Centro Federal de Educação Tecnológica de Santa Catarina
Departamento de Eletrônica
Eletrônica Básica e Projetos Eletrônicos

Transistores Bipolares de Junção

Clóvis Antônio Petry, professor.

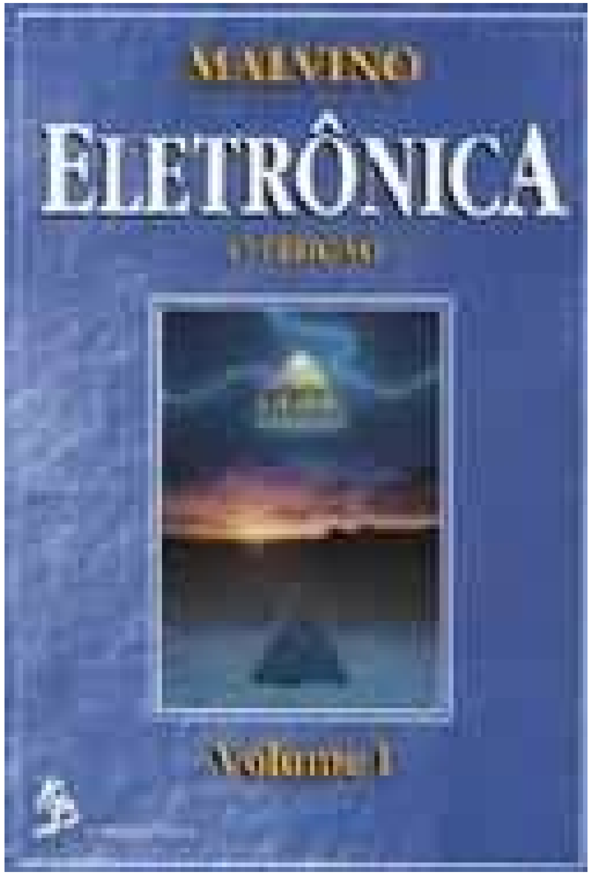
Florianópolis, abril de 2007.

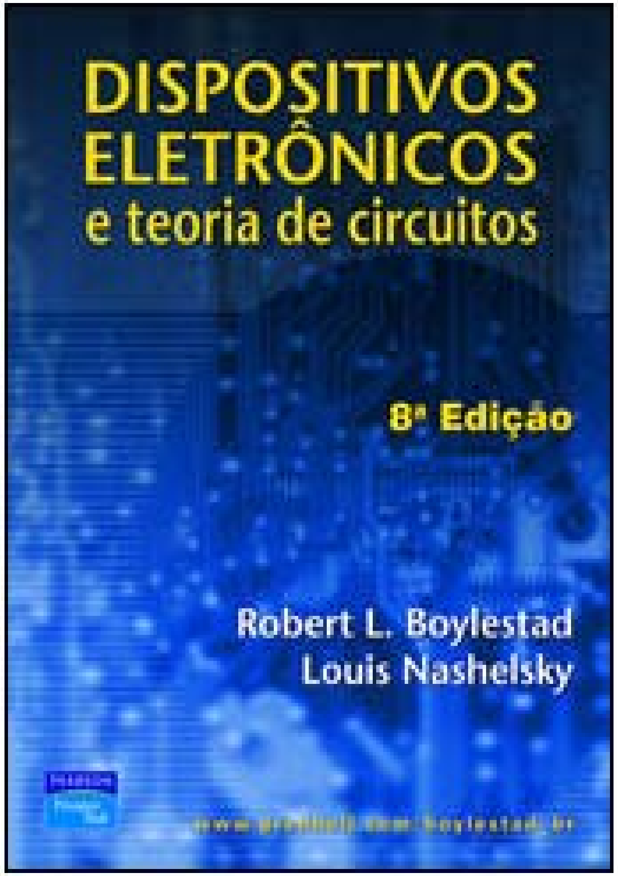
Nesta aula

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

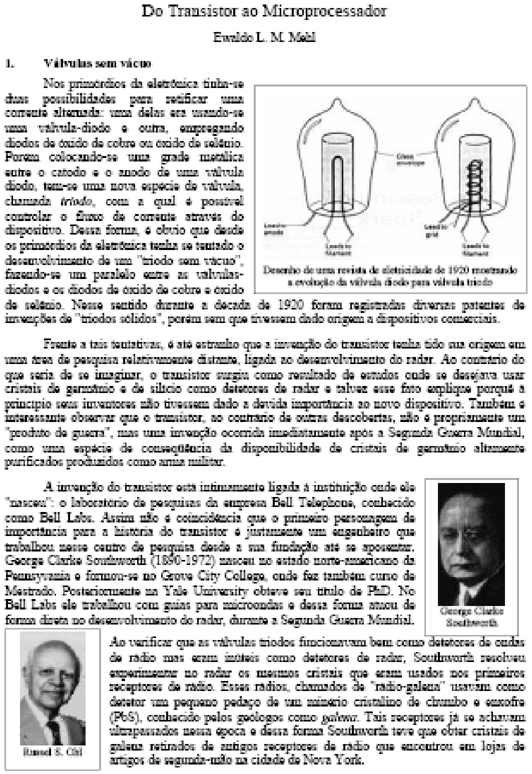




Introdução

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

Ewaldo L. M. Mehl

1. Válvulas sem vácuo

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

Desenho de uma revista de eletricidade de 1920 mostrando a evolução da válvula diodo para válvula triodo

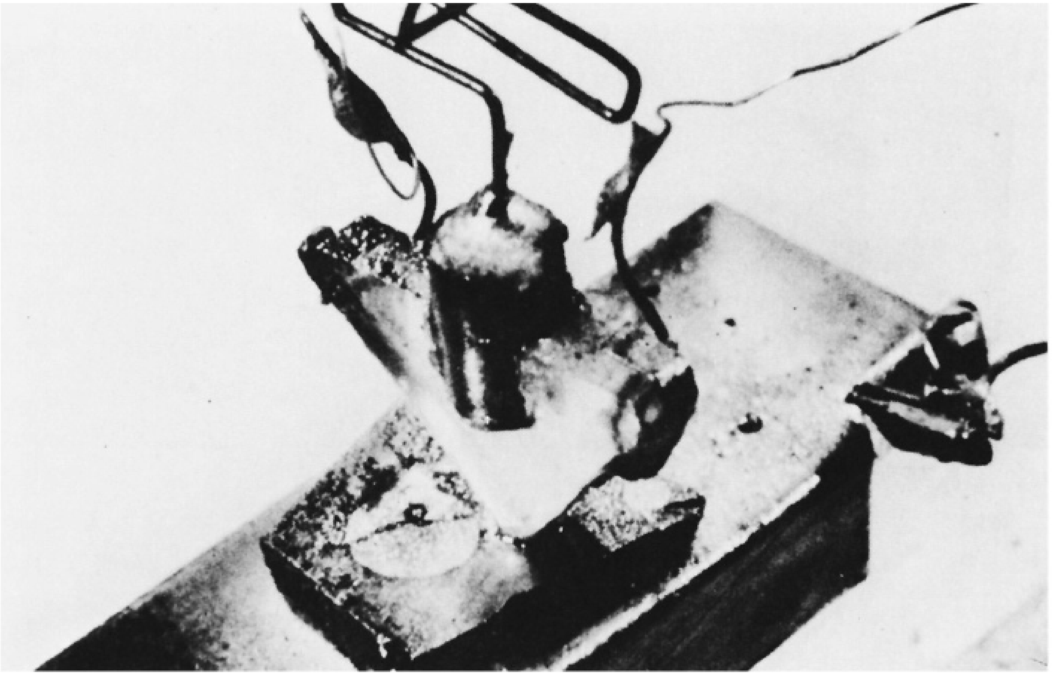
Frente a tais tentativas, é até estranho que a invenção do transistor tenha tido sua origem em uma área de pesquisa relativamente distante, ligada ao desenvolvimento do radar. Ao contrário do que seria de se imaginar, o transistor surgiu como resultado de estudos onde se desejava usar cristais de germânio e de silício como detetores de radar e talvez esse fato explique porquê a principio seus inventores não tivessem dado a devida importância ao novo dispositivo. Também é interessante observar que o transistor, ao contrário de outras descobertas, não é propriamente um "produto de guerra", mas uma invenção ocorrida imediatamente após a Segunda Guerra Mundial, como uma espécie de conseqüência da disponibilidade de cristais de germânio altamente purificados produzidos como arma militar.

A invenção do transistor está intimamente ligada à instituição onde ele "nasceu": o laboratório de pesquisas da empresa Bell Telephone, conhecido como Bell Labs. Assim não é coincidência que o primeiro personagem de importância para a historia do transistor é justamente um engenheiro que trabalhou nesse centro de pesquisa desde a sua fundação até se aposentar. George Clarke Southworth (1890-1972) nasceu no estado norte-americano da Pennsyvania e formou-se no Grove City College, onde fez também curso de Mestrado. Posteriormente na Yale University obteve seu título de PhD. No Bell Labs ele trabalhou com guias para microondas e dessa forma atuou de forma direta no desenvolvimento do radar, durante a Segunda Guerra Mundial.

George Clarke Southworth

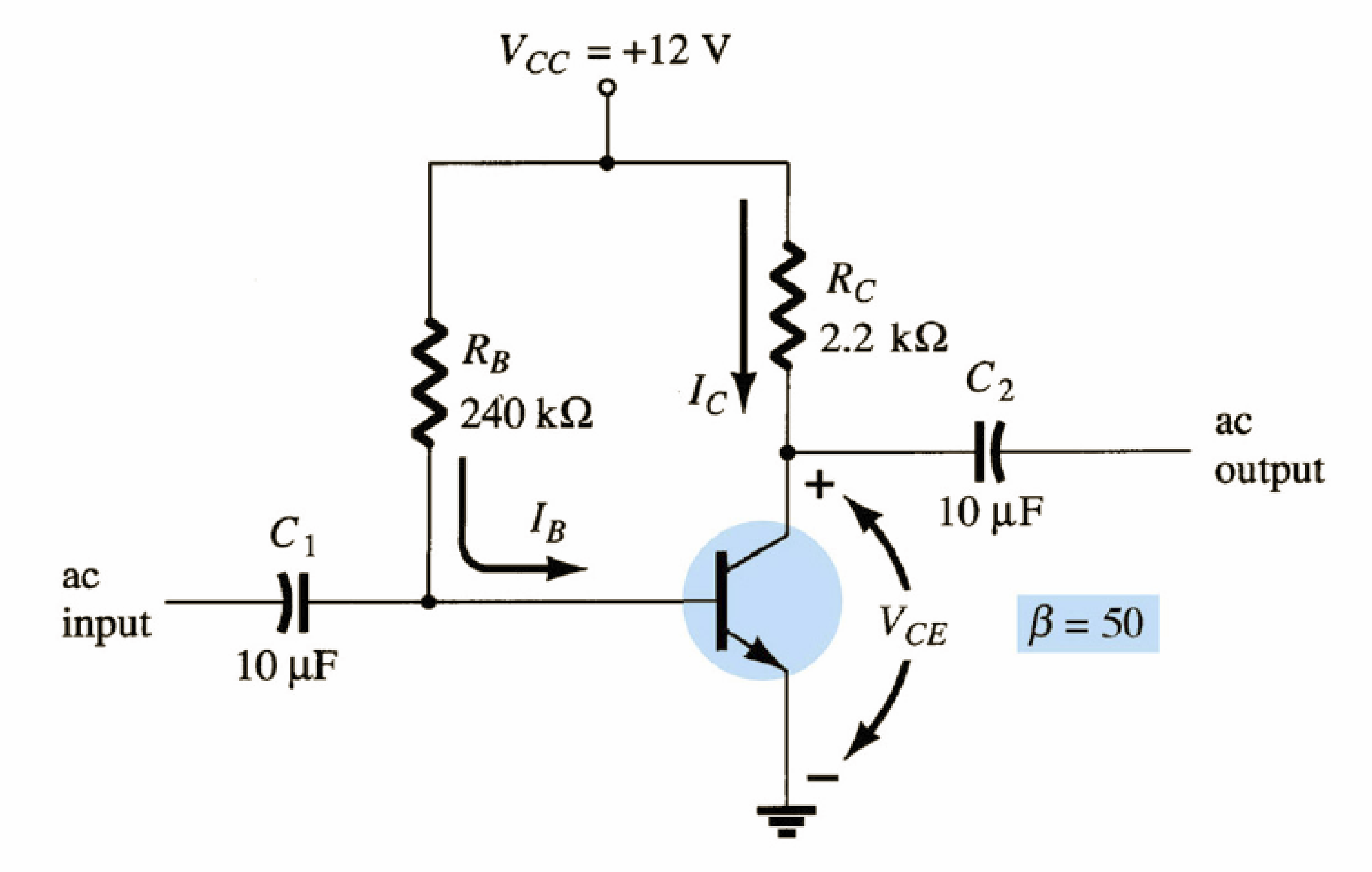
Ao verificar que as válvulas triodos funcionavam bem como detetores de ondas de rádio mas eram inúteis como detetores de radar, Southworth resolveu experimentar no radar os mesmos cristais que eram usados nos primeiros receptores de rádio. Esses rádios, chamados de "radio-galena" usavam como detetor um pequeno pedaço de um minério cristalino de chumbo e enxofre (PbS), conhecido pelos geólogos como *galena*. Tais receptores já se achavam ultrapassados nessa época e dessa forma Southworth teve que obter cristais de galena retirados de antigos receptores de rádio que encontrou em lojas de artigos de segunda-mão na cidade de Nova York.

Russel S. Ohl



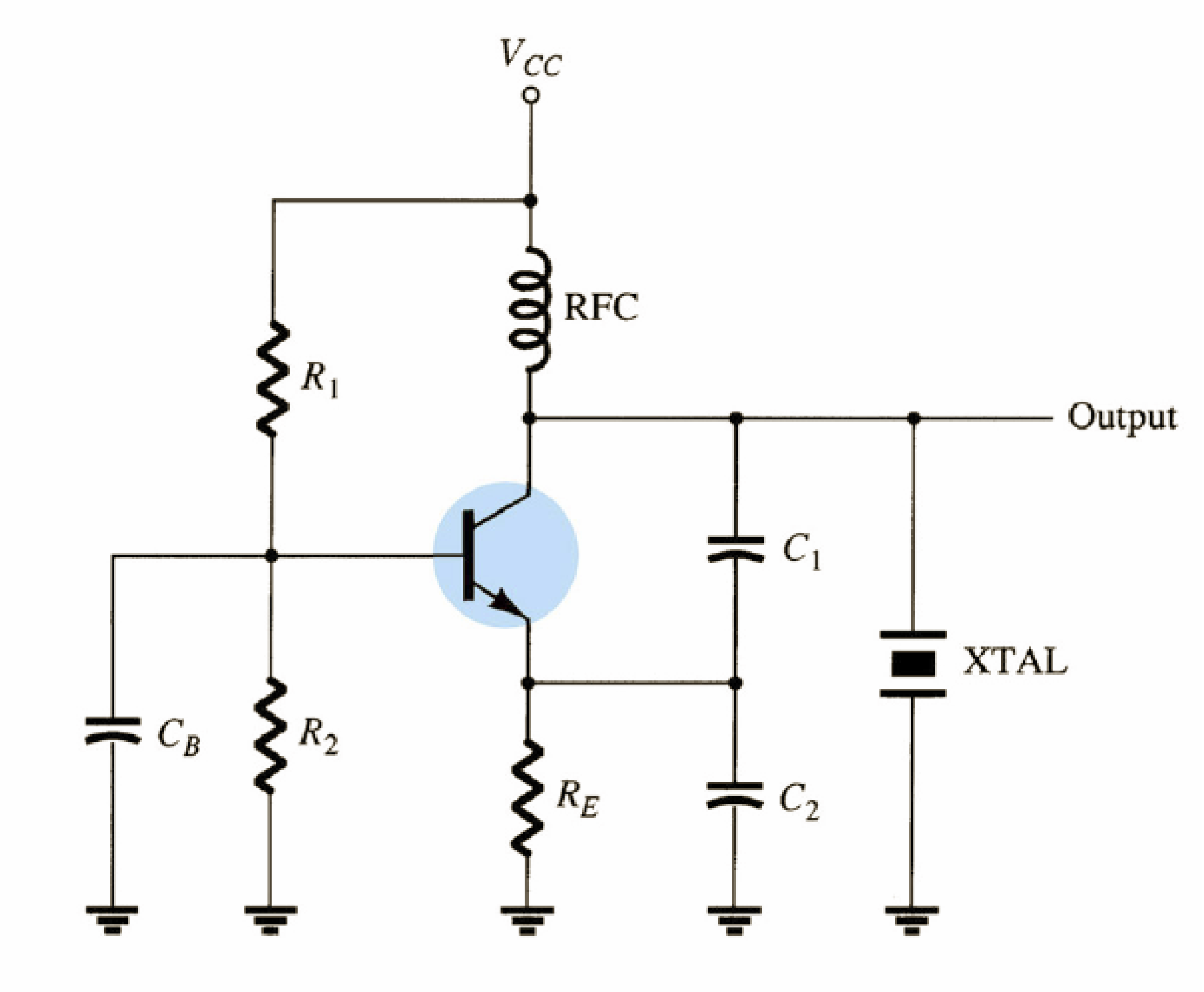
http://www.eletrica.ufpr.br/mehl/te040/historia_transistor.pdf

