Centro Federal de Educação Tecnológica de Santa Catarina
Departamento Acadêmico de Eletrônica
Conversores Estáticos

Semicondutores Aplicados a Conversores CA-CA (IGBTs e MOSFETs)

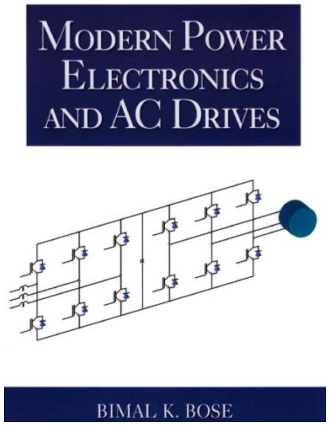
Prof. Clóvis Antônio Petry.

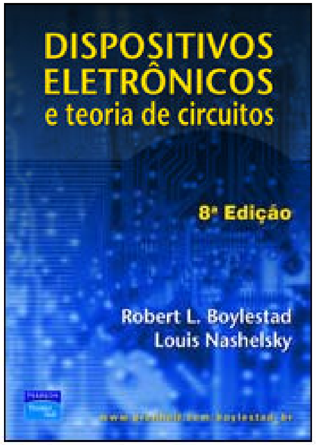
Florianópolis, março de 2008.

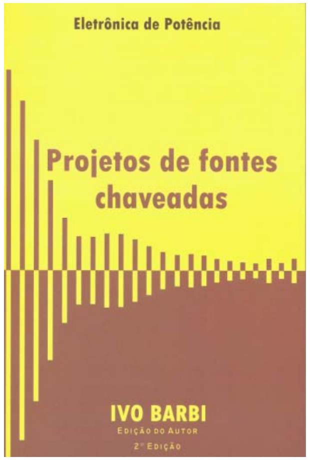
Bibliografia para esta aula

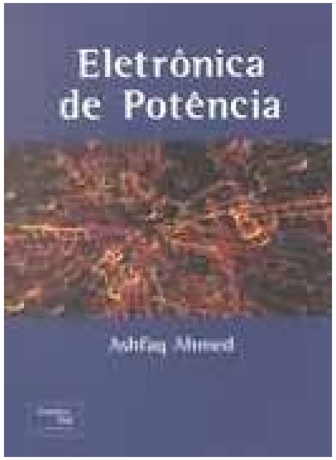
Capítulo 3: Transistores de potência

1. Semicondutores aplicados a conversores CA-CA.









www.cefetsc.edu.br/~petry

http://www.dsce.fee.unicamp.br/~antenor/

Nesta aula

Semicondutores aplicados a conversores CA-CA:

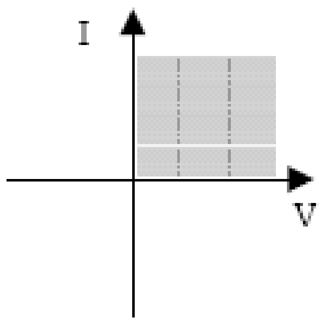
1. Introdução;
2. Revisão dos principais componentes semicondutores de potência;
3. MOSFET de potência;
4. IGBT;
5. Comparativo BJT x MOSFET x IGBT.

Quadrantes de condução de semicondutores

Operações Básicas Desejadas

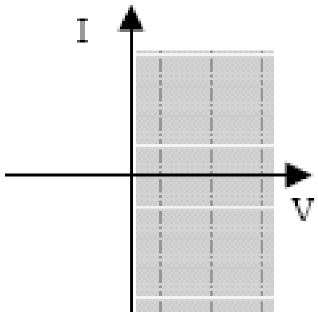
Operação em um quadrante

- Diodos (bloqueio reverso)
- SCR (bloqueio direto)
- Transistor Bipolar
- IGBT



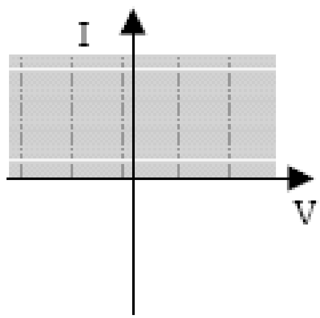
Operação em dois quadrantes com corrente bidirecional

- MOSFET
- SCR + diodo em anti-paralelo
- IGBT + diodo em anti-paralelo
- Transistor Bipolar + diodo em anti-paralelo



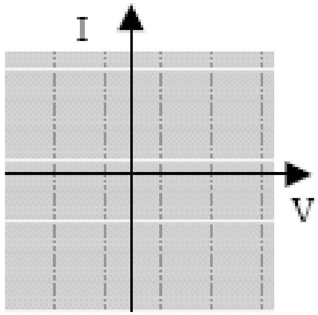
Operação em dois quadrantes com tensão bidirecional

- SCR (bloqueio direto e reverso)
- Transistor Bipolar + diodo em série



Operação em quatro quadrantes

- Arranjo de diodos com transistores bipolares

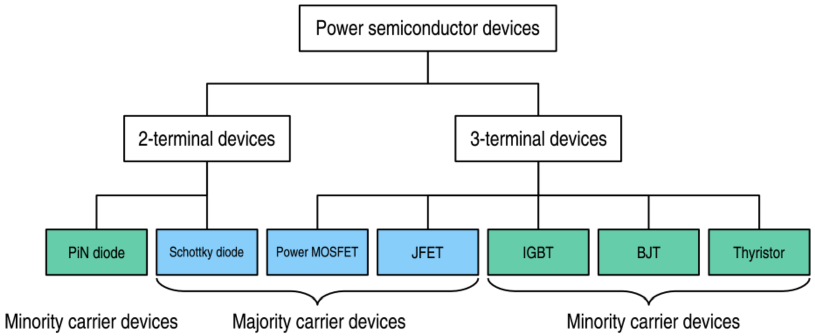


http://www.dee.feis.unesp.br/gradua/elepot/principal.html

Semicondutores para eletrônica de potência

Semicondutores utilizados em eletrônica de potência:

- Diode
- Thyristor or silicon-controlled rectifier (SCR)
- Triac
- Gate turn-off thyristor (GTO)
- Bipolar junction transistor (BJT or BPT)
- Power MOSFET
- Static induction transistor (SIT)
- Insulated gate bipolar transistor (IGBT)
- MOS-controlled thyristor (MCT)
- Integrated gate-commutated thyristor (IGCT)



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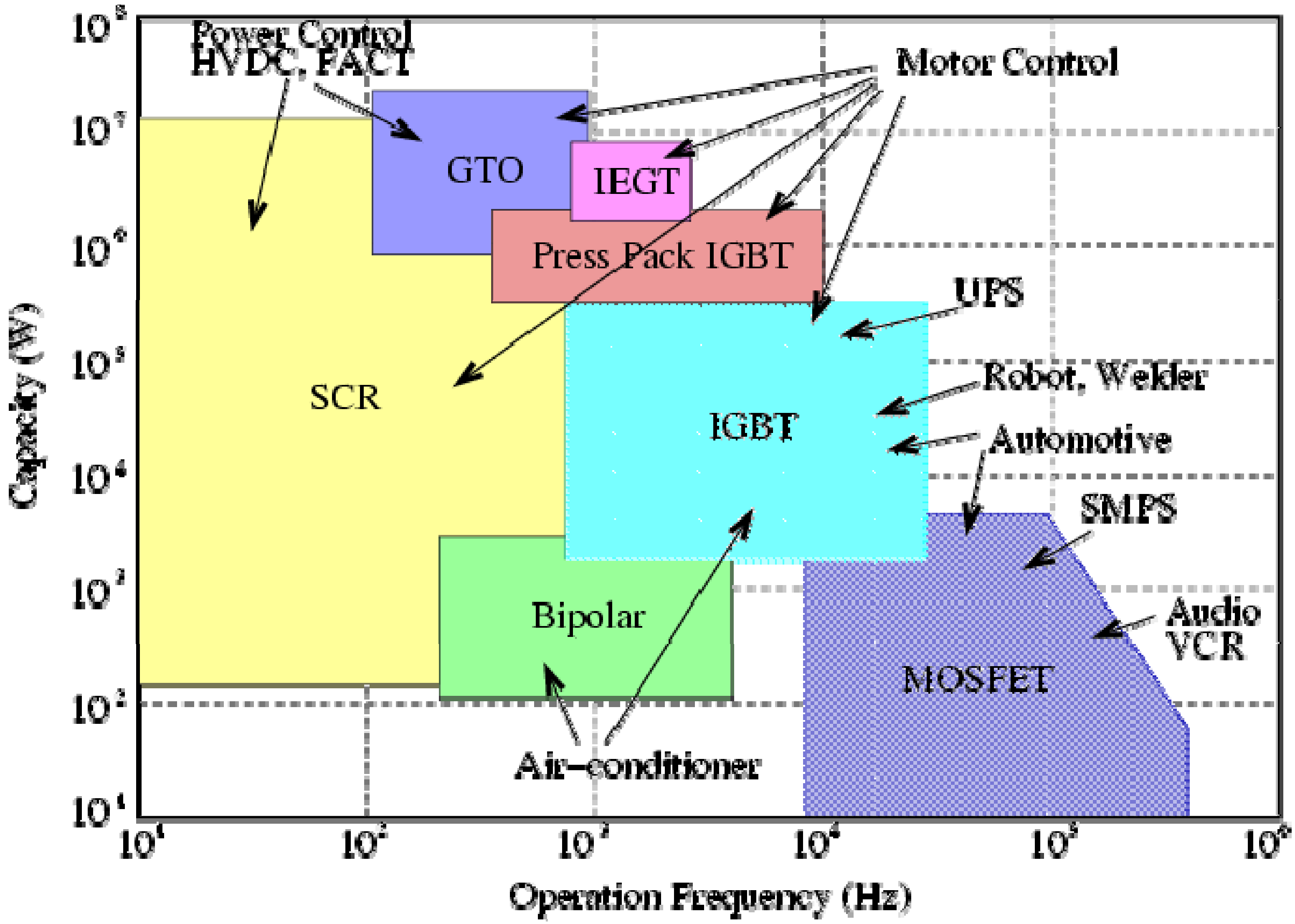
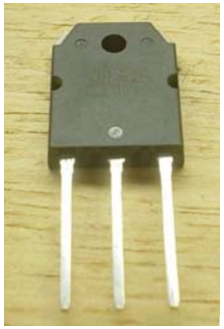
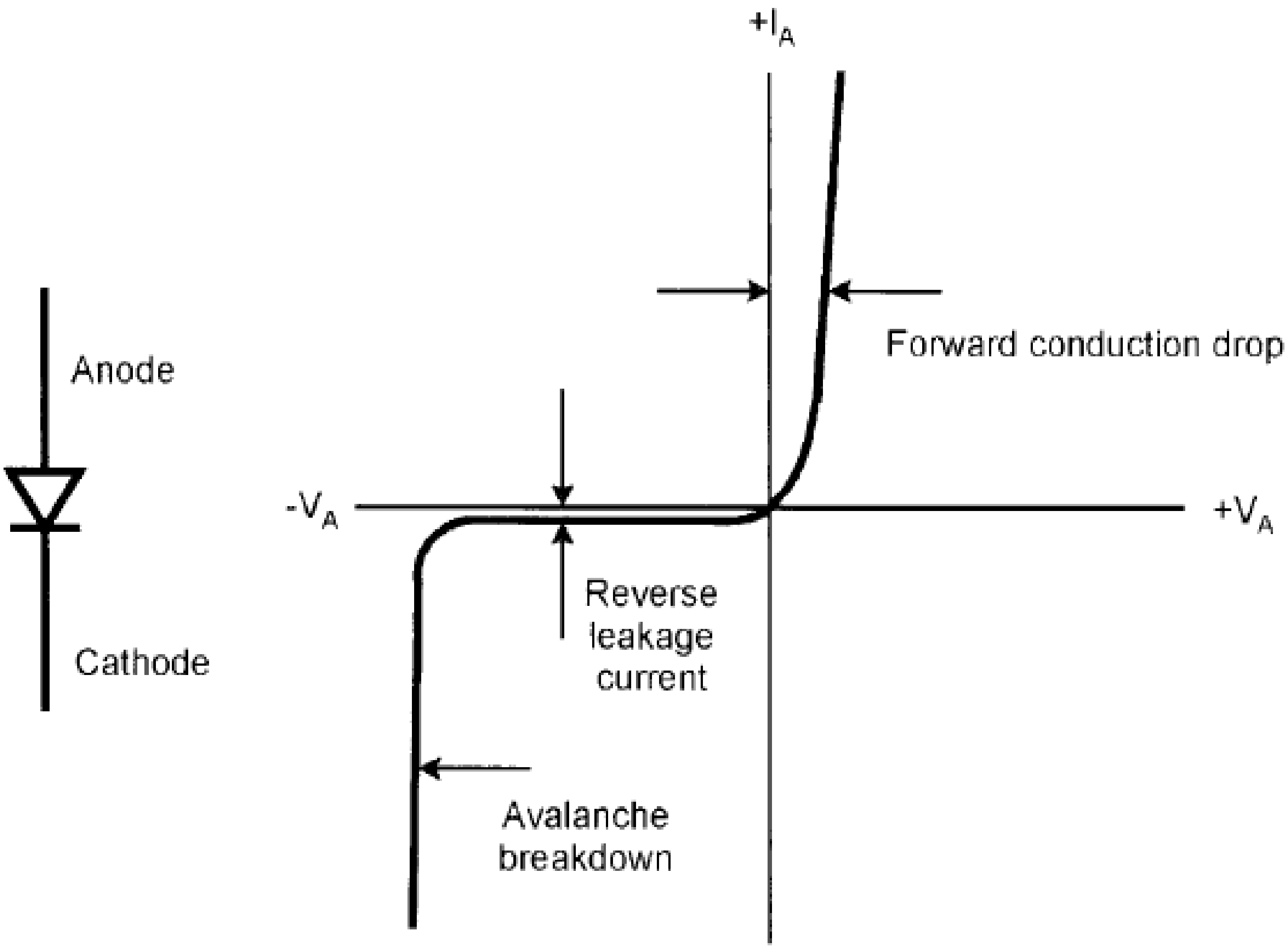


