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

Semicondutores Aplicados a Conversores CA-CC
Diodos

Prof. Clóvis Antônio Petry.

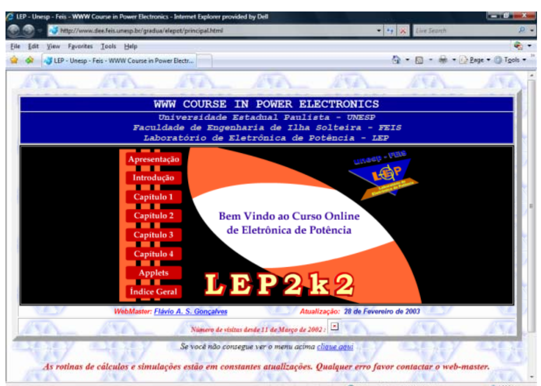
Florianópolis, julho de 2008.

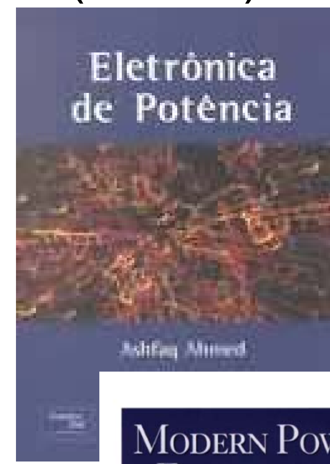
Bibliografia para esta aula

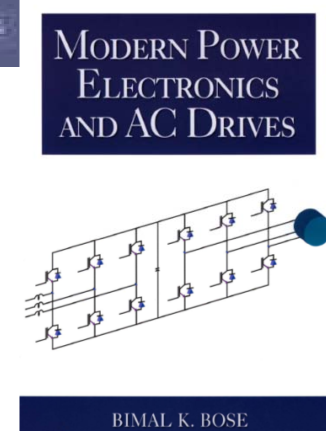
Capítulo 2: Diodos de potência

1. Semicondutores aplicados aos conversores CA-CC (diodos).

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







www.cefetsc.edu.br/~petry

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

Nesta aula

Semicondutores aplicados a conversores CA-CC (diodos):

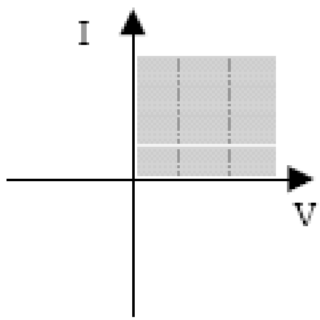
1. Introdução;
2. Características dos componentes ideais;
3. Características dos componentes reais;
4. Perdas no diodo;
5. Cálculo de dissipador de calor.

Quadrantes de condução de semicondutores

Operações Básicas Desejadas

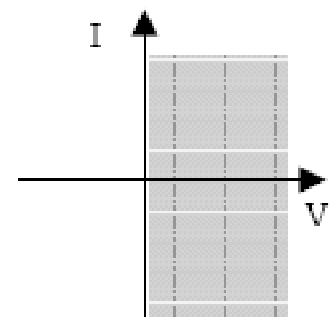
Operação em um quadrante

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



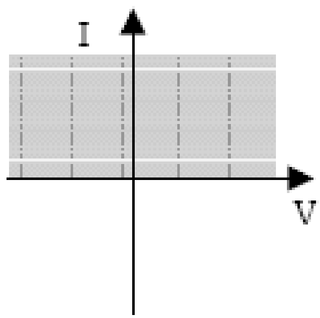
Operação em dois quadrantes com corrente bidirecional

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



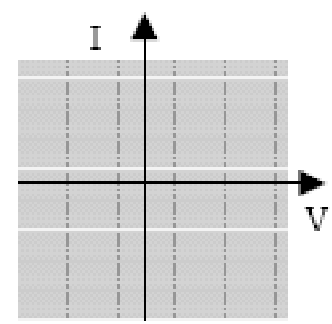
Operação em dois quadrantes com tensão bidirecional

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



Operação em quatro quadrantes

- Arranjo de diodos com transistores bipolares

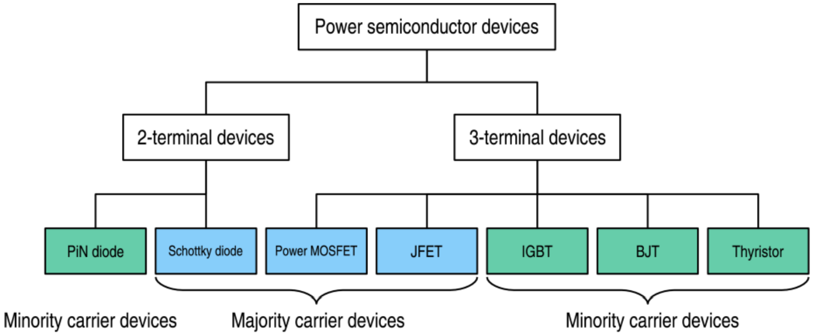


http://www.dee.feis.unesp.br/gradua/elepot/principal.html

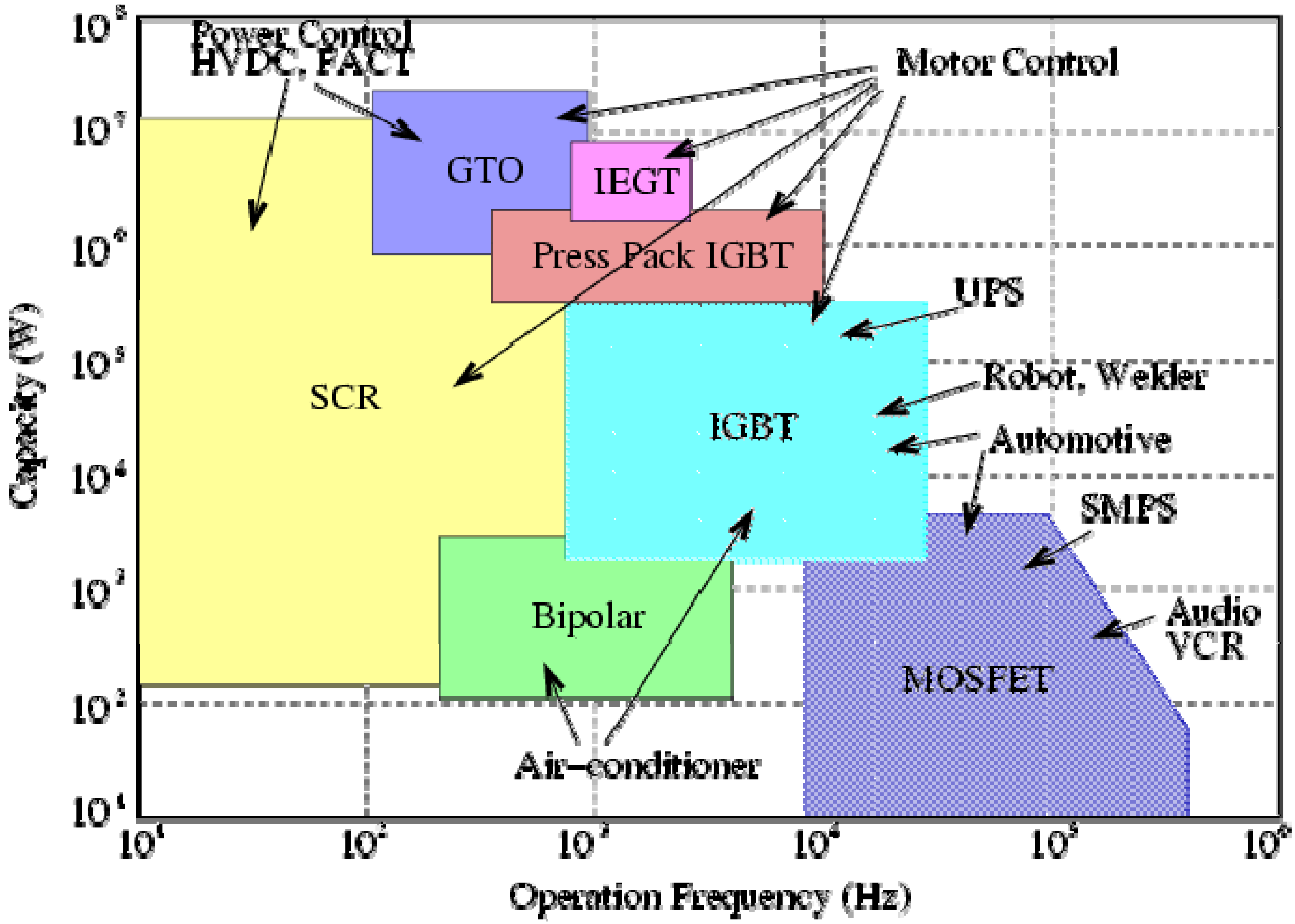
Semicondutores para eletrônica de potência