Introdução



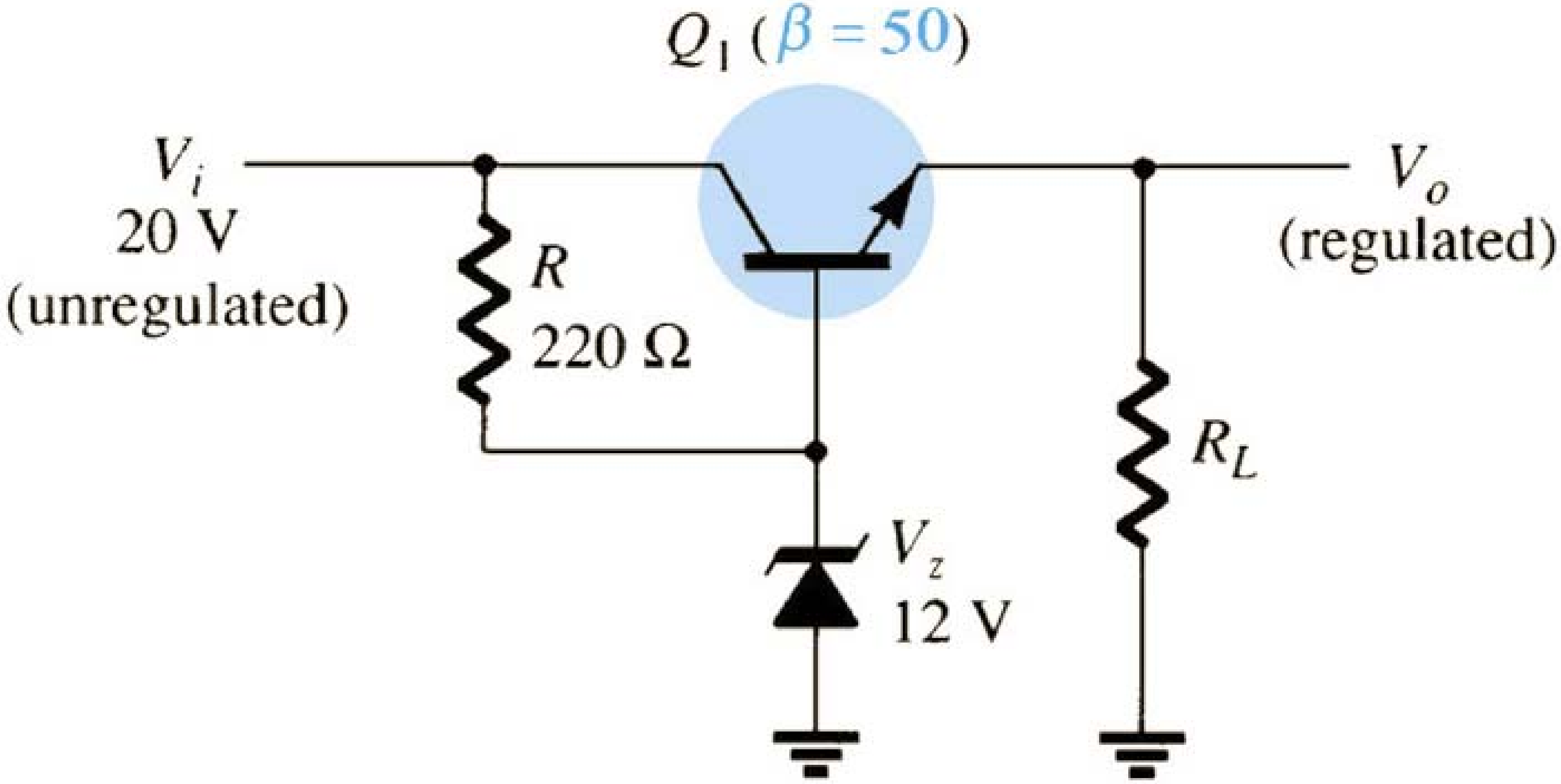
Amplificador com transistor bipolar.

Introdução



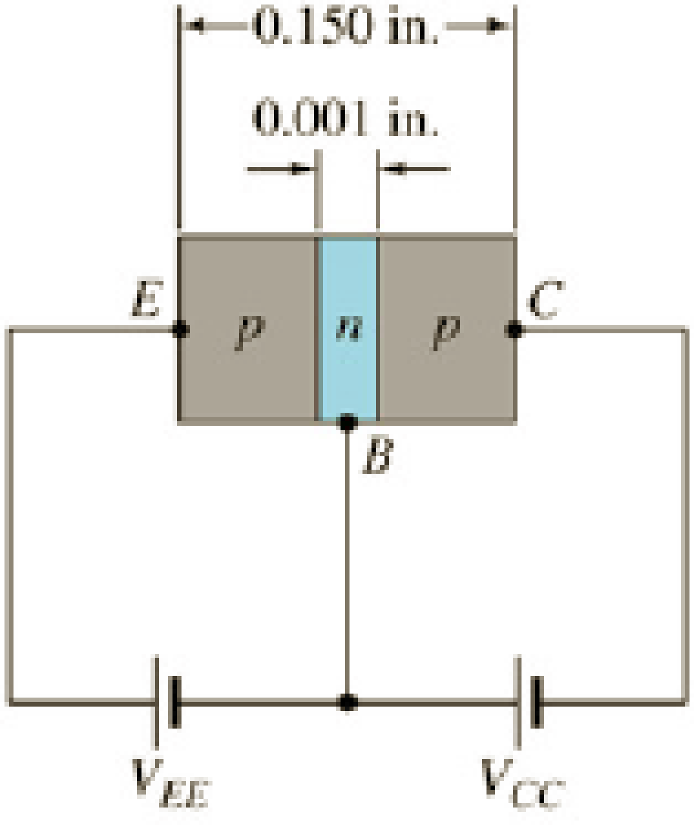
Oscilador controlado a cristal.

Introdução

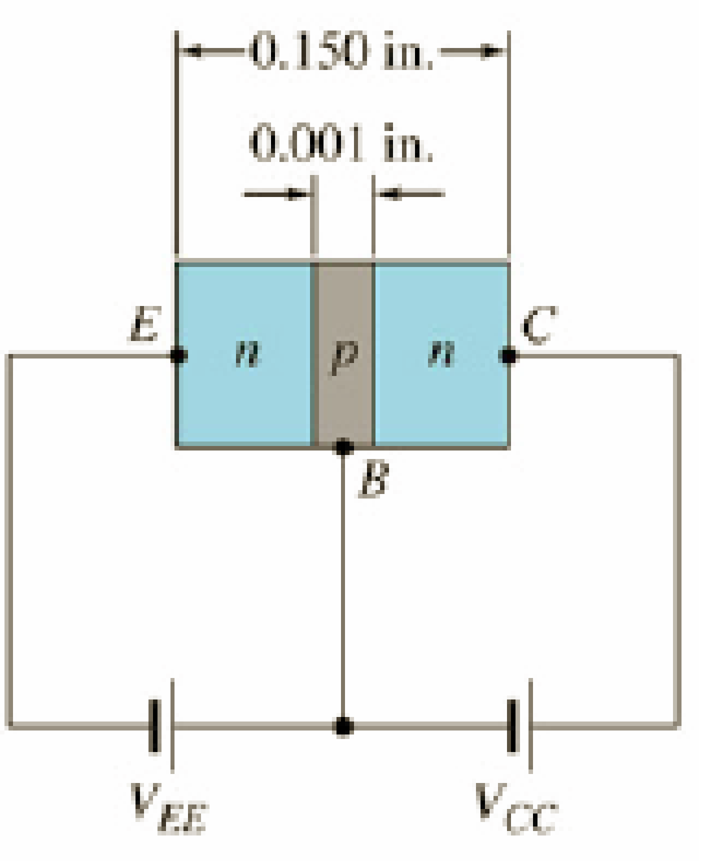


Regulador de tensão com transistor bipolar.

Construção do transistor



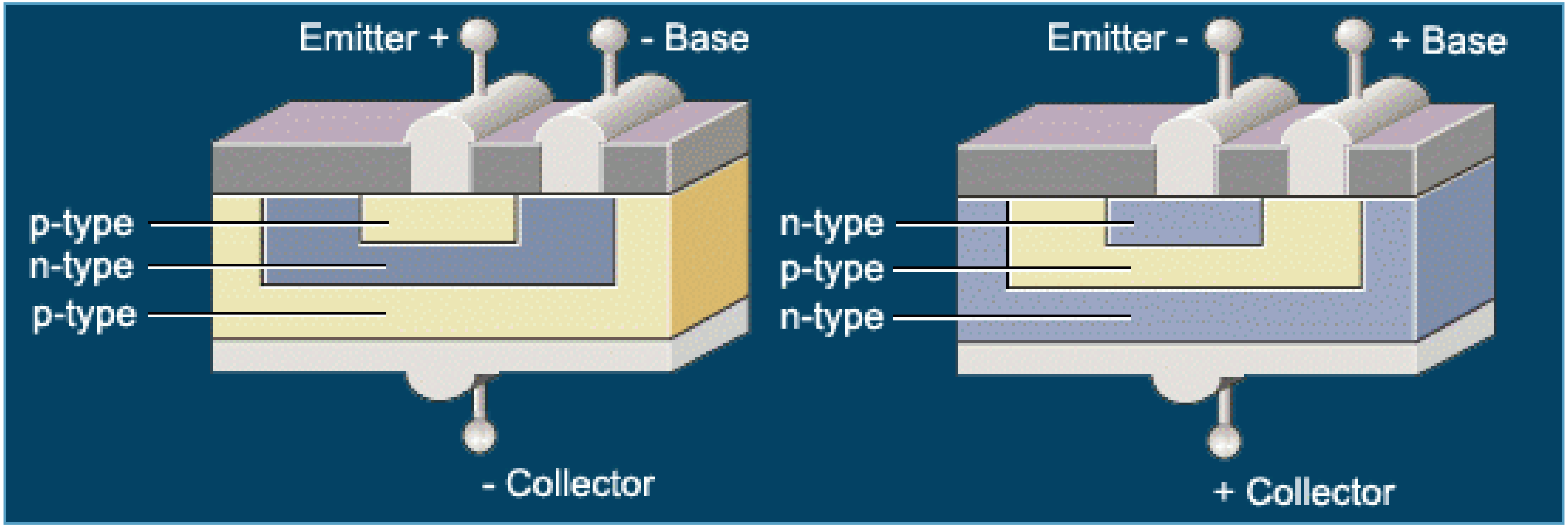
PNP

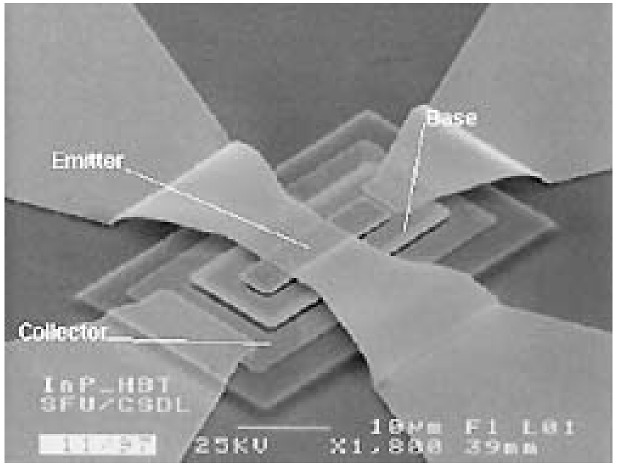


NPN

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

Construção do transistor

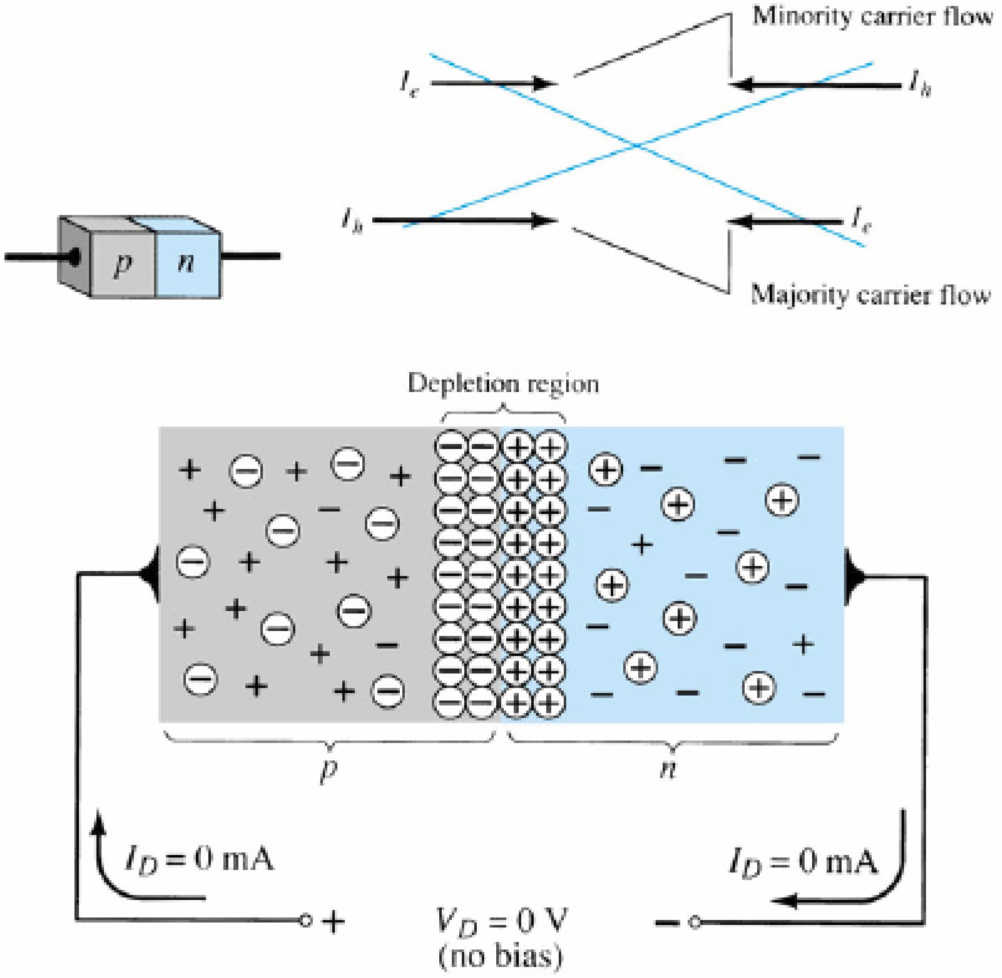




Operação do transistor

Relembrando os diodos:

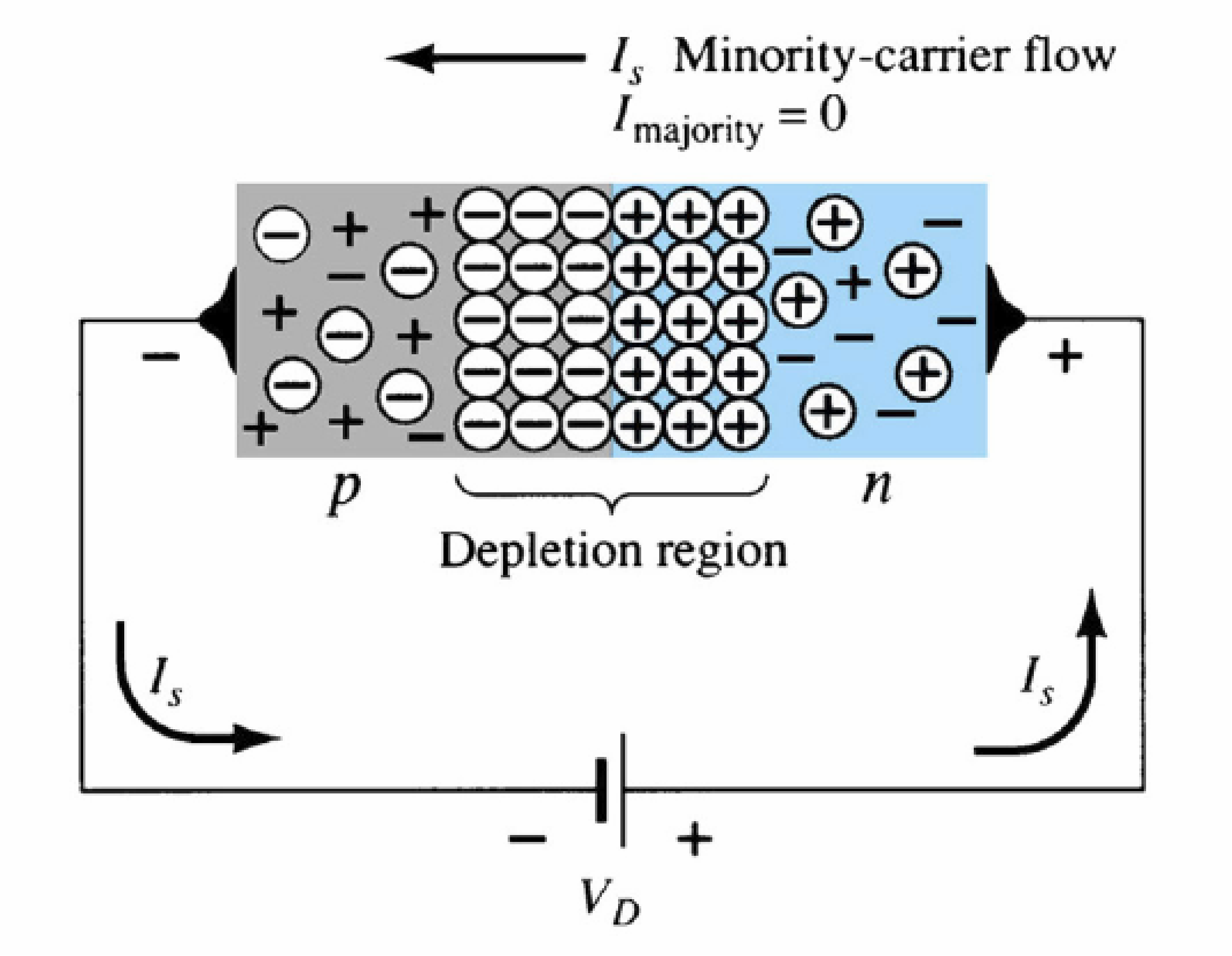
$$V_D = 0V$$



Operação do transistor

Relembrando os diodos:

