

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 2015.

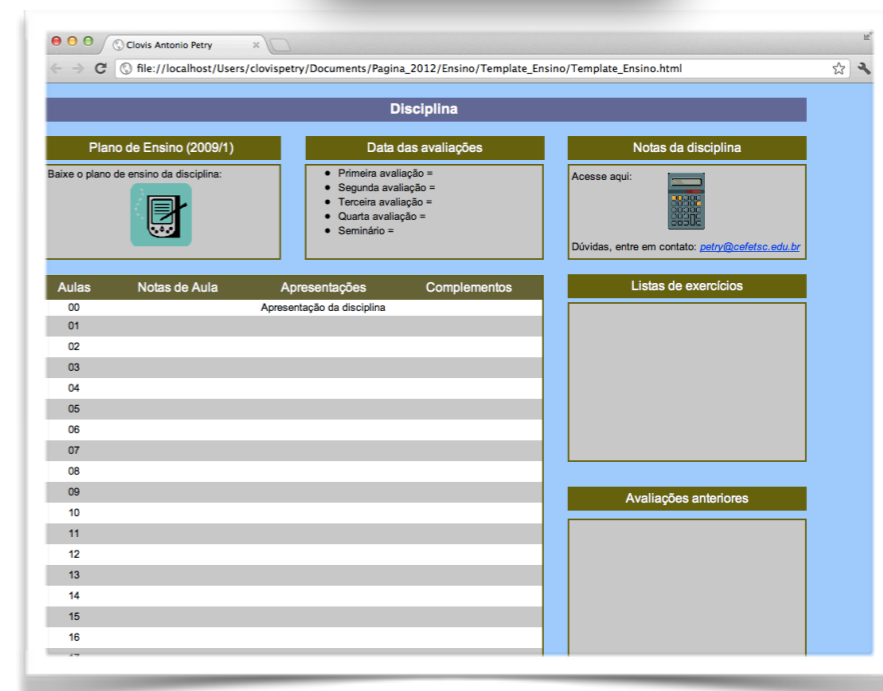
# Biografia para Esta Aula

## Capítulos 3:



- Transistores de potência.



[www.ProfessorPetry.com.br](http://www.ProfessorPetry.com.br)



A screenshot of a web browser displaying a course page. The browser address bar shows the file path: file:///localhost/Users/clovispetry/Documents/Pagina\_2012/Ensino/Template\_Ensino/Template\_Ensino.html. The page content includes:

- Disciplina**
- Plano de Ensino (2009/1)**: Baixe o plano de ensino da disciplina: 
- Data das avaliações**:
  - Primeira avaliação =
  - Segunda avaliação =
  - Terceira avaliação =
  - Quarta avaliação =
  - Seminário =
- Notas da disciplina**: Acesse aqui:   
Dúvidas, entre em contato: [petry@cefetsc.edu.br](mailto:petry@cefetsc.edu.br)
- Table with 4 columns: Aulas, Notas de Aula, Apresentações, Complementos**
- Listas de exercícios**
- Avaliações anteriores**

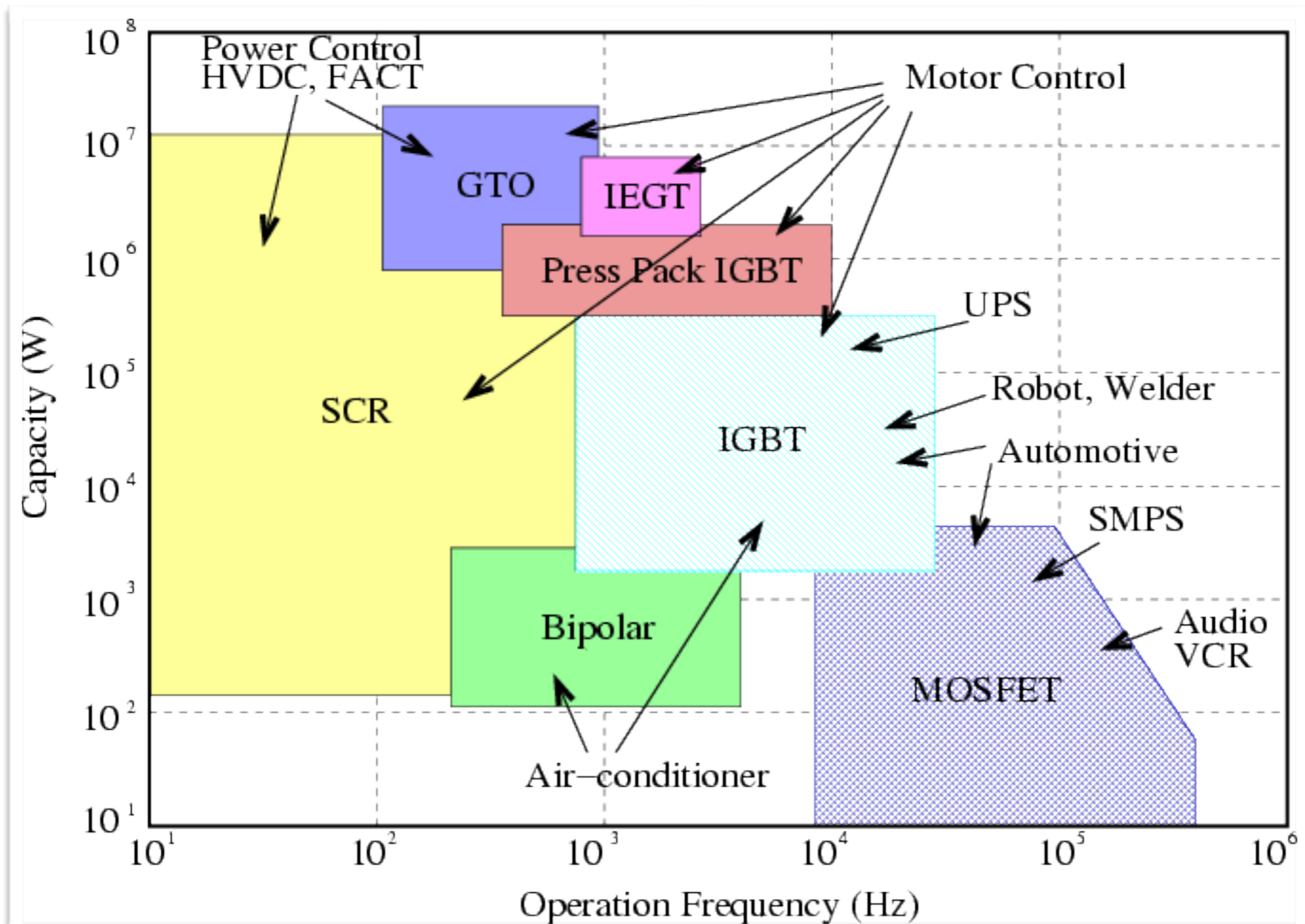
Aulas	Notas de Aula	Apresentações	Complementos
00		Apresentação da disciplina	
01			
02			
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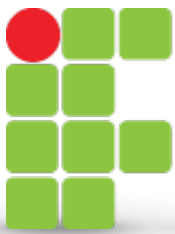
## Semicondutores de potência:

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

# Semicondutores de Potência

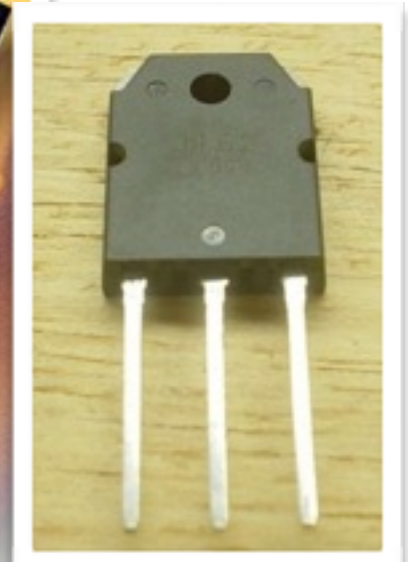
Semicondutores aplicados à eletrônica de potência:





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# Semicondutores de Potência





Électronique - Internet Explorer provided by Dell

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

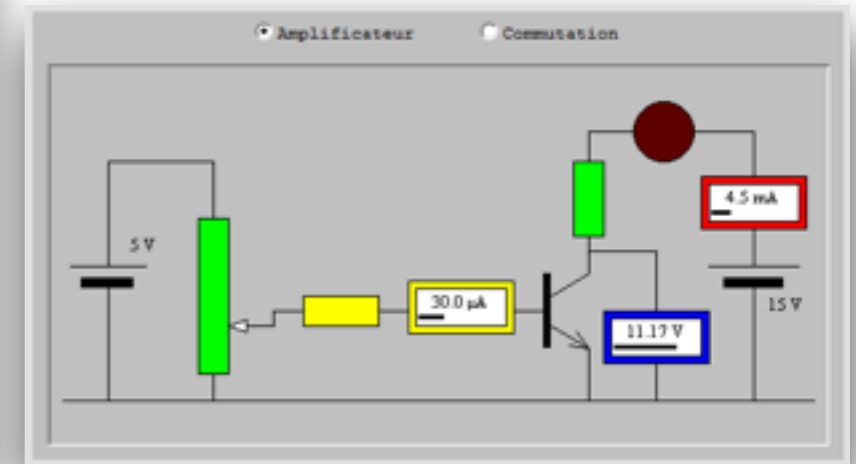
File Edit View Favorites Tools Help

Électronique

## Électronique

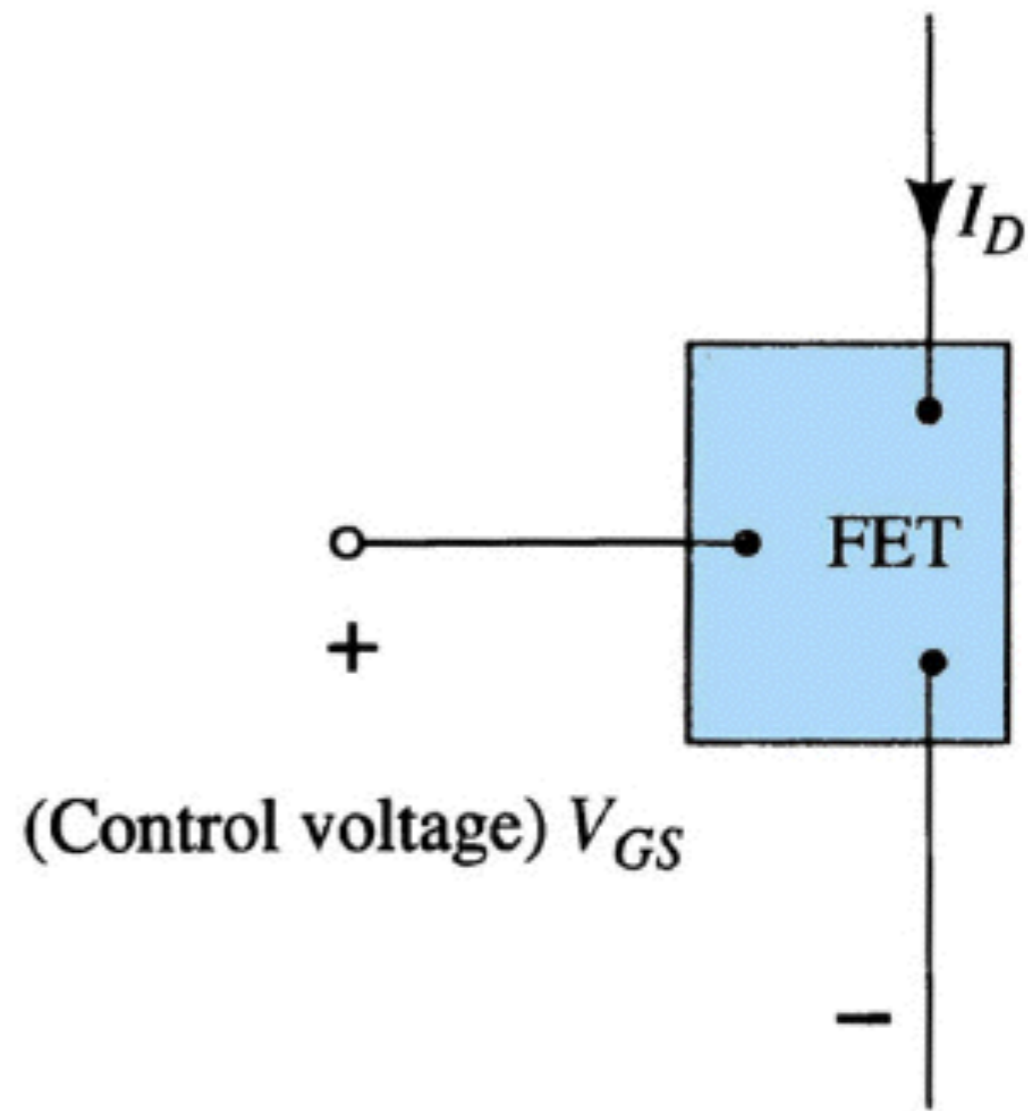
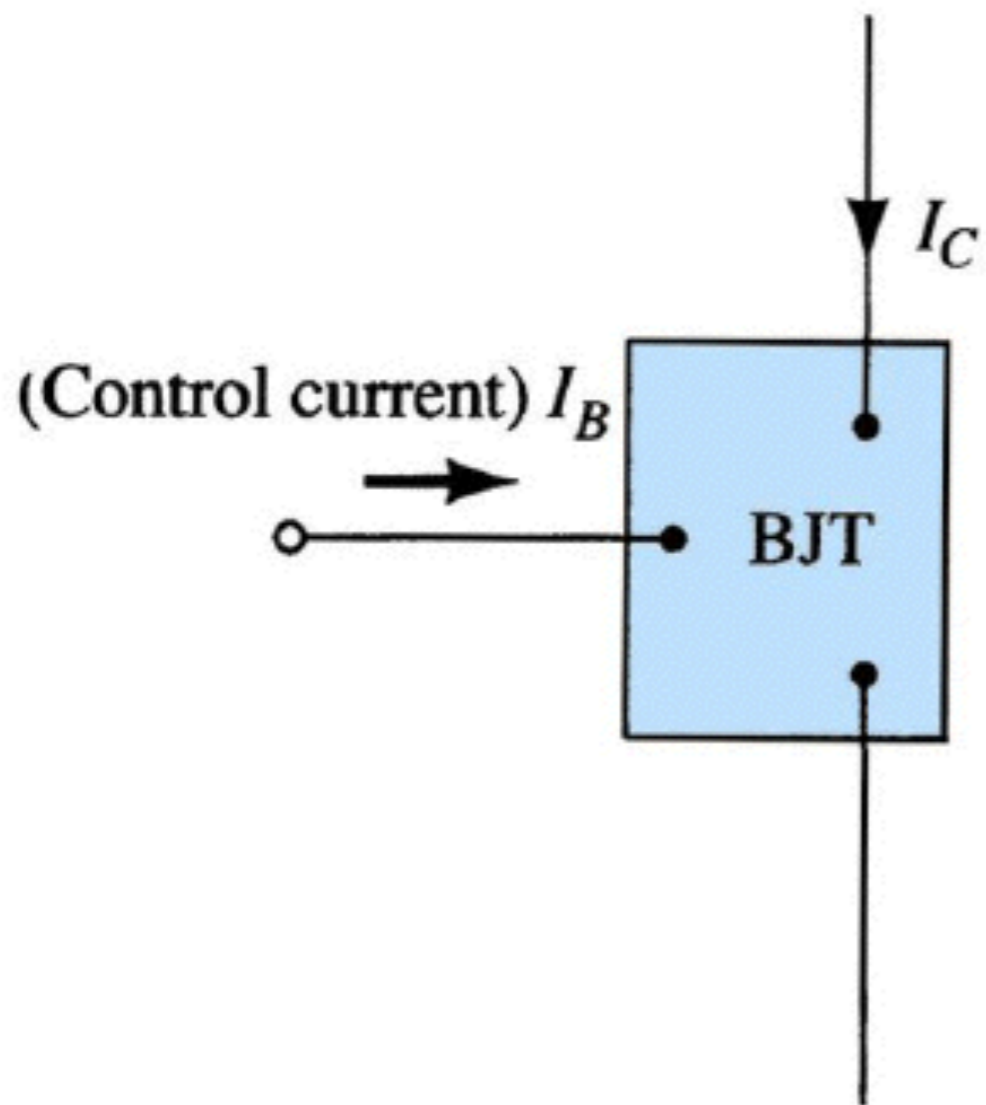
<b>Oscilloscope cathodique</b> <ul style="list-style-type: none"> <li>Principe</li> <li>Synchronisation</li> <li>Fonctionnement en bicourbe</li> <li>Figures de Lissajous</li> <li>Mesure de déphasage</li> <li>Mesure de fréquences</li> <li>Balayage télévision</li> </ul>	<b>Diodes et transistors</b> <ul style="list-style-type: none"> <li>Pont de Graetz</li> <li>Filtrage (animation)</li> <li>Redressement et filtrage</li> <li>Régulateur à diode Zener</li> <li>Transistor (principe)</li> <li>Transistor en régime variable</li> </ul>	<b>Filtres</b> <ul style="list-style-type: none"> <li>Filtres passifs (exemples)</li> <li>Filtres passifs (général)</li> <li>Filtres en L, T et Pi</li> <li>Filtres en T et T ponté</li> <li>Filtres de Sallen et Kay</li> <li>Filtres de Rauch</li> </ul>	<b>Logique</b> <ul style="list-style-type: none"> <li>Portes logiques</li> <li>Associations de NANDs</li> <li>Associations de NORs</li> <li>Bascules R-S et D</li> <li>Bascules J-K</li> <li>Additionneur binaire</li> </ul>
<b>Circuits simples</b> <ul style="list-style-type: none"> <li>Amplificateur opérationnel</li> <li>Diviseur de tension</li> <li>Circuits RC. Filtres Dérivateur Intégrateur</li> <li>Circuits R, L, C série et //</li> <li>Relaxateur à néon</li> <li>Déphaseur passif</li> <li>Déphaseur à AOP</li> <li>Générateur de courant constant</li> <li>Adaptation d'impédances</li> </ul>	<b>Commutation</b> <ul style="list-style-type: none"> <li>Astable</li> <li>Astable à comparateur</li> <li>Monostable</li> <li>Comparateur de Schmitt</li> </ul>	<b>Convertisseurs</b> <ul style="list-style-type: none"> <li>Convertisseur N/A R-2R</li> <li>Convertisseur A/N simple rampe</li> <li>Convertisseur A/N à approximations</li> </ul>	<b>Capteurs</b> <ul style="list-style-type: none"> <li>Thermistance</li> <li>Thermomètre à diode</li> <li>Thermomètre Pt500</li> <li>Impédance d'un quartz</li> </ul>
<b>Divers</b>	<b>Divers</b>		

Internet | Protected Mode: On 100%

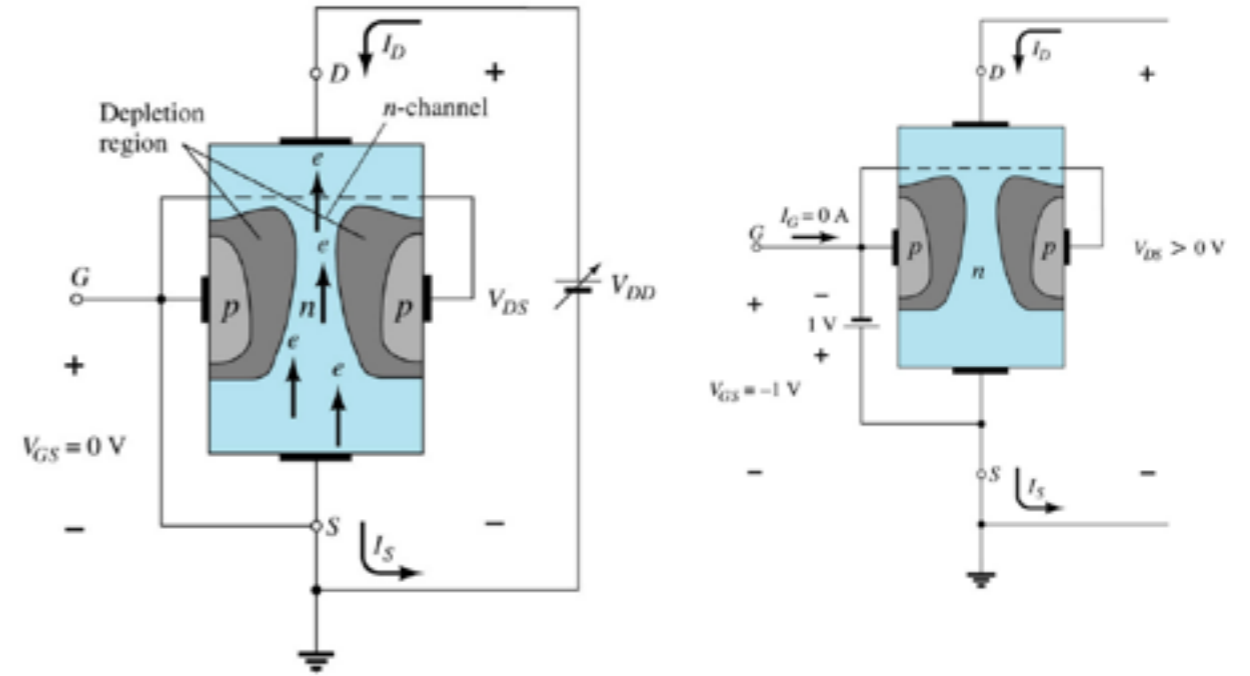
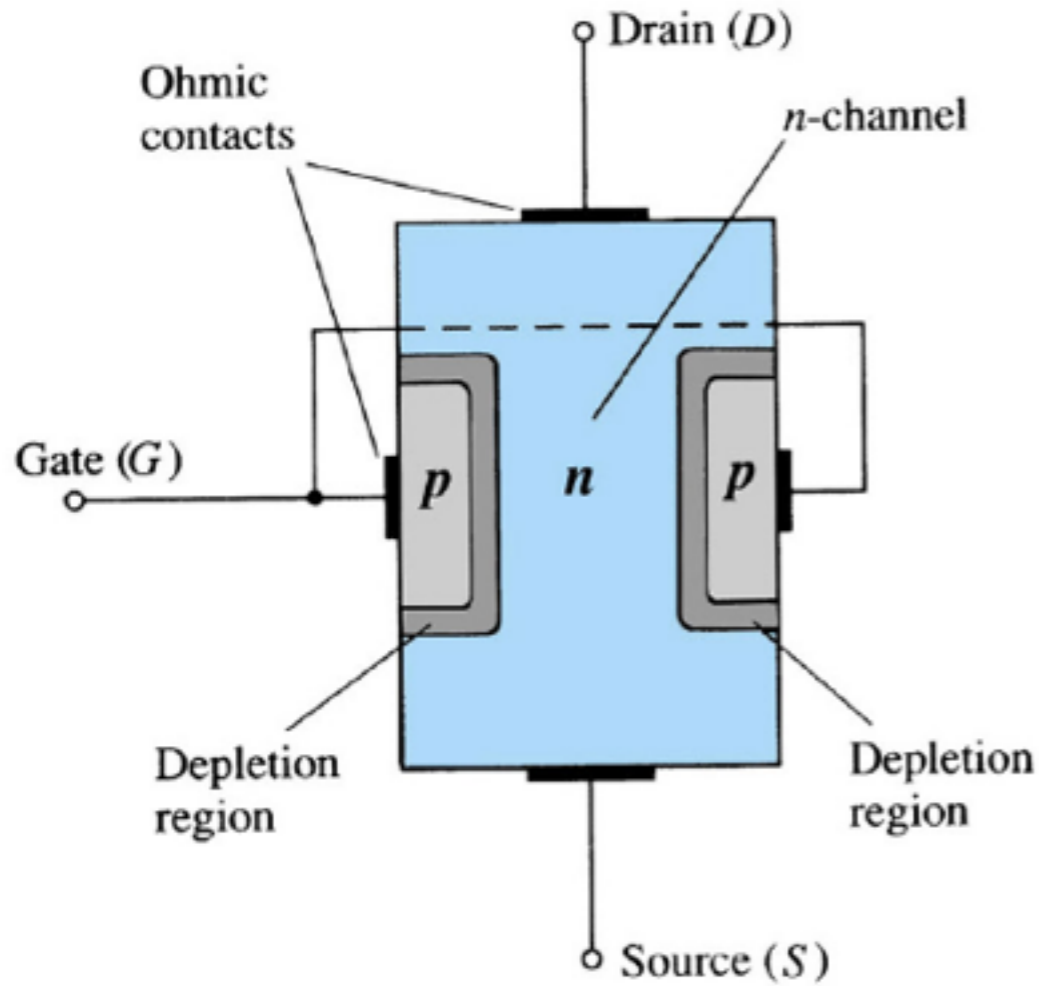


# BJT x FET

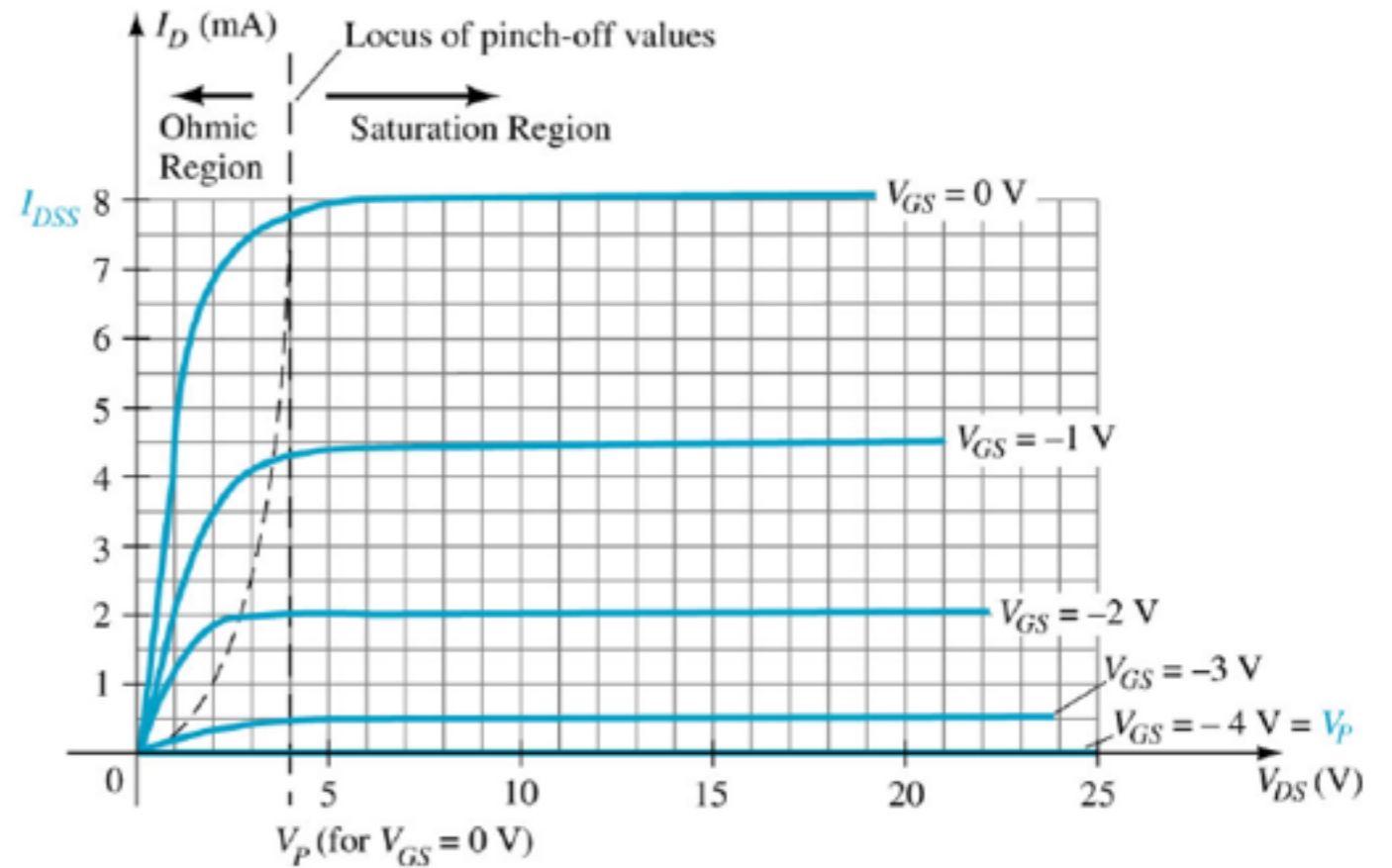
FET - Transistor de efeito de campo



# FET



JFET: Operação básica



Semiconductor Applet Services - Internet Explorer provided by Dell

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

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Semiconductor Applet Services

**JAS**

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XRD Sites

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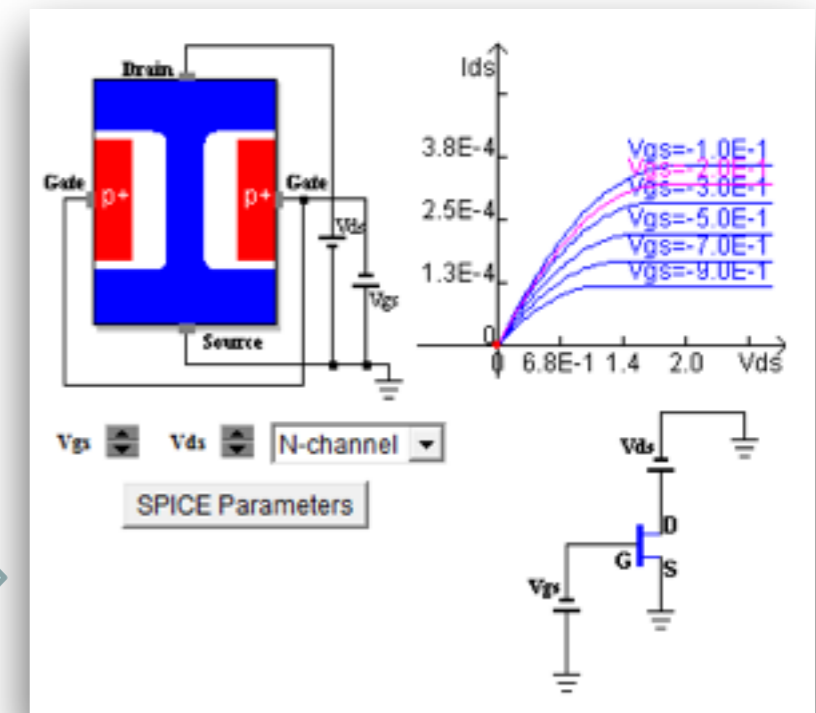
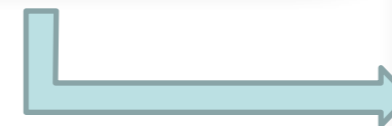
## The Semiconductor Applet Service

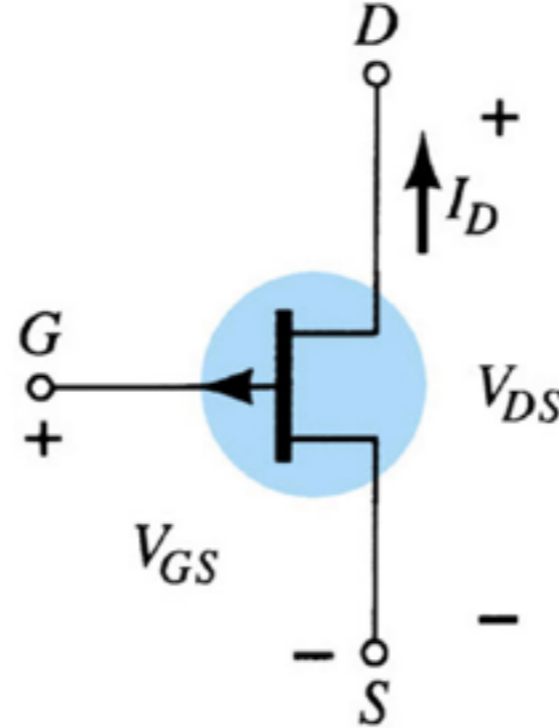
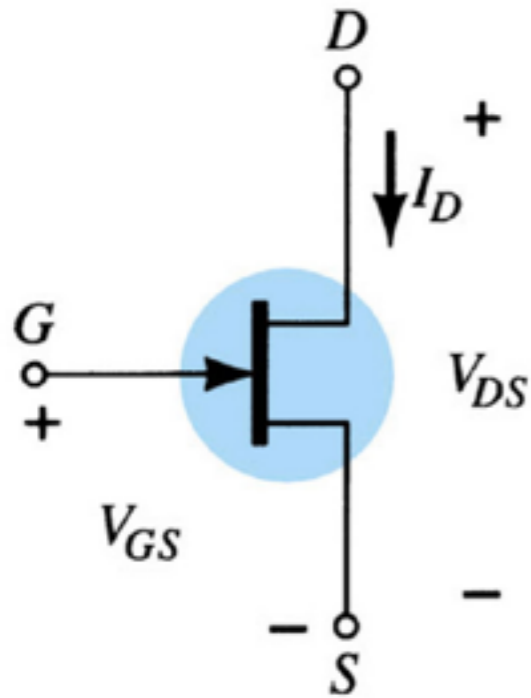
(Supported in part by the National Science Foundation)

### List of Simulation Applets

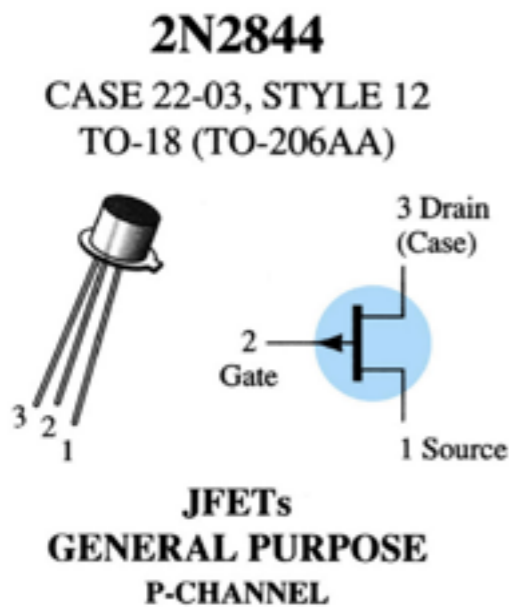
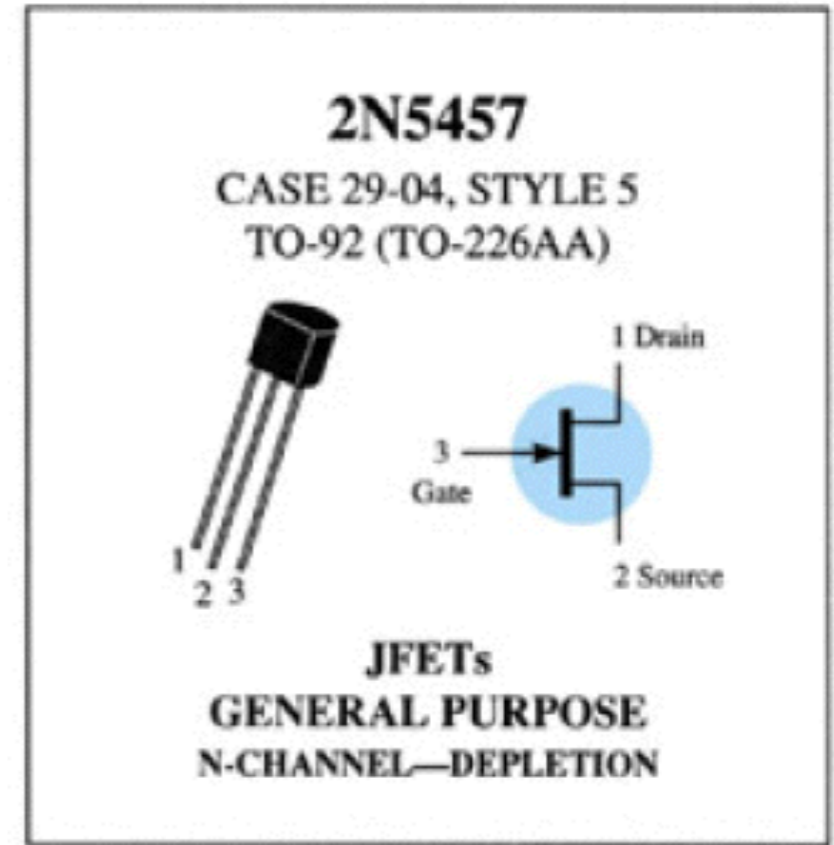
- Crystal Structure**
  - Zincblende and Diamond structures ( GaAs, Si, etc. ): [unitcell with a list of material property](#). It gives you the 3D views of the unitcell and the covalent bonds.
  - [Hexagonal Closed Packed structures](#) (ZnS, GaN, SiC, etc.). An interactive 3D view of the crystal unitcell.
  - [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/>

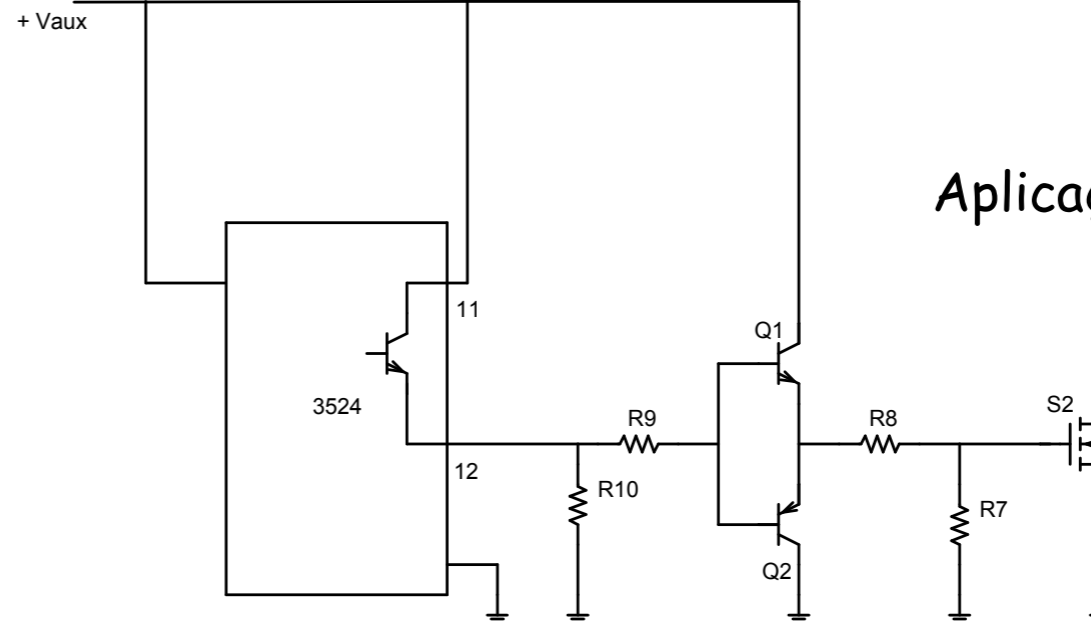




JFET canal n e canal p



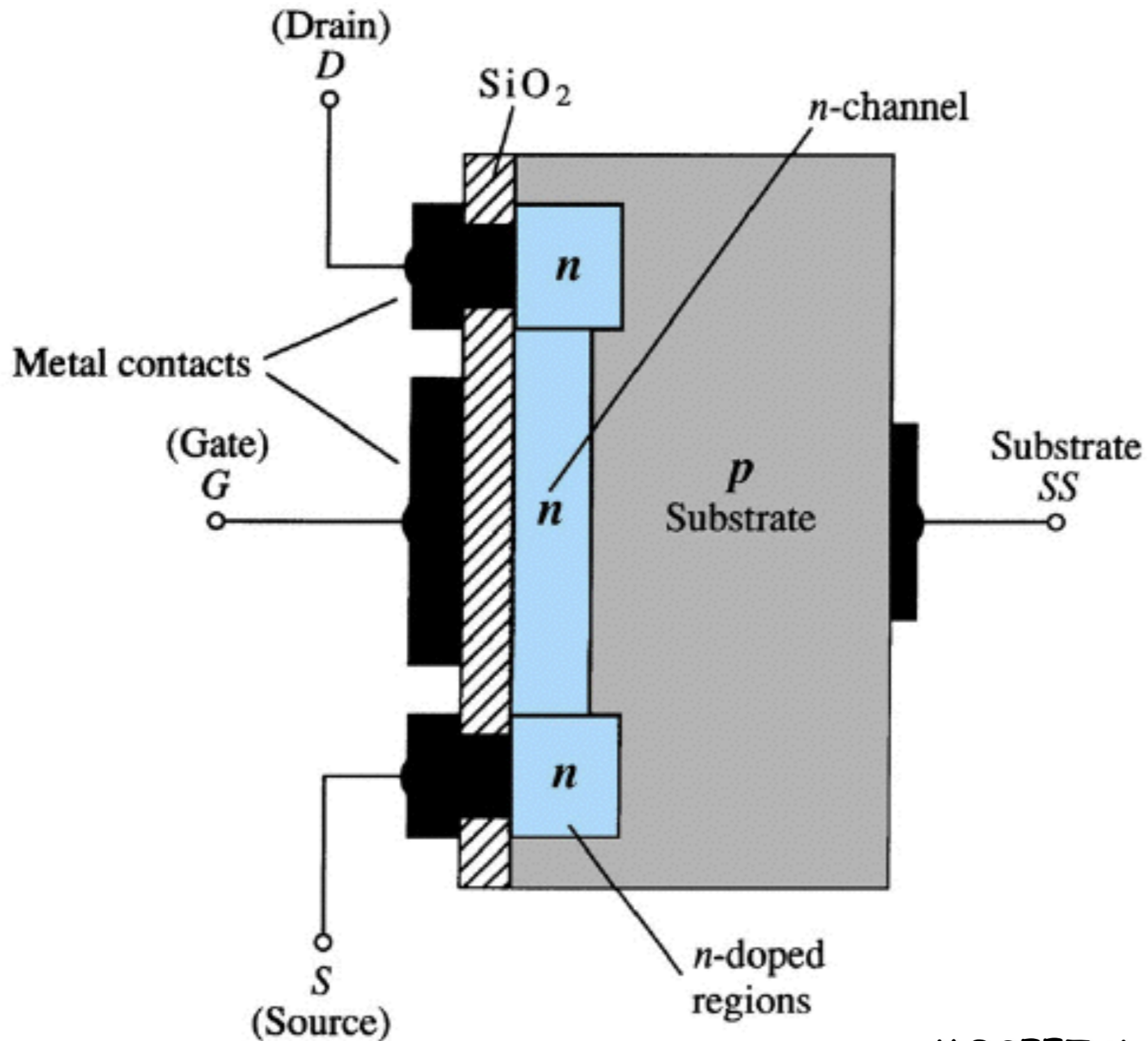
Positivo da Fonte Auxiliar



Aplicação do JFET

# MOSFET

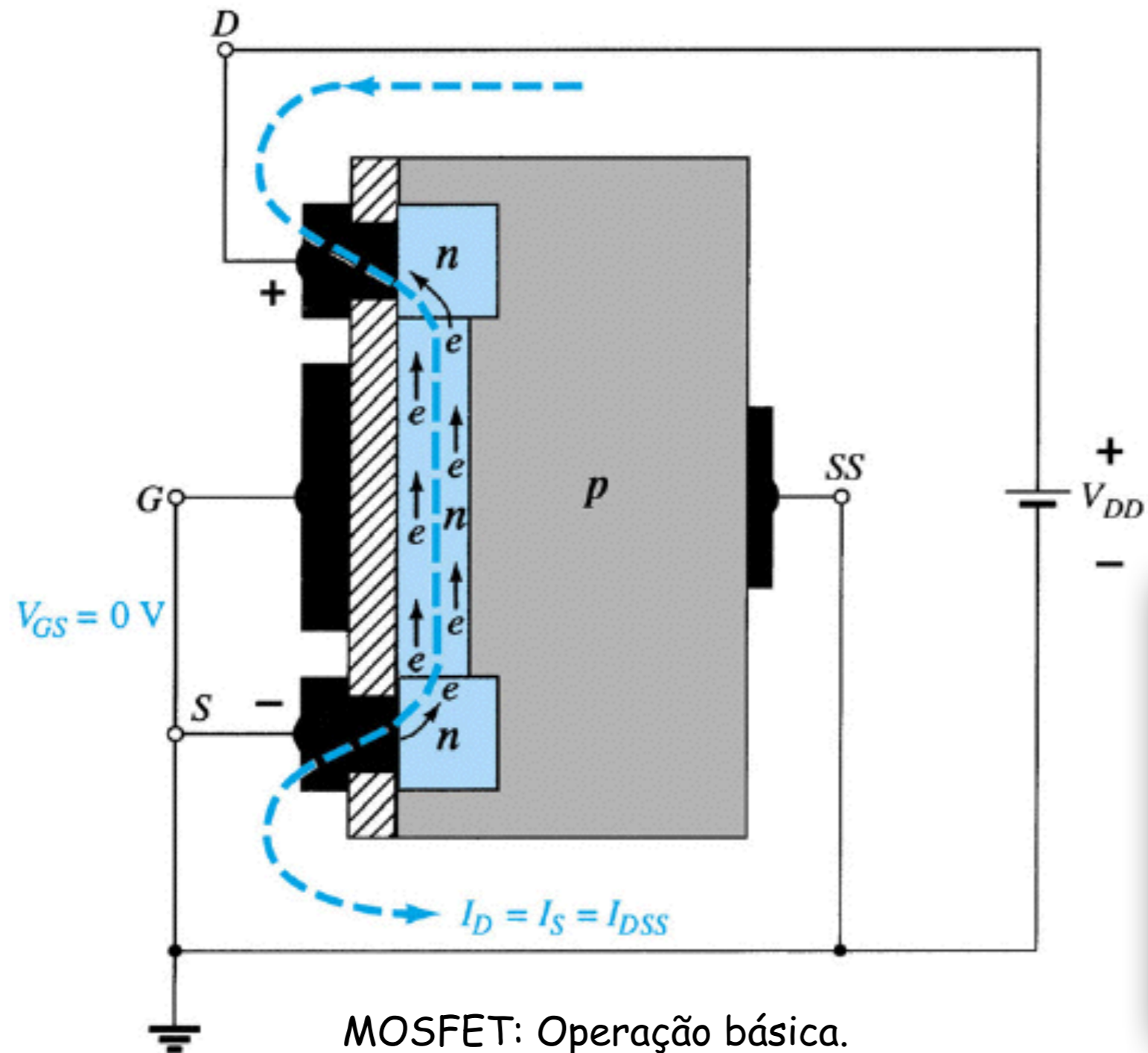
MOSFET - Metal Oxide Semiconductor Field Effect Transistor



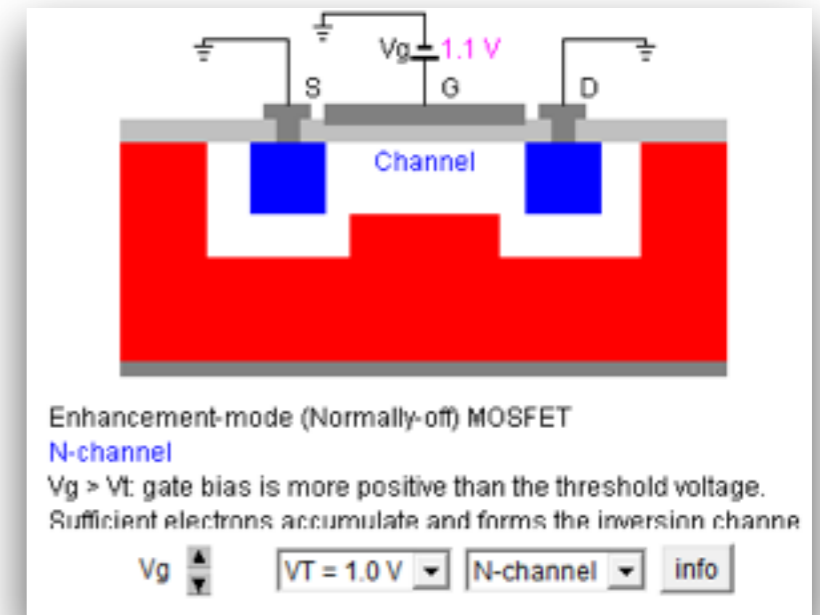
MOSFET tipo Depleção

# MOSFET

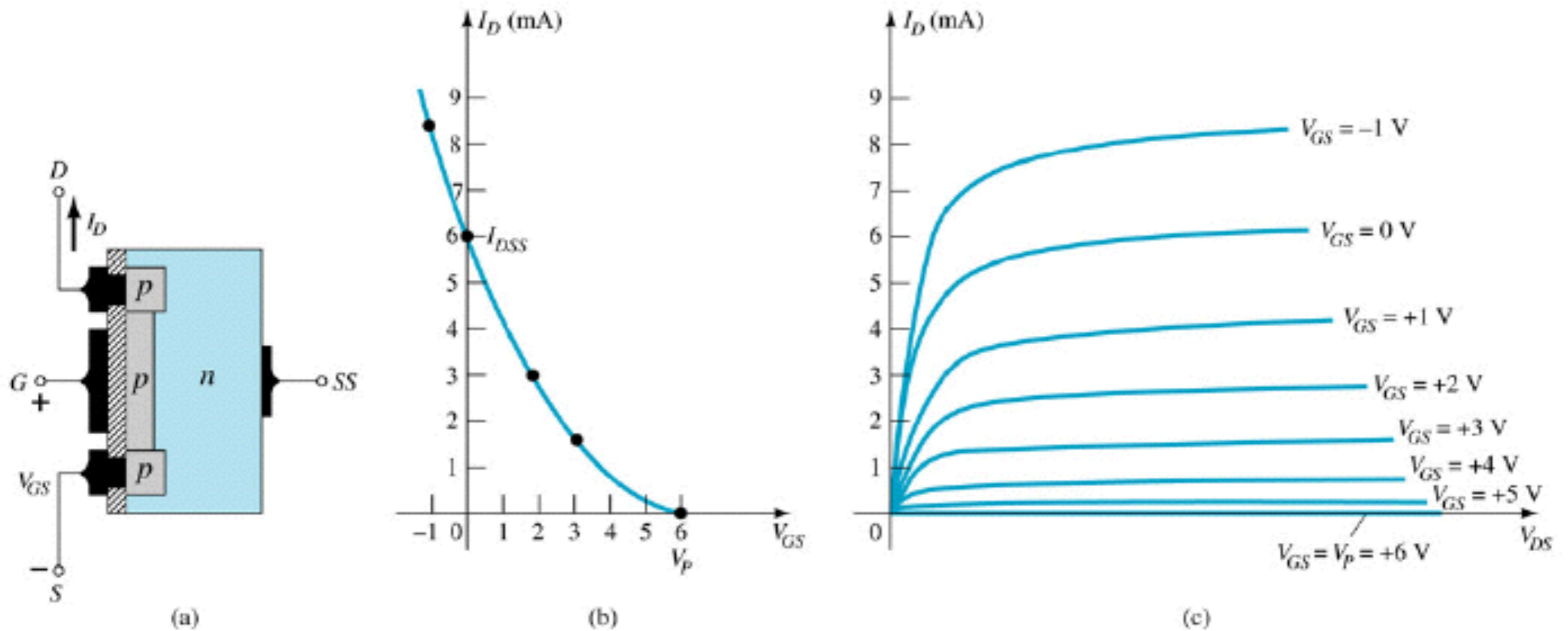
## MOSFET tipo Depleção



MOSFET: Operação básica.



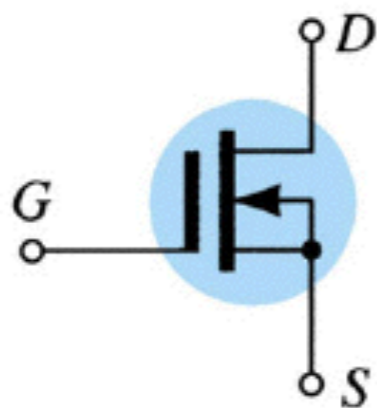
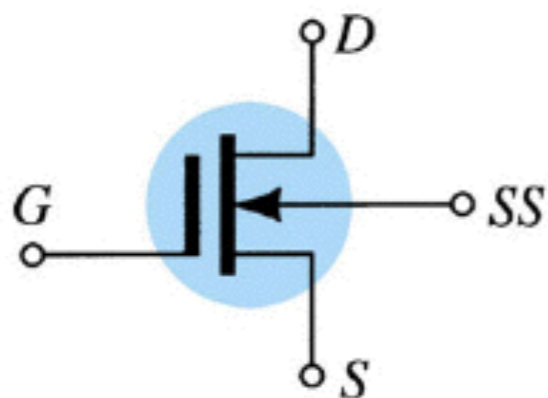
## MOSFET tipo Depleção



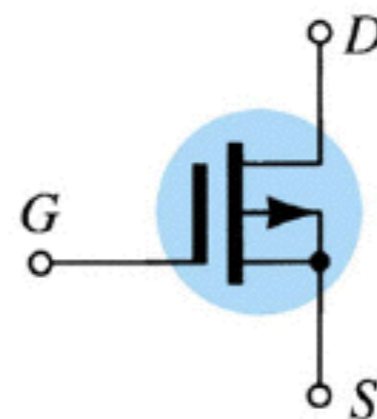
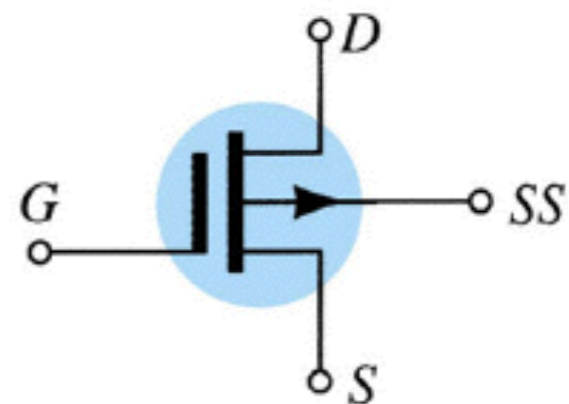
MOSFET: Operação básica.

## MOSFET tipo Depleção

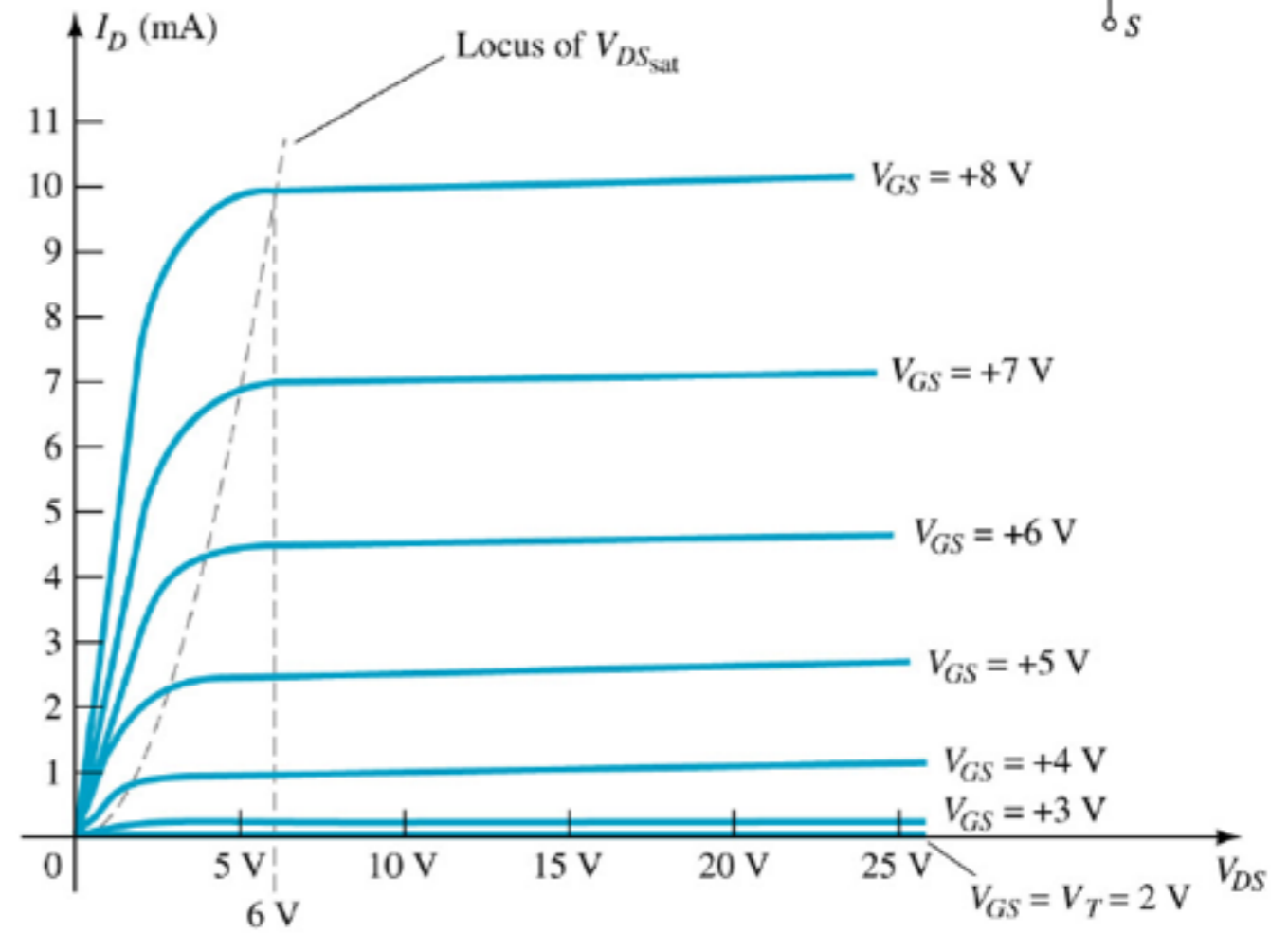
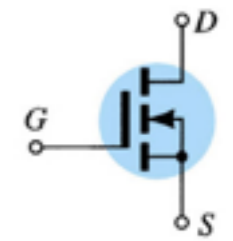
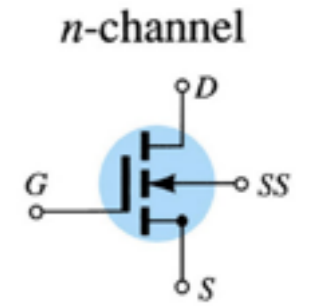
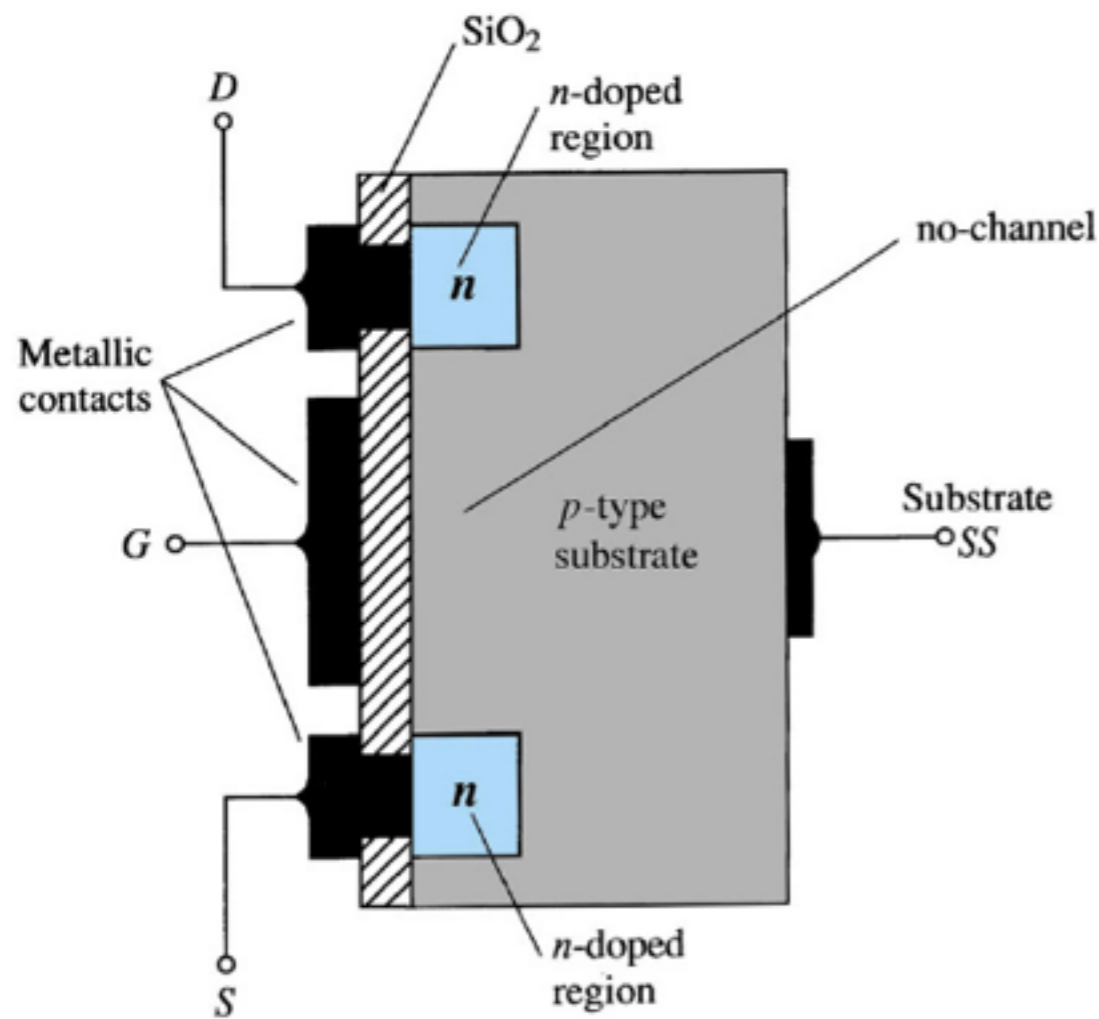
*n*-channel



*p*-channel

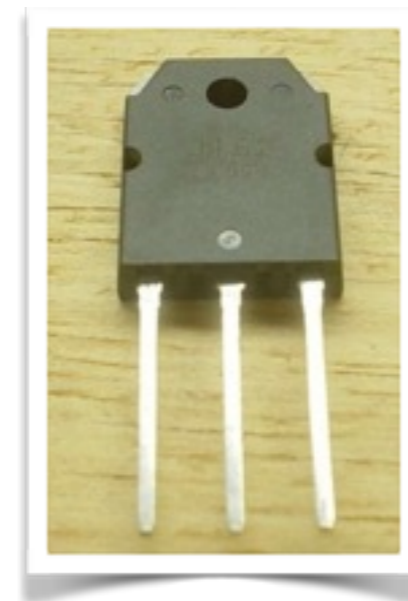
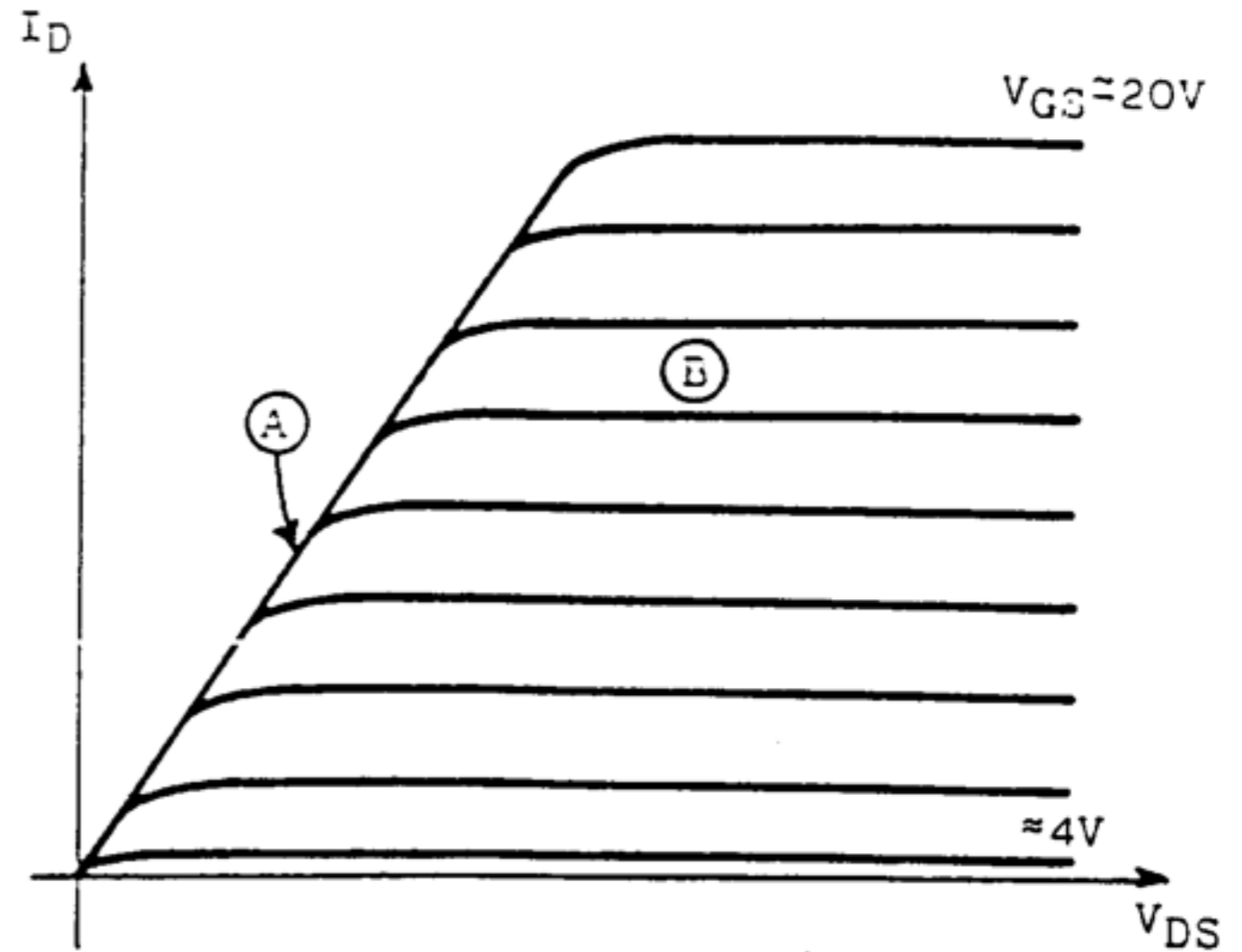
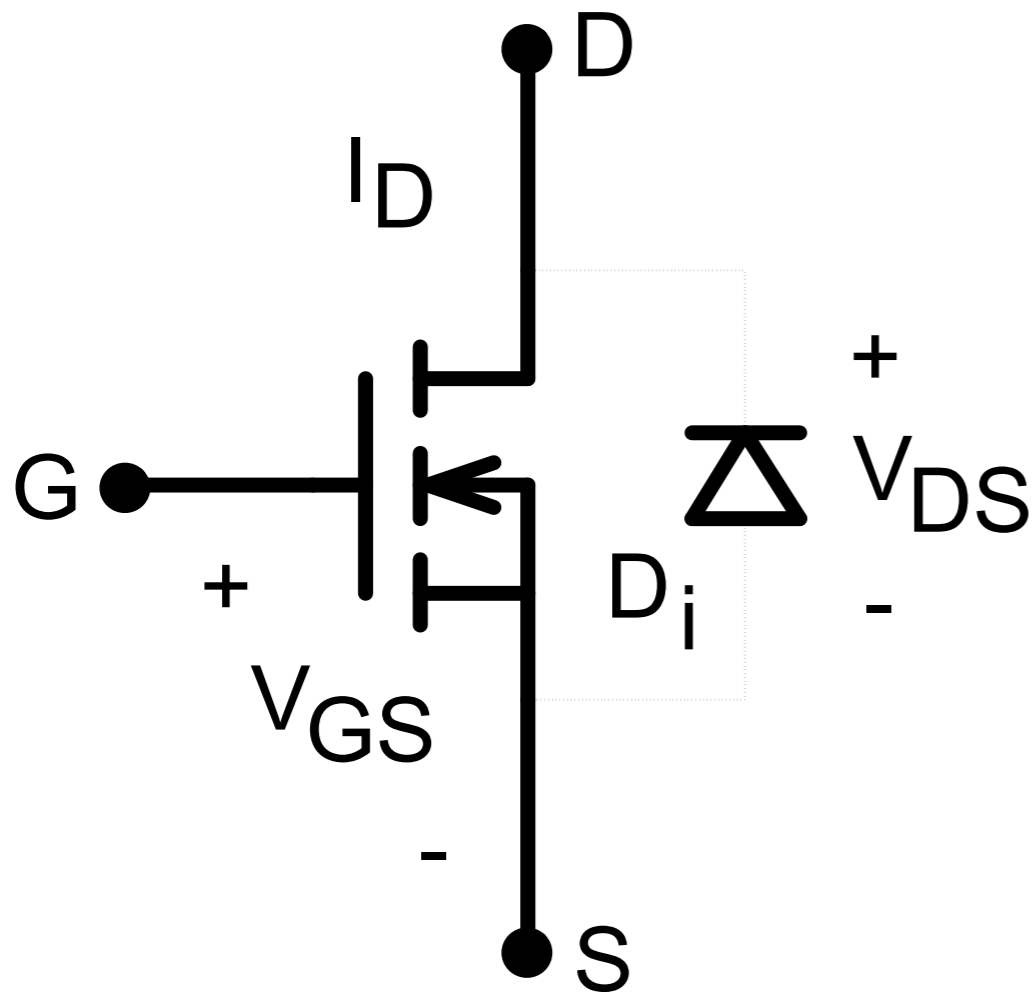


## MOSFET tipo Intensificação

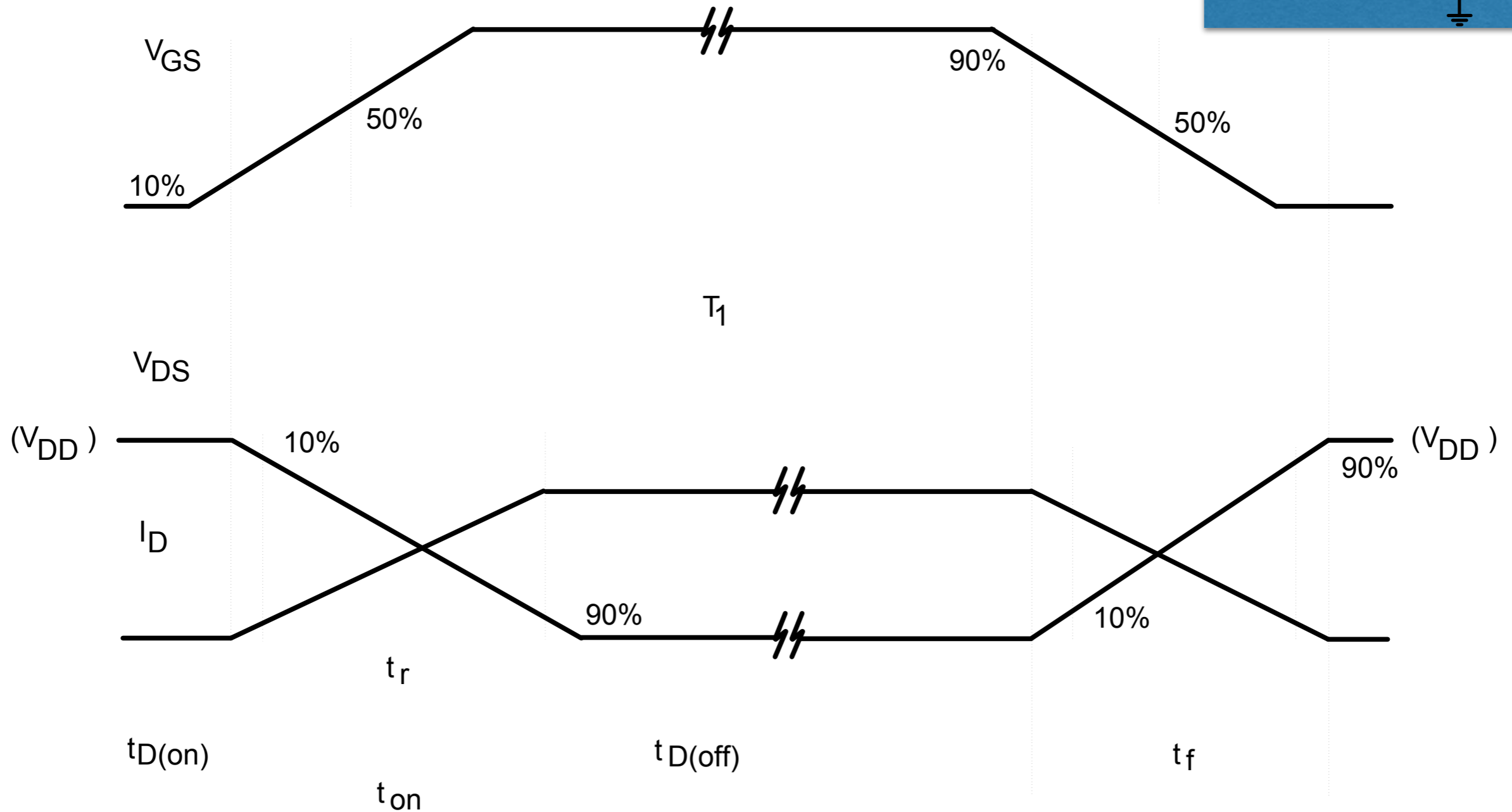
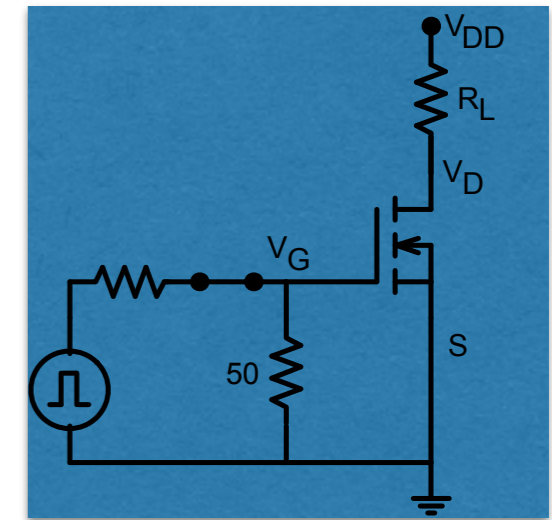


Canal n

## MOSFET de Potência

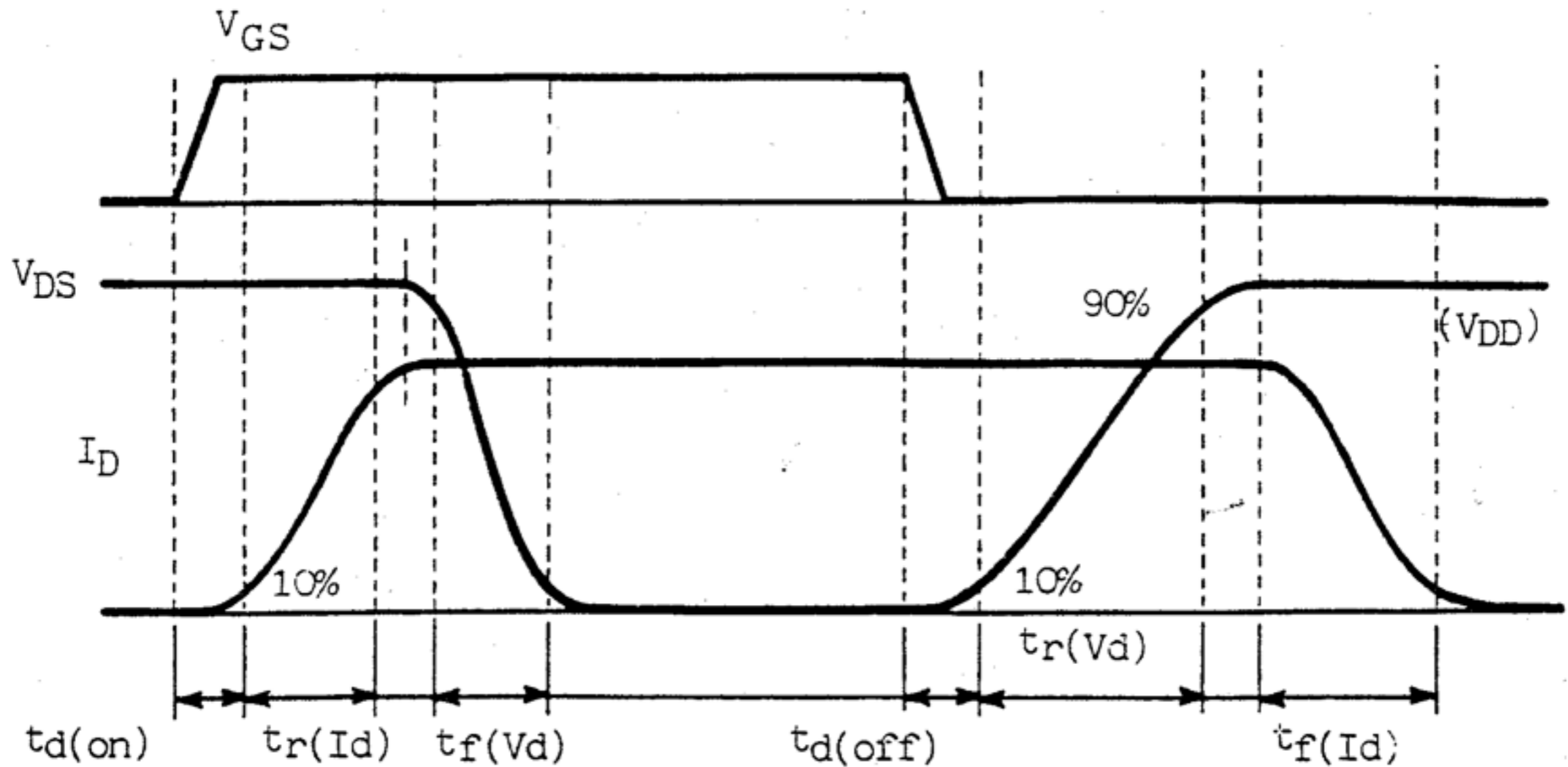
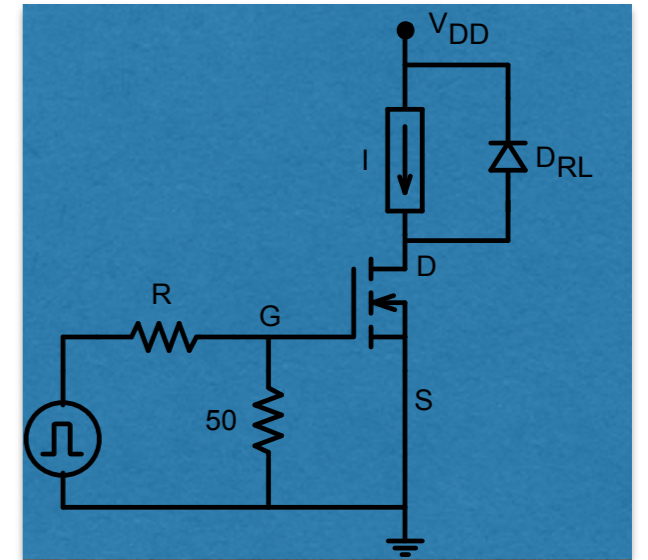


## MOSFET de Potência



Comutação do MOSFET com carga resistiva

## MOSFET de Potência



Comutação do MOSFET com carga indutiva

## 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:

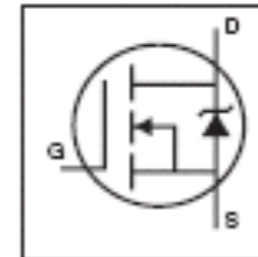
### International IR Rectifier

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 $\text{\textcircled{D}}$	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	$\pm 20$	V
$I_{AS}$	Avalanche Current $\text{\textcircled{D}}$	28	A
$E_{AS}$	Repetitive Avalanche Energy $\text{\textcircled{D}}$	20	mJ
$dv/dt$	Peak Diode Recovery $dv/dt$ $\text{\textcircled{D}}$	5.8	V/ns
$T_J$	Operating Junction and	-55 to +175	°C
$T_{STG}$	Storage Temperature Range		
	Soldering Temperature, for 10 seconds		
	Mounting torque, 6-32 or M3 screw	10 lb-in (1.1 N-m)	

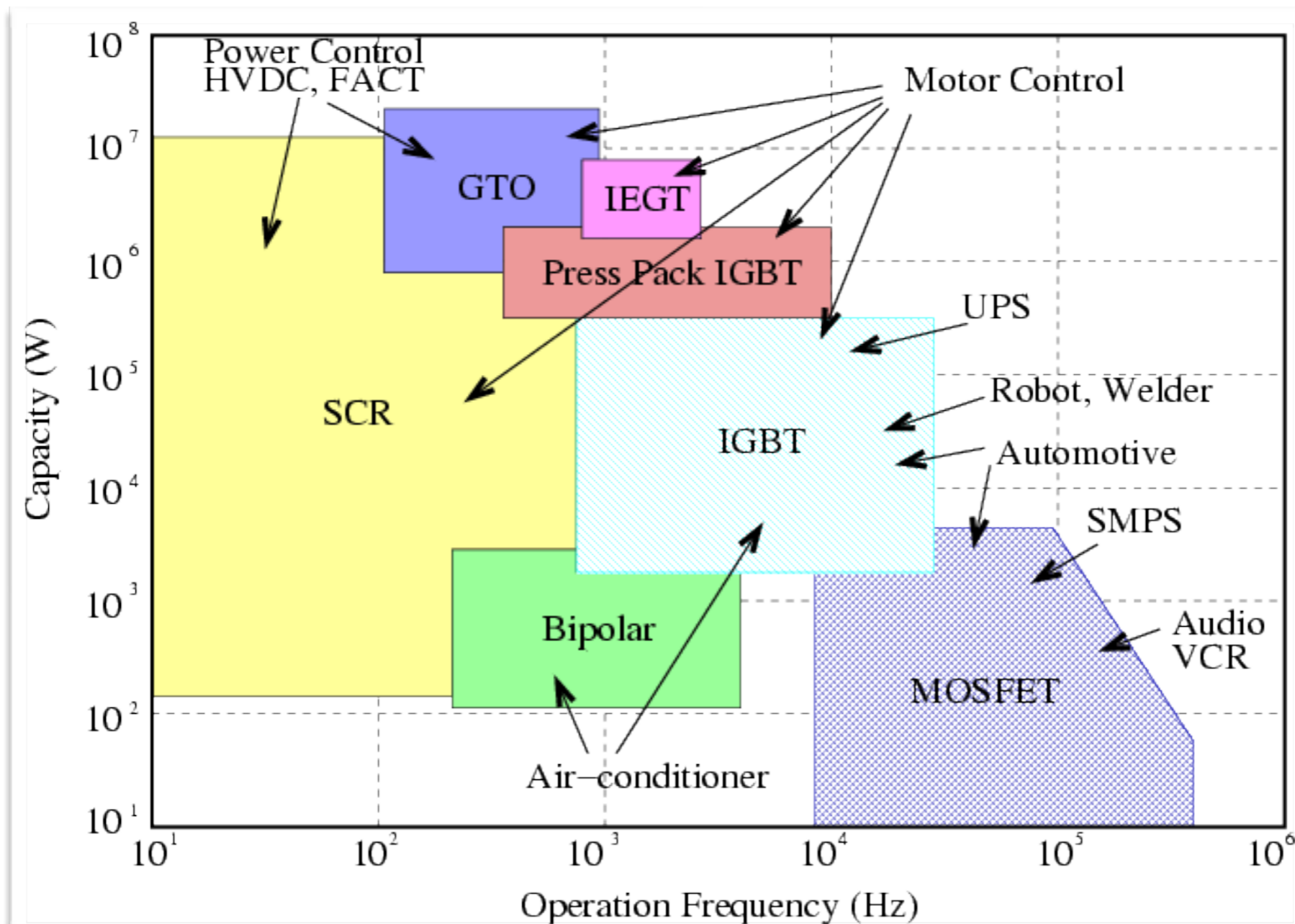
### Thermal Resistance

	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	

# MOSFET

## Quando usar MOSFET:

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



## Demonstração

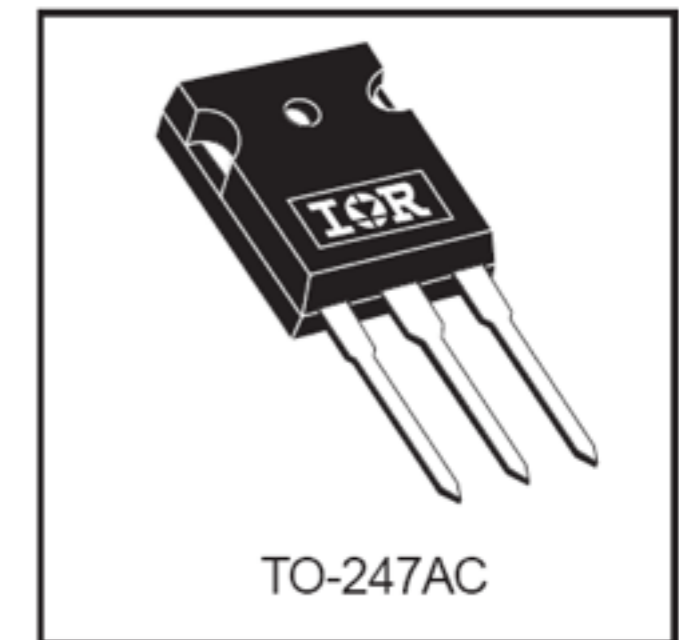
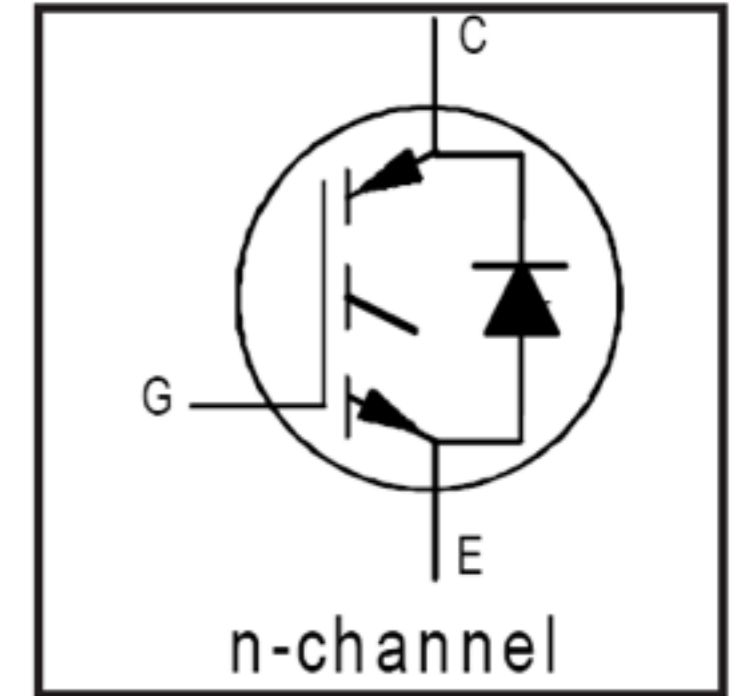
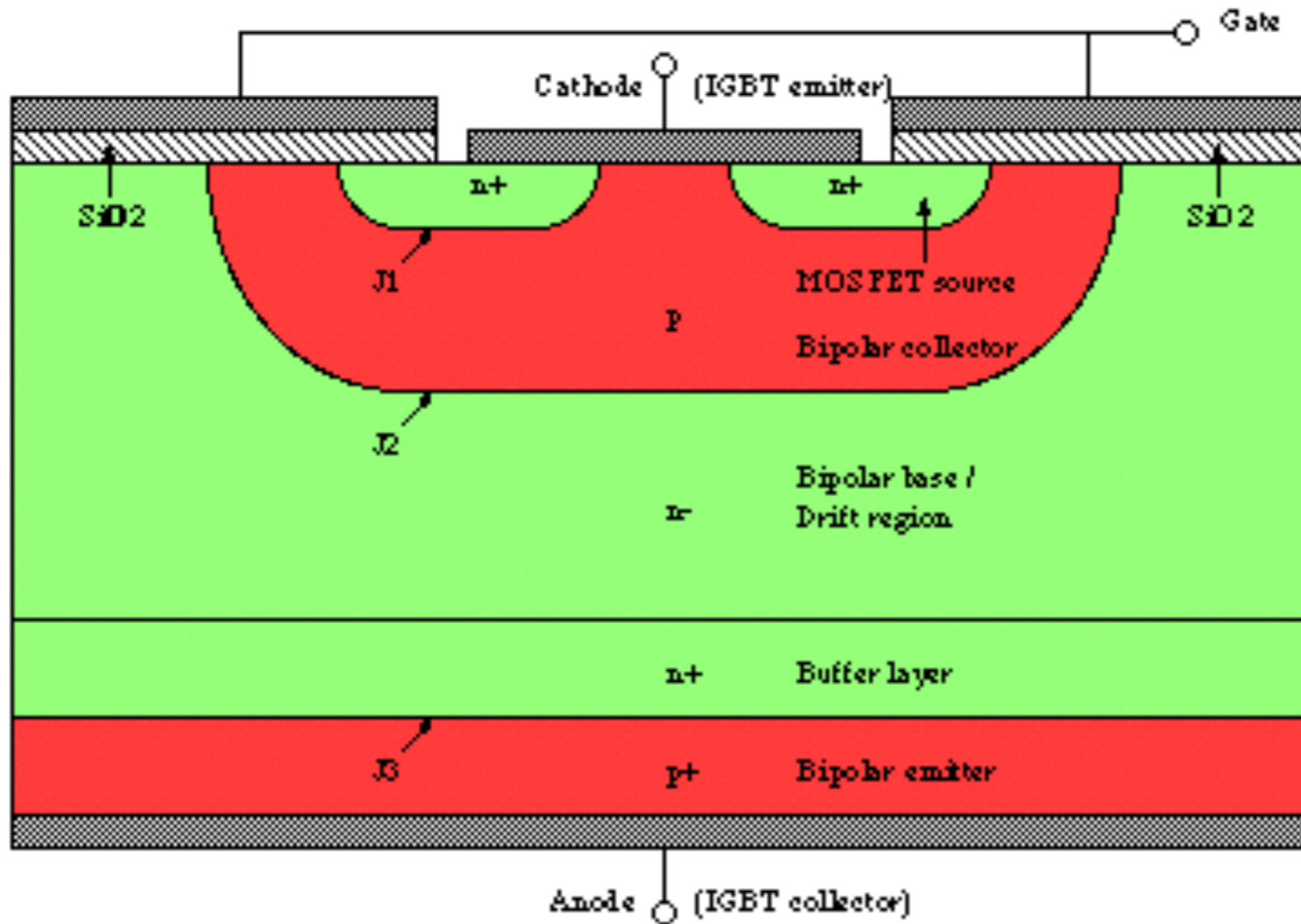
### Demo

- Testes de MOSFET com multímetro.