Semicondutores para eletrônica de potência



Revisão - Diodos



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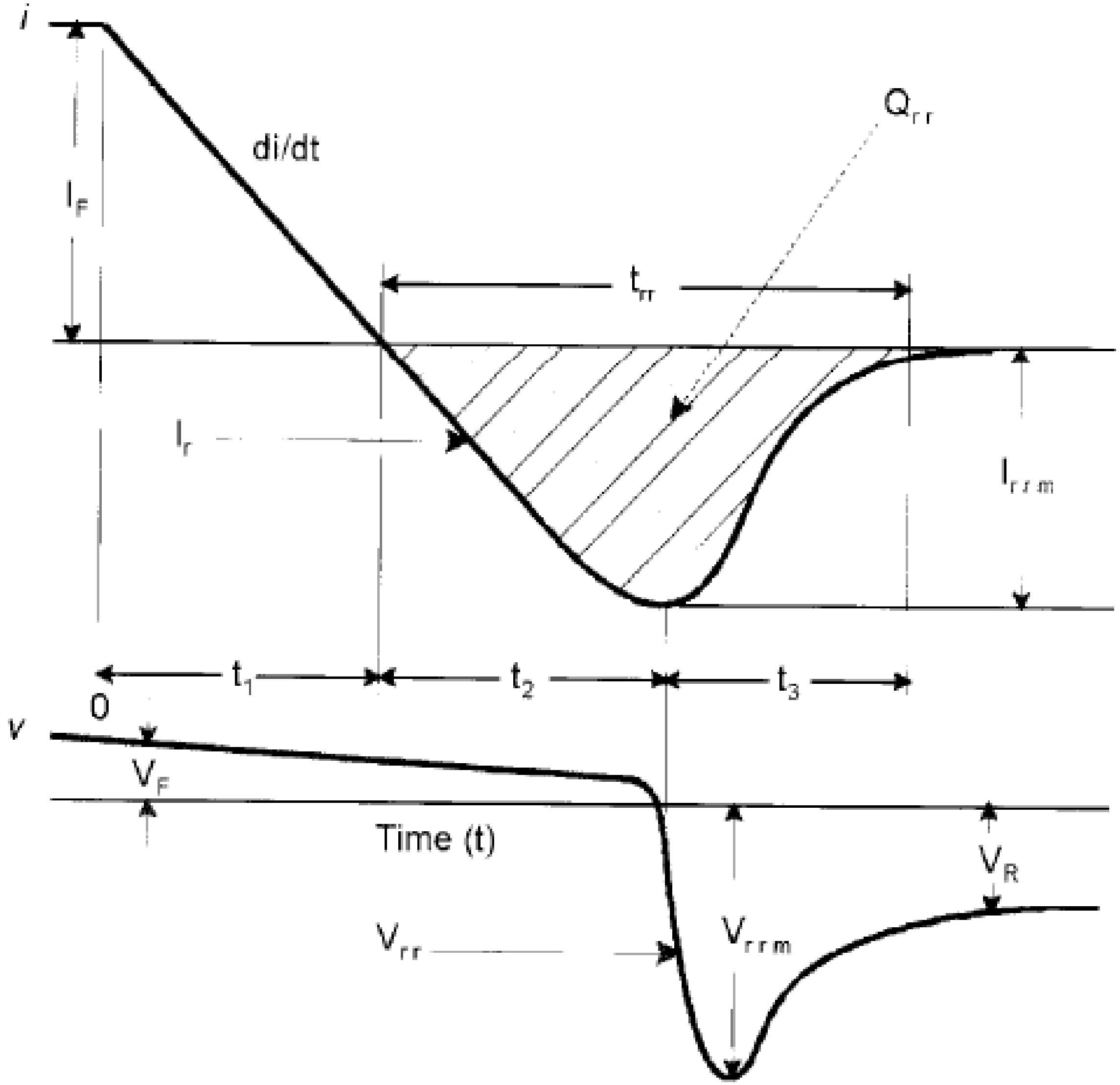

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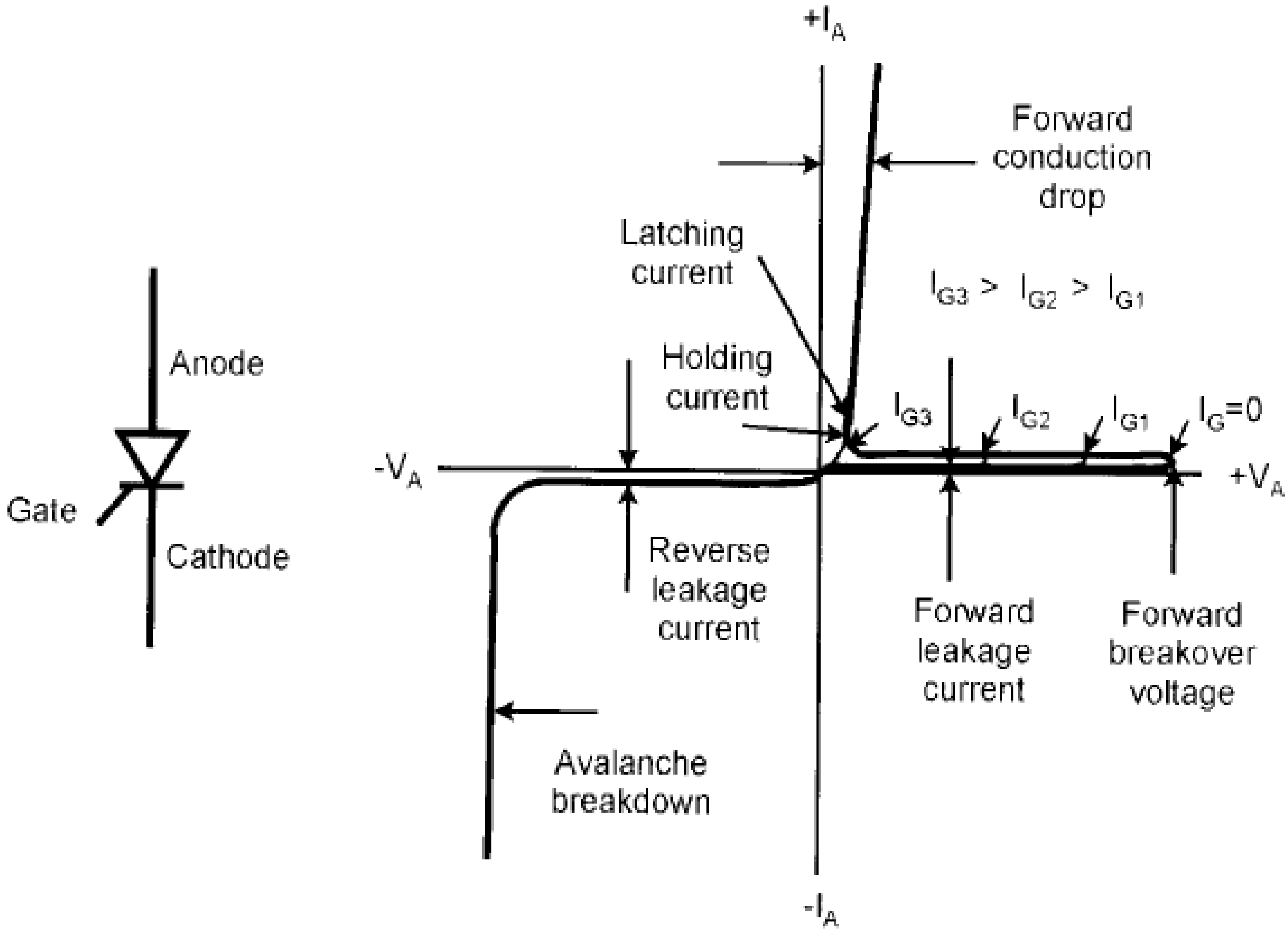

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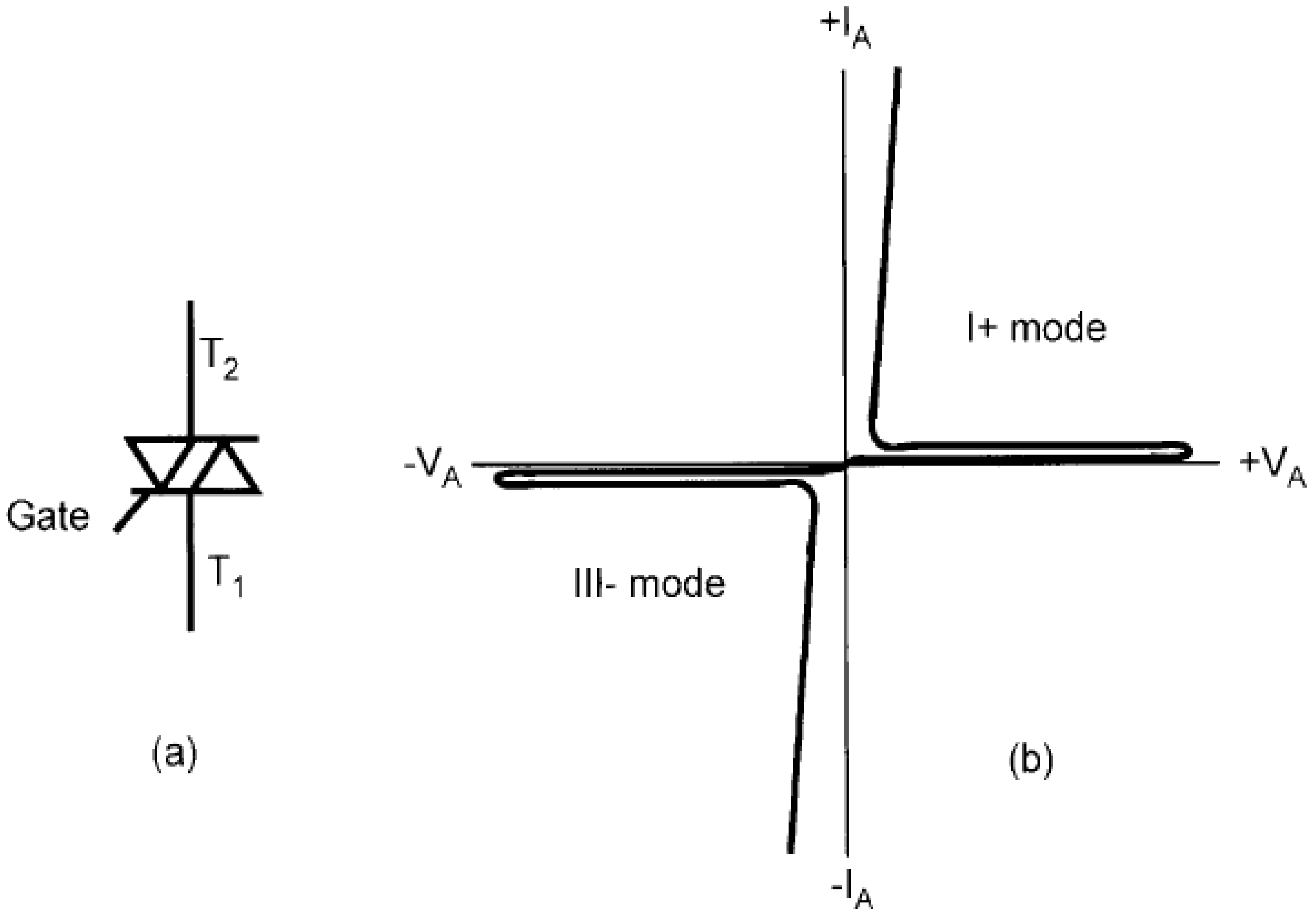
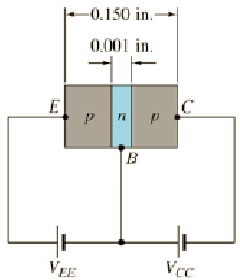