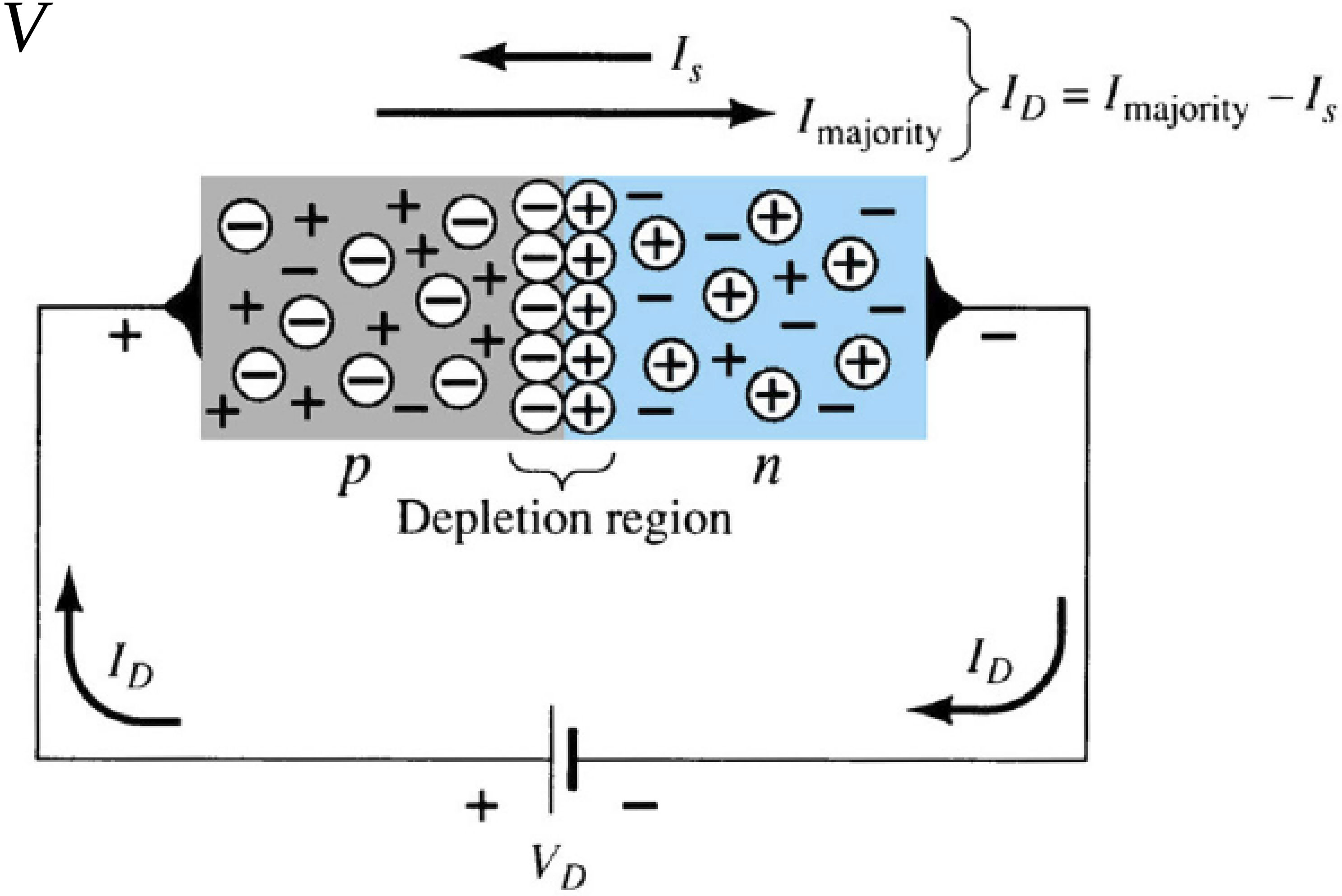
$V_D < 0V$



Operação do transistor

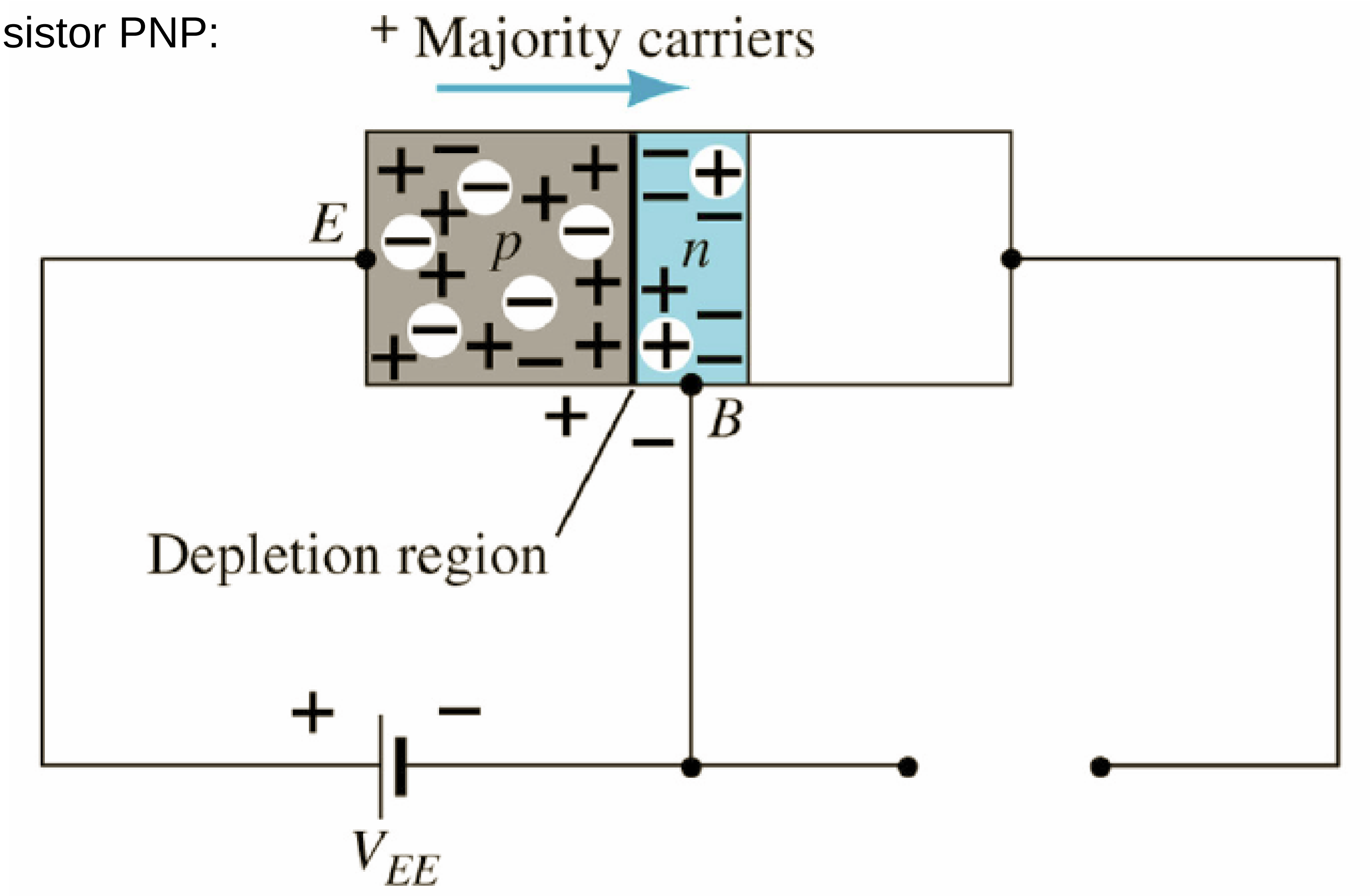
Relembrando os diodos:

$V_D > 0V$



Operação do transistor

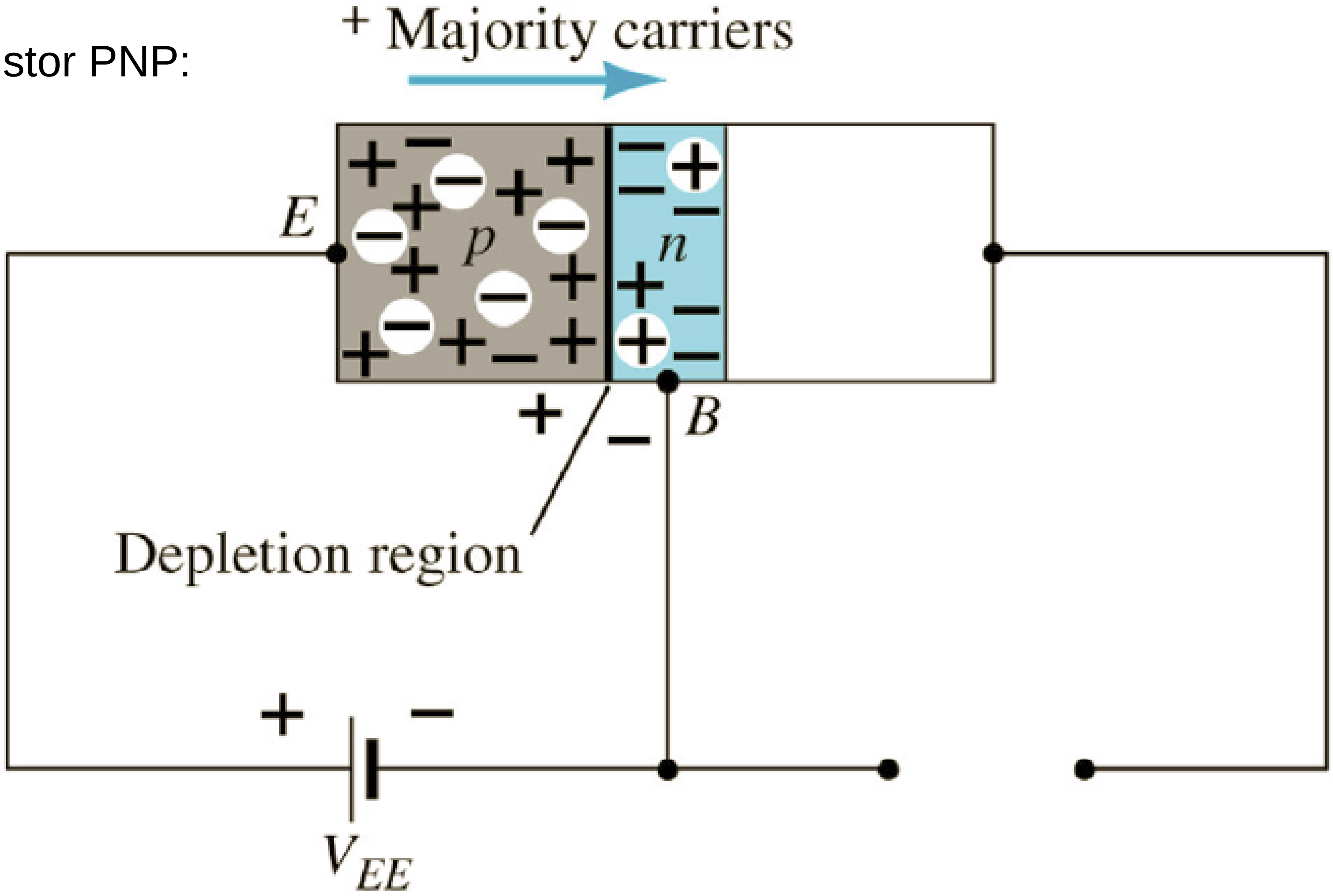
Transistor PNP:



Junção Base – emissor polarizada diretamente.

Operação do transistor

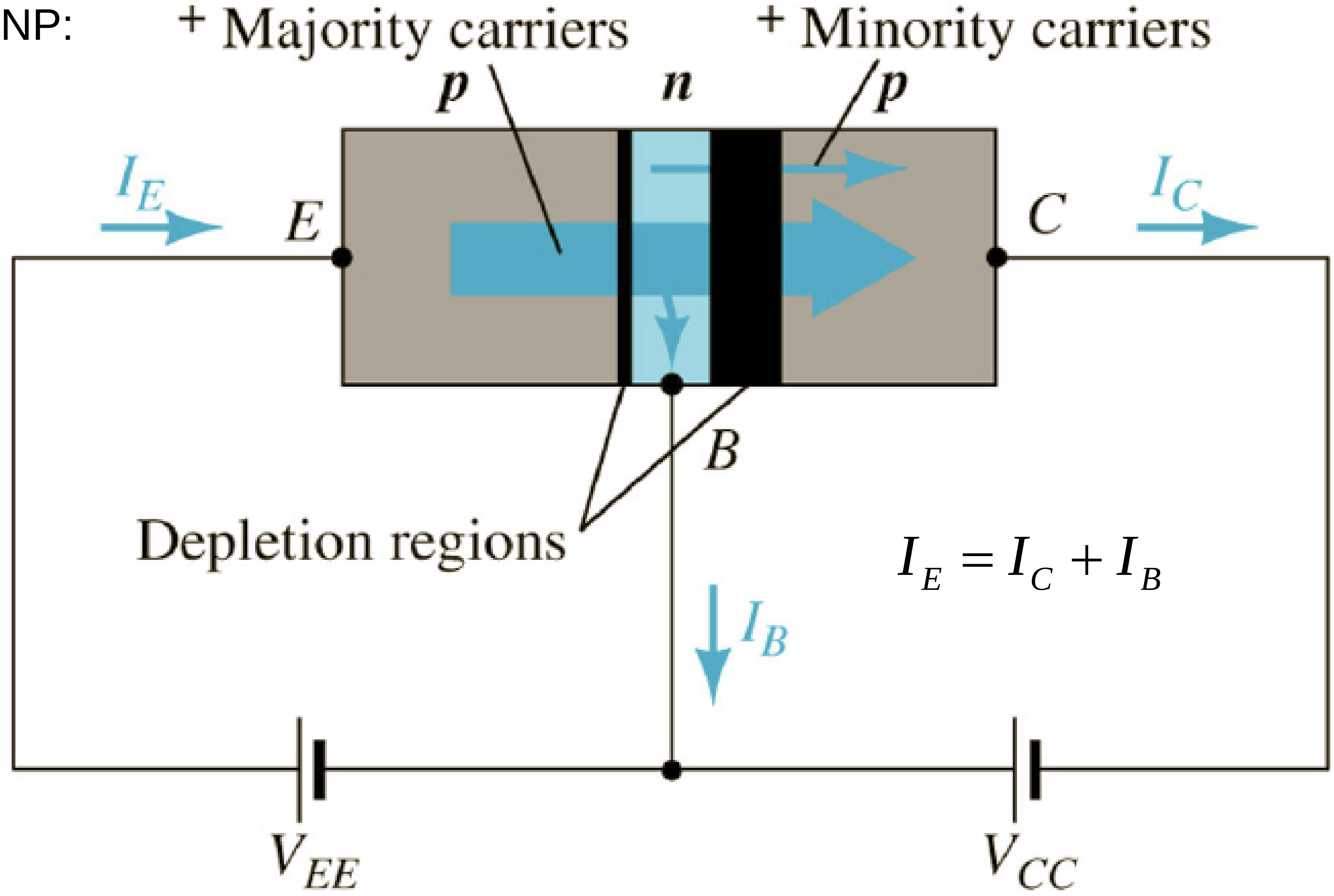
Transistor PNP:



Junção Base – coletor polarizada reversamente.

Operação do transistor

Transistor PNP:



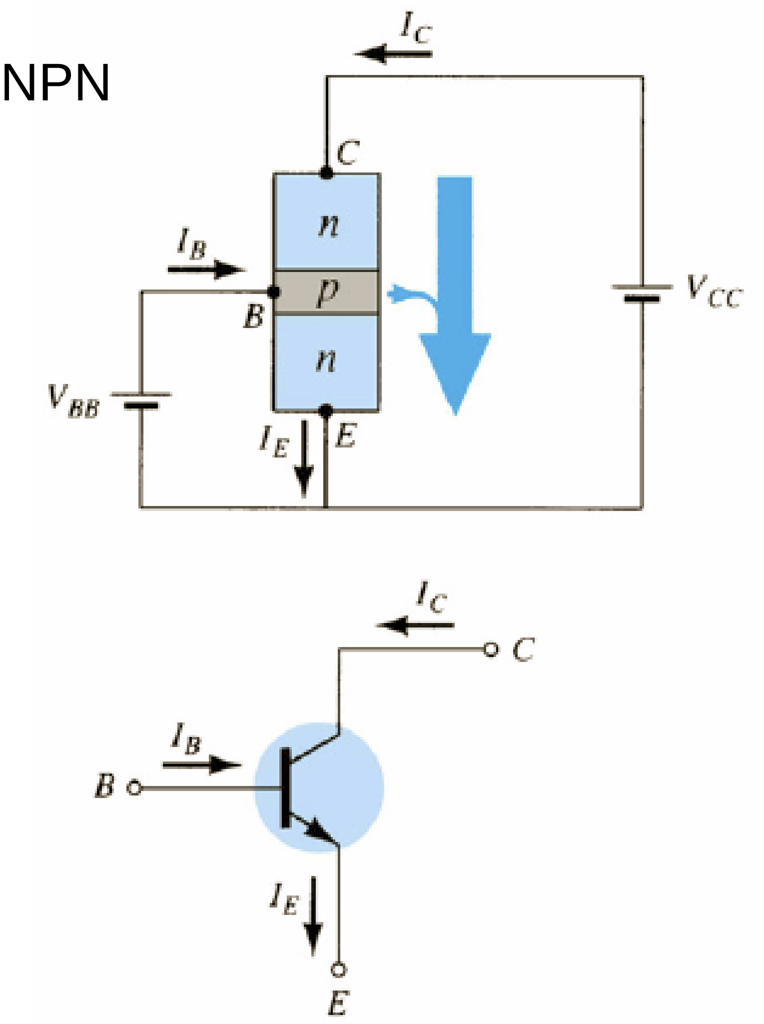
$$I_E = I_C + I_B$$

Correntes no transistor bipolar de junção.

