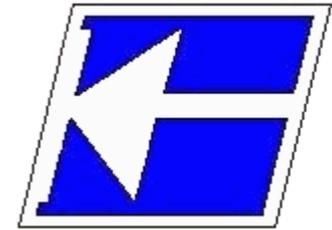


Instituto Federal de Educação, Ciência e Tecnologia de Santa Catarina

Departamento Acadêmico de Eletrônica

Eletrônica de Potência



Semicondutores de Potência

Diodos e Tiristores

Prof. Clovis Antonio Petry.

Florianópolis, agosto de 2018.

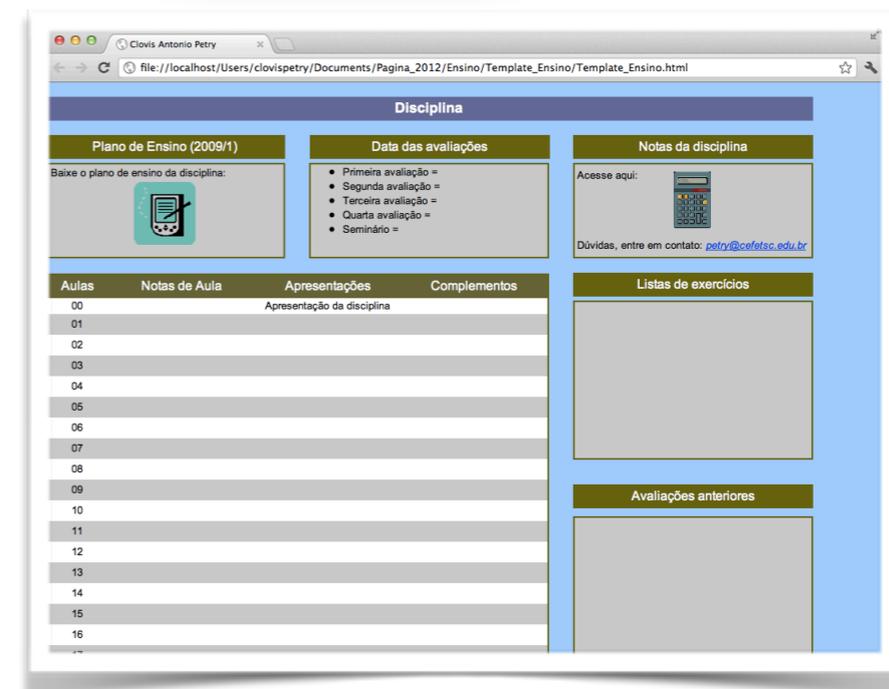
Biografia para Esta Aula

Capítulos 2 e 4:

- Diodos de potência;
- Dispositivos tiristores.

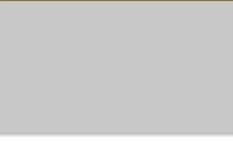


www.ProfessorPetry.com.br



A screenshot of a web browser displaying a course page. The browser address bar shows the URL: file:///localhost/Users/clovispetry/Documents/Pagina_2012/Ensino/Template_Ensino/Template_Ensino.html. The page title is 'Disciplina'. The content is organized into several sections:

- 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
- Table with 4 columns: Aulas, Notas de Aula, Apresentações, Complementos**:

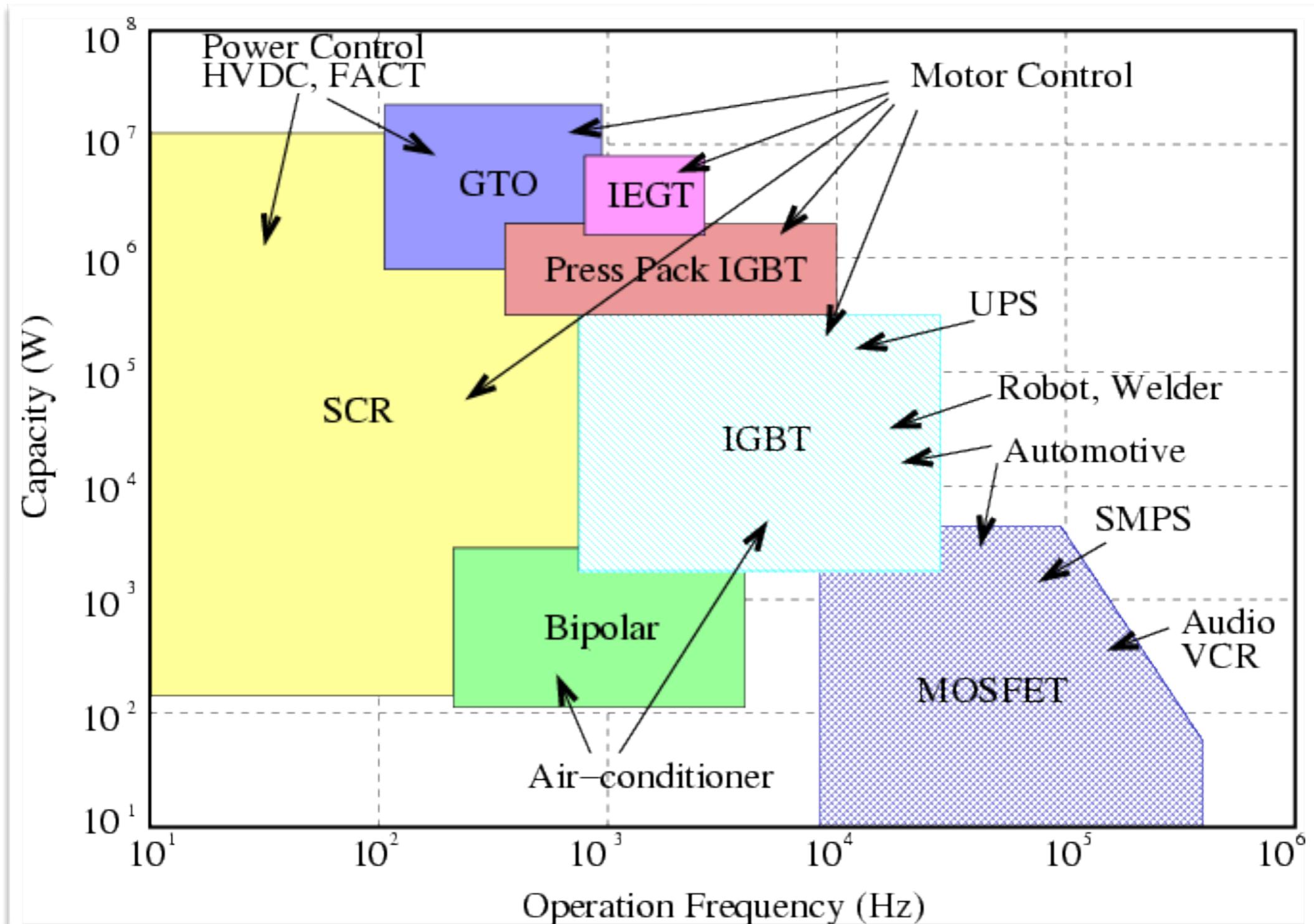
Aulas	Notas de Aula	Apresentações	Complementos
00		Apresentação da disciplina	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
- Listas de exercícios**: 
- Avaliações anteriores**: 

Semicondutores de potência:

- Semicondutores para eletrônica de potência;
- Diodos ideais;
- Diodos reais;
- Comutação de diodos;
- Perdas em diodos;
- Características importantes de diodos;
- Tiristores;
- Tiristores ideais e reais;
- Comutação de tiristores;
- Perdas nos tiristores;
- Características importantes de tiristores;
- Acionamento de tiristores.

Semicondutores de Potência

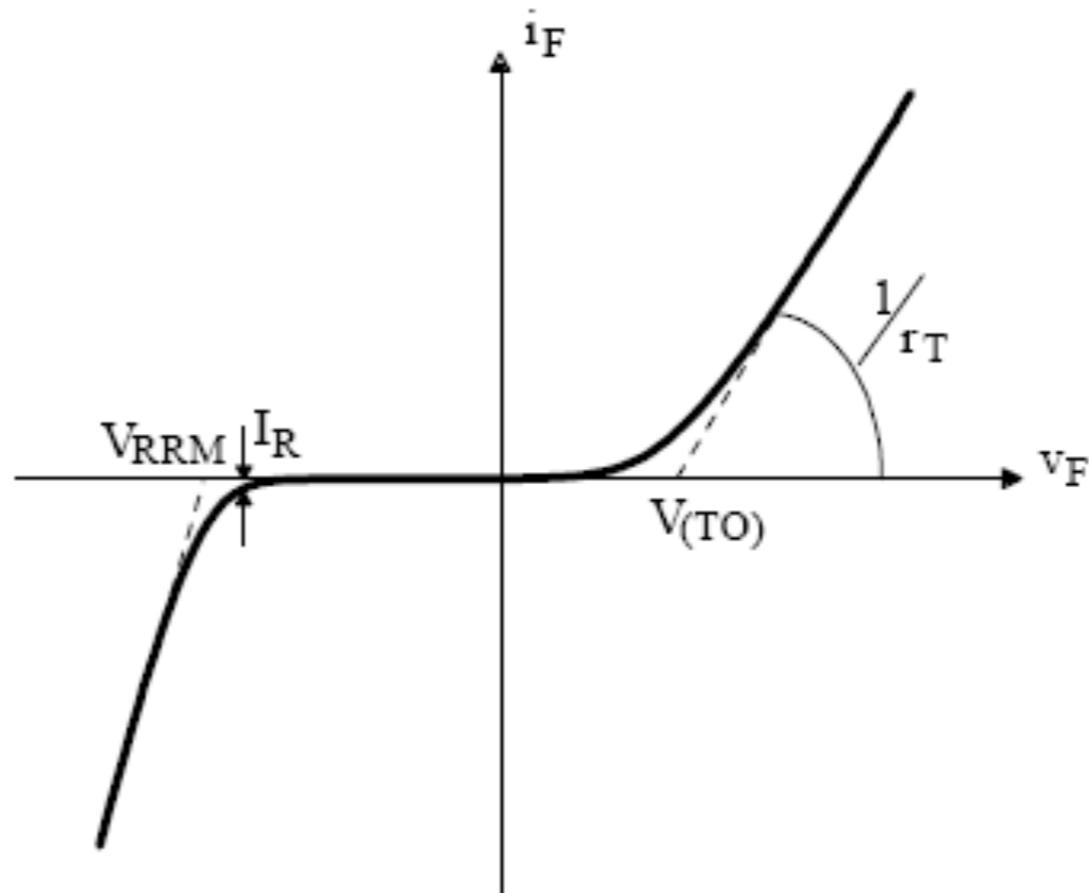
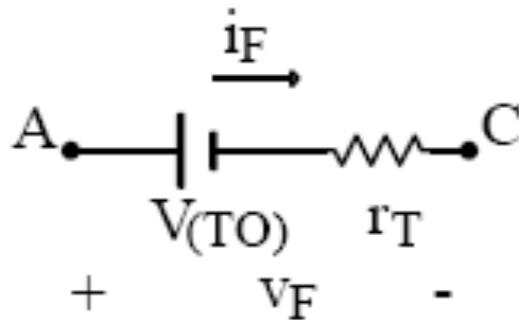
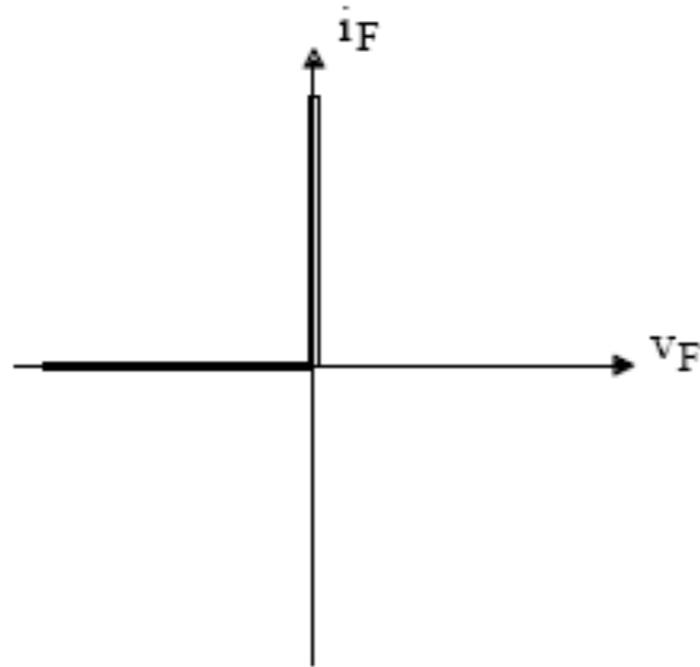
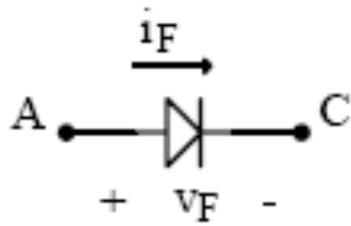
Semicondutores aplicados à eletrônica de potência:



Diodo Ideal x Diodo Real

Exemplo: Diodo SKN20/08

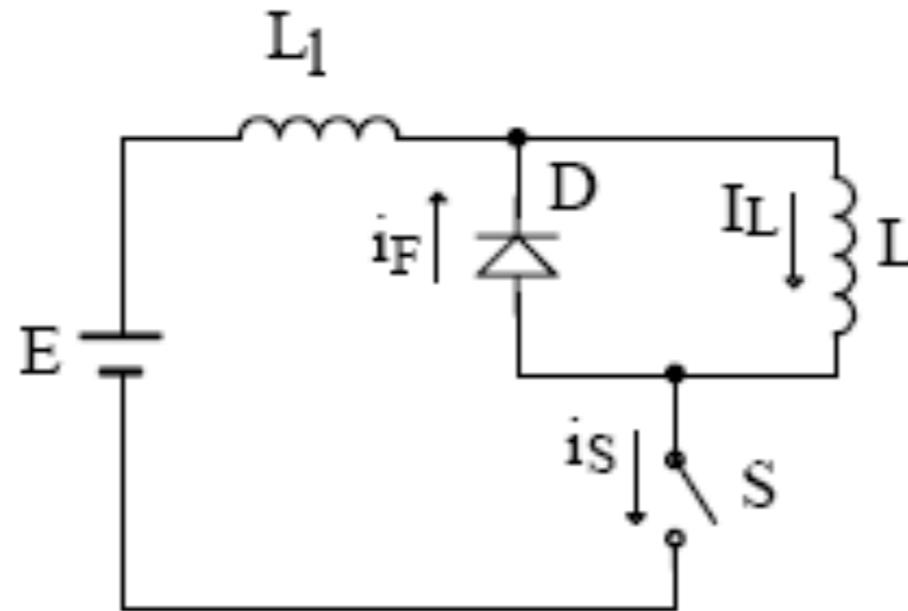
- $V_{RRM} = 800 \text{ V}$;
- $V_{(TO)} = 0,85 \text{ V}$;
- $r_T = 11 \text{ m}\Omega$;
- $I_{Dmed} = 20 \text{ A}$;
- $I_R = 0,15 \text{ mA}$.



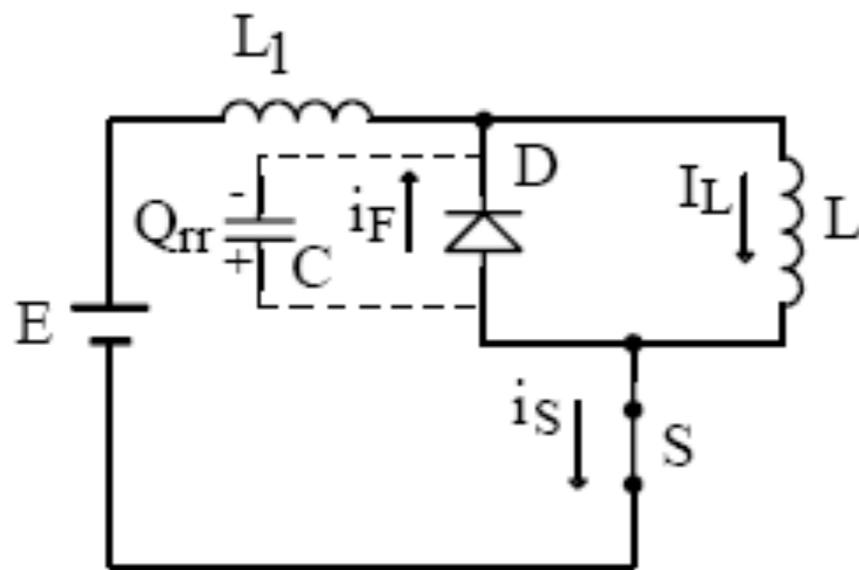
Característica estática

Comutação de Diodos

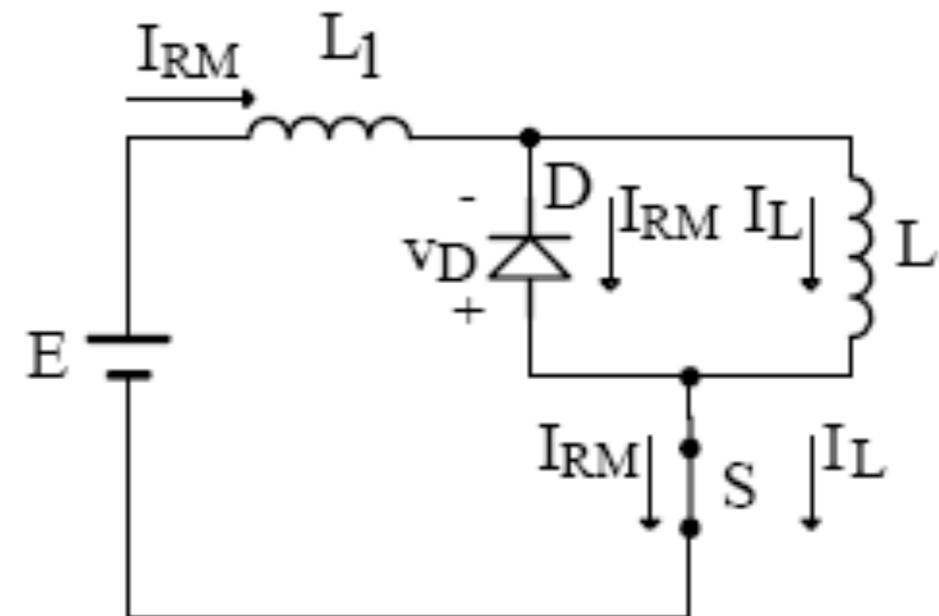
Bloqueio:



Circuito para estudo da comutação



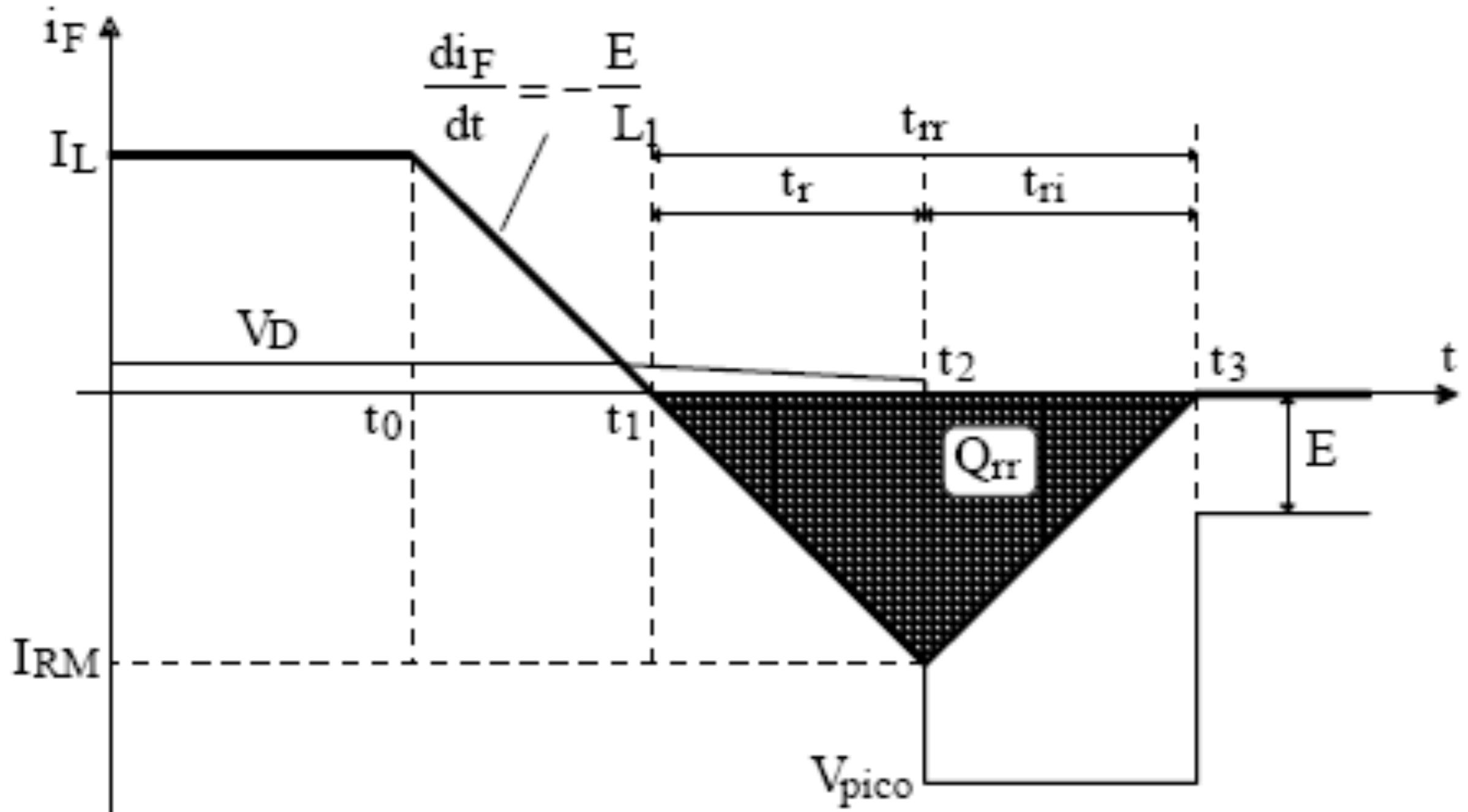
Primeira etapa de comutação



Segunda etapa de comutação

Comutação de Diodos

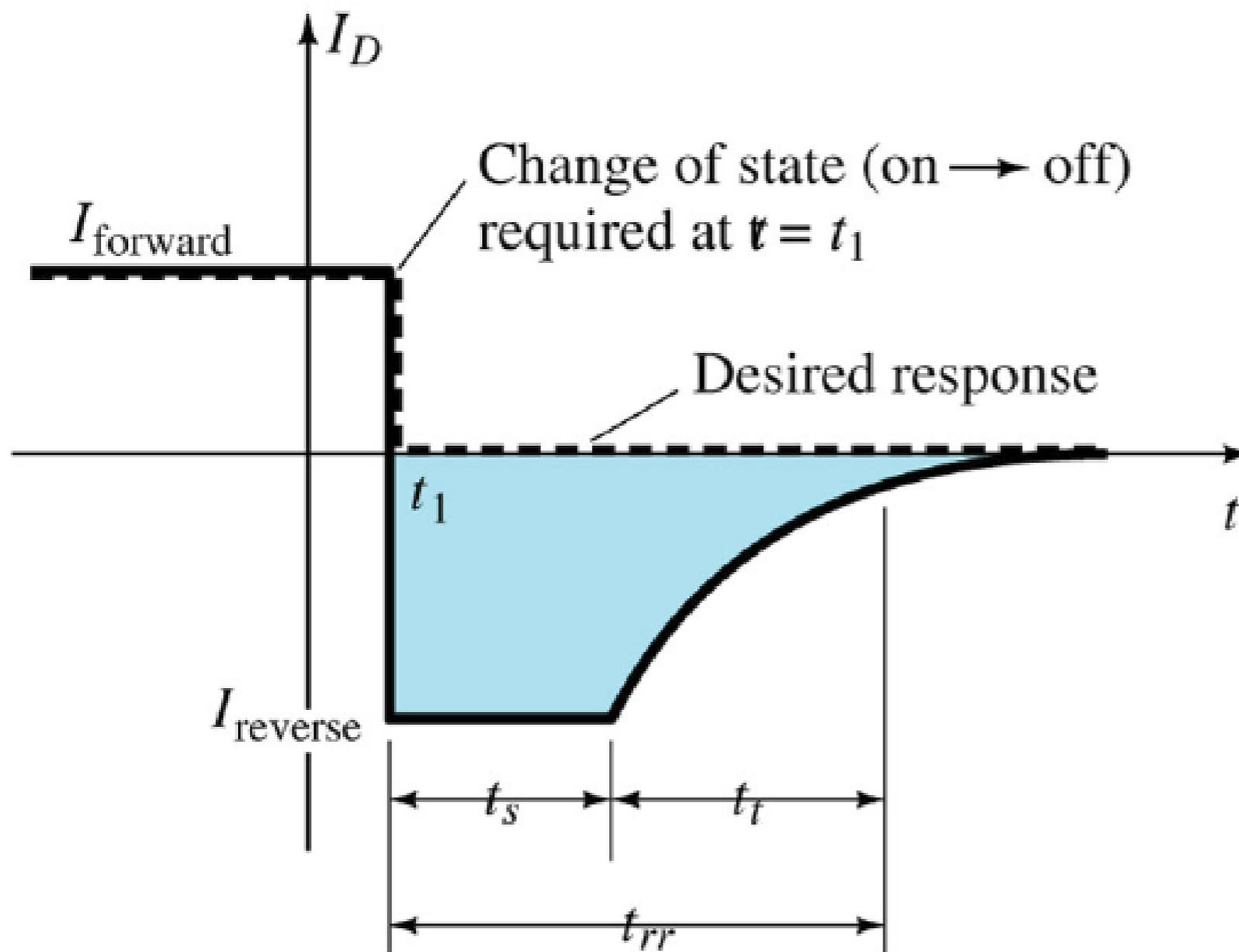
Bloqueio:



Comutação de Diodos

Diodos de carbeto de silício (silicon carbide):

- Diminuem acentuadamente o fenômeno da recuperação reversa.



www.infineon.com

www.cree.com

Comutação de Diodos

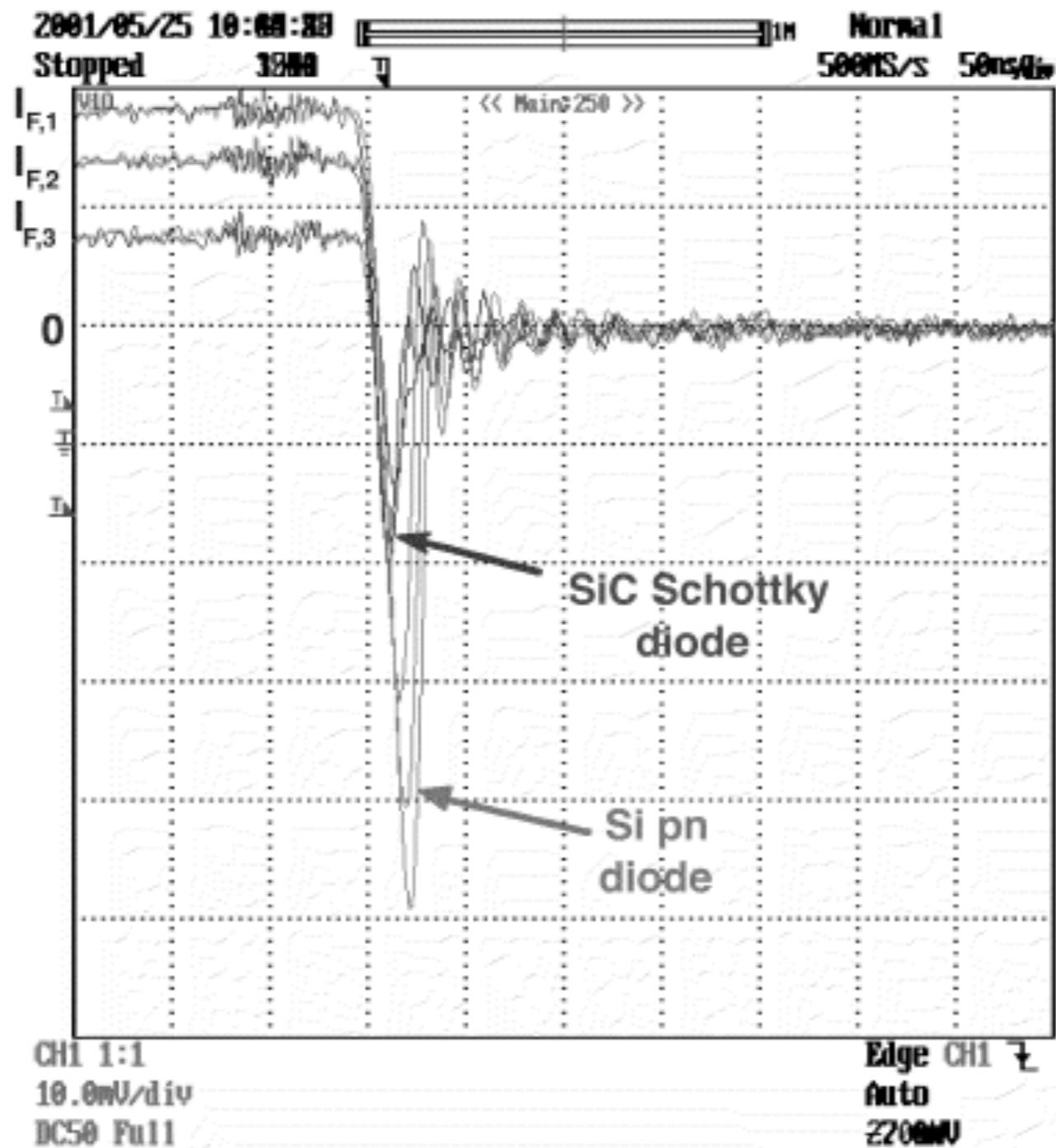


Fig. 5. Typical reverse recovery waveforms of the Si pn and SiC Schottky diode for three different forward currents (2 A/div.).

Comutação de Diodos

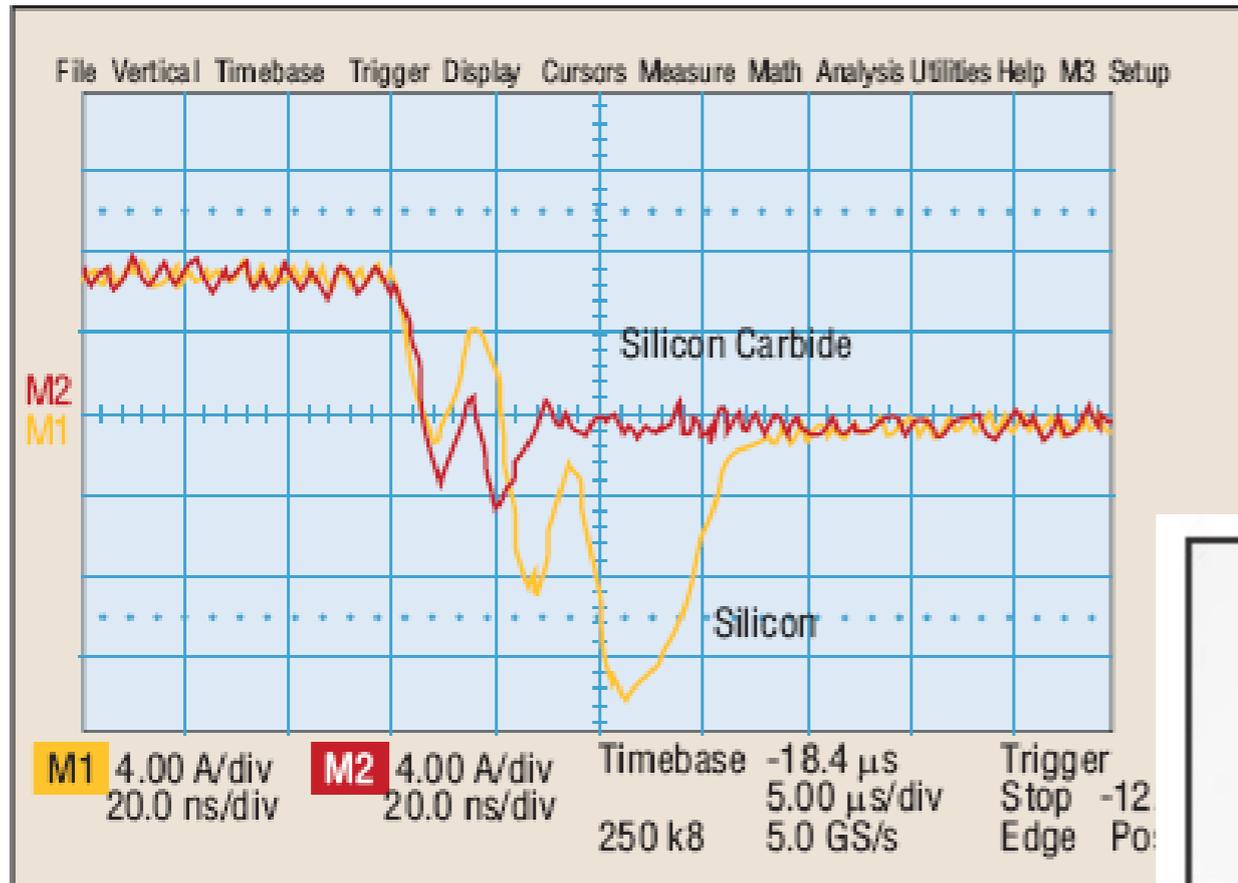


Fig. 4. Low-line diode recovery currents in PFC front-end converter

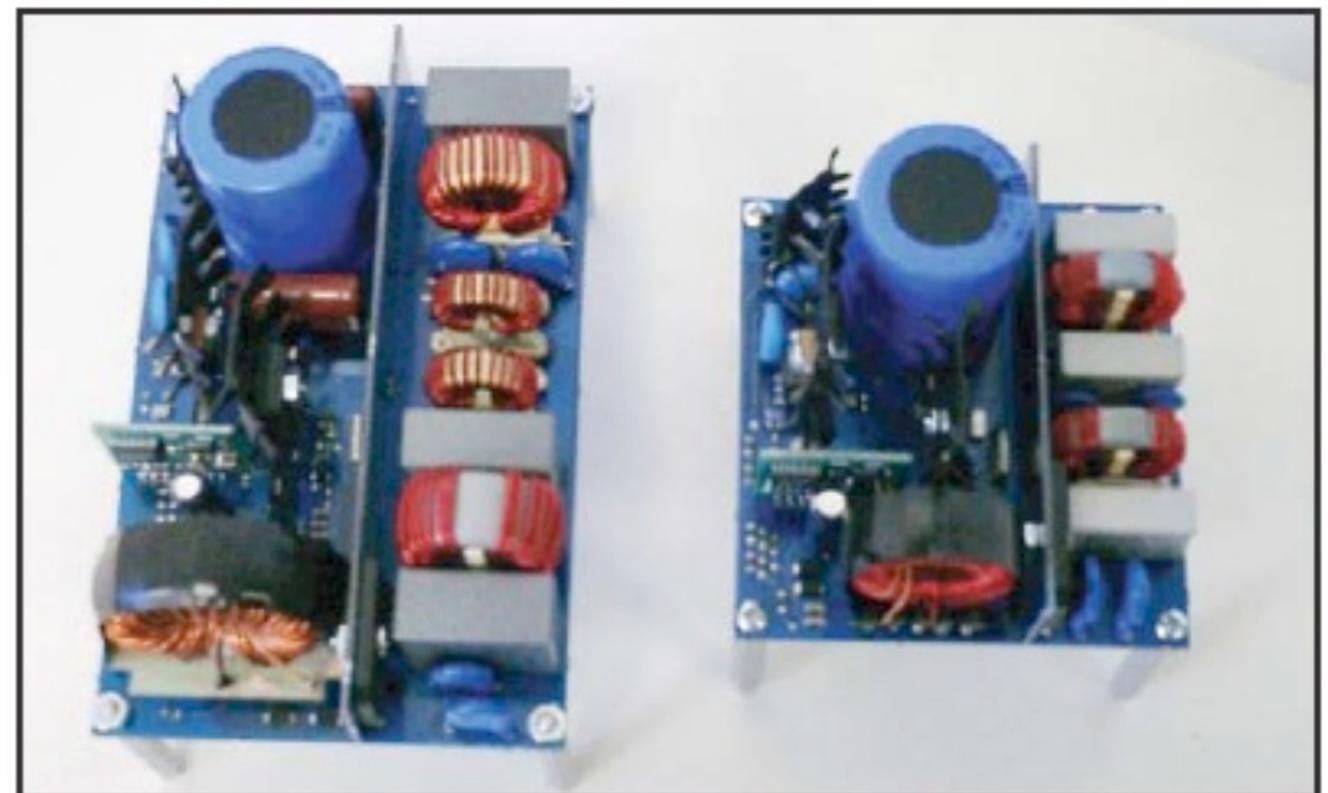


Fig. 8. A size comparison of an 80-kHz PFC front-end built with Si rectifiers (left) and a 200-kHz PFC front-end with SiC rectifiers.