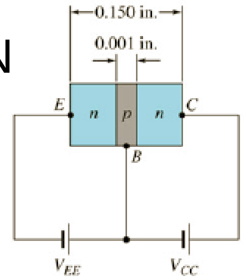
Revisão - BJT

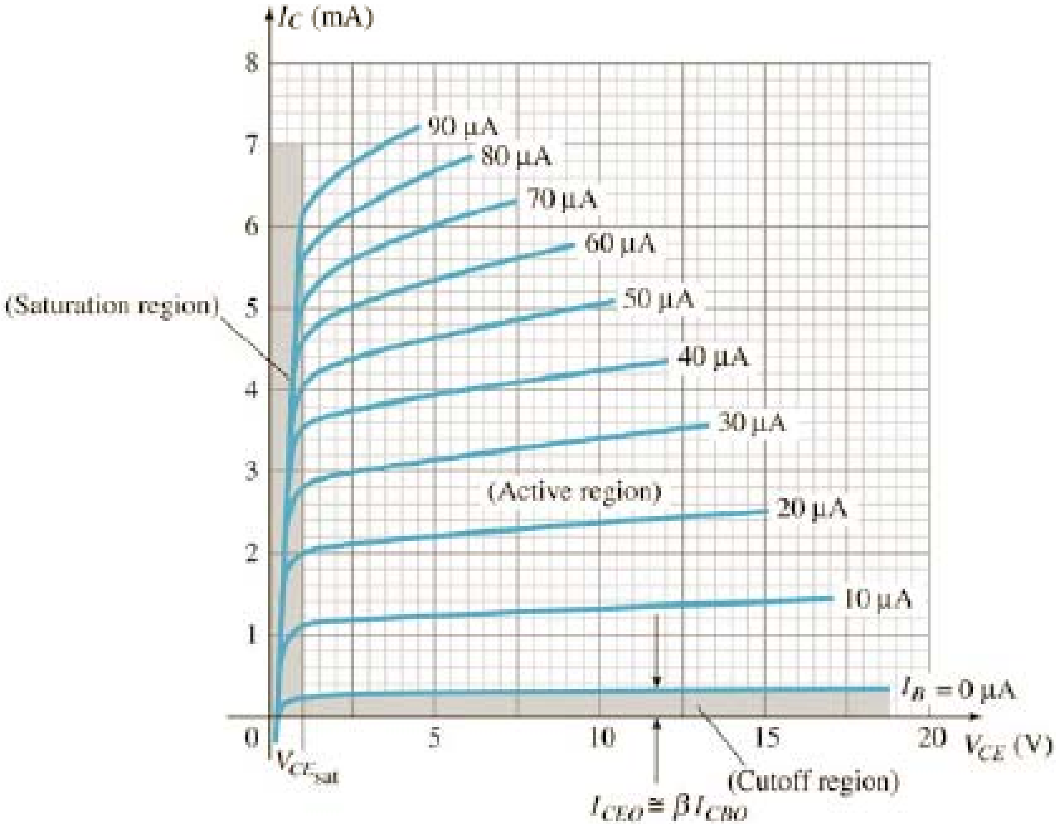
BJT – Transistor bipolar de junção

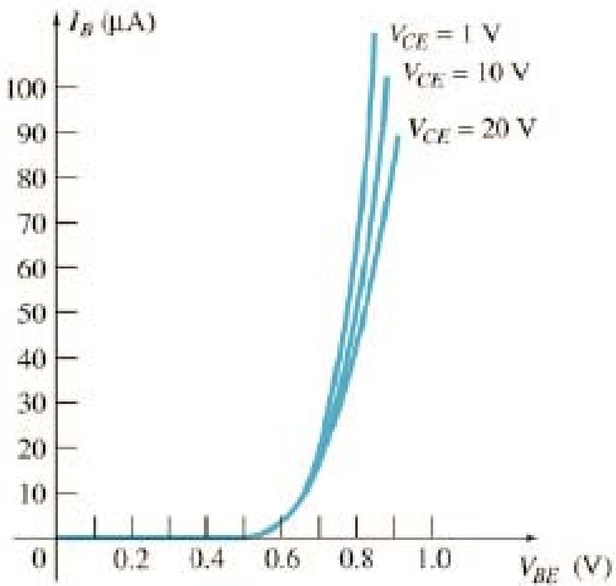
PNP



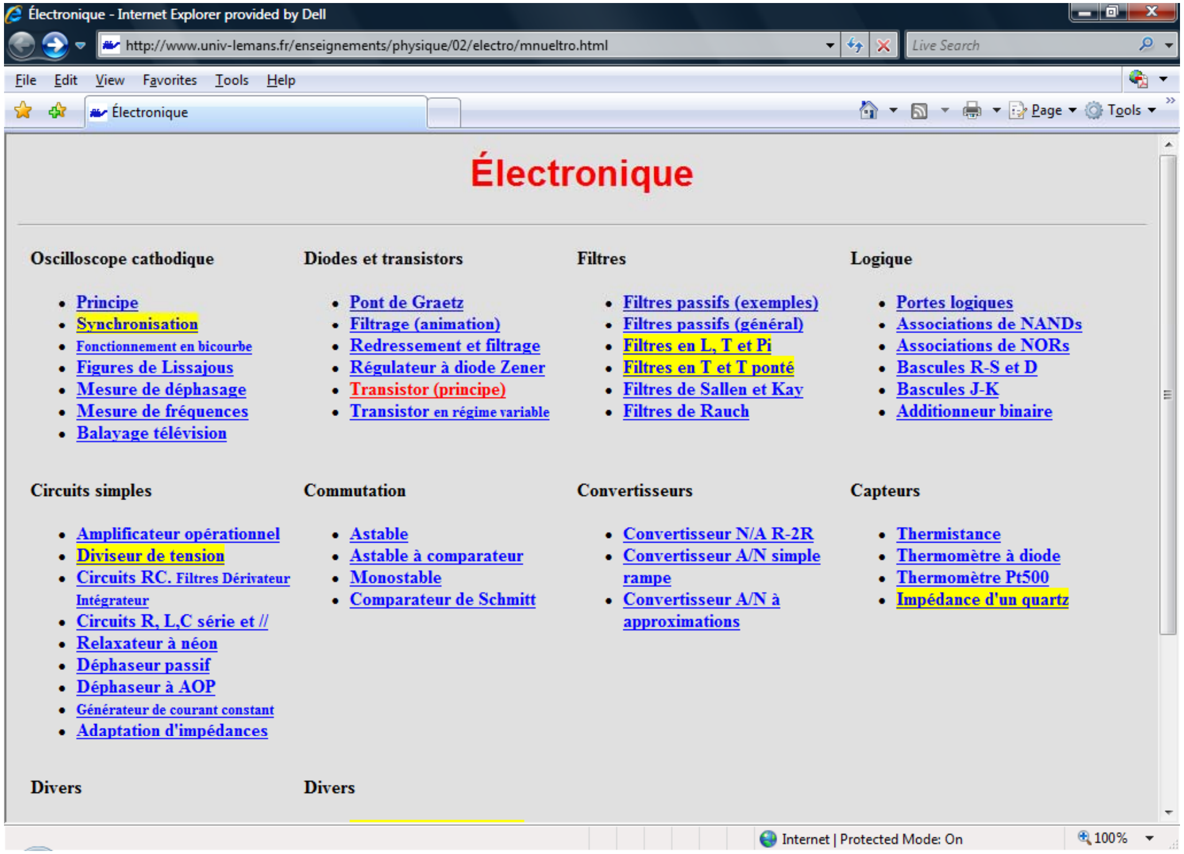
NPN

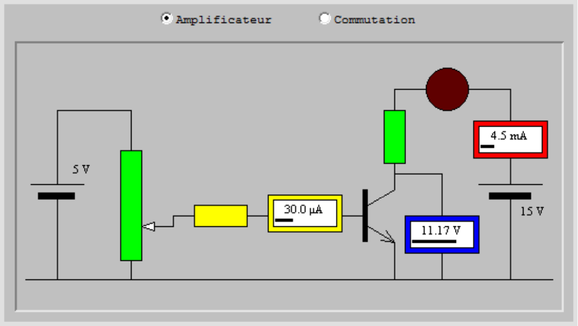






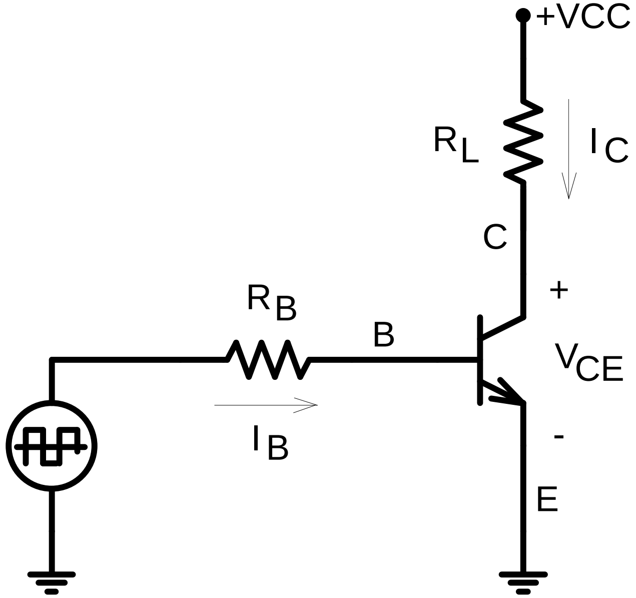
Revisão - BJT





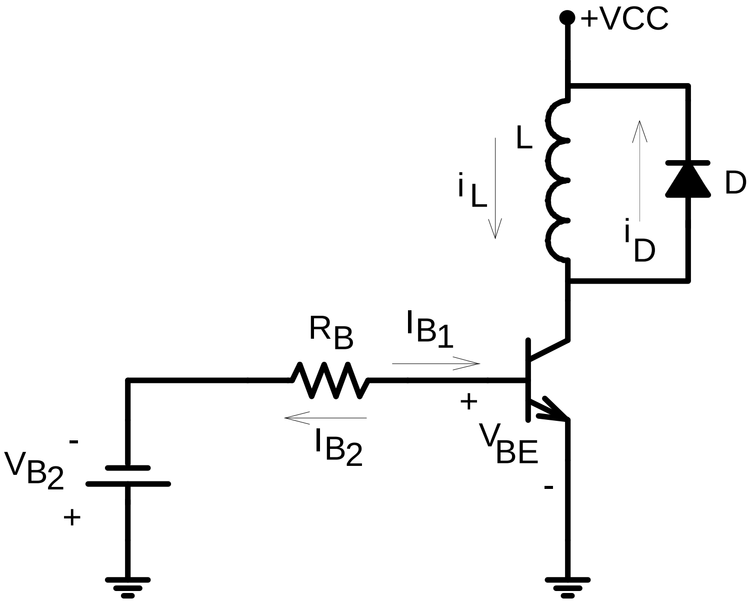
http://www.univ-lemans.fr/enseignements/physique/02/electro/mnueltro.html