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)

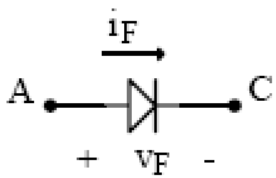


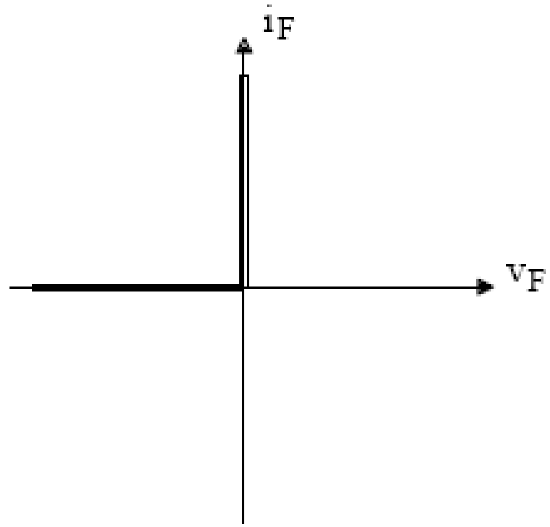
Semicondutores para eletrônica de potência



Semicondutores para eletrônica de potência

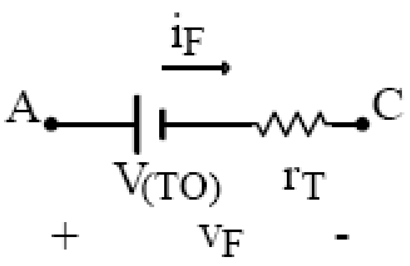
Diodo ideal e real

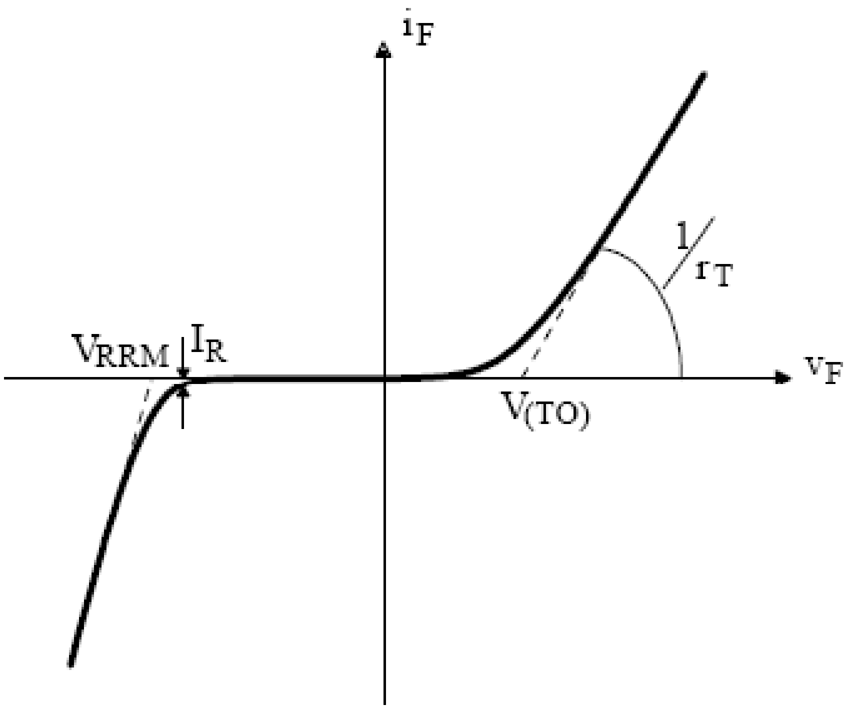




Exemplo: Diodo SKN20/08

- V_{RRM} = 800 V;
- $V_{(TO)}$ = 0,85 V;
- r_T = 11 mΩ;
- I_{Dmed} = 20 A;
- I_R = 0,15 mA.