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;

Por simulação

- Bloqueio.

Por simulação

Características de Diodos Comerciais

Principais características:

- Tensão de pico reversa;
- Queda de tensão direta;
- Corrente de pico;
- Corrente média;
- Corrente eficaz;
- Tempo de recuperação reversa.

MURD320

THERMAL CHARACTERISTICS

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

ELECTRICAL CHARACTERISTICS

Maximum Instantaneous Forward Voltage Drop (Note 2) ($i_F = 3$ Amps, $T_J = 25^{\circ}C$) ($i_F = 3$ Amps, $T_J = 125^{\circ}C$)	V_F	0.95 0.75	Volts
Maximum Instantaneous Reverse Current (Note 2) ($T_J = 25^{\circ}C$, Rated dc Voltage) ($T_J = 125^{\circ}C$, 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, $T_J = 25^{\circ}C$) ($I_F = 0.5$ Amp, $i_R = 1$ Amp, $I_{REC} = 0.25$ A, $V_R = 30$ V, $T_J = 25^{\circ}C$)	t_{rr}	35 25	ns

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 , $T_C = 158^{\circ}C$)	$I_{F(AV)}$	3.0	A
Peak Repetitive Forward Current (Rated V_R , Square Wave, 20 kHz, $T_C = 158^{\circ}C$)	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	$^{\circ}C$

Características de Diodos Comerciais

Tipos de diodos:

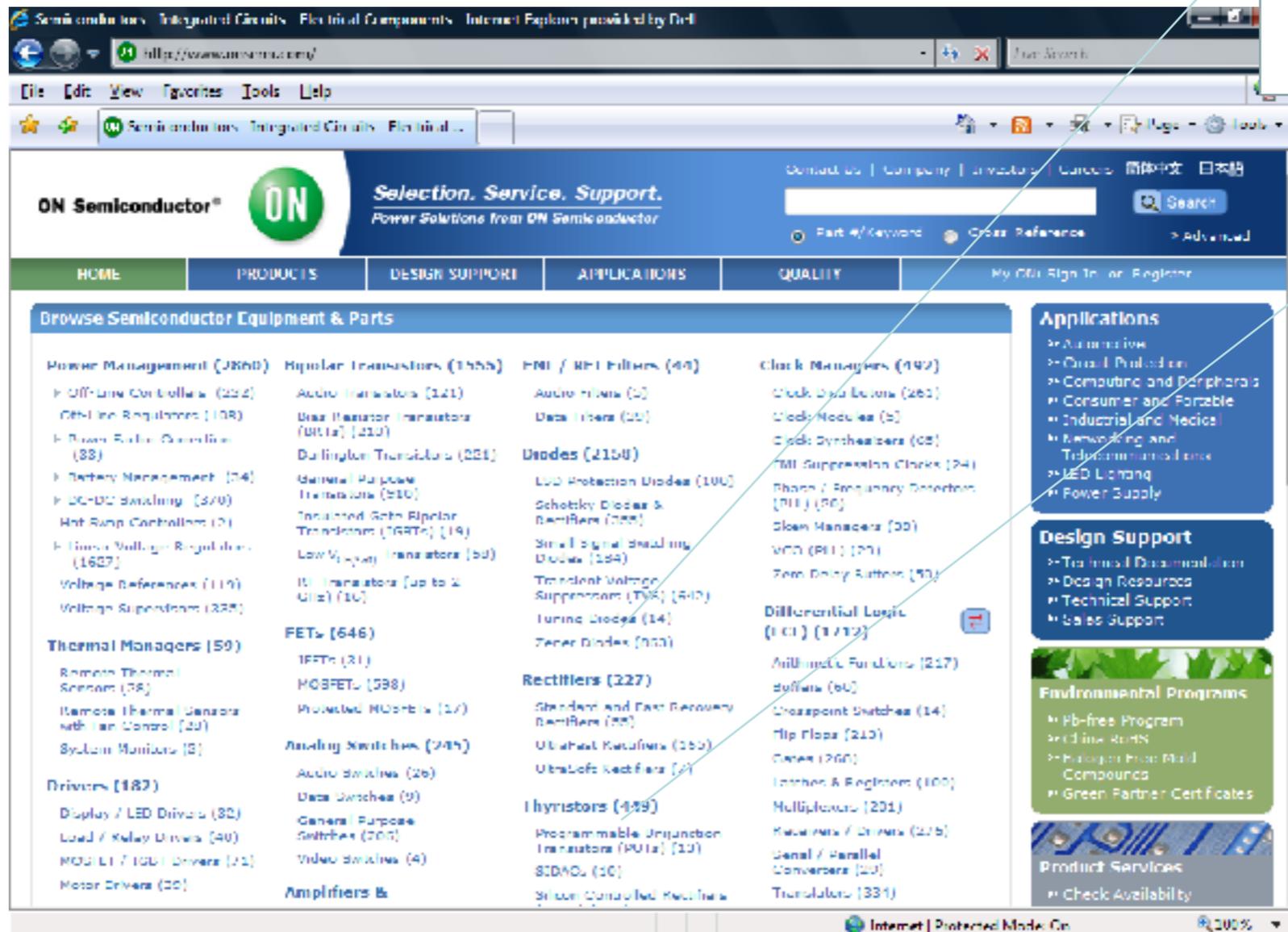
1. Standard and fast recovery;
2. Ultrafast rectifiers;
3. Ultrafast rectifiers;
4. Silicon carbide (zero recovery).

Rectifiers (227)

Standard and Fast Recovery Rectifiers (55)

UltraFast Rectifiers (165)

UltraSoft Rectifiers (7)



The screenshot shows the ON Semiconductor website interface. The main navigation bar includes 'HOME', 'PRODUCTS', 'DESIGN SUPPORT', 'APPLICATIONS', and 'QUALITY'. Below this, there's a 'Browse Semiconductor Equipment & Parts' section with a grid of product categories. The 'Rectifiers (227)' category is highlighted with a red box and an arrow pointing to the summary box on the right. Other categories visible include Power Management (2860), Bipolar Transistors (1555), FMI / RFI Filters (40), Clock Managers (197), Thermal Managers (59), Drivers (187), Amplifiers & (partially visible), Audio Transistors (121), Dual Transistor Transistors (BICM) (210), Darlingtons Transistors (221), General Purpose Transistors (GPT) (210), Transistors with Bipolar Transistors (TGBTs) (19), Low Voltage Transistors (20), IGBT Transistors (up to 2 GHz) (10), FETs (546), IGBTs (21), MOSFETs (598), Protected MOSFETs (17), Analog Switches (245), Audio Switches (26), Data Switches (9), General Purpose Switches (200), Video Switches (4), and Amplifiers & (partially visible).



C2D20120D–Silicon Carbide Schottky Diode *ZERO RECOVERY*[®] RECTIFIER

$$V_{RRM} = 1200 \text{ V}$$

$$I_F = 20 \text{ A}$$

$$Q_c = 122 \text{ nC}$$

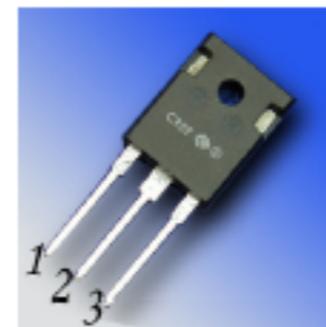
Features

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

Benefits

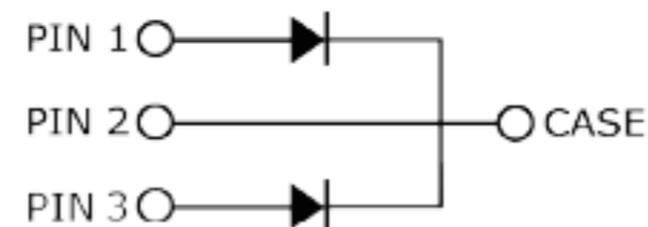
- Replace Bipolar with Unipolar Rectifiers
- Essentially No Switching Losses
- Higher Efficiency
- Reduction of Heat Sink Requirements
- Parallel Devices Without Thermal Runaway

Package



TO-247-3

www.cree.com



Características de Diodos Comerciais

Demonstração

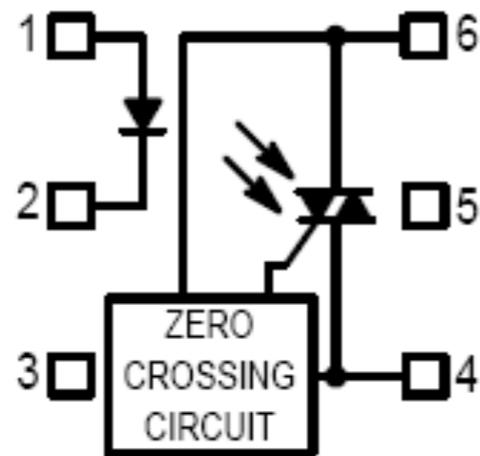
Demo

- Testes de diodos com multímetro.