Revisão - BJT

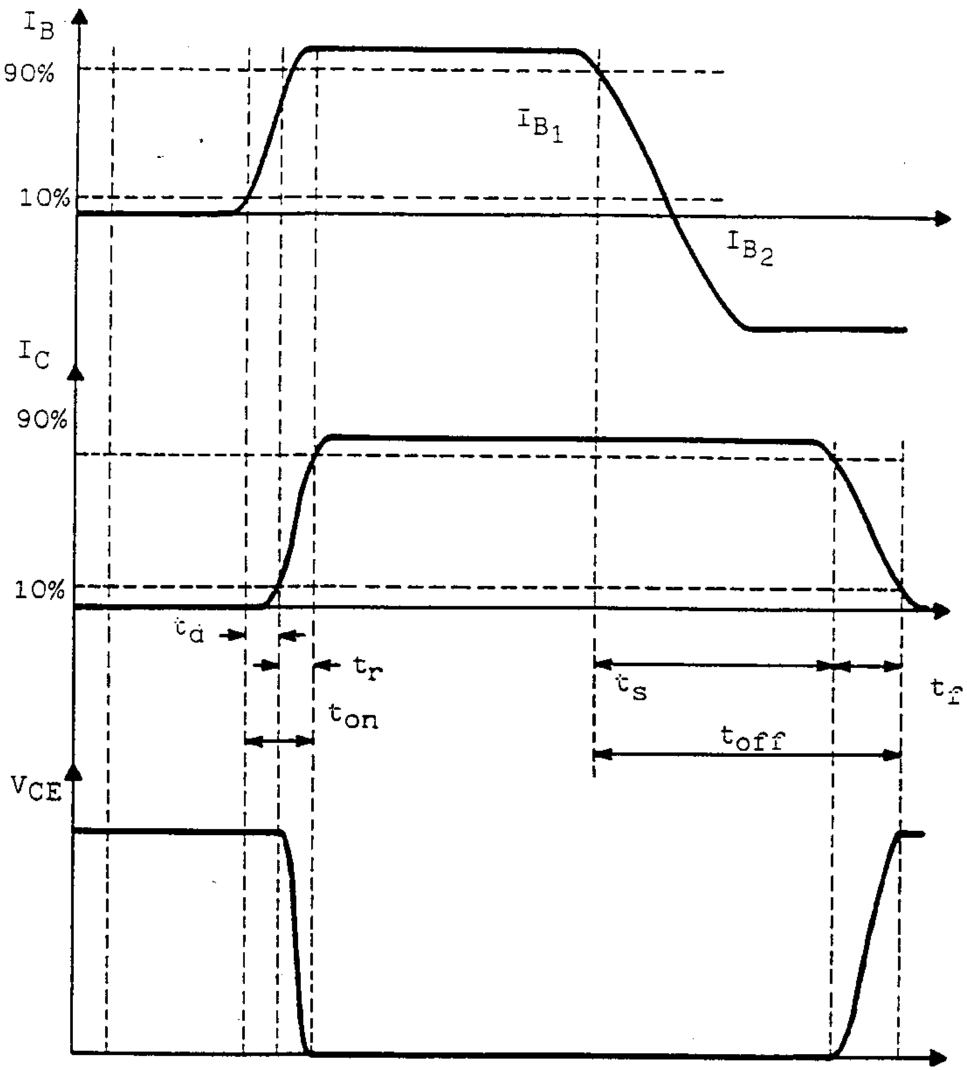


Comutação do BJT com carga resistiva

Comutação do BJT com carga indutiva



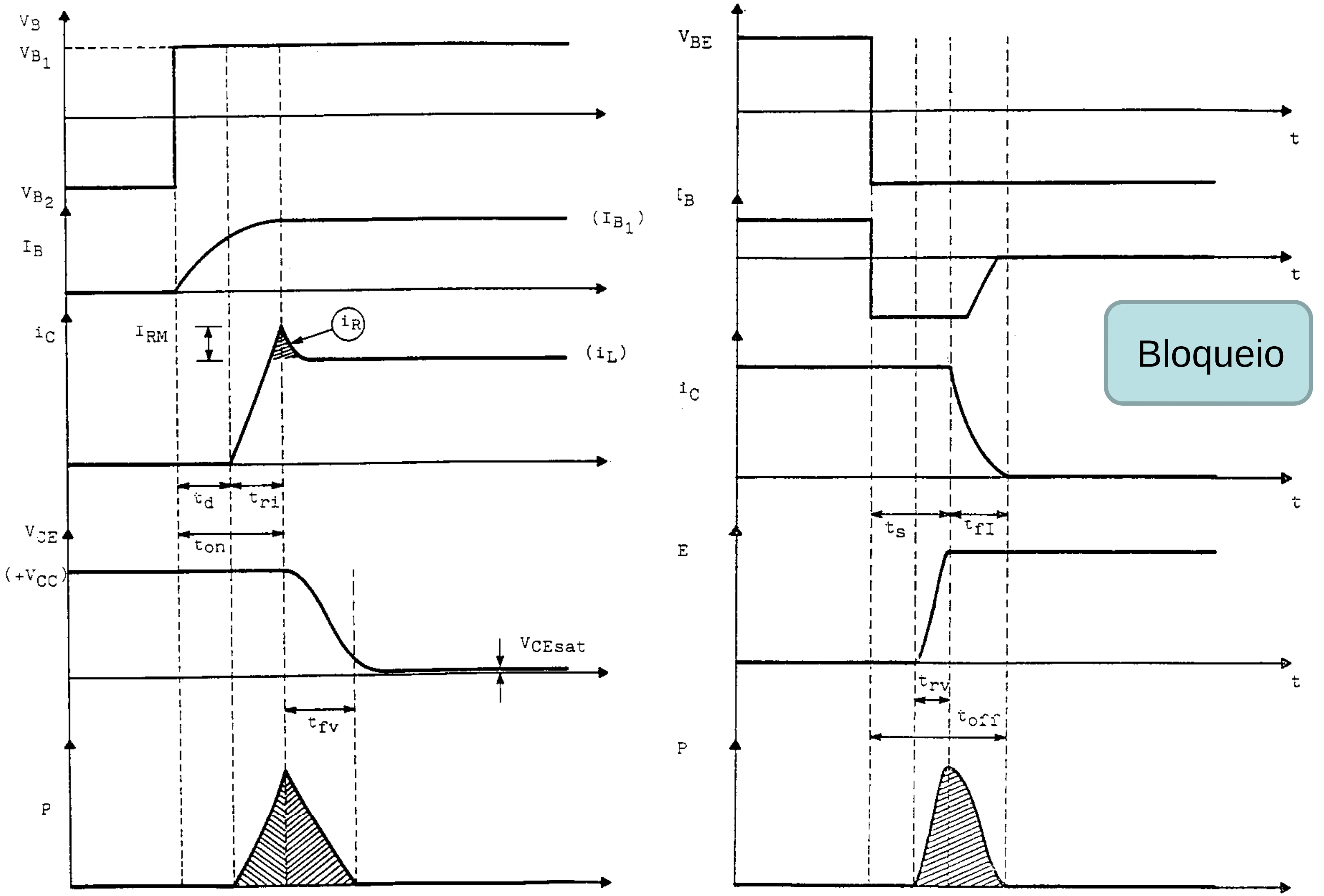
Revisão - BJT



Comutação do BJT com carga resistiva

Revisão - BJT

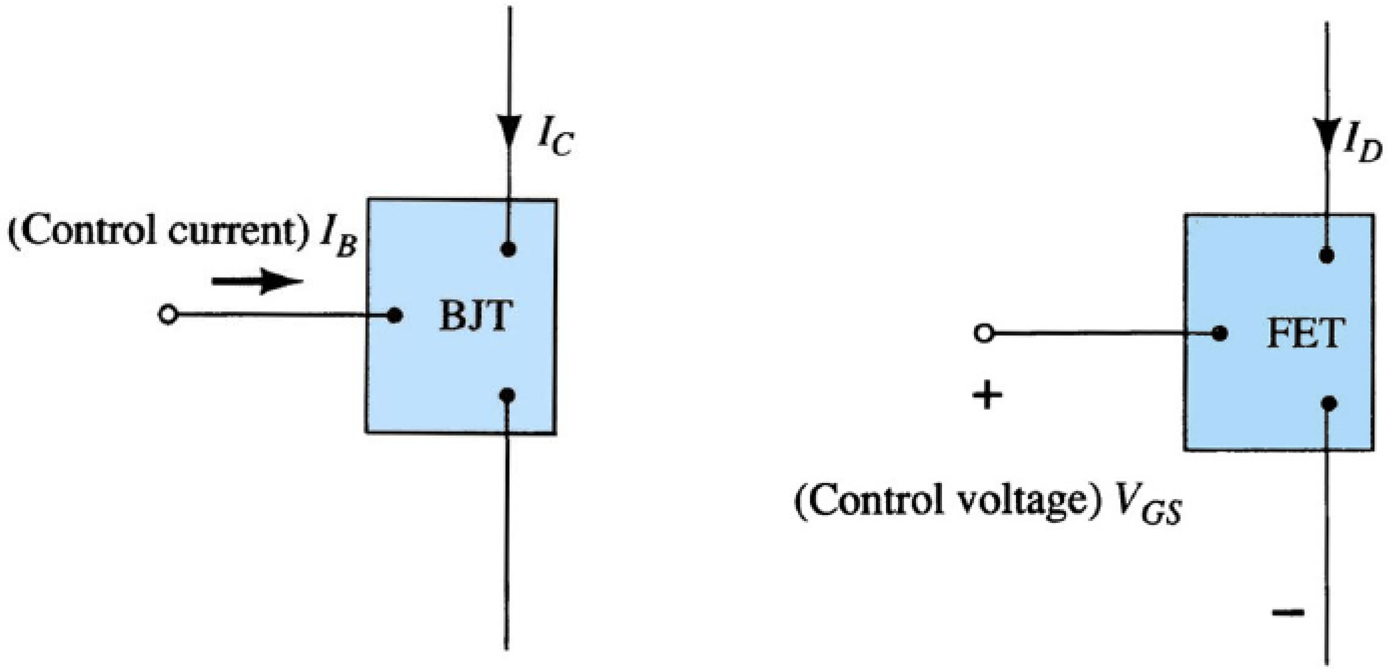
Entrada em condução



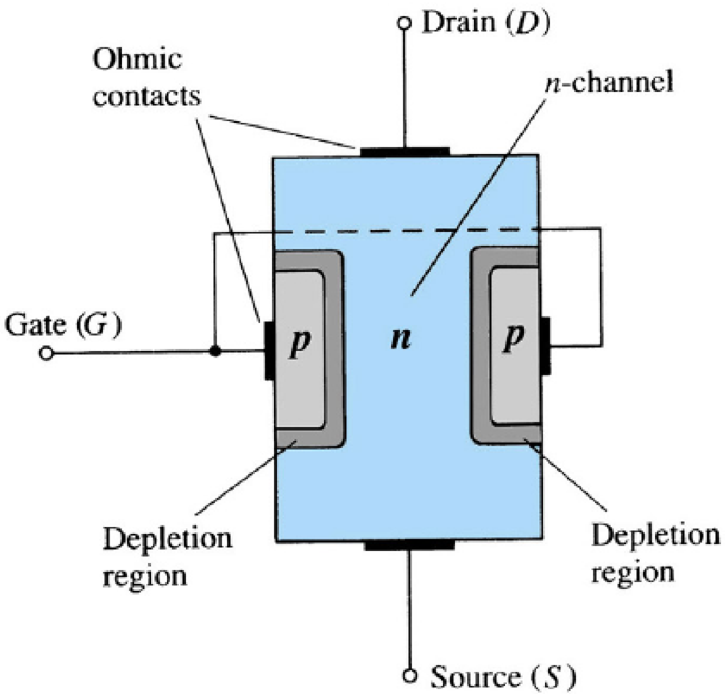
Comutação do BJT com carga indutiva

BJT x FET

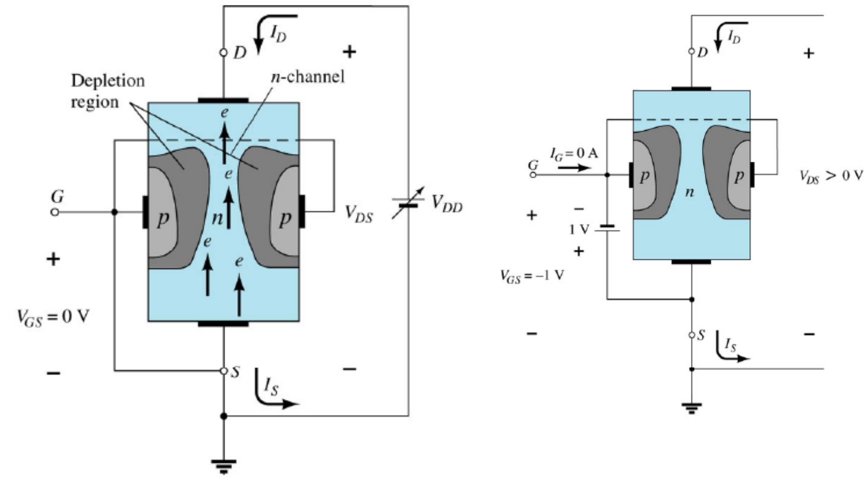
FET – Transistor de efeito de campo

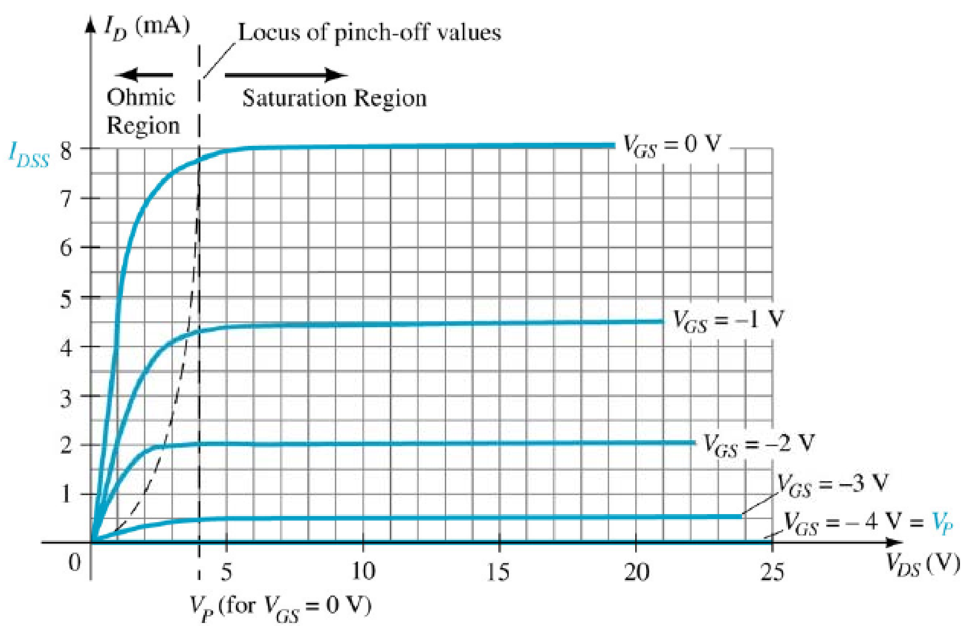


FET

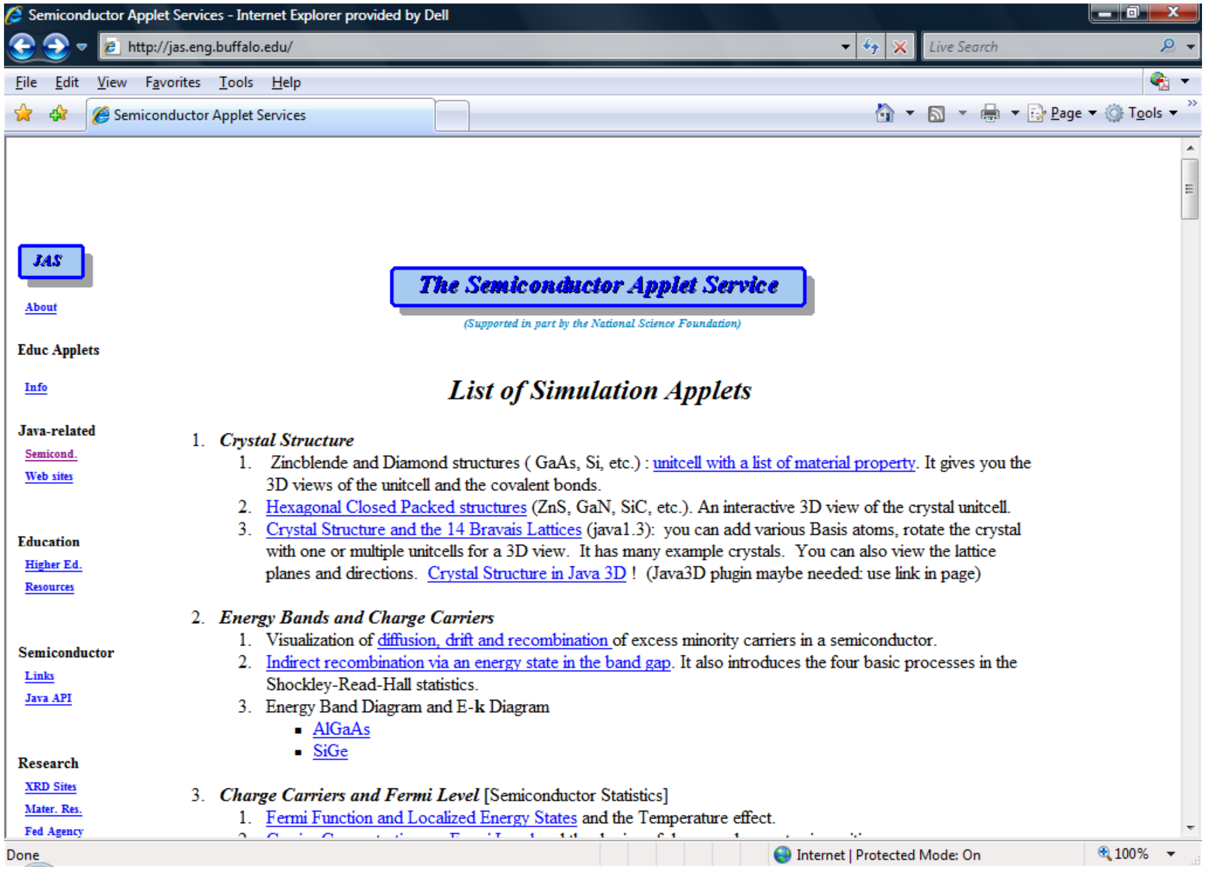


JFET: Operação básica.