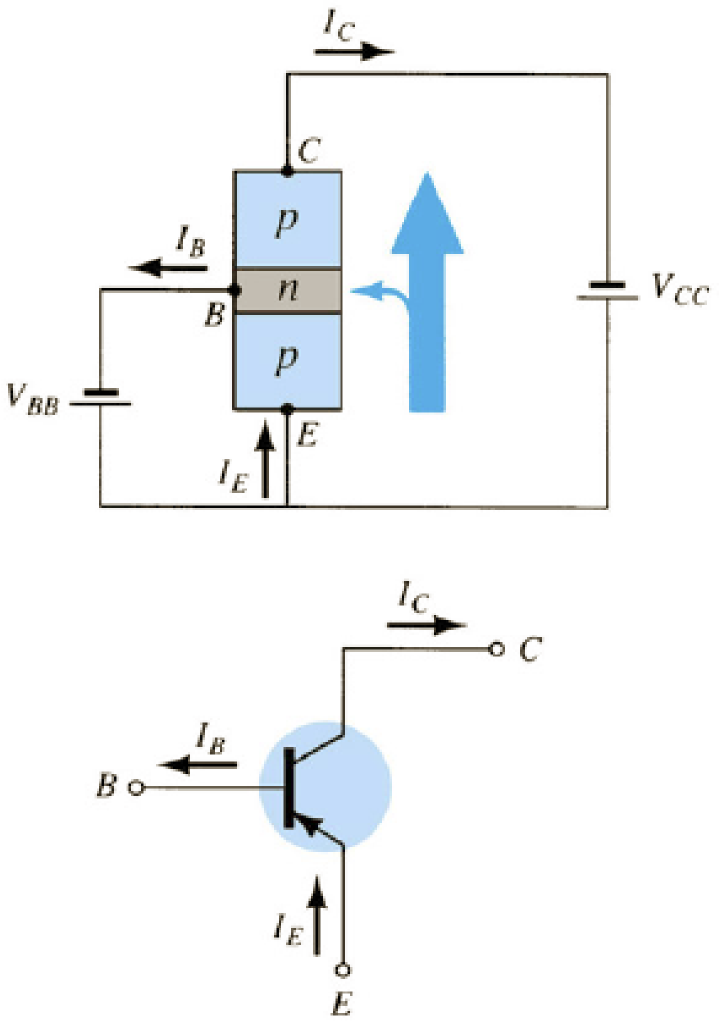
Configuração Emissor-Comum

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

NPN

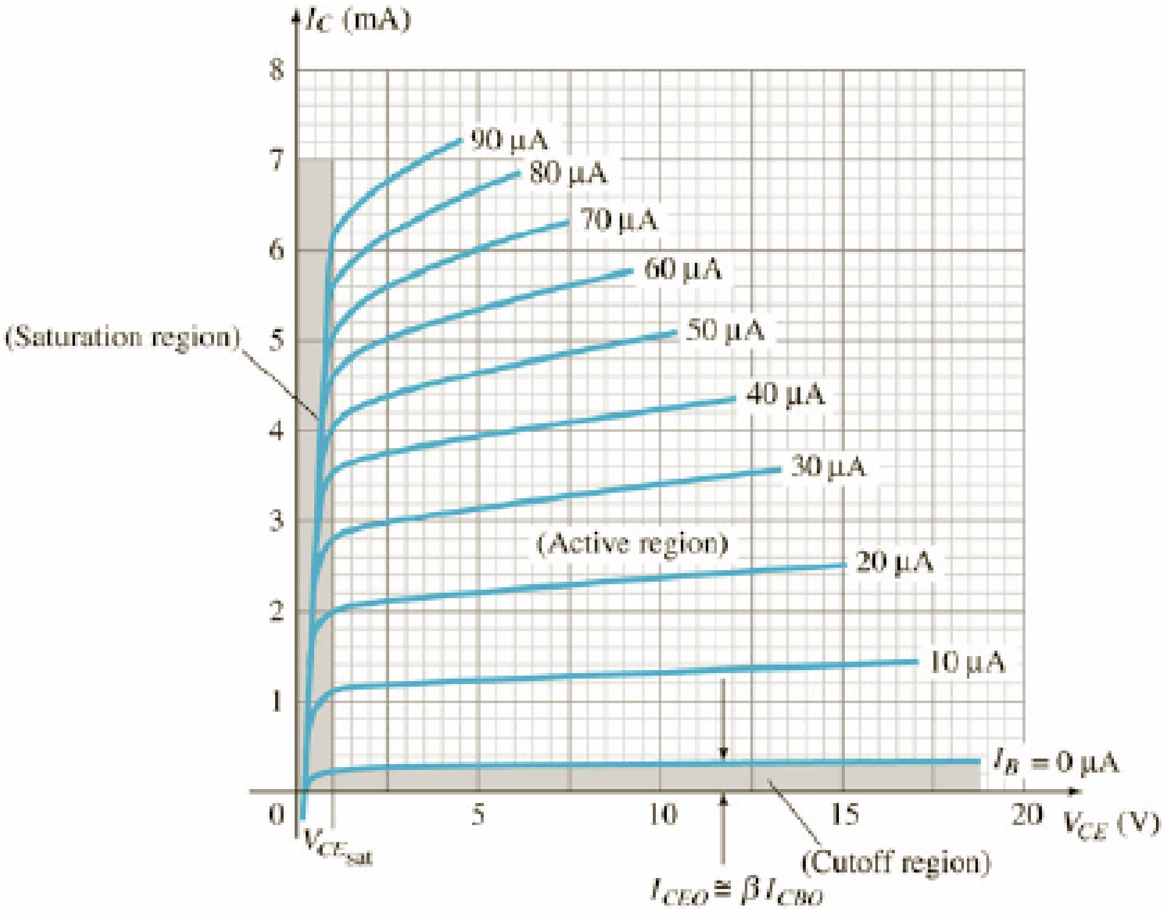


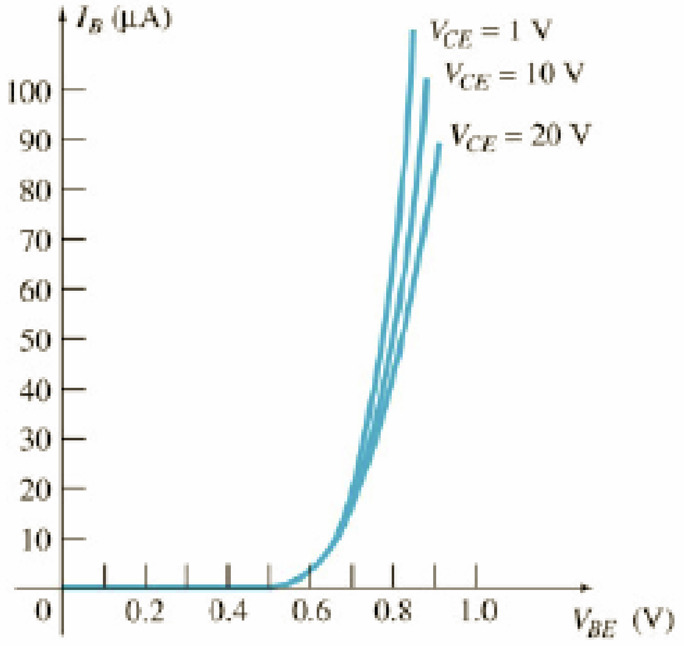
PNP



Configuração Emissor-Comum

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

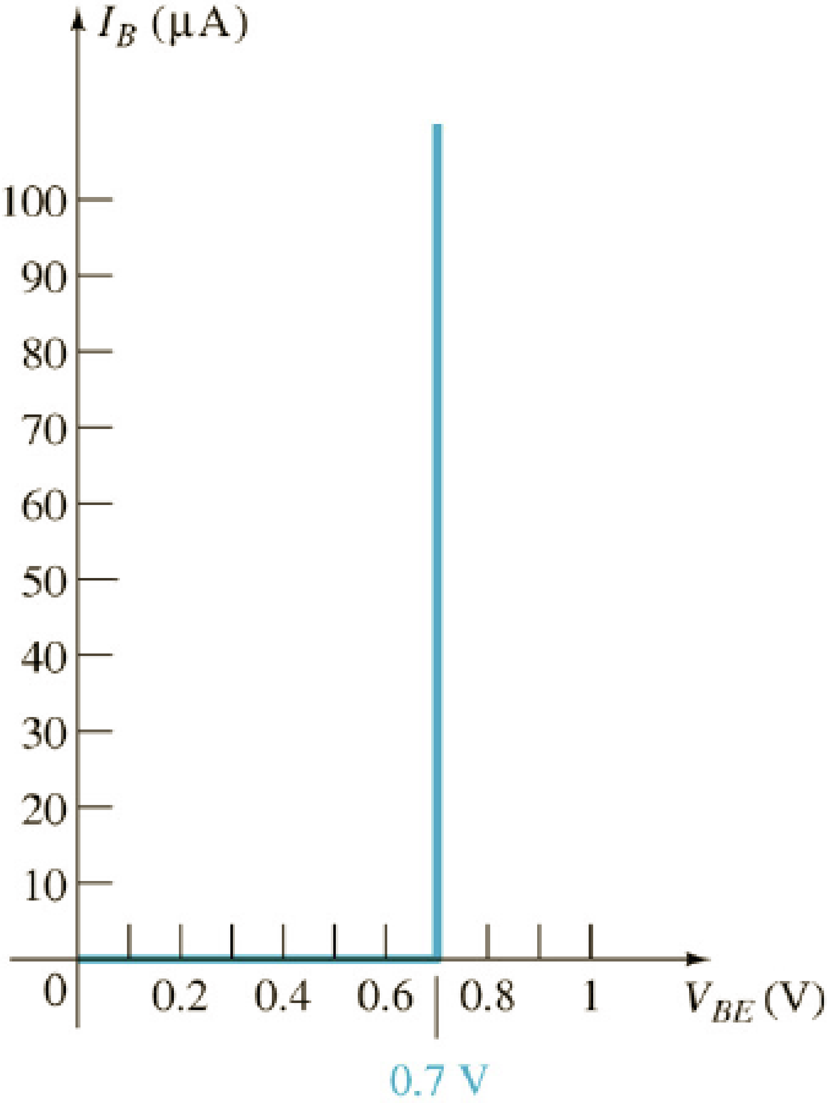




Configuração Emissor-Comum

Aproximação linear das características de base:

$$V_{BE} > 0V$$



Configuração Emissor-Comum

$$I_E = I_B + I_C$$

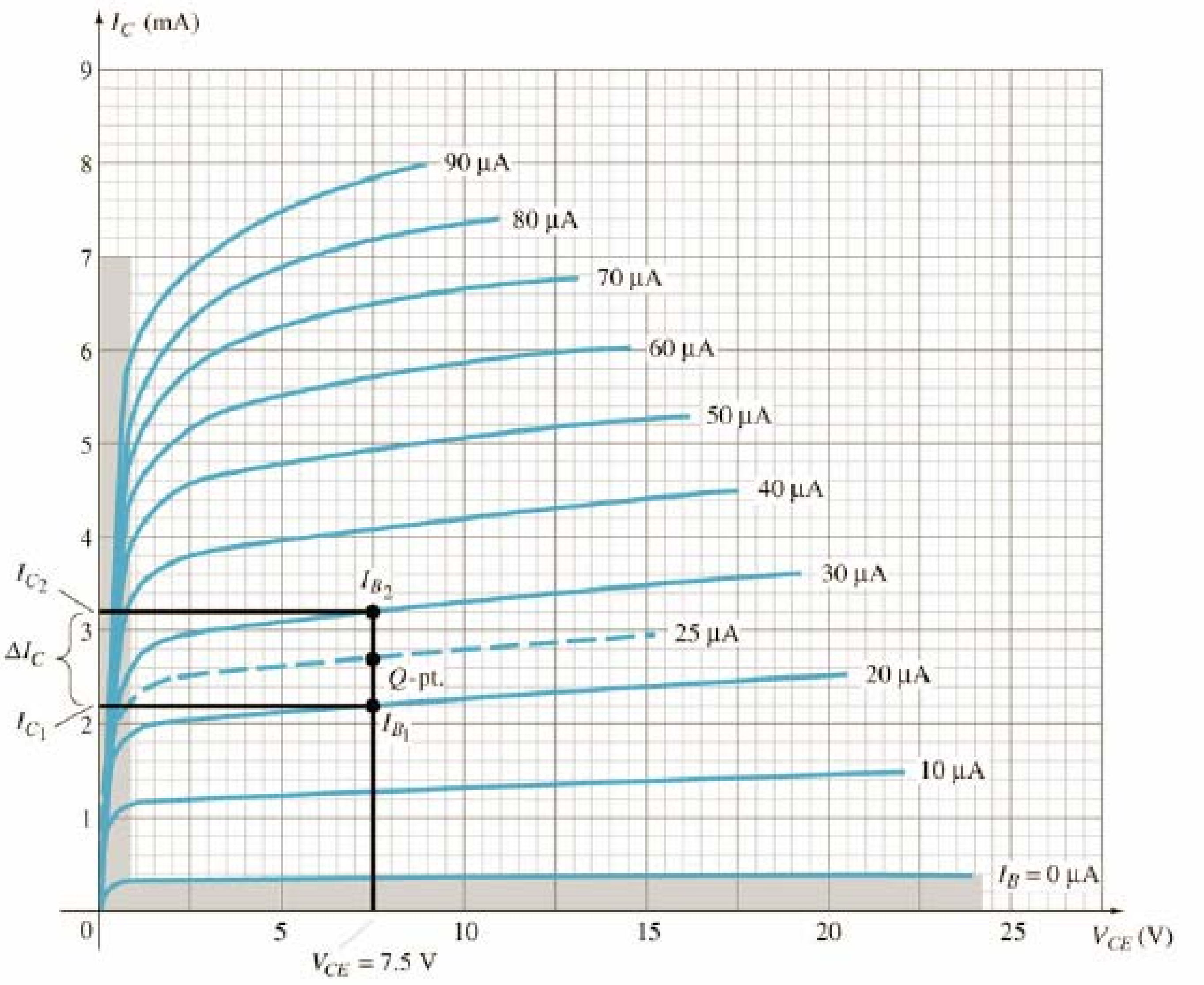
$$I_C = \alpha \cdot I_E$$

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

Ganho CC

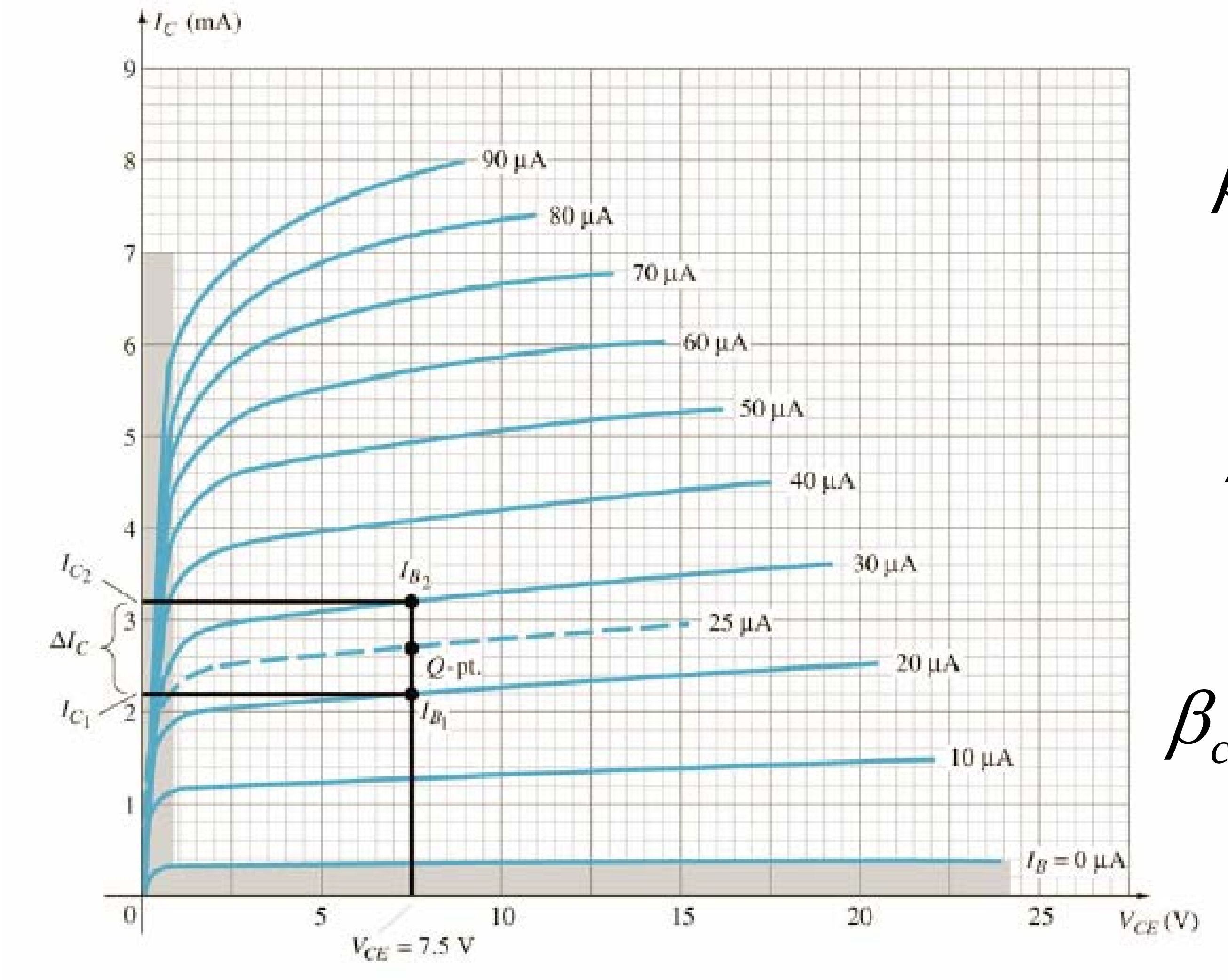
Ganho CA

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



Configuração Emissor-Comum

Exemplo:

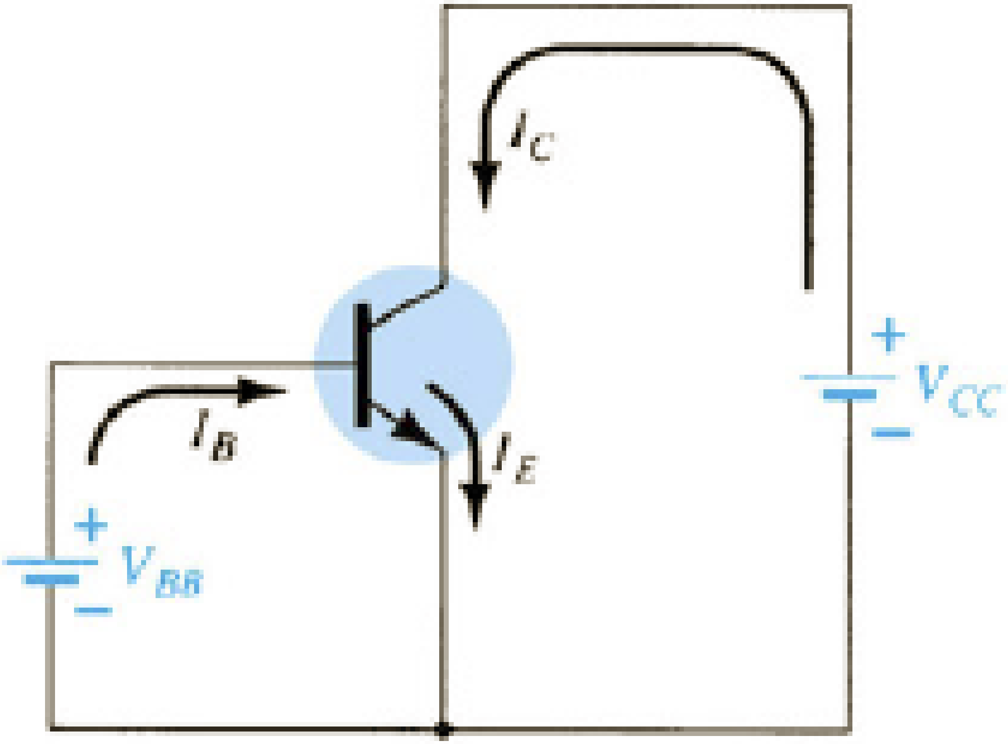


$$\beta_{cc} = \frac{I_C}{I_B} = \frac{2,7m}{25\mu} = 108$$

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

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

Polarização



$$I_C = \beta \cdot I_B$$

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

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

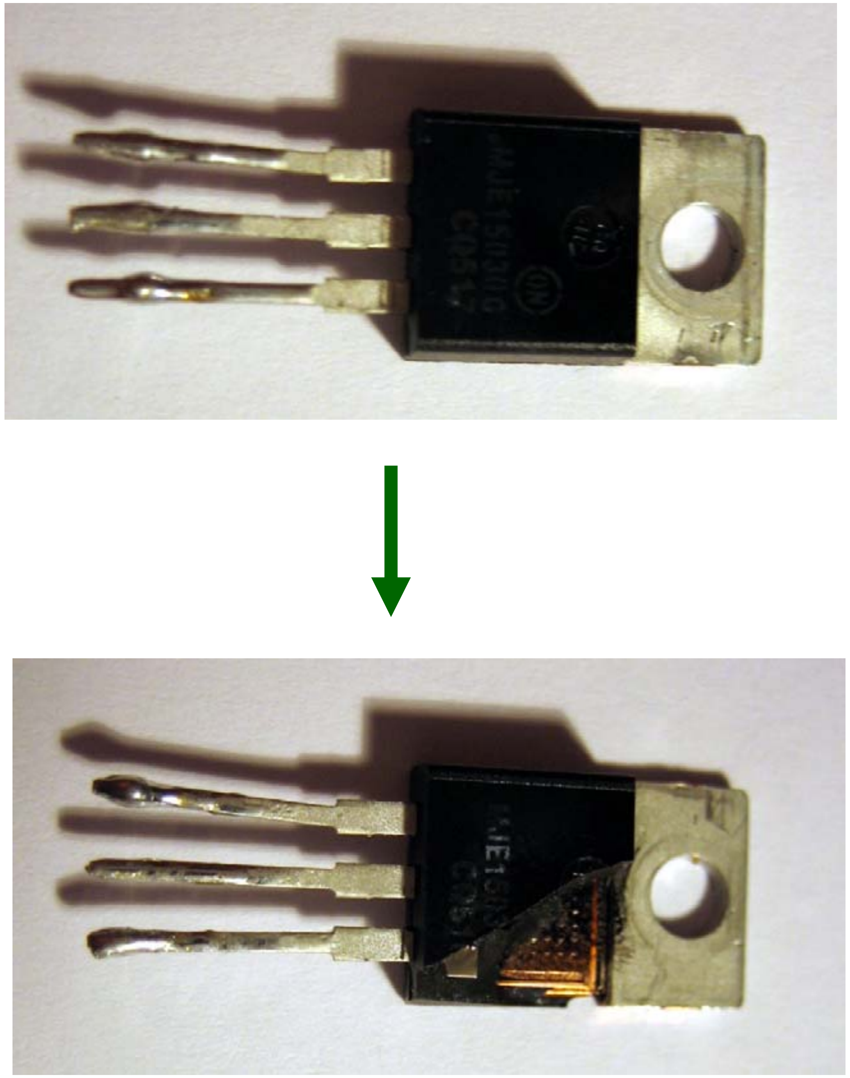
Limites de operação

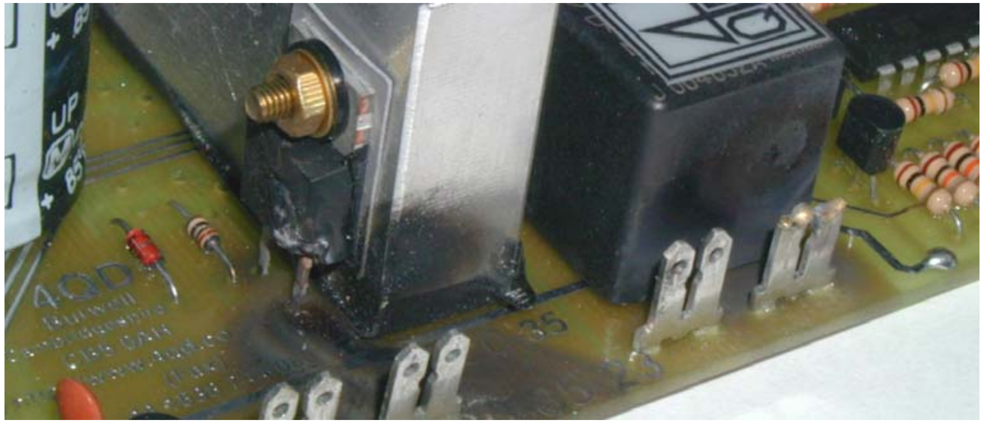
$$P_{Cmax} = V_{CE} \cdot I_C$$

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

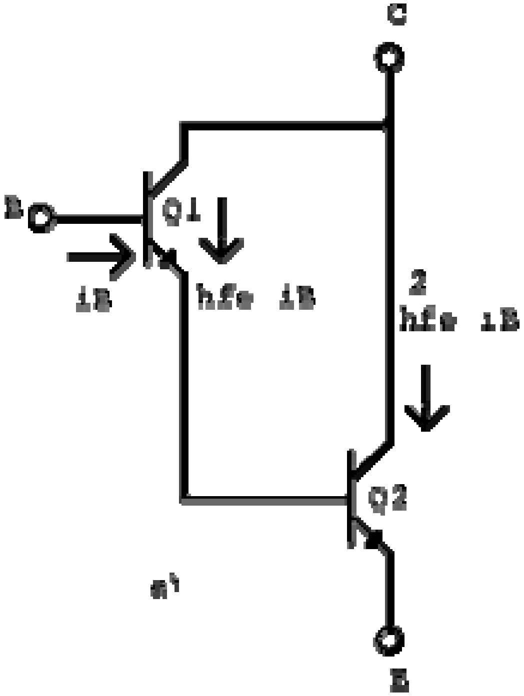
$$V_{CEsat} \le V_{CE} \le V_{CEmax}$$

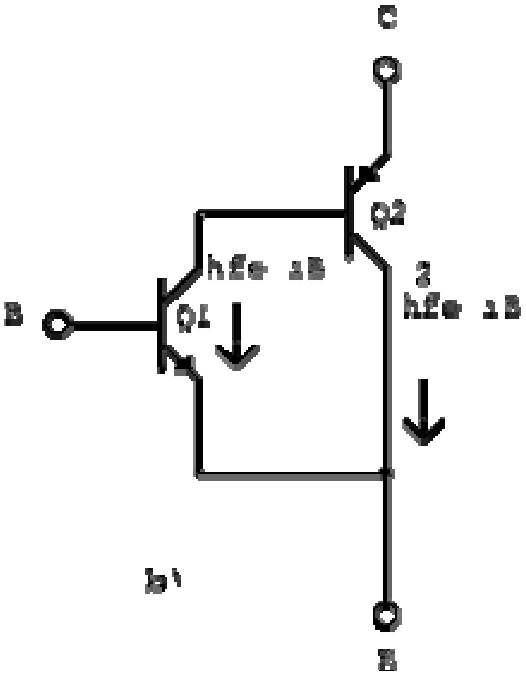
$$V_{CE} \cdot I_C \le P_{Cmax}$$

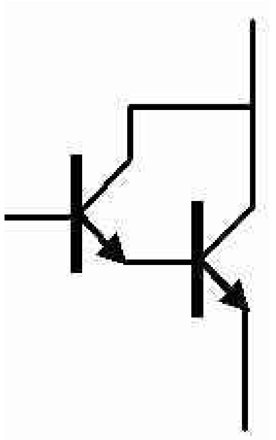




Transistores Darlington

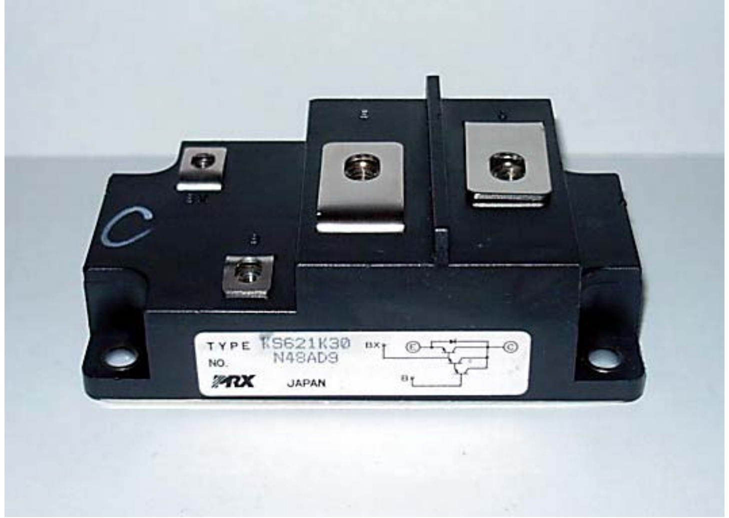


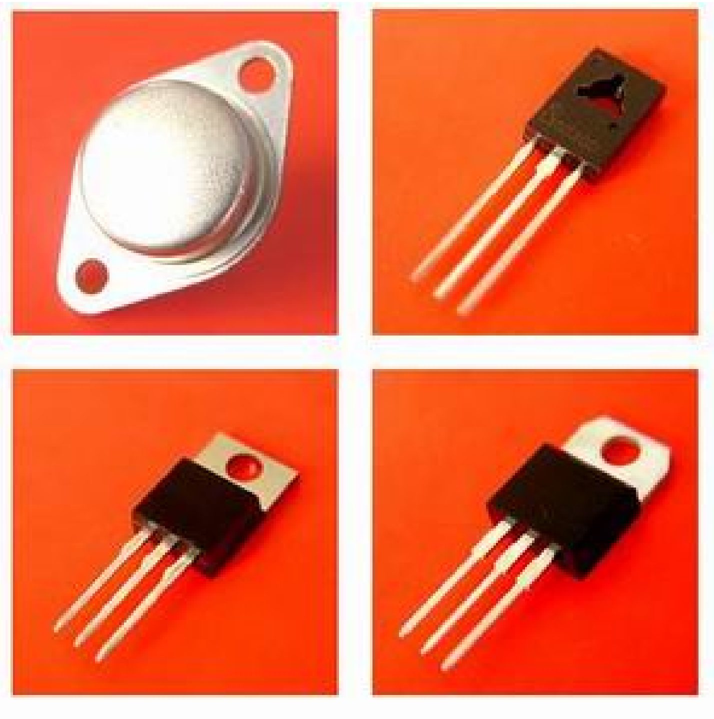




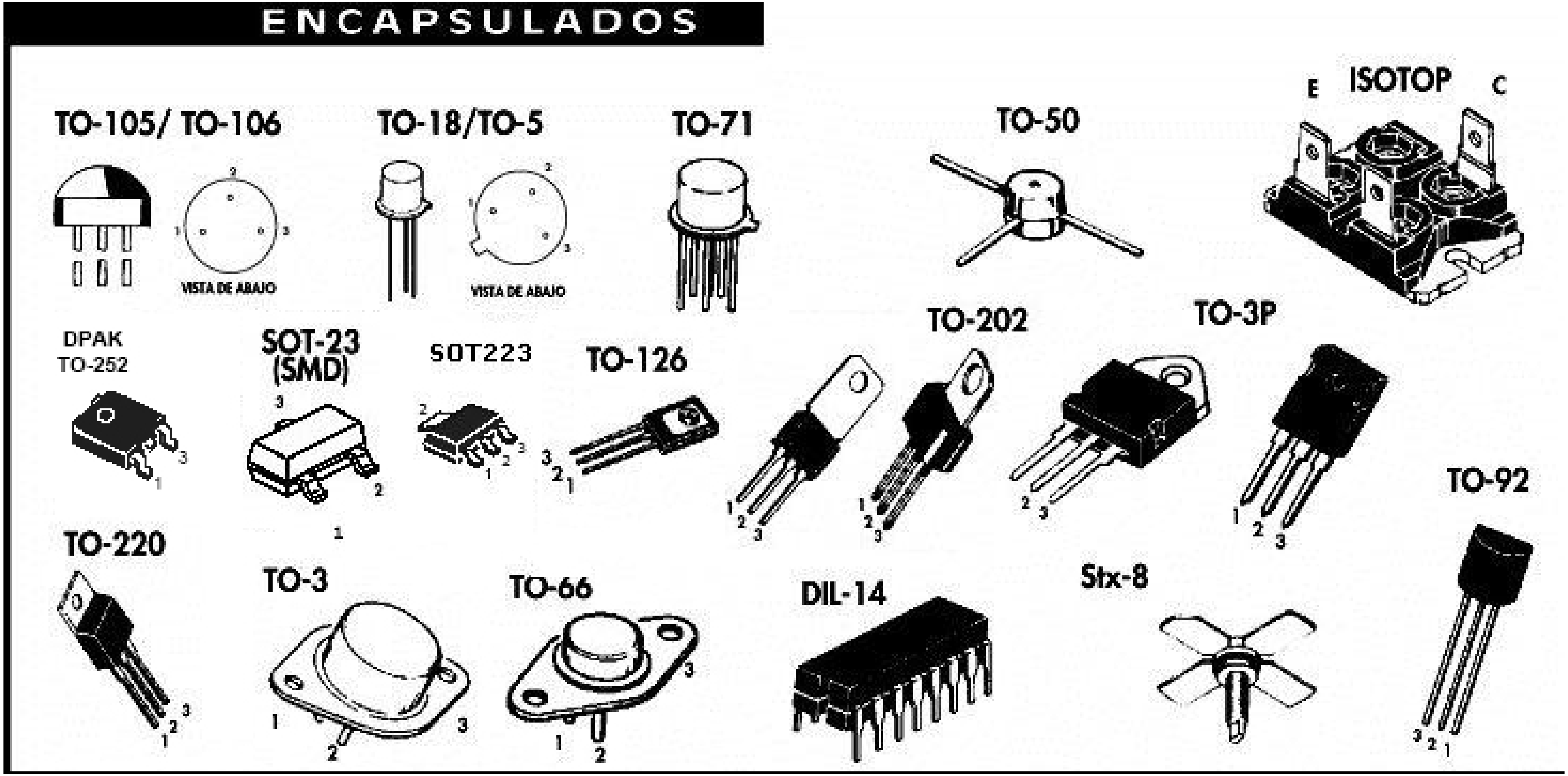
$$\beta_{total} = \beta_1 \cdot \beta_2$$