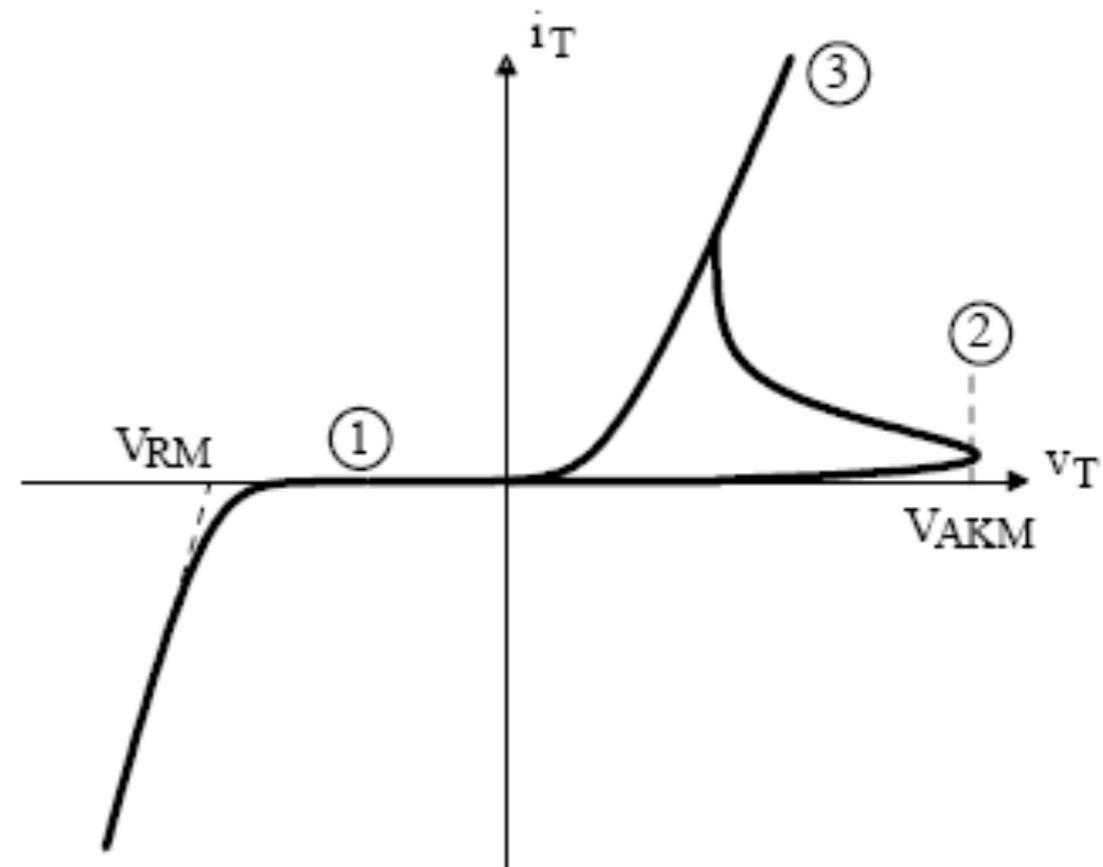
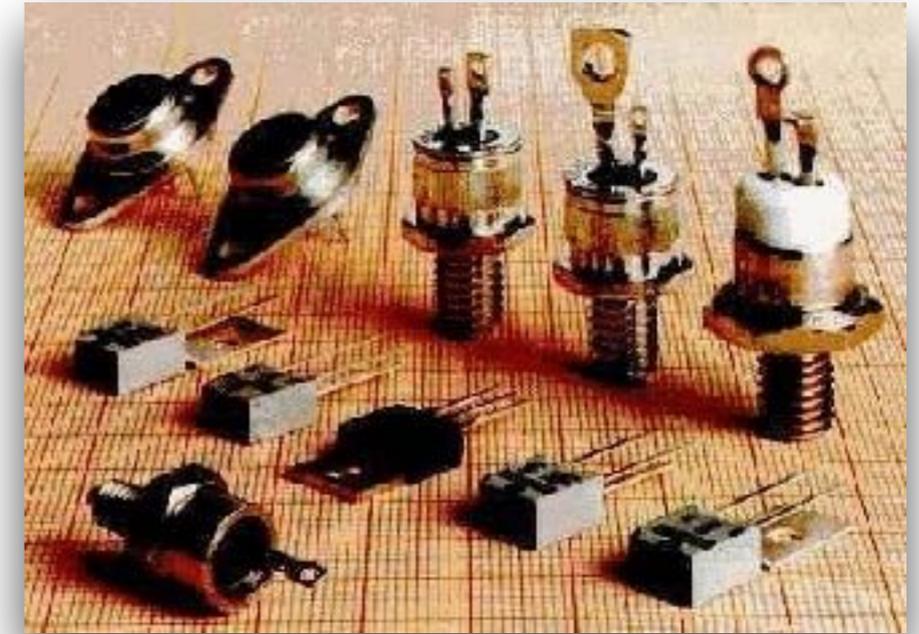


Tiristores

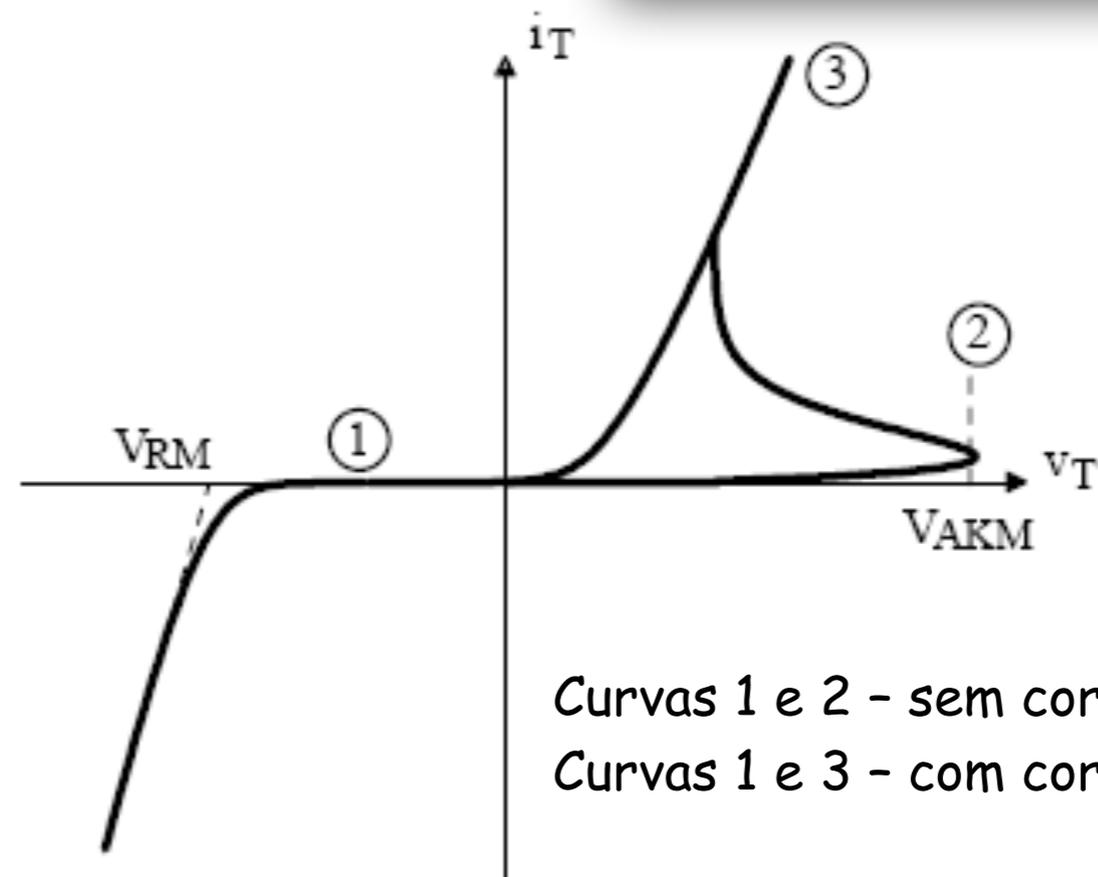
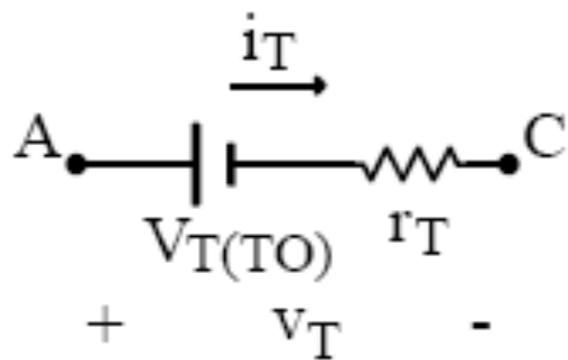
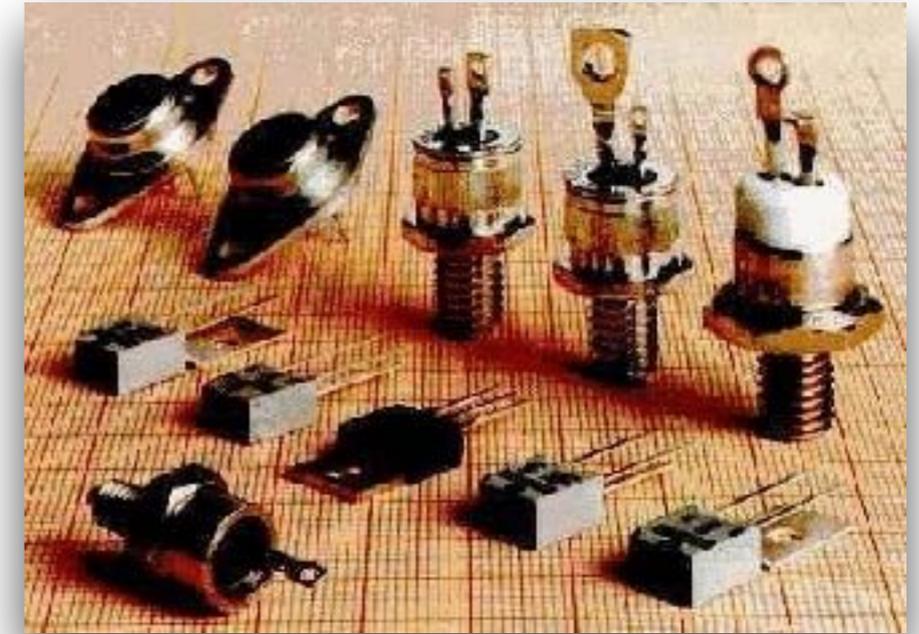
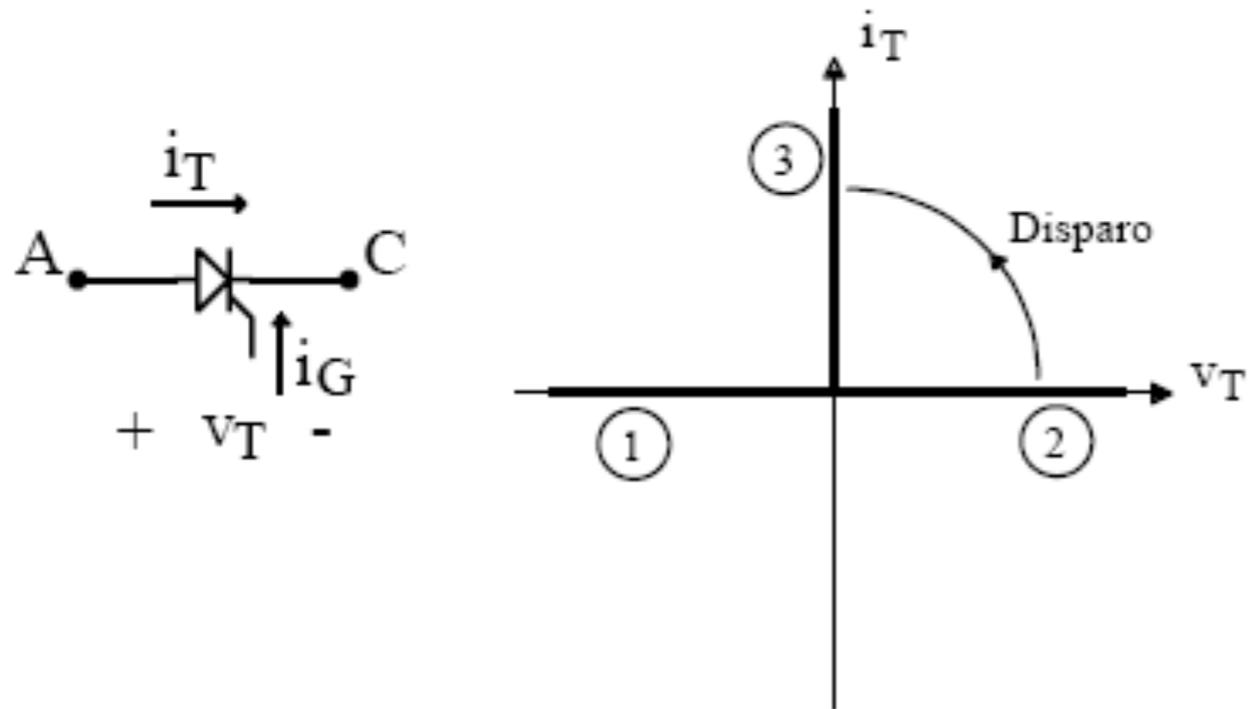
COUPLER SCHEMATIC



1. ANODE
2. CATHODE
3. NC
4. MAIN TERMINAL
5. SUBSTRATE
DO NOT CONNECT
6. MAIN TERMINAL



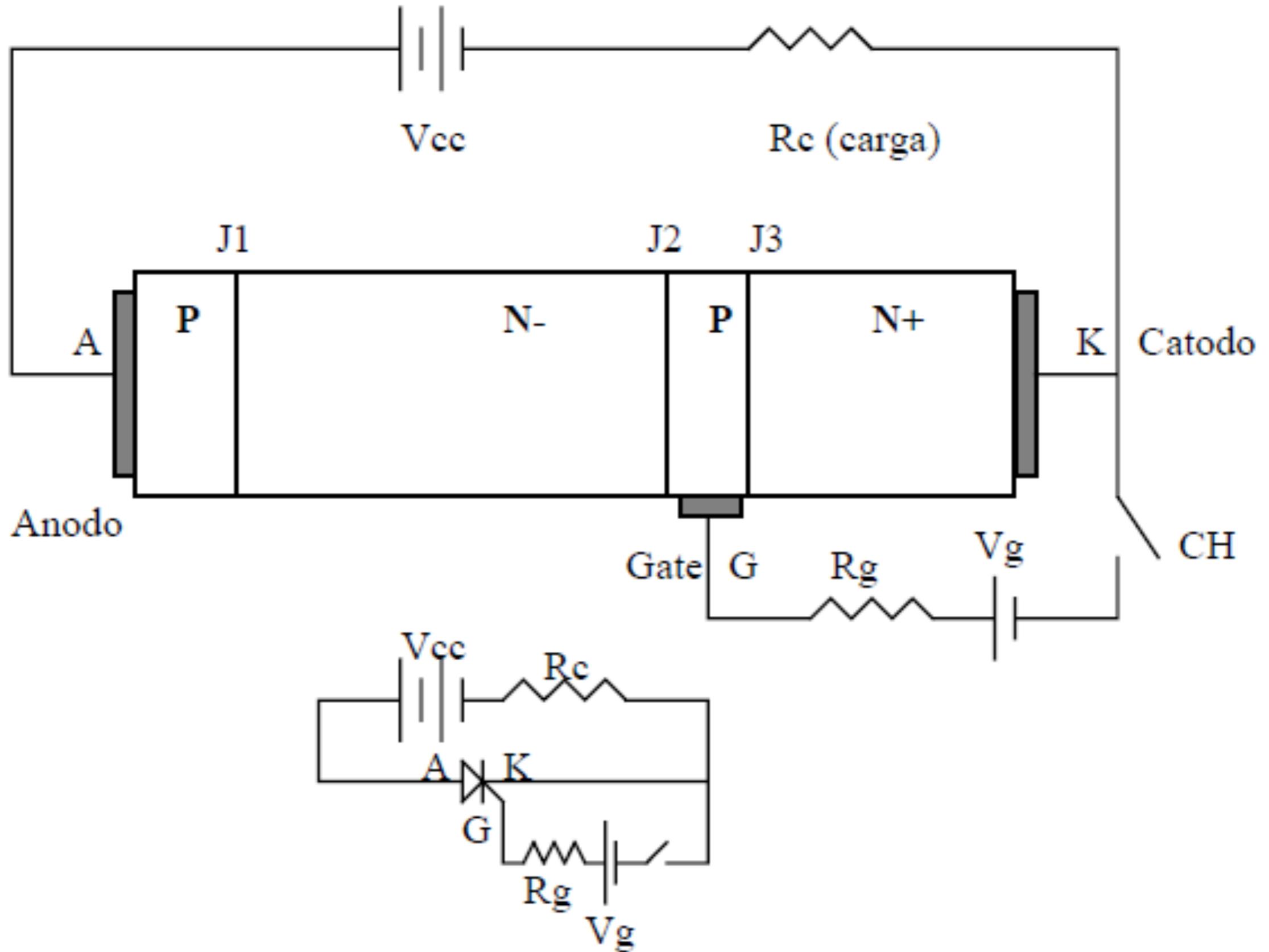
Tiristor Ideal e Tiristor Real



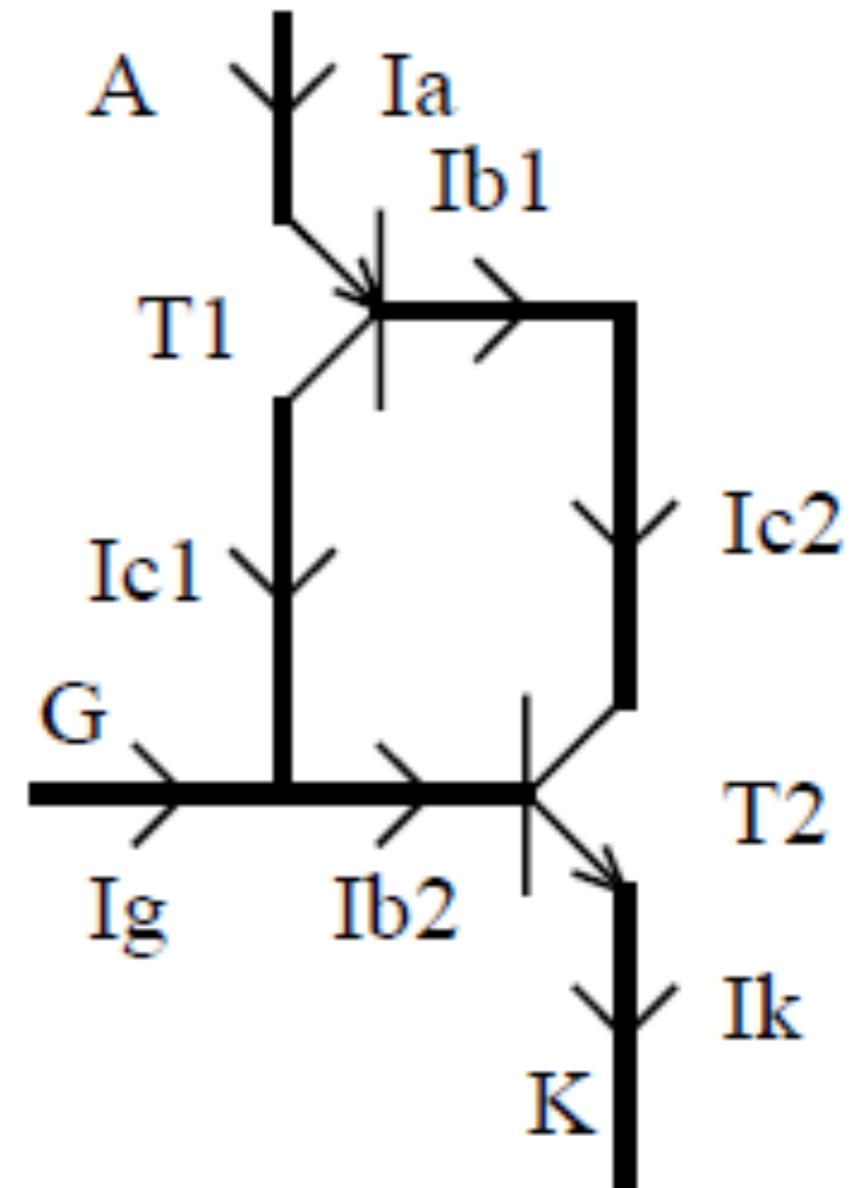
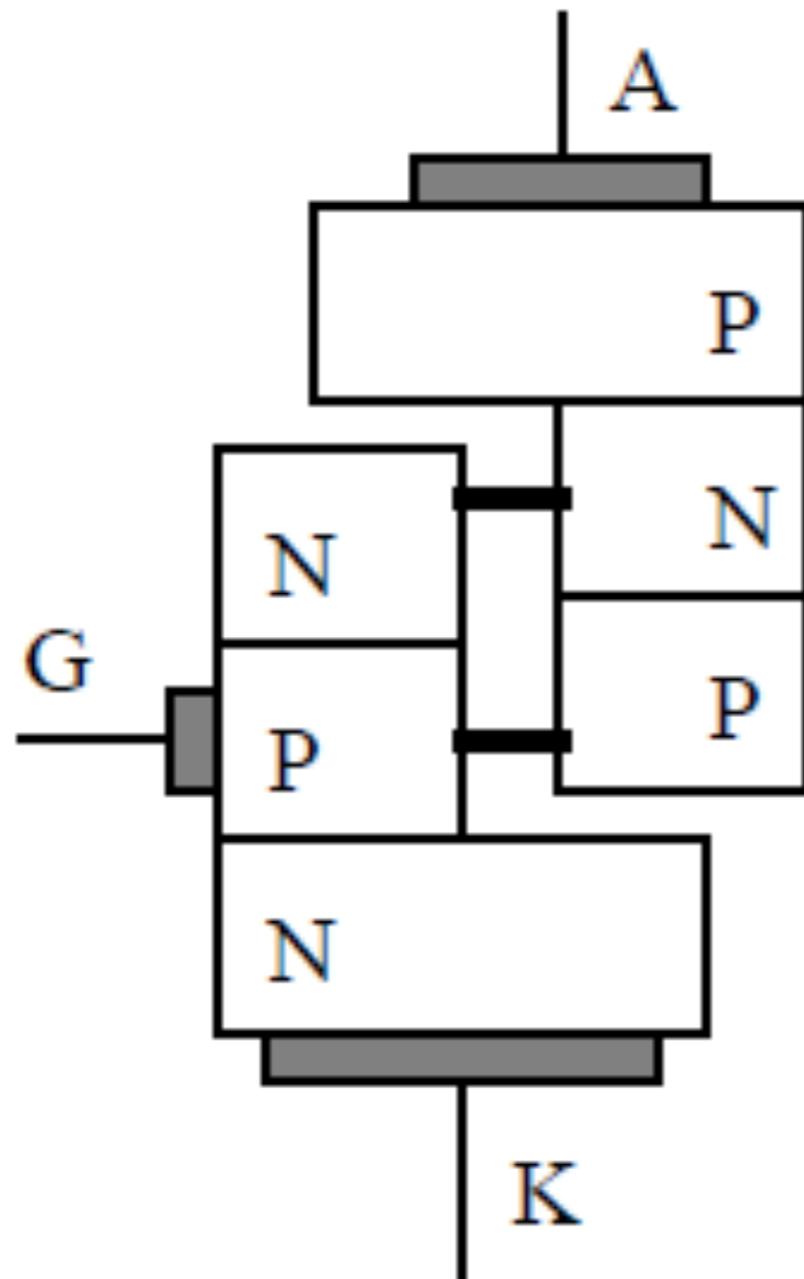
Curvas 1 e 2 - sem corrente de gatilho
Curvas 1 e 3 - com corrente de gatilho