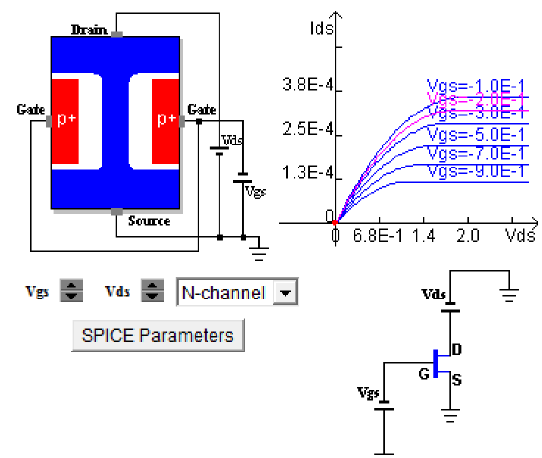




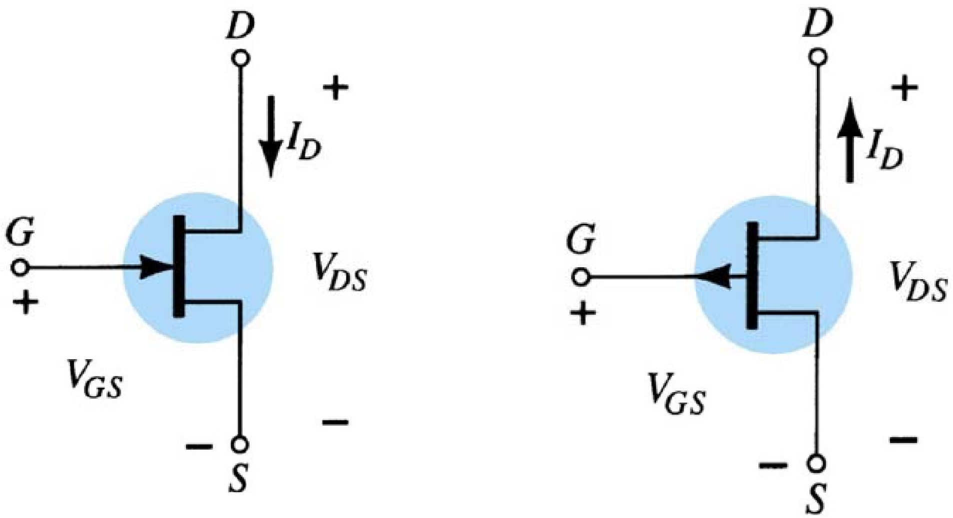
FET

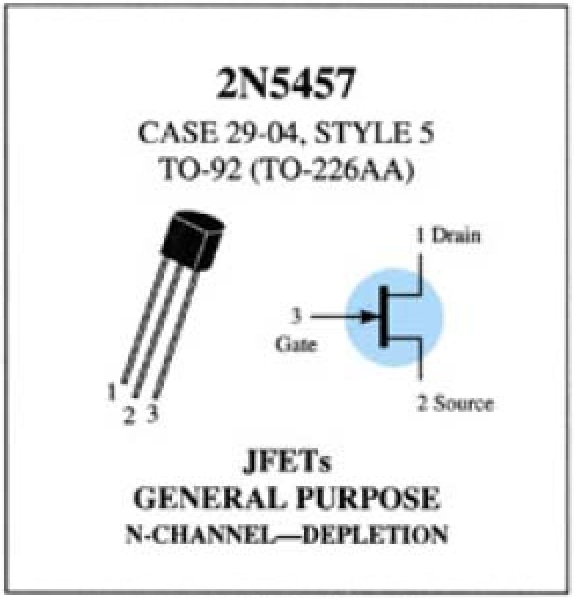


http://jas.eng.buffalo.edu/

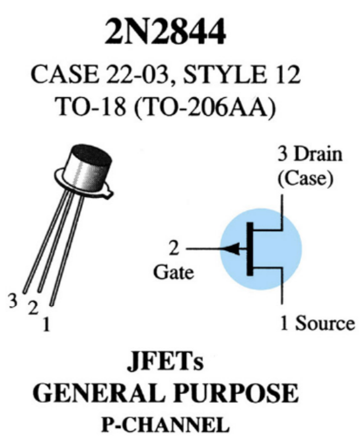


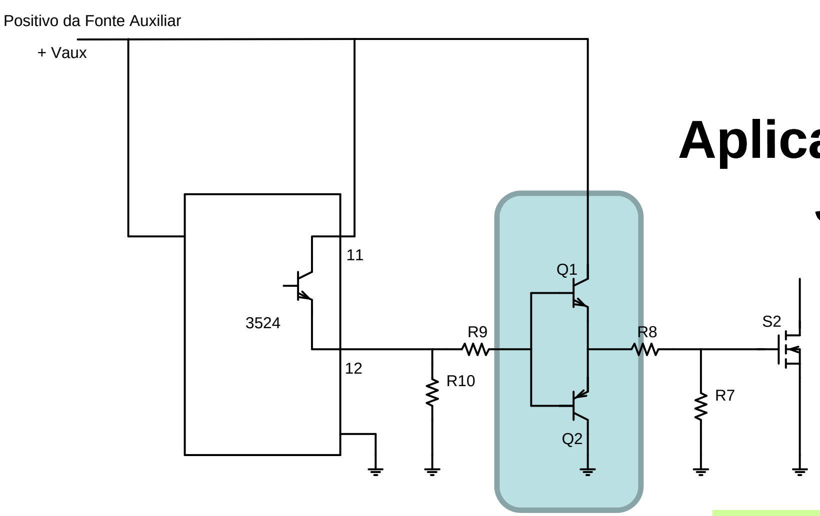
FET





JFET canal n e canal p

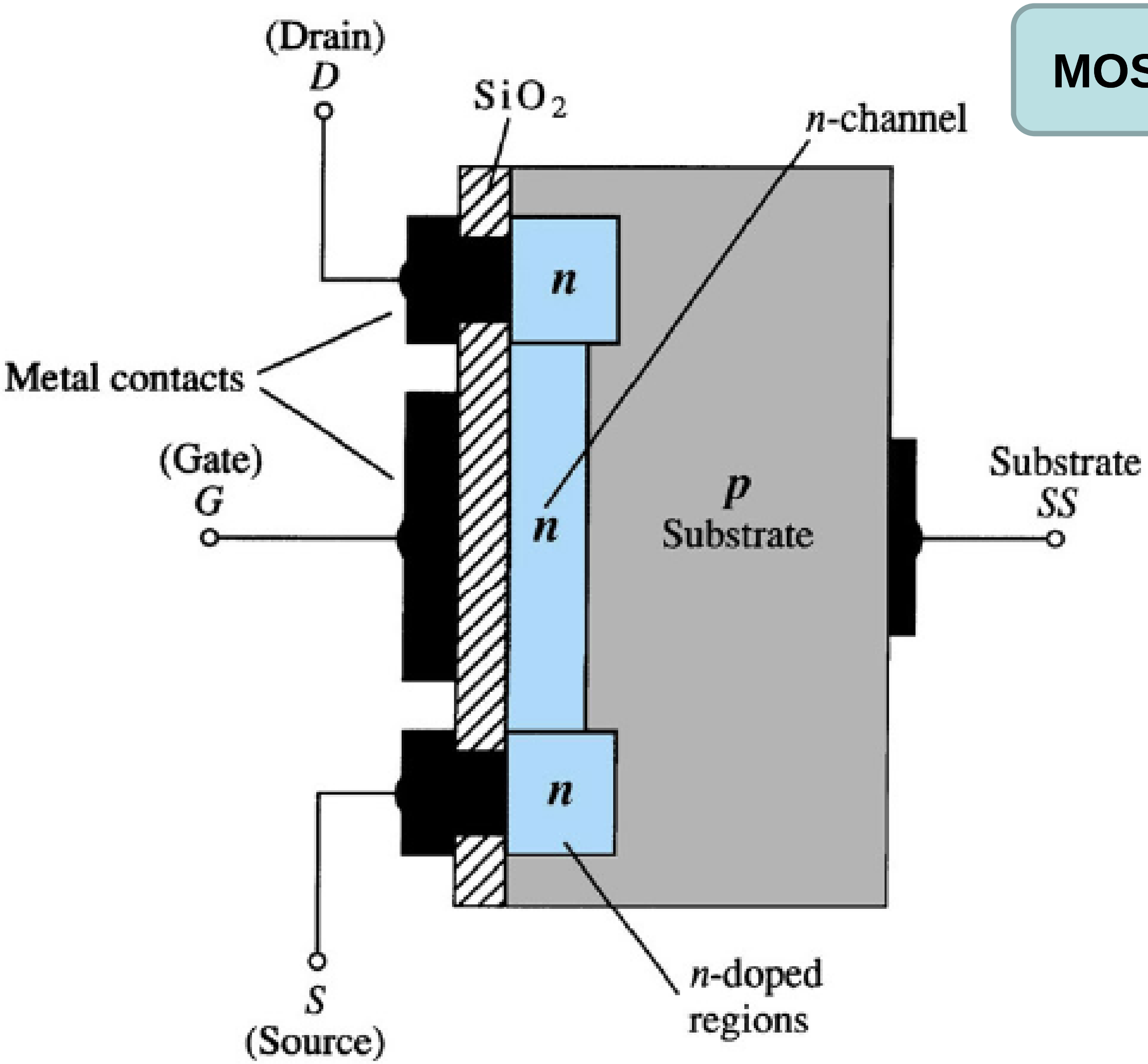




Aplicação do JFET

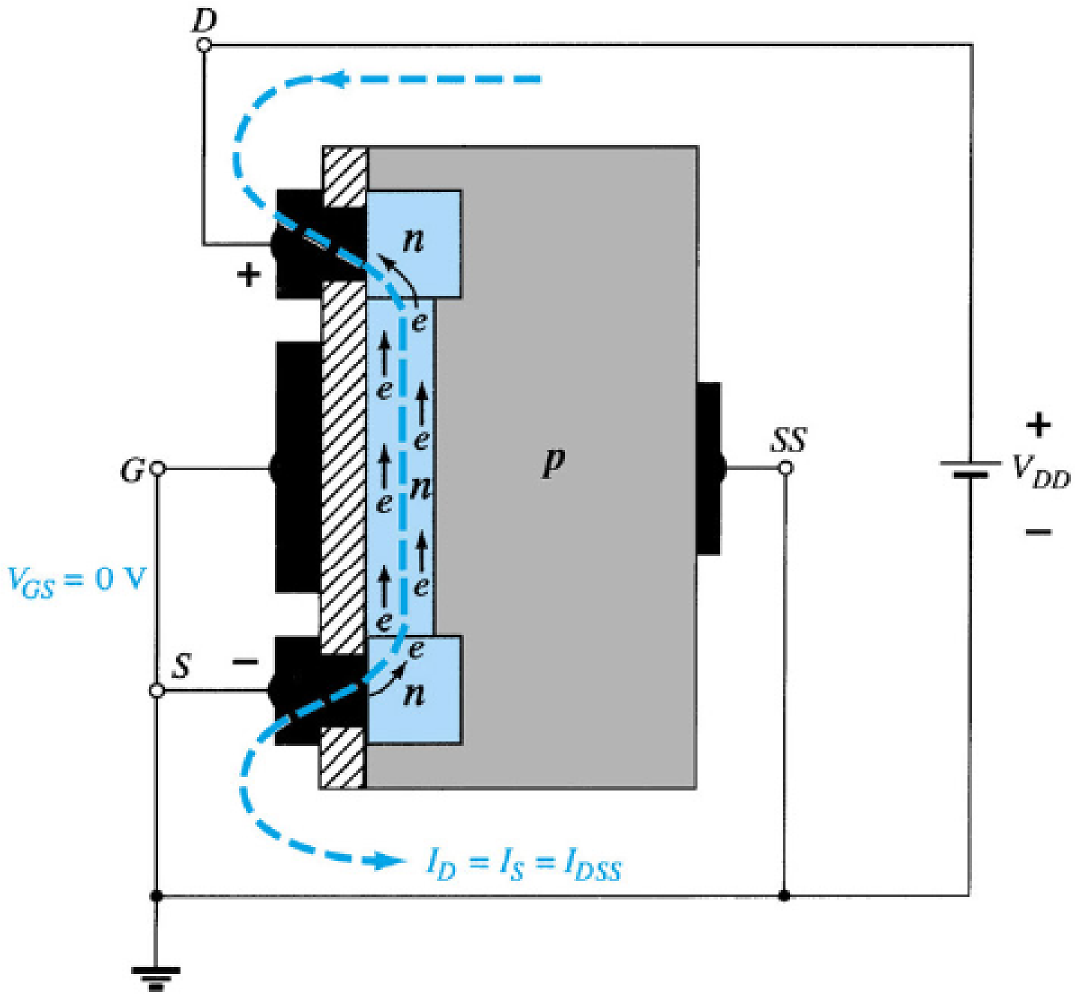
MOSFET

MOSFET tipo Depleção

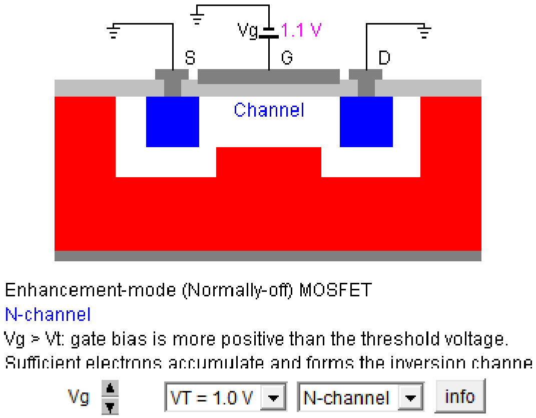


MOSFET – Metal Oxide Semiconductor Field Effect Transistor

MOSFET



MOSFET tipo Depleção

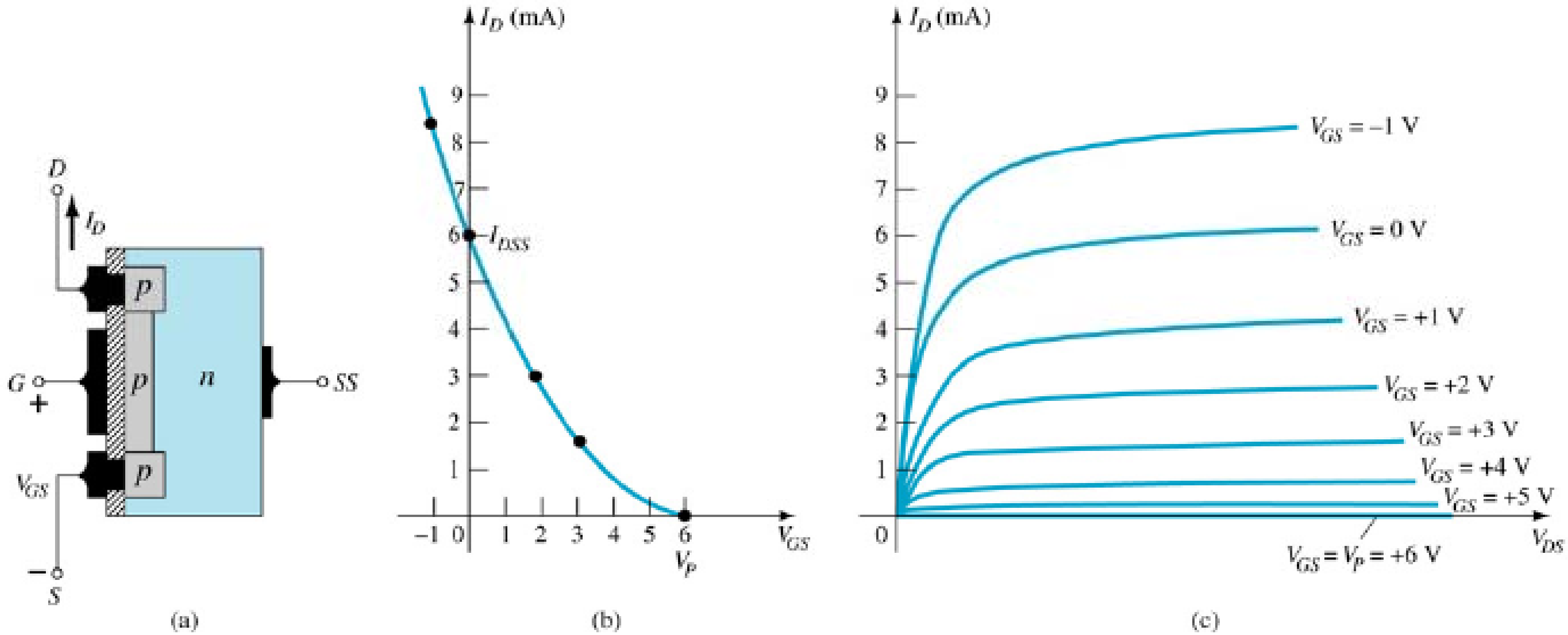


MOSFET: Operação básica.

http://jas.eng.buffalo.edu/

MOSFET

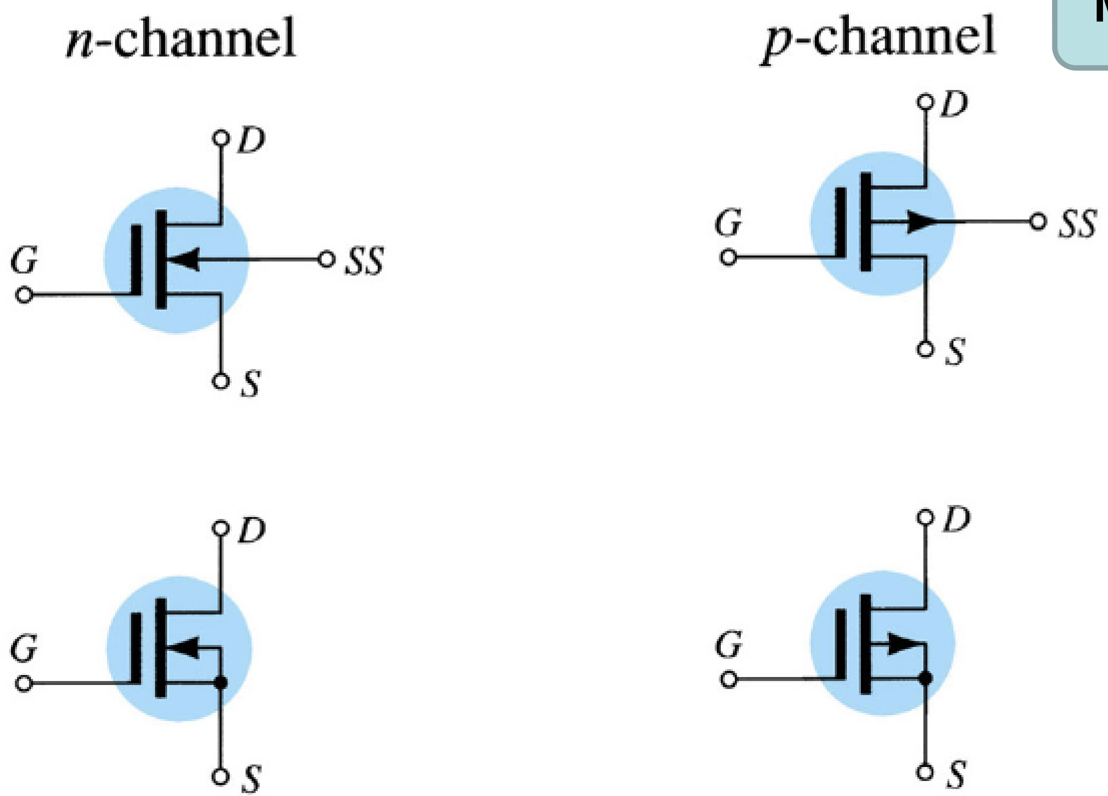
MOSFET tipo Depleção



MOSFET: Operação básica.