# IGBT

## IGBT - Insulated Gate Bipolar Transistor



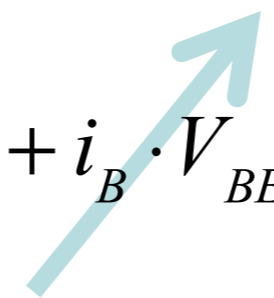
Características de BJT e MOSFET

## Classificação das perdas:

### 1. Condução;

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

0



### 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



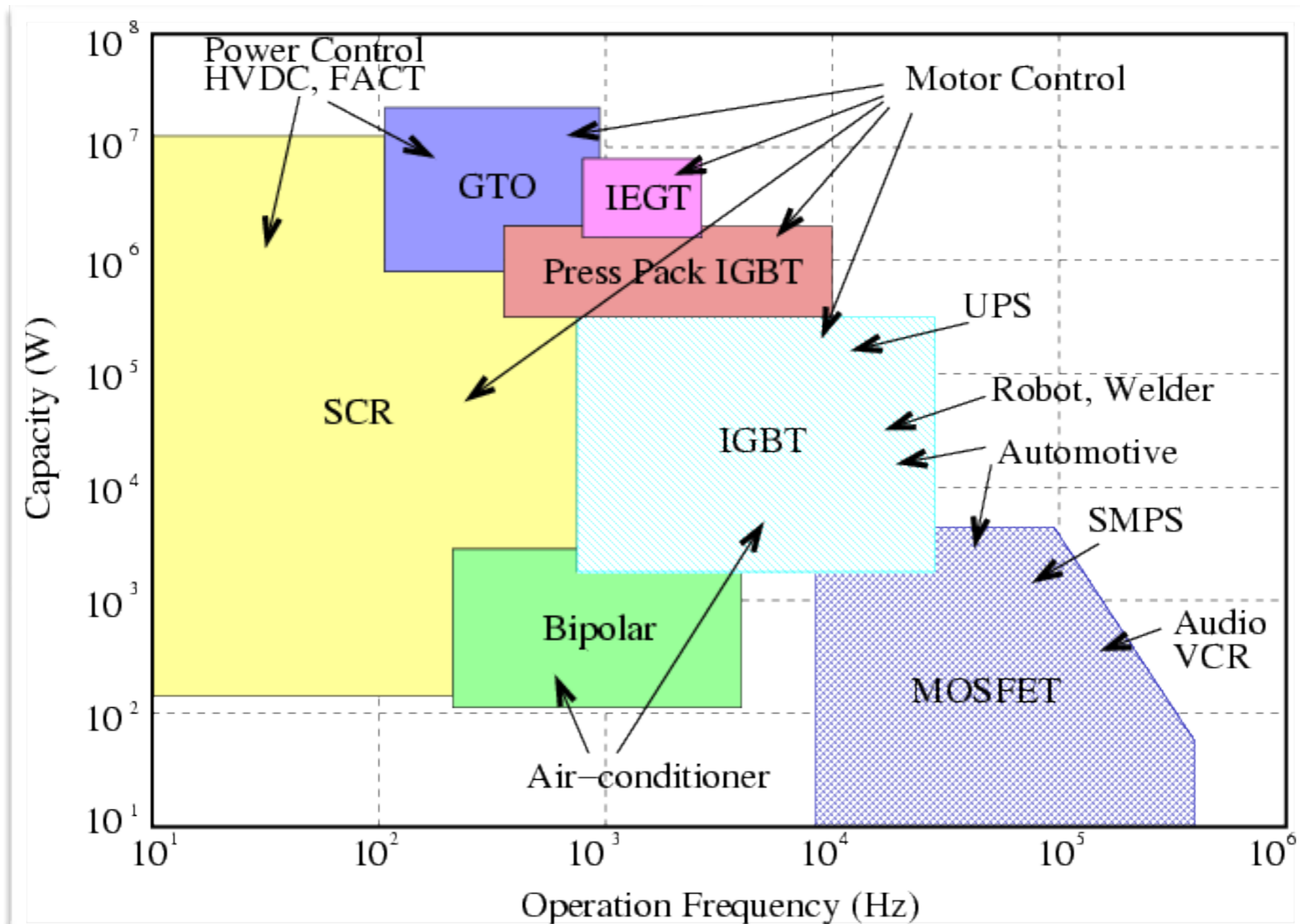
# IGBT

## 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
IRG4PC20S	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
IRG3L4C40L	IGBT Discretes	D2-Pak	Discrete	Low-Vce(on)
IRGPH020	IGBT Discretes	TO-247AC	Discrete	Low-Vce(on)



## Quando usar IGBT:

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



[www.irf.com](http://www.irf.com)

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

Encapsulamentos:



[www.semikron.com](http://www.semikron.com)



SEMISTRANS™



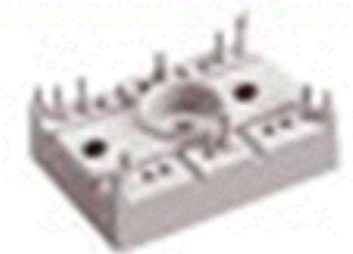
SEMiX®



SKiM™

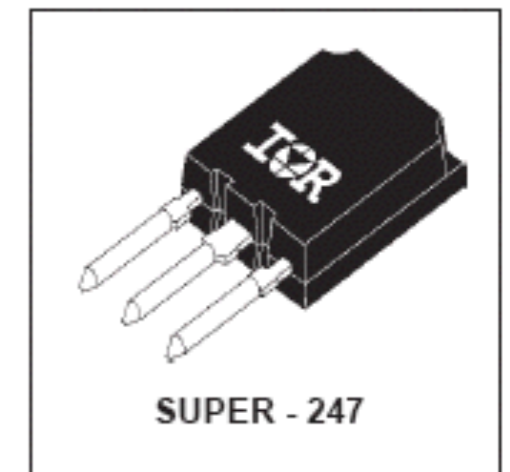
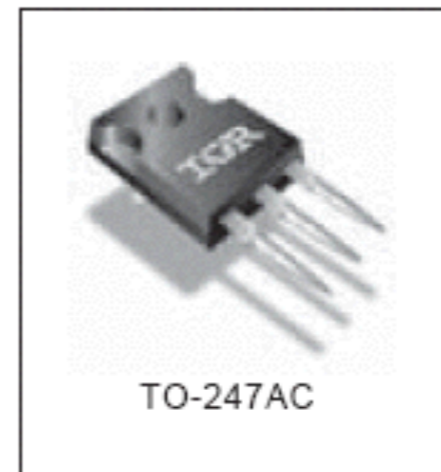
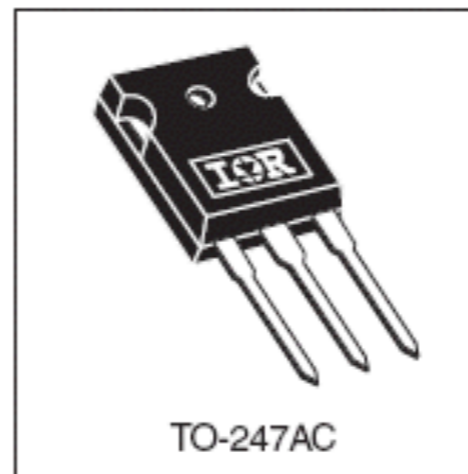
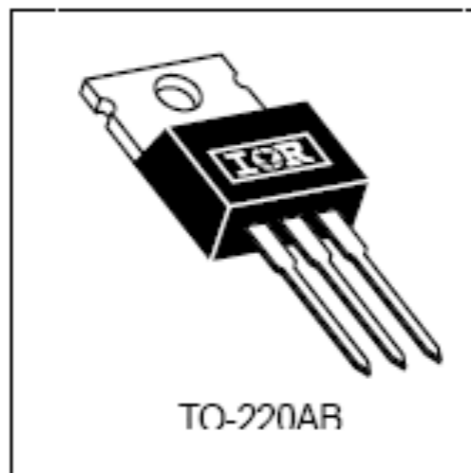
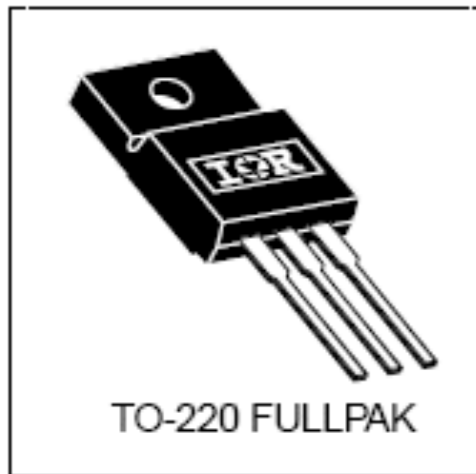
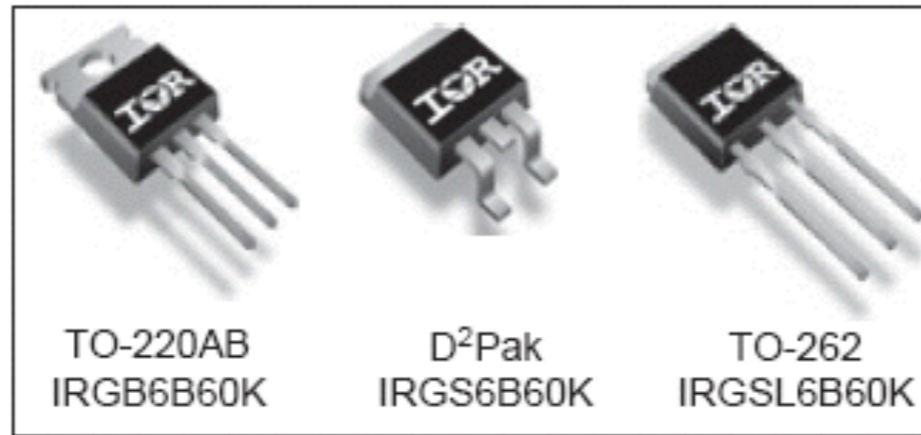
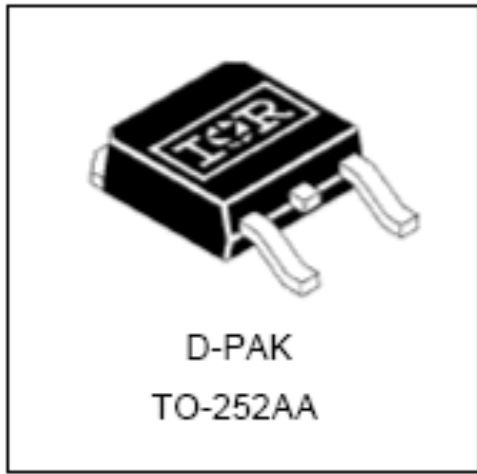


MiniSKiiP®



SEMITOP®

## Encapsulamentos:



[www.irf.com](http://www.irf.com)



## Dados de catalogo:

### International IOR Rectifier INSULATED GATE BIPOLAR TRANSISTOR

PD - 94443

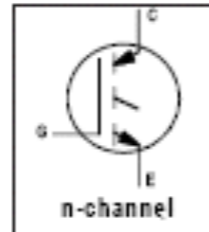
### IRG4PC60U UltraFast Speed IGBT

#### Features

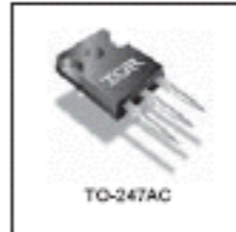
- UltraFast: Optimized for high operating frequencies up to 50 kHz in hard switching, >200 kHz in resonant mode.
- Generation 4 IGBT design provides tighter parameter distribution and higher efficiency.
- Industry standard TO-247AC package.

#### 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.



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



#### 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	
$I_{CM}$	300	
$I_{LM}$	300	
$V_{GE}$	$\pm 20$	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	°C
$T_{STG}$		
	300 (0.083 in. (1.6mm) from case)	
	10 lbf-in (1.1N-m)	

#### Thermal Resistance

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

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### International IOR Rectifier

PD 9.14670

### IRG4PC40UD

INSULATED GATE BIPOLAR TRANSISTOR WITH UltraFast CoPack IGBT  
ULTRAFAST SOFT RECOVERY DIODE

#### 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

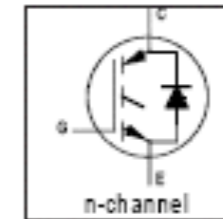
- Generation -4 IGBT's offer highest efficiencies available
- IGBT's optimized for specific application conditions
- HEXFRED diodes optimized for performance with IGBT's. Minimized recovery characteristics require less snubbing
- Designed to be a "drop-in" replacement for equivalent industry-standard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

#### Absolute Maximum Ratings

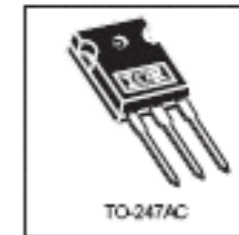
Parameter	Max.	Units
$V_{CES}$	600	V
$I_C @ T_C = 25^\circ C$	40	A
$I_C @ T_C = 100^\circ C$	20	
$I_{CM}$	160	
$I_{LM}$	160	
$I_F @ T_C = 100^\circ C$	15	A
$I_{FM}$	160	
$V_{GE}$	$\pm 20$	V
$P_D @ T_C = 25^\circ C$	160	W
$P_D @ T_C = 100^\circ C$	65	
$T_J$	-55 to +150	°C
$T_{STG}$		
	300 (0.083 in. (1.6mm)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

#### Thermal Resistance

Parameter	Min.	Typ.	Max.	Units
$R_{\theta JC}$	---	---	0.77	°C/W
$R_{\theta CS}$	---	---	1.7	
$R_{\theta JA}$	---	0.24	---	
$R_{\theta JA}$	---	---	40	
$Wt$	---	8 (0.21)	---	g (oz)



$V_{CES} = 600V$
$V_{CE(sat) typ.} = 1.72V$
@ $V_{GE} = 15V, I_C = 20A$



## Demonstração

### Demo

- Testes de IGBT com multímetro.



# BJT x MOSFET x IGBT

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

## Componentes Semicondutores:

- Dimensionamento e especificação de semicondutores.