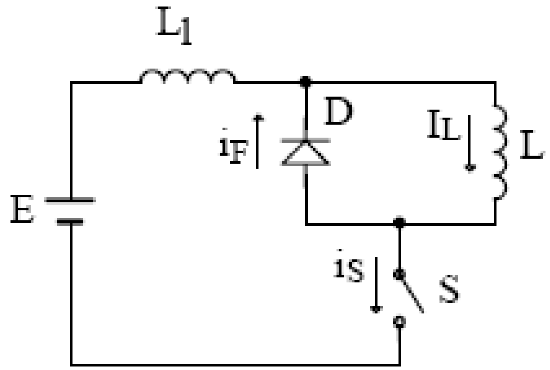




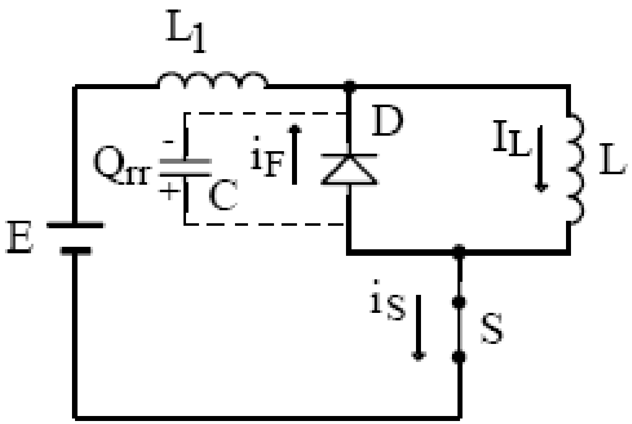
Característica estática

Comutação – Características dinâmicas

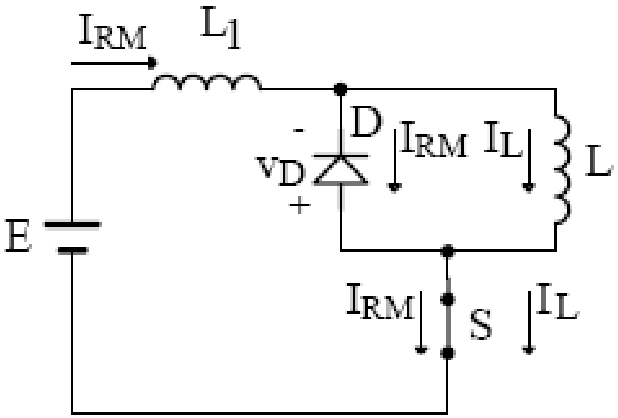
Bloqueio



Circuito para estudo da comutação



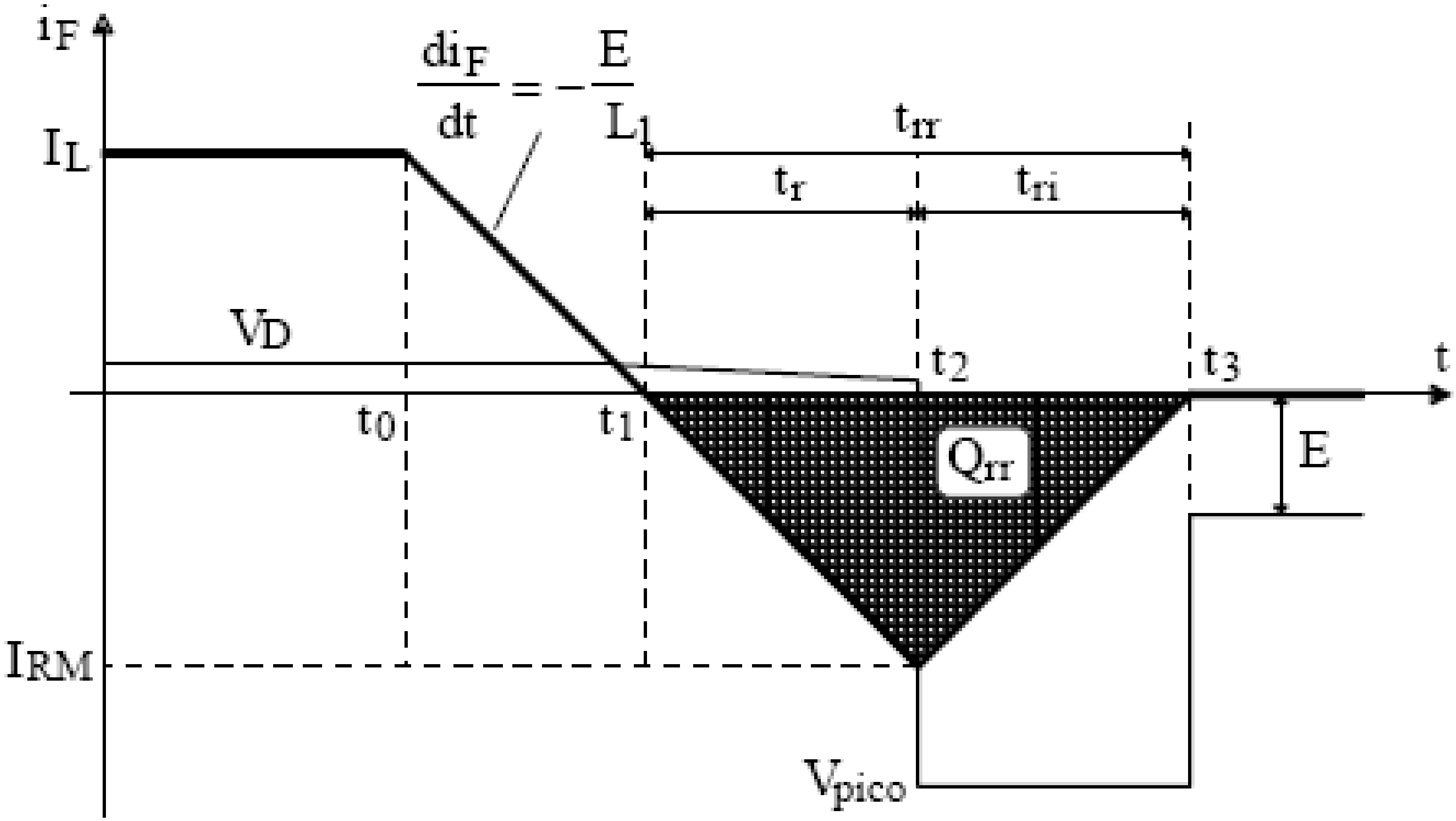
Primeira etapa de comutação



Segunda etapa de comutação

Comutação – Características dinâmicas

Bloqueio



Comutação – Características dinâmicas

No bloqueio do diodo (comutação crítica):

