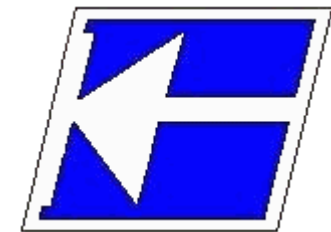


Instituto Federal de Educação, Ciência e Tecnologia de Santa Catarina

Departamento Acadêmico de Eletrônica

Eletrônica de Potência



Semicondutores de Potência

BJT, MOSFET e IGBT

Prof. Clovis Antonio Petry.

Florianópolis, fevereiro de 2014.

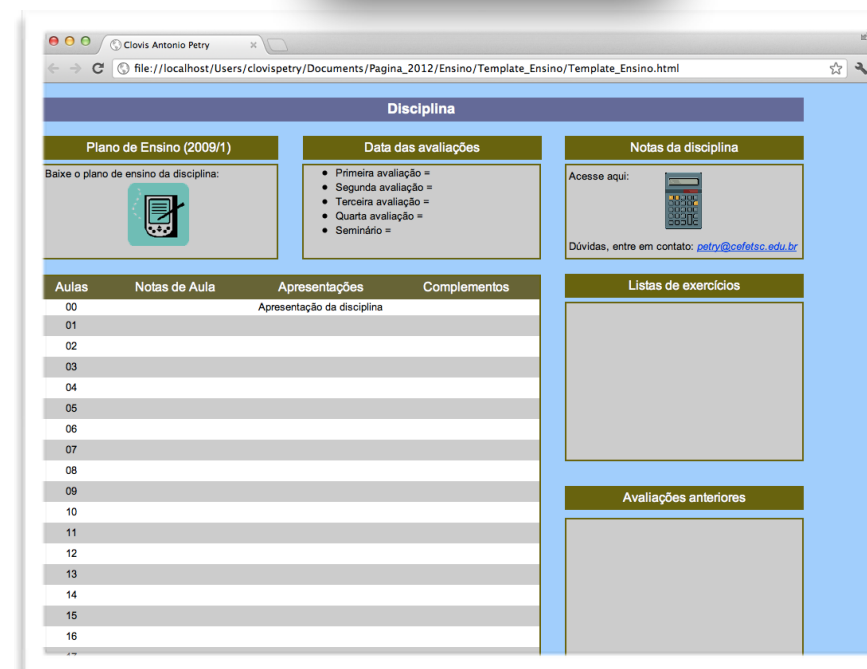
Biografia para Esta Aula

Capítulos 3:

- Transistores de potência.



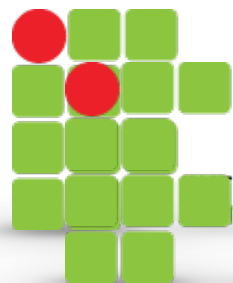
www.ProfessorPetry.com.br



Nesta Aula

Semicondutores de potência:

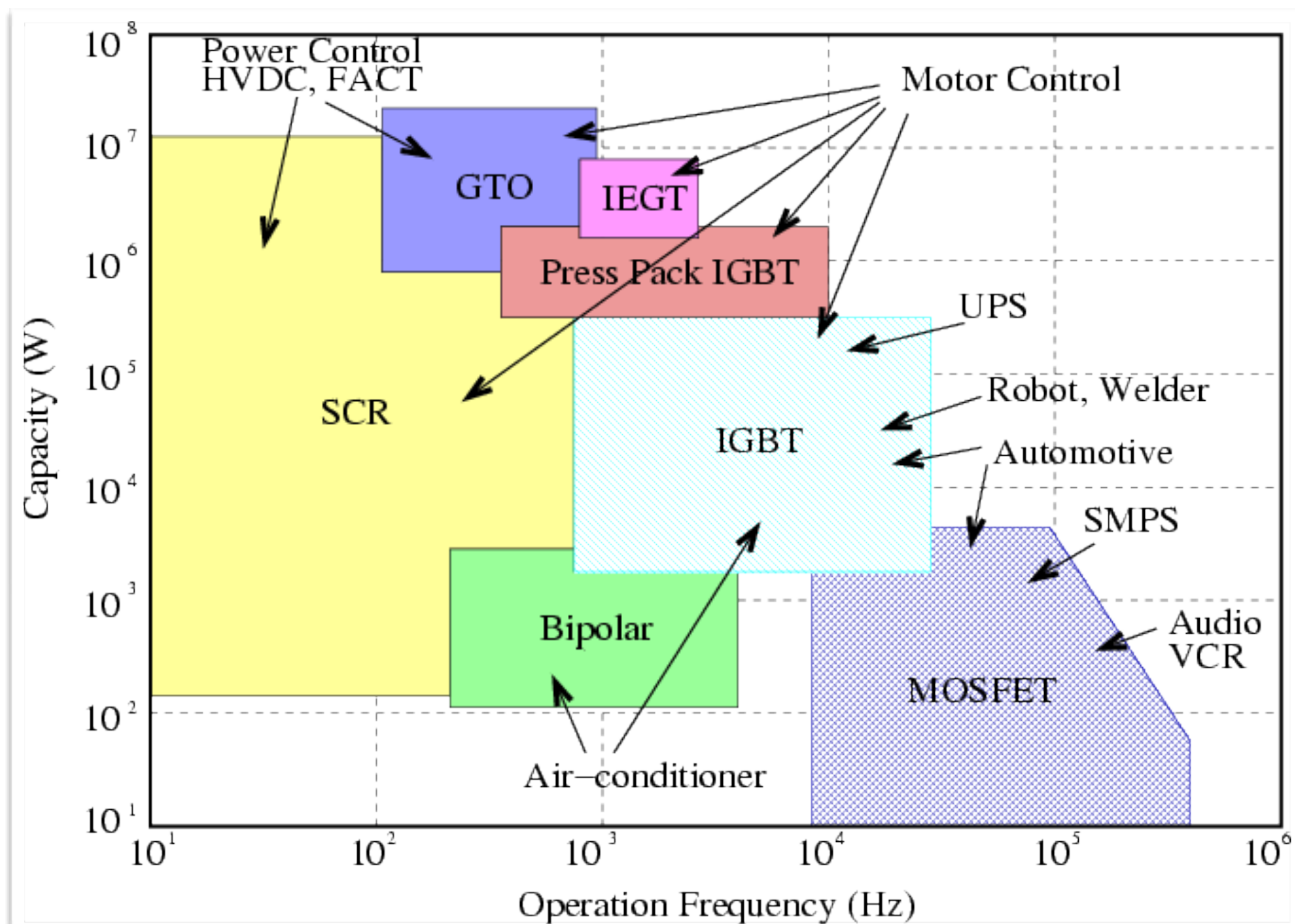
- Semicondutores para eletrônica de potência;
- Revisão de BJT;
- BJT x FET;
- FETs;
- MOSFETs;
- IGBTs.

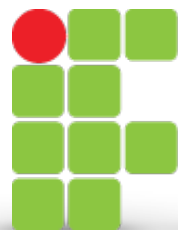


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Semicondutores de Potência

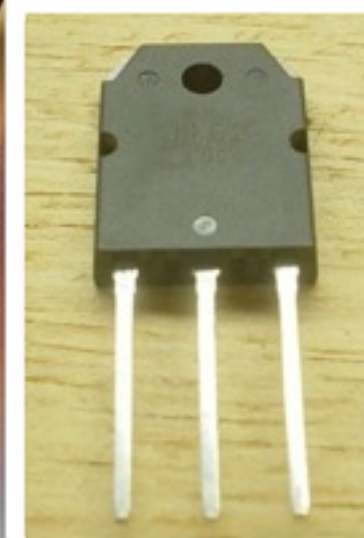
Semicondutores aplicados à eletrônica de potência:





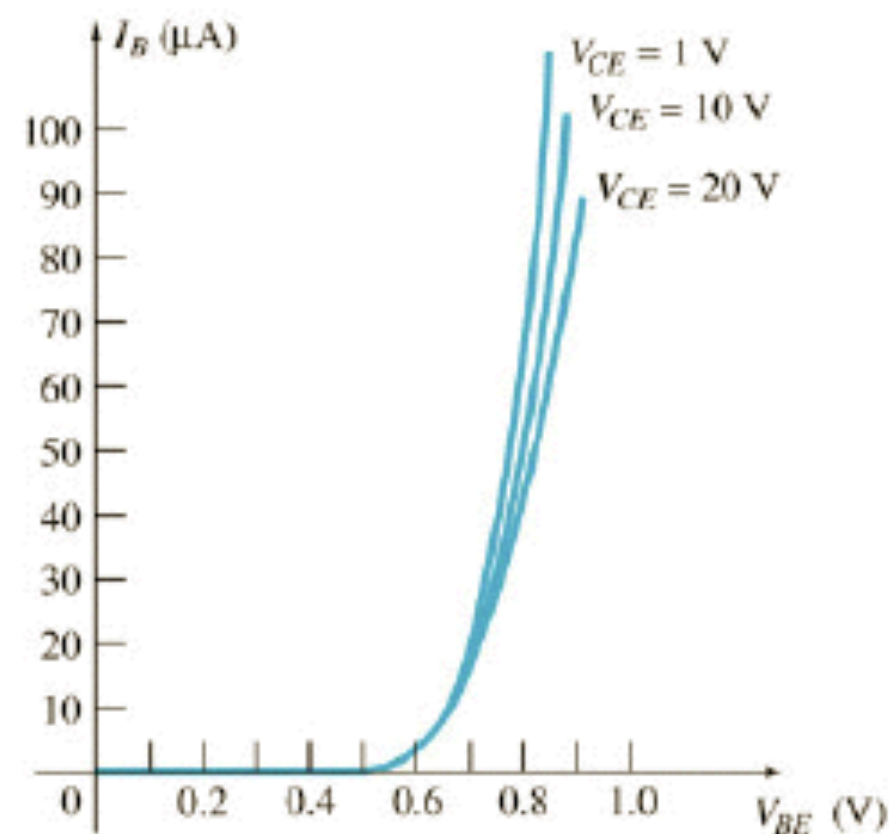
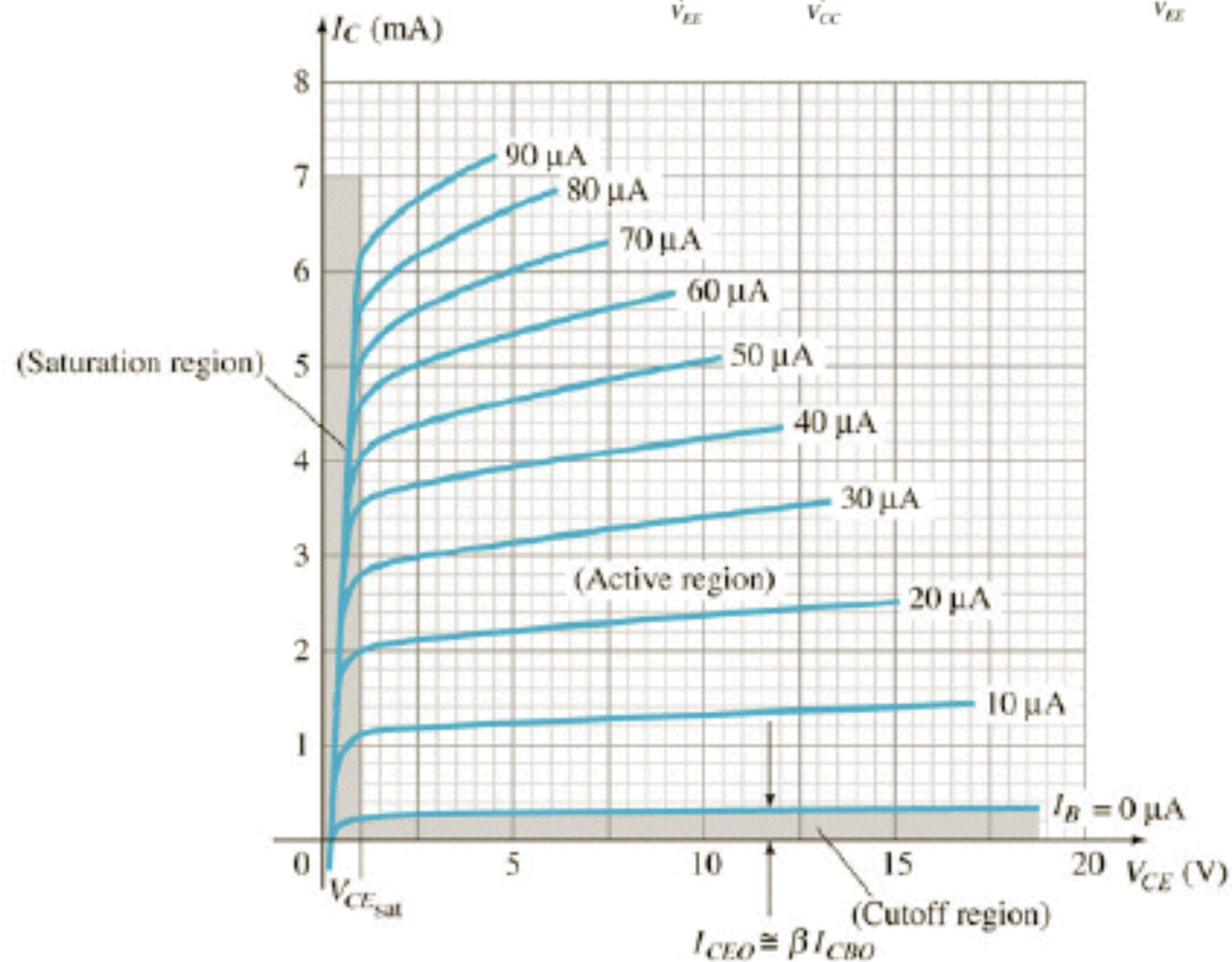
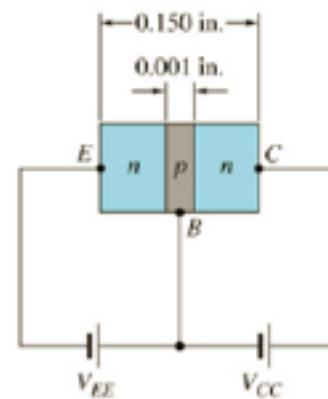
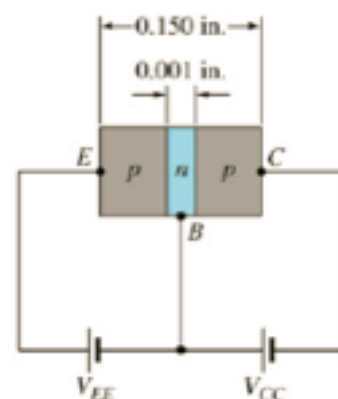
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Semicondutores de Potência



Revisão - BJT

BJT - Transistor bipolar de junção



Revisão - BJT

Électronique - Internet Explorer provided by Dell

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

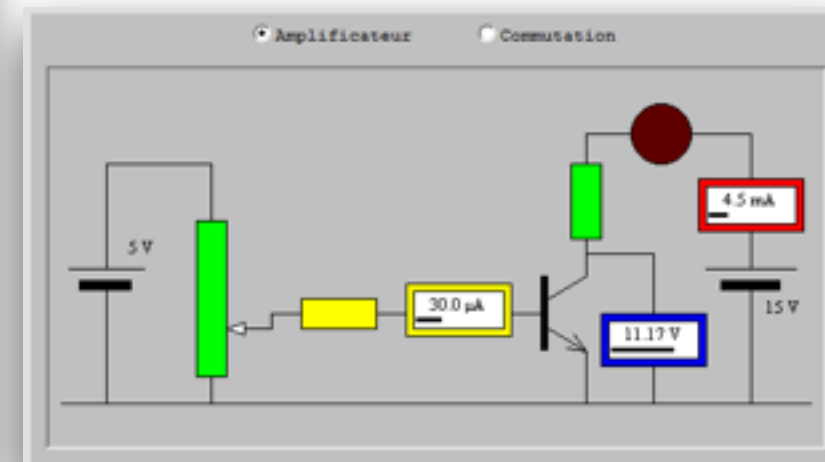
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Électronique

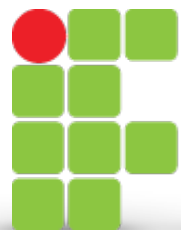
Électronique

Oscilloscope cathodique	Diodes et transistors	Filtres	Logique
- Principe - Synchronisation - Fonctionnement en bicourbe - Figures de Lissajous - Mesure de déphasage - Mesure de fréquences - Balayage télévision	- Pont de Graetz - Filtrage (animation) - Redressement et filtrage - Régulateur à diode Zener - Transistor (principe) - Transistor en régime variable	- Filtres passifs (exemples) - Filtres passifs (général) - Filtres en L, T et Pi - Filtres en T et T ponté - Filtres de Sallen et Kay - Filtres de Rauch	- Portes logiques - Associations de NANDs - Associations de NORs - Bascules R-S et D - Bascules J-K - Additionneur binaire
Circuits simples	Commutation	Convertisseurs	Capteurs
- Amplificateur opérationnel - Diviseur de tension - Circuits RC, Filtres Dérivateur Intégrateur - Circuits R, L, C série et // - Relaxateur à néon - Déphaseur passif - Déphaseur à AOP - Générateur de courant constant - Adaptation d'impédances	- Astable - Astable à comparateur - Monostable - Comparateur de Schmitt	- Convertisseur N/A R-2R - Convertisseur A/N simple rampe - Convertisseur A/N à approximations	- Thermistance - Thermomètre à diode - Thermomètre Pt500 - Impédance d'un quartz
Divers	Divers		

Internet | Protected Mode: On 100%



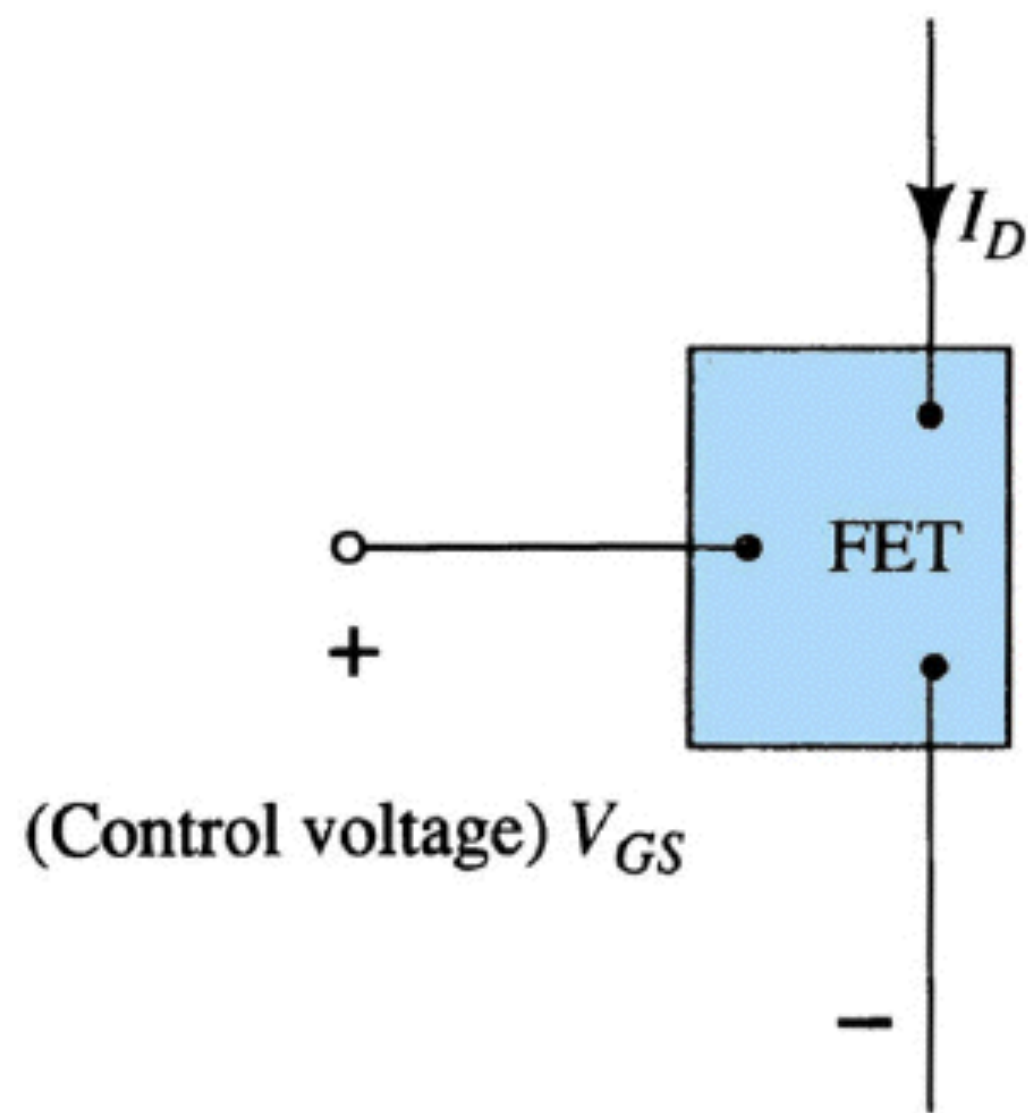
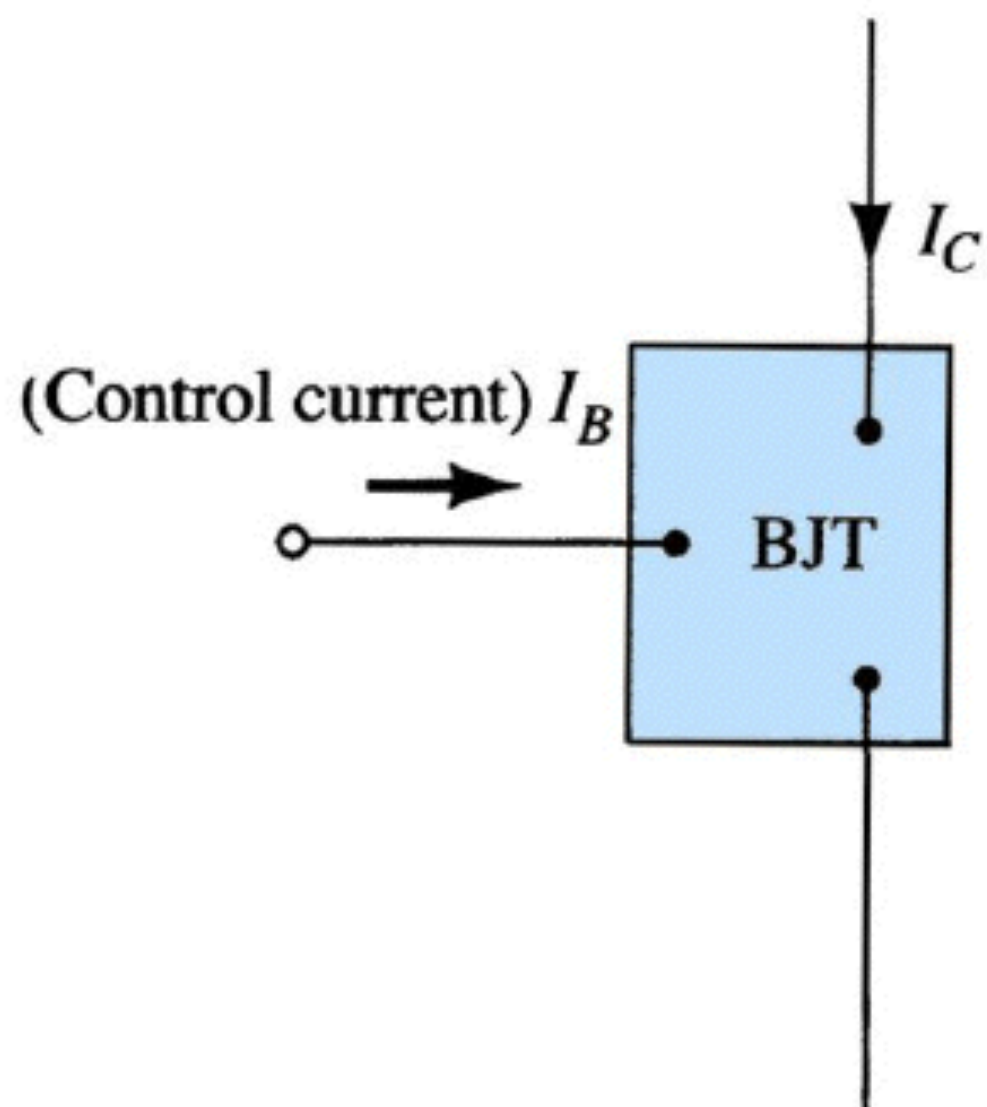
<http://www.univ-lemans.fr/enseignements/physique/02/electro/mnueltro.html>

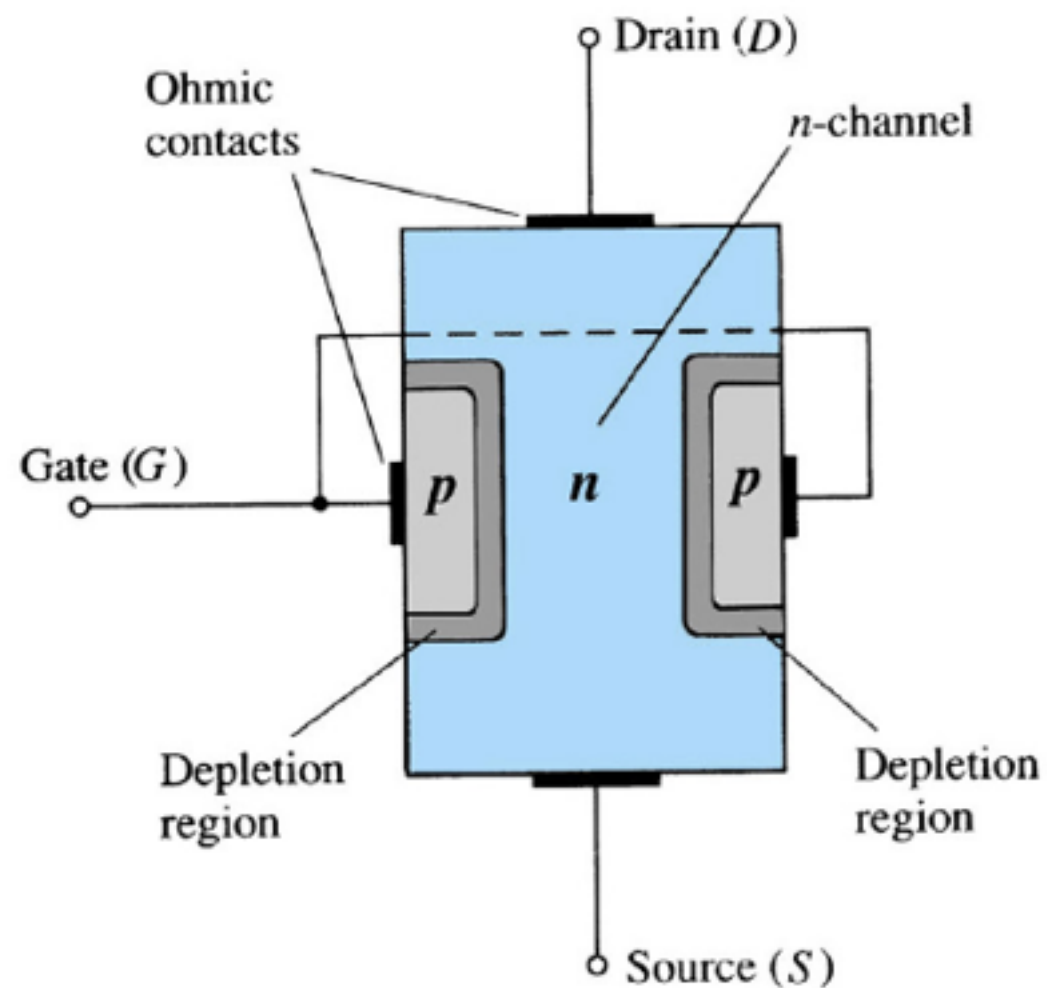


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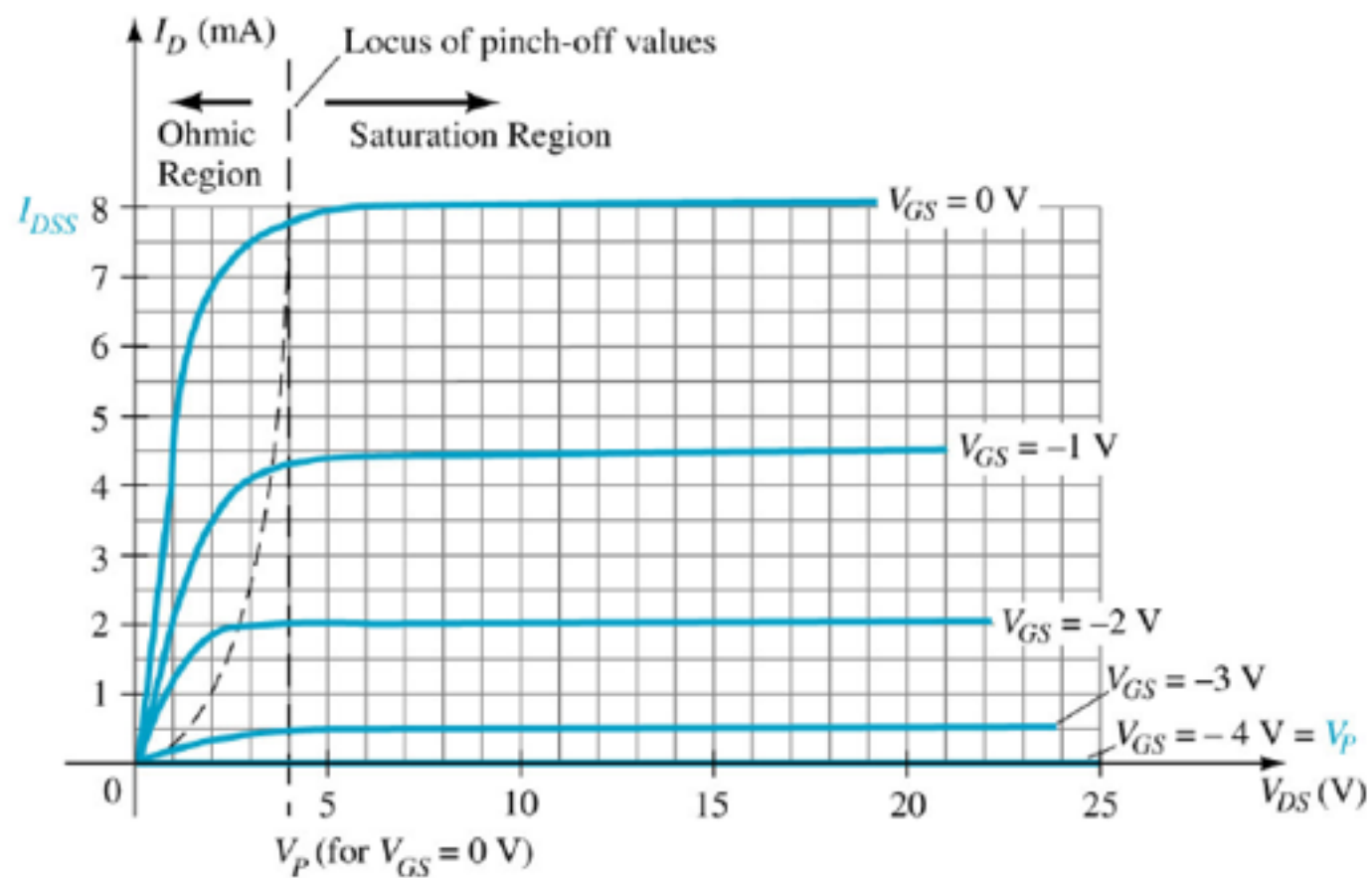
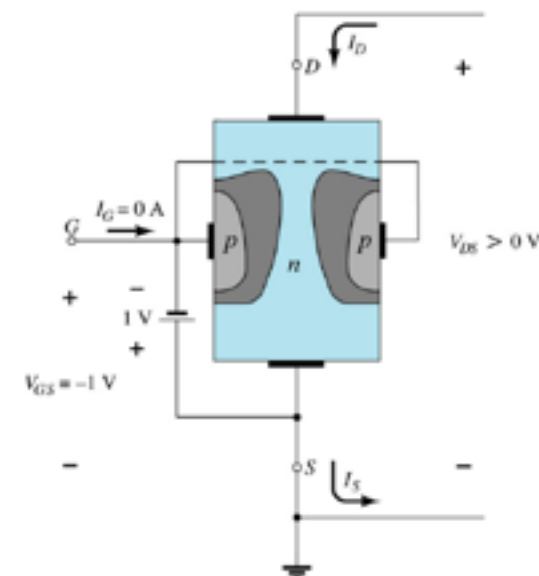
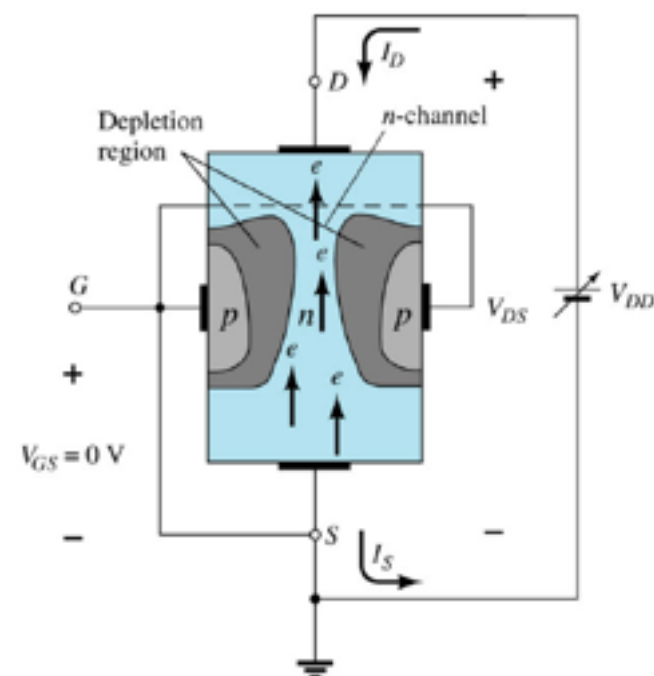
BJT x FET

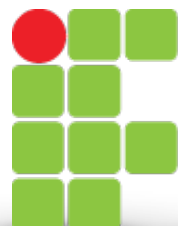
FET - Transistor de efeito de campo





JFET: Operação básica





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FET

Semiconductor Applet Services - Internet Explorer provided by Dell

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

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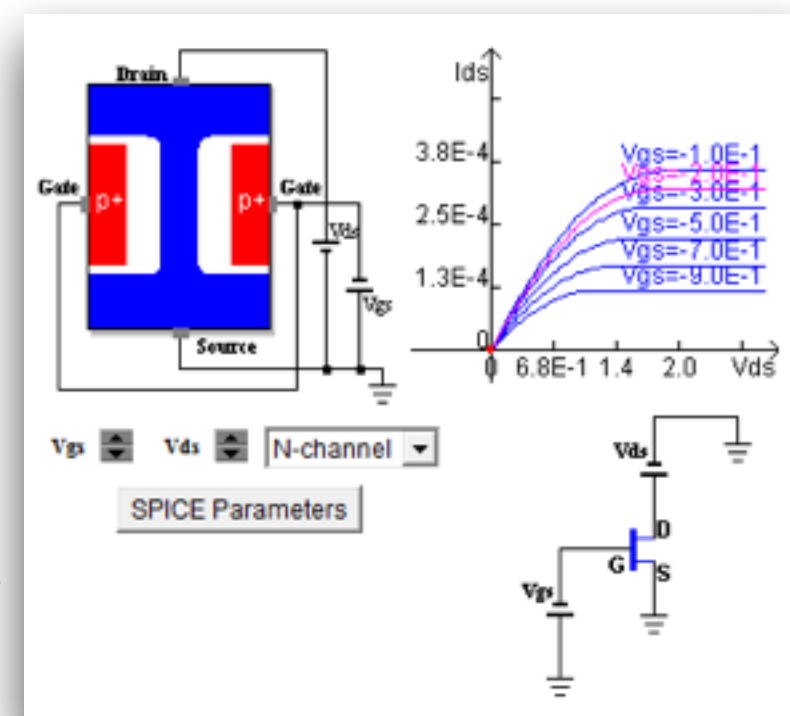
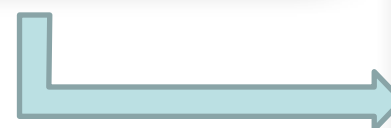
The Semiconductor Applet Service

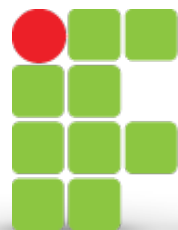
(Supported in part by the National Science Foundation)

List of Simulation Applets

- Crystal Structure**
 - Zincblende and Diamond structures (GaAs, Si, etc.): [unitcell with a list of material property](#). It gives you the 3D views of the unitcell and the covalent bonds.
 - [Hexagonal Closed Packed structures](#) (ZnS, GaN, SiC, etc.). An interactive 3D view of the crystal unitcell.
 - [Crystal Structure and the 14 Bravais Lattices](#) (java1.3): you can add various Basis atoms, rotate the crystal with one or multiple unitcells for a 3D view. It has many example crystals. You can also view the lattice planes and directions. [Crystal Structure in Java 3D !](#) (Java3D plugin maybe needed: use link in page)
- Energy Bands and Charge Carriers**
 - Visualization of [diffusion, drift and recombination](#) of excess minority carriers in a semiconductor.
 - [Indirect recombination via an energy state in the band gap](#). It also introduces the four basic processes in the Shockley-Read-Hall statistics.
 - Energy Band Diagram and E-k Diagram
 - [AlGaAs](#)
 - [SiGe](#)
- Charge Carriers and Fermi Level** [Semiconductor Statistics]
 - [Fermi Function and Localized Energy States](#) and the Temperature effect.

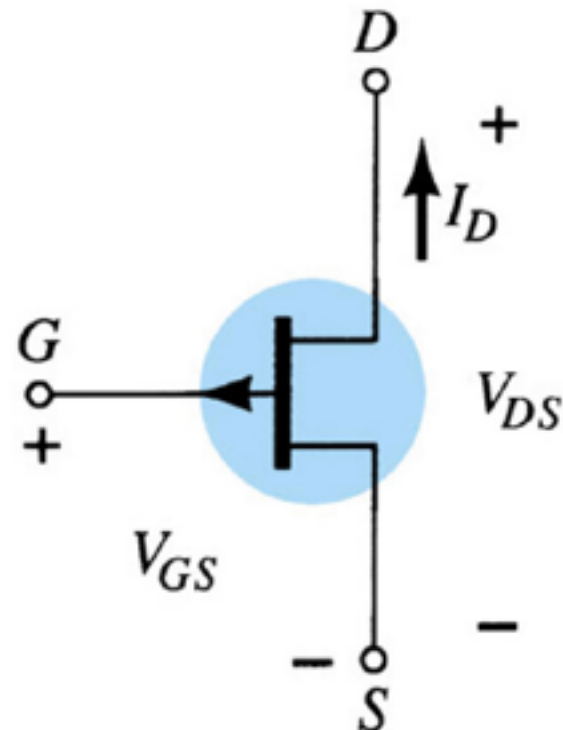
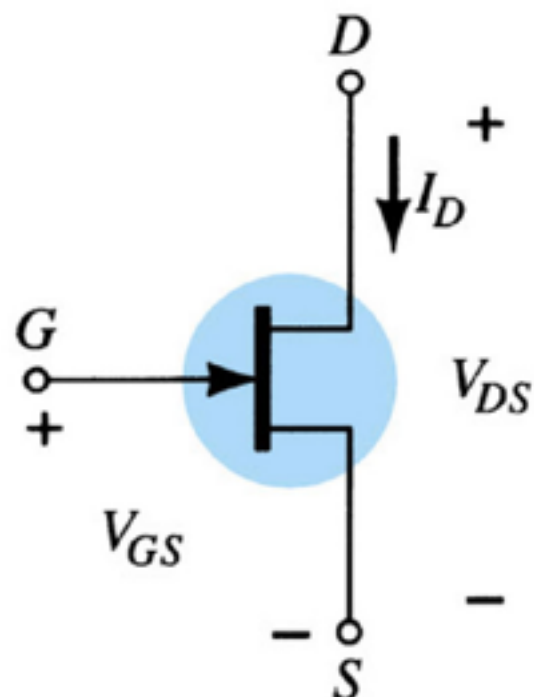
<http://jas.eng.buffalo.edu/>



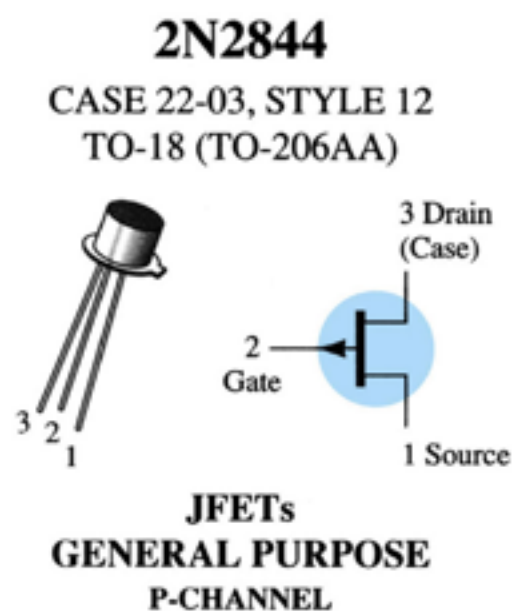
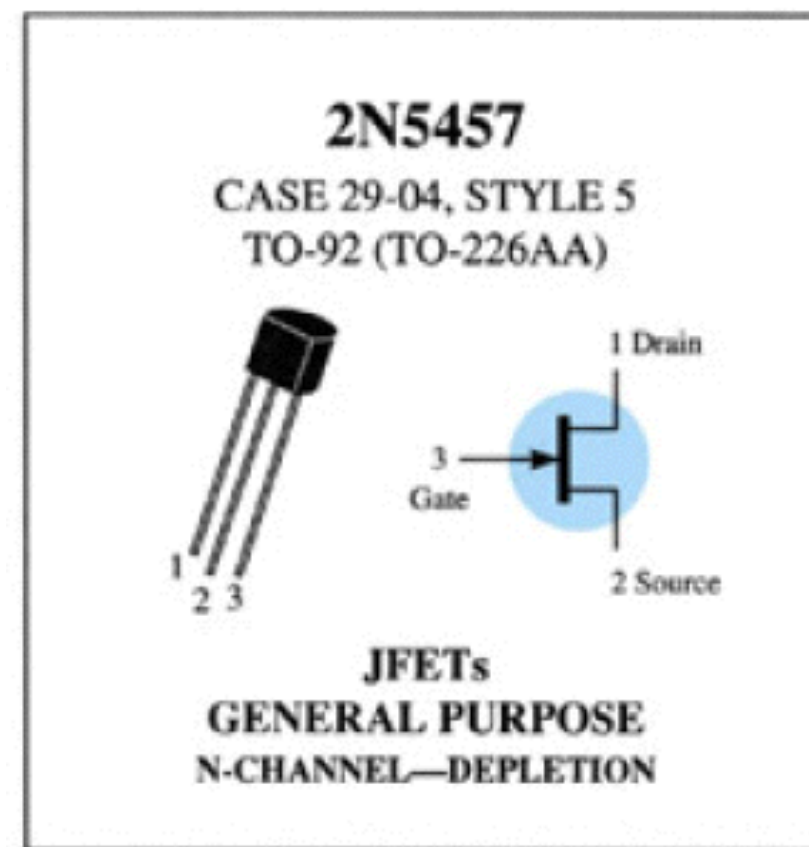


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FET

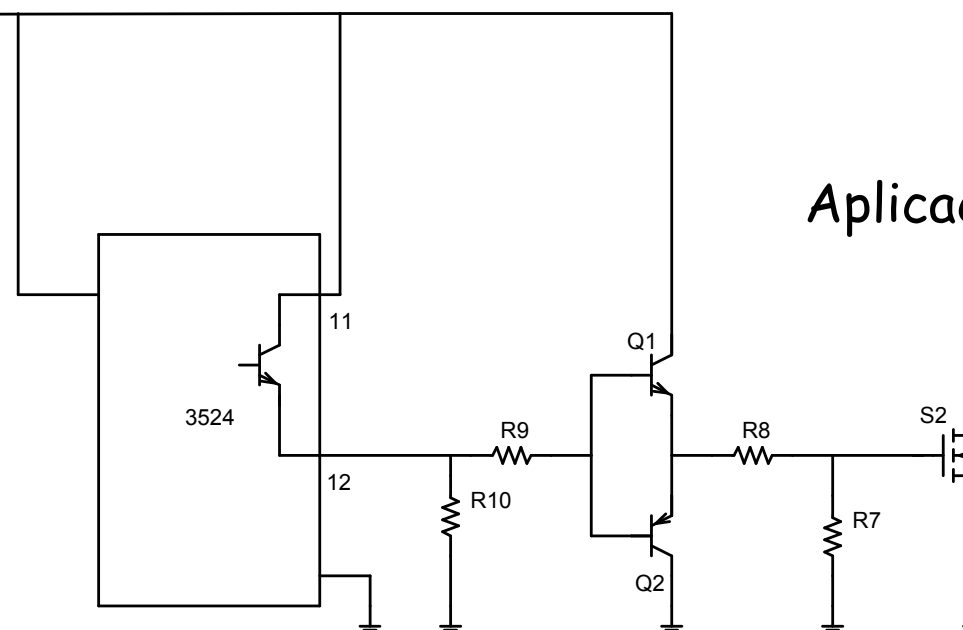


JFET canal n e canal p



Positivo da Fonte Auxiliar

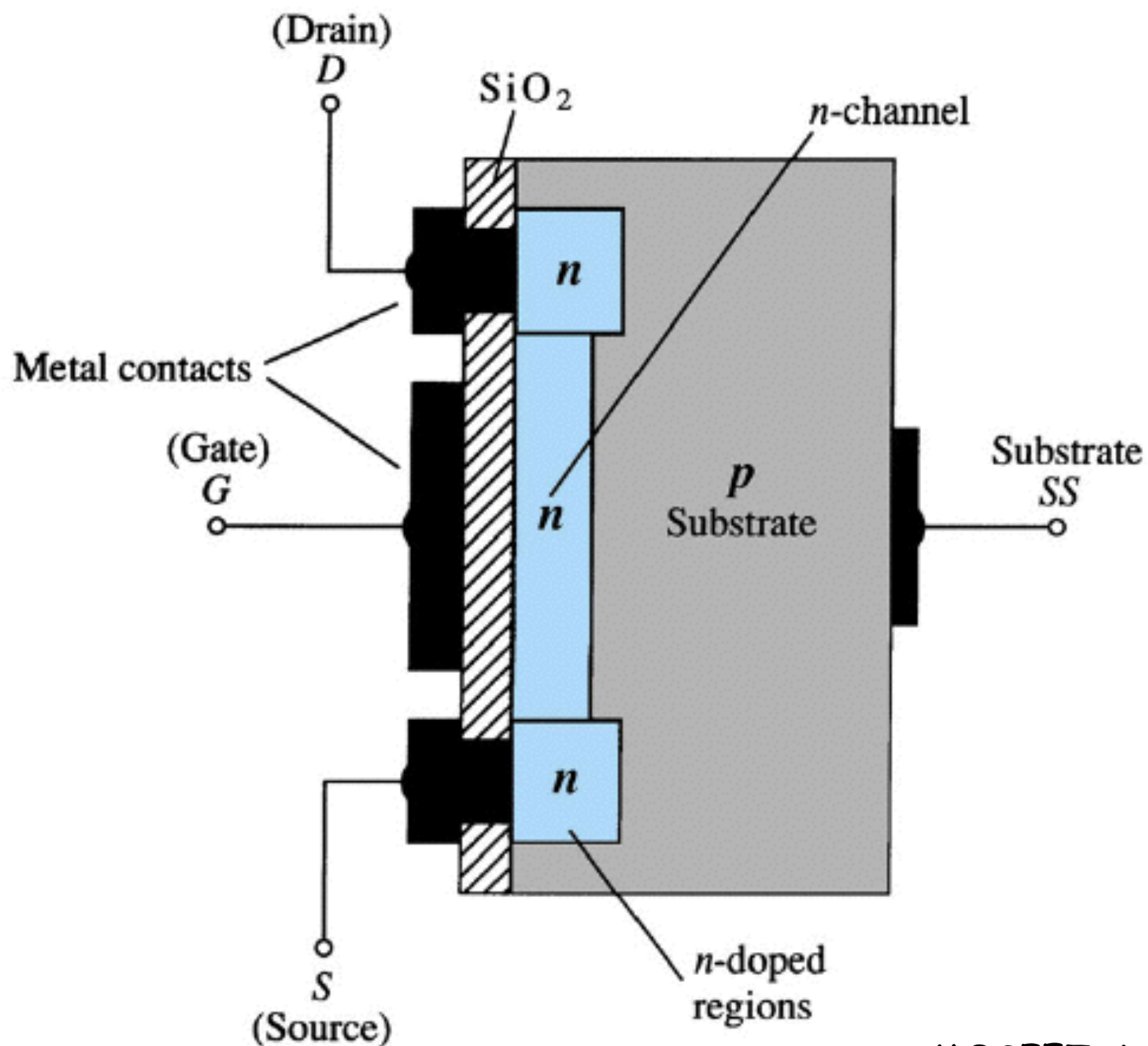
+ Vaux



Aplicação do JFET

MOSFET

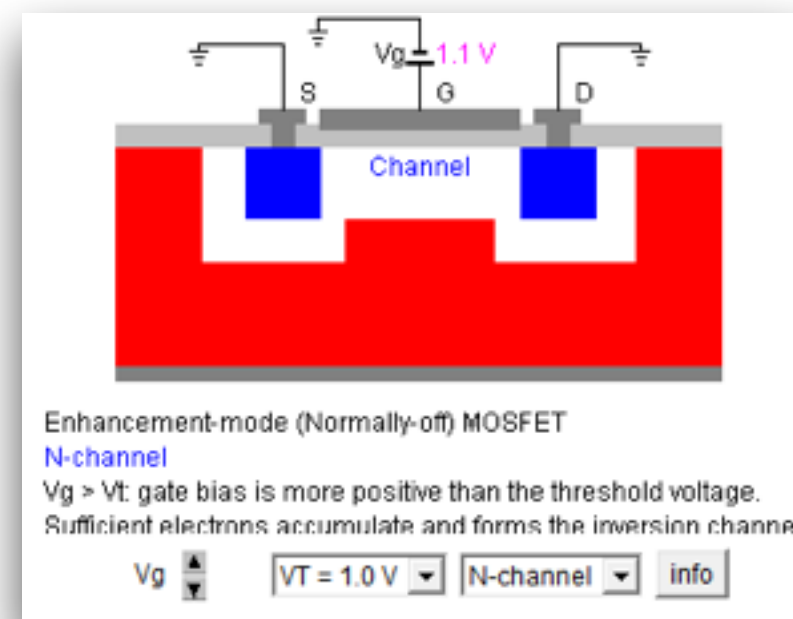
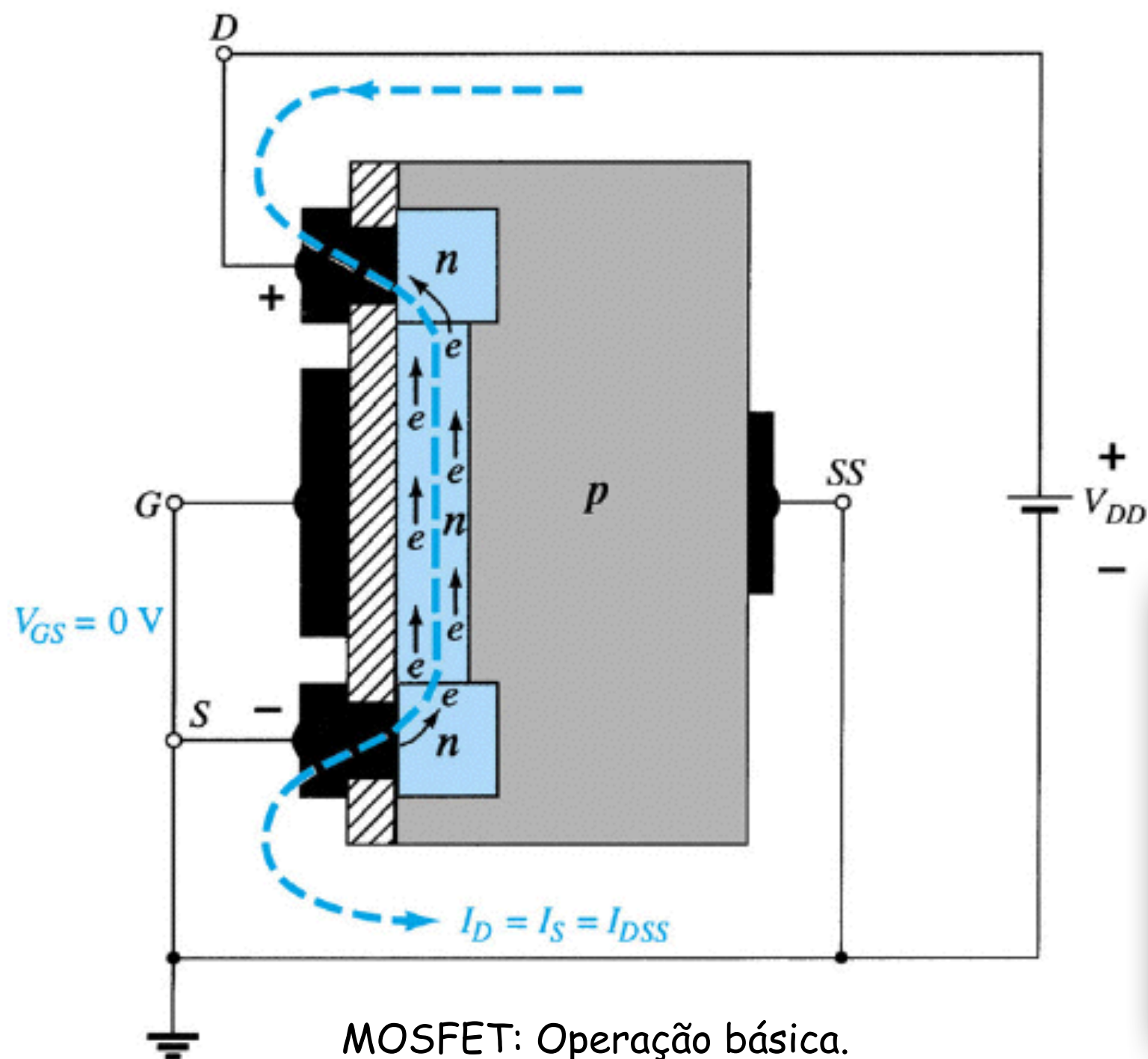
MOSFET - Metal Oxide Semiconductor Field Effect Transistor



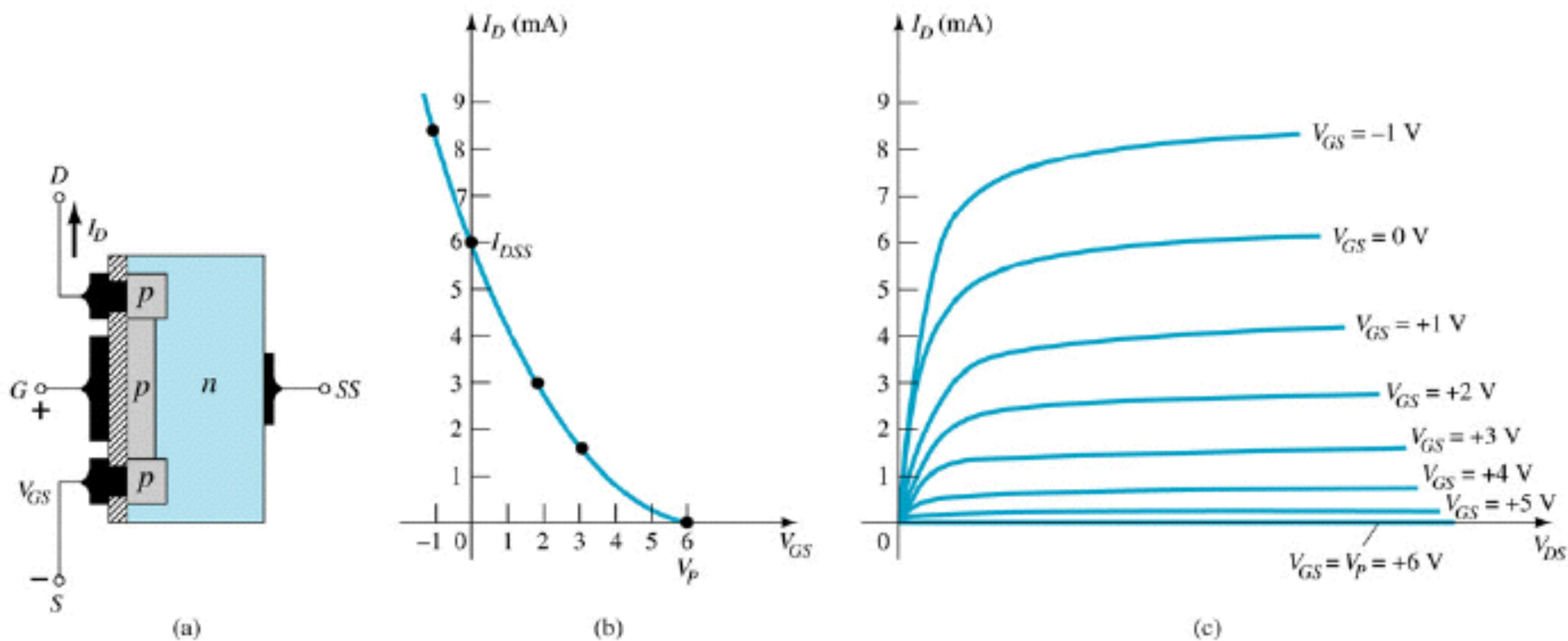
MOSFET tipo Depleção

MOSFET

MOSFET tipo Depleção



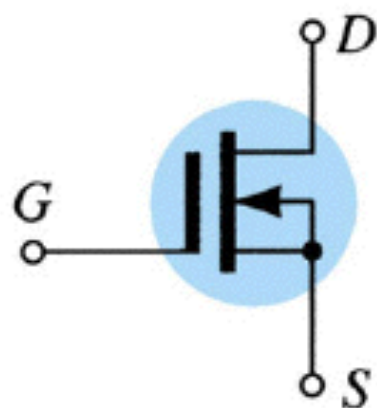
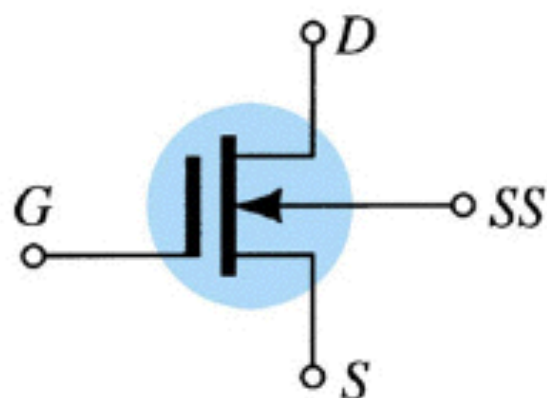
MOSFET tipo Depleção



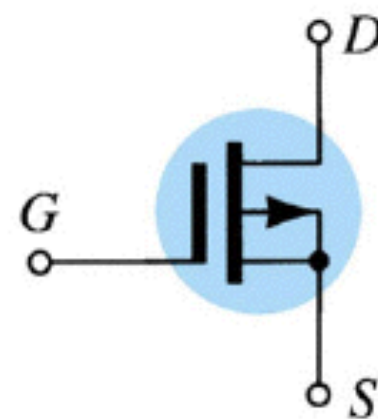
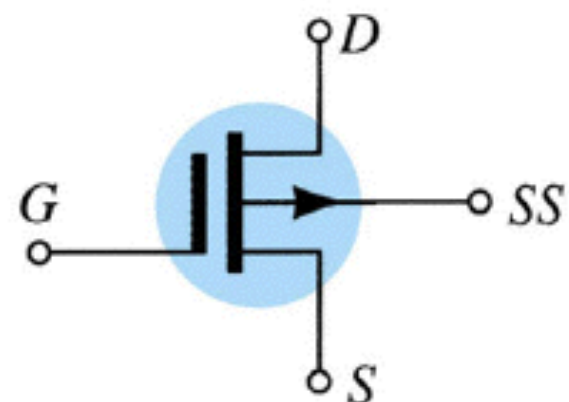
MOSFET: Operação básica.

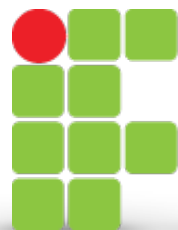
MOSFET tipo Depleção

n-channel



p-channel

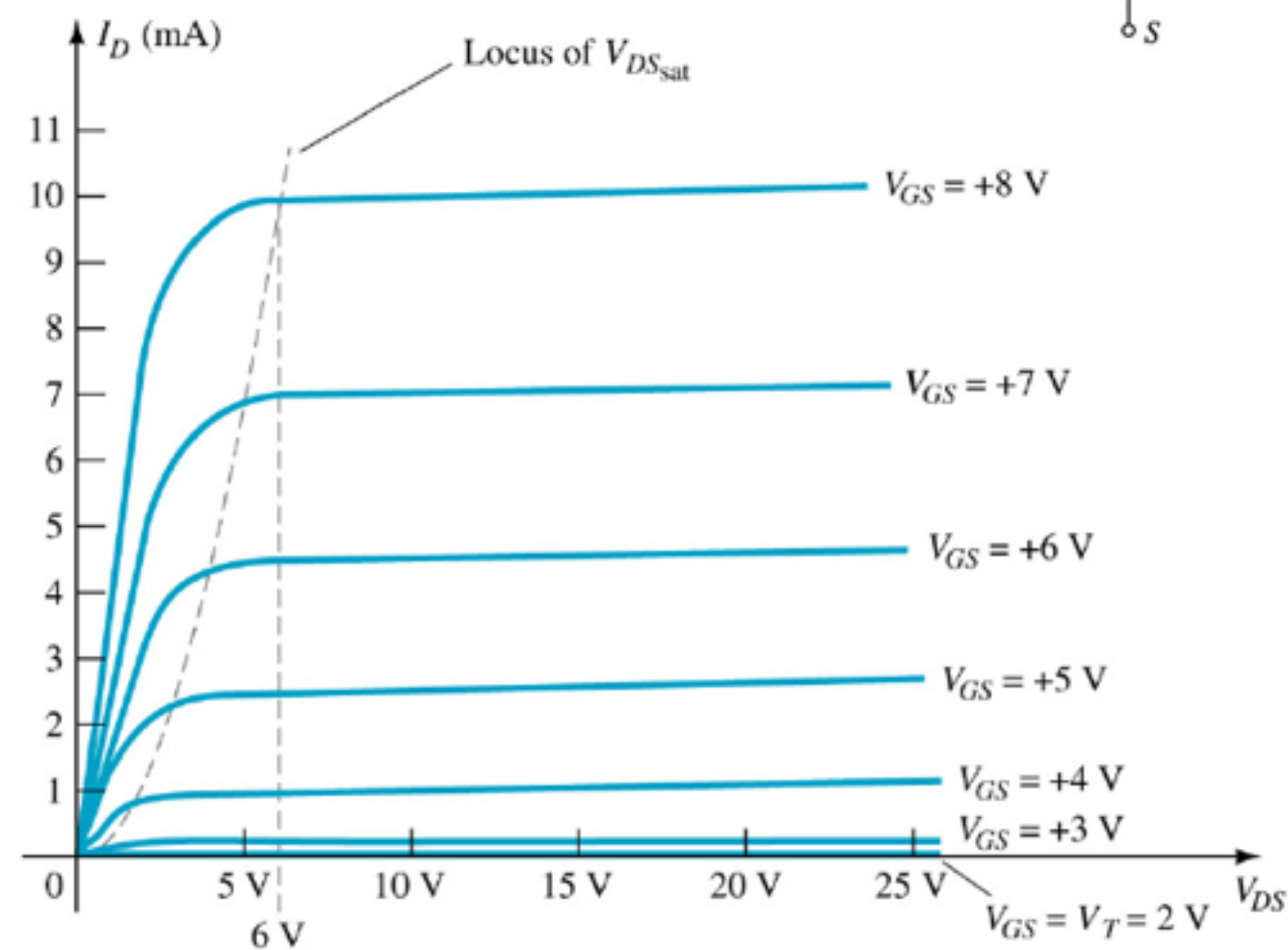
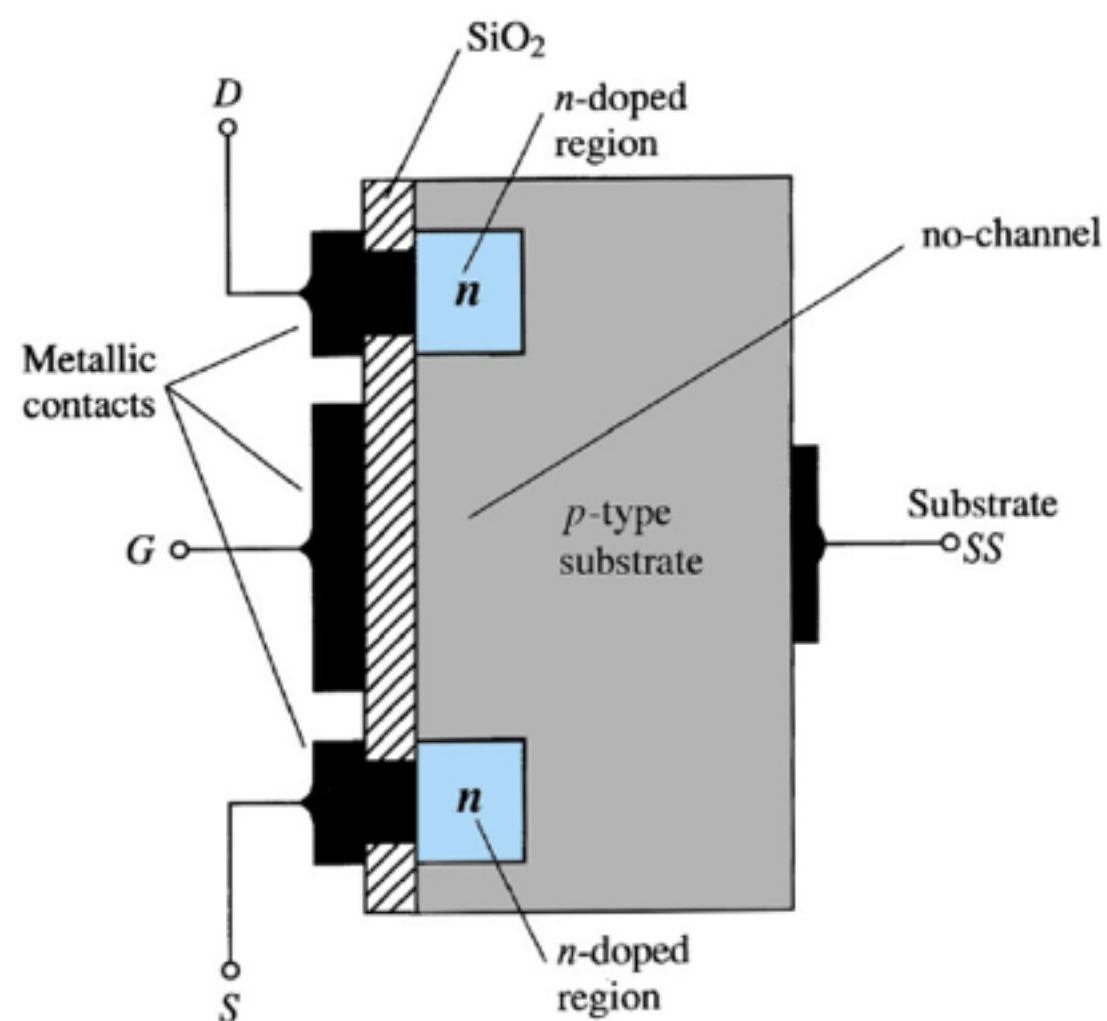




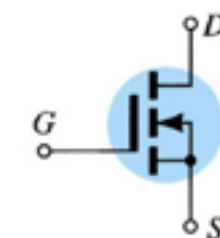
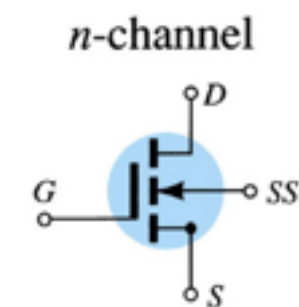
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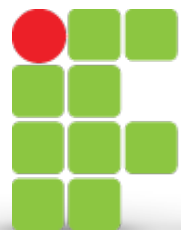
MOSFET

MOSFET tipo Intensificação



Canal n

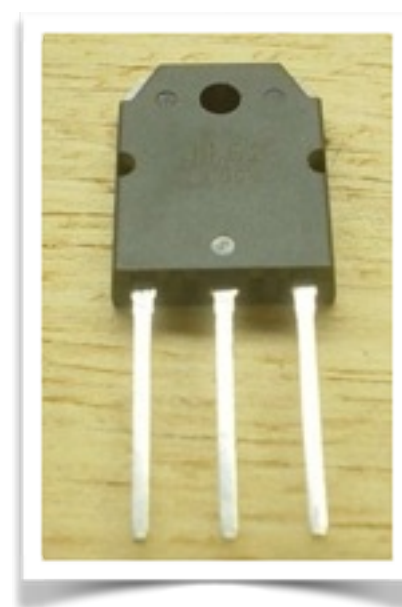
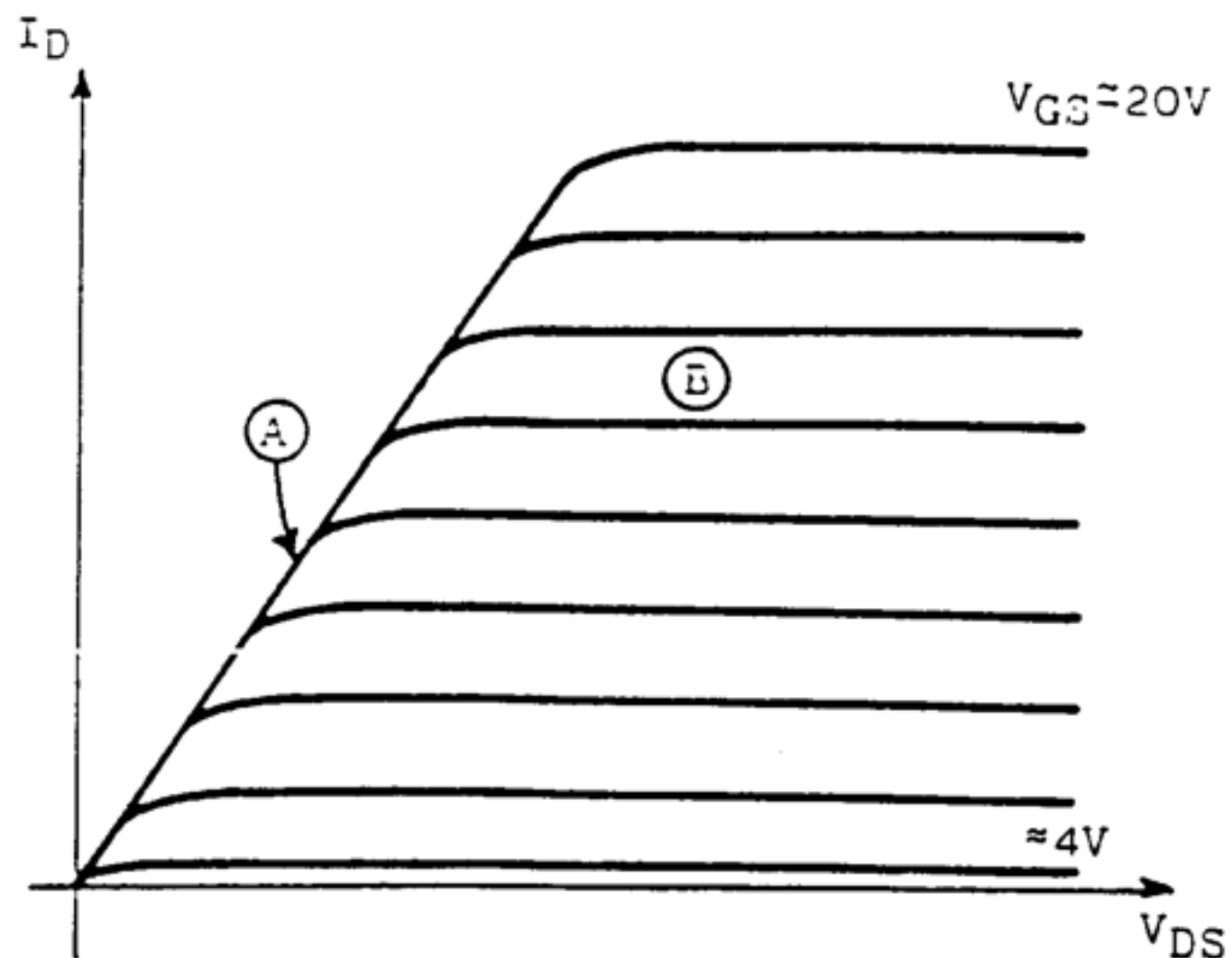
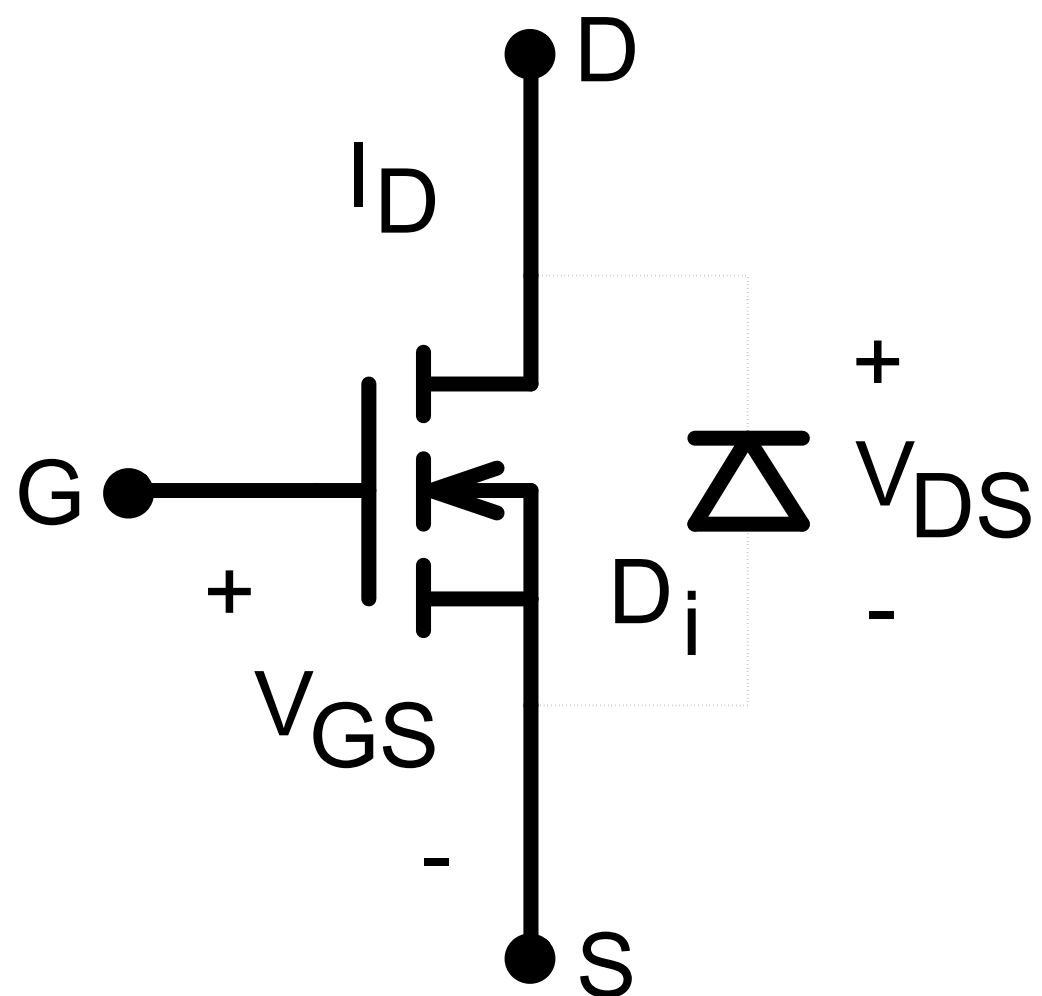




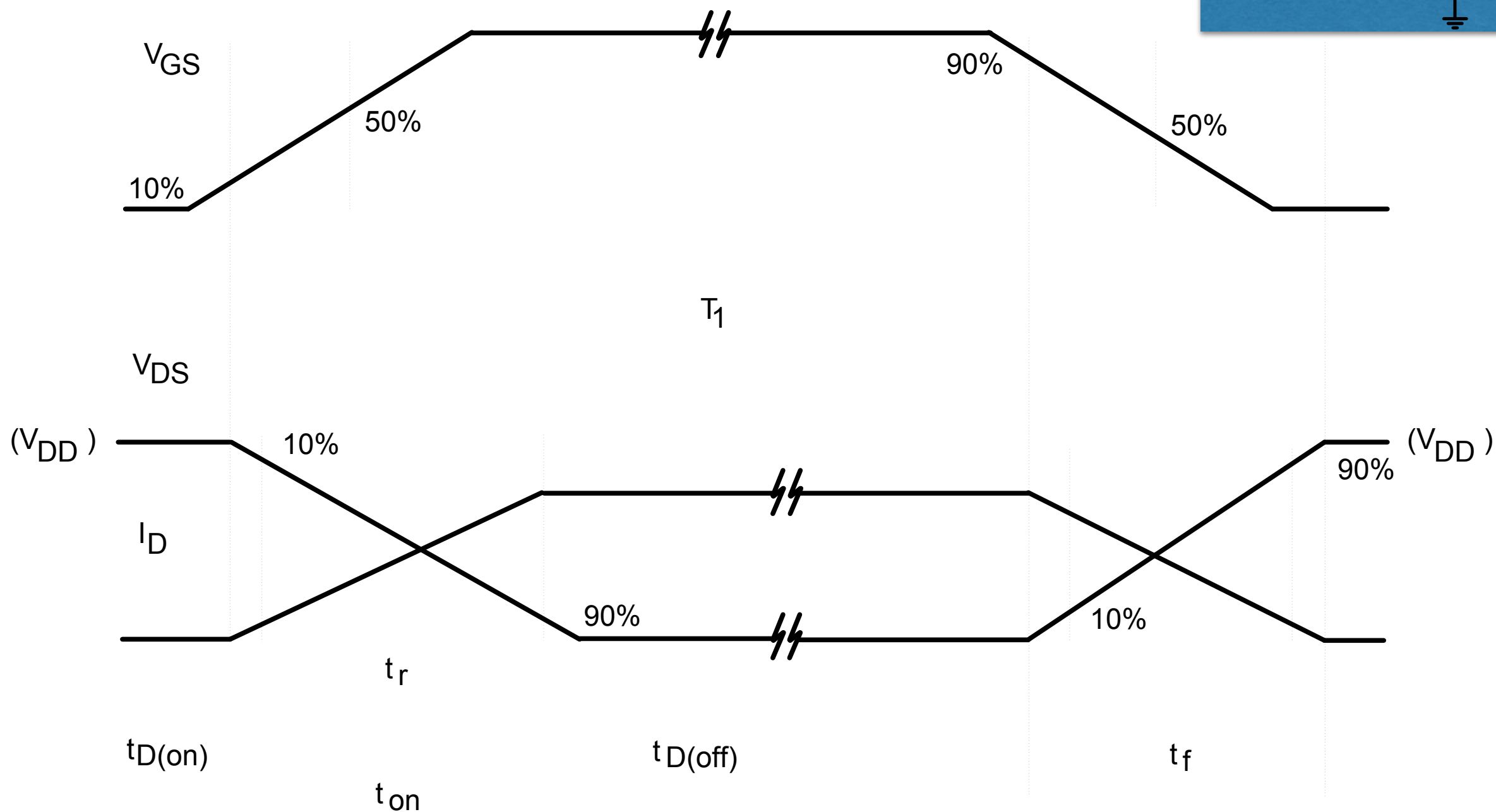
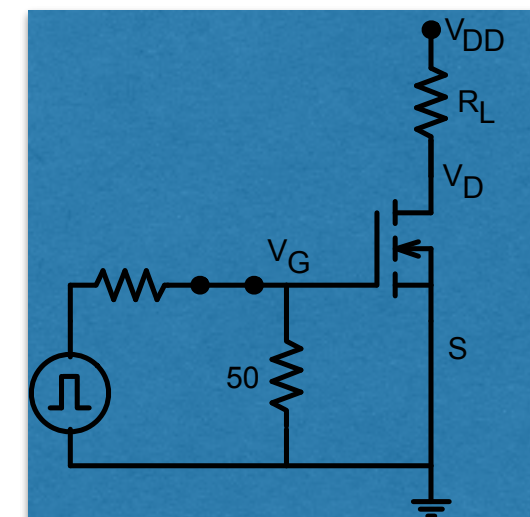
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MOSFET

MOSFET de Potência

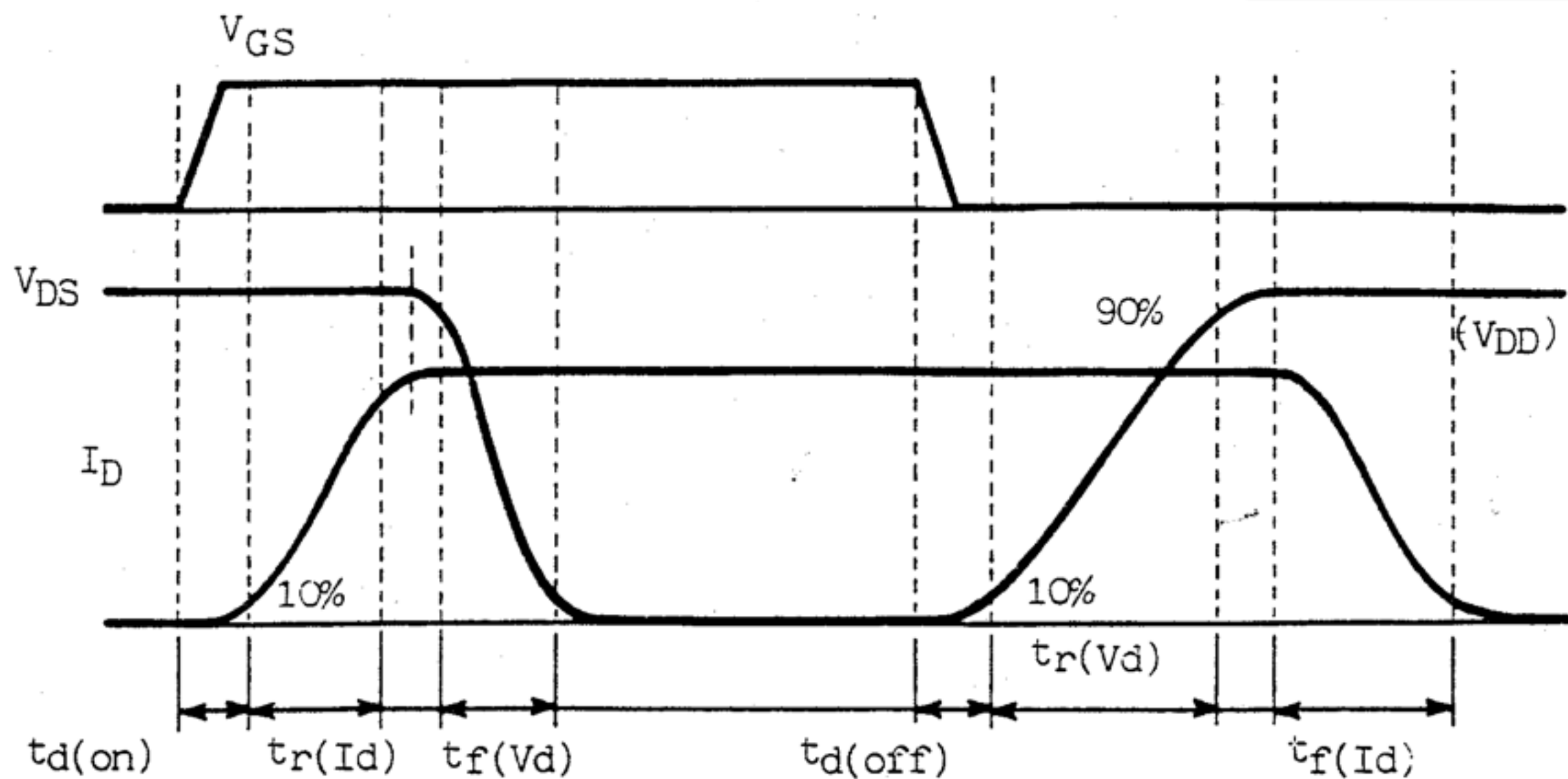
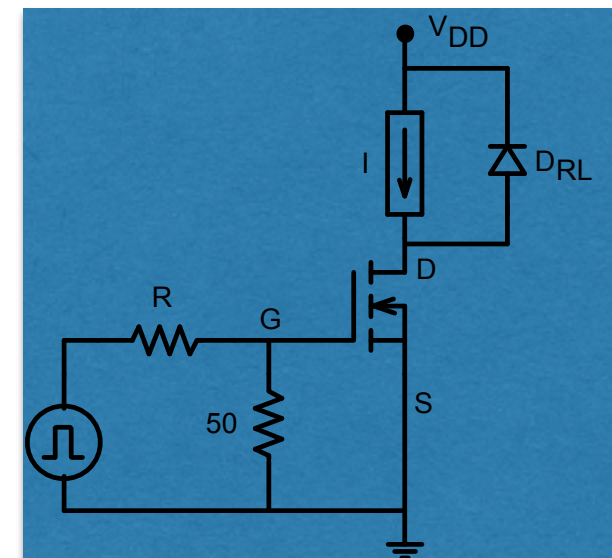


MOSFET de Potência



Comutação do MOSFET com carga resistiva

MOSFET de Potência



Comutação do MOSFET com carga indutiva

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;

- Onde:

$$t_f \cong t_{on}$$

$$t_r \cong t_{off}$$

Dados de catalogo:

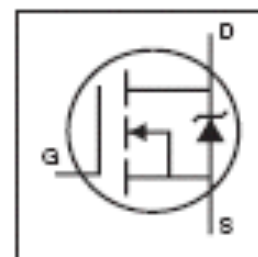
International
IR Rectifier

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



$$V_{DS} = 100V$$

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

$$I_D = 47A$$

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 package because of its isolated mounting hole.



Absolute Maximum Ratings

	Parameter	Max.	Units
$I_D @ T_C = 25^\circ C$	Continuous Drain Current, $V_{GS} @ 10V$	48	A
$I_D @ T_C = 100^\circ C$	Continuous Drain Current, $V_{GS} @ 10V$	32	
I_{DM}	Pulsed Drain Current ①	230	
$P_D @ T_C = 25^\circ C$	Power Dissipation	140	W
	Linear Derating Factor	0.01	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
I_{AR}	Avalanche Current ②	28	A
E_{AR}	Repetitive Avalanche Energy ③	20	mJ
dv/dt	Peak Diode Recovery dv/dt ④	5.8	V/ns
T_J	Operating Junction and	-55 to +175	°C
T_{STG}	Storage Temperature Range		
	Soldering Temperature, for 10 seconds	300 (1.8mm from case)	
	Mounting torque, 6-32 or M3 screw	10 lbf-in (1.1 Nm)	

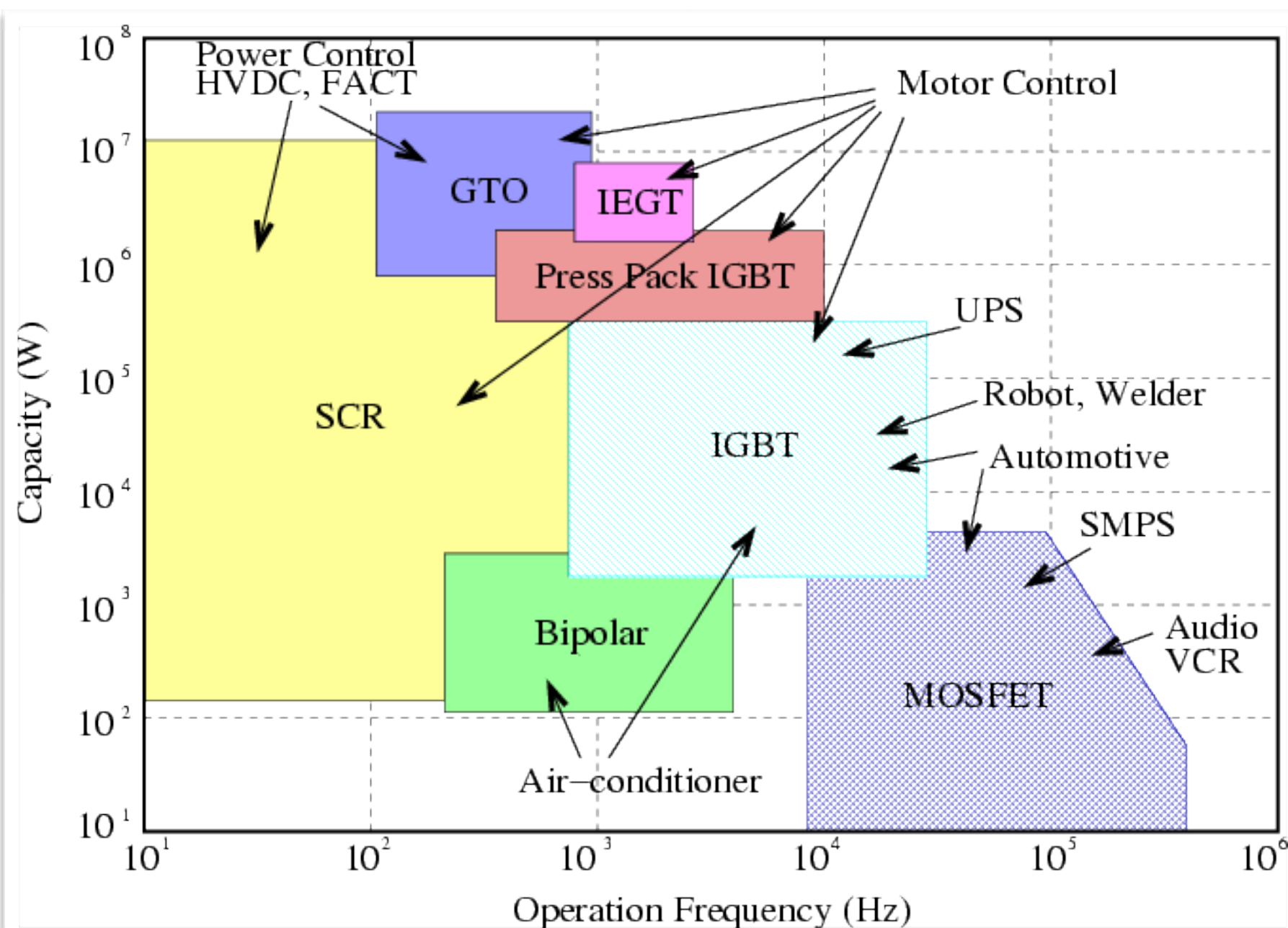
Thermal Resistance

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

MOSFET

Quando usar MOSFET:

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

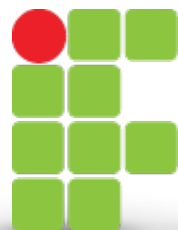


Demonstração

Demo

- Testes de MOSFET com multímetro.

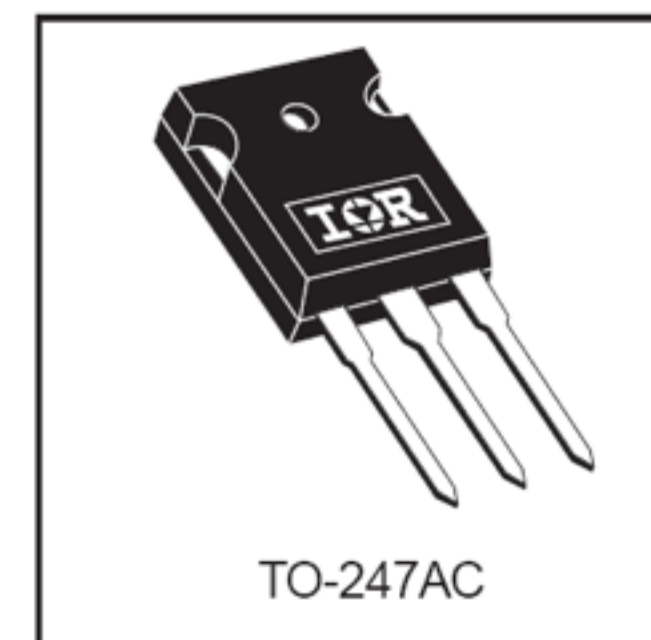
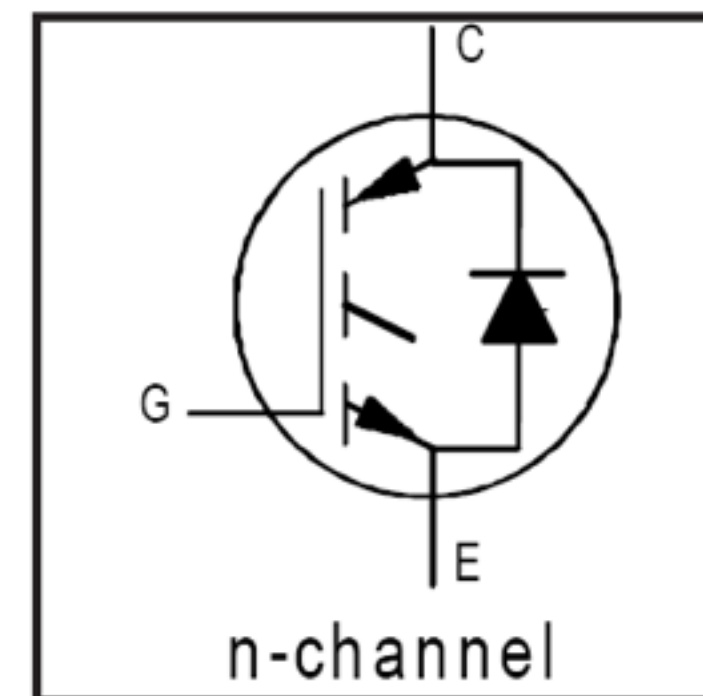
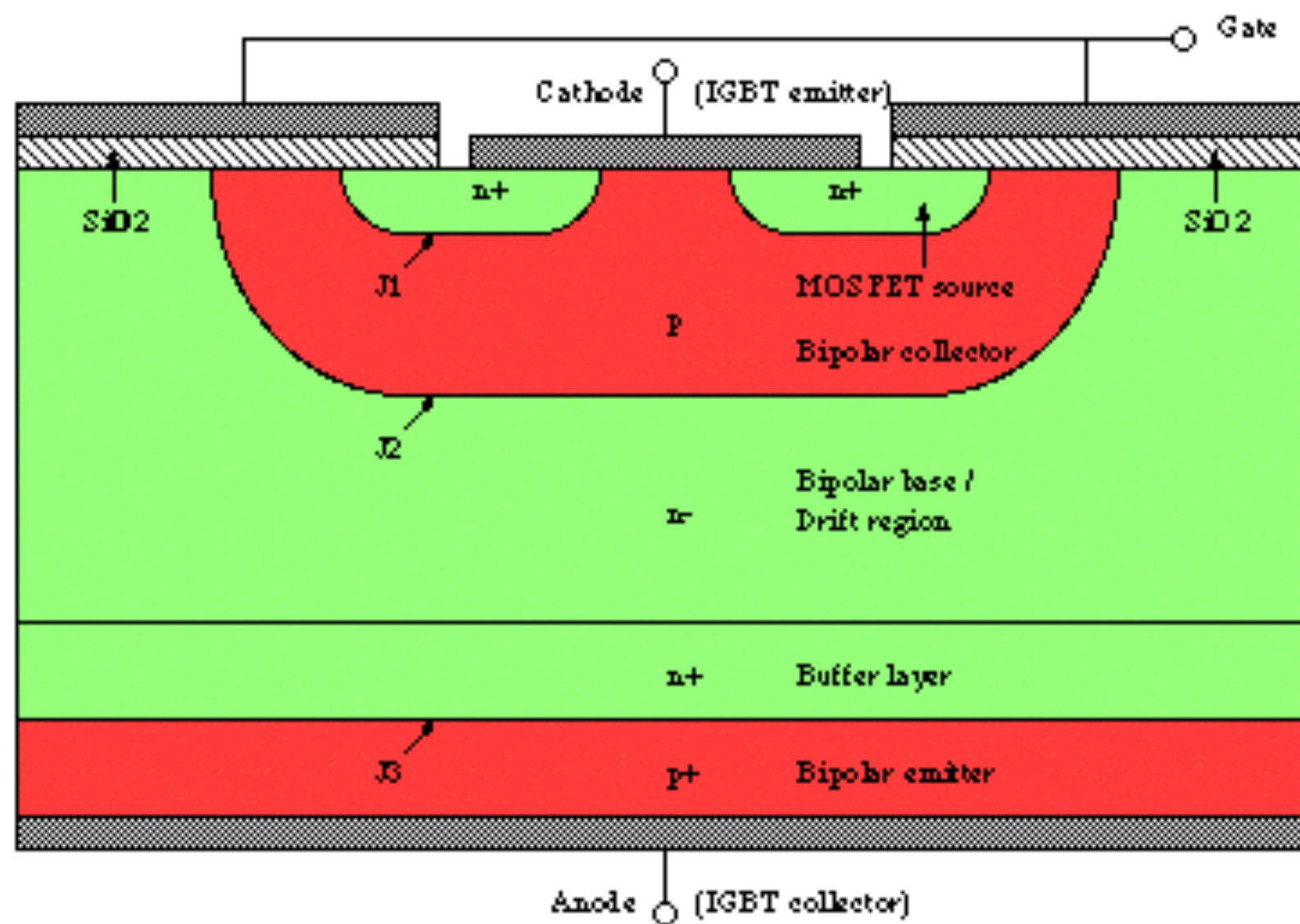




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IGBT

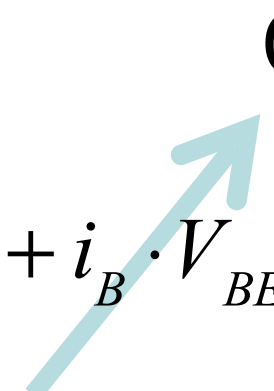
IGBT - Insulated Gate Bipolar Transistor



Características de BJT e MOSFET

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:

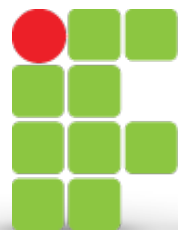
- Entrada em condução e bloqueio;

- Onde:

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

Detalhamento do cálculo de perdas





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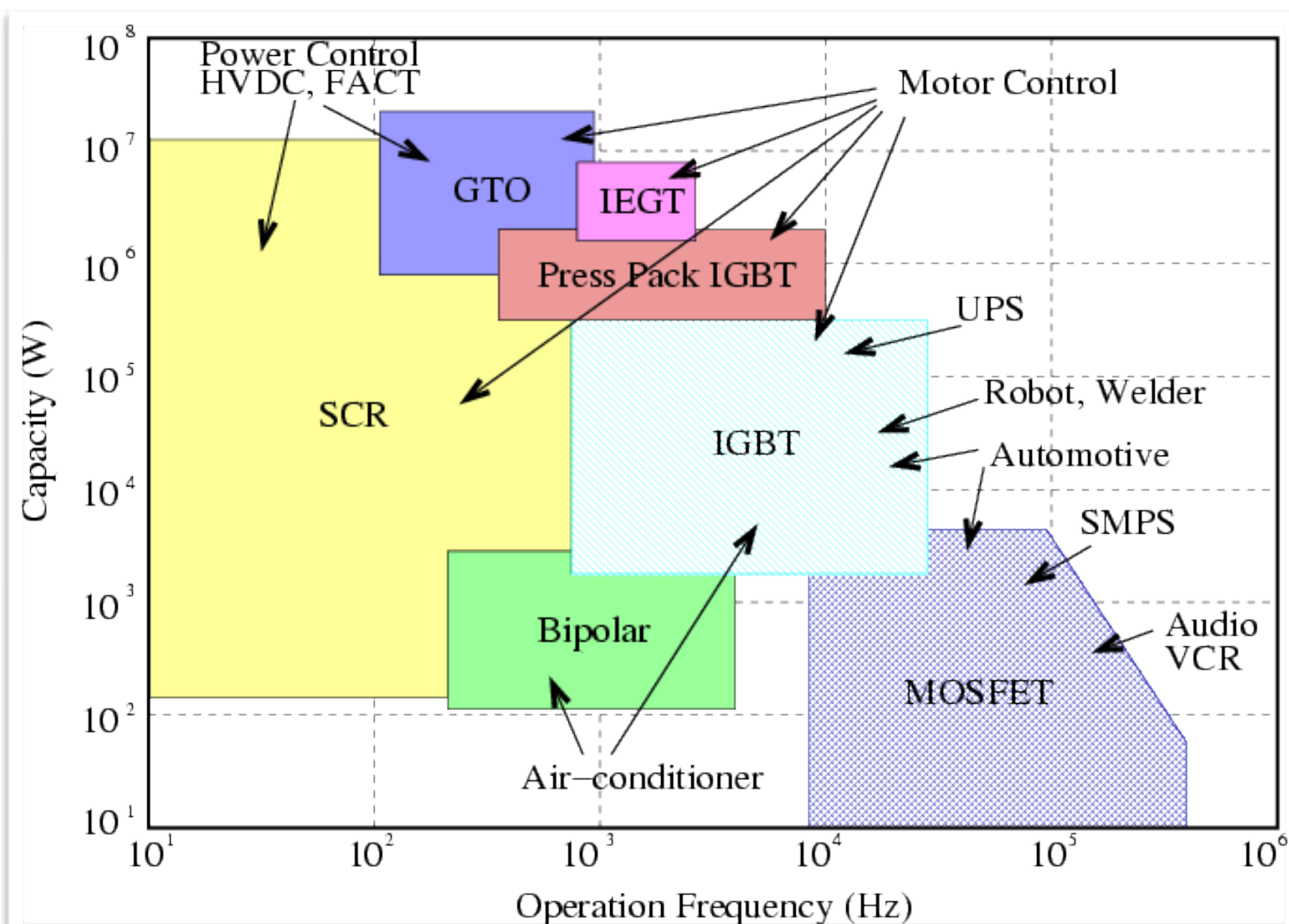
IGBT

Quando usar IGBT:

1. Frequências 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
IRG830B60K	IGBT Discretes	TO-220AB	Discrete	ULTRAFAST 10-30 kHz
IRG8B60K	IGBT Discretes	TO-220AB	Discrete	ULTRAFAST 10-30 kHz
IRG8B60K	IGBT Discretes	D2-Pak	Discrete	ULTRAFAST 10-30 kHz
IRG814C40L	IGBT Discretes	D2-Pak	Discrete	Low-Vceon
IRGP40S2	IGBT Discretes	TO-247AC	Discrete	Low-Vceon



Quando usar IGBT:

1. Frequências 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

Encapsulamentos:



www.semikron.com



Encapsulamentos:



D-PAK
TO-252AA



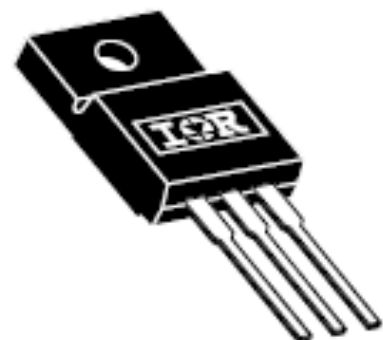
TO-220AB
IRGB6B60K



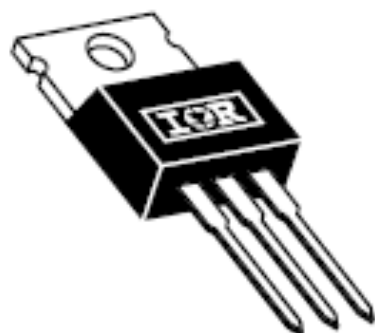
D²Pak
IRGS6B60K



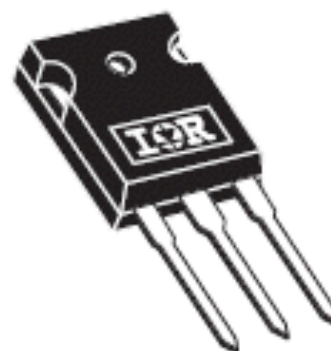
TO-262
IRGSL6B60K



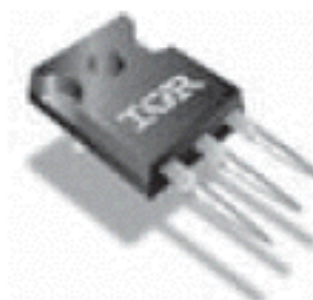
TO-220 FULLPAK



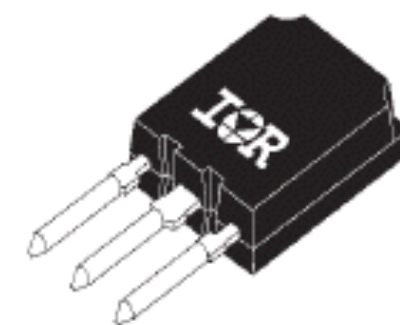
TO-220AB



TO-247AC



TO-247AC



SUPER - 247



www.irf.com



Dados de catalogo:

International IR Rectifier

INSULATED GATE BIPOLAR TRANSISTOR

PD - 94443

IRG4PC60U

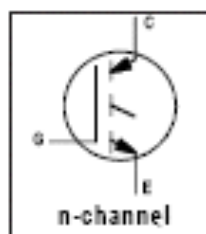
UltraFast Speed IGBT

Features

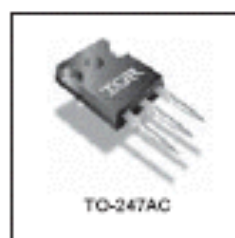
- UltraFast: Optimized for high operating frequencies up to 50 kHz in hard switching, >200 kHz in resonant mode.
- Generation 4 IGBT design provides tighter parameter distribution and higher efficiency.
- Industry standard TO-247AC package.

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.



$V_{CES} = 600V$
 $V_{CE(sat)} \text{ typ.} = 1.6V$
@ $V_{GE} = 15V, I_C = 40A$



Absolute Maximum Ratings

Parameter	Max.	Units
V_{CES}	600	V
$I_C @ T_C = 25^\circ C$	75	A
$I_C @ T_C = 100^\circ C$	40	
I_{CS}	300	
I_{CL}	300	
V_{GE}	± 20	V
E_{AS}	200	mJ
$P_D @ T_C = 25^\circ C$	520	W
$P_D @ T_C = 100^\circ C$	210	
T_J	-55 to +150	$^\circ C$
T_{stg}		
	300 (0.083 in. (1.6mm) from case)	
	10 lbf-in (1.1N-m)	

Thermal Resistance

Parameter	Typ.	Max.	Units
R_{JC}	----	0.24	$^\circ C/W$
R_{CS}	0.24	----	
R_{JA}	----	40	
Wt	8 (0.21)	----	

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04/28/02

International IR Rectifier

INSULATED GATE BIPOLAR TRANSISTOR WITH
ULTRAFAST SOFT RECOVERY DIODE

PD 9.1467D

IRG4PC40UD

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.

Benefits

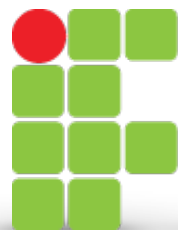
- Generation -4 IGBT's offer highest efficiencies available.
- IGBT's optimized for specific application conditions.
- HEXFRED diodes optimized for performance with IGBT's. Minimized recovery characteristics require less snubbing.
- Designed to be a "drop-in" replacement for equivalent industry-standard Generation 3 IR IGBT's.

Absolute Maximum Ratings

Parameter	Max.	Units
V_{CES}	600	V
$I_C @ T_C = 25^\circ C$	40	A
$I_C @ T_C = 100^\circ C$	20	
I_{CS}	160	
I_{CL}	160	
$I_F @ T_C = 100^\circ C$	15	A
I_{FS}	160	
V_{GE}	± 20	
$P_D @ T_C = 25^\circ C$	160	
$P_D @ T_C = 100^\circ C$	65	W
T_J	-55 to +150	$^\circ C$
T_{stg}		
	300 (0.083 in. (1.6mm) from case)	
	10 lbf-in (1.1 N-m)	

Thermal Resistance

Parameter	Min.	Typ.	Max.	Units
R_{JC}	----	----	0.77	$^\circ C/W$
R_{CS}	----	----	1.7	
R_{JA}	----	0.24	----	
Wt	----	8 (0.21)	----	



INSTITUTO FEDERAL
SANTA CATARINA

IGBT

Demonstração

Demo

- Testes de IGBT com multímetro.



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

Componentes Semicondutores:

- Dimensionamento e especificação de semicondutores.