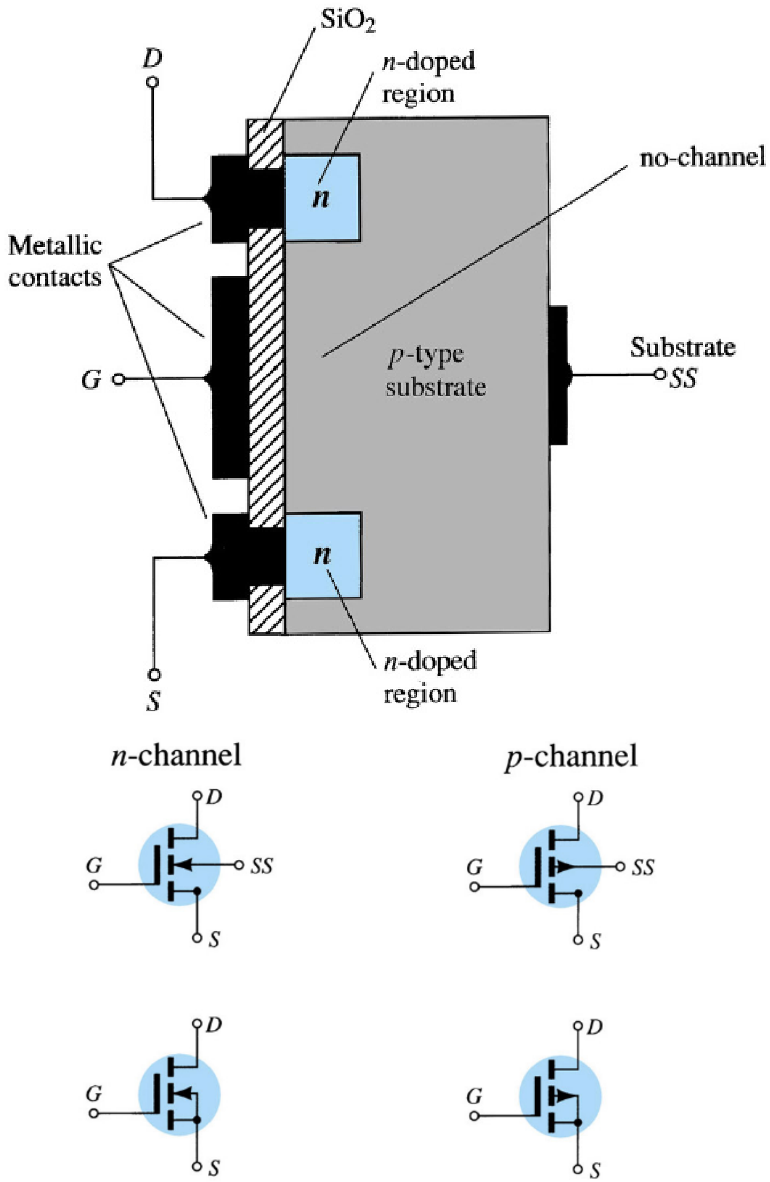
MOSFET

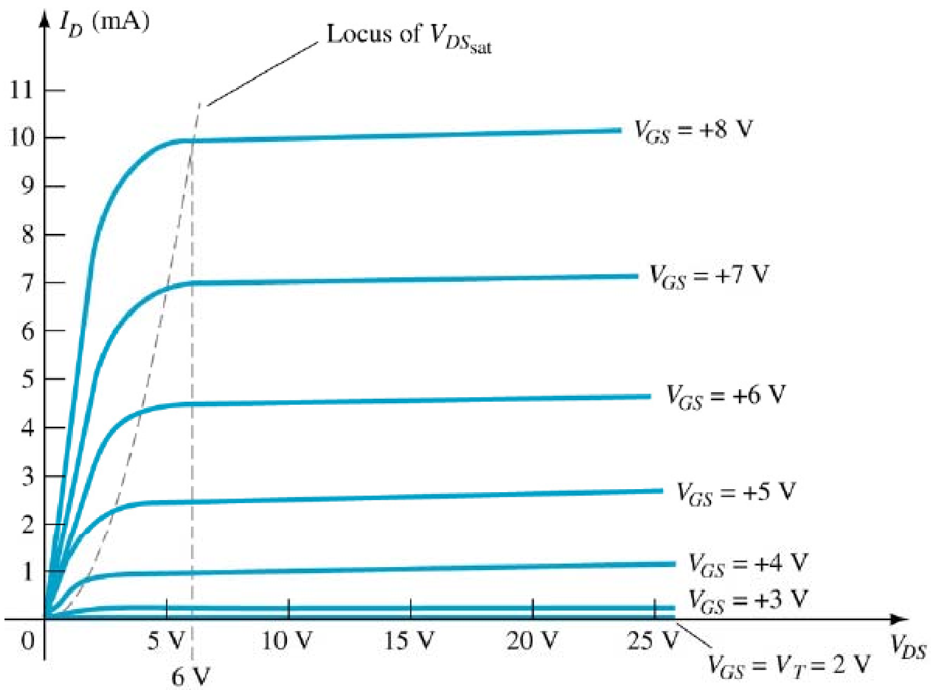
MOSFET tipo Depleção



MOSFET

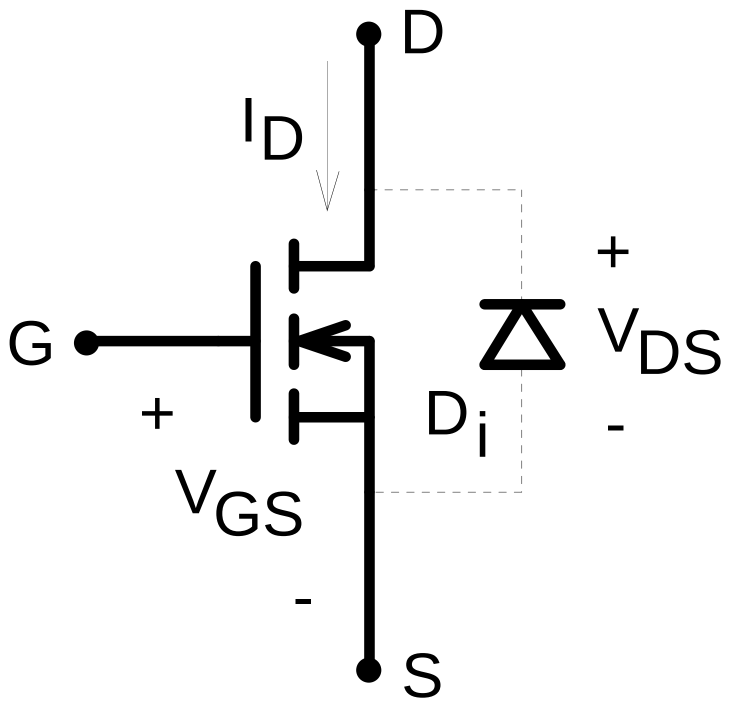
MOSFET tipo Intensificação

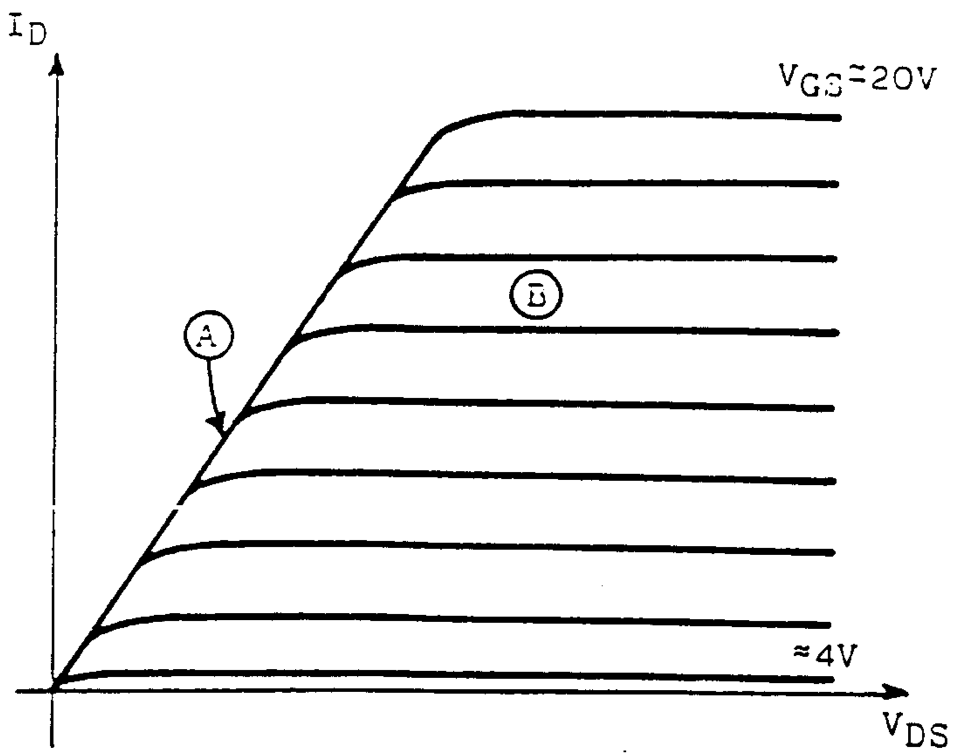




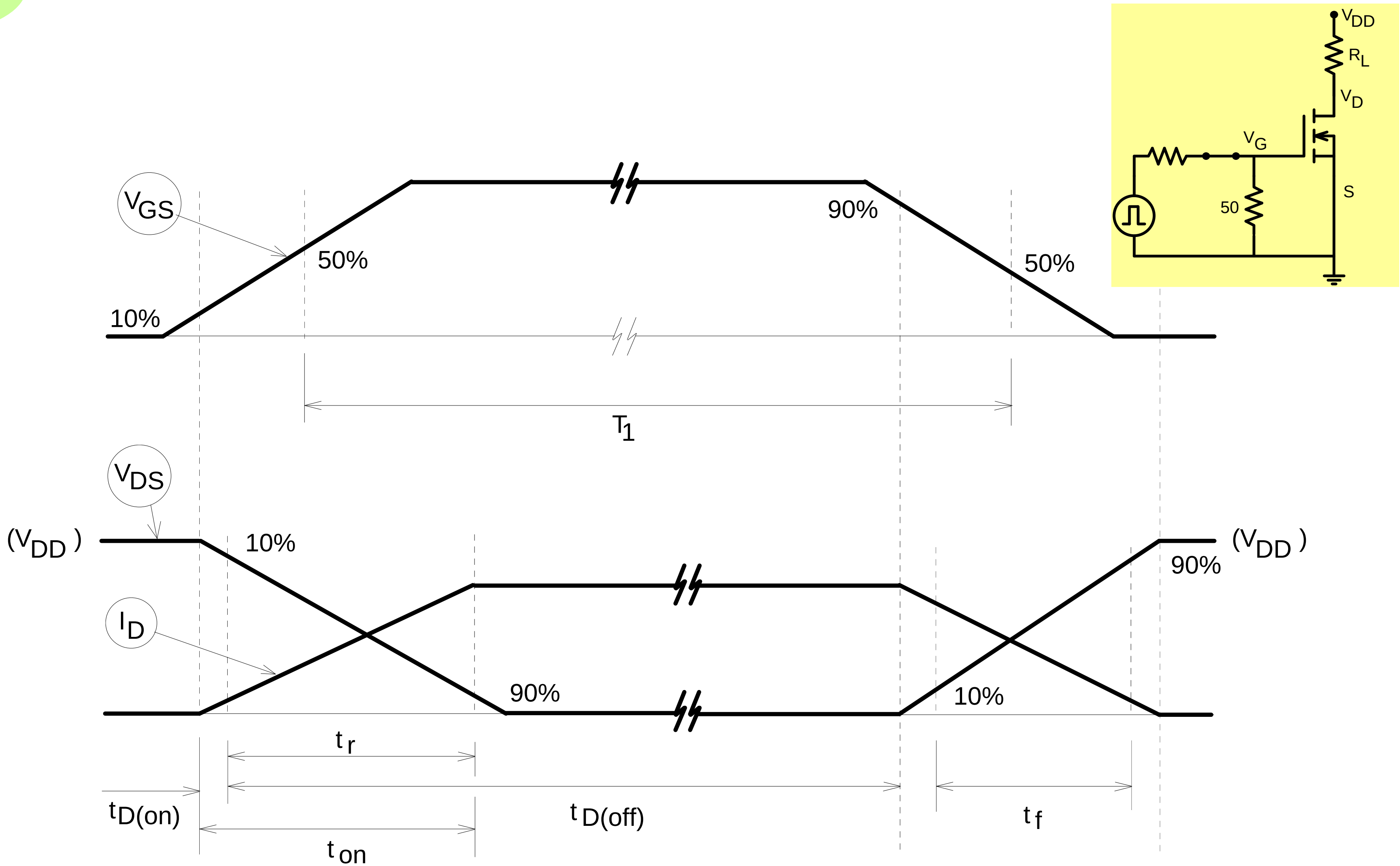
Canal n

MOSFET de potência



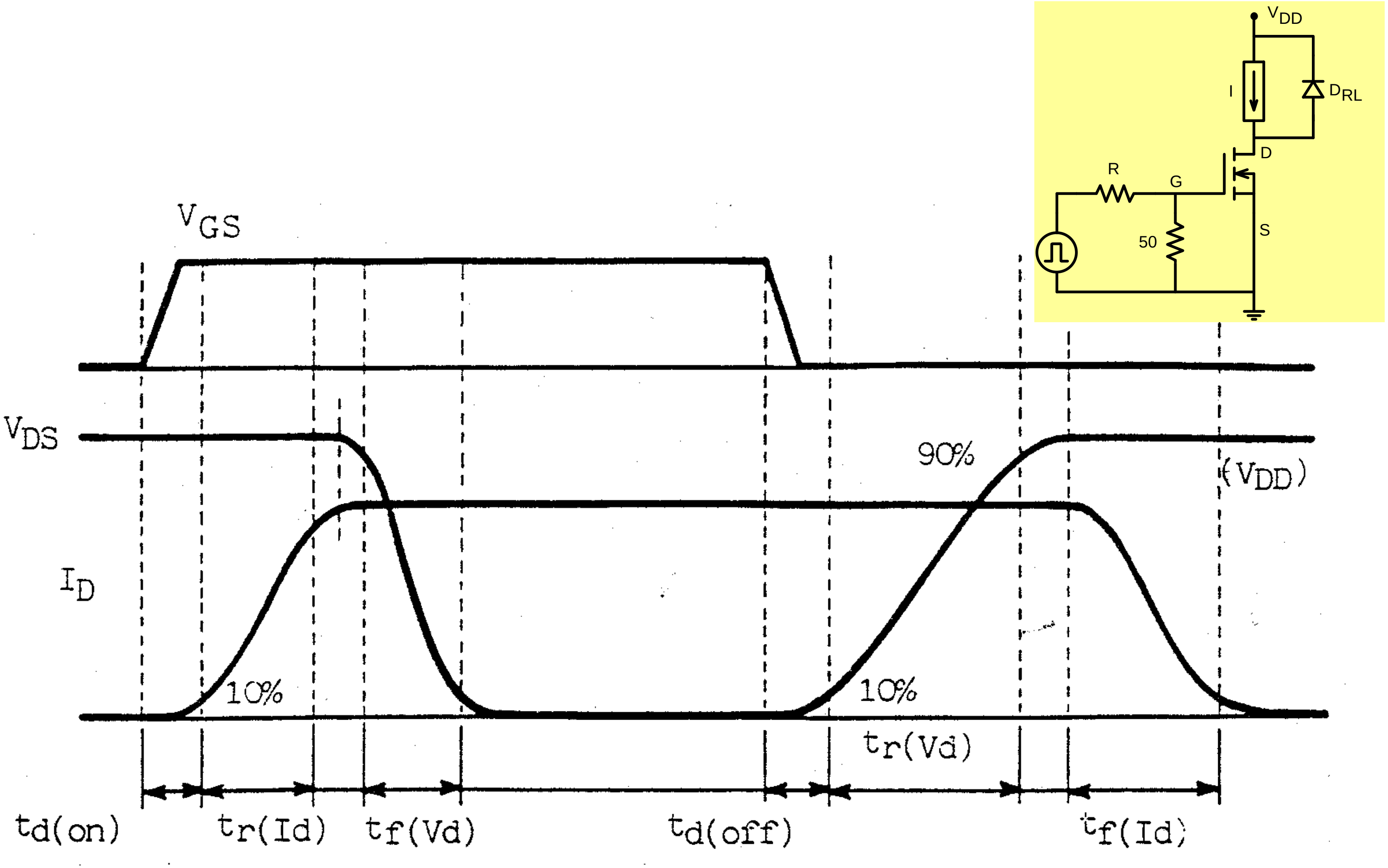


MOSFET de potência



Comutação do MOSFET com carga resistiva

MOSFET de potência



Comutação do MOSFET com carga indutiva

MOSFET de potência

Classificação das perdas:

1. Condução;

$$P_{cond} = \frac{t_{on}}{T} \cdot r_{ds(on)} \cdot i_{d(on)}{}^{2}$$

2. Comutação:
   - Entrada em condução e bloqueio;

$$P_{com} = \frac{f}{2}\left(t_r + t_f\right) \cdot i_{d(on)} \cdot v_{ds(off)}$$

   - Onde:

$$t_f \cong t_{on}$$

$$t_r \cong t_{off}$$

MOSFET de potência

Dados de catalogo:

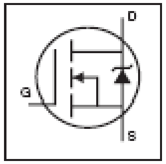
International
IOR Rectifier

PD - 94459A

IRFP150V

HEXFET® Power MOSFET

- Advanced Process Technology
- Ultra Low On-Resistance
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated



$V_{DSS} = 100V$

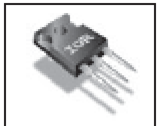
$R_{DS(on)} = 24m\Omega$

$I_D = 47A$

Description