Bloqueio

$$\frac{di_F}{dt} = -\frac{E}{L_1}$$

Derivada da corrente depende da indutância

$$t_{rr} \cong \sqrt{\left(\frac{3Q_{rr}}{di_F / dt} \right)}$$

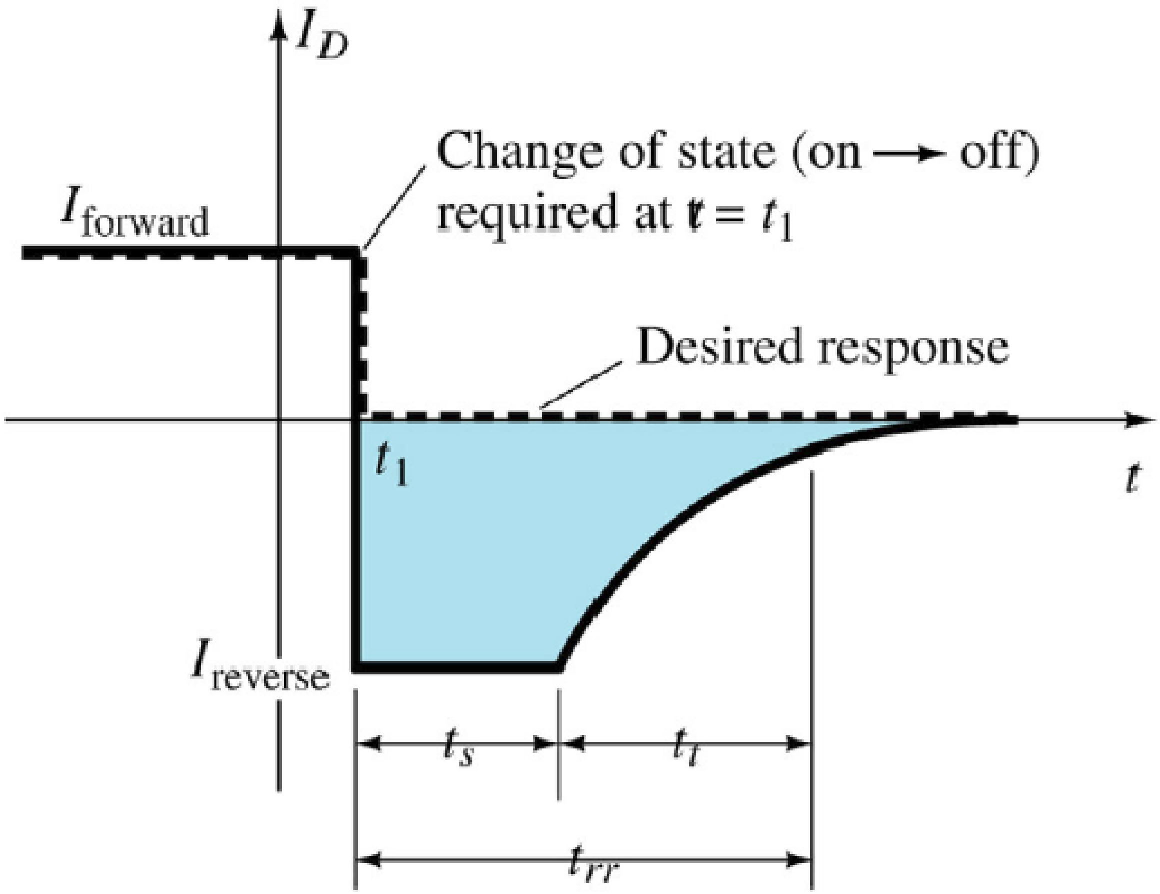
Tempo de recuperação reversa

$$I_{RM} \cong \sqrt{\left(\frac{4}{3} Q_{rr} \frac{di_F}{dt} \right)}$$

Corrente máxima devido a recuperação reversa

Comutação – Características dinâmicas

Diodos de carbeto de sílicio (silicon carbide):
Diminuem acentuadamente o fenômeno da **recuperação reversa**.



http://www.infineon.com

http://www.cree.com

Comutação – Características dinâmicas

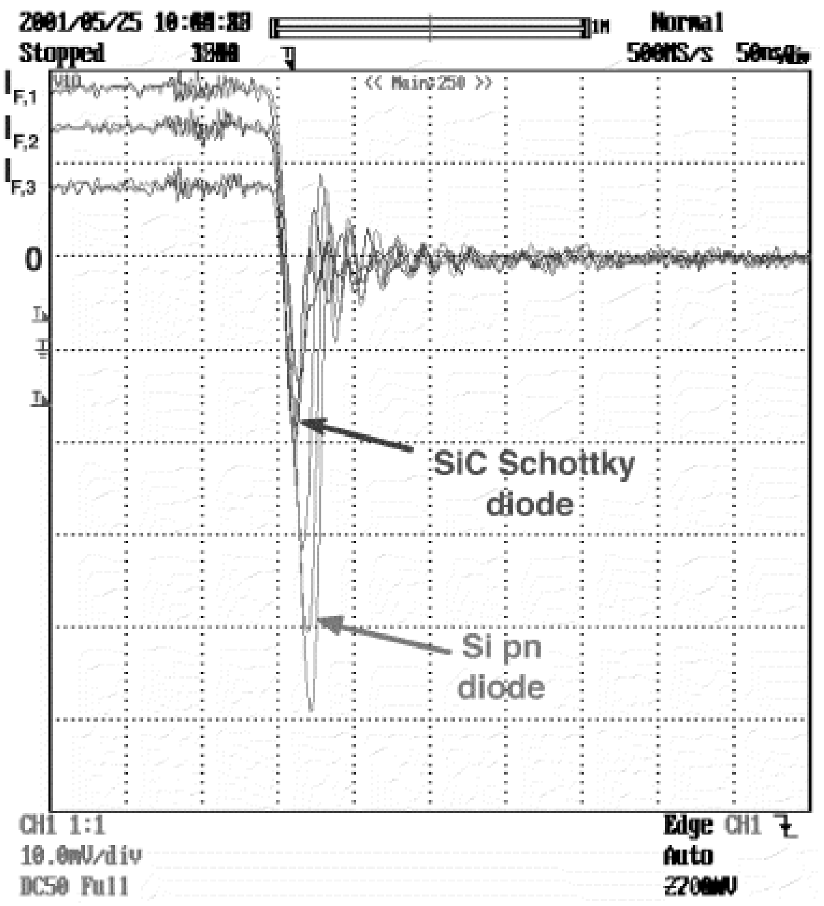


Fig. 5. Typical reverse recovery waveforms of the Si pn and SiC Schottky diode for three different forward currents (2 A/div.).