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

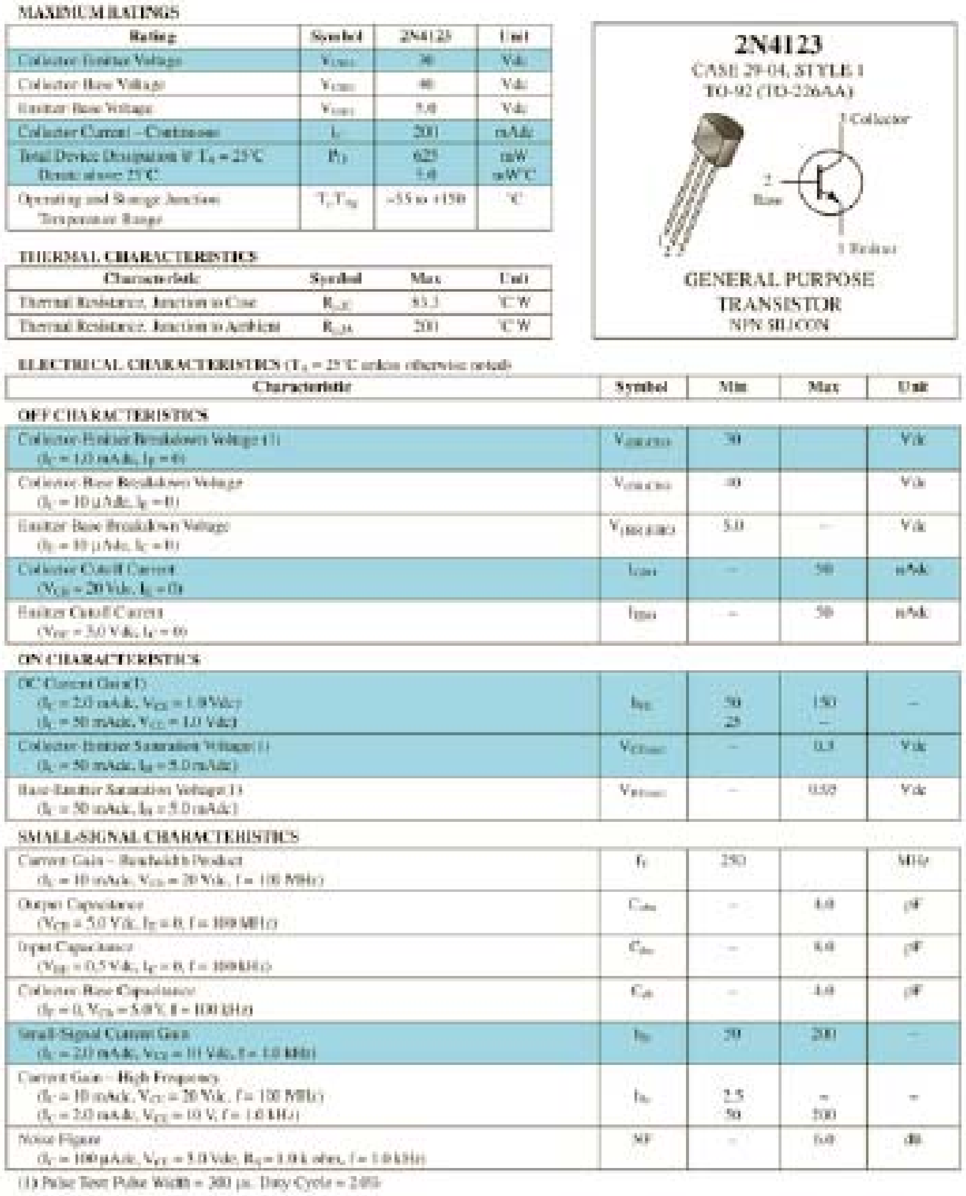




Encapsulamento de transistores



Características de catálogo



MAXIMUM RATINGS

Rating	Symbol	2N4123	Unit
Collector-Emitter Voltage	V_{CEO}	30	Vdc
Collector-Base Voltage	V_{CBO}	40	Vdc
Emitter-Base Voltage	V_{EBO}	5.0	Vdc
Collector Current – Continuous	I_C	200	mAdc
Total Device Dissipation @ T_A = 25°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	$R_{\theta JC}$	83.3	°C/W
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	200	°C/W

2N4123

CASE 29-04, STYLE 1

TO-92 (TO-226AA)

GENERAL PURPOSE
TRANSISTOR
NPN SILICON

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Max	Unit
OFF CHARACTERISTICS				
Collector-Emitter Breakdown Voltage (1) (I_C = 1.0 mAdc, I_B = 0)	$V_{(BR)CEO}$	30		Vdc
Collector-Base Breakdown Voltage (I_C = 10 μAdc, I_E = 0)	$V_{(BR)CBO}$	40		Vdc
Emitter-Base Breakdown Voltage (I_E = 10 μAdc, I_C = 0)	$V_{(BR)EBO}$	5.0	–	Vdc
Collector Cutoff Current (V_{CB} = 20 Vdc, I_E = 0)	I_{CBO}	–	50	nAdc
Emitter Cutoff Current (V_{BE} = 3.0 Vdc, I_C = 0)	I_{EBO}	–	50	nAdc
ON CHARACTERISTICS				
DC Current Gain(1) (I_C = 2.0 mAdc, V_{CE} = 1.0 Vdc) (I_C = 50 mAdc, V_{CE} = 1.0 Vdc)	h_{FE}	50 25	150 –	–
Collector-Emitter Saturation Voltage (1) (I_C = 50 mAdc, I_B = 5.0 mAdc)	$V_{CE(sat)}$	–	0.3	Vdc
Base-Emitter Saturation Voltage (1) (I_C = 50 mAdc, I_B = 5.0 mAdc)	$V_{BE(sat)}$	–	0.95	Vdc
SMALL-SIGNAL CHARACTERISTICS				
Current Gain – Bandwidth Product (I_C = 10 mAdc, V_{CE} = 20 Vdc, f = 100 MHz)	f_T	250		MHz
Output Capacitance (V_{CB} = 5.0 Vdc, I_E = 0, f = 100 kHz)	C_{obo}	–	4.0	pF
Input Capacitance (V_{EB} = 0.5 Vdc, I_C = 0, f = 100 kHz)	C_{ibo}	–	8.0	pF
Collector-Base Capacitance (I_E = 0, V_{CB} = 5.0 V, f = 100 kHz)	C_{cb}	–	4.0	pF
Small-Signal Current Gain (I_C = 2.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{fe}	50	200	–
Current Gain – High Frequency (I_C = 10 mAdc, V_{CE} = 20 Vdc, f = 100 MHz) (I_C = 2.0 mAdc, V_{CE} = 10 V, f = 1.0 kHz)	h_{fe}	2.5 50	– 200	–
Noise Figure (I_C = 100 μAdc, V_{CE} = 5.0 Vdc, R_S = 1.0 k ohm, f = 1.0 kHz)	NF	–	6.0	dB

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

Exemplos:

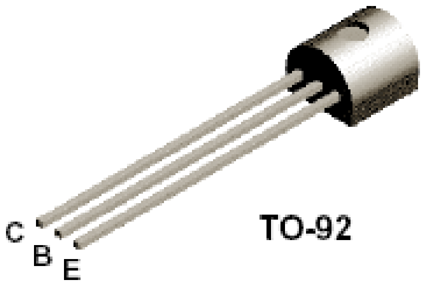
BC548

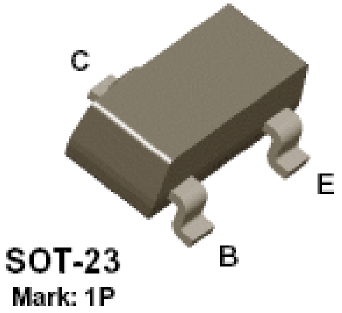
2N3055

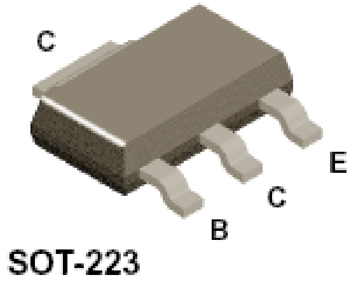
Tipos de transistores

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*

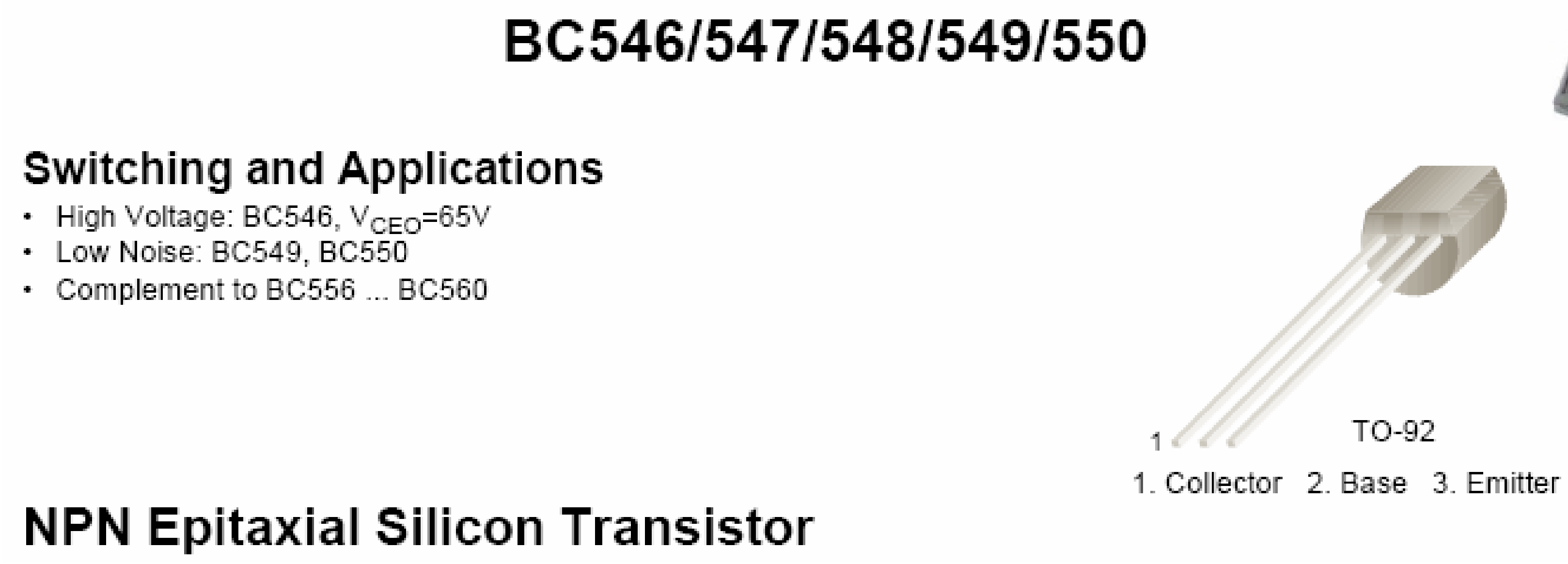
T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	75	V
V_{EBO}	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