Característica estática

Funcionamento do Tiristor

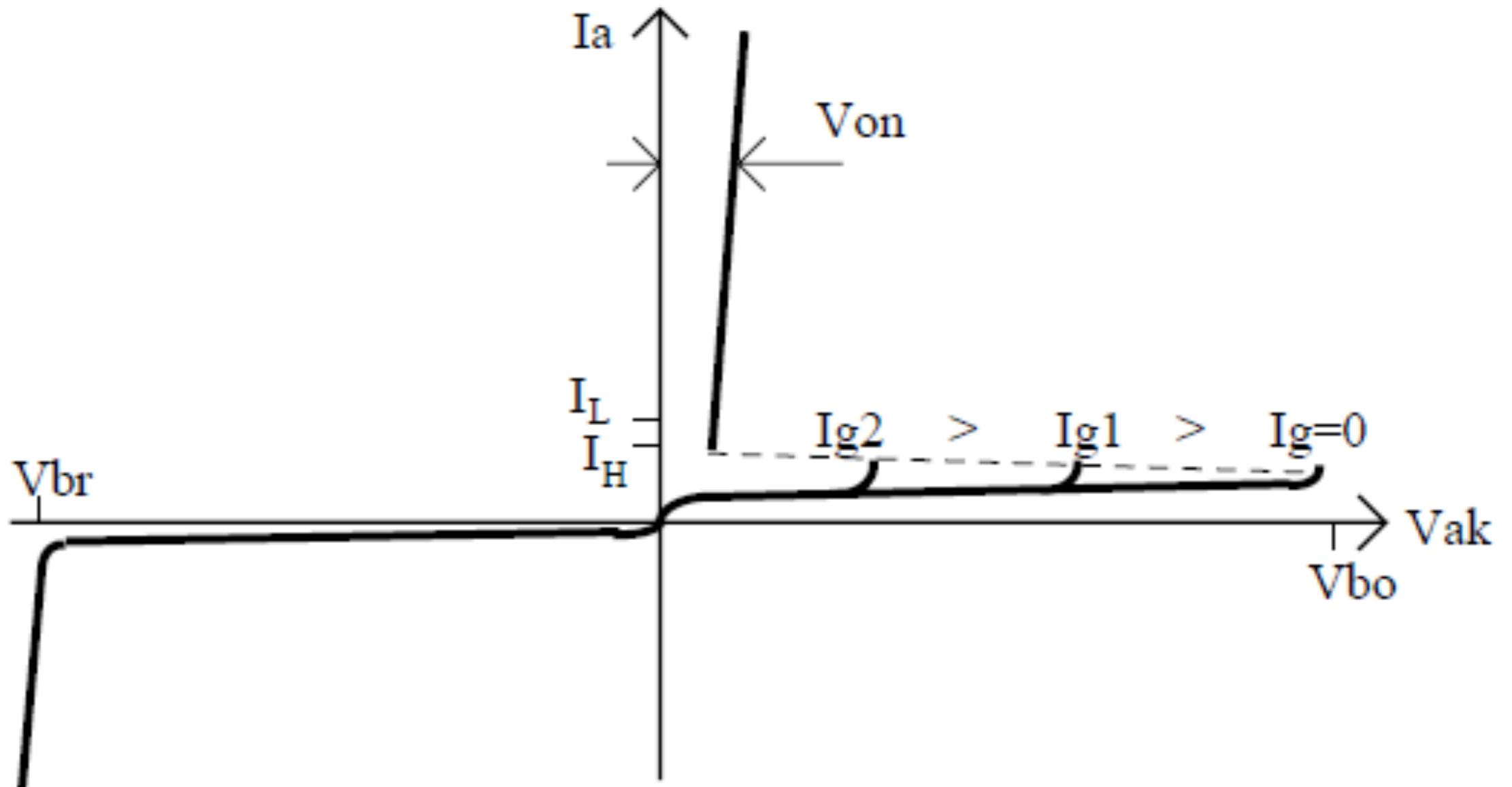


Funcionamento do Tiristor



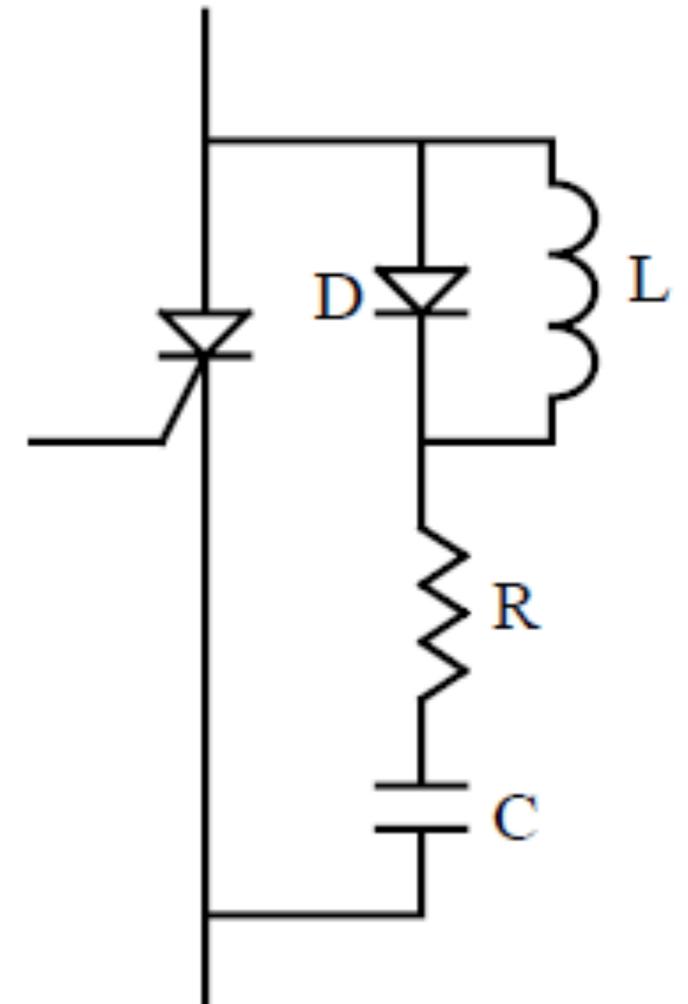
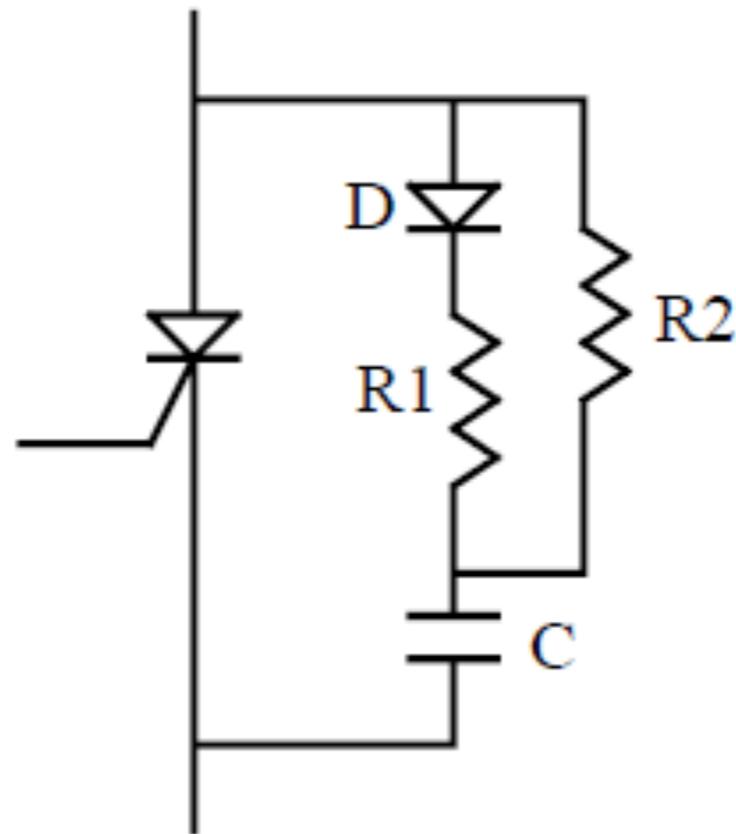
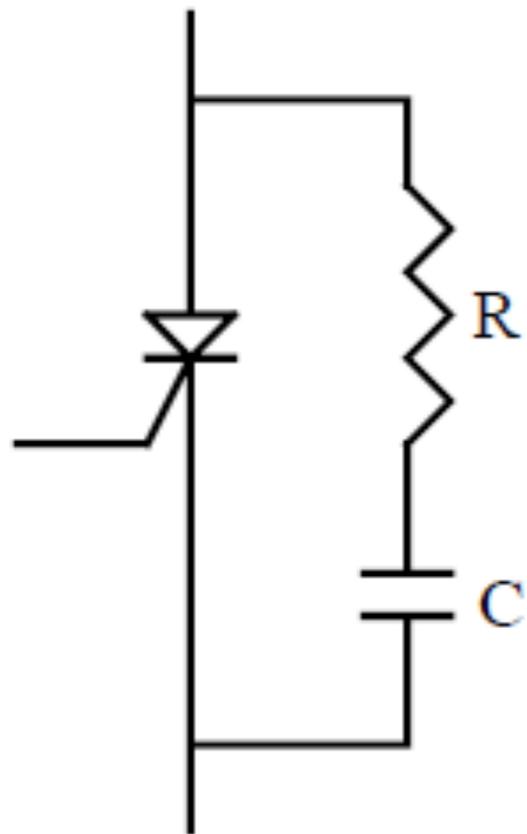
Estrutura interna e analogia com BJT

Funcionamento do Tiristor



Curva característica $V \times I$

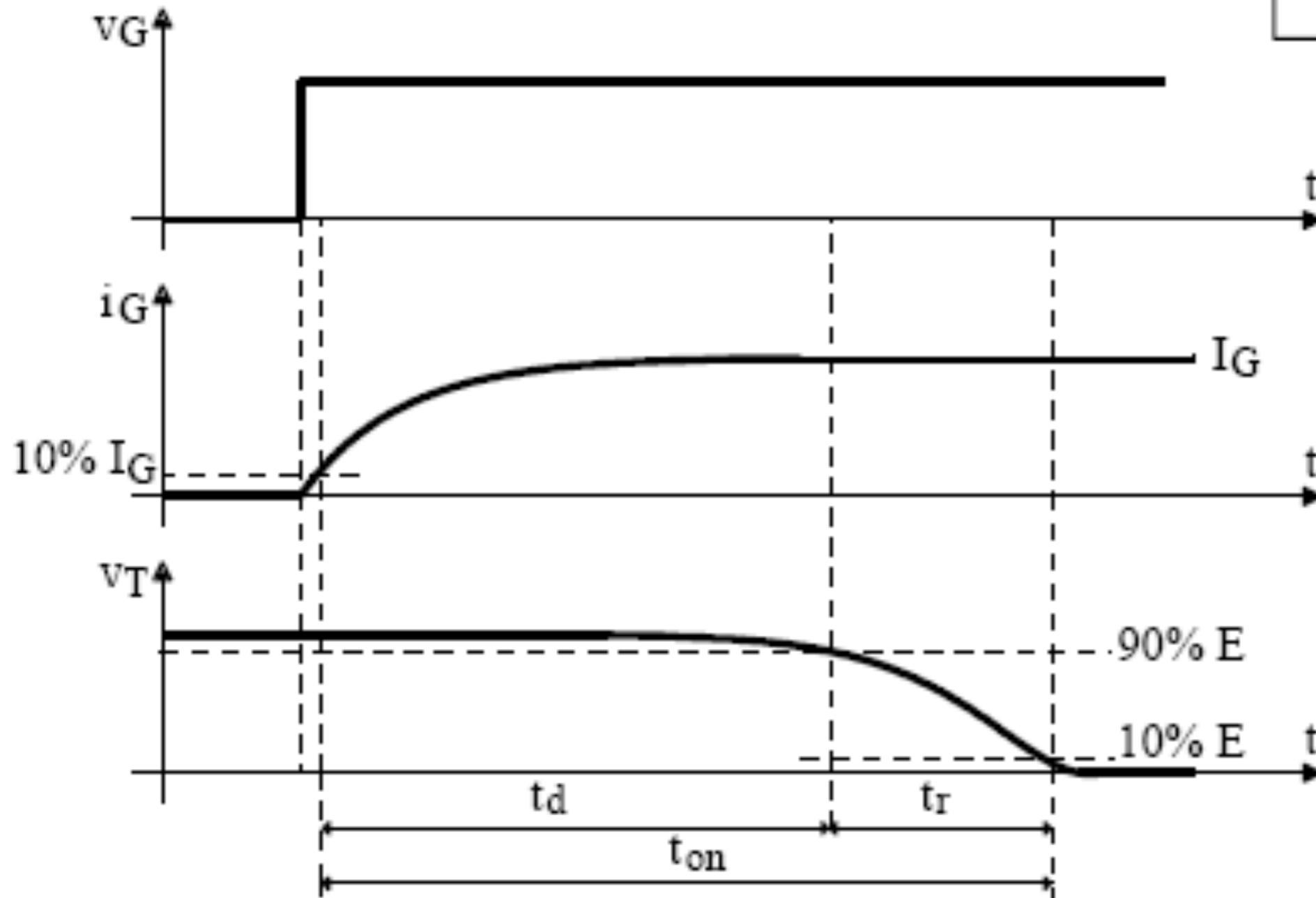
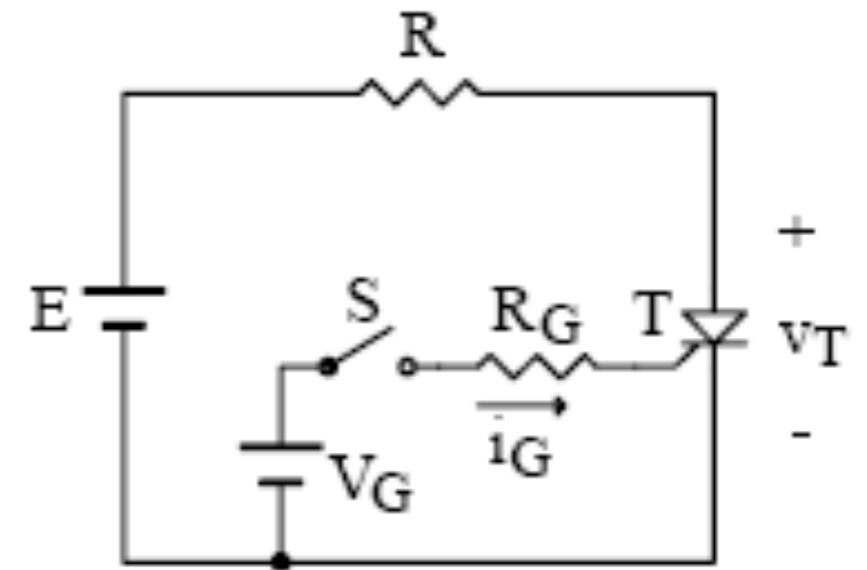
Funcionamento do Tiristor



Circuitos para auxiliar na proteção de tiristores e evitar disparos intempestivos

Comutação de Tiristores

Disparo:

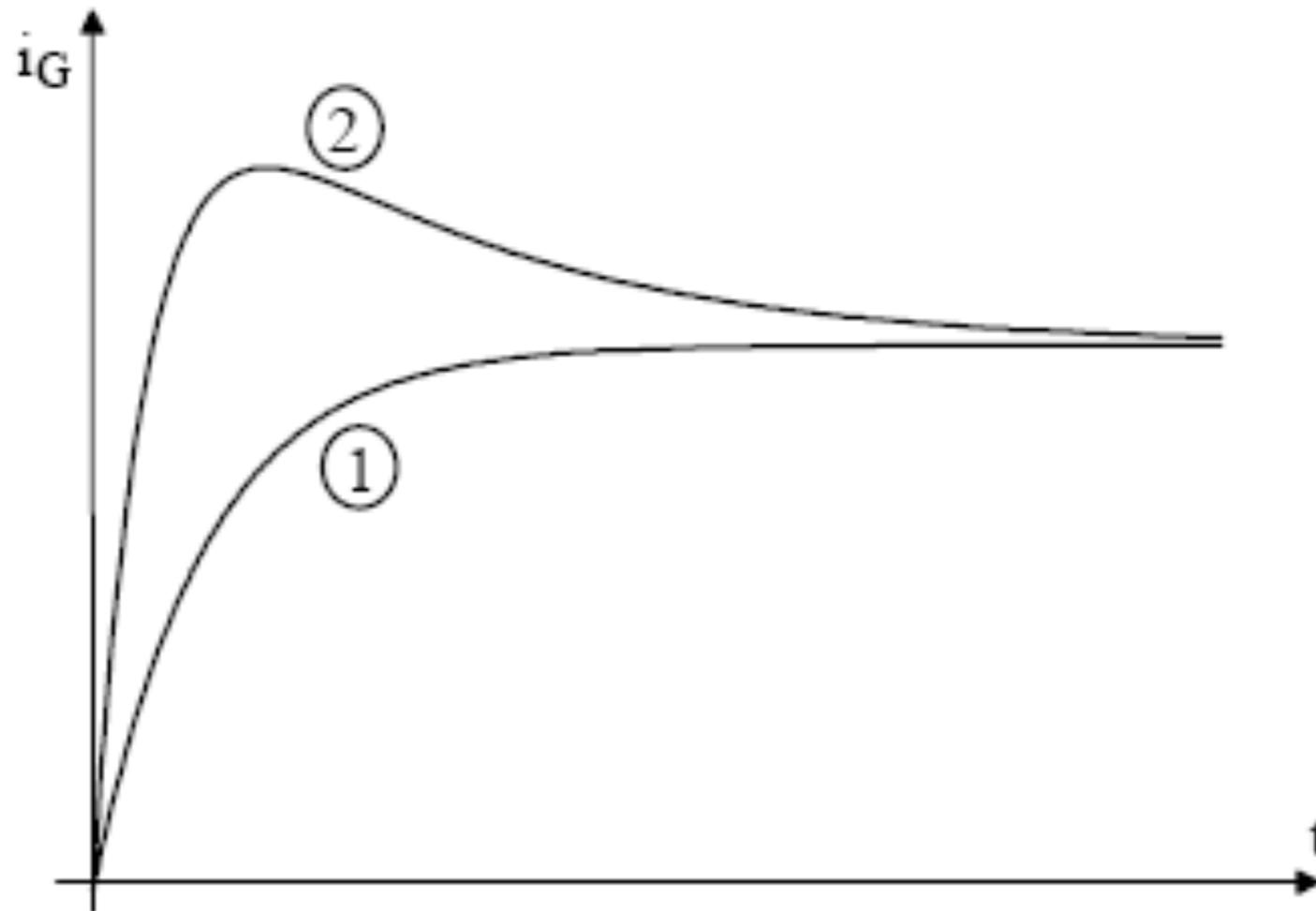


Comutação de Tiristores

Disparo:

- t_{on} - tempo de fechamento;
- t_d - tempo de retardo;
- t_r - tempo de descida da tensão anodo-catodo.

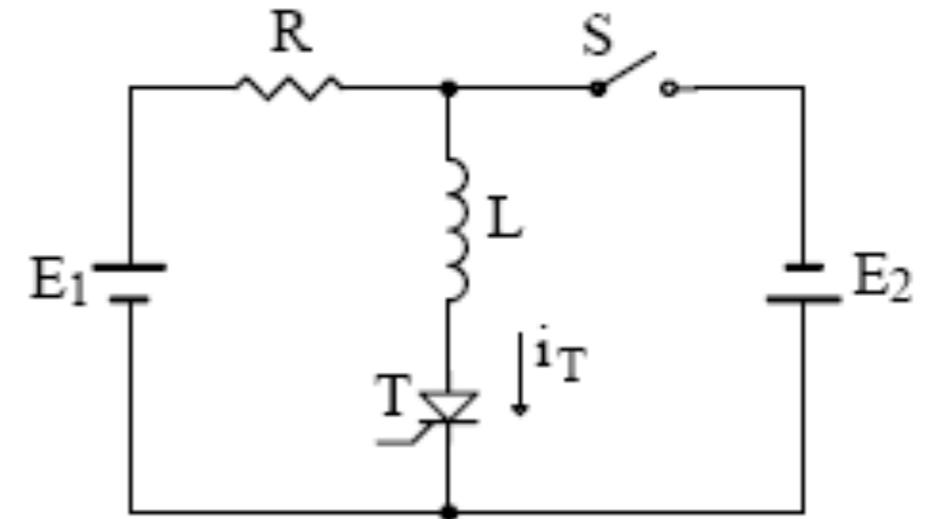
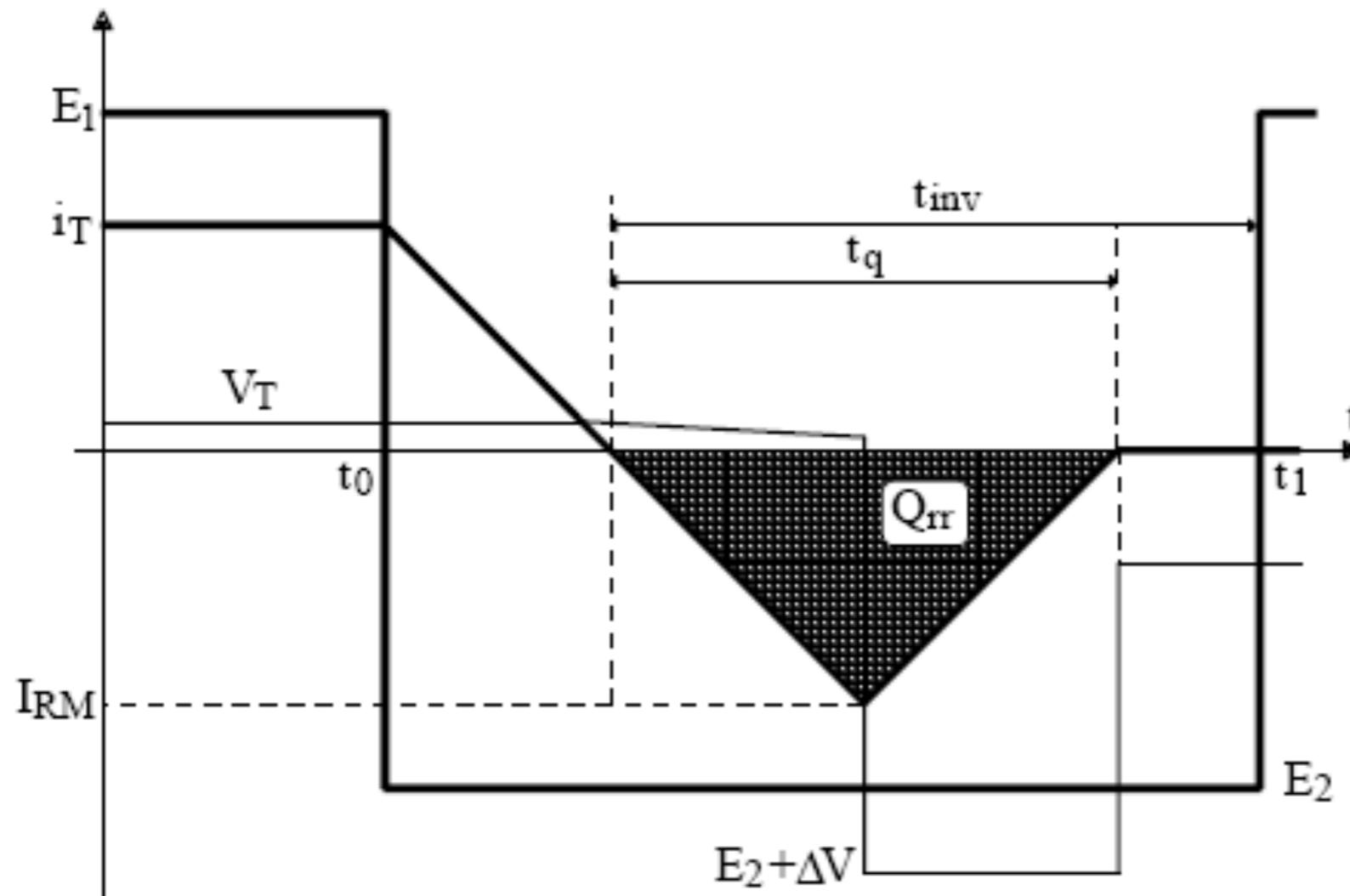
$$t_{on} = t_d + t_r$$



Influência da corrente de gatilho no tempo de retardo

Comutação de Tiristores

Bloqueio:



- t_q - tempo de aplicação da tensão reversa para bloquear o tiristor;
- Para tiristores rápidos é da ordem de $10 \mu s$ à $200 \mu s$.

Perdas nos Tiristores

Classificação das perdas:

1. Condução;

$$P = V_{(TO)} \cdot I_{Tmed} + r_T \cdot I_{Tef}^2$$

2. Comutação:

- Entrada em condução;

Por simulação

- Bloqueio.

Por simulação

Características de Tiristores Comerciais

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.