http://powerelec.ece.utk.edu/pubs/pels_letters_SiC_june_2003.pdf

Comutação – Características dinâmicas

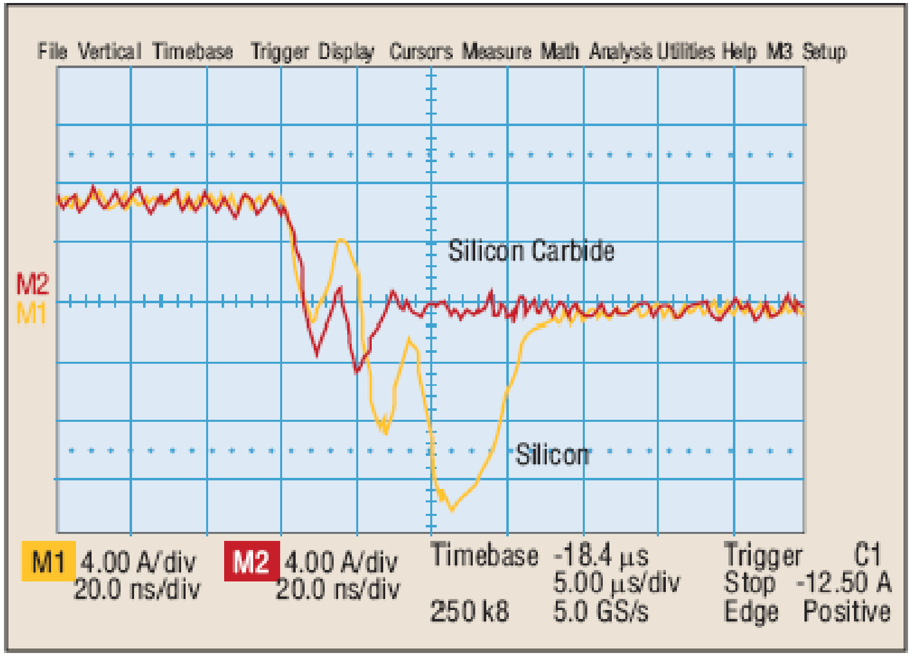


Fig. 4. *Low-line diode recovery currents in PFC front-end converter.*

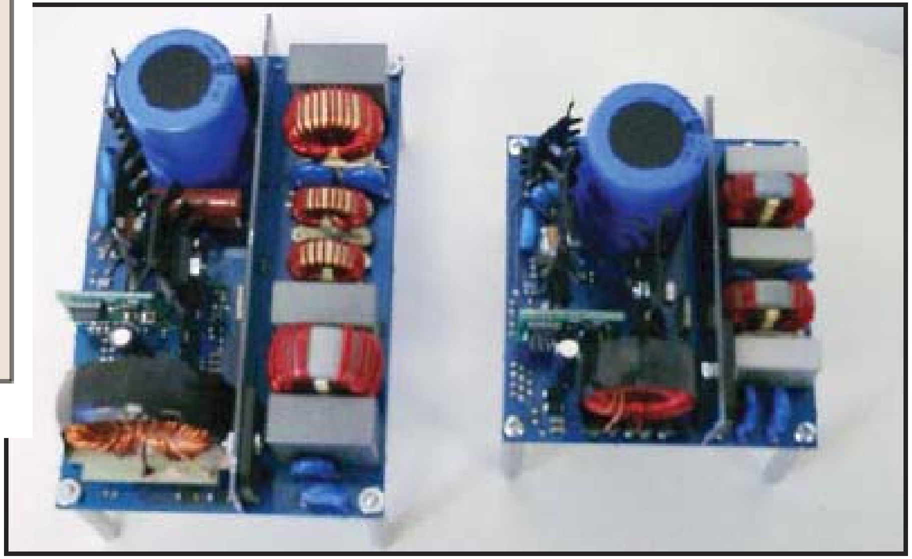
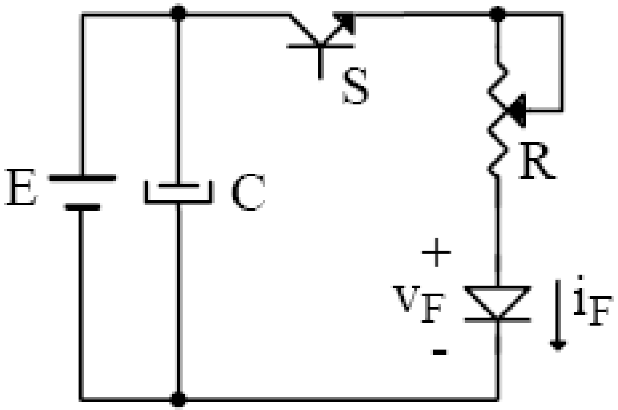


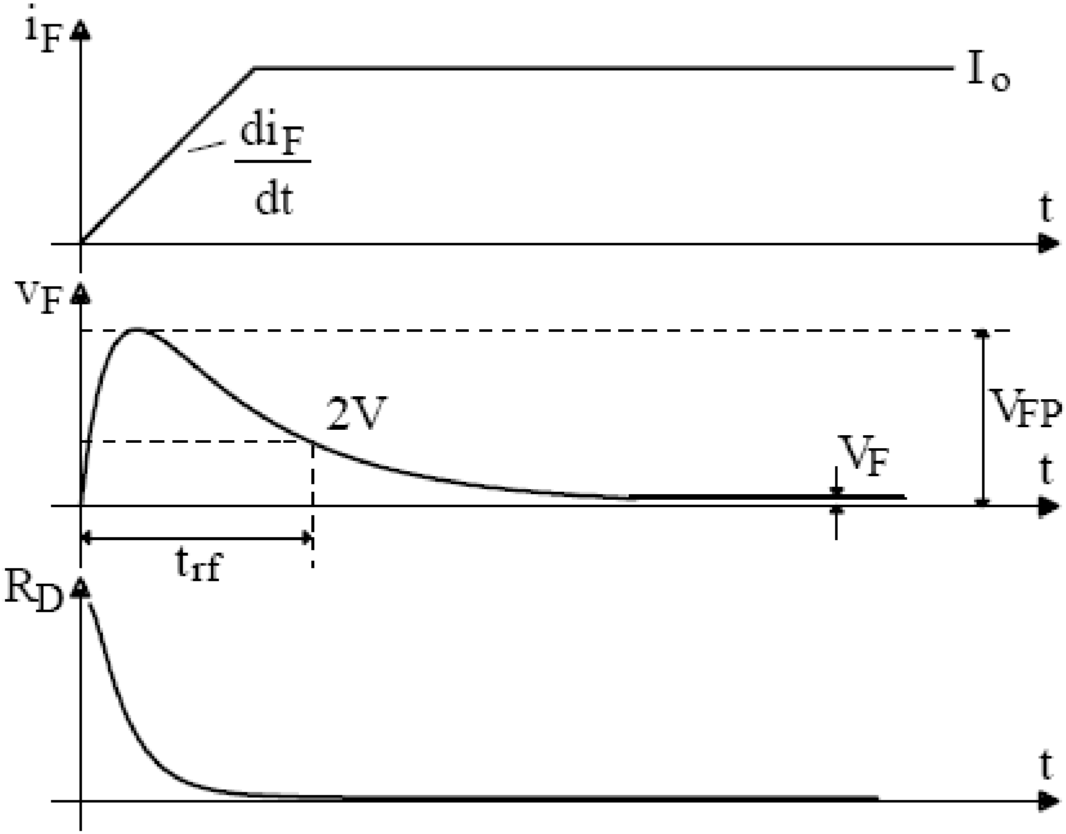
Fig. 8. *A size comparison of an 80-kHz PFC front-end built with Si rectifiers (left) and a 200-kHz PFC front-end with SiC rectifiers.*

http://www.cree.com/Products/pdf/Power_Article_1.pdf

Comutação – Características dinâmicas

Entrada em condução





Perdas nos diodos

Classificação das perdas:

1. Condução;

$$P = V_{(TO)} \cdot I_{Dmed} + r_T \cdot I_{Def}^{\;2}$$

2. Comutação:
   - Entrada em condução;

$$P_1 = 0{,}5\left(V_{FP} - V_F\right) I_o \cdot t_{rf} \cdot f$$

   - Bloqueio.

$$P_2 = Q_{rr} \cdot E \cdot f$$

Características importantes

Principais características:

1. Tensão de pico reversa;
2. Queda de tensão direta;
3. Corrente de pico;
4. Corrente média;
5. Corrente eficaz;
6. Tempo de recuperação reversa.