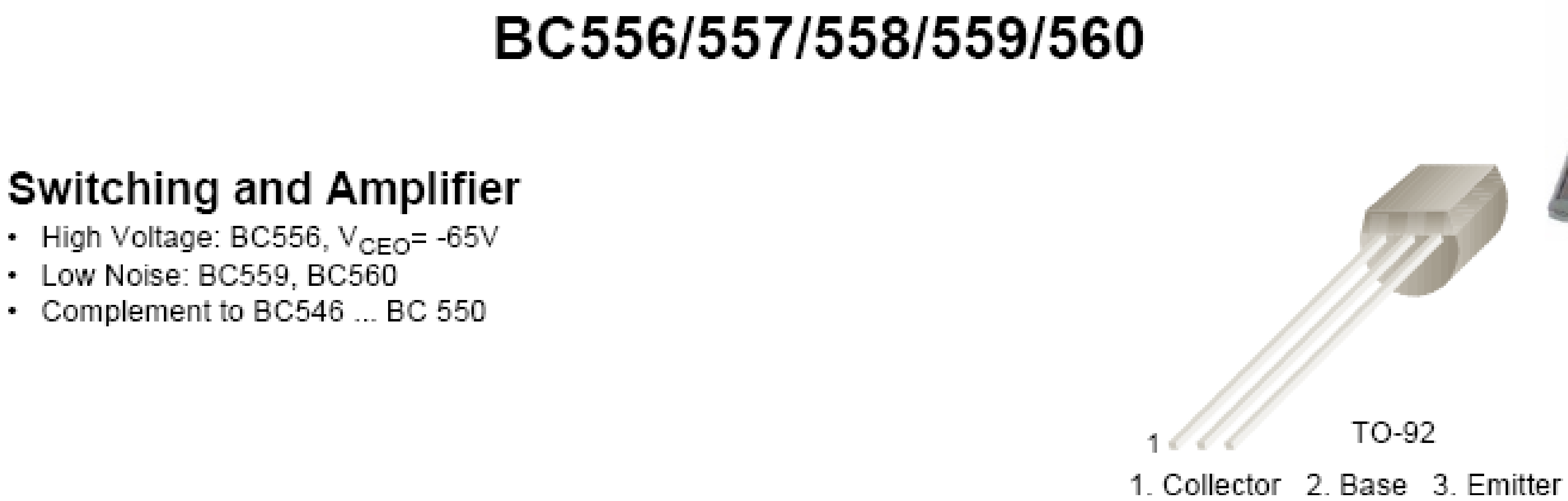


BC546/547/548/549/550

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

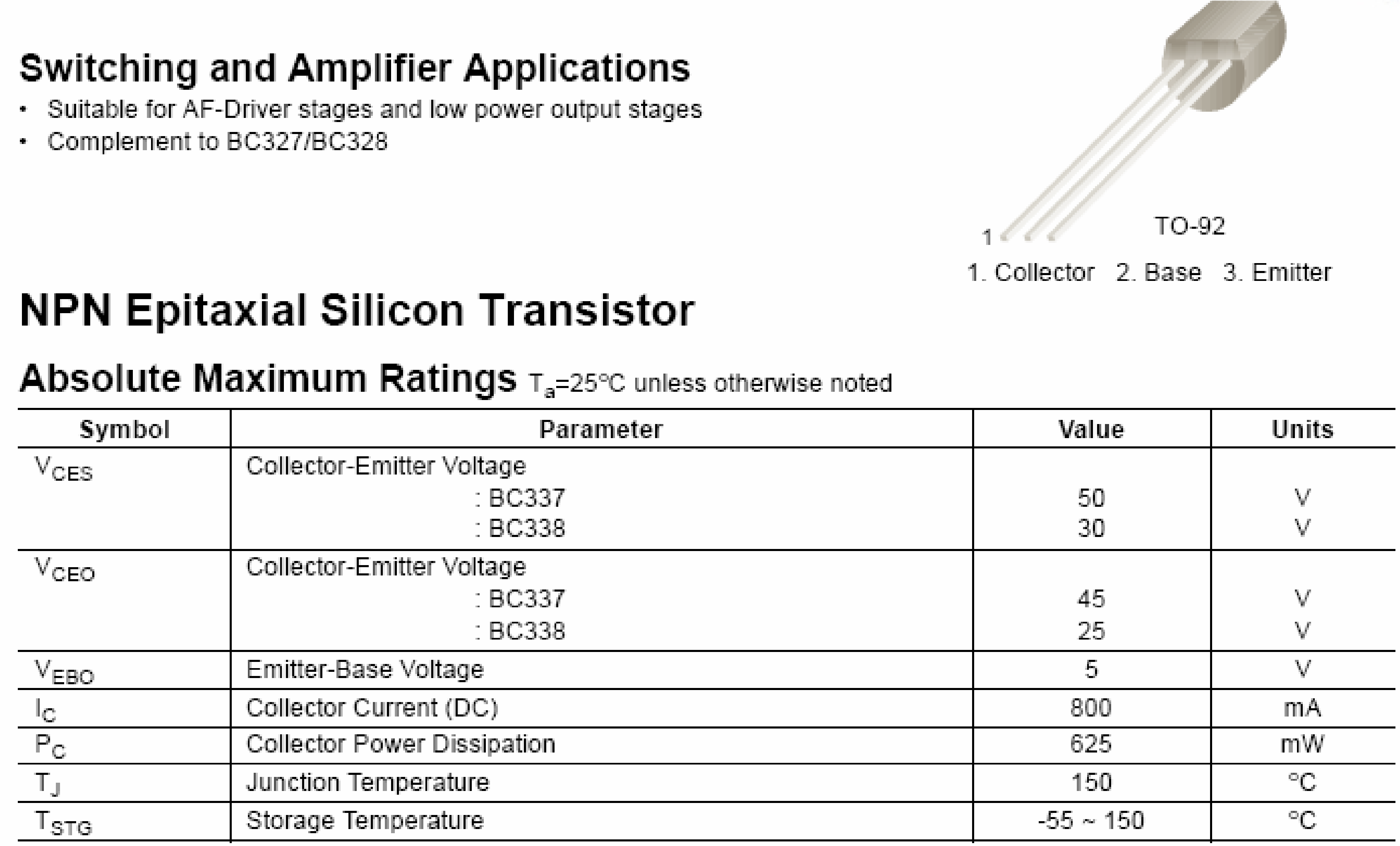
Switching and Amplifier

- 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

TO-92

1

1. Collector 2. Base 3. Emitter

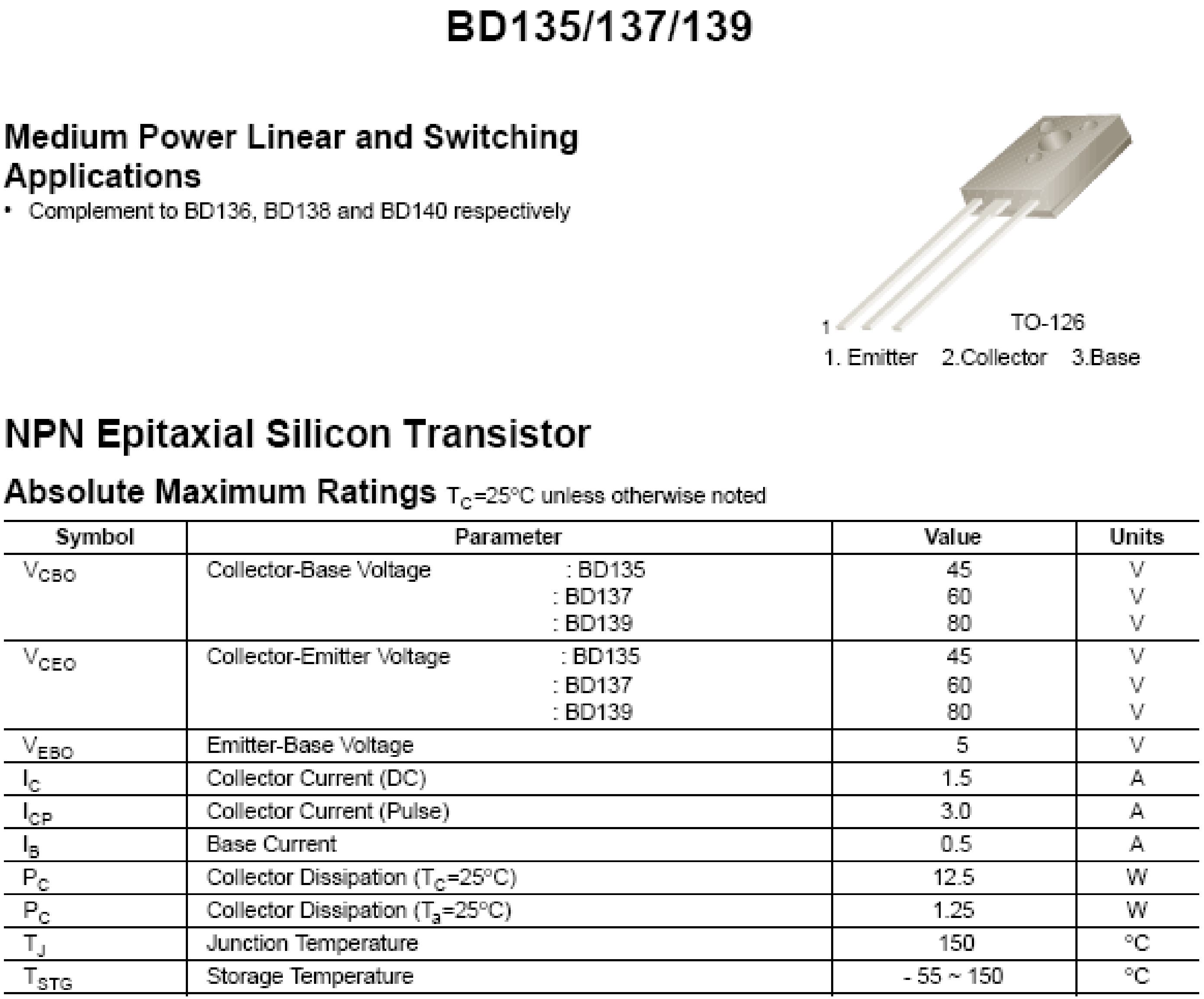
NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings T_a=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CES}	Collector-Emitter Voltage : BC337 : BC338	 50 30	 V V
V_{CEO}	Collector-Emitter Voltage : BC337 : BC338	 45 25	 V 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	°C
T_{STG}	Storage Temperature	-55 ~ 150	°C

Tipos de transistores

Transistores de média potência:



BD135/137/139

Medium Power Linear and Switching Applications

- Complement to BD136, BD138 and BD140 respectively

1

TO-126

1. Emitter 2.Collector 3.Base

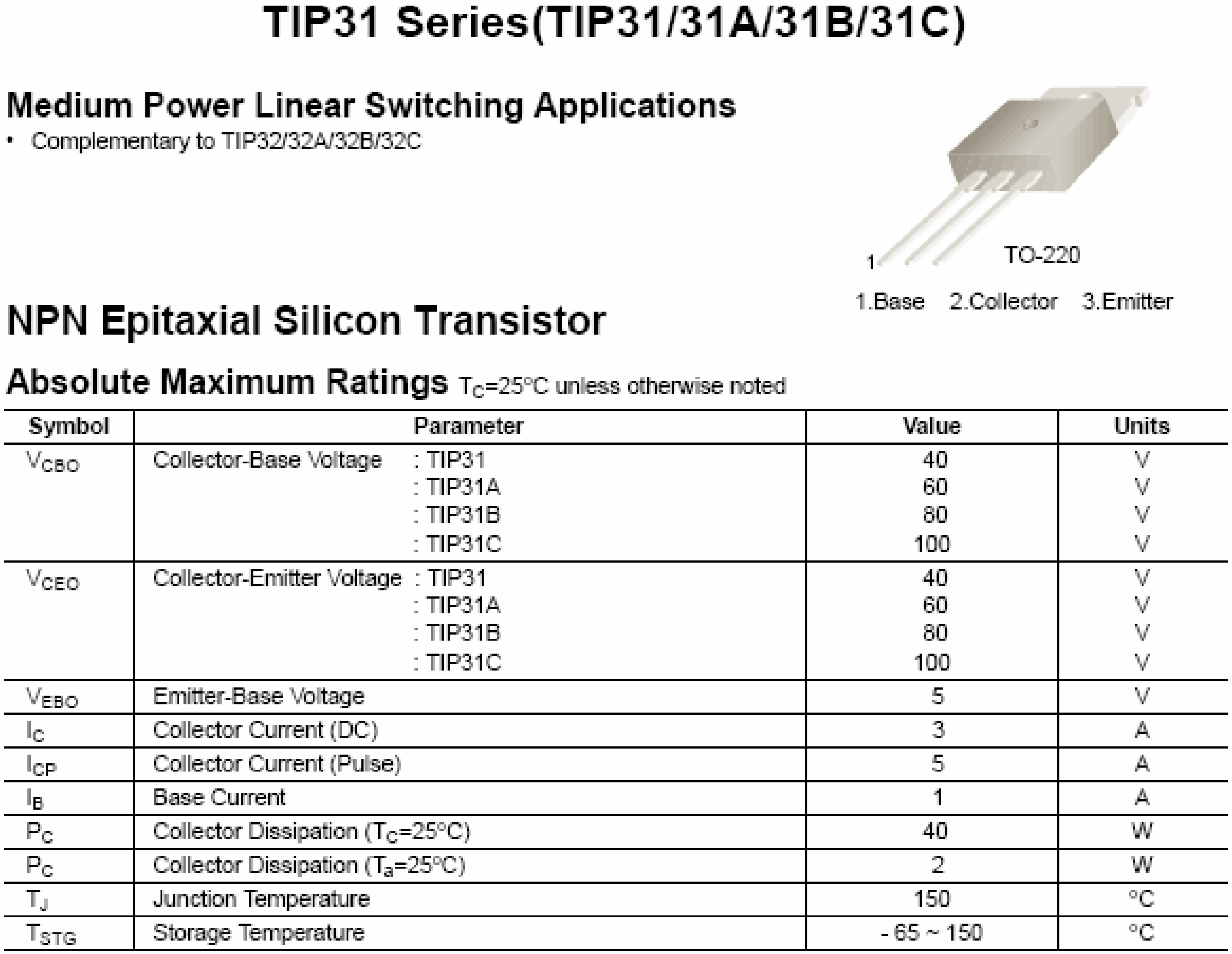
NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings T_C=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage : BD135 : BD137 : BD139	45 60 80	V V V
V_{CEO}	Collector-Emitter Voltage : BD135 : BD137 : BD139	45 60 80	V V 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°C)	12.5	W
P_C	Collector Dissipation (T_a=25°C)	1.25	W
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	- 55 ~ 150	°C

Tipos de transistores

Transistores de média potência:



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

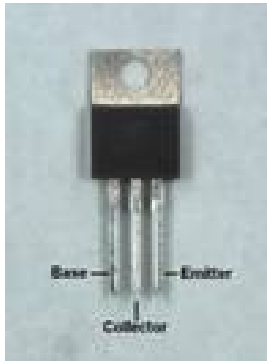
Medium Power Linear Switching Applications

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

NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings T_C=25°C unless otherwise noted

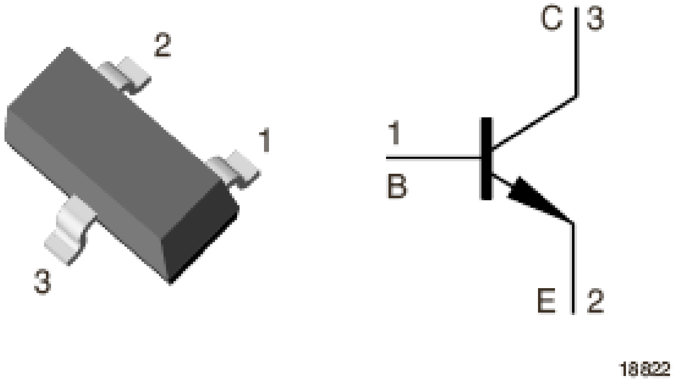
Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage : TIP31 : TIP31A : TIP31B : TIP31C	40 60 80 100	V V V V
V_{CEO}	Collector-Emitter Voltage : TIP31 : TIP31A : TIP31B : TIP31C	40 60 80 100	V V V V
V_{EBO}	Emitter-Base Voltage	5	V
I_C	Collector Current (DC)	3	A
I_{CP}	Collector Current (Pulse)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



Tipos de transistores

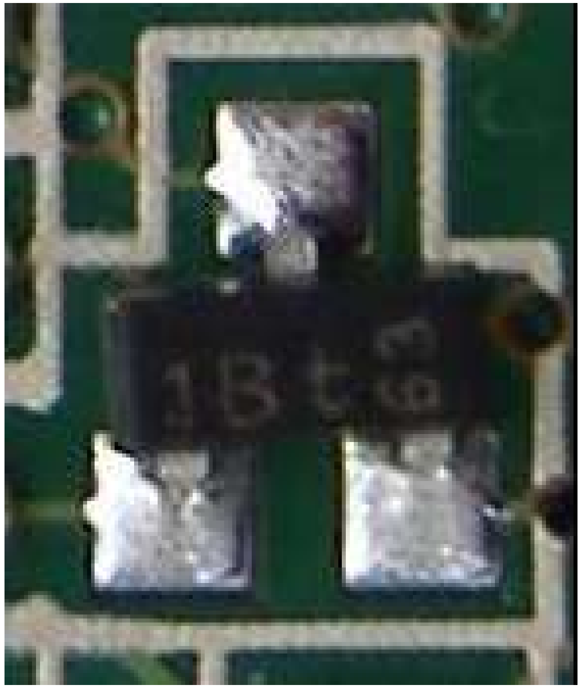
Transistores SMD:

Small Signal Transistors (NPN)



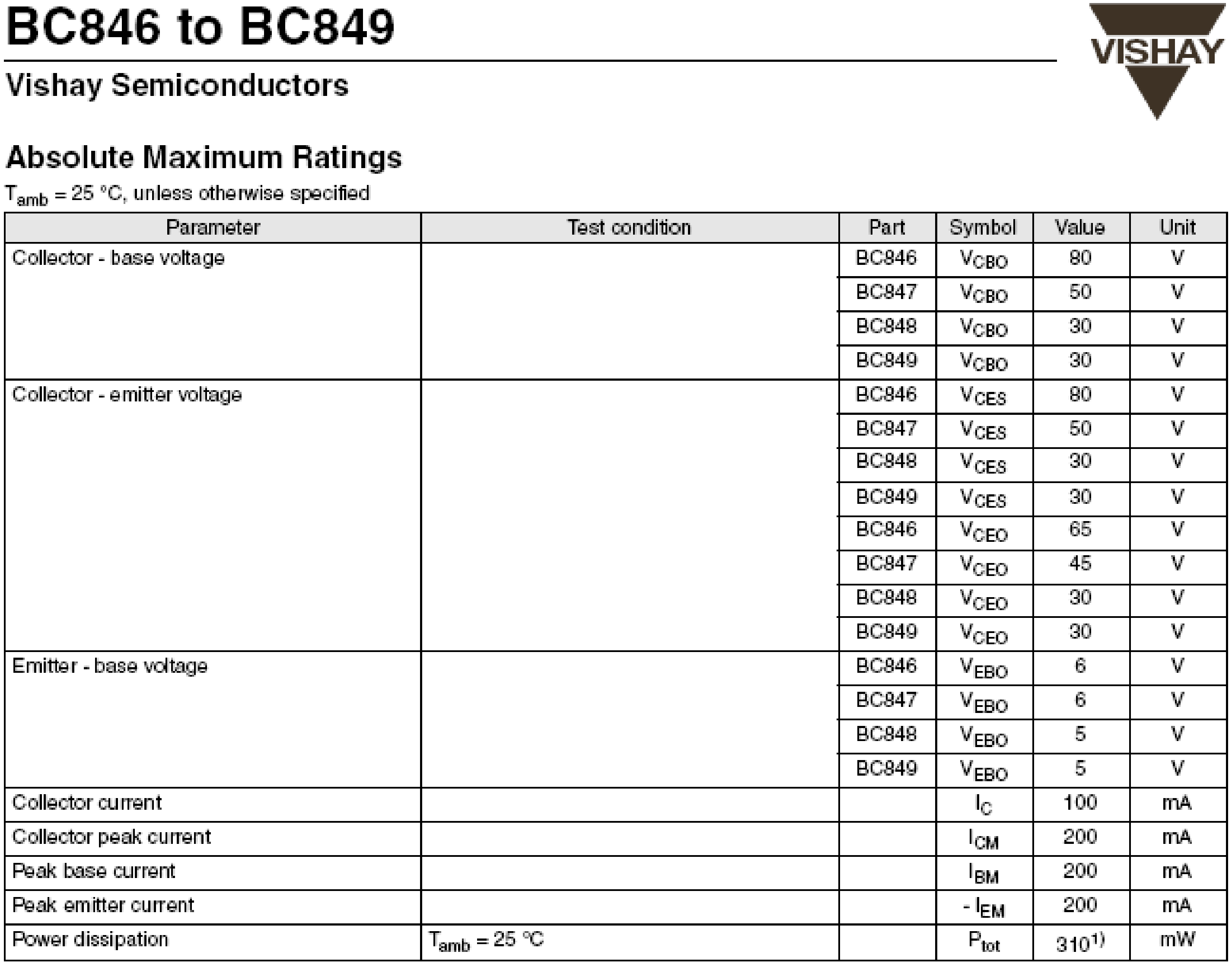
Features

- 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.



Tipos de transistores

Transistores SMD:



BC846 to BC849

Vishay Semiconductors

Absolute Maximum Ratings

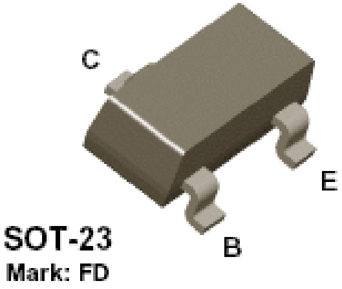
T_{amb} = 25 °C, unless otherwise specified

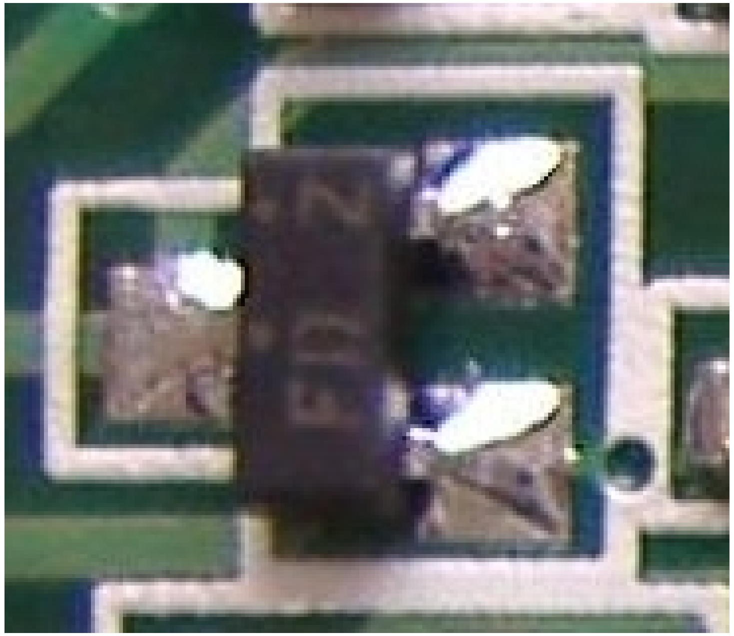
Parameter	Test condition	Part	Symbol	Value	Unit
Collector - base voltage		BC846	V_{CBO}	80	V
		BC847	V_{CBO}	50	V
		BC848	V_{CBO}	30	V
		BC849	V_{CBO}	30	V
Collector - emitter voltage		BC846	V_{CES}	80	V
		BC847	V_{CES}	50	V
		BC848	V_{CES}	30	V
		BC849	V_{CES}	30	V
		BC846	V_{CEO}	65	V
		BC847	V_{CEO}	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 °C		P_{tot}	310[1)]	mW

Tipos de transistores

Transistores SMD:

BCV26





PNP Darlington Transistor

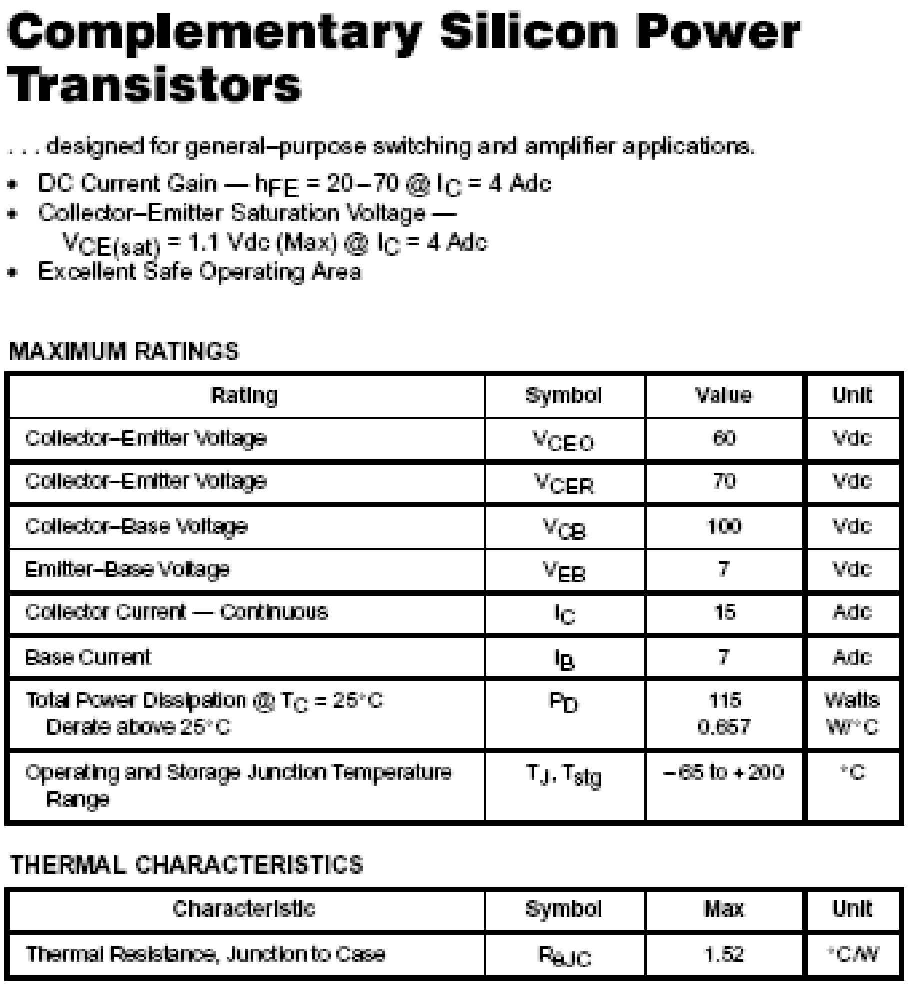
This device is designed for applications requiring extremely high current gain at currents to 800 mA. Sourced from Process 61.

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

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	30	V
V_{CBO}	Collector-Base Voltage	40	V
V_{EBO}	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.

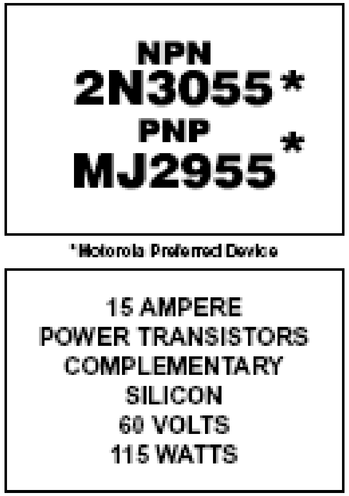
- DC Current Gain — h_{FE} = 20 – 70 @ I_C = 4 Adc
- Collector–Emitter Saturation Voltage —
  $V_{CE(sat)}$ = 1.1 Vdc (Max) @ I_C = 4 Adc
- Excellent Safe Operating Area

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	Adc
Base Current	I_B	7	Adc
Total Power Dissipation @ T_C = 25°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	°C

THERMAL CHARACTERISTICS

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



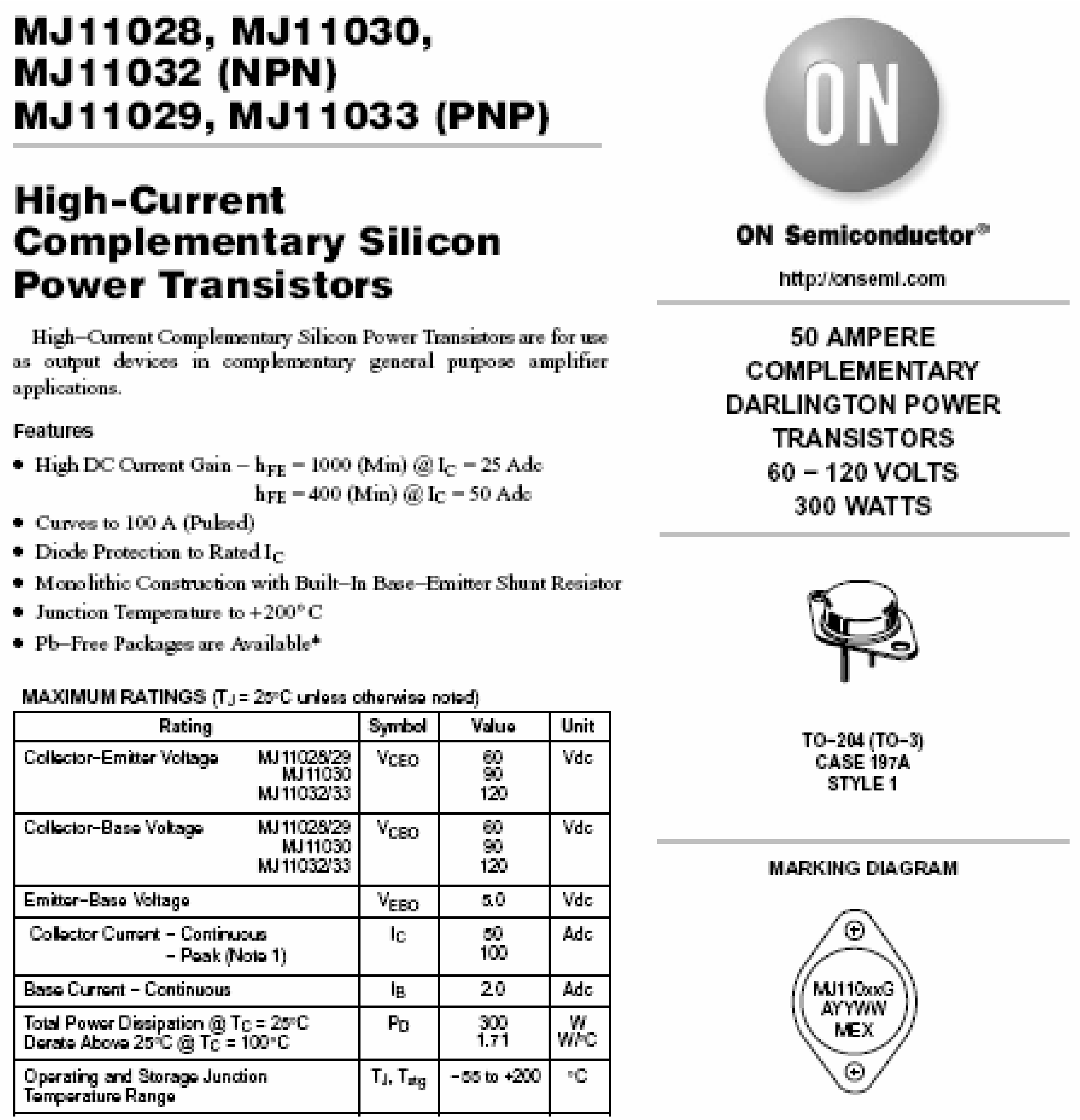
NPN
2N3055*
PNP
MJ2955*

*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 ($T_J = 25°C$ unless otherwise noted)

Rating		Symbol	Value	Unit
Collector–Emitter Voltage	MJ11028/29 MJ11030 MJ11032/33	V_{CEO}	60 90 120	Vdc
Collector–Base Voltage	MJ11028/29 MJ11030 MJ11032/33	V_{CBO}	60 90 120	Vdc
Emitter–Base Voltage		V_{EBO}	5.0	Vdc
Collector Current – Continuous – Peak (Note 1)		I_C	50 100	Adc
Base Current – Continuous		I_B	2.0	Adc
Total Power Dissipation @ $T_C = 25°C$ Derate Above 25°C @ $T_C = 100°C$		P_D	300 1.71	W W/°C
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

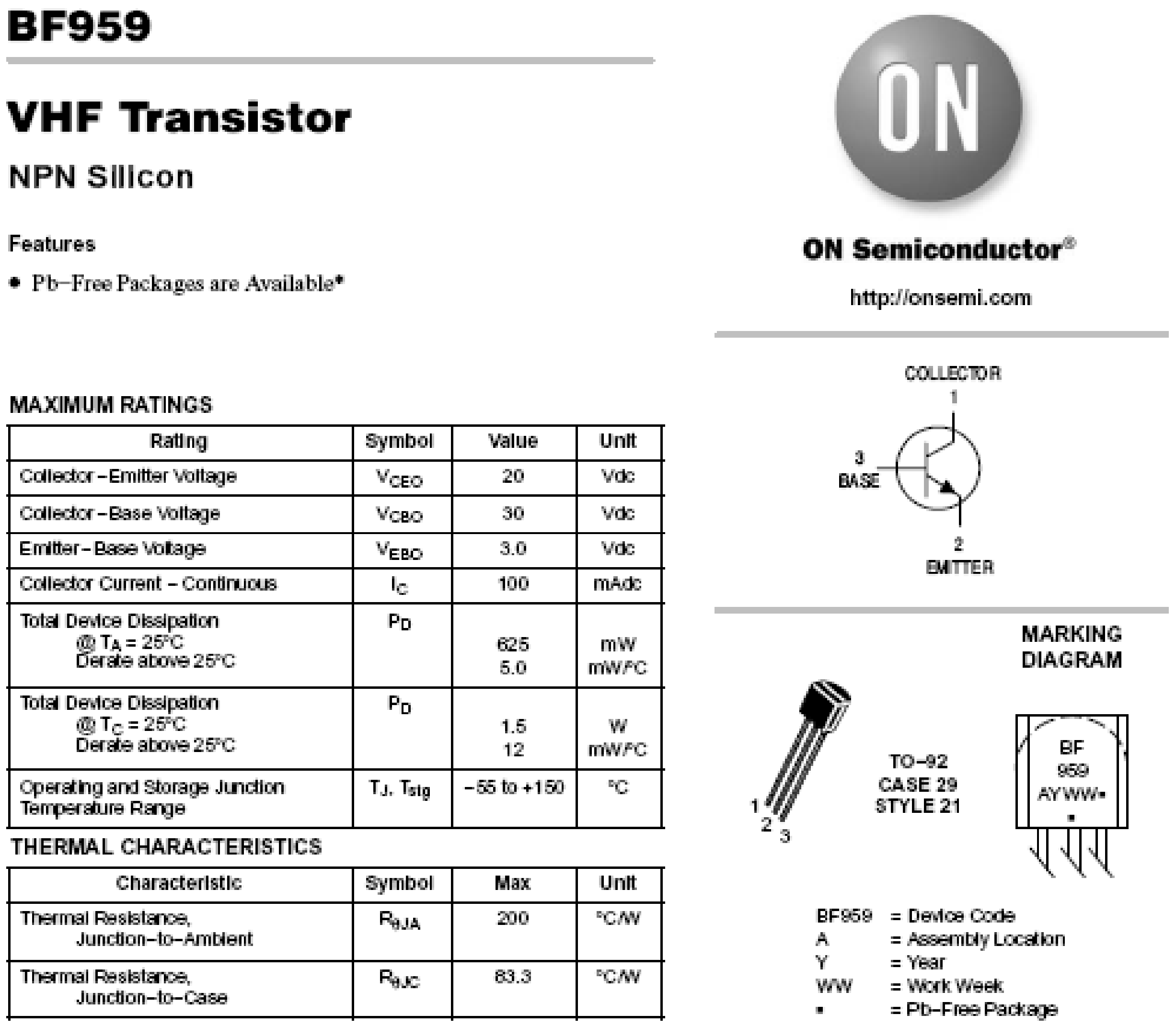
TO–204 (TO–3)
CASE 197A
STYLE 1

MARKING DIAGRAM

MJ110xxG
AYYWW
MEX

Tipos de transistores

Transistores de rádio freqüência:



BF959

VHF Transistor

NPN Silicon

Features

- Pb−Free Packages are Available*

ON Semiconductor®

http://onsemi.com

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector−Emitter Voltage	V_{CEO}	20	Vdc
Collector−Base Voltage	V_{CBO}	30	Vdc
Emitter−Base Voltage	V_{EBO}	3.0	Vdc
Collector Current − Continuous	I_C	100	mAdc
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	 625 5.0	 mW mW/°C
Total Device Dissipation @ T_C = 25°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

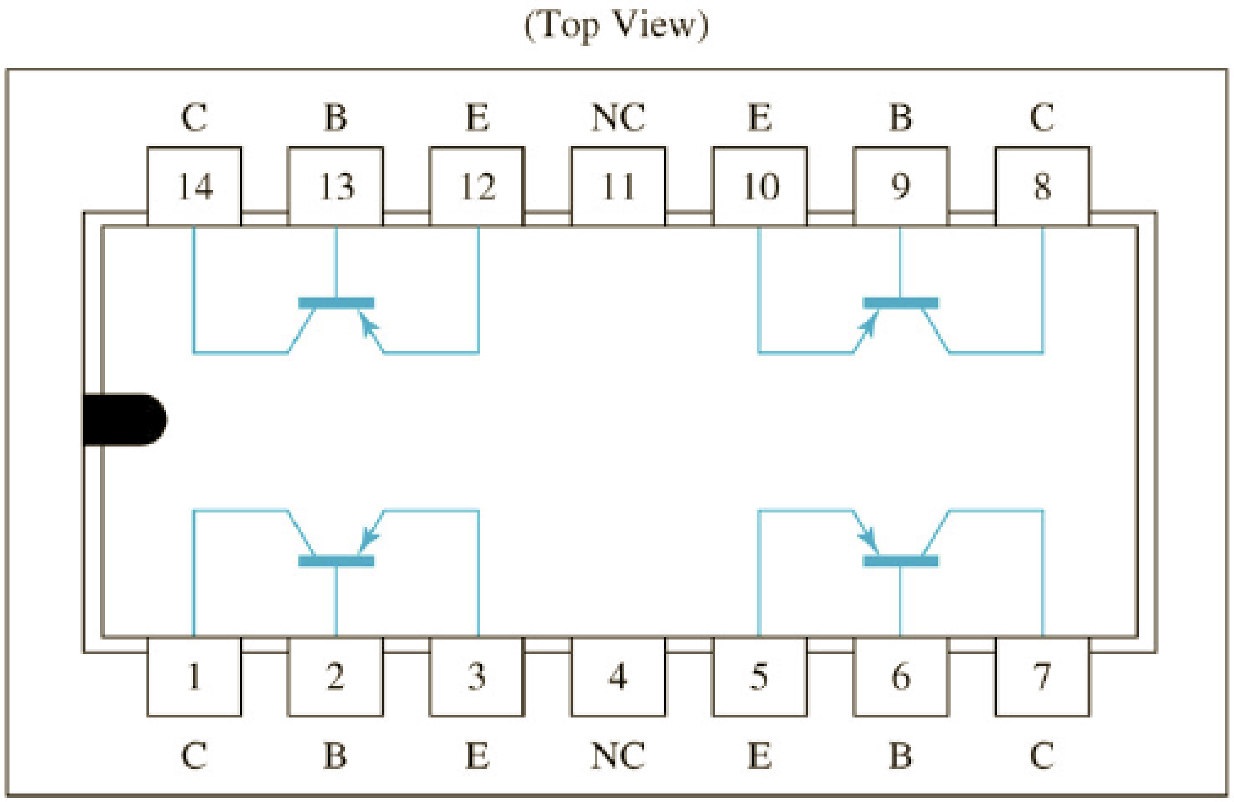
Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction−to−Ambient	$R_{\theta JA}$	200	°C/W
Thermal Resistance, Junction−to−Case	$R_{\theta JC}$	83.3	°C/W

MARKING DIAGRAM

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

Tipos de transistores

Transistores integrados:



NC – No internal connection

Na próxima aula

Seqüência de conteúdos:

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