ln(0,1 / 1), \text{ que resulta em } V_{BE2} = 0,64 \text{ V}.$$

ii) De modo similar:

$$V_{BE2} - 0,7 = 0,025 \ln(10 / 1) \Rightarrow V_{BE2} = 0,76 \text{ V}$$

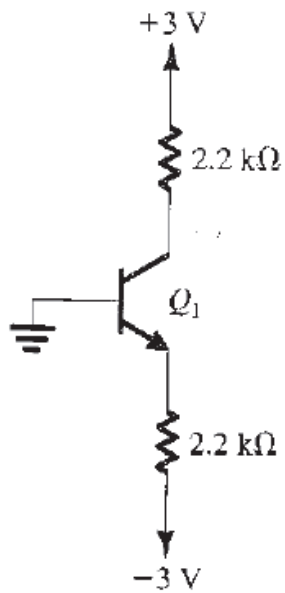
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Considere que o ganho de corrente  $\beta$  para cada transistor a seguir é muito elevado ( $\beta \gg 1$ ) e que os transistores se encontram operando na região ativa. Calcule os parâmetros indicados.

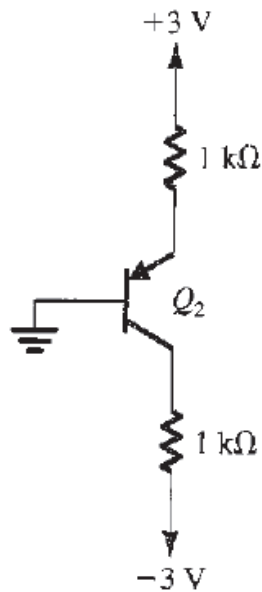


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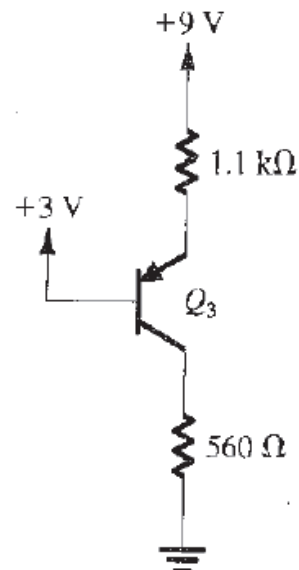
Considere que o ganho de corrente  $\beta = 30$  e que  $|V_{BE}| = 0,7 \text{ V}$ .  
Calcule  $I_C$ .



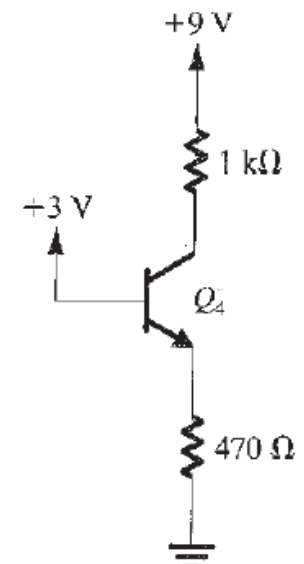
(a)



(b)



(c)



(d)