MURD320

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	200	V
Average Rectified Forward Current (Rated V_R, T_C = 158°C)	$I_{F(AV)}$	3.0	A
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20 kHz, T_C = 158°C)	I_{FRM}	6.0	A
Non−Repetitive Peak Surge Current (Surge Applied at Rated Load Conditions Halfwave, 60 Hz)	I_{FSM}	75	A
Operating Junction and Storage Temperature Range	T_J, T_{stg}	−65 to +175	°C

THERMAL CHARACTERISTICS

Rating	Symbol	Value	Unit
Thermal Resistance − Junction−to−Case	$R_{\theta JC}$	6	°C/W
Thermal Resistance − Junction−to−Ambient (Note 1)	$R_{\theta JA}$	80	°C/W

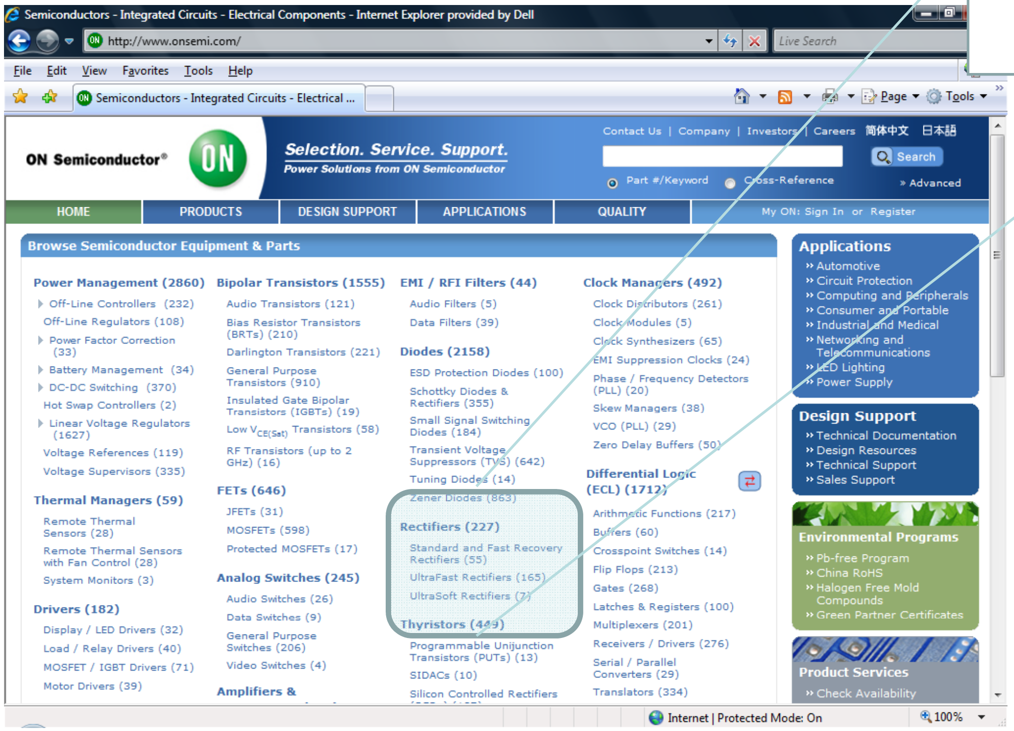
ELECTRICAL CHARACTERISTICS

Maximum Instantaneous Forward Voltage Drop (Note 2) (i_F = 3 Amps, T_J = 25°C) (i_F = 3 Amps, T_J = 125°C)	v_F	 0.95 0.75	Volts
Maximum Instantaneous Reverse Current (Note 2) (T_J = 25°C, Rated dc Voltage) (T_J = 125°C, Rated dc Voltage)	i_R	 5 500	μA
Maximum Reverse Recovery Time (I_F = 1 Amp, di/dt = 50 Amps/μs, V_R = 30 V, T_J = 25°C) (I_F = 0.5 Amp, i_R = 1 Amp, I_{REC} = 0.25 A, V_R = 30 V, T_J = 25°C)	t_{rr}	 35 25	ns

Características de diodos comerciais

Tipos de diodos de potência:

1. Standard and fast recovery;
2. Ultrafast rectifiers;
3. Ultrasoft rectifers;
4. Silicon carbide (zero recovery).



Rectifiers (227)

Standard and Fast Recovery Rectifiers (55)

UltraFast Rectifiers (165)

UltraSoft Rectifiers (7)

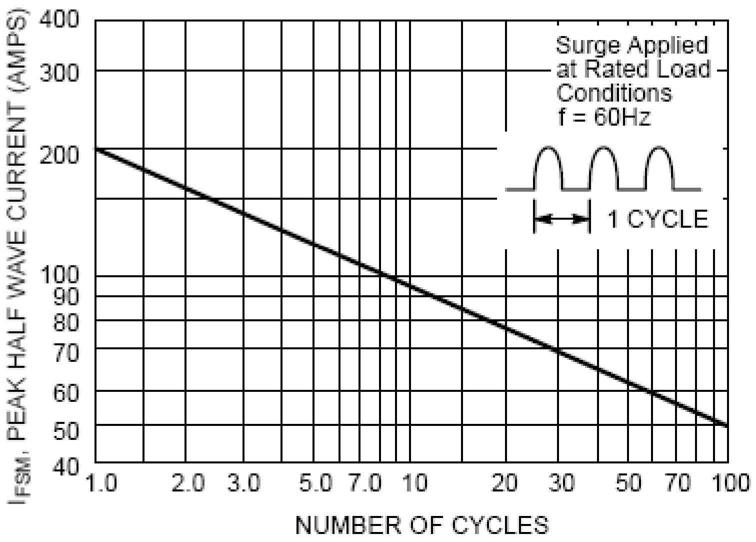
http://www.onsemi.com

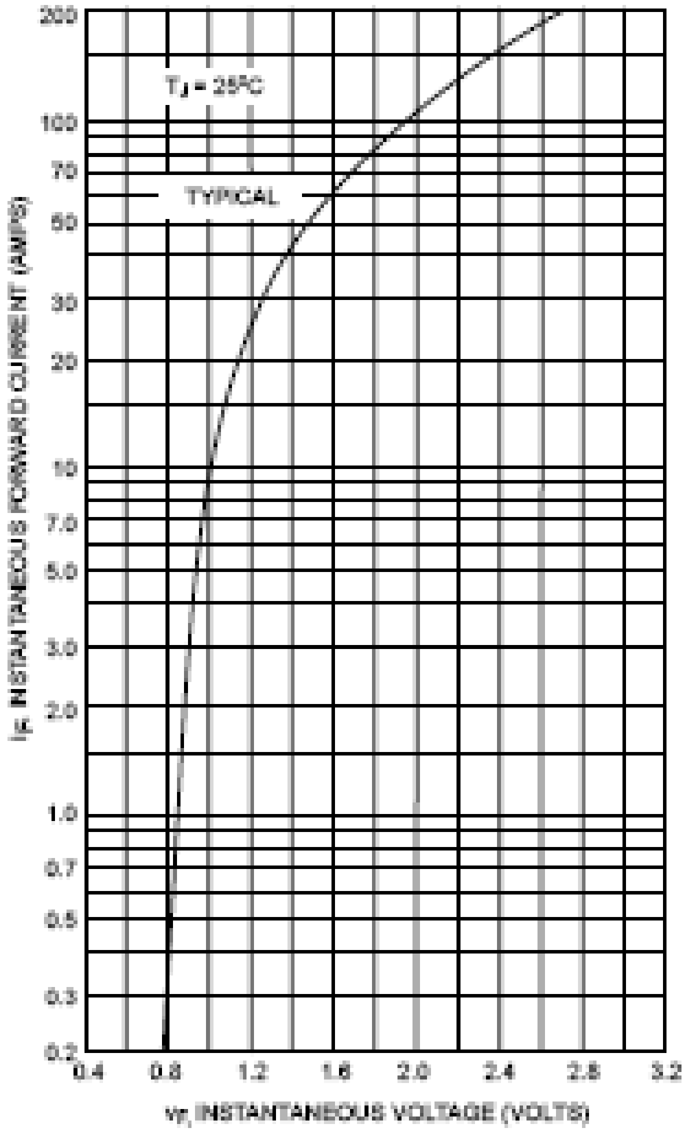
Características de diodos comerciais

1N5400 thru 1N5408

1N5404 and 1N5406 are Preferred Devices

Axial-Lead Standard Recovery Rectifiers





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Características de diodos comerciais

