

Centro Federal de Educação Tecnológica de Santa Catarina
Departamento de Eletrônica
Eletrônica Básica



Transistores Bipolares de Junção

Prof. Clóvis Antônio Petry.

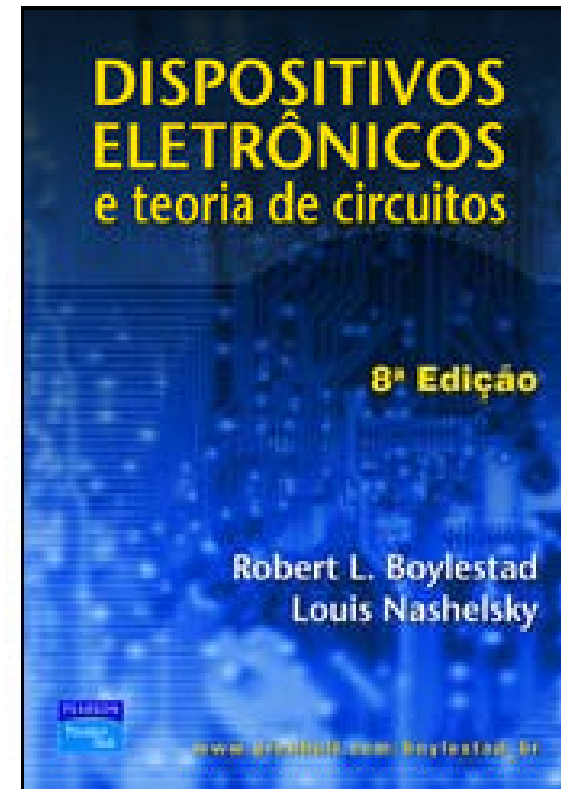
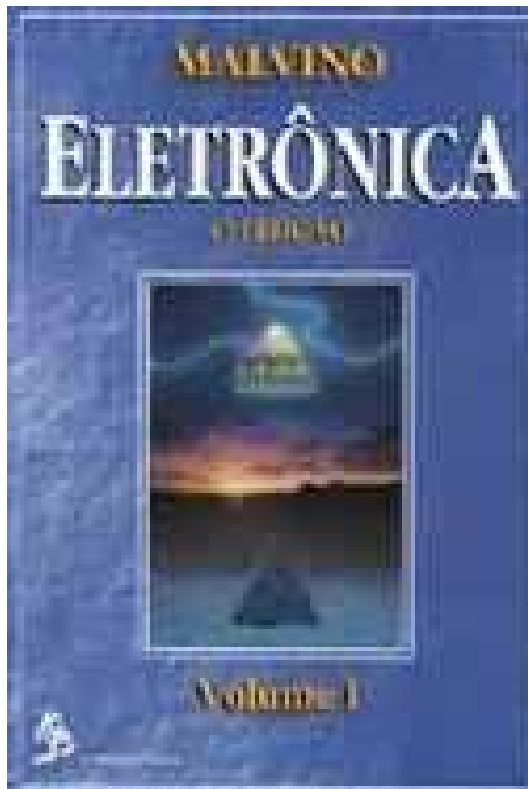
Florianópolis, outubro de 2007.

Nesta aula

Seqüência de conteúdos:

1. Introdução;
2. Construção dos transistores;
3. Operação 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.

Bibliografia



Introdução

Histórico:

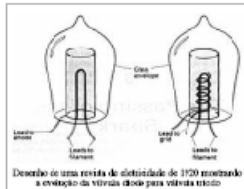
- Diodo a válvula – 1904 por J. A. Fleming;
- Triodo a válvula – 1906 por Lee De Forest;
- Transistor – 1947 por Walter H. Brattain e John Bardeen.
- Posteriormente: Mosfet, IGBT, Silicon Carbide, etc.

Do Transistor ao Microprocessador

Envido L. M. Mehl

1. Válvulas sem vácuo

Nos primórdios da eletrônica tinha-se duas possibilidades para regular uma corrente alternada: uma delas era usando-se uma válvula-diodo e outra, empregando diodos de ânodo de cobre ou óxido de selênio. Porém colocando-se uma grade metálica entre o cátodo e o ânodo de uma válvula, criou-se uma nova espécie de válvula, chamada triodo, com a qual é possível controlar o fluxo de corrente através do dispositivo. Dessa forma, é óbvio que desde os primórdios da eletrônica tinha-se tentado o desenvolvimento de um "triodo sem vácuo", fazendo-se um paralelo entre os triodos-diodos e os diodos de cobre e óxido de selênio. Nesse sentido durante a década de 1920 foram registradas diversas patentes de invenções de "tíodos sólidos", porém sem que tivessem dado origem a dispositivos concretos.

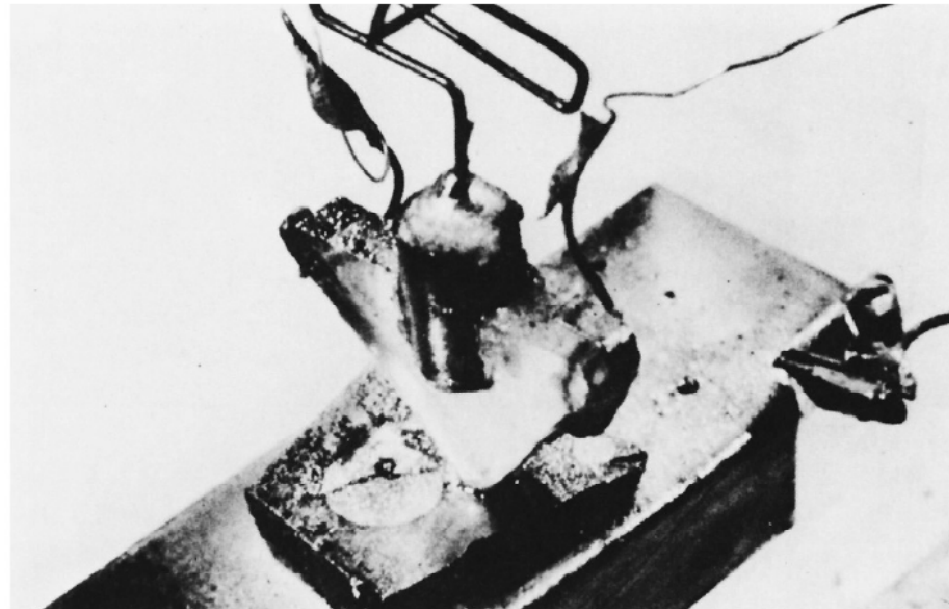


Frente a isso, porém, é até estranho que a invenção do transistor tenha sido sua origem em uma área de pesquisa relativamente distinta, ligada ao desenvolvimento do radar. Ao contrário do que costuma-se imaginar, o transistor surgiu como resultado de estudos feitos no âmbito das cristais de germânio e de silício como detectores de radar e sobre esse fato explica porque a principal motivação para a invenção do transistor não foi a criação de um novo dispositivo. Também é interessante observar que o transistor, ao contrário de outras descobertas, não é propriamente um "produto de guerra", mas sua invenção ocorreu imediatamente após a Segunda Guerra Mundial, como uma espécie de consequência da disponibilidade de cristais de germânio altamente purificados produzidos como um subproduto.

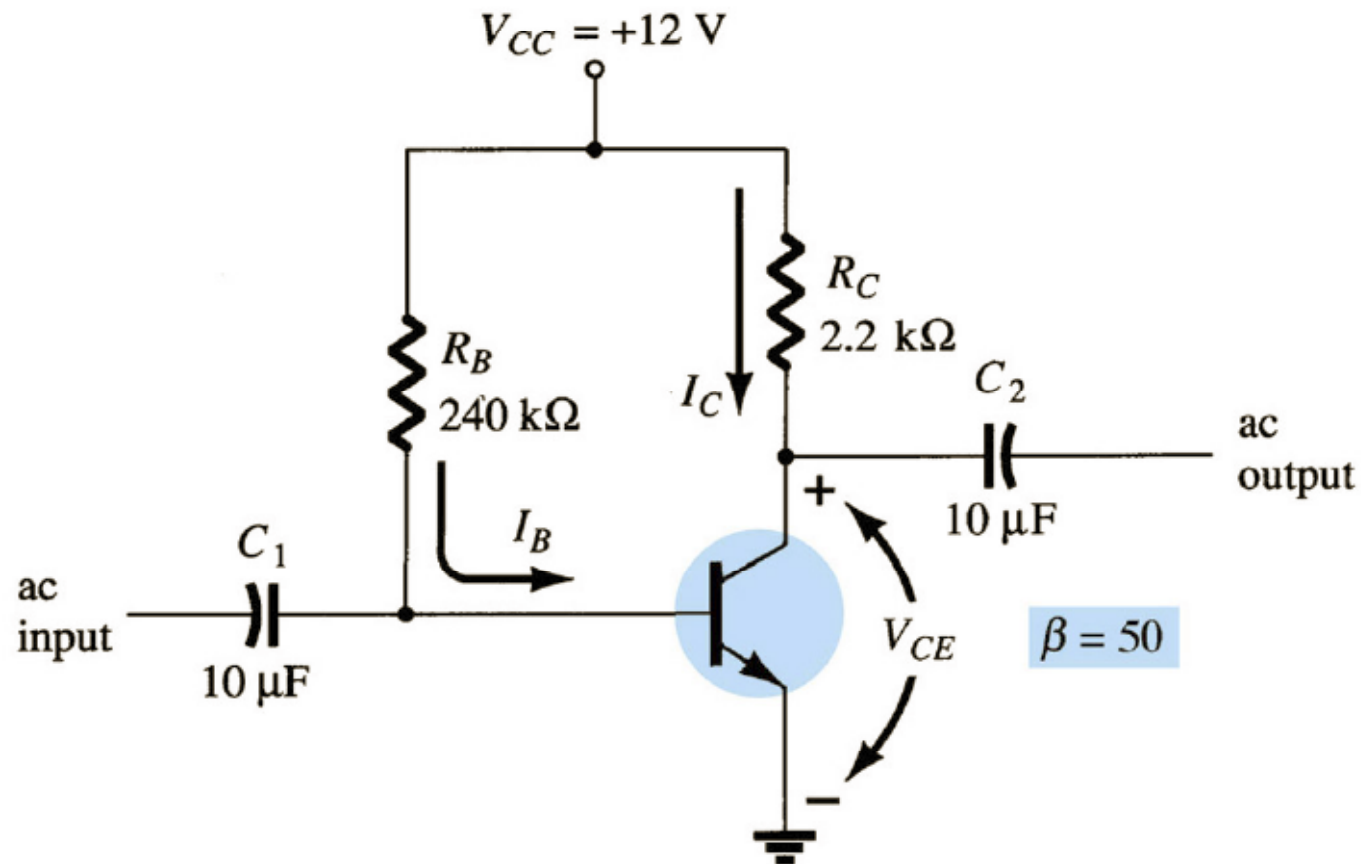
A invenção do transistor está intimamente ligada à instituição onde ele "nasceu": o laboratório de pesquisas da empresa Bell Telephone, conhecida como Bell Labs. Assim não é coincidência que o primeiro personagem de importância para a história do transistor é justamente um engenheiro que trabalhou nesse centro de pesquisa desde a sua fundação até se aposentar. George Clark Southworth (1895-1977) nasceu no estado norte-americano da Pensilvânia e formou-se no Grove City College, onde fez também curso de Engenharia. Posteriormente na Yale University obteve seu título de Ph.D. No Bell Labs ele trabalhou com guias para microondas e dessa forma acabou de fazer parte do desenvolvimento de radar, durante a Segunda Guerra Mundial.



Para verificar que as válvulas triodos funcionavam bem como detectores de ondas de rádio mais sensíveis do que os detectores de radar, Southworth resolveu experimentar no arduo os mesmos cristais que eram usados nos primeiros receptores de rádio. Esses rádios, chamados de "radio-germânio" usavam como detector um pequeno pedaço de um minério cristalino de chumbo e selênio (PbSe), conhecido pelos geólogos como galena. Tais receptores já se saíram ultrapassados nessa época e dessa forma Southworth teve que obter cristais de galena refinados de antigos receptores de rádio que encontrou em lojas de artigos de segunda mão na cidade de Nova York.

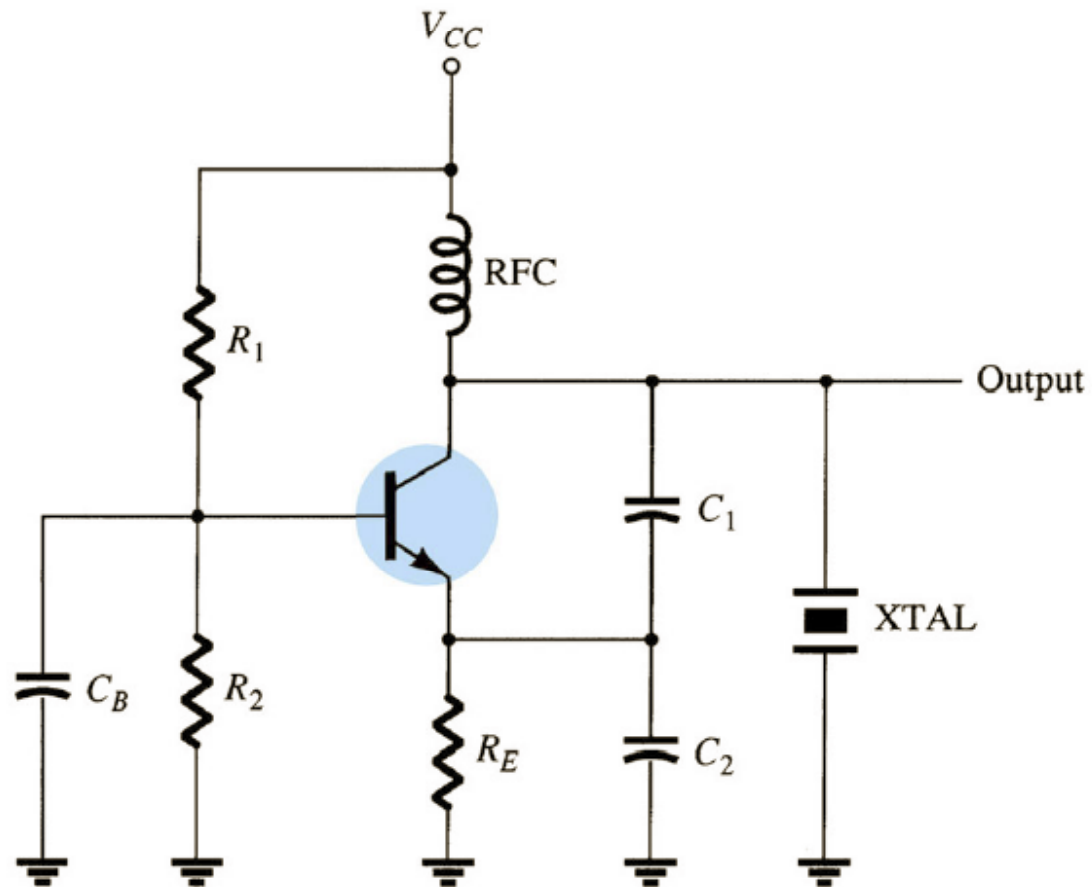


Introdução



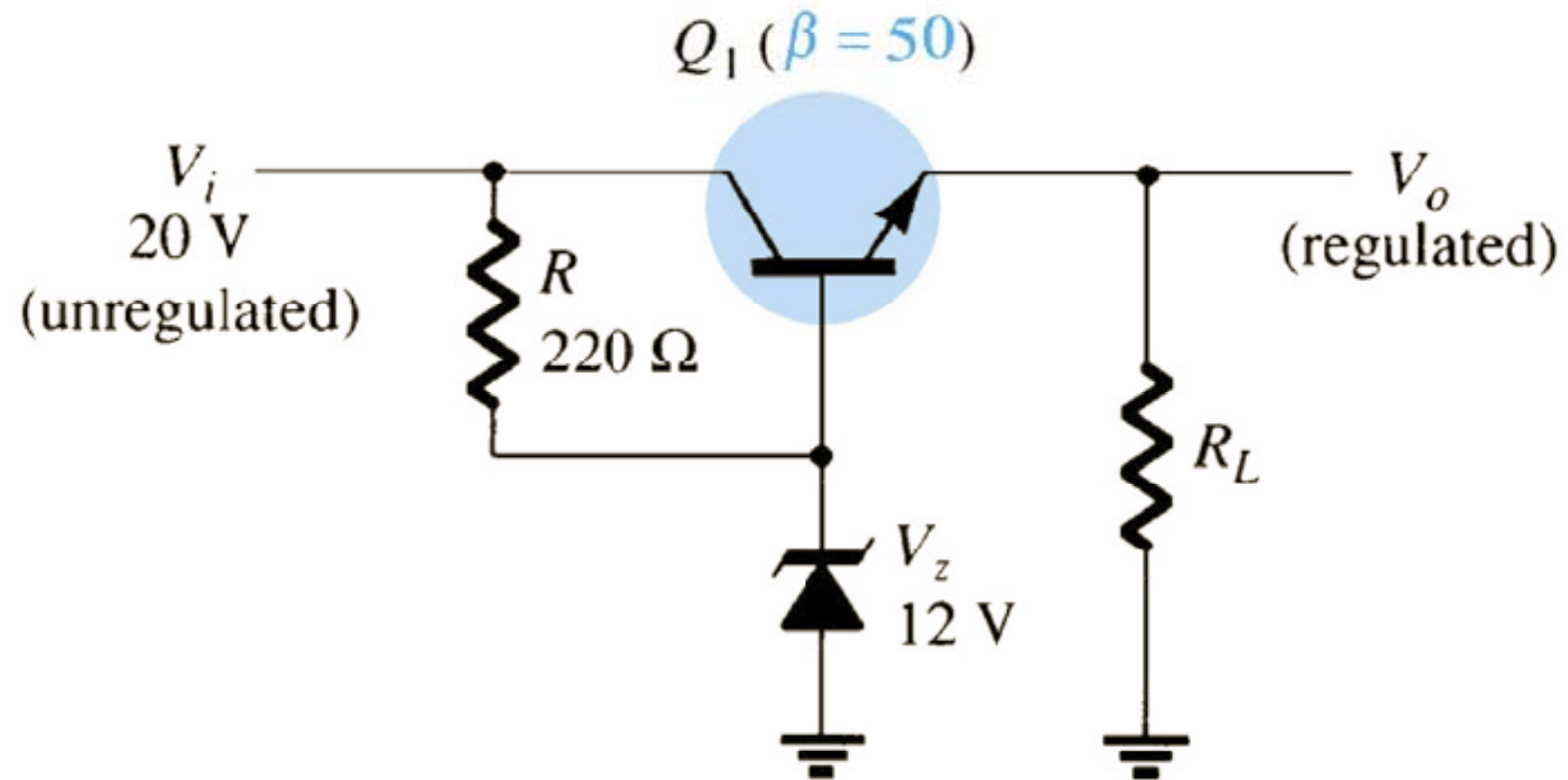
Amplificador com transistor bipolar.

Introdução



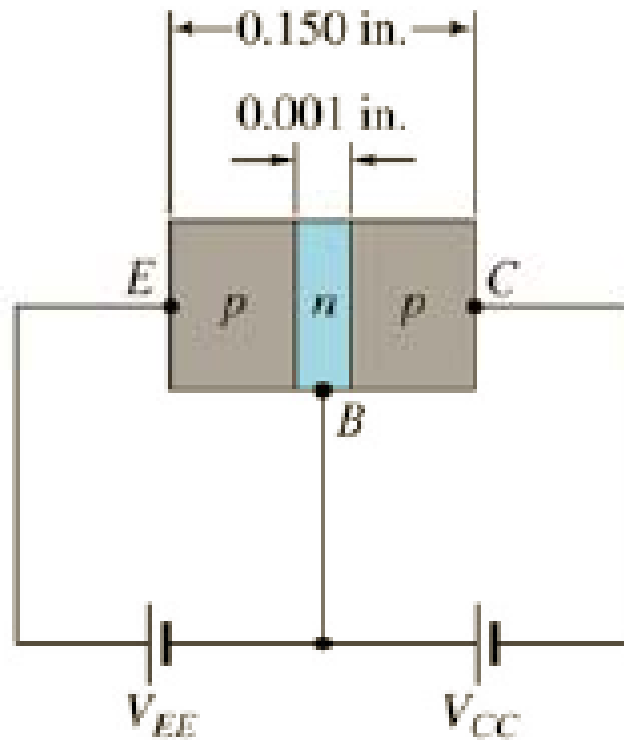
Oscilador controlado a cristal.

Introdução

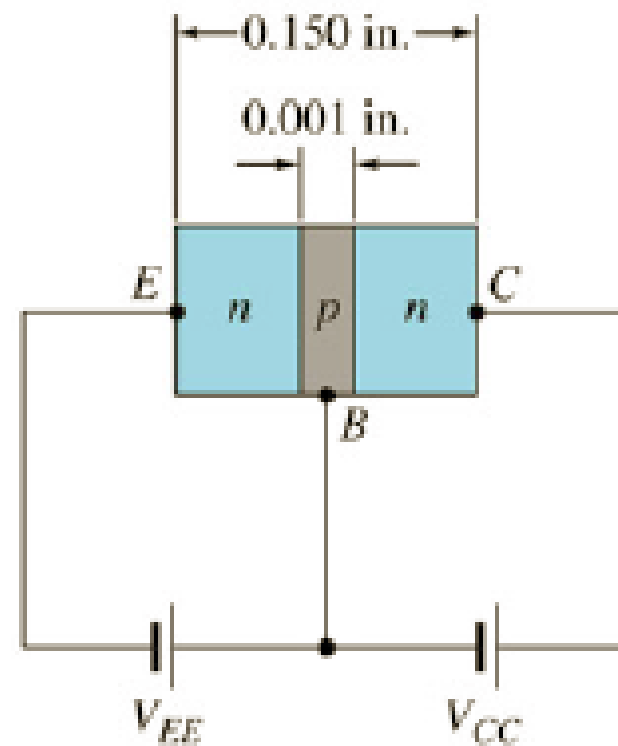


Regulador de tensão com transistor bipolar.

Construção do transistor



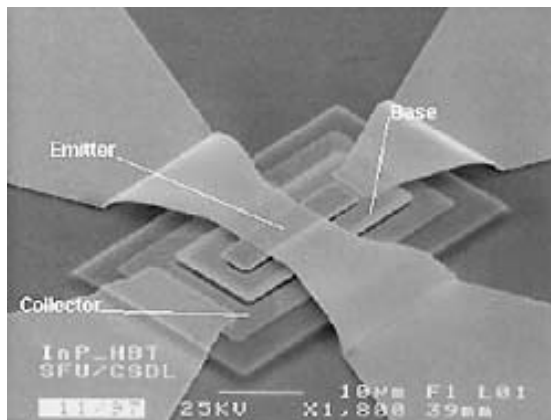
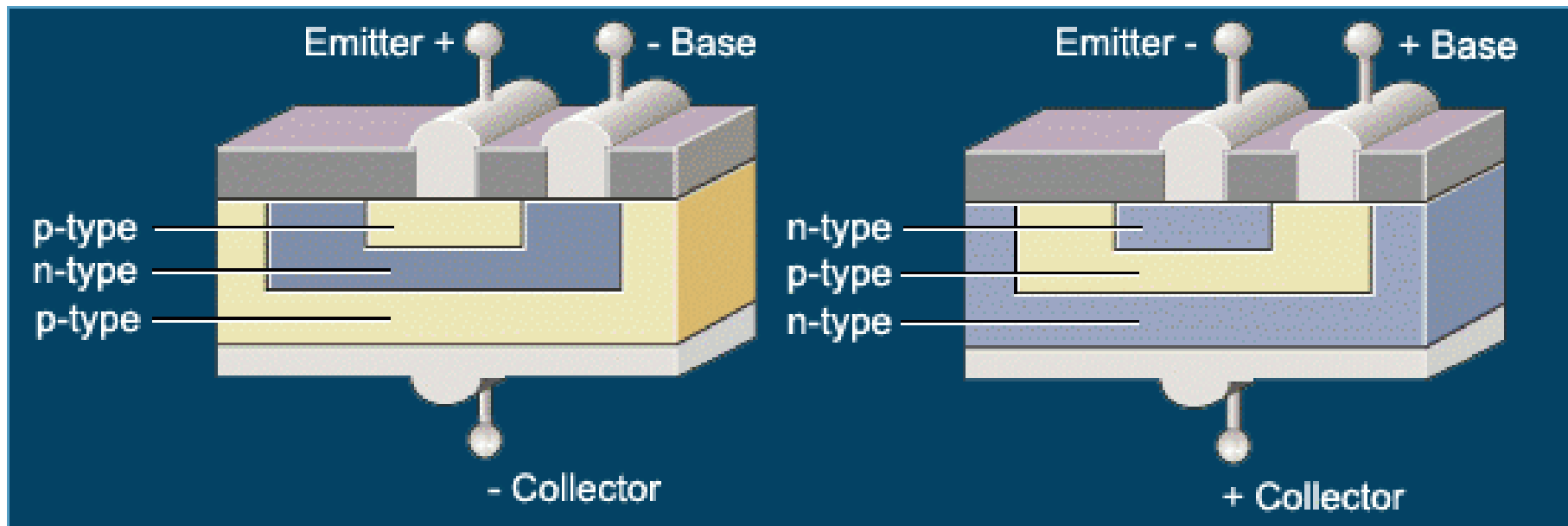
PNP



NPN

BJT – Transistor Bipolar de Junção: Lacunas e elétrons formam as correntes.

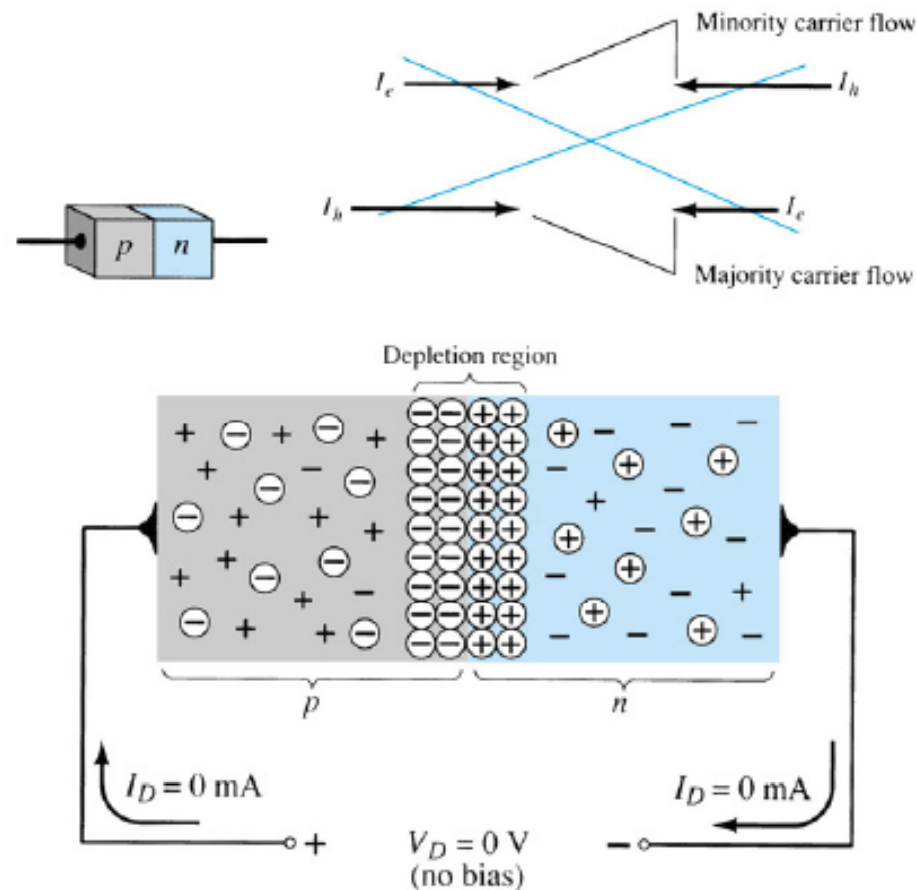
Construção do transistor



Operação do transistor

Relembrando os diodos:

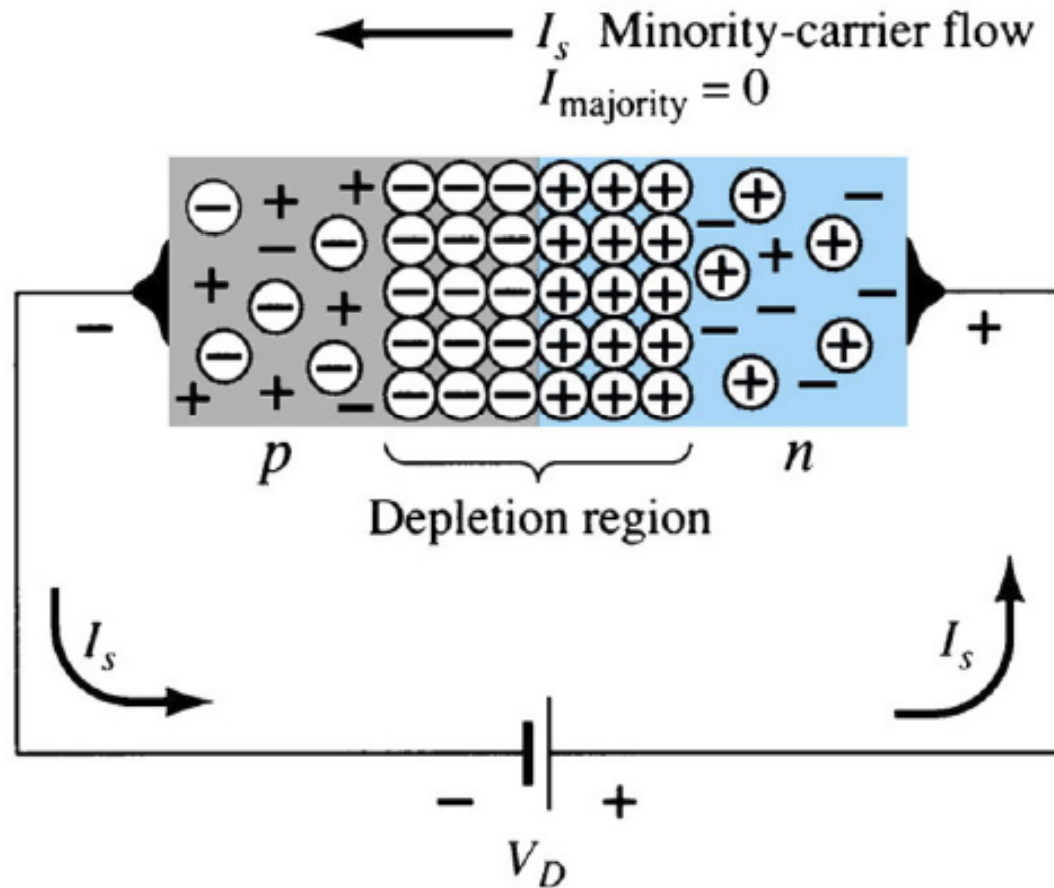
$$V_D = 0V$$



Operação do transistor

Relembrando os diodos:

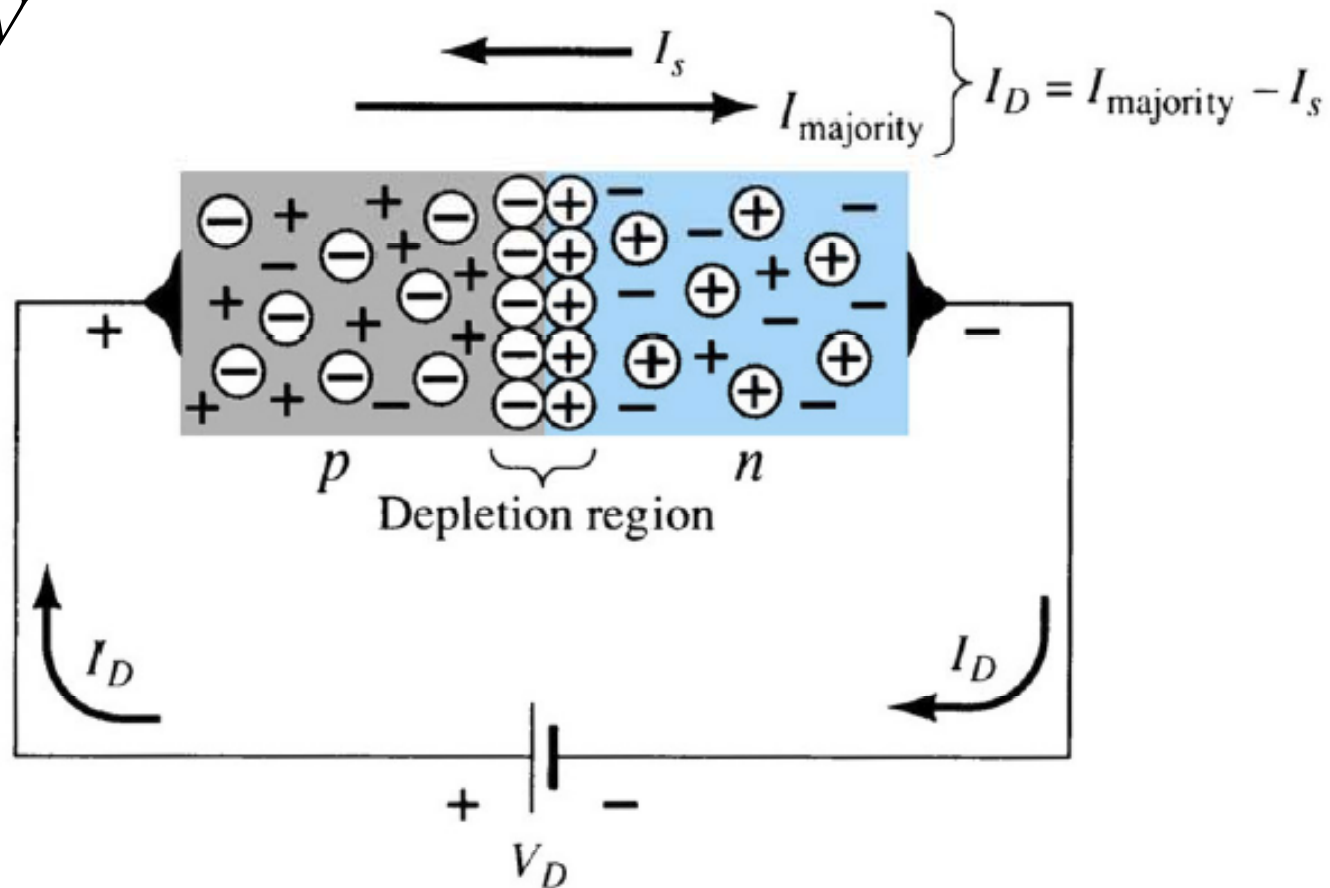
$$V_D < 0V$$



Operação do transistor

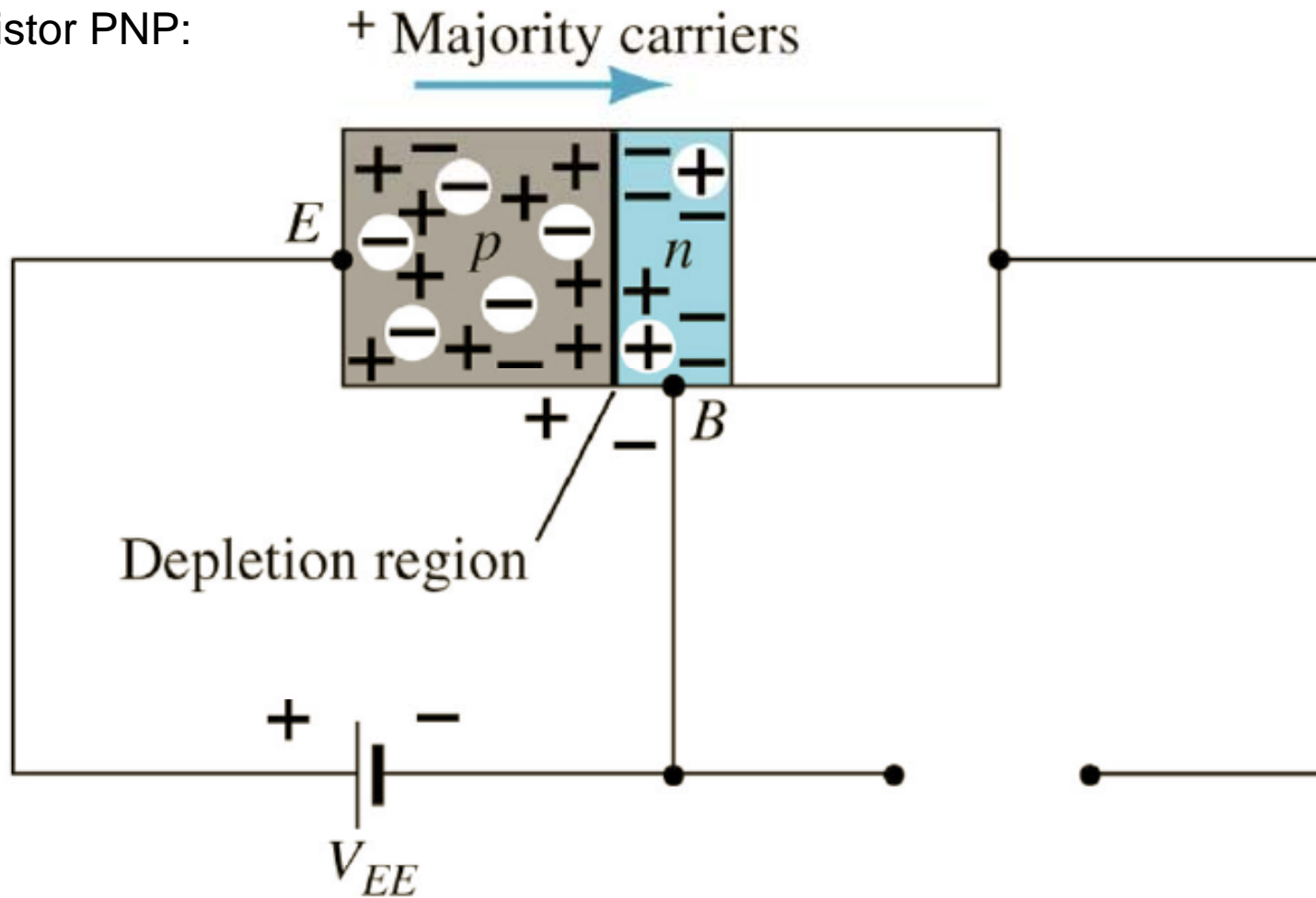
Relembrando os diodos:

$$V_D > 0V$$



Operação do transistor

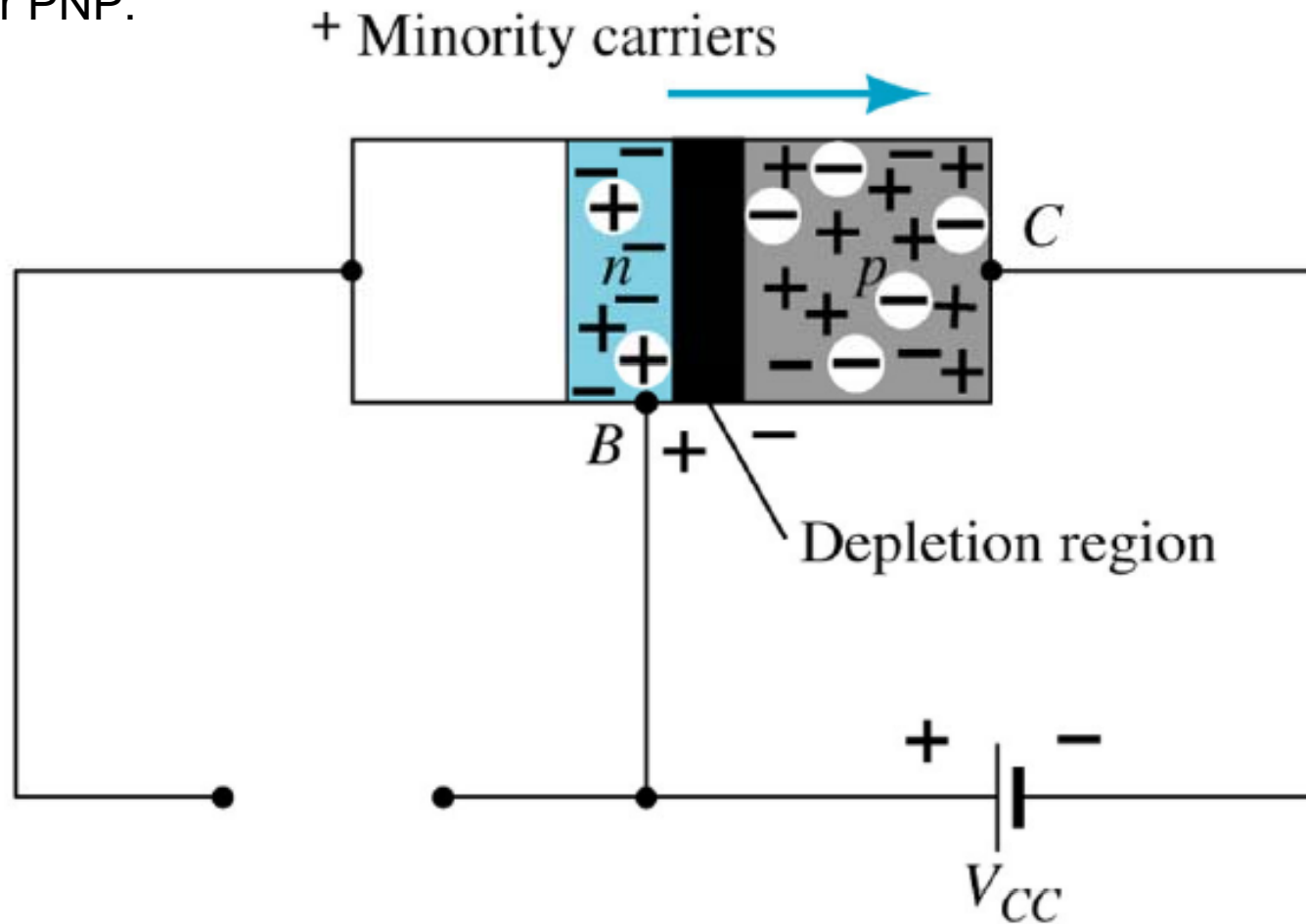
Transistor PNP:



Junção Base – emissor polarizada diretamente.

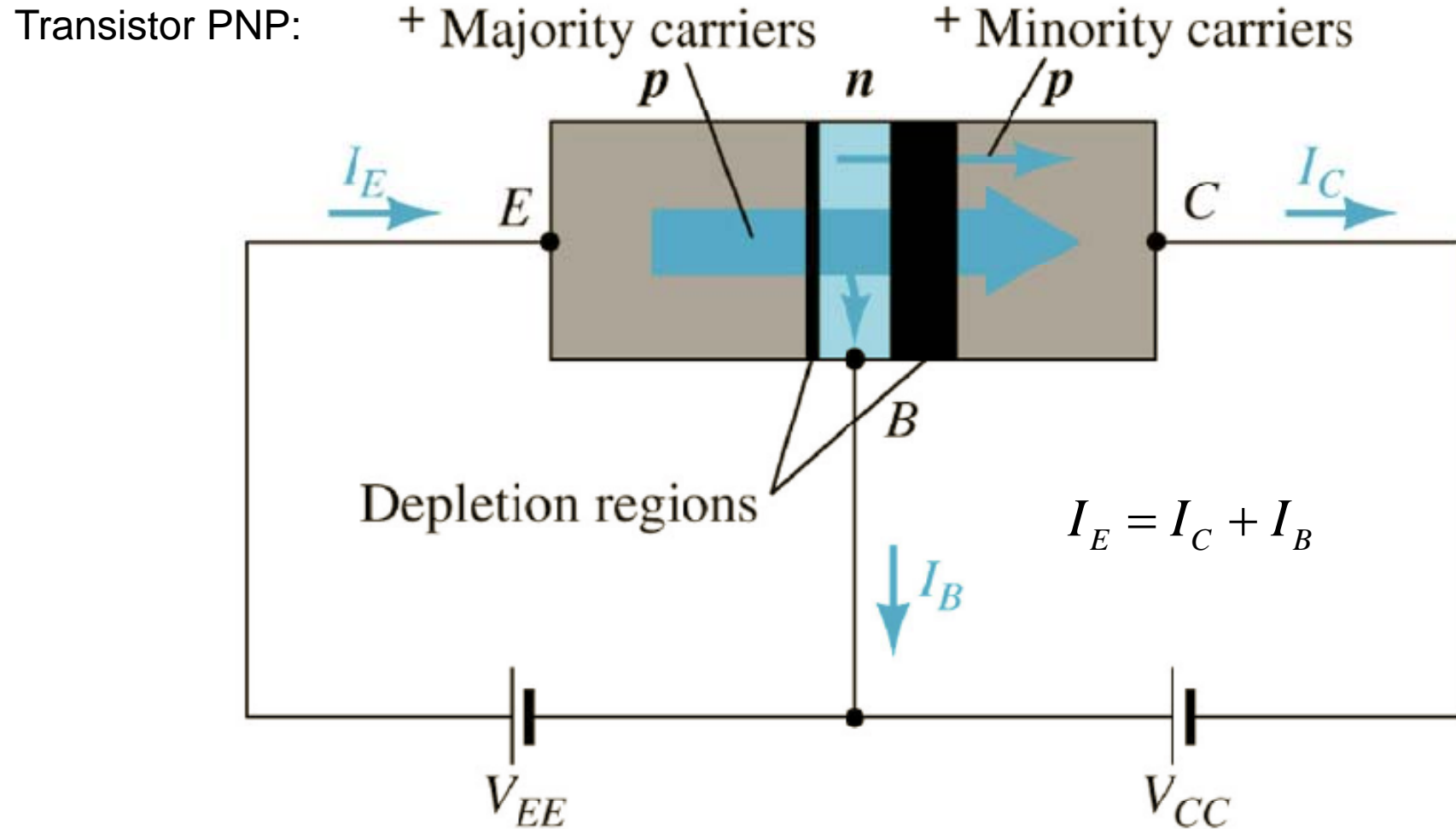
Operação do transistor

Transistor PNP:



Junção Base – coletor polarizada reversamente.

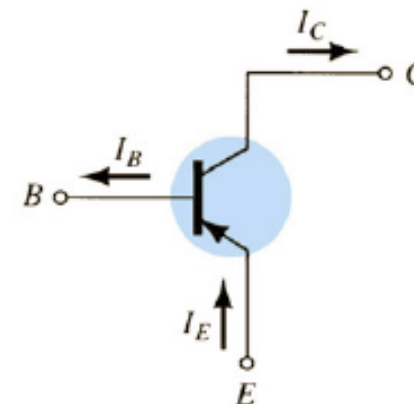
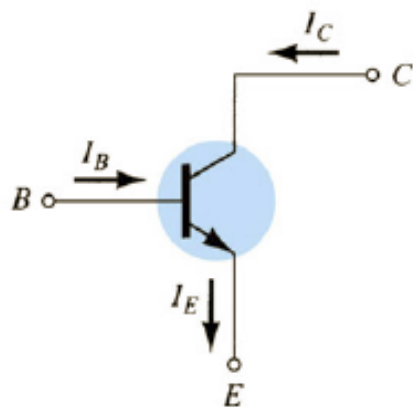
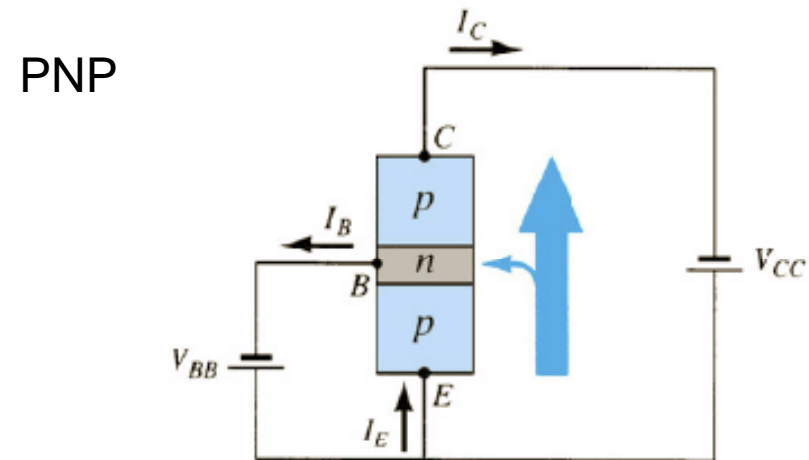
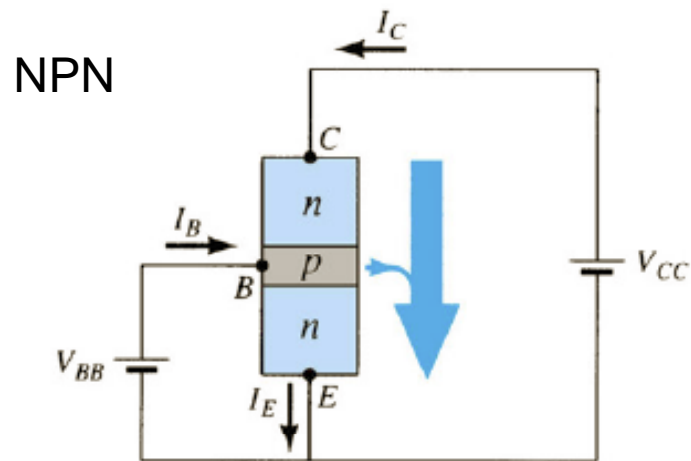
Operação do transistor



Correntes no transistor bipolar de junção.

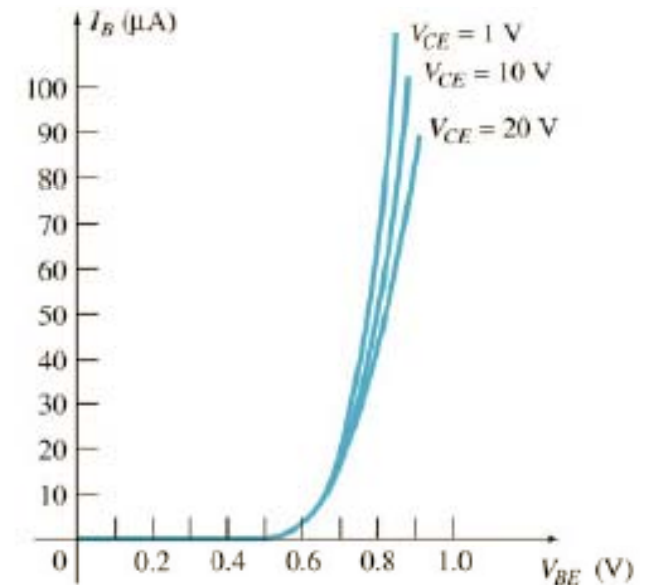
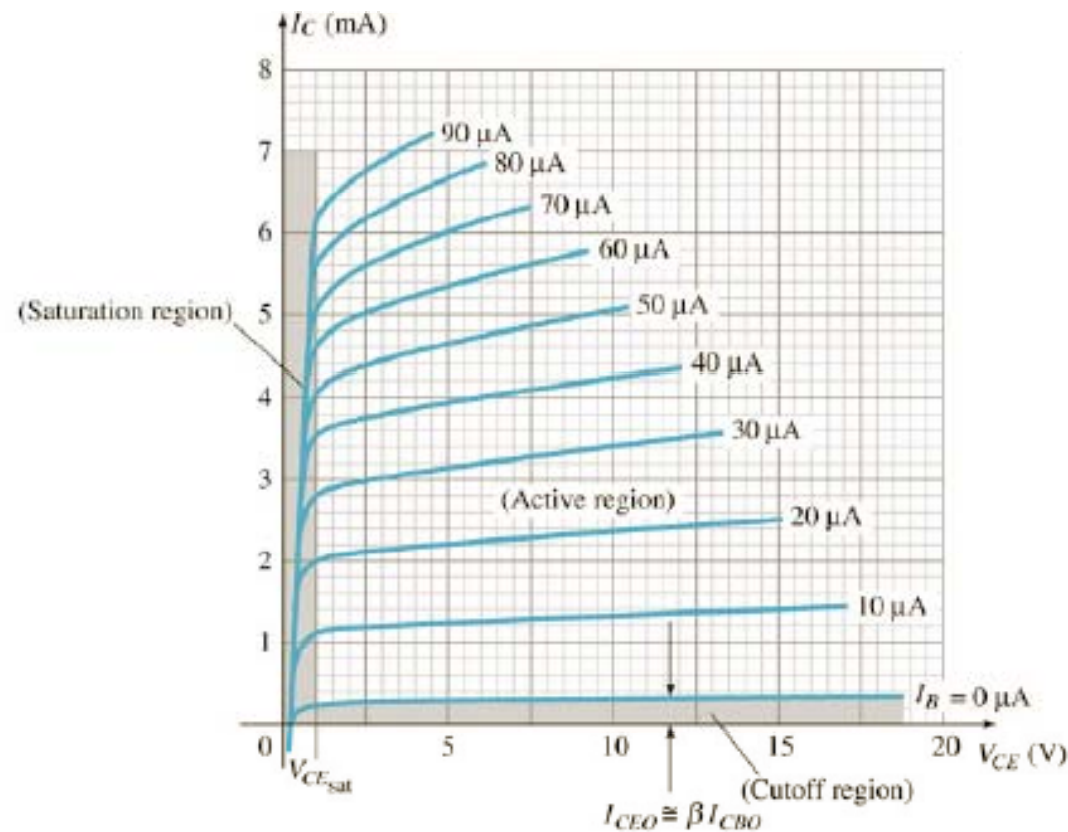
Configuração Emissor-Comum

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



Configuração Emissor-Comum

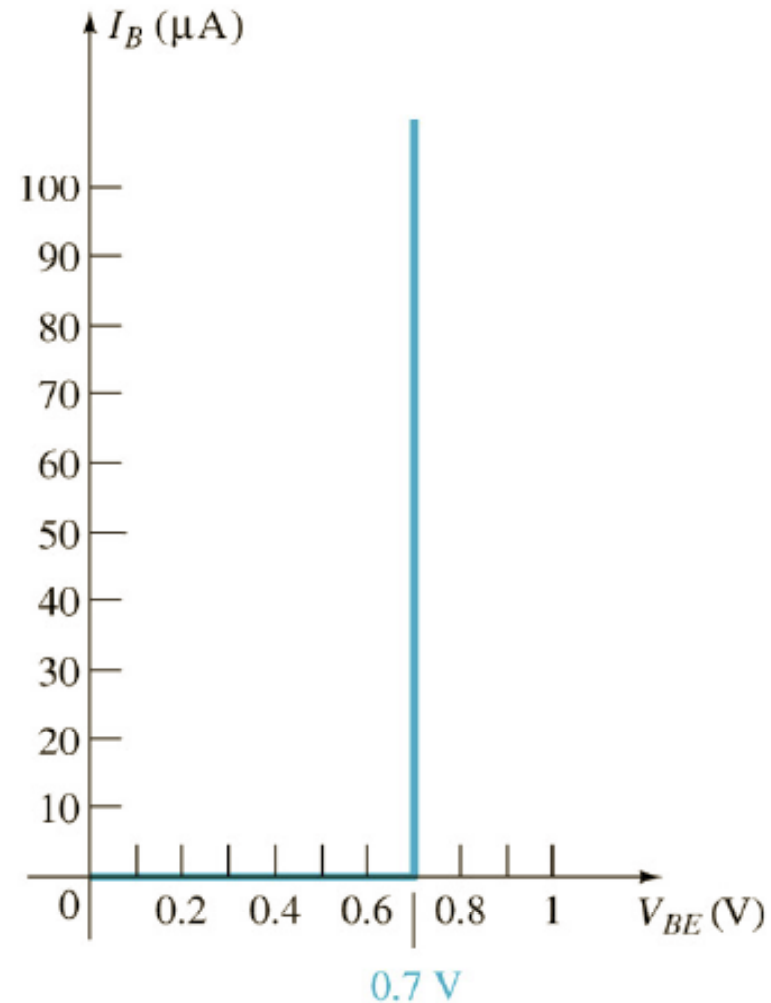
Na região ativa, a junção base-coletor é polarizada reversamente, enquanto a junção base-emissor é polarizada diretamente.



Configuração Emissor-Comum

Aproximação linear das características de base:

$$V_{BE} > 0V$$



Configuração Emissor-Comum

$$I_E = I_B + I_C$$

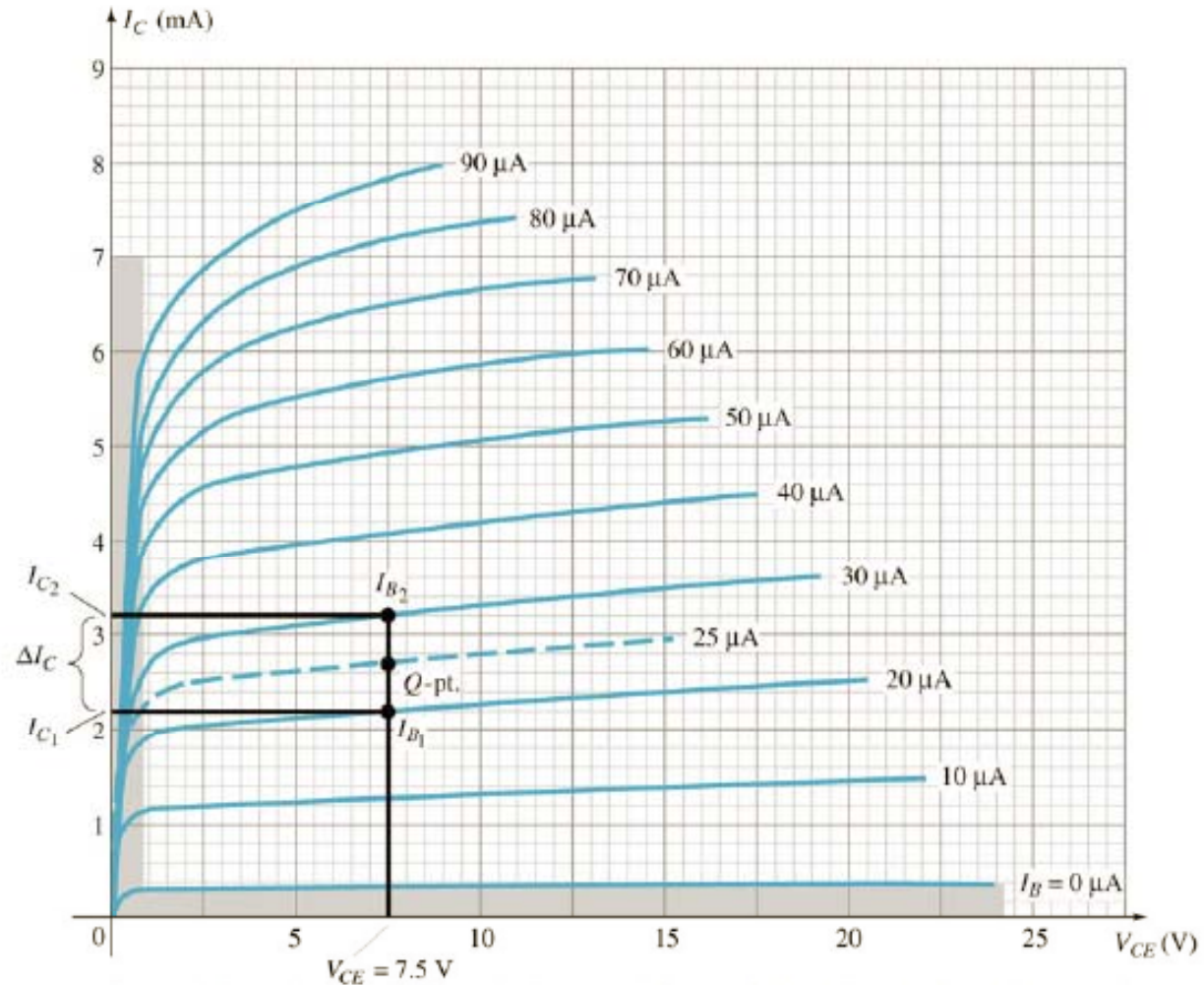
$$I_C = \alpha \cdot I_E$$

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

Ganho CC

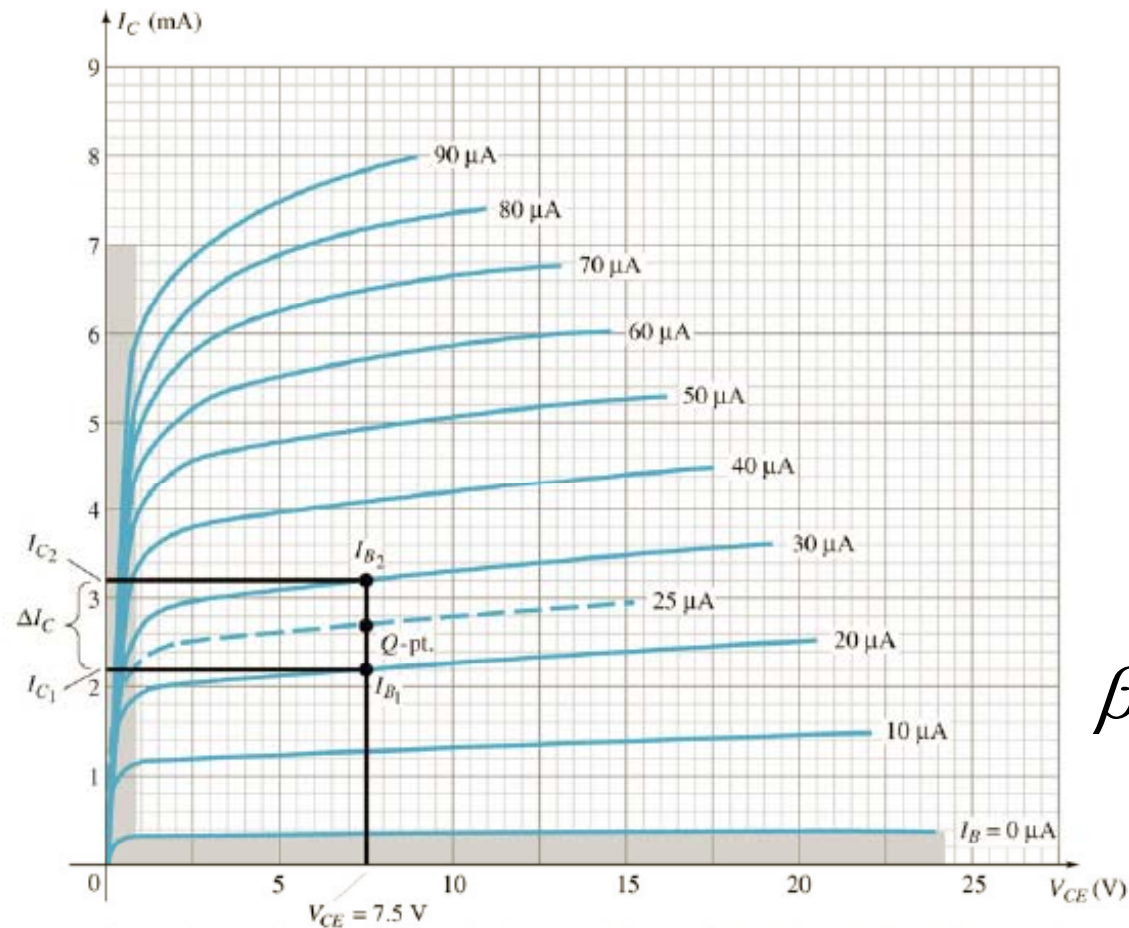
Ganho CA

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



Configuração Emissor-Comum

Exemplo:

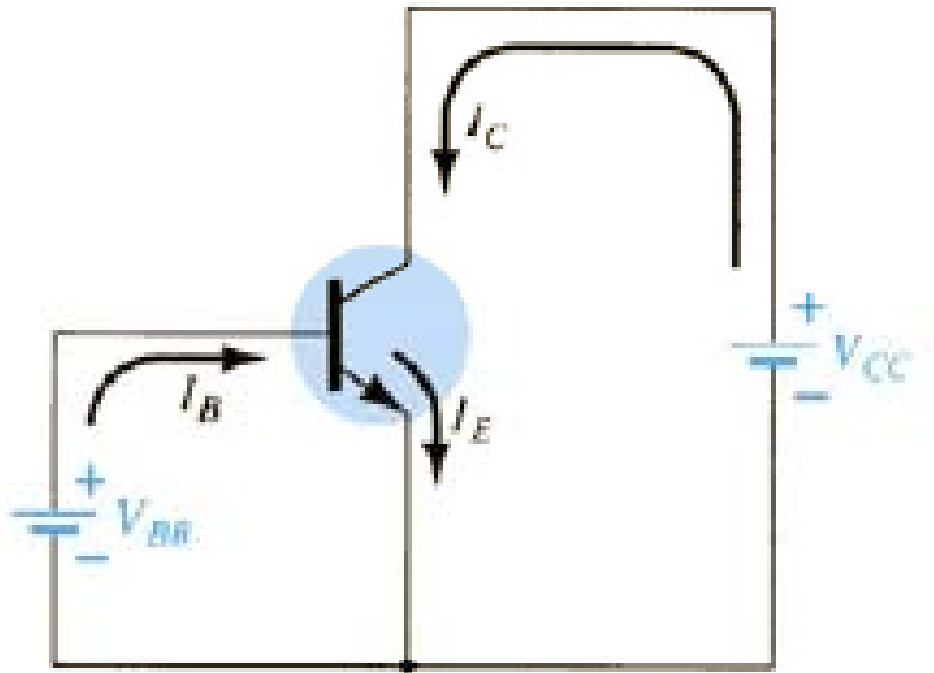


$$\beta_{cc} = \frac{I_C}{I_B} = \frac{2,7m}{25\mu} = 108$$

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

$$\beta_{ca} = \frac{3,2m - 2,2m}{30\mu - 20\mu} = 100$$

Polarização



$$I_C = \beta \cdot I_B$$

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

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

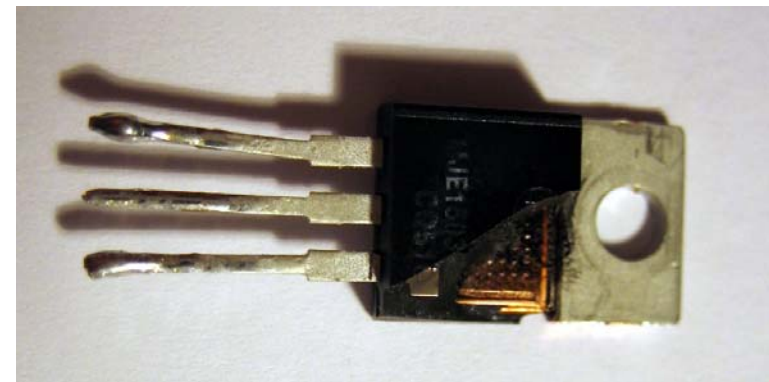
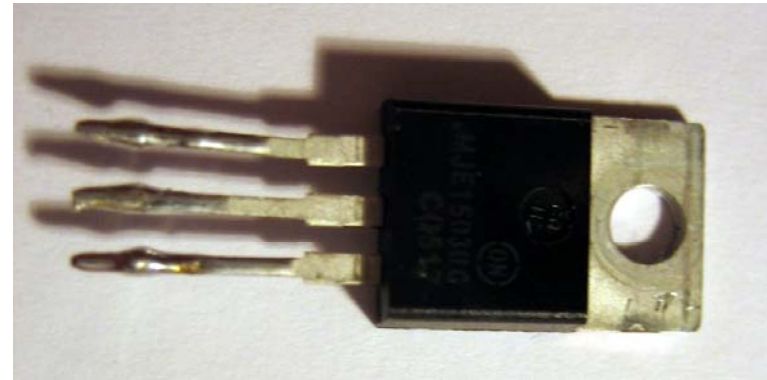
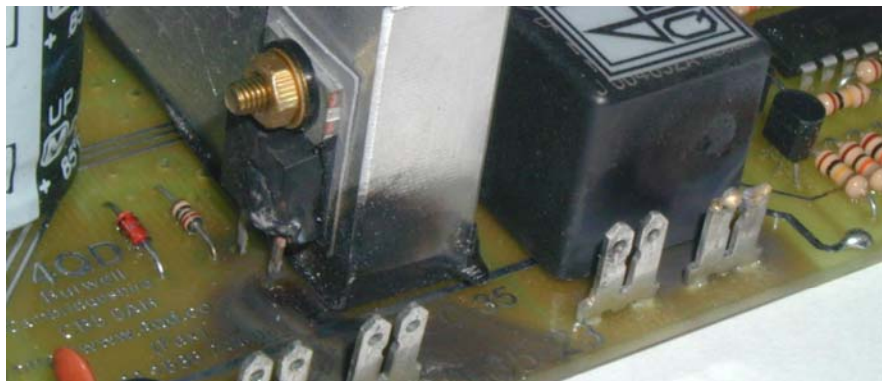
Limites de operação

$$P_{Cmax} = V_{CE} \cdot I_C$$

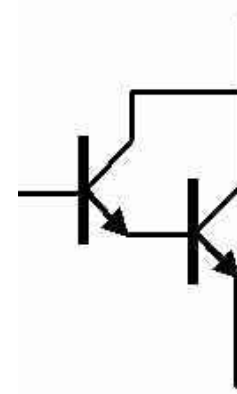
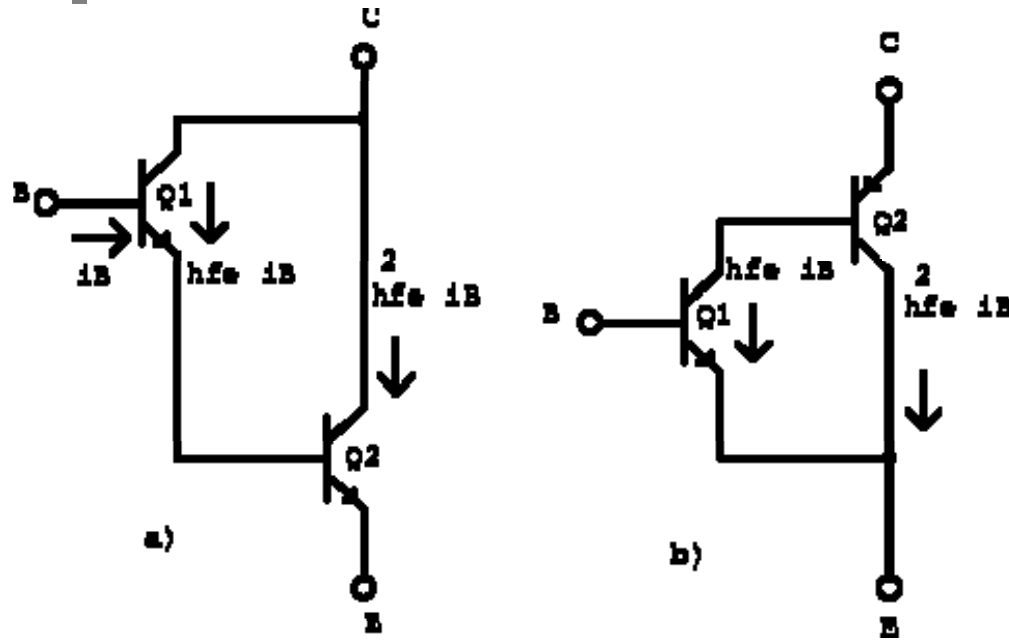
$$I_{CEO} \leq I_C \leq I_{Cmax}$$

$$V_{CEsat} \leq V_{CE} \leq V_{CEmax}$$

$$V_{CE} \cdot I_C \leq P_{Cmax}$$

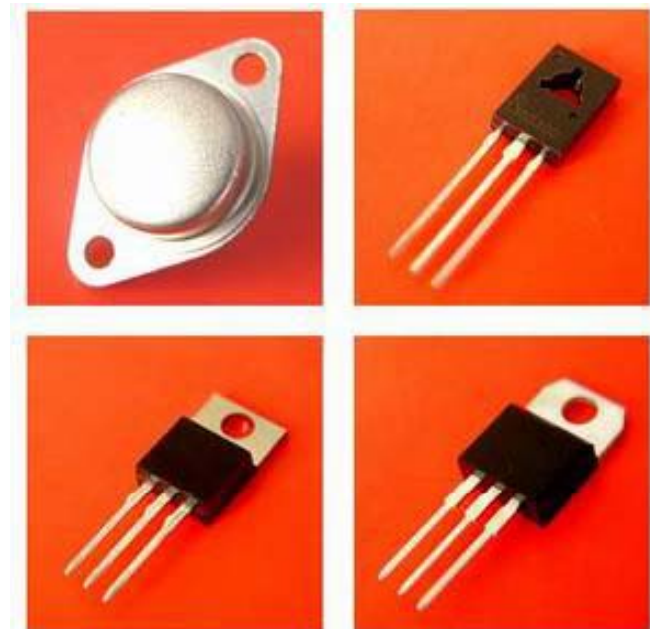
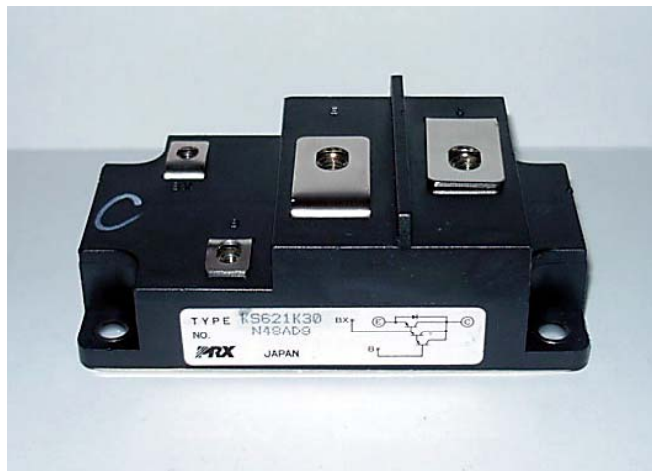


Transistores Darlington



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

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



Encapsulamento de transistores

ENCAPSULADOS

TO-105/ TO-106



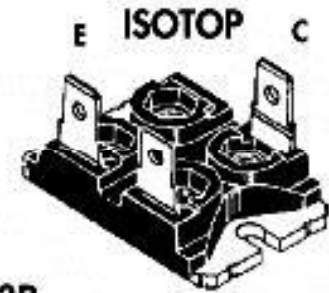
TO-18/TO-5



TO-71



TO-50



DPAK
TO-252



SOT-23
(SMD)



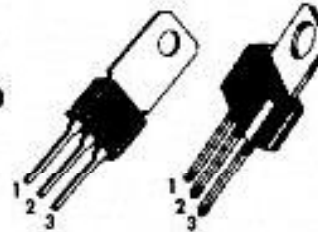
SOT223



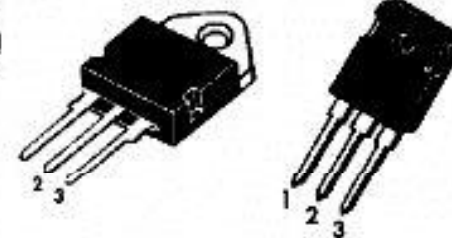
TO-126



TO-202



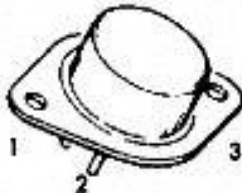
TO-3P



TO-220



TO-3



TO-66



DIL-14



Stx-8



TO-92



Características de catálogo

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°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	$R_{\theta(j-c)}$	55.3	°C/W
Thermal Resistance, Junction to Ambient	$R_{\theta(j-a)}$	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-Base Breakdown Voltage (1) ($I_C = 1.0\text{ mAdc}, I_B = 0$)	$V_{CE0(BR)}$	50		Vdc
Collector-Base Breakdown Voltage ($I_C = 10\text{ }\mu\text{A}, I_B = 0$)	$V_{CE0(BR)}$	40		Vdc
Emitter-Base Breakdown Voltage ($I_E = 10\text{ }\mu\text{A}, I_C = 0$)	$V_{EB0(BR)}$	5.0	-	Vdc
Collector Cutoff Current ($V_{CE} = 20\text{ Vdc}, I_B = 0$)	I_{C0}	-	50	μA
Emitter Cutoff Current ($V_{EB} = 5.0\text{ Vdc}, I_C = 0$)	I_{E0}	-	50	μA

ON CHARACTERISTICS

DC Current Gain ($I_C = 2.0\text{ mAdc}, V_{CE} = 1.0\text{ Vdc}$) ($I_E = 50\text{ mAdc}, V_{CE} = 1.0\text{ Vdc}$)	β_{DC}	50 25	150 -	-
Collector-Emitter Saturation Voltage (1) ($I_C = 50\text{ mAdc}, I_B = 5.0\text{ mAdc}$)	$V_{CE(sat)}$	-	0.1	Vdc
Base-Emitter Saturation Voltage (1) ($I_E = 50\text{ mAdc}, I_B = 5.0\text{ mAdc}$)	$V_{BE(sat)}$	-	0.55	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 ($V_{CE} = 5.0\text{ Vdc}, I_C = 0, f = 100\text{ MHz}$)	C_{out}	-	4.0	pF
Input Capacitance ($V_{BE} = 0.5\text{ Vdc}, I_C = 0, f = 100\text{ kHz}$)	C_{in}	-	8.0	pF
Collector-Base Capacitance ($I_C = 0, V_{CB} = 5.0\text{ V}, f = 100\text{ kHz}$)	C_{cb}	-	4.0	pF
Small-Signal Current Gain ($I_C = 2.0\text{ mAdc}, V_{CE} = 1.0\text{ Vdc}, f = 1.0\text{ kHz}$)	β_{ac}	50	200	-
Current Gain - High Frequency ($I_C = 10\text{ mAdc}, V_{CE} = 20\text{ Vdc}, f = 100\text{ MHz}$) ($I_C = 2.0\text{ mAdc}, V_{CE} = 1.0\text{ Vdc}, f = 1.0\text{ kHz}$)	β_{ac}	2.5 50	- 200	-
Noise Figure ($I_C = 100\text{ }\mu\text{A}, V_{CE} = 5.0\text{ Vdc}, R_L = 1.0\text{ k}\Omega, f = 1.0\text{ kHz}$)	NF	-	6.0	dB

(1) Pulse Test: Pulse Width = 300 μs ; Duty Cycle = 2.0%



Exemplos:

BC548



2N3055



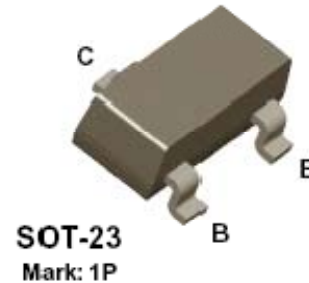
Tipos de transistores

Transistores de uso geral:

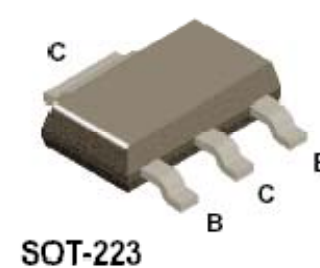
PN2222A



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

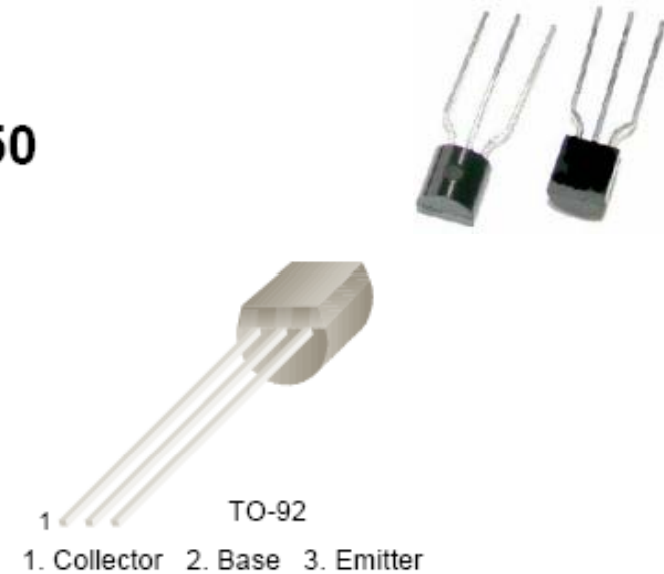
Transistores de uso geral:

BC546/547/548/549/550

Switching and Applications

- High Voltage: BC546, $V_{CE0}=65V$
- Low Noise: BC549, BC550
- Complement to BC556 ... BC560

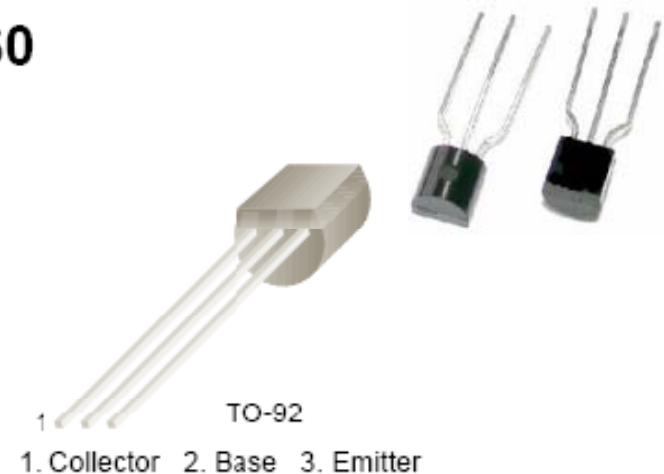
NPN Epitaxial Silicon Transistor



BC556/557/558/559/560

Switching and Amplifier

- High Voltage: BC556, $V_{CE0} = -65V$
- Low Noise: BC559, BC560
- Complement to BC546 ... BC 550



Pares complementares

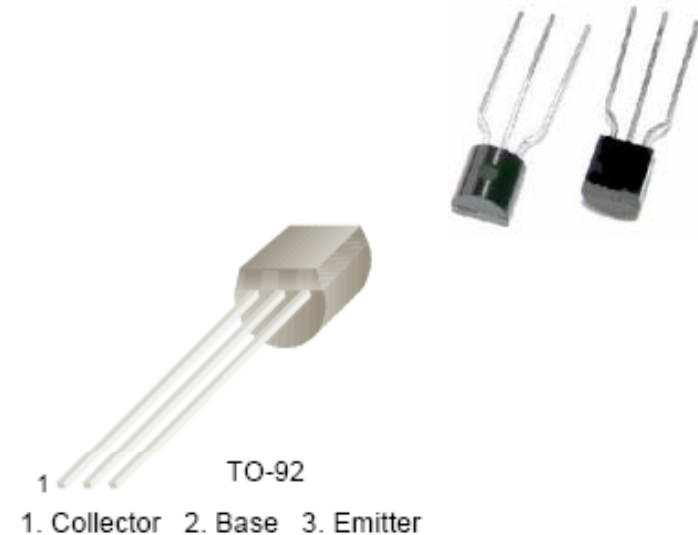
Tipos de transistores

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	$^\circ\text{C}$

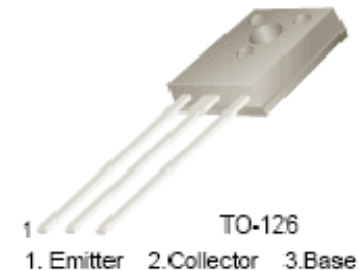
Tipos de transistores

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_{CEO}	Collector-Emitter Voltage : BD135	45	V
	: BD137	60	V
	: BD139	80	V
V_{EBO}	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	$^\circ\text{C}$

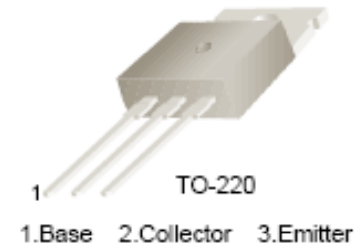
Tipos de transistores

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_{CB0}	Collector-Base Voltage	: TIP31	40	V
		: TIP31A	60	V
		: TIP31B	80	V
		: TIP31C	100	V
		V_{CE0}	Collector-Emitter Voltage	: TIP31
: TIP31A	60			V
: TIP31B	80			V
: TIP31C	100			V
V_{EB0}	Emitter-Base Voltage			5
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	$^\circ\text{C}$	



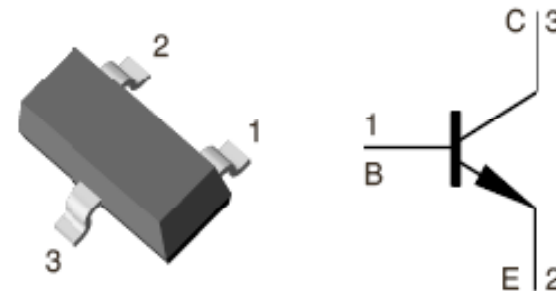
Tipos de transistores

Transistores SMD:

Small Signal Transistors (NPN)

Features

- These transistors are subdivided into three groups (A, B, and C) according to their current gain. The type BC846 is available in groups A and B, however, the types BC847 and BC848 can be supplied in all three groups. The BC849 is a low noise type available in groups B and C. As complementary types, the PNP transistors BC856...BC859 are recommended.
- NPN Silicon Epitaxial Planar Transistors for switching and AF amplifier applications.



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Tipos de transistores

Transistores SMD:

BC846 to BC849

Vishay Semiconductors



Absolute Maximum Ratings

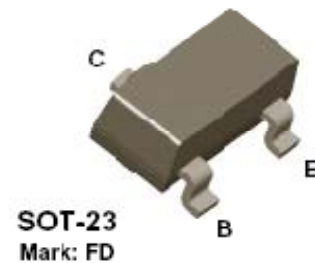
$T_{amb} = 25\text{ }^{\circ}\text{C}$, unless otherwise specified

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
		BC849	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

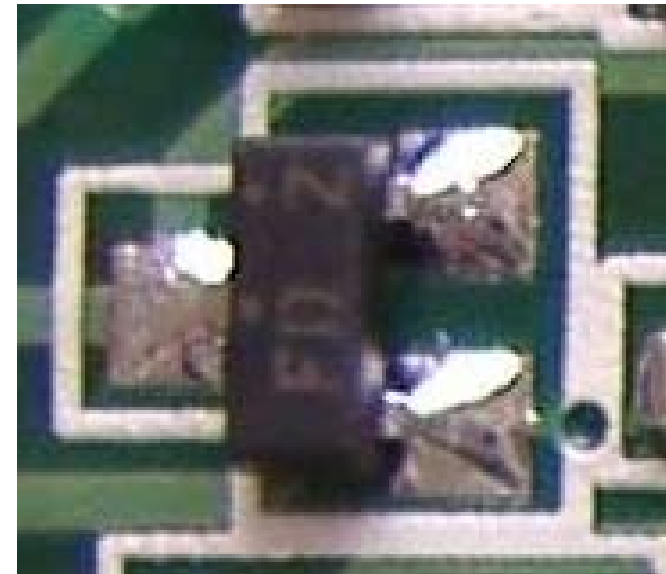
Transistores SMD:

BCV26



PNP Darlington Transistor

This device is designed for applications requiring extremely high current gain at currents to 800 mA. Sourced from Process 61.



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

Symbol	Parameter	Value	Units
V_{CE0}	Collector-Emitter Voltage	30	V
V_{CB0}	Collector-Base Voltage	40	V
V_{EB0}	Emitter-Base Voltage	10	V
I_c	Collector Current - Continuous	1.2	A
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

Tipos de transistores

Transistores de alta potência:

Complementary Silicon Power Transistors

... designed for general-purpose switching and amplifier applications.

- DC Current Gain — $h_{FE} = 20-70 @ I_C = 4 \text{ Adc}$
- Collector-Emitter Saturation Voltage —
 $V_{CE(sat)} = 1.1 \text{ Vdc (Max) @ } I_C = 4 \text{ Adc}$
- Excellent Safe Operating Area

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	Watts W°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +200	$^\circ\text{C}$

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.52	$^\circ\text{C/W}$

NPN
2N3055 *
PNP
MJ2955 *

* Motorola Preferred Device

15 AMPERE
POWER TRANSISTORS
COMPLEMENTARY
SILICON
60 VOLTS
115 WATTS



Tipos de transistores

Transistores de alta potência:

**MJ11028, MJ11030,
MJ11032 (NPN)
MJ11029, MJ11033 (PNP)**

High-Current Complementary Silicon Power Transistors

High-Current Complementary Silicon Power Transistors are for use as output devices in complementary general purpose amplifier applications.

Features

- High DC Current Gain – $h_{FE} = 1000$ (Min) @ $I_C = 25$ Adc
 $h_{FE} = 400$ (Min) @ $I_C = 50$ Adc
- Curves to 100 A (Pulsed)
- Diode Protection to Rated I_C
- Monolithic Construction with Built-In Base-Emitter Shunt Resistor
- Junction Temperature to +200°C
- Pb-Free Packages are Available*

MAXIMUM RATINGS ($T_J = 25^\circ\text{C}$ unless otherwise noted)

Rating	Symbol	Value	Unit
Collector-Emitter Voltage MJ11028/29 MJ11030 MJ11032/33	V_{CE0}	60 90 120	Vdc
Collector-Base Voltage MJ11028/29 MJ11030 MJ11032/33	V_{CB0}	60 90 120	Vdc
Emitter-Base Voltage	V_{EB0}	5.0	Vdc
Collector Current – Continuous – Peak (Note 1)	I_C	50 100	A dc
Base Current – Continuous	I_B	2.0	A dc
Total Power Dissipation @ $T_C = 25^\circ\text{C}$ Derate Above 25°C @ $T_C = 100^\circ\text{C}$	P_D	300 1.71	W W/WC
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-55 to +200	°C



ON Semiconductor®

<http://onsemi.com>

50 AMPERE
COMPLEMENTARY
DARLINGTON POWER
TRANSISTORS
60 – 120 VOLTS
300 WATTS



TO-204 (TO-3)
CASE 107A
STYLE 1

MARKING DIAGRAM



Tipos de transistores

Transistores de 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}	50	Vdc
Emitter-Base Voltage	V_{EB0}	3.0	Vdc
Collector Current - Continuous	I_C	100	mAdc
Total Device Dissipation @ $I_A = 25^\circ\text{C}$ 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

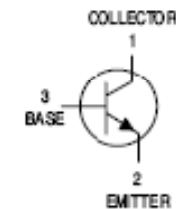
THERMAL CHARACTERISTICS

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



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<http://onsemi.com>



MARKING DIAGRAM



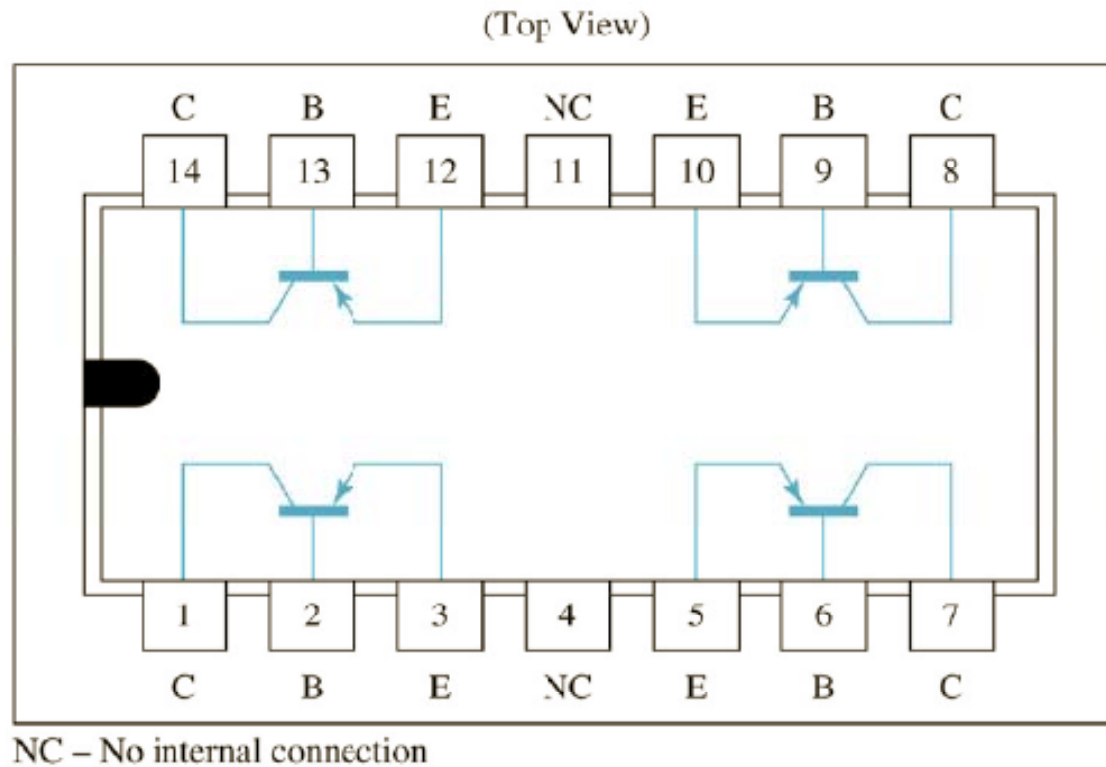
TO-92
CASE 29
STYLE 21



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

Tipos de transistores

Transistores integrados:



Na próxima aula

Seqüência de conteúdos:

1. Polarização de transistores;
2. Operação do transistor como chave;
3. Aplicações.