Advanced HEXFET® Power MOSFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-247 package is preferred for commercial-industrial applications where higher power levels preclude the use of TO-220 devices. The TO-247 is similar but superior to the earlier TO-218 packcage because of its isolated mounting hole.



TO-247AC

Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ $T_C = 25°C$	Continuous Drain Current, V_{GS} @ 10V	46	A
I_D @ $T_C = 100°C$	Continuous Drain Current, V_{GS} @ 10V	32	
I_{DM}	Pulsed Drain Current ①	230	
P_D @ $T_C = 25°C$	Power Dissipation	140	W
	Linear Derating Factor	0.91	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
I_{AR}	Avalanche Current①	28	A
E_{AR}	Repetitive Avalanche Energy①	20	mJ
dv/dt	Peak Diode Recovery dv/dt ③	5.8	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 screw	10 lbf•in (1.1N•m)	

Thermal Resistance

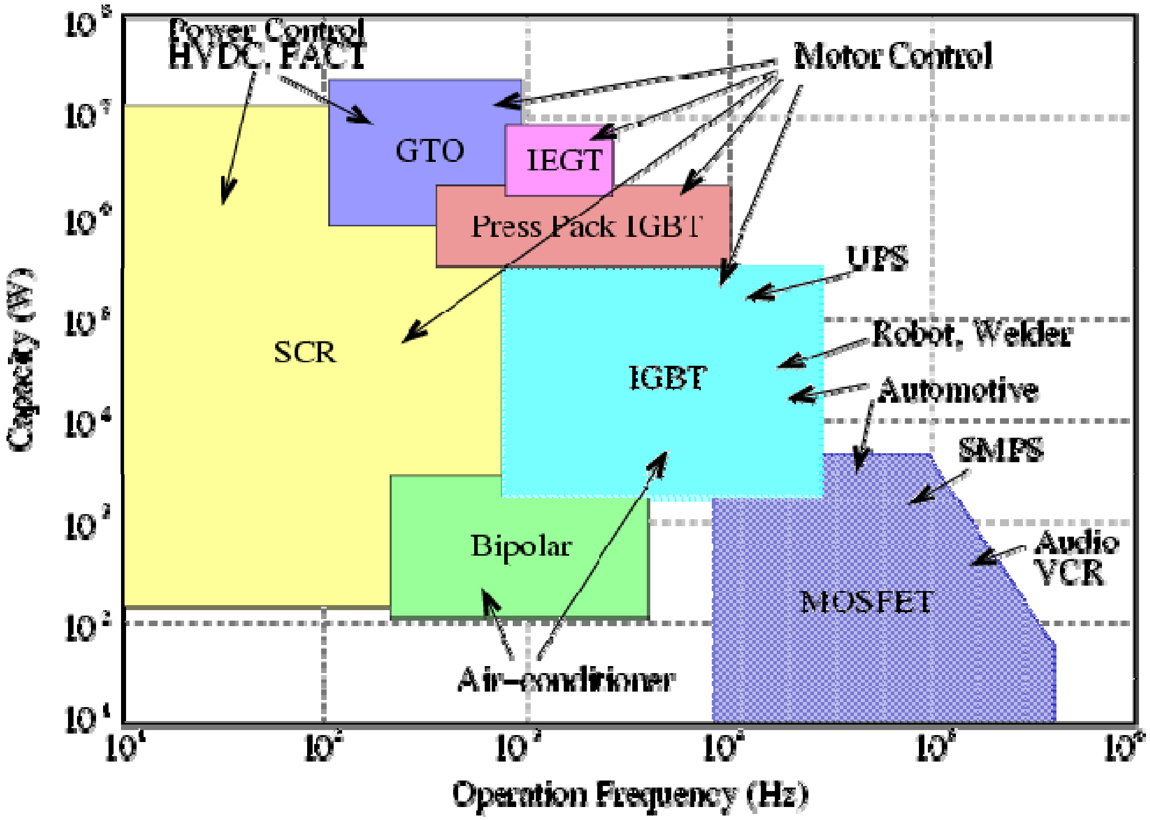
	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	1.1	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.24	—	
$R_{\theta JA}$	Junction-to-Ambient	—	40	

02/03/03

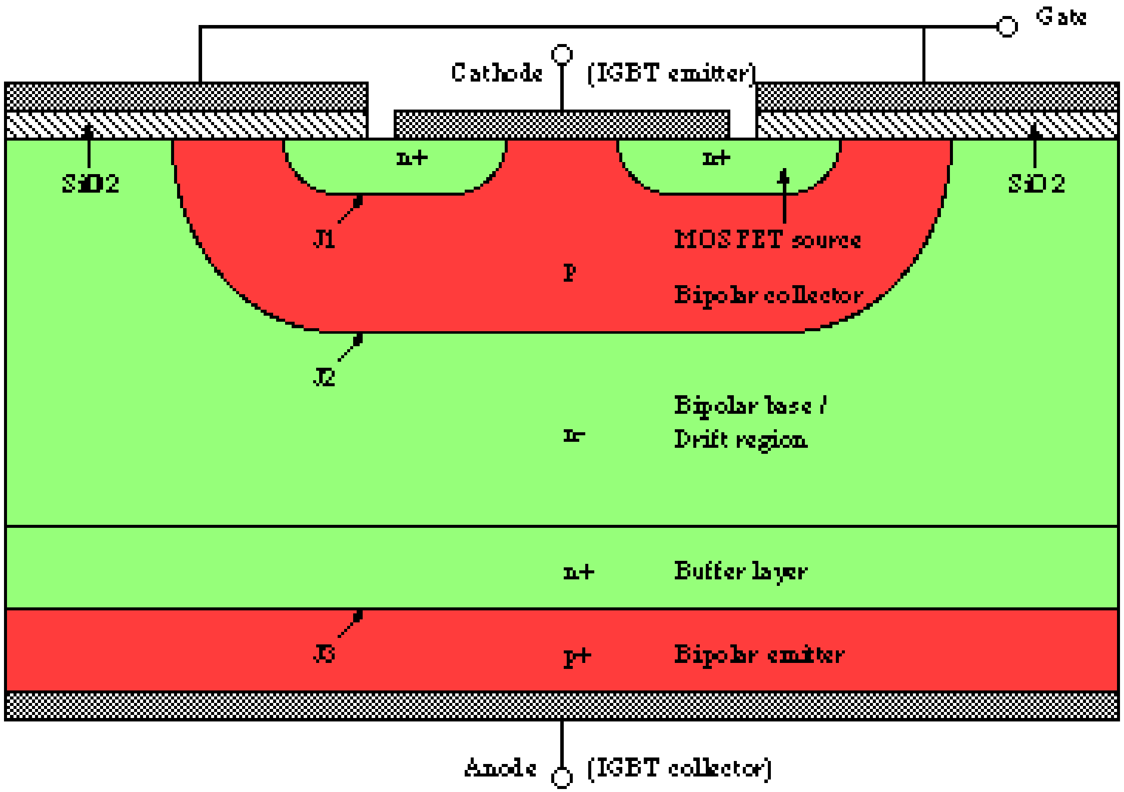
MOSFET de potência

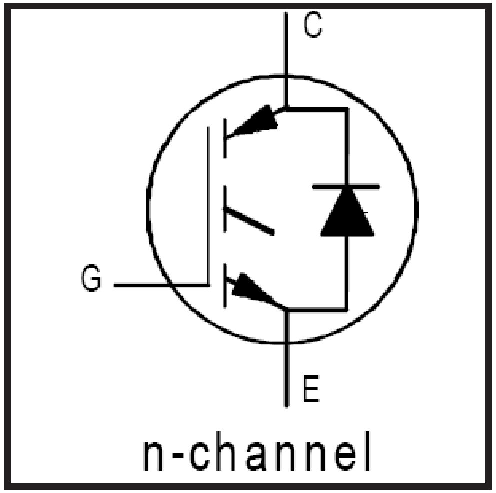
Quando usar MOSFET:

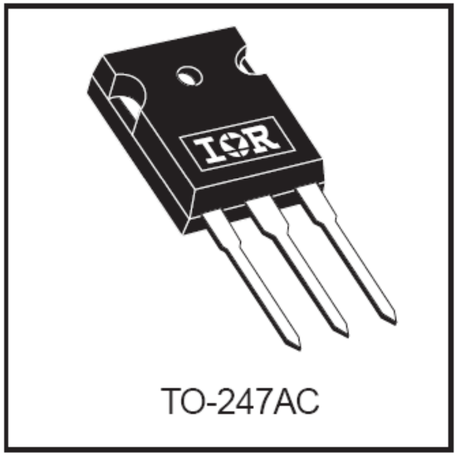
1. Freqüências altas (acima de 50 kHz);
2. Tensões muito baixas (< 500 V);
3. Potências baixas (< 1 kW).



IGBT







Características de BJT e MOSFET

IGBT – Insulated Gate Bipolar Transistor

IGBT

Classificação das perdas:

1. Condução;

$$P_{cond} = \left(i_C \cdot V_{CEsat} + i_B \cdot V_{BEsat}\right) \cdot t_{on} \cdot f$$

2. Comutação:
   - Entrada em condução e bloqueio;

$$P_{com} = \frac{1}{2}\left(t_r + t_f\right) \cdot I \cdot E \cdot f$$

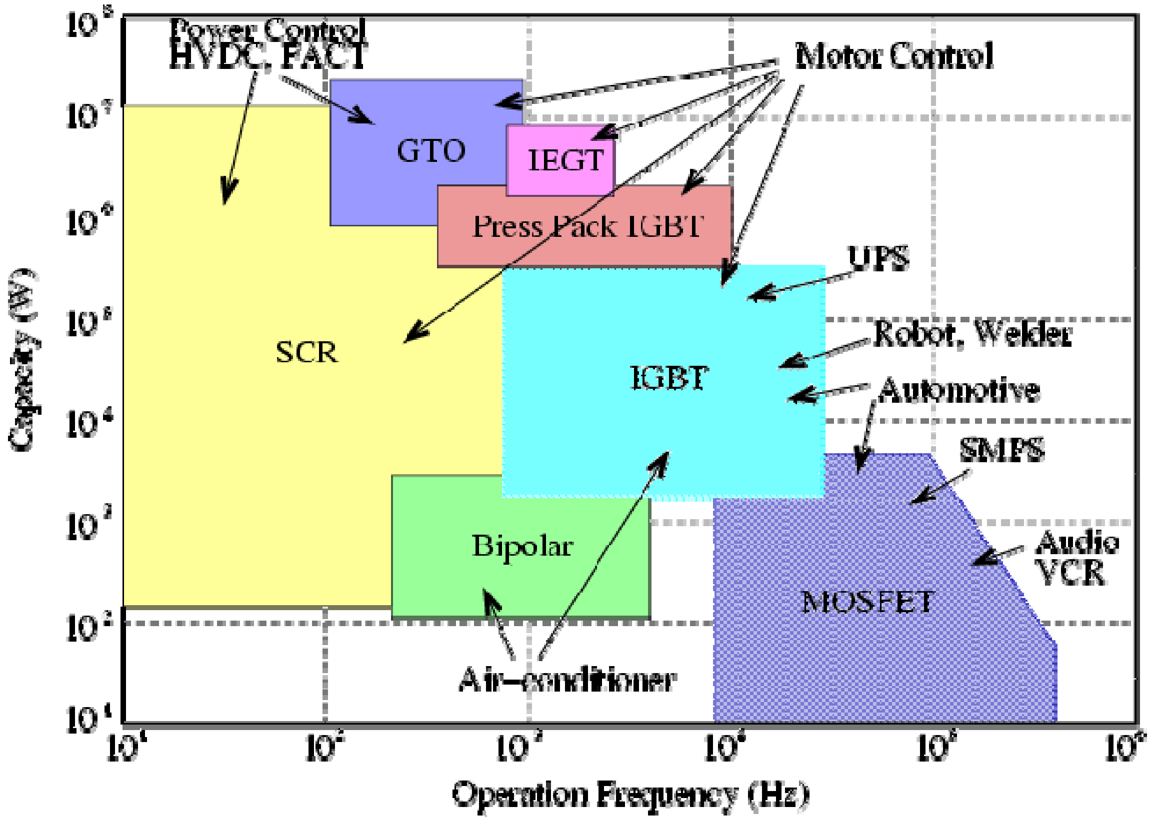
Detalhamento do cálculo de perdas

IGBT

Quando usar IGBT:

1. Freqüências baixas (menor que 50 kHz);
2. Tensões altas (> 500 V);
3. Potências altas (> 1 kW).

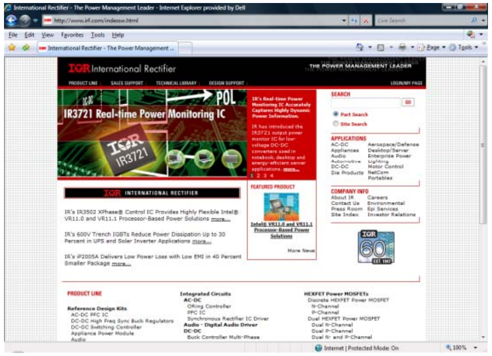
Part	Family	Package	Circuit	Switching Speed
IRG4PH30K	IGBT Discretes	TO-247AC	Discrete	ULTRAFAST 4-20 kHz
IRG4PC20U	IGBT Discretes	TO-247AC	Discrete	ULTRAFAST 8-60 kHz
IRG4PC30S	IGBT Discretes	TO-247AC	Discrete	DC-1 kHz (STANDARD)
IRG4PC60U	IGBT Discretes	TO-247AC	Discrete	ULTRAFAST 8-60 kHz
IRG4BC30W	IGBT Discretes	TO-220AB	Discrete	WARP 60-150 kHz
IRGB30B60K	IGBT Discretes	TO-220AB	Discrete	ULTRAFAST 10-30 kHz
IRGB8B60K	IGBT Discretes	TO-220AB	Discrete	ULTRAFAST 10-30 kHz
IRGS6B60K	IGBT Discretes	D2-Pak	Discrete	ULTRAFAST 10-30 kHz
IRGS14C40L	IGBT Discretes	D2-Pak	Discrete	Low-Vceon
IRGP4050	IGBT Discretes	TO-247AC	Discrete	Low-Vceon



IGBT

Quando usar IGBT:

1. Freqüências baixas (menor que 50 kHz);
2. Tensões altas (> 500 V);
3. Potências altas (> 1 kW).



www.irf.com

Part	Family	Package	Circuit	Switching Speed	VCES (V)	VCE(ON) (V)	IC @ 25C (A)	IC @ 100C (A)	PD @25C (W)
IRG4PH30K	IGBT Discretes	TO-247AC	Discrete	ULTRAFAST 4-20 kHz	1200	4.20	20	10	100
IRG4PC20U	IGBT Discretes	TO-247AC	Discrete	ULTRAFAST 8-60 kHz	600	2.1	13	6.5	60
IRG4PC30S	IGBT Discretes	TO-247AC	Discrete	DC-1 kHz (STANDARD)	600	1.60	34	18	100
IRG4PC60U	IGBT Discretes	TO-247AC	Discrete	ULTRAFAST 8-60 kHz	600	2.00	75	40	520
IRG4BC30W	IGBT Discretes	TO-220AB	Discrete	WARP 60-150 kHz	600	2.70	23	12	100
IRGB30B60K	IGBT Discretes	TO-220AB	Discrete	ULTRAFAST 10-30 kHz	600	2.35	78	50	370
IRGB8B60K	IGBT Discretes	TO-220AB	Discrete	ULTRAFAST 10-30 kHz	600	2.2	17	9.0	140
IRGS6B60K	IGBT Discretes	D2-Pak	Discrete	ULTRAFAST 10-30 kHz	600	1.80	13	7	90
IRGS14C40L	IGBT Discretes	D2-Pak	Discrete	Low-Vceon	430	1.40	20	14	125
IRGP4050	IGBT Discretes	TO-247AC	Discrete	Low-Vceon	250	1.90	104	56	330

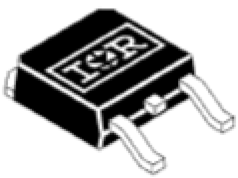
IGBT

Encapsulamentos:

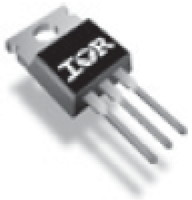
www.semikron.com.br

IGBT

Encapsulamentos:

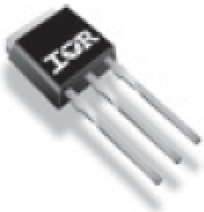


D-PAK
TO-252AA

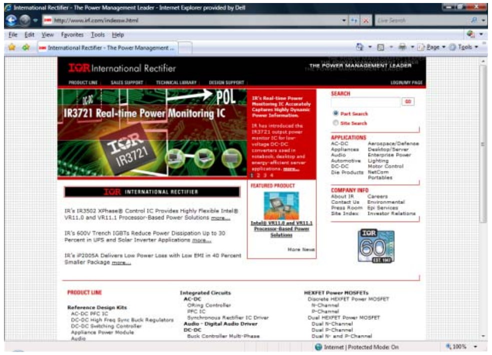


TO-220AB
IRGB6B60K

D^{2}Pak
IRGS6B60K



TO-262
IRGSL6B60K



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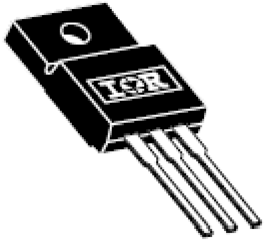
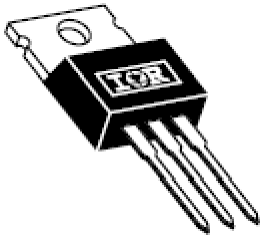
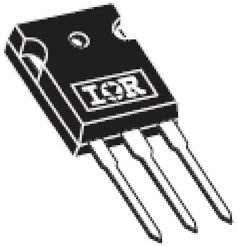


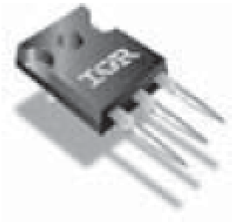
TO-220 FULLPAK



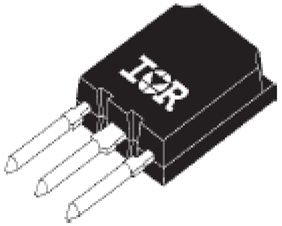
TO-220AB



TO-247AC



TO-247AC



SUPER - 247

IGBT

Dados de catalogo:

International
IOR Rectifier

PD - 94443

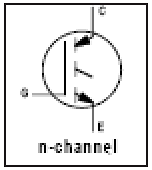
IRG4PC60U

INSULATED GATE BIPOLAR TRANSISTOR

UltraFast Speed IGBT

Features

- UltraFast: Optimized for high operating frequencies up to 50 kHz in hard switching, >200 kHz in resonant mode.
- Generation 4 IGBT design provides tighter parameter distribution and higher efficiency.
- Industry standard TO-247AC package.



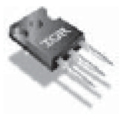
$V_{CES} = 600V$

$V_{CE(on)\,typ.} = 1.6V$

$@V_{GE} = 15V, I_C = 40A$

Benefits

- Generation 4 IGBT's offer highest efficiency available.
- IGBT's optimized for specified application conditions.
- Designed for best performance when used with IR Hexfred & IR Fred companion diodes.



TO-247AC

Absolute Maximum Ratings

	Parameter	Max.	Units
V_{CES}	Collector-to-Emitter Breakdown Voltage	600	V
I_C @ T_C = 25°C	Continuous Collector Current	75	A
I_C @ T_C = 100°C	Continuous Collector Current	40	
I_{CM}	Pulsed Collector Current ①	300	
I_{LM}	Clamped Inductive Load Current ②	300	
V_{GE}	Gate-to-Emitter Voltage	± 20	V
E_{ARV}	Reverse Voltage Avalanche Energy ③	200	mJ
P_D @ T_C = 25°C	Maximum Power Dissipation	520	W
P_D @ T_C = 100°C	Maximum Power Dissipation	210	
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 150	°C
	Soldering Temperature, for 10 seconds	300 (0.063 in. (1.6mm from case)	
	Mounting torque, 6-32 or M3 screw.	10 lbf•in (1.1N•m)	

Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	----	0.24	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.24	----	
$R_{\theta JA}$	Junction-to-Ambient, typical socket mount	----	40	
Wt	Weight	6 (0.21)	----	g (oz)

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04/28/02

International
IOR Rectifier

PD 9.1467D

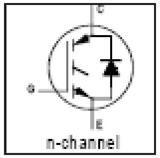
IRG4PC40UD

INSULATED GATE BIPOLAR TRANSISTOR WITH ULTRAFAST SOFT RECOVERY DIODE

UltraFast CoPack IGBT

Features

- UltraFast: Optimized for high operating frequencies 8-40 kHz in hard switching, >200 kHz in resonant mode
- Generation 4 IGBT design provides tighter parameter distribution and higher efficiency than Generation 3
- IGBT co-packaged with HEXFRED™ ultrafast, ultra-soft-recovery anti-parallel diodes for use in bridge configurations
- Industry standard TO-247AC package



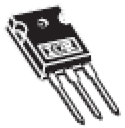
$V_{CES} = 600V$

$V_{CE(on)\,typ.} = 1.72V$

$@V_{GE} = 15V, I_C = 20A$

Benefits

- Generation -4 IGBT's offer highest efficiencies available
- IGBT's optimized for specific application conditions
- HEXFRED diodes optimized for performance with IGBT's . Minimized recovery characteristics require less/no snubbing
- Designed to be a "drop-in" replacement for equivalent Industry-standard Generation 3 IR IGBT's



TO-247AC

Absolute Maximum Ratings

	Parameter	Max.	Units
V_{CES}	Collector-to-Emitter Voltage	600	V
I_C @ T_C = 25°C	Continuous Collector Current	40	A
I_C @ T_C = 100°C	Continuous Collector Current	20	
I_{CM}	Pulsed Collector Current ①	160	
I_{LM}	Clamped Inductive Load Current ②	160	
I_F @ T_C = 100°C	Diode Continuous Forward Current	15	
I_{FM}	Diode Maximum Forward Current	160	
V_{GE}	Gate-to-Emitter Voltage	± 20	V
P_D @ T_C = 25°C	Maximum Power Dissipation	160	W
P_D @ T_C = 100°C	Maximum Power Dissipation	65	
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to +150	°C
	Soldering Temperature, for 10 sec.	300 (0.063 in. (1.6mm) from case)	
	Mounting Torque, 6-32 or M3 Screw.	10 lbf•in (1.1 N•m)	

Thermal Resistance

	Parameter	Min.	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case - IGBT	——	——	0.77	°C/W
$R_{\theta JC}$	Junction-to-Case - Diode	——	——	1.7	
$R_{\theta CS}$	Case-to-Sink, flat, greased surface	——	0.24	——	
$R_{\theta JA}$	Junction-to-Ambient, typical socket mount	——	——	40	
Wt	Weight	——	6 (0.21)	——	g (oz)

4/17/97

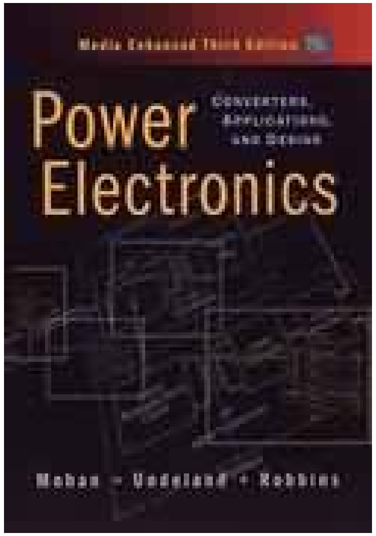
BJT x MOSFET x IGBT

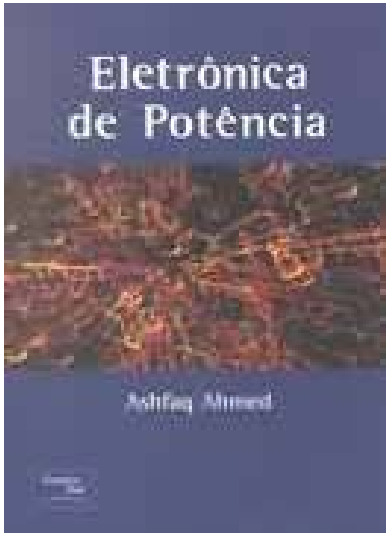
	MOSFET	IGBT	BJT
Tipo de comando	Tensão	Tensão	Corrente
Potência do comando	Mínima	Mínima	Grande
Complexidade do comando	Simples	Simples	Média
Densidade de corrente	Elevada em baixas tensões e Baixa em altas tensões	Muito elevada	Média
Perdas de comutação	Muito baixa	Baixa para Média	Média para Alta

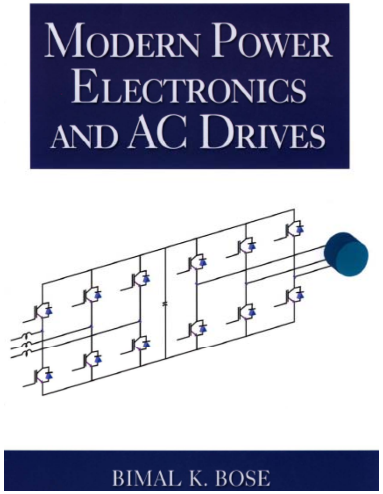
Próxima aula

Conversores CA-CA:

1. Gradadores.







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