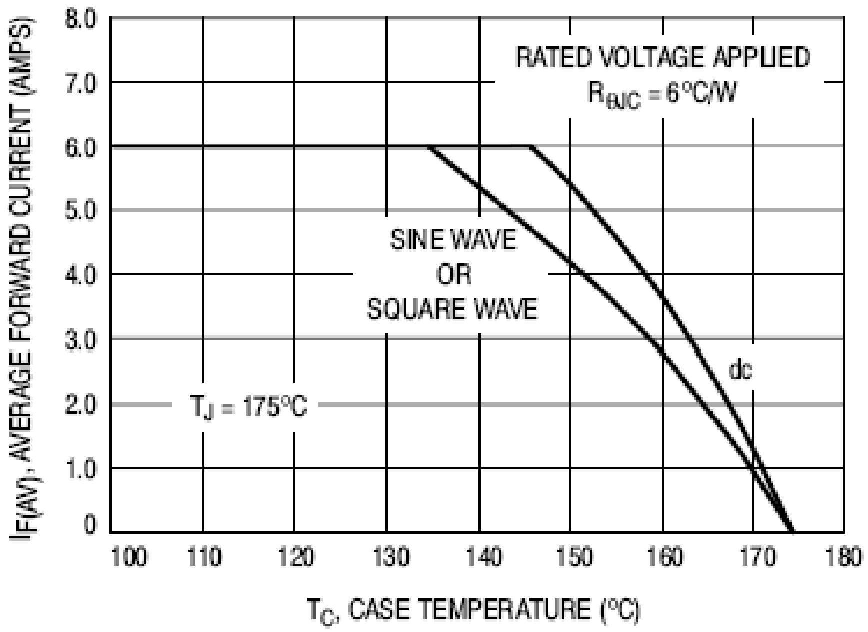
MURD320

Preferred Device

SWITCHMODE™
Power Rectifier

DPAK Surface Mount Package

ULTRAFAST RECTIFIER
3.0 AMPERES, 200 VOLTS



ELECTRICAL CHARACTERISTICS

Maximum Instantaneous Forward Voltage Drop (Note 2) (i_F = 3 Amps, T_J = 25°C) (i_F = 3 Amps, T_J = 125°C)	v_F	 0.95 0.75	Volts
Maximum Instantaneous Reverse Current (Note 2) (T_J = 25°C, Rated dc Voltage) (T_J = 125°C, Rated dc Voltage)	i_R	 5 500	μA
Maximum Reverse Recovery Time (I_F = 1 Amp, di/dt = 50 Amps/μs, V_R = 30 V, T_J = 25°C) (I_F = 0.5 Amp, i_R = 1 Amp, I_{REC} = 0.25 A, V_R = 30 V, T_J = 25°C)	t_{rr}	 35 25	ns

http://www.onsemi.com

Características de diodos comerciais

MSRD620CT

SWITCHMODE™
Soft Ultrafast Recovery
Power Rectifier

SOFT ULTRAFAST
RECTIFIER
6.0 AMPERES, 200 VOLTS

ELECTRICAL CHARACTERISTICS

Rating	Symbol	Value		Unit
Maximum Instantaneous Forward Voltage (Note 1) (See Figure 2) Per Leg	V_F	$T_J = 25°C$	$T_J = 150°C$	V
(I_F = 3.0 A)		1.15	1.05	
(I_F = 6.0 A)		1.35	1.30	
Maximum Instantaneous Reverse Current (See Figure 4) Per Leg	I_R	$T_J = 25°C$	$T_J = 150°C$	μA
(V_R = 200 V)		5.0	200	
(V_R = 100 V)		2.0	100	
Maximum Reverse Recovery Time (Note 2) Per Leg	t_{rr}			ns
(V_R = 30 V, I_F = 1.0 A, di/dt = 50 A/μs)		45		
(V_R = 30 V, I_F = 3.0 A, di/dt = 50 A/μs)		55		
Maximum Peak Reverse Recovery Current Per Leg	I_{RM}			A
(V_R = 30 V, I_F = 1.0 A, di/dt = 50 A/μs)		2.0		
(V_R = 30 V, I_F = 3.0 A, di/dt = 50 A/μs)		3.0		

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Características de diodos comerciais

C2D20120D–Silicon Carbide Schottky Diode

ZERO RECOVERY® RECTIFIER

V_{RRM} = 1200 V

I_F = 20 A

Q_c =122 nC

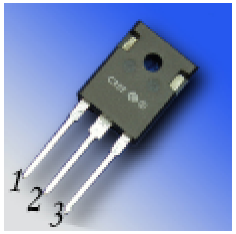
Features

- 1200-Volt Schottky Rectifier
- Zero Reverse Recovery
- Zero Forward Recovery
- High-Frequency Operation
- Temperature-Independent Switching Behavior
- Extremely Fast Swtitching
- Positive Temperature Coefficient on V_F

Benefits

- Replace Bipolar with Unipolar Rectifiers
- Essentially No Switching Losses
- Higher Efficiency
- Reduction of Heat Sink Requirements
- Parallel Devices Without Thermal Runaway

Package



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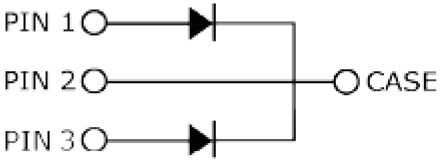

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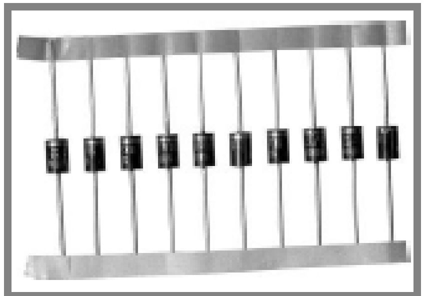
Características de diodos comerciais

SK 3 THYRISTOR BRIDGE,SCR,BRIDGE



Axial Lead Diode

V_{RSM} V	V_{RRM} V	I_{FRMS} = 6,7 A (maximum value for continuous operation) I_{FAV} = 3 A (sin. 180; T_r = 90 °C)		
1000	1000	SK 3/10		
1200	1200	SK 3/12		
1400	1400	SK 3/14		
1600	1600	SK 3/16		

Rectifier Diode

SK 3

Symbol	Conditions	Values	Units
I_{FAV}	sin. 180; L = 10 mm; T_r = 85 (100) °C	3,3 (2,7)	A
I_{FSM}	T_{vj} = 25 °C; 10 ms	180	A
	T_{vj} = 150 °C; 10 ms	150	A
i^2t	T_{vj} = 25 °C; 8,3 ... 10 ms	162	A^2s
	T_{vj} = 150 °C; 8,3 ... 10 ms	112,5	A^2s
V_F	T_{vj} = 25 °C; I_F = 10 A	max. 1,2	V
$V_{(TO)}$	T_{vj} = 150 °C	max. 0,85	V
r_T	T_{vj} = 150 °C	max. 30	mΩ
I_{RD}	T_{vj} = 150 °C; V_{RD} = V_{RRM}	max. 0,5	mA
Q_{rr}	T_{vj} = 150 °C; - di_F/dt = 10 A/µs; I_F = 10A	25	µC
$R_{th(j-r)}$	L = 10 mm	18	K/W
$R_{th(j-a)}$	PCB 50 x 50 mm	60	K/W
T_{vj}		- 40 ... + 150	°C
T_{stg}		- 40 ... + 150	°C
T_{sold}	max. 10 s; L > 9mm	250	°C
V_{isol}		-	V~
a		5 * 9,81	m/s^2
m	approx.	1	g
Case	1500 diodes per reel	E 34	

Features

- Reverse voltages up to 1600 V
- Taped for automatic insertion
- Available with formed leads on request
- Plastic material used carries Underwriter Laboratories flammability classification 94V-0

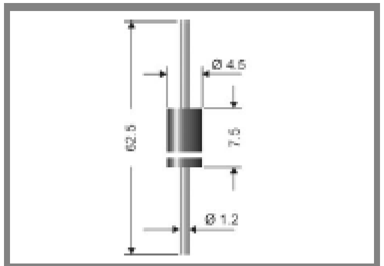
Typical Applications

- All-purpose rectifier diodes

http://www.semikron.com

Características de diodos comerciais

1N 5820...1N 5822



Axial lead diode

Type	Repetitive peak reverse voltage V_{RRM} V	Surge peak reverse voltage V_{RSM} V	Max. reverse recovery time I_F = - A I_R = - A I_{RR} = - A t_{rr} ns	Max. forward voltage V_F [2]
1N 5820	20	20	-	0,85
1N 5821	30	30	-	0,90
1N 5822	40	40	-	0,95

Schottky barrier rectifiers diodes

1N 5820...1N 5822

Forward Current: 3 A

Reverse Voltage: 20 to 40 V

Absolute Maximum Ratings T_A = 25 °C, unless otherwise specified

Symbol	Conditions	Values	Units
I_{FAV}	Max. averaged fwd. current, R-load, T_A = 50 °C [1]	3	A
I_{FRM}	Repetitive peak forward current f > 15 Hz [1]	15	A
I_{FSM}	Peak forward surge current 50 Hz half sinus-wave [3]	100	A
i^2t	Rating for fusing, t < 10 ms [3]	110	A^2s
R_{thA}	Max. thermal resistance junction to ambient [1]	25	K/W
R_{thT}	Max. thermal resistance junction to terminals [1]	8	K/W
T_j	Operating junction temperature	-50...+150	°C
T_s	Storage temperature	-50...+175	°C

Features

- Max. solder temperature: 260°C
- Plastic material has UL classification 94V-0

Mechanical Data

- Plastic case DO-201
- Weight approx.: 1 g
- Terminals: plated terminals solderable per MIL-STD-750
- Mounting position: any
- Standard packaging: 1700 pieces per ammo

Characteristics T_A = 25 °C, unless otherwise specified

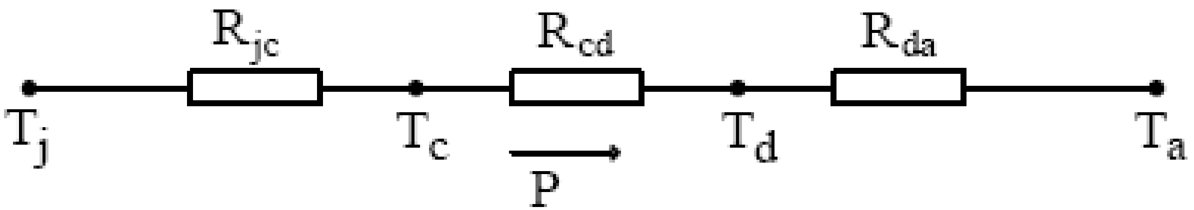
Symbol	Conditions	Values	Units
I_R	Maximum leakage current, T_j = 25 °C; $V_R = V_{RRM}$	<2	mA
	T_j = 100 °C; $V_R = V_{RRM}$	<20	mA
C_J	Typical junction capacitance (at MHz and applied reverse voltage of V)	-	pF
Q_{rr}	Reverse recovery charge (U_R = V; I_F = A; dI_F/dt = A/ms)	-	µC
E_{RSM}	Non repetitive peak reverse avalanche energy (I_R = mA; T_j = °C; inductive load switched off)	-	mJ

http://www.semikron.com

Cálculo térmico

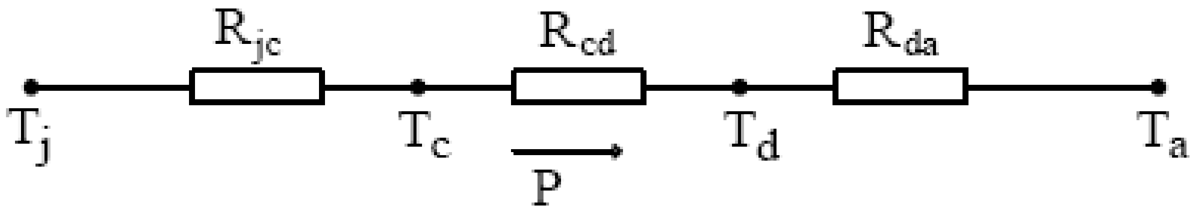
Cálculo térmico:

- Objetivo de verificar a necessidade de uso de dissipador de calor ou não.
- Modelo térmico:



- T_j = temperatura na junção (^oC);
- T_c = temperatura na cápsula (^oC);
- T_d = temperatura no dissipador (^oC);
- T_a = temperatura ambiente (^oC);
- R_{jc} = resistência térmica entre junção e cápsula ($^oC/W$);
- R_{cd} = resistência térmica entre cápsula e dissipador ($^oC/W$);
- R_{da} = resistência térmica entre dissipador e ambiente ($^oC/W$);
- P = potência dissipada no componente (W).

Cálculo térmico



$$R_{ja} = R_{jc} + R_{cd} + R_{da}$$

$$T_j - T_a = R_{ja} \cdot P \quad \Rightarrow \quad R_{ja} = \frac{T_j - T_a}{P}$$

$$R_{da} = R_{ja} - R_{jc} - R_{cd}$$

Cálculo térmico

Exemplo:

- Determinar o dissipador necessário:
  - Diodo MSR15660;
  - Corrente média = eficaz = 10 A;
  - Temperatura ambiente de 35 ^{o}C;
  - Considerar R_{cd} = 1 ^{o}C/W;
  - Considerar apenas as perdas por condução.

Próxima aula

Conversores CA-CC:

1. Retificadores monofásicos não-controlados.