

Instituto Federal de Educação, Ciência e Tecnologia de Santa Catarina

Departamento Acadêmico de Eletrônica

Eletrônica Analógica I



Transistores Bipolares de Junção

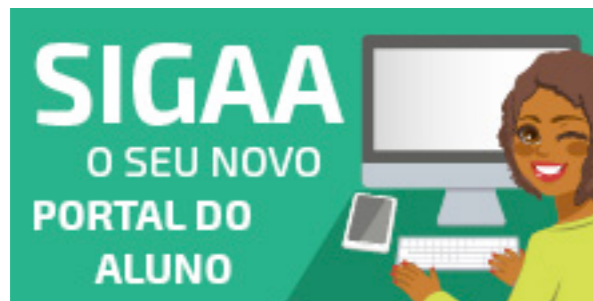
Prof. Clovis Antonio Petry.

Florianópolis, outubro de 2025.

Eletrônica Analógica I

O material do curso está disponível em:

1. SIGAA para os alunos matriculados na disciplina;
2. Página do professor;
3. Canal no youtube do professor.



<https://sigaa.ifsc.edu.br>

ProfessorPetry
Conhecimento para uma vida plena

PRINCIPAL PROJETO PUBLICAÇÕES CONTATO



Bem vindo ao Website pessoal de Clovis Antonio Petry

O objetivo desta página é a divulgação de informações sobre eletrônica, em especial eletrônica de potência. Todos os materiais disponibilizados podem ser livremente utilizados, desde que citados os autores. As disciplinas do semestre corrente podem ser acessadas clicando na imagem da esquerda abaixo. Material didático pode ser encontrado clicando na imagem da direita abaixo.



Eventos

Outubro, 2020
SNCT 2020
Semana Nacional de Ciência e Tecnologia 2020, Florianópolis, SC.
[Acesse...](#)

Setembro, 2020
COBENGE 2020
XLVIII Congresso Brasileiro de Educação em Engenharia (COBENGE) e III Simpósio Internacional de Educação em Engenharia da ABENGE, Bento Gonçalves, RS. [Acesse...](#)

www.ProfessorPetry.com.br



<https://www.youtube.com>

Agenda

Esta aula está organizada em:

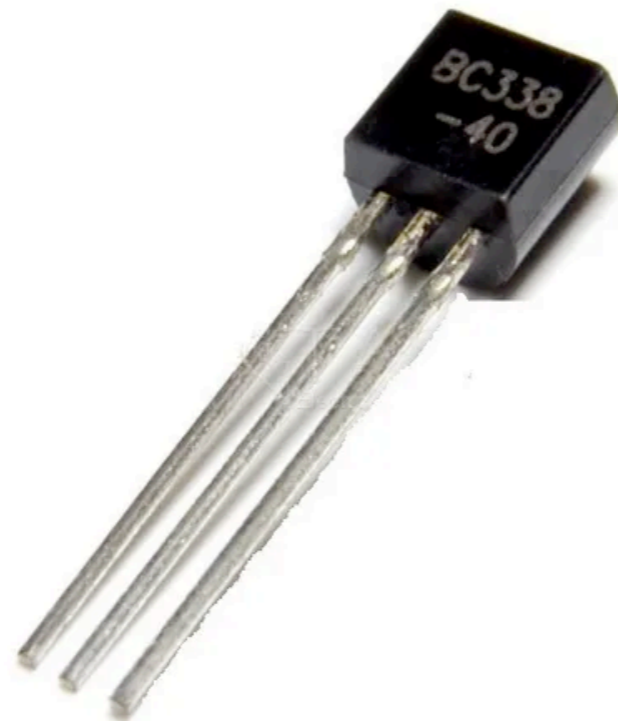
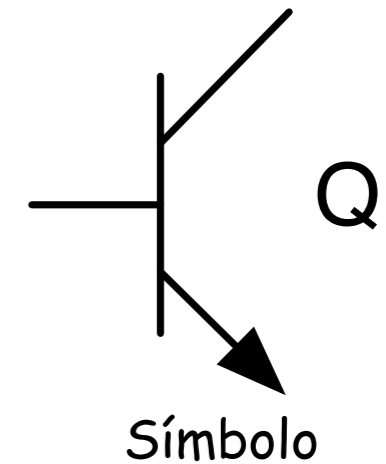
1. Introdução;
2. Construção dos transistores;
3. Funcionamento dos transistores;
4. Configuração emissor-comum;
5. Polarização;
6. Limites de operação;
7. Transistores Darlington;
8. Encapsulamento de transistores;
9. Principais características de catálogo;
10. Tipos de transistores.



Transistor bipolar de junção (BJT)

Transistor bipolar de junção (BJT):

- Dispositivos controlados, permitem a amplificação de sinais;
- Possuem inúmeras aplicações em eletrônica;
- Aplicados em fontes, amplificadores, portas lógicas, etc.;
- Podem operar desde miliwatts até centenas de watts;
- Disponíveis em diferentes encapsulamentos, tensões e correntes.

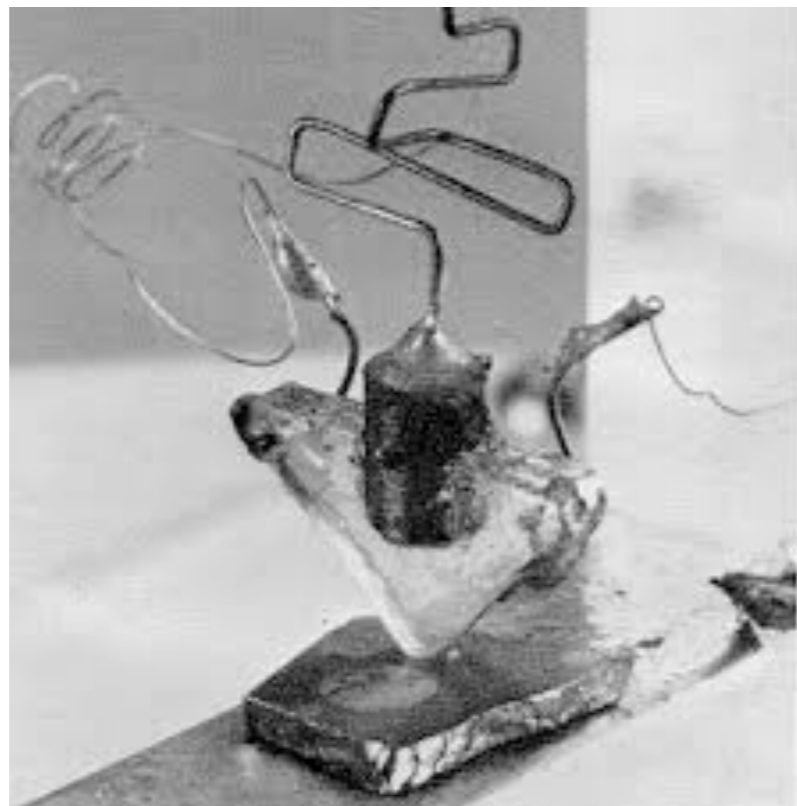


Aspectos físicos

Transistor bipolar de junção (BJT)

Transistor bipolar de junção (história):

- Inicialmente foi desenvolvido o diodo a válvula em 1904 por J. A. Fleming;
- Posteriormente o tríodo a válvula em 1906 por Lee De Forest;
- O transistor foi desenvolvido em 1947 por Walter H. Brattain e John Bardeen nos laboratórios da Bell Labs da AT&T em Murray Hill, Nova Jersey, nos Estados Unidos;
- Posteriormente surgiram os transistores Mosfet, Igbt, Silicon Carbide, etc.



Primeiro transistor bipolar de junção e sua réplica

Transistor bipolar de junção (BJT)

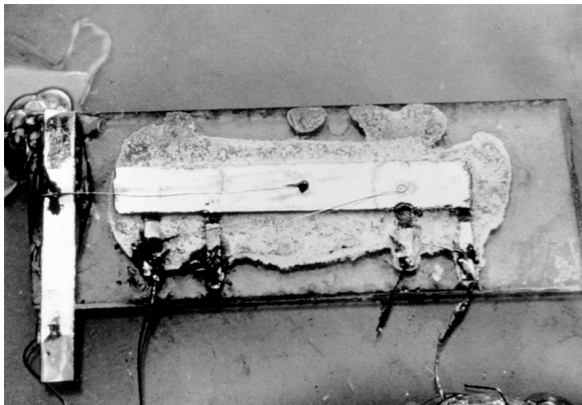
Escalas de integração de transistores em circuitos integrados:

Ano	Nível de Integração	Número de Transistores
1963	Small scale integration (SSI)	<100
1970	Medium scale integration (MSI)	100 - 300
1975	Large scale integration (LSI)	300 - 30.000
1980	Very large scale integration (VLSI)	30.000 a 1 milhão
1990	Ultra large scale integration (ULSI)	> 1 milhão
2010	Giga scale integration (GSI)	> 1 bilhão

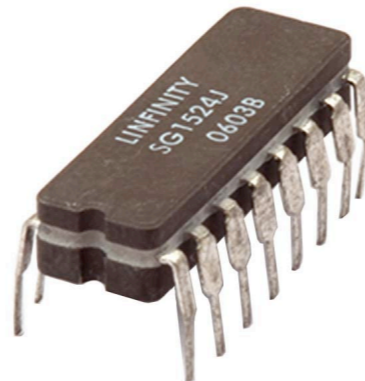
Transistor bipolar de junção (BJT)

Evolução dos circuitos integrados:

- O primeiro circuito integrado (CI) foi criado por Jack Kilby da Texas Instruments em 1958, tinha cinco componentes. Era feito de germânio e continha um transistor, um capacitor e três resistores. No mesmo ano, Robert Noyce da Fairchild Semiconductor desenvolveu um circuito integrado usando silício;
- O computador Apple I, lançado em 1976, possuía dezenas de circuitos integrados, sendo que o processador 6502 tinha 4.528 transistores;
- O amplificador operacional LM741 de 1968 da Fairchild Semiconductor tem 20 transistores. Já o primeiro CI para fontes chaveadas foi o SG1524 de 1976;
- Um Iphone 17, do ano de 2025, possui em torno de 30 bilhões de transistores

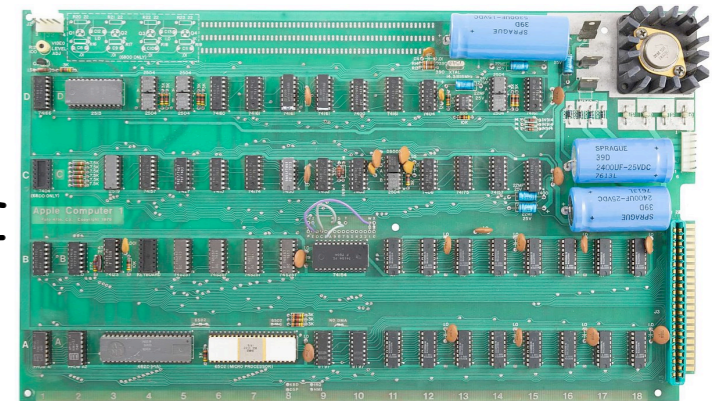


Primeiro circuito integrado



SG1524

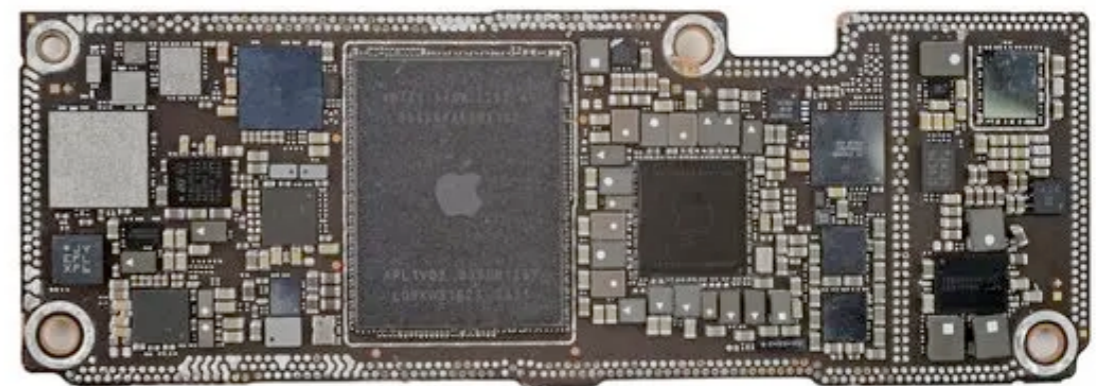
Placa do Apple I



LM741



Placa de um Iphone 17



Transistor bipolar de junção (BJT)

Transistor bipolar de junção (aplicações):



Fontes



Amplificadores



Rádios



Televisores

Transistor bipolar de junção (BJT)

Transistor bipolar de junção (aplicações):



Inversores de frequência



Reatores eletrônicos



Linha branca



Computadores



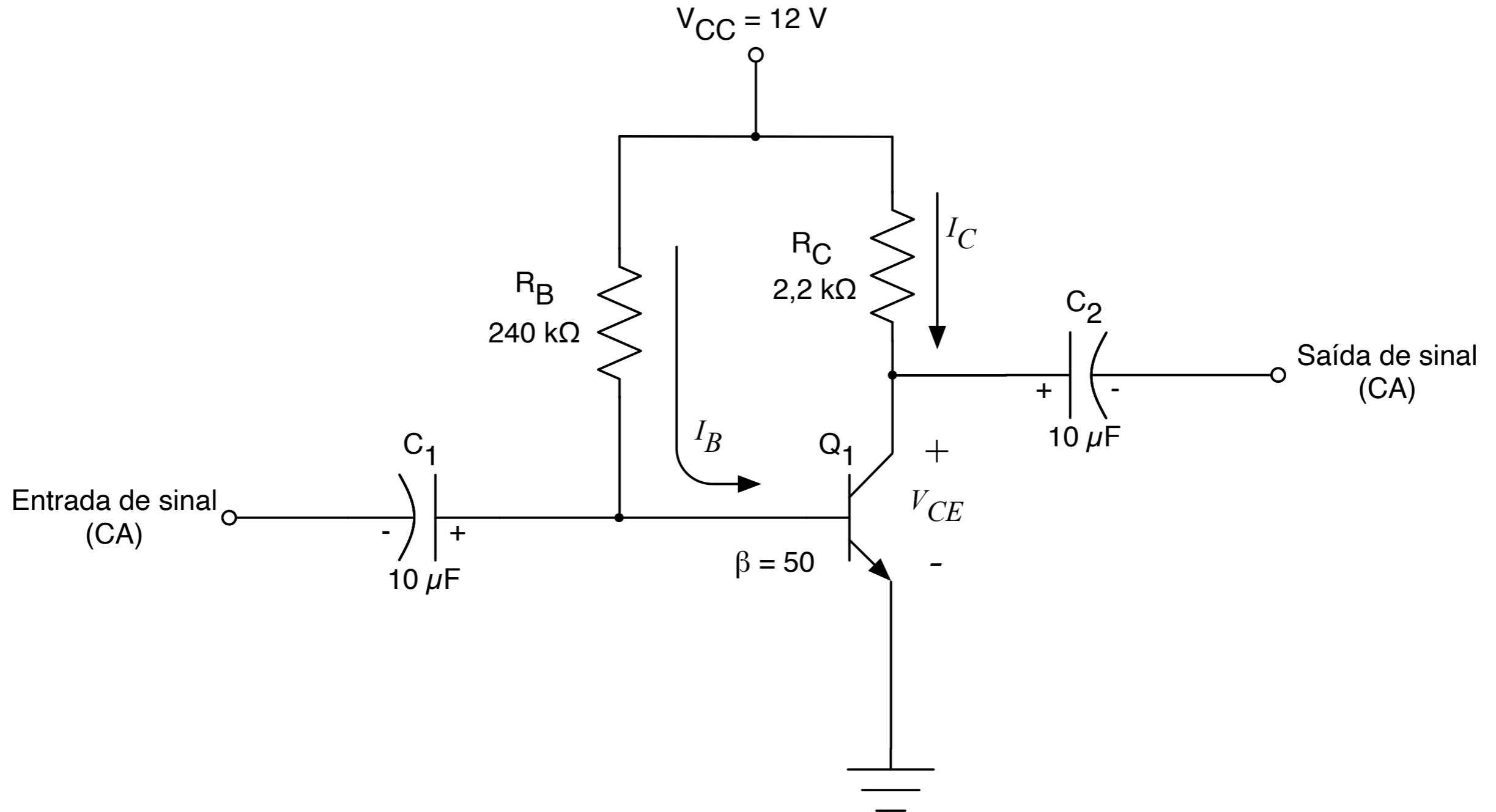
Telefones



Carregadores de baterias

Transistor bipolar de junção (BJT)

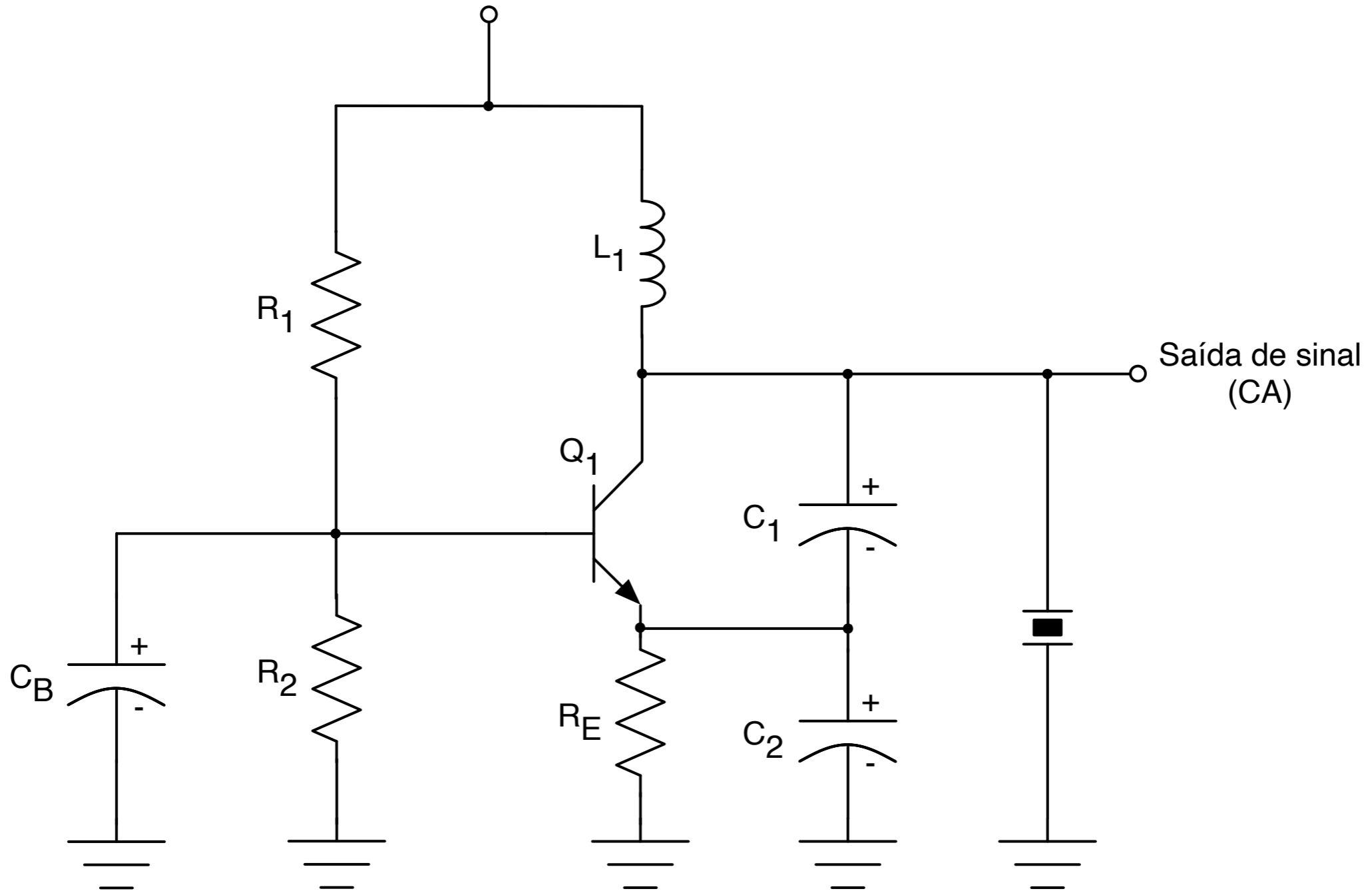
Transistor bipolar de junção (aplicações):



Amplificador com transistor bipolar

Transistor bipolar de junção (BJT)

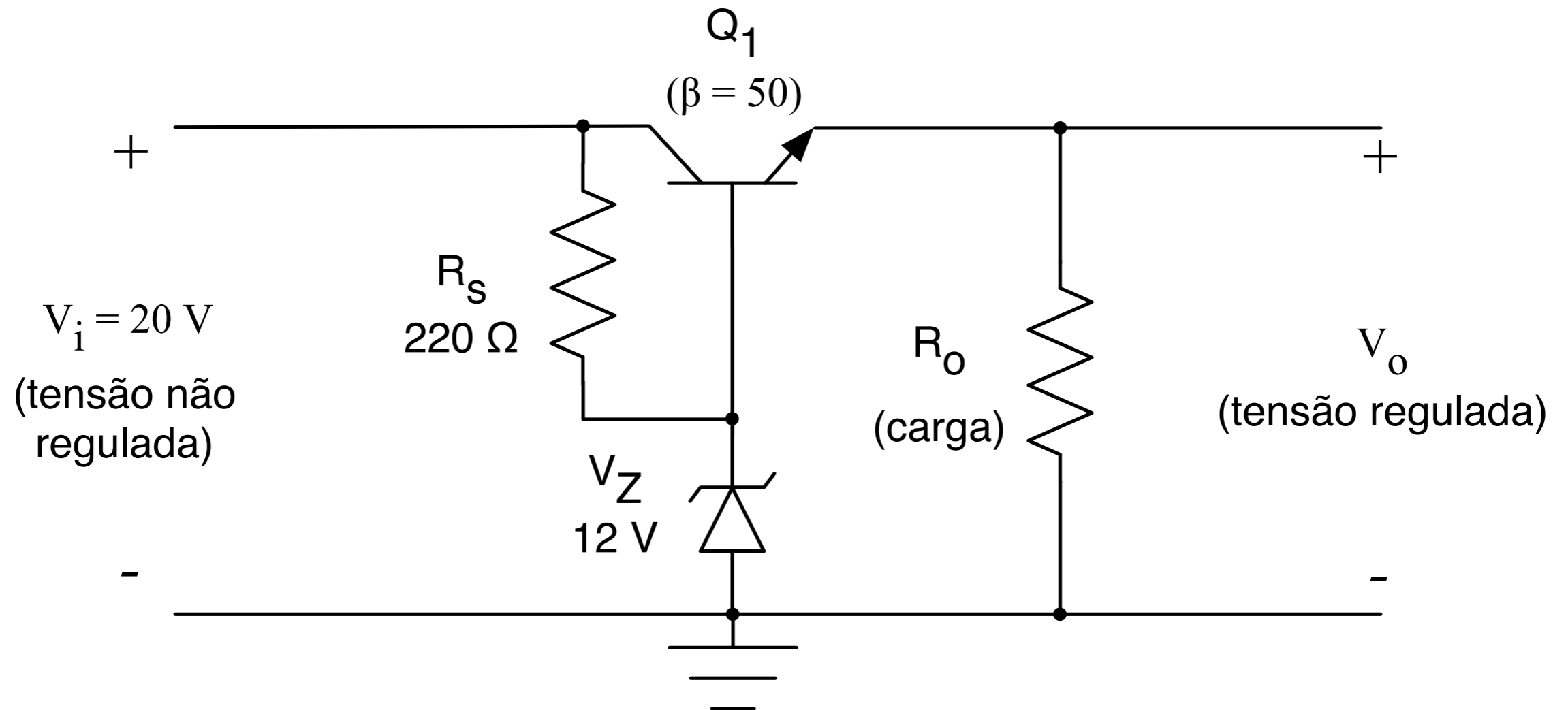
Transistor bipolar de junção (aplicações):



Oscilador controlado a cristal

Transistor bipolar de junção (BJT)

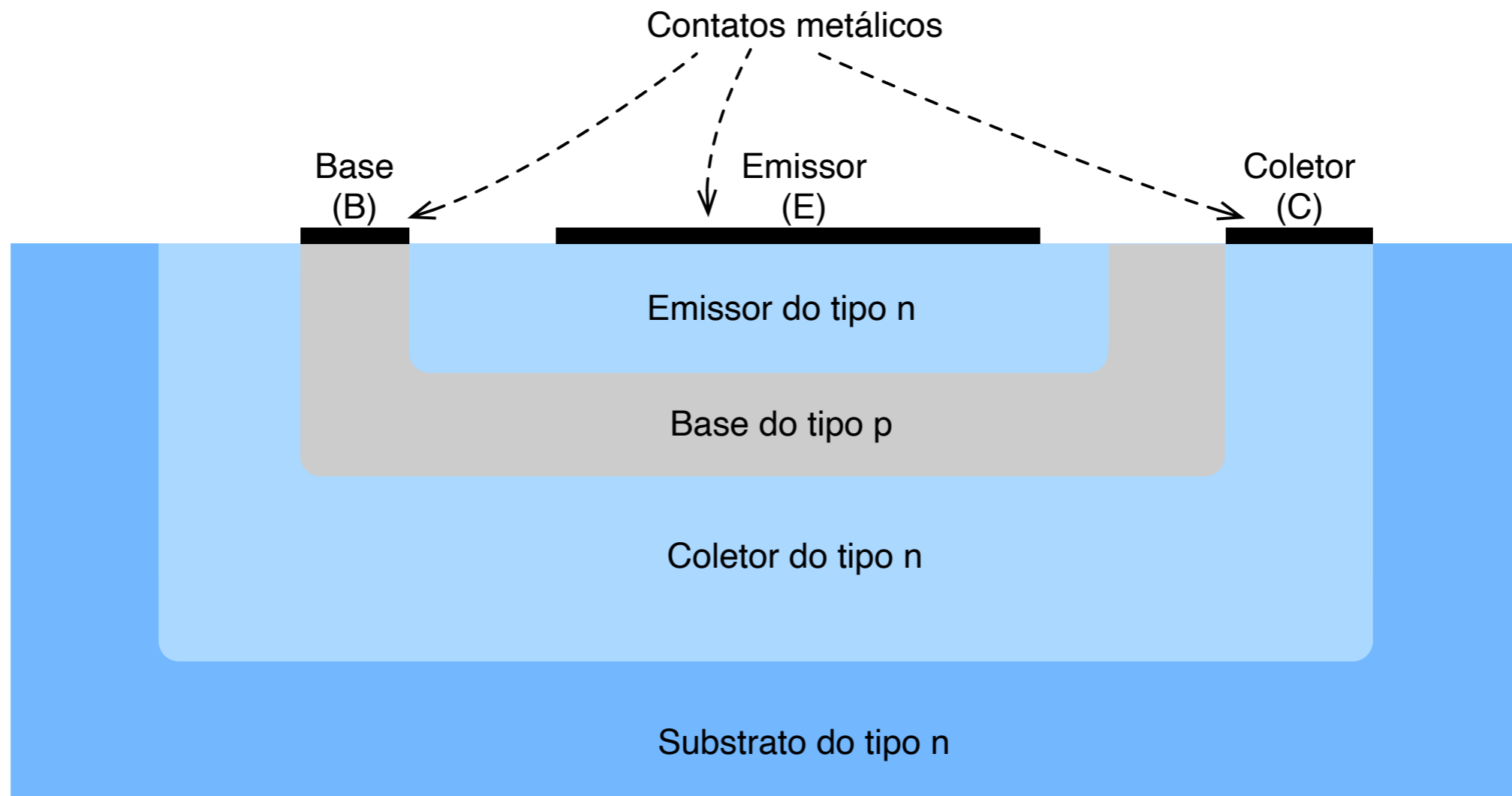
Transistor bipolar de junção (aplicações):



Regulador de tensão com transistor bipolar

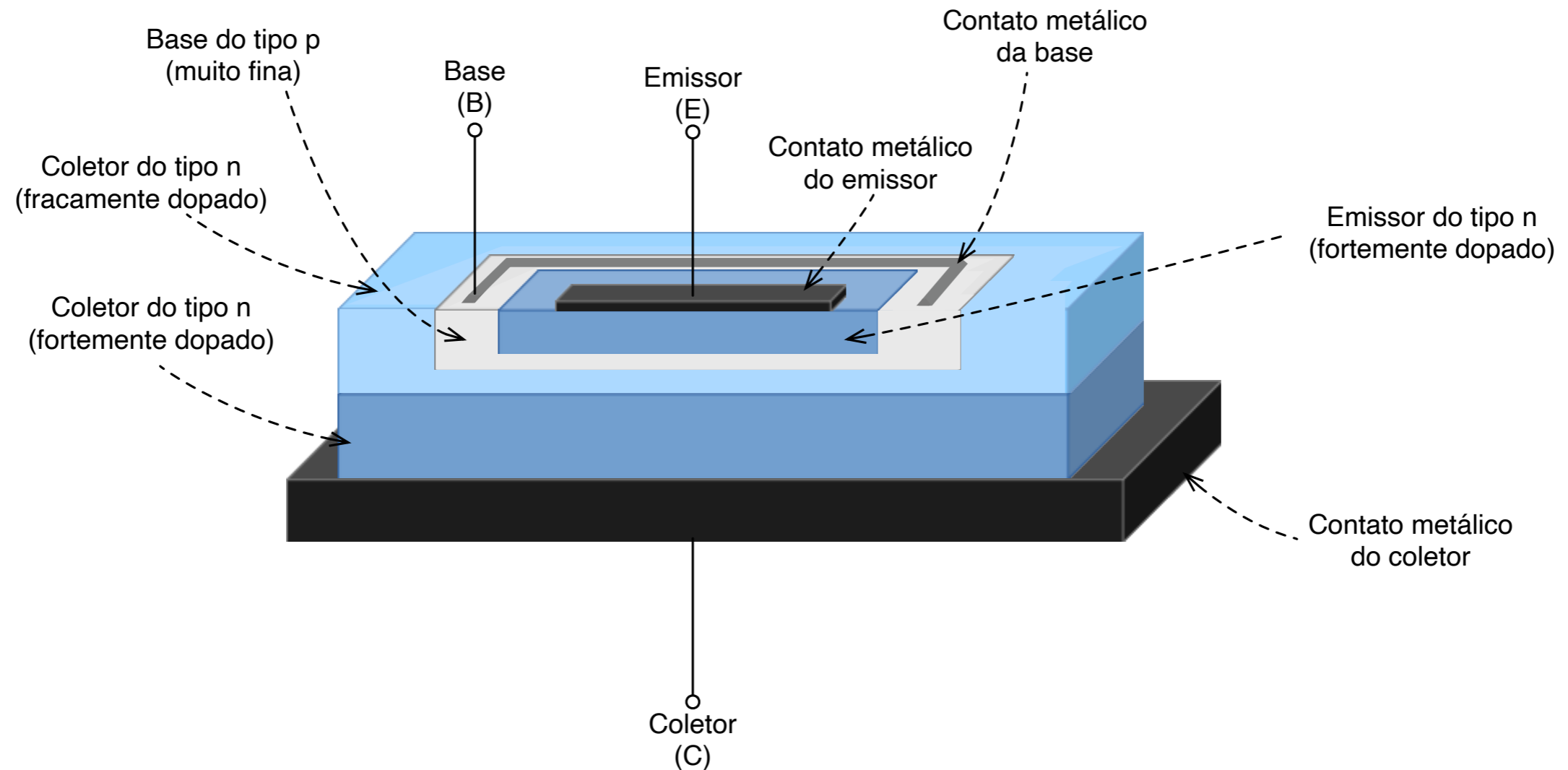
Construção dos transistores

Camadas internas do transistor bipolar de junção:



Construção dos transistores

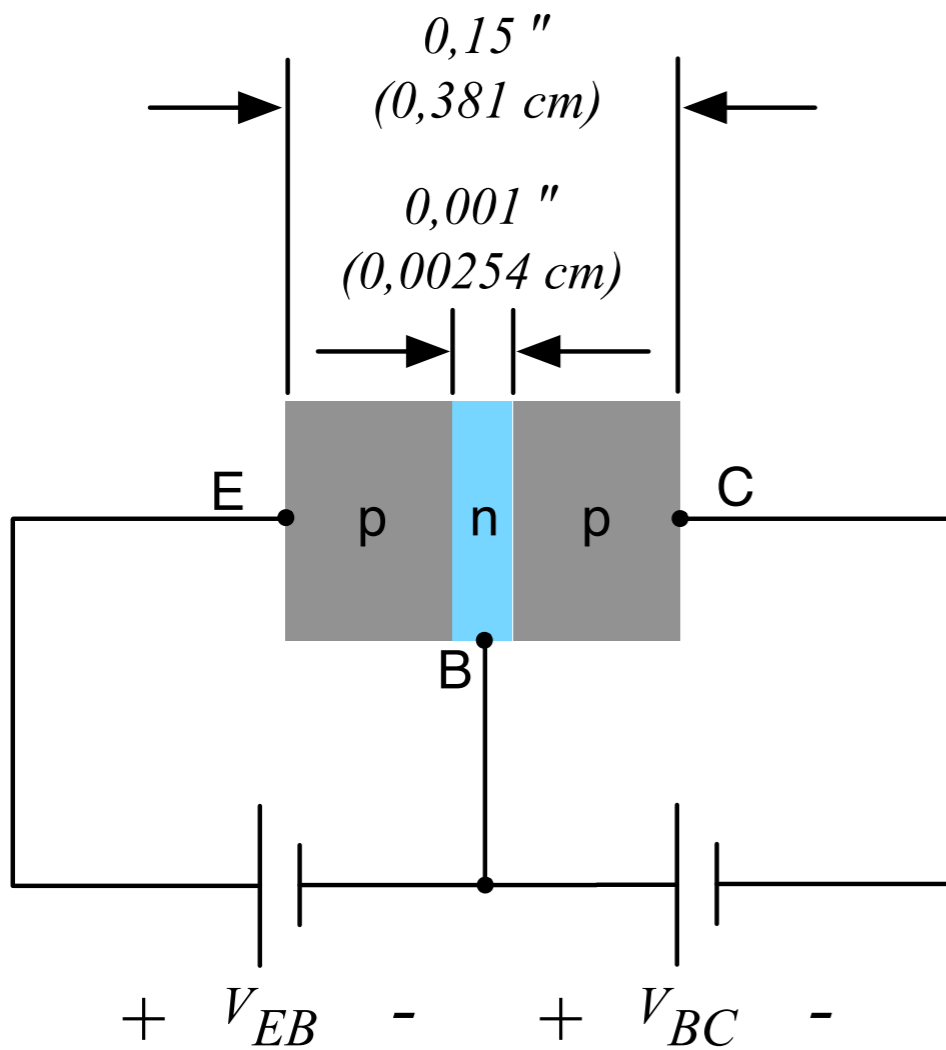
Construção planar de um transistor bipolar de junção:



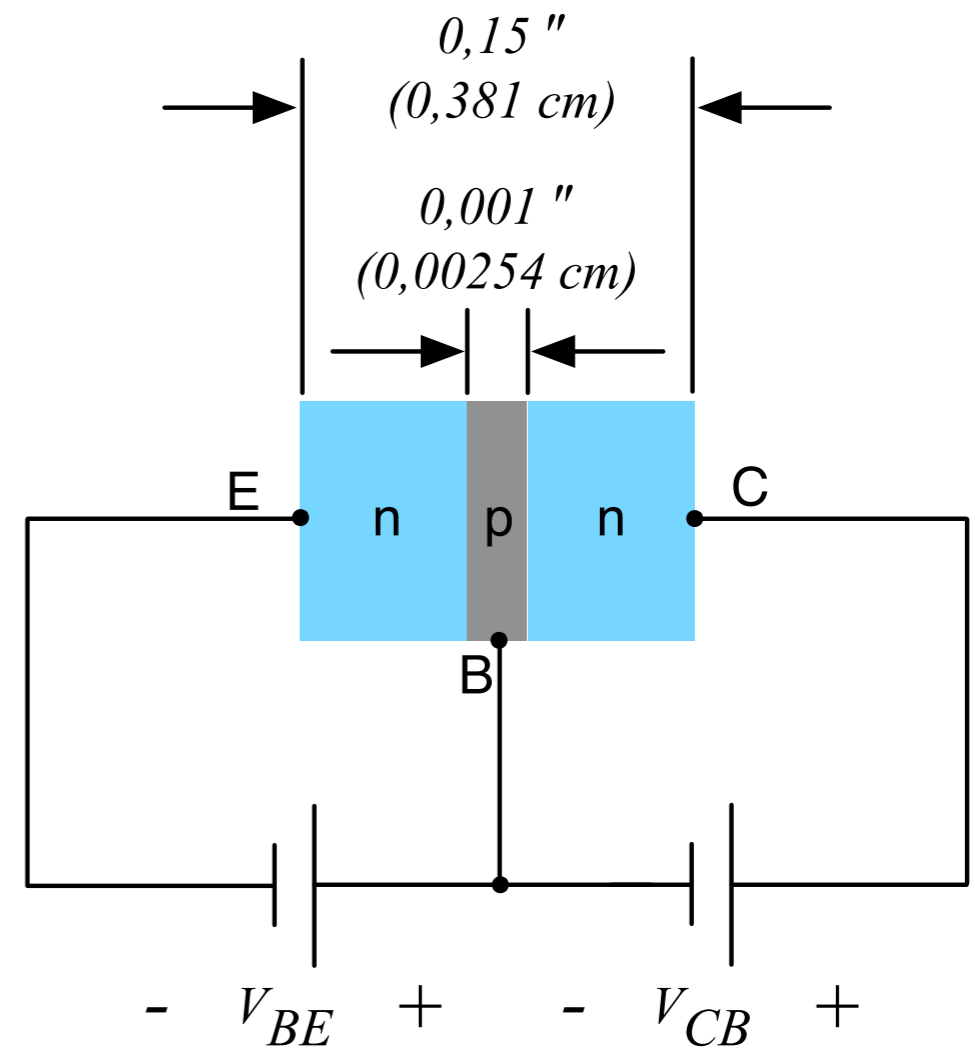
Construção dos transistores

Dimensões características de um transistor bipolar de junção:

Transistor PNP



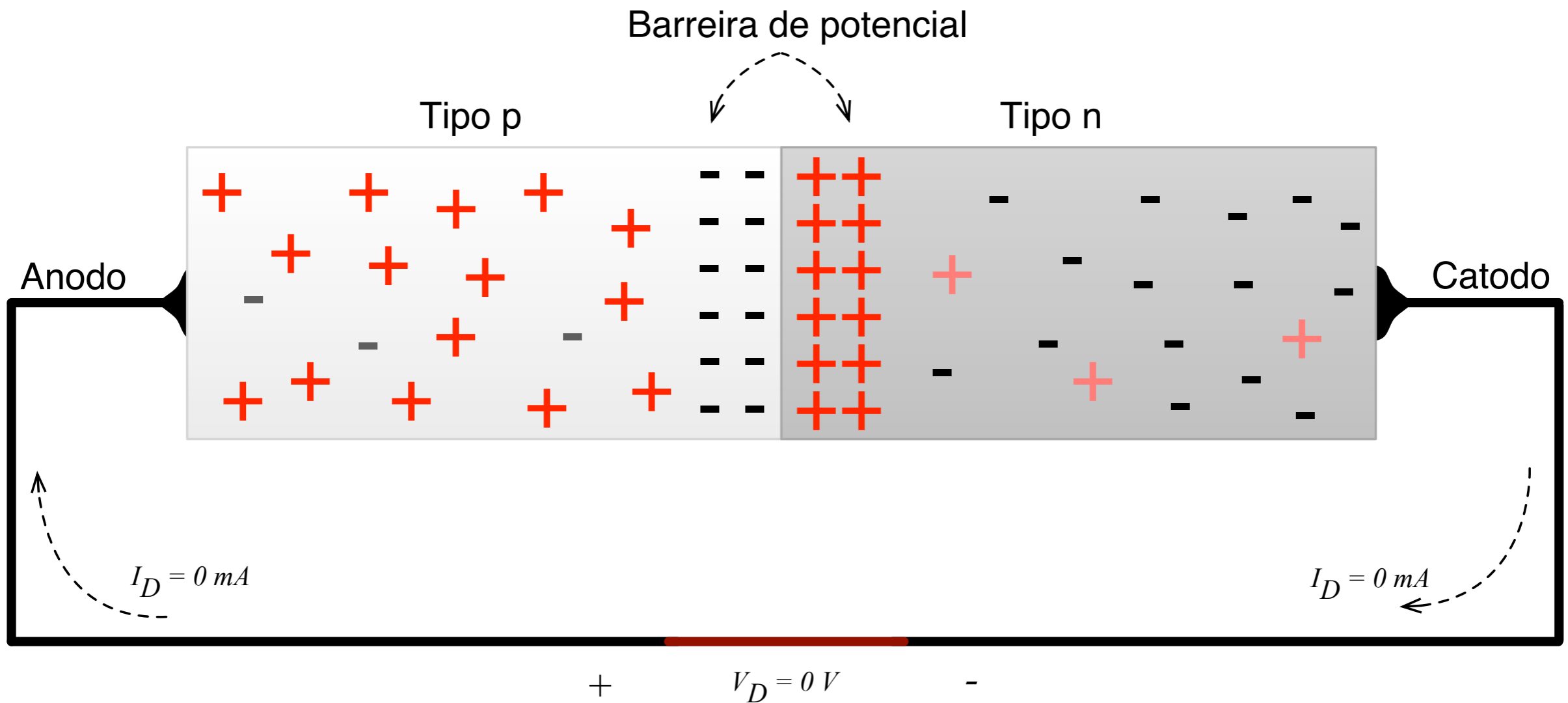
Transistor NPN



Funcionamento dos transistores

Relembrando o funcionamento do diodo de junção PN:

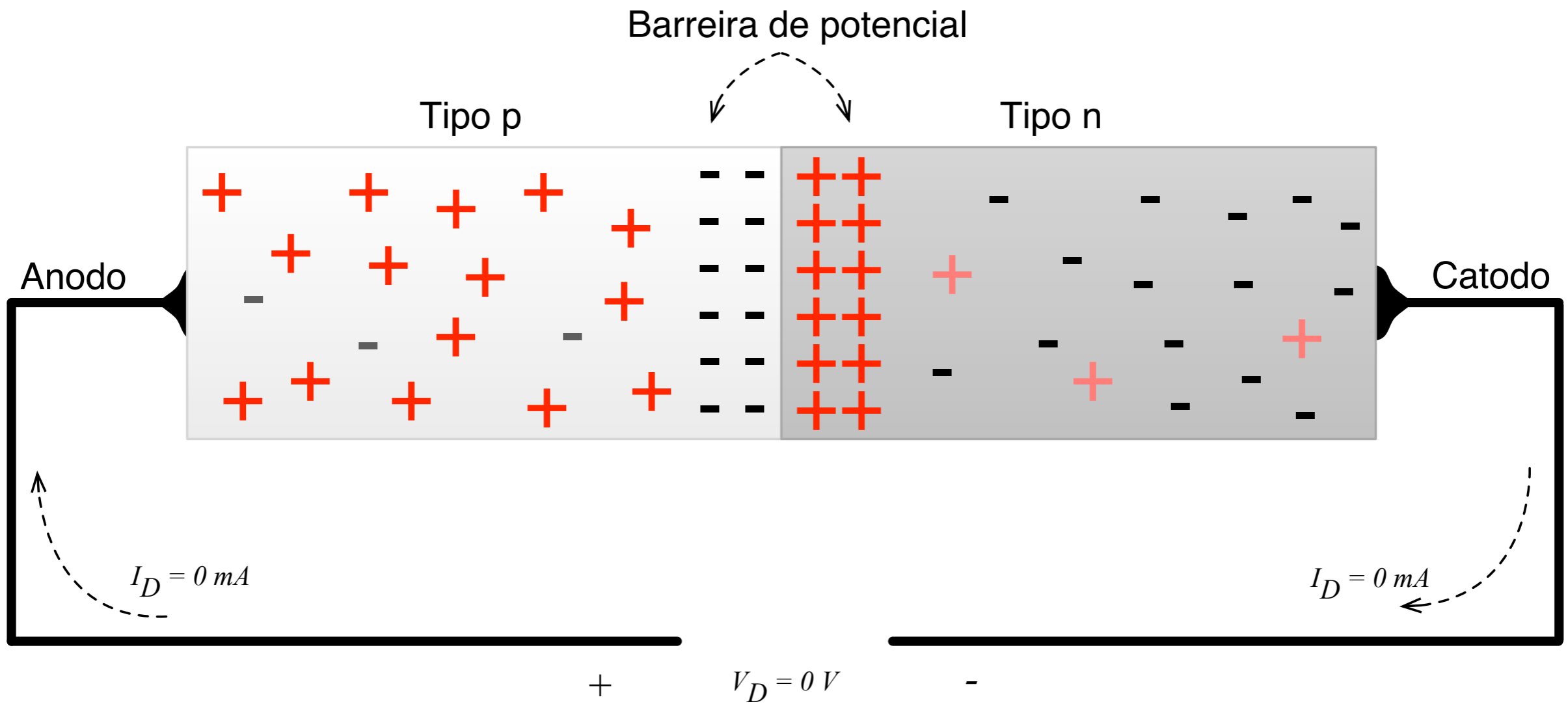
- Sem polarização ($V_D = 0\text{ V}$).



Funcionamento dos transistores

Relembrando o funcionamento do diodo de junção PN:

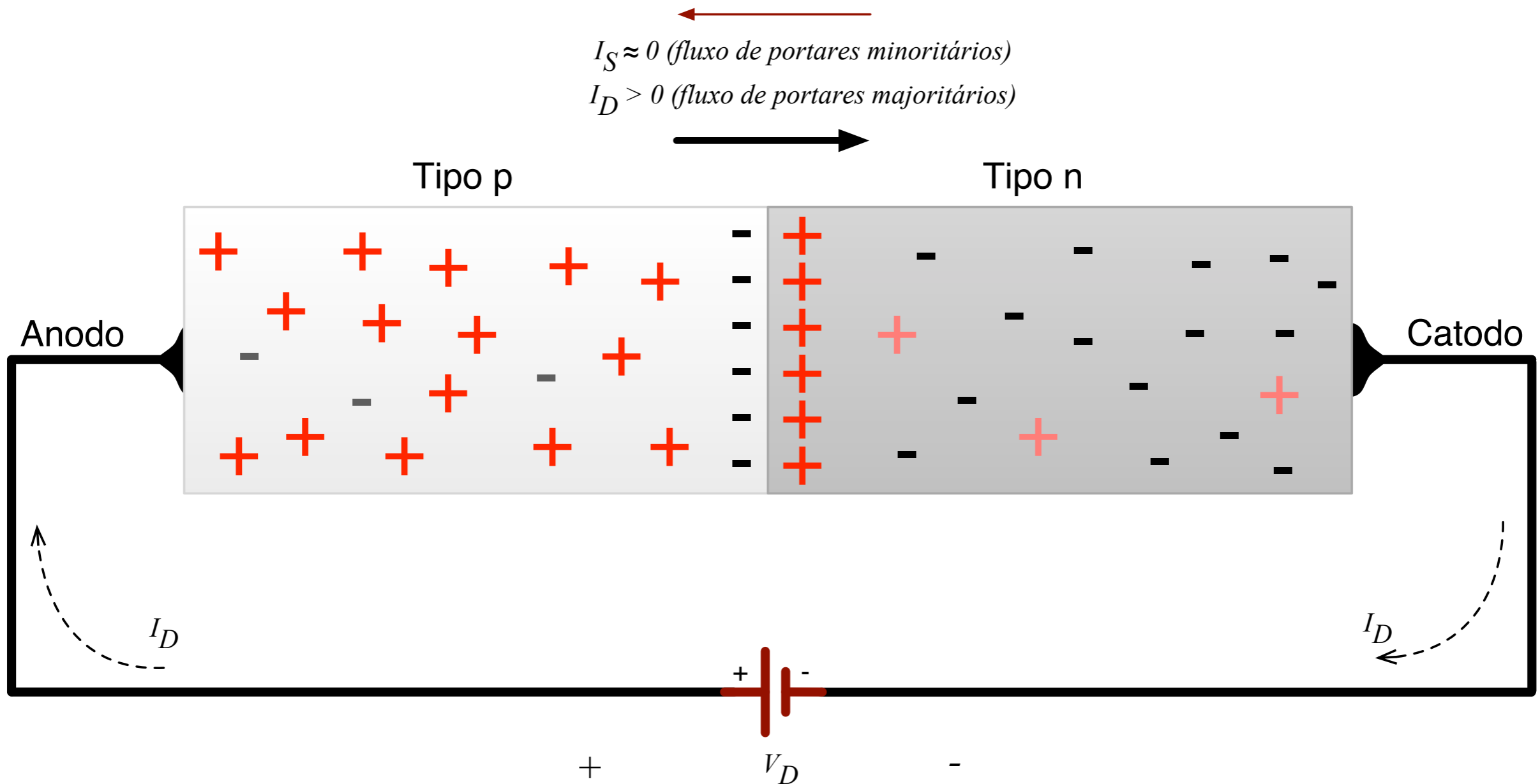
- Sem polarização ($V_D = 0\text{ V}$).



Funcionamento dos transistores

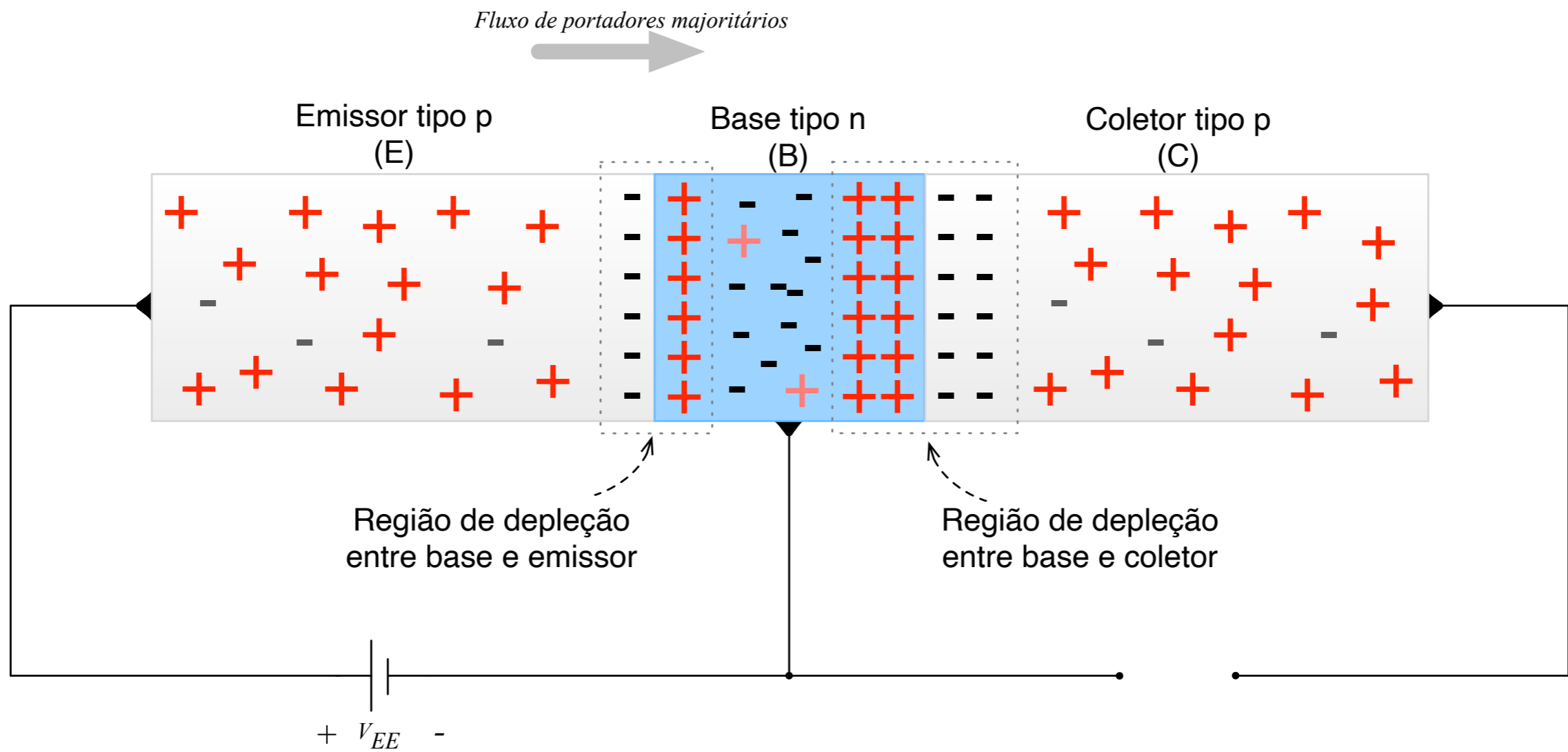
Relembrando o funcionamento do diodo de junção PN:

- Polarização direta ($V_D > 0$ V).



Funcionamento dos transistores

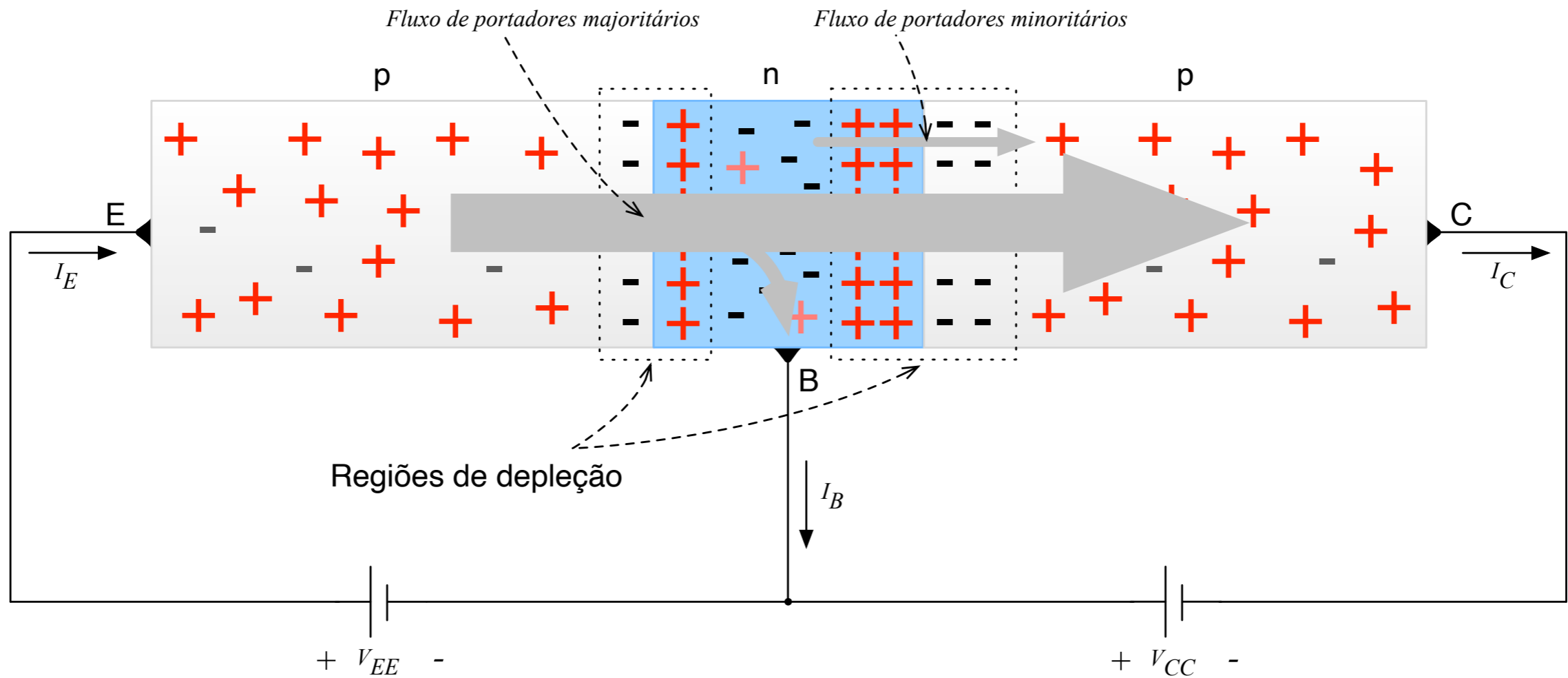
Transistor PNP:



Junção base - emissor diretamente polarizada

Funcionamento dos transistores

Transistor PNP:

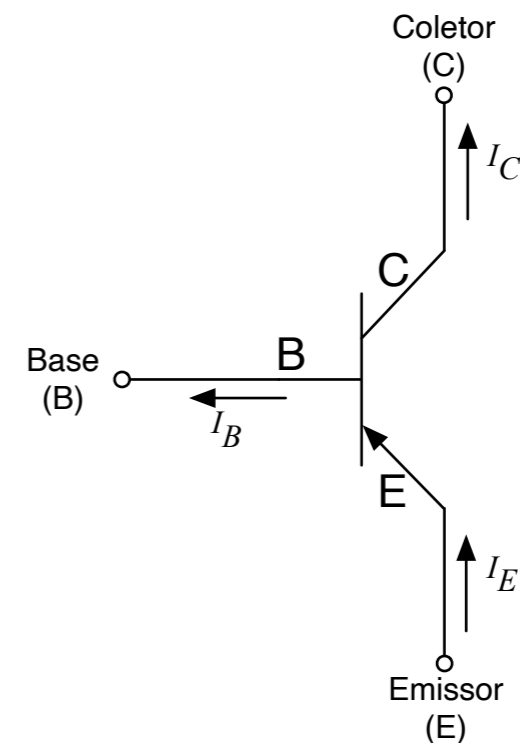
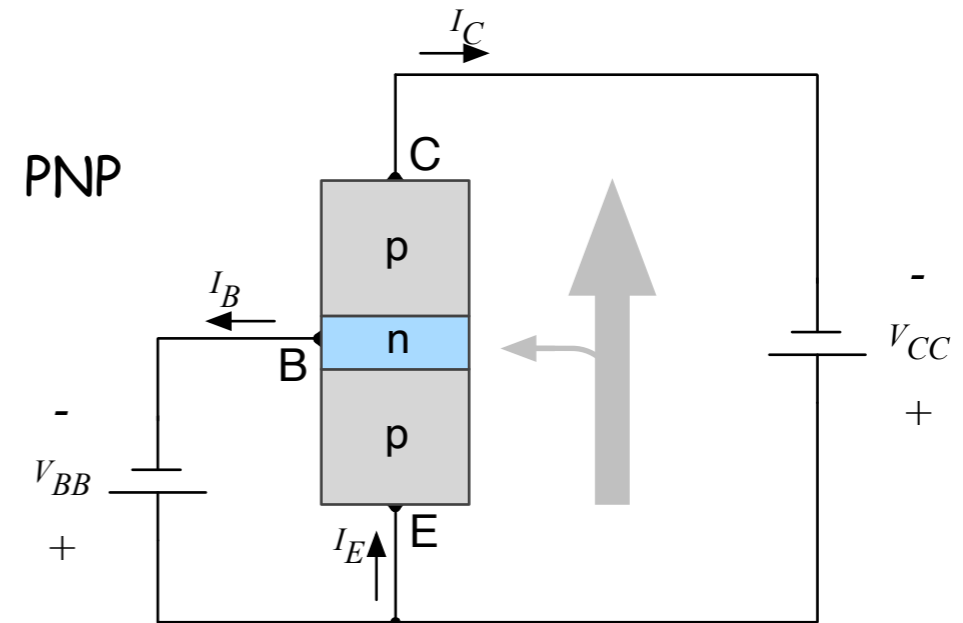
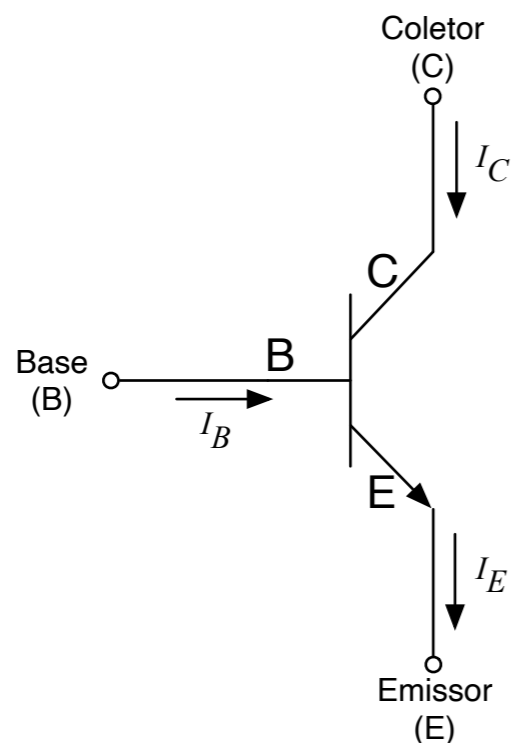
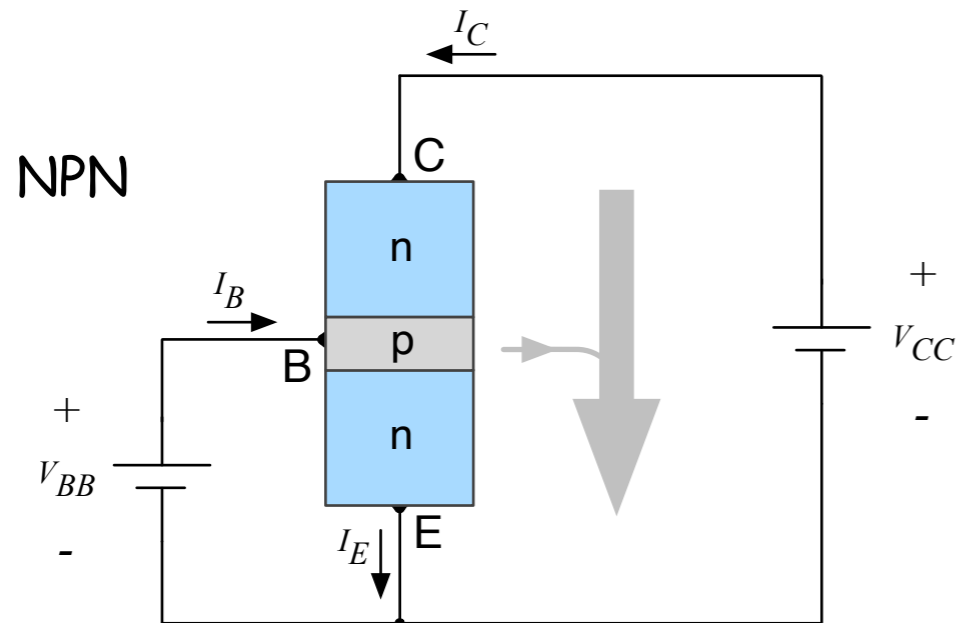


Correntes no transistor bipolar de junção

Configuração emissor-comum

Identificação do transistor pelo seu símbolo:

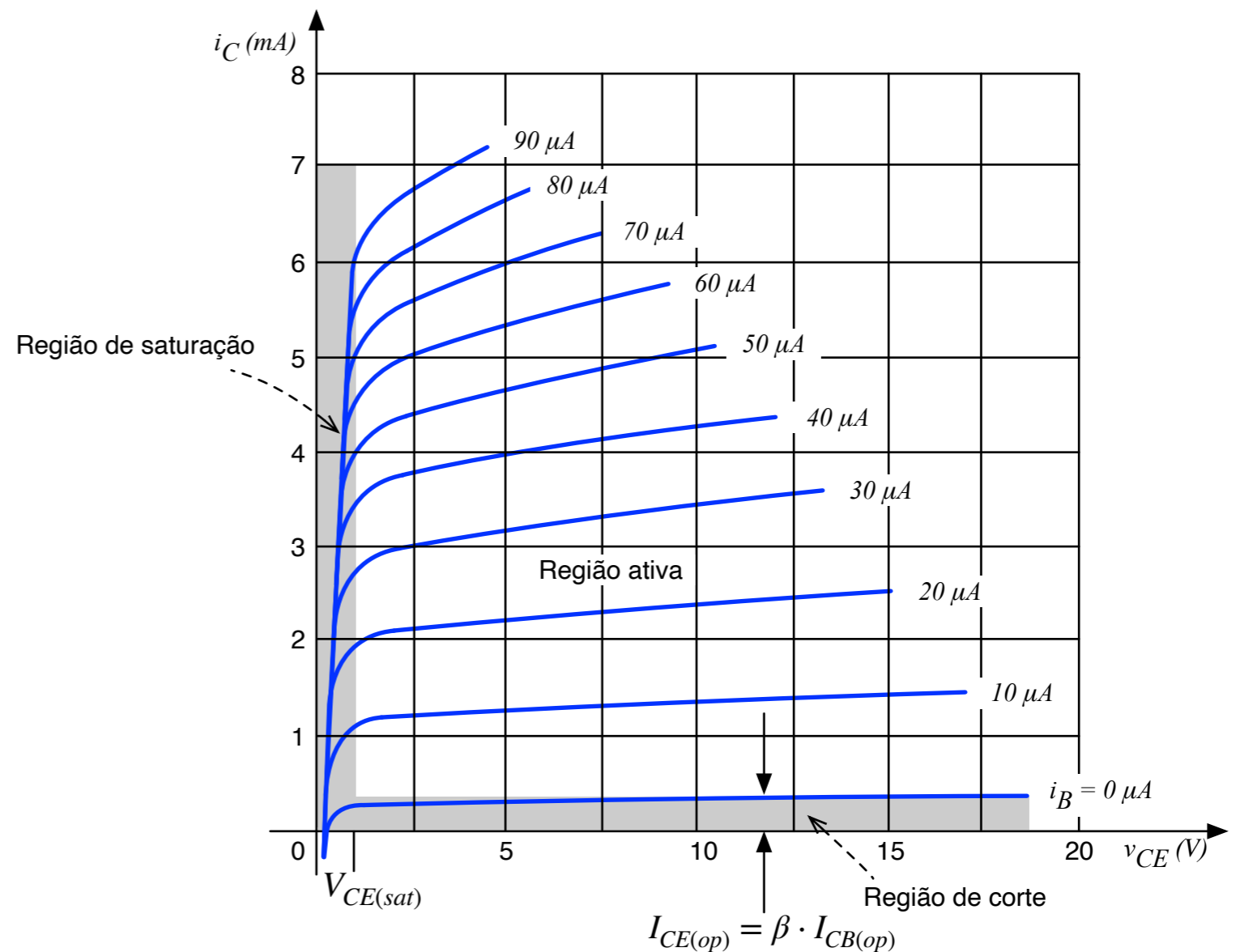
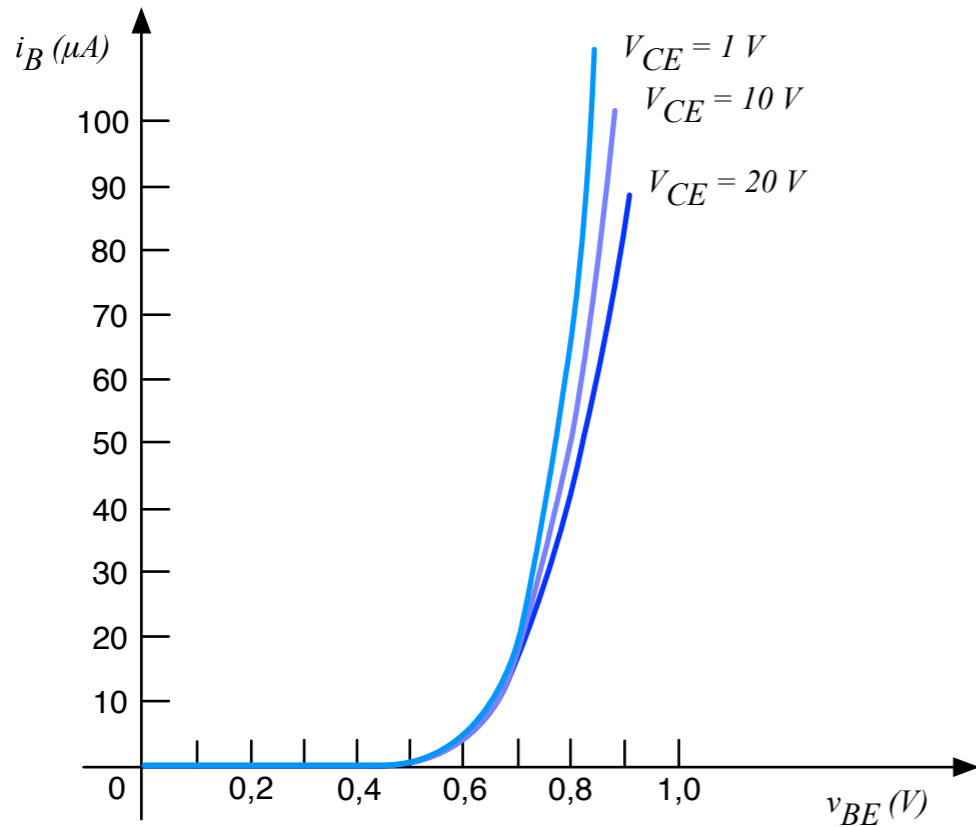
- A seta do símbolo gráfico define o sentido da corrente de emissor (fluxo convencional) através do dispositivo.



Configuração emissor-comum

Curvas características dos transistores bipolares de junção:

- Na região ativa, a junção base-coletor é polarizada reversamente, enquanto a junção base-emissor é polarizada diretamente.

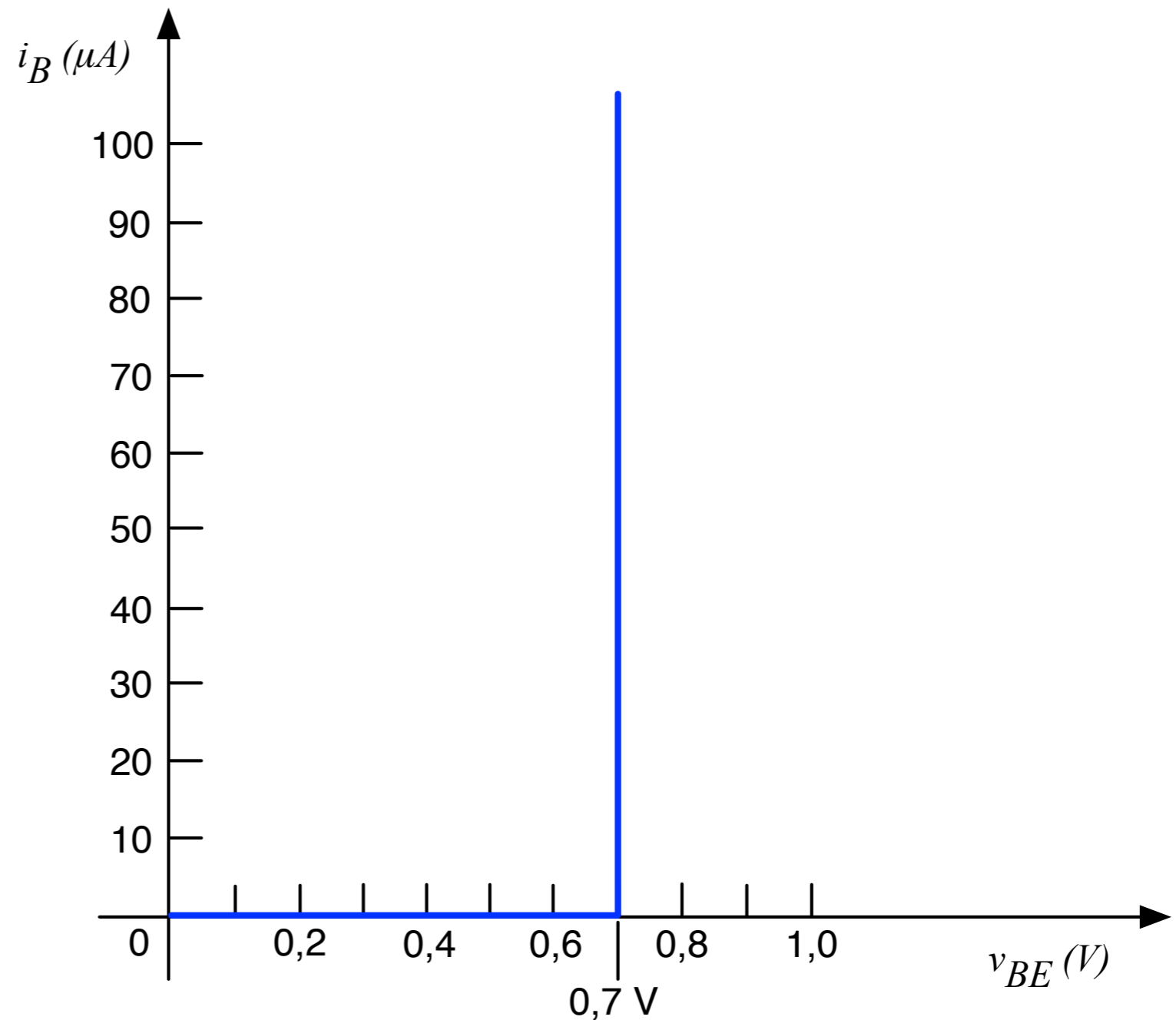


Configuração emissor-comum

Curvas características dos transistores bipolares de junção:

- Aproximação linear das características de base.

$$V_{BE} > 0V$$



Configuração emissor-comum

$$I_E = I_B + I_C$$

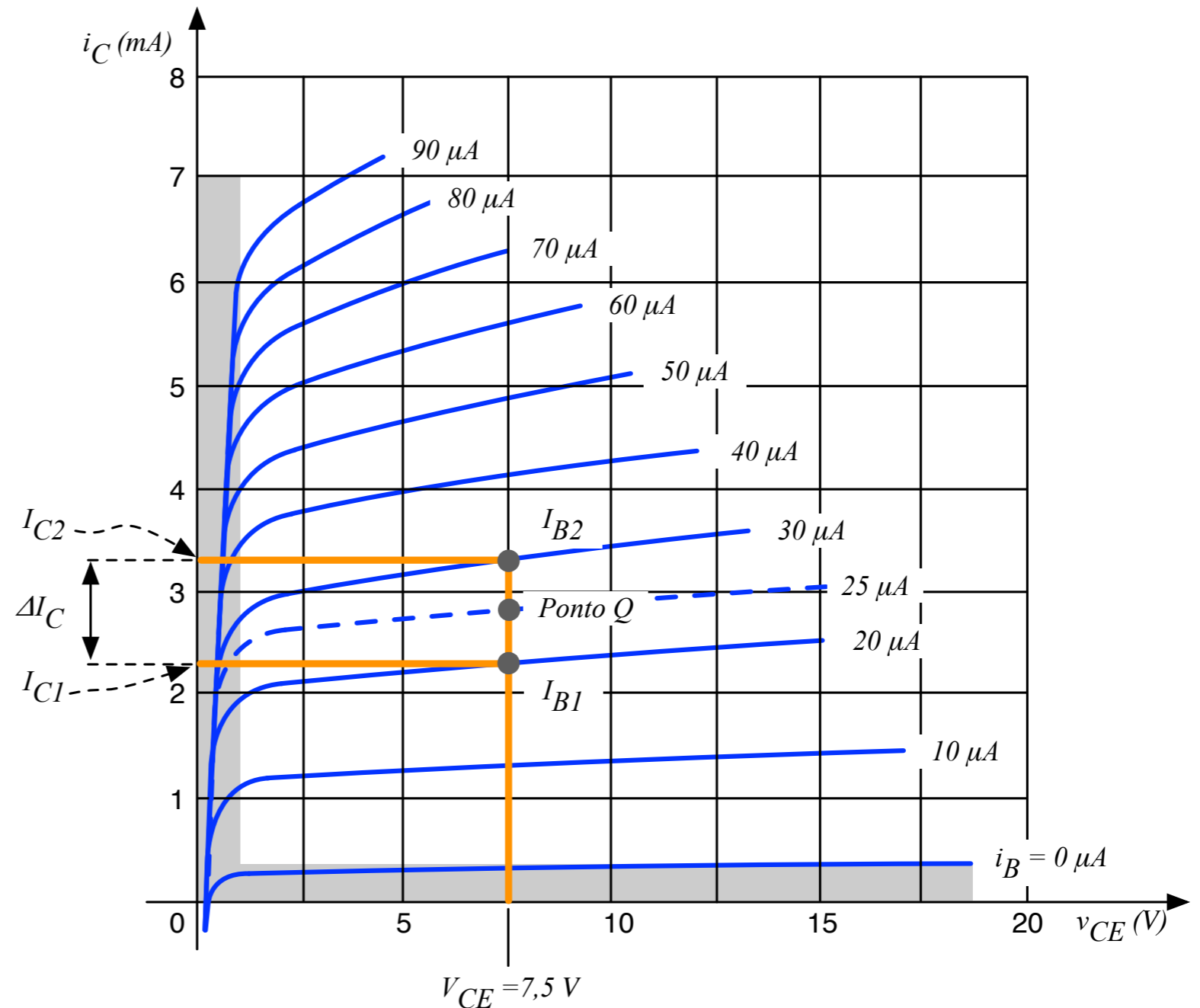
$$I_C = \alpha \cdot I_E$$

$$\beta_{CC} = \frac{I_C}{I_B}$$

Ganho CC

Ganho CA

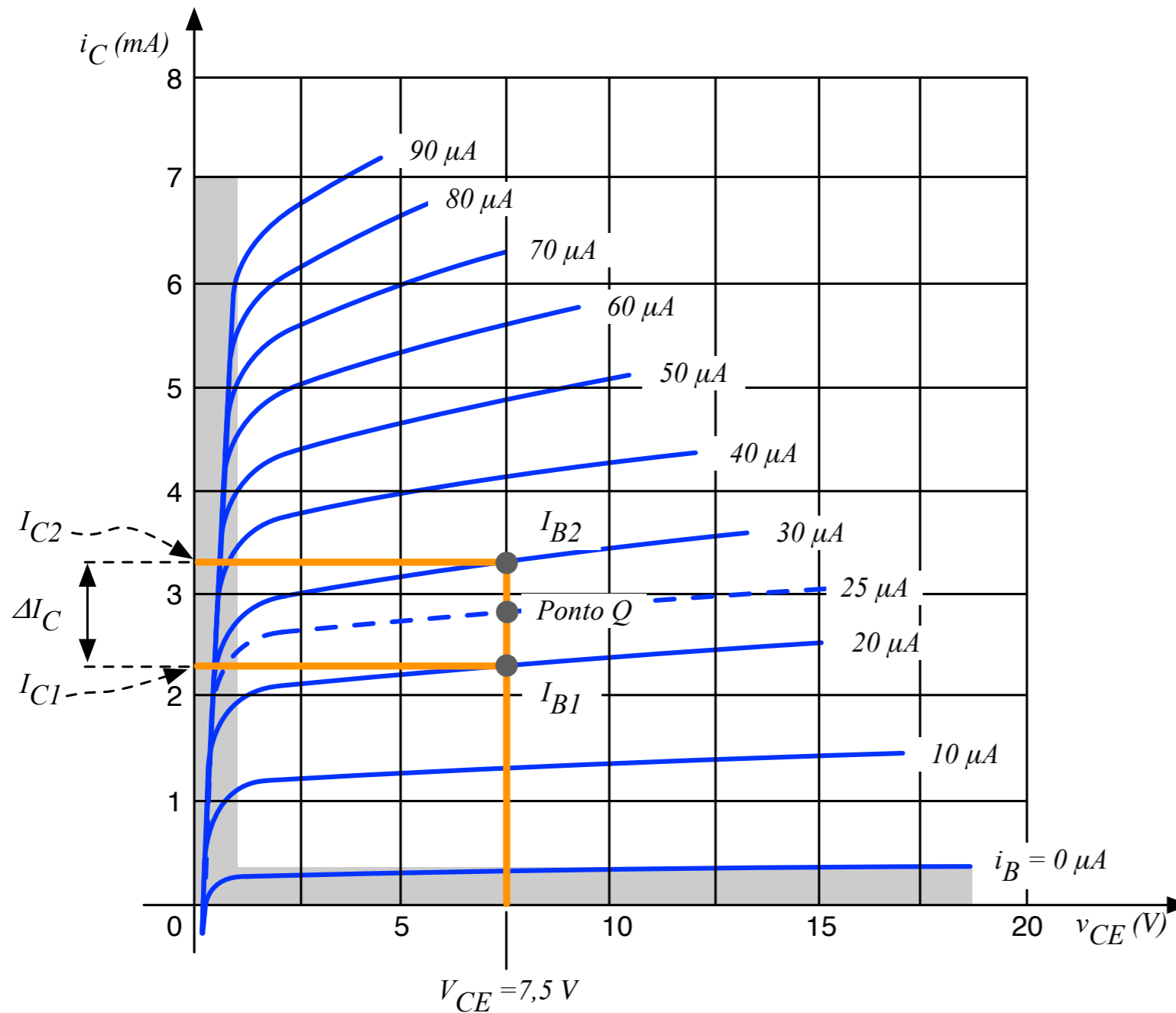
$$\beta_{CA} = \frac{\Delta I_C}{\Delta I_B}$$



Configuração emissor-comum

Correntes e ganhos de um transistor:

- Exemplo:



$$\beta_{CC} = \frac{I_C}{I_B} = \frac{2,7 \text{ mA}}{25 \mu} = 108$$

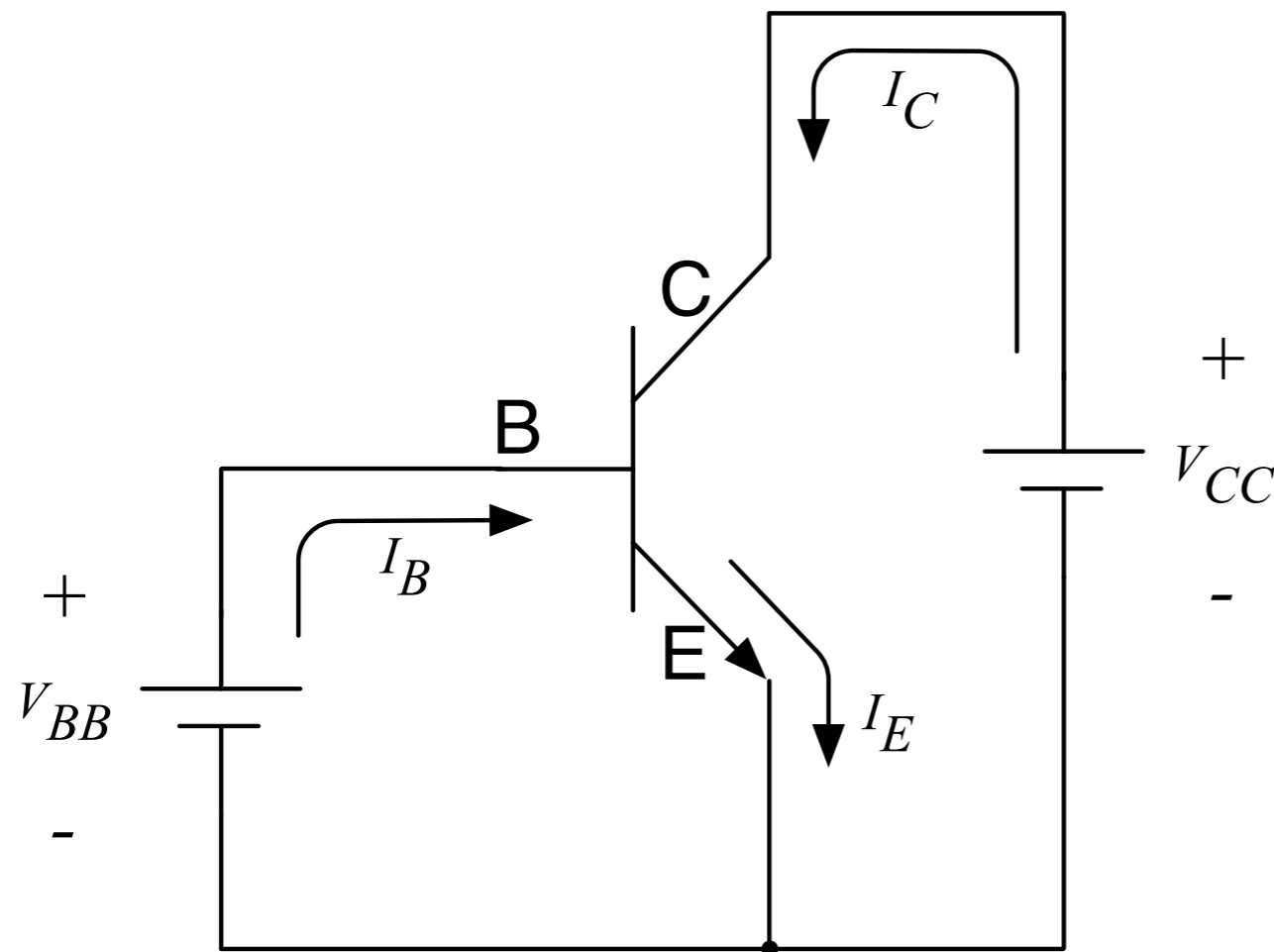
$$\beta_{CA} = \frac{\Delta I_C}{\Delta I_B} = \frac{I_{C2} - I_{C1}}{I_{B2} - I_{B1}}$$

$$\beta_{CA} = \frac{3,2 \text{ mA} - 2,2 \text{ mA}}{30 \mu - 20 \mu} = 100$$

Polarização dos transistores bipolares de junção

Configuração emissor-comum:

- Principais correntes e tensão de polarização entre base e emissor.



$$I_C = \beta \cdot I_B$$

$$I_E = (\beta + 1) \cdot I_B$$

$$V_{BE} \cong 0,7V$$

Limites de operação dos transistores

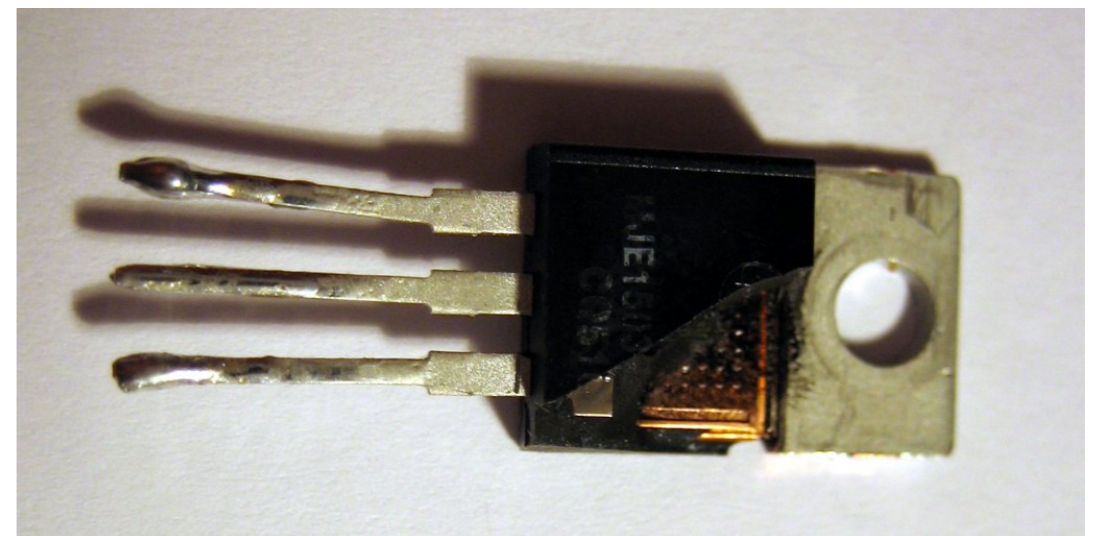
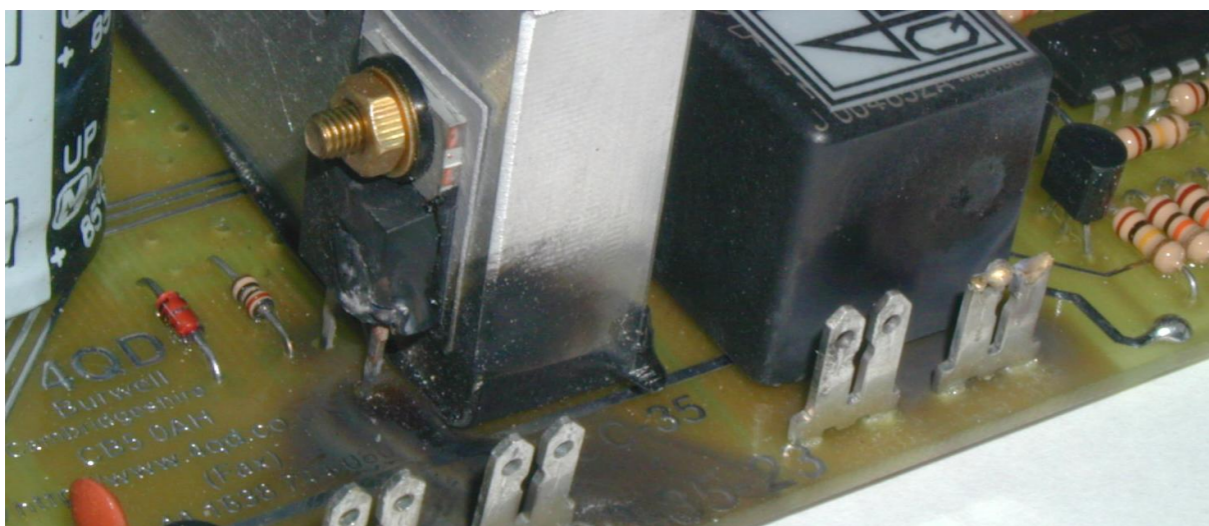
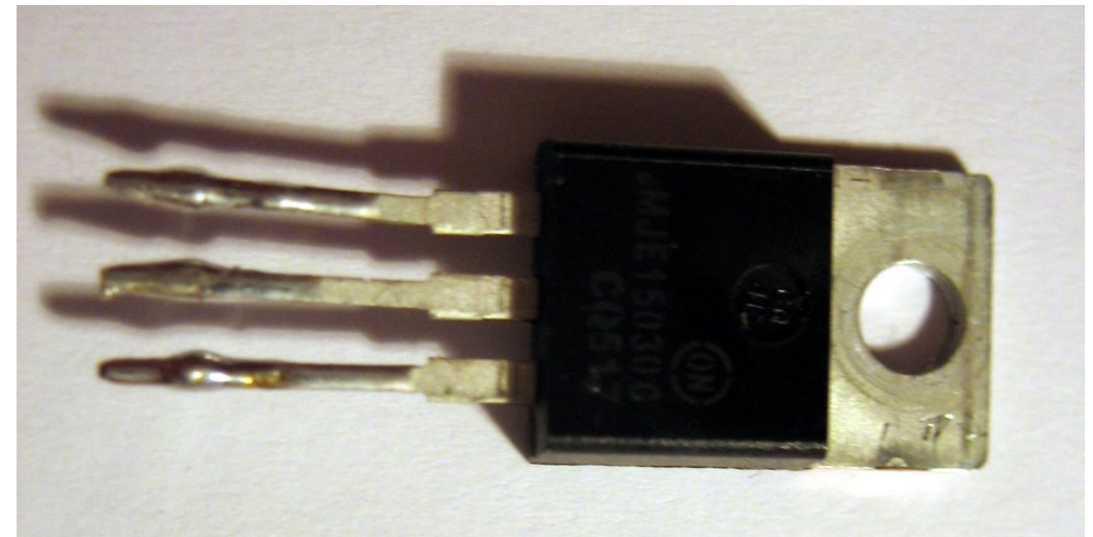
Operação segura de transistores:

$$P_{C(max)} = V_{CE} \cdot I_C$$

$$I_{CE(O)} \leq I_C \leq I_{C(max)}$$

$$V_{CE(sat)} \leq V_{CE} \leq V_{CE(max)}$$

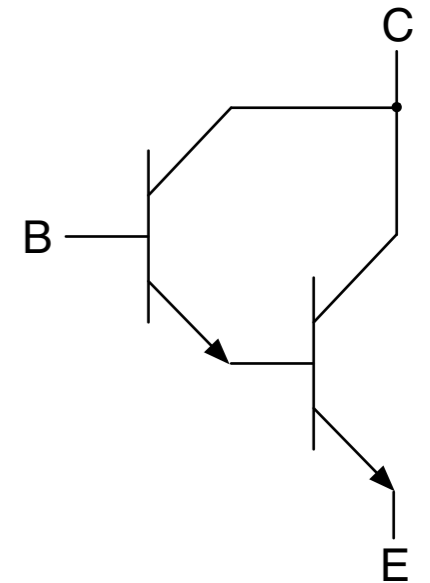
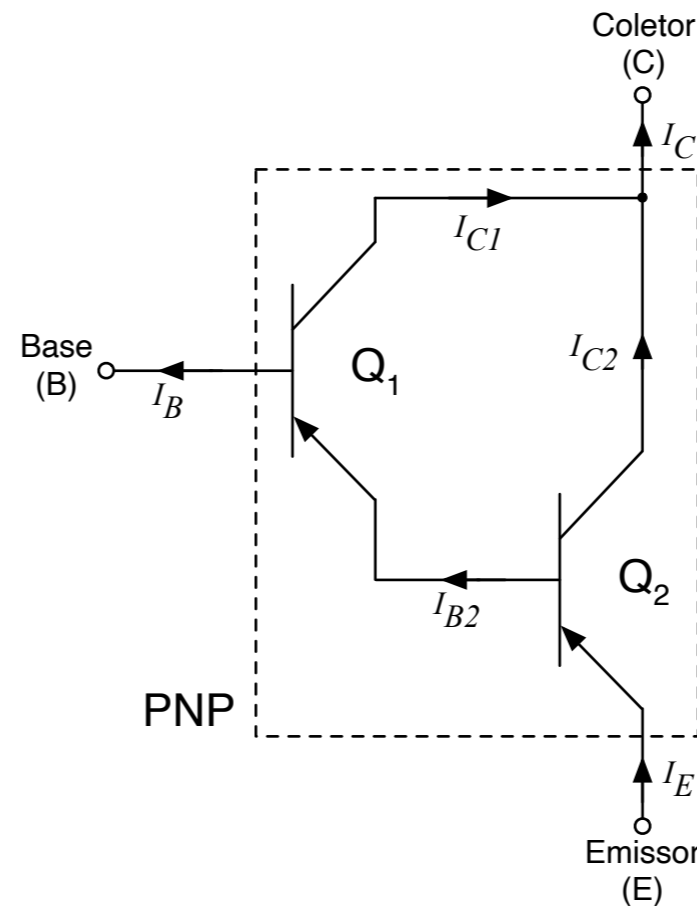
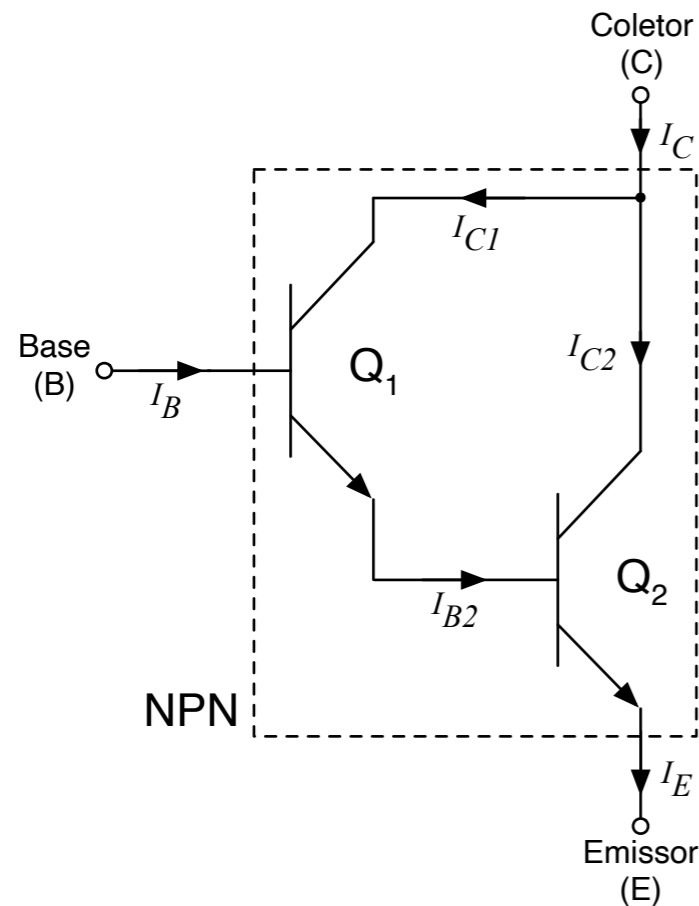
$$V_{CE} \cdot I_C \leq P_{C(max)}$$



Transistores conectados em cascata

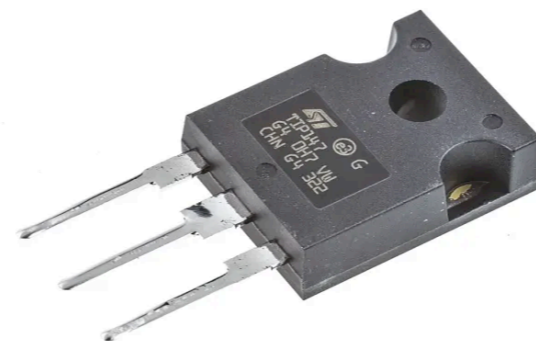
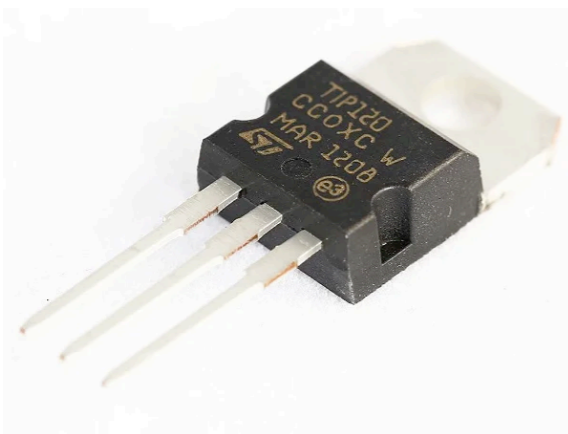
Conexão em cascata de transistores:

- Aumento do ganho do conjunto ($G_{total} = G_1 \times G_2$).



$$\beta_{total} = \beta_1 \cdot \beta_2$$

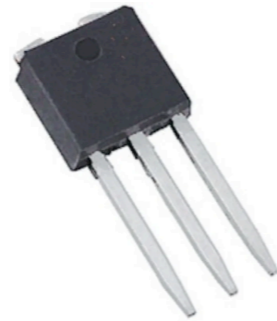
$$I_B = \frac{I_C}{\beta_{total}}$$



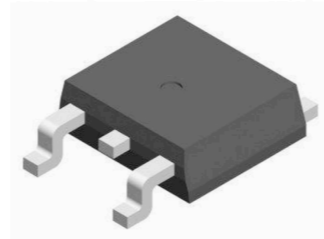
Principais encapsulamentos de transistores



DPAK



IPAK



D²PAK



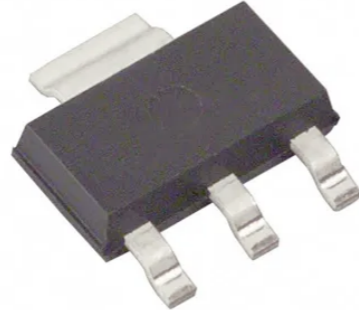
TO-92



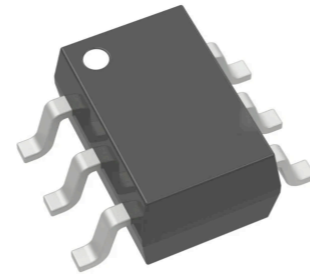
TO-39



TO-3



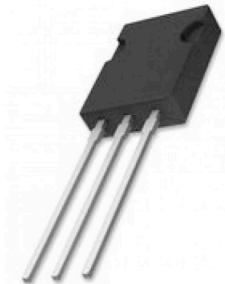
SOT-223



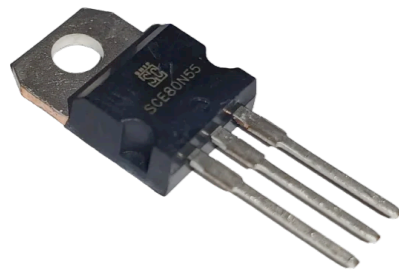
SOT23-6L



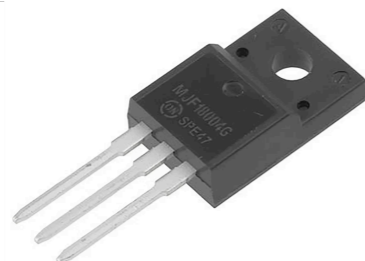
SOT32 / TO-126



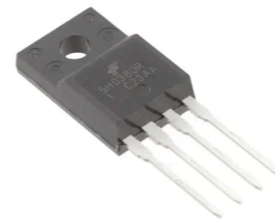
SOT-82



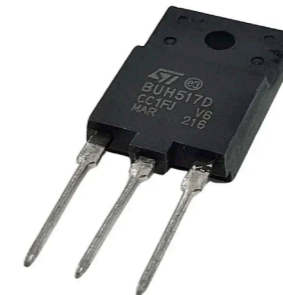
TO-220



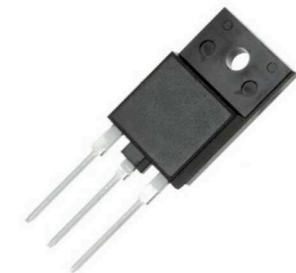
TO-220FP



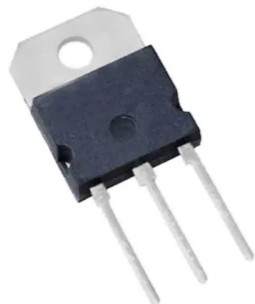
TO-220FH



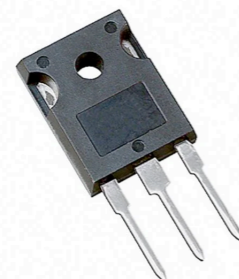
ISOWATT218



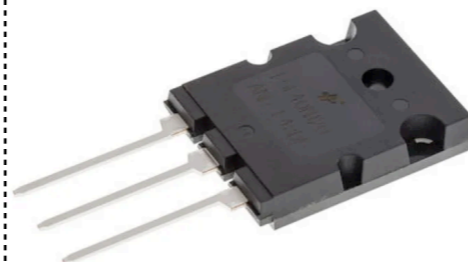
ISOWATT218FX



SOT-93 / TO-218



TO-247



TO-264



ISOTOP



SEMITRANS

Transistores bipolares de junção

Principais informações técnicas do catálogo:

- Tensão entre coletor e emissor;
- Corrente contínua de coletor;
- Corrente máxima de coletor;
- Tensão entre coletor e emissor de saturação;
- Ganho do transistor.

Amplifier Transistors NPN Silicon

MAXIMUM RATINGS

Rating	Symbol	BC337	BC338	Unit
Collector–Emitter Voltage	V_{CEO}	45	25	Vdc
Collector–Base Voltage	V_{CBO}	50	30	Vdc
Emitter–Base Voltage	V_{EBO}	5.0		Vdc
Collector Current – Continuous	I_C	800		mAdc
Total Device Dissipation @ $T_A = 25^\circ\text{C}$ Derate above 25°C	P_D	625	5.0	mW mW/°C
Total Device Dissipation @ $T_C = 25^\circ\text{C}$ Derate above 25°C	P_D	1.5	12	Watt mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–55 to +150		°C

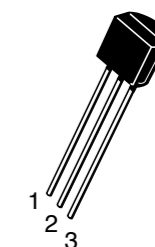
Tensão coletor-emissor →

Corrente contínua de coletor →

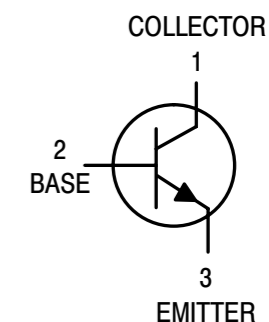
THERMAL CHARACTERISTICS

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

**BC337,
BC337-16,
BC337-25,
BC337-40,
BC338-25**



CASE 29–04, STYLE 17
TO–92 (TO–226AA)



Transistores bipolares de junção

Principais informações técnicas do catálogo:

- Tensão entre coletor e emissor;
- Tensão entre coletor e emissor de saturação;
- Tensão entre base e emissor;
- Corrente contínua de coletor;
- Ganho do transistor.

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

Characteristic	Symbol	Min	Typ	Max	Unit
ON CHARACTERISTICS					
DC Current Gain ($I_C = 100\text{ mA}$, $V_{CE} = 1.0\text{ V}$)	h_{FE}	100	–	630	–
		100	–	250	
		160	–	400	
		250	–	630	
($I_C = 300\text{ mA}$, $V_{CE} = 1.0\text{ V}$)		60	–	–	
Base–Emitter On Voltage ($I_C = 300\text{ mA}$, $V_{CE} = 1.0\text{ V}$)	$V_{BE(on)}$	–	–	1.2	Vdc
Collector–Emitter Saturation Voltage ($I_C = 500\text{ mA}$, $I_B = 50\text{ mA}$)	$V_{CE(sat)}$	–	–	0.7	Vdc
SMALL–SIGNAL CHARACTERISTICS					
Output Capacitance ($V_{CB} = 10\text{ V}$, $I_E = 0$, $f = 1.0\text{ MHz}$)	C_{ob}	–	15	–	pF
Current–Gain – Bandwidth Product ($I_C = 10\text{ mA}$, $V_{CE} = 5.0\text{ V}$, $f = 100\text{ MHz}$)	f_T	–	210	–	MHz

Ganho do transistor →

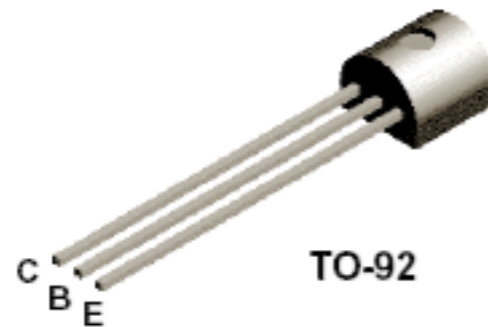
Tensão base-emissor →

Tensão coletor-emissor sat. →

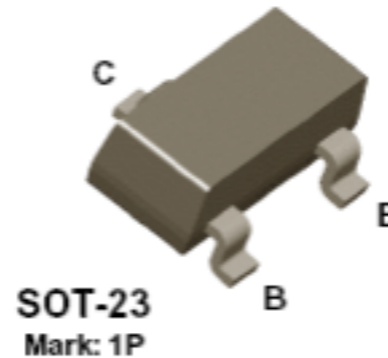
Tipos de transistores

Transistores de uso geral:

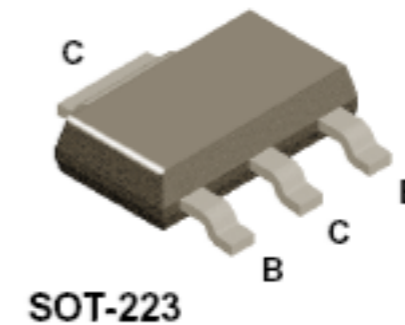
PN2222A



MMBT2222A



PZT2222A



NPN General Purpose Amplifier

This device is for use as a medium power amplifier and switch requiring collector currents up to 500 mA. Sourced from Process 19.

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V _{CE0}	Collector-Emitter Voltage	40	V
V _{CB0}	Collector-Base Voltage	75	V
V _{EB0}	Emitter-Base Voltage	6.0	V
I _C	Collector Current - Continuous	1.0	A
T _J , T _{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

Tipos de transistores

Transistores de uso geral:

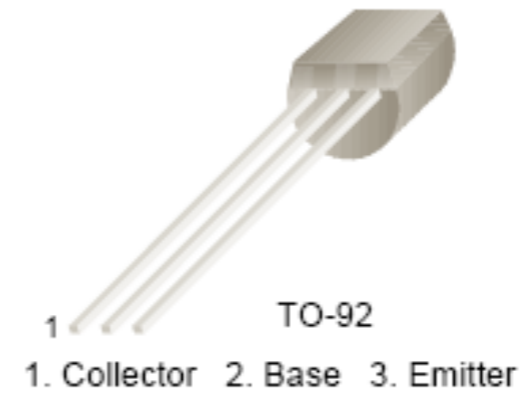
Pares complementares

BC546/547/548/549/550

Switching and Applications

- High Voltage: BC546, $V_{CEO}=65V$
- Low Noise: BC549, BC550
- Complement to BC556 ... BC560

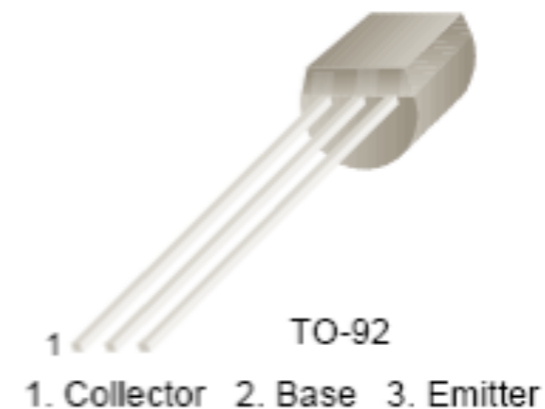
NPN Epitaxial Silicon Transistor



BC556/557/558/559/560

Switching and Amplifier

- High Voltage: BC556, $V_{CEO} = -65V$
- Low Noise: BC559, BC560
- Complement to BC546 ... BC 550



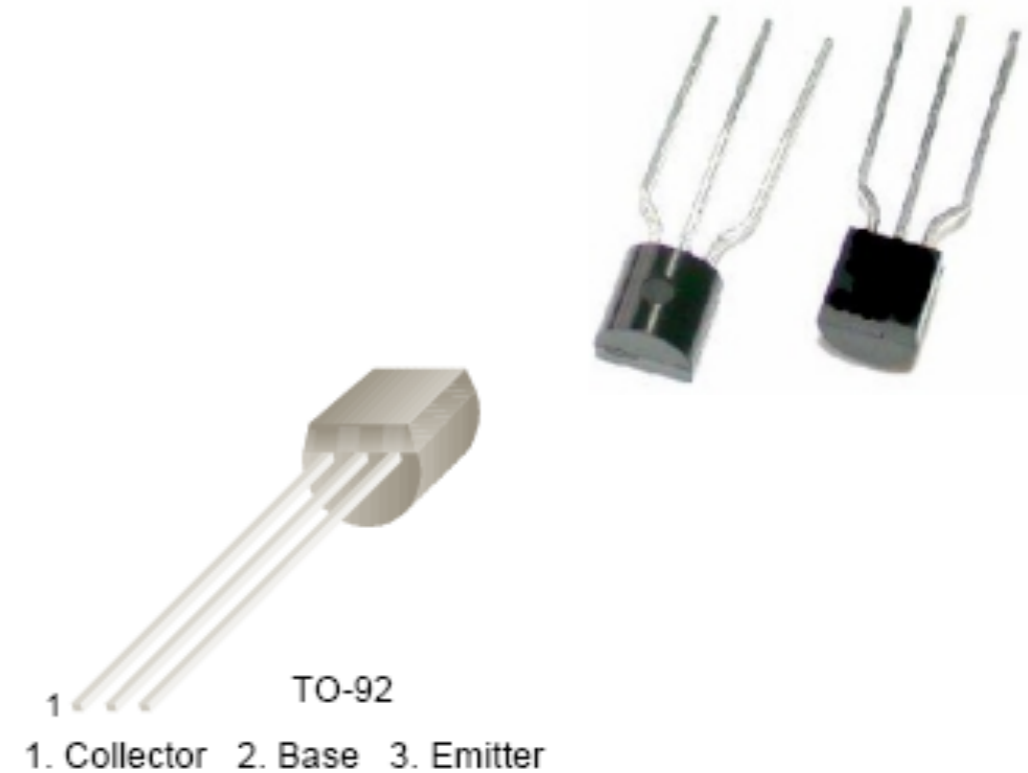
Tipos de transistores

Transistores de uso geral:

BC337/338

Switching and Amplifier Applications

- Suitable for AF-Driver stages and low power output stages
- Complement to BC327/BC328



NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings $T_a=25^\circ\text{C}$ unless otherwise noted

Symbol	Parameter	Value	Units
V_{CES}	Collector-Emitter Voltage		
	: BC337	50	V
	: BC338	30	V
V_{CEO}	Collector-Emitter Voltage		
	: BC337	45	V
	: BC338	25	V
V_{EBO}	Emitter-Base Voltage	5	V
I_C	Collector Current (DC)	800	mA
P_C	Collector Power Dissipation	625	mW
T_J	Junction Temperature	150	$^\circ\text{C}$
T_{STG}	Storage Temperature	-55 ~ 150	$^\circ\text{C}$

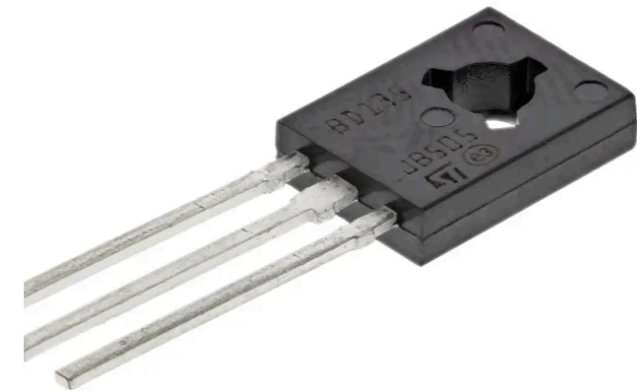
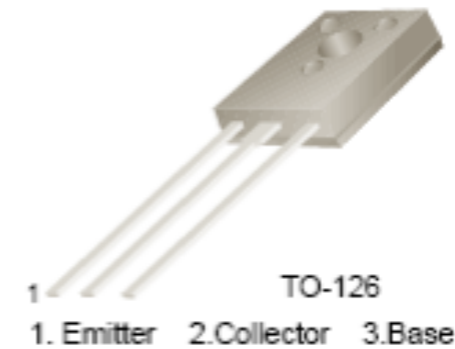
Tipos de transistores

Transistores de média potência:

BD135/137/139

Medium Power Linear and Switching Applications

- Complement to BD136, BD138 and BD140 respectively



NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings $T_C=25^\circ\text{C}$ unless otherwise noted

Symbol	Parameter	Value	Units
V_{CB0}	Collector-Base Voltage : BD135	45	V
	: BD137	60	V
	: BD139	80	V
V_{CE0}	Collector-Emitter Voltage : BD135	45	V
	: BD137	60	V
	: BD139	80	V
V_{EB0}	Emitter-Base Voltage	5	V
I_C	Collector Current (DC)	1.5	A
I_{CP}	Collector Current (Pulse)	3.0	A
I_B	Base Current	0.5	A
P_C	Collector Dissipation ($T_C=25^\circ\text{C}$)	12.5	W
P_C	Collector Dissipation ($T_a=25^\circ\text{C}$)	1.25	W
T_J	Junction Temperature	150	$^\circ\text{C}$
T_{STG}	Storage Temperature	- 55 ~ 150	$^\circ\text{C}$

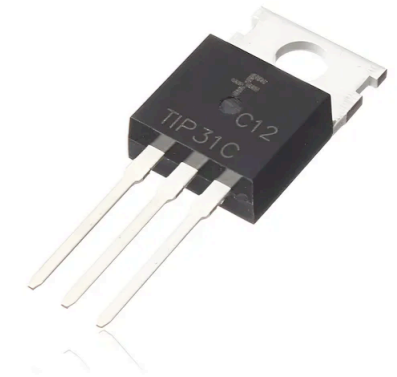
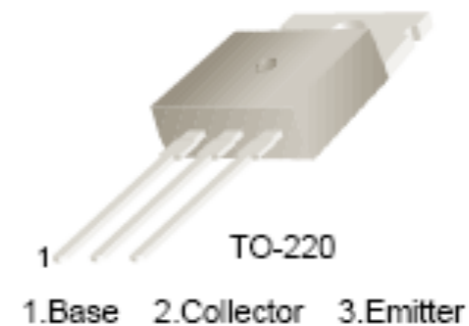
Tipos de transistores

Transistores de média potência:

TIP31 Series(TIP31/31A/31B/31C)

Medium Power Linear Switching Applications

- Complementary to TIP32/32A/32B/32C



NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings $T_C=25^\circ\text{C}$ unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage : TIP31	40	V
	: TIP31A	60	V
	: TIP31B	80	V
	: TIP31C	100	V
V_{CEO}	Collector-Emitter Voltage : TIP31	40	V
	: TIP31A	60	V
	: TIP31B	80	V
	: TIP31C	100	V
V_{EBO}	Emitter-Base Voltage	5	V
I_C	Collector Current (DC)	3	A
I_{CP}	Collector Current (Pulse)	5	A
I_B	Base Current	1	A
P_C	Collector Dissipation ($T_C=25^\circ\text{C}$)	40	W
P_C	Collector Dissipation ($T_a=25^\circ\text{C}$)	2	W
T_J	Junction Temperature	150	$^\circ\text{C}$
T_{STG}	Storage Temperature	- 65 ~ 150	$^\circ\text{C}$

Tipos de transistores

Transistores SMD (Surface Mounted Device):

BC846 to BC849

Vishay Semiconductors



Absolute Maximum Ratings

$T_{amb} = 25\text{ }^{\circ}\text{C}$, unless otherwise specified

Parameter	Test condition	Part	Symbol	Value	Unit
Collector - base voltage		BC846	V_{CBO}	80	V
		BC847	V_{CBO}	50	V
		BC848	V_{CBO}	30	V
		BC849	V_{CBO}	30	V
Collector - emitter voltage		BC846	V_{CES}	80	V
		BC847	V_{CES}	50	V
		BC848	V_{CES}	30	V
		BC849	V_{CES}	30	V
		BC846	V_{CEO}	65	V
		BC847	V_{CEO}	45	V
		BC848	V_{CEO}	30	V
Emitter - base voltage		BC846	V_{EBO}	6	V
		BC847	V_{EBO}	6	V
		BC848	V_{EBO}	5	V
		BC849	V_{EBO}	5	V
Collector current			I_C	100	mA
Collector peak current			I_{CM}	200	mA
Peak base current			I_{BM}	200	mA
Peak emitter current			$-I_{EM}$	200	mA
Power dissipation	$T_{amb} = 25\text{ }^{\circ}\text{C}$		P_{tot}	310 ¹⁾	mW



Tipos de transistores

Transistores de alta potência:

onsemi™

DATA SHEET

www.onsemi.com

Complementary Silicon Power Transistors

2N3055(NPN), MJ2955(PNP)

Complementary silicon power transistors are designed for general-purpose switching and amplifier applications.

Features

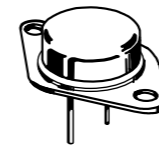
- DC Current Gain – $h_{FE} = 20-70 @ I_C = 4 \text{ A dc}$
- Collector–Emitter Saturation Voltage –
 $V_{CE(sat)} = 1.1 \text{ Vdc (Max) @ } I_C = 4 \text{ A dc}$
- Excellent Safe Operating Area
- Pb–Free Packages are Available*

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector–Emitter Voltage	V_{CEO}	60	Vdc
Collector–Emitter Voltage	V_{CER}	70	Vdc
Collector–Base Voltage	V_{CB}	100	Vdc
Emitter–Base Voltage	V_{EB}	7	Vdc
Collector Current – Continuous	I_C	15	A dc
Base Current	I_B	7	A dc
Total Power Dissipation @ $T_C = 25^\circ\text{C}$ Derate Above 25°C	P_D	115 0.657	W W/ $^\circ\text{C}$
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +200	$^\circ\text{C}$

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

15 AMPERE
POWER TRANSISTORS
COMPLEMENTARY SILICON
60 VOLTS, 115 WATTS



TO-204AA (TO-3)
CASE 1-07
STYLE 1

MARKING DIAGRAM



xxxx55 = Device Code
xxxx = 2N30 or MJ20
G = Pb–Free Package
A = Location Code
YY = Year
WW = Work Week
MEX = Country of Origin

ORDERING INFORMATION



Tipos de transistores

Transistores para rádio-frequência:

BF959

VHF Transistor

NPN Silicon

Features

- Pb-Free Packages are Available*

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CE0}	20	Vdc
Collector-Base Voltage	V_{CB0}	30	Vdc
Emitter-Base Voltage	V_{EB0}	3.0	Vdc
Collector Current - Continuous	I_C	100	mAdc
Total Device Dissipation @ $T_A = 25^\circ\text{C}$ Derate above 25°C	P_D	625 5.0	mW mW/°C
Total Device Dissipation @ $T_C = 25^\circ\text{C}$ Derate above 25°C	P_D	1.5 12	W mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-55 to +150	°C

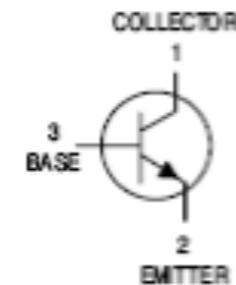
THERMAL CHARACTERISTICS

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



ON Semiconductor®

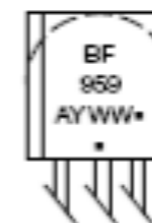
<http://onsemi.com>



MARKING DIAGRAM



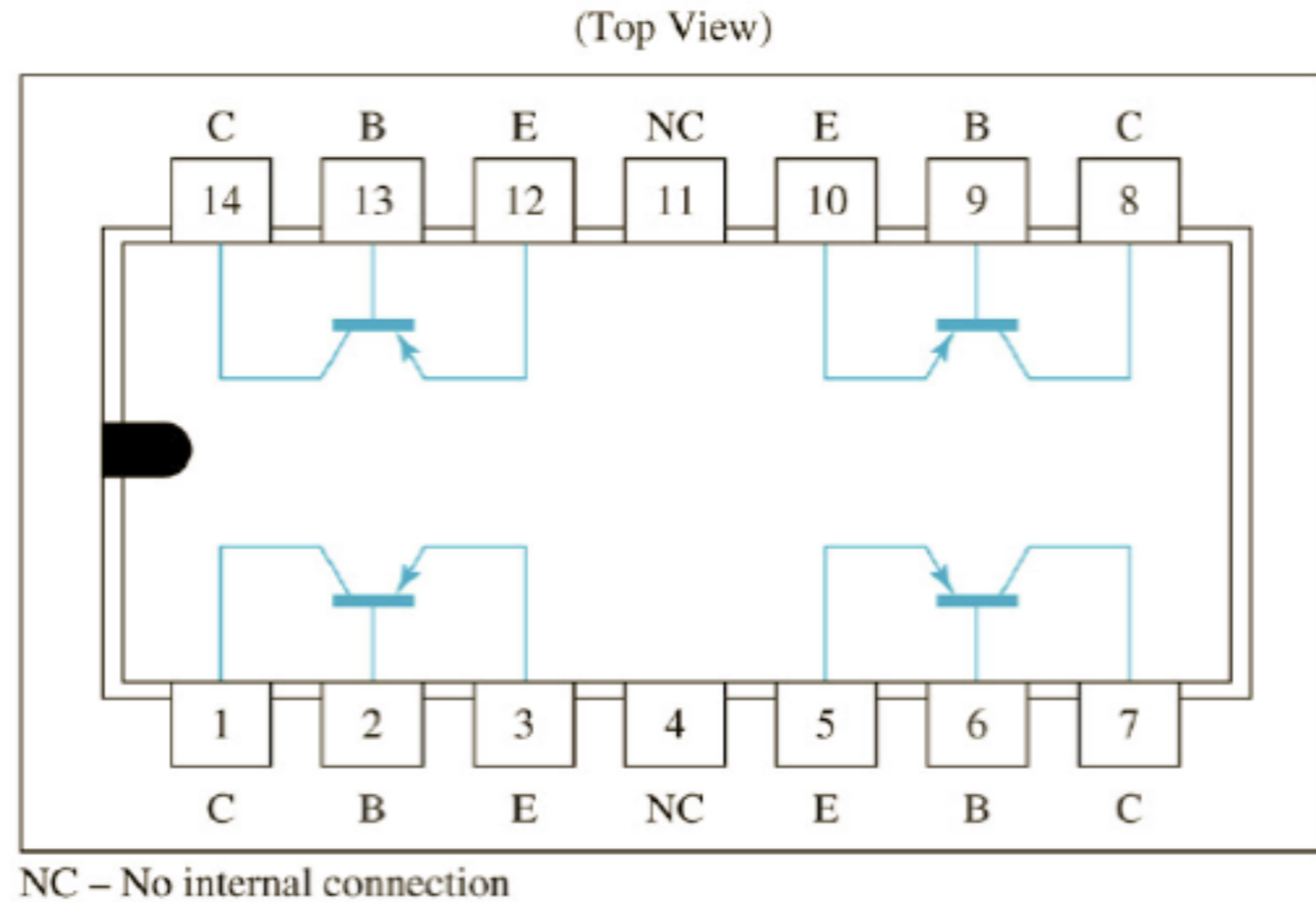
TO-92
CASE 29
STYLE 21



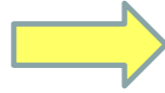
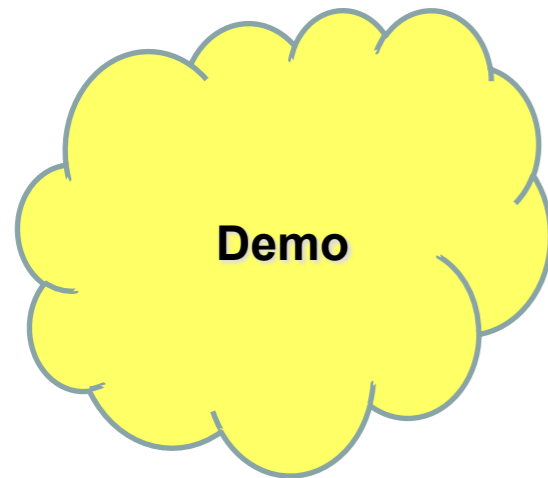
- BF959 = Device Code
- A = Assembly Location
- Y = Year
- WW = Work Week
- = Pb-Free Package

Tipos de transistores

Transistores integrados:



Transistores bipolares de junção



Demo:

- Teste de transistores.

Próxima Aula

Polarização de transistores bipolares de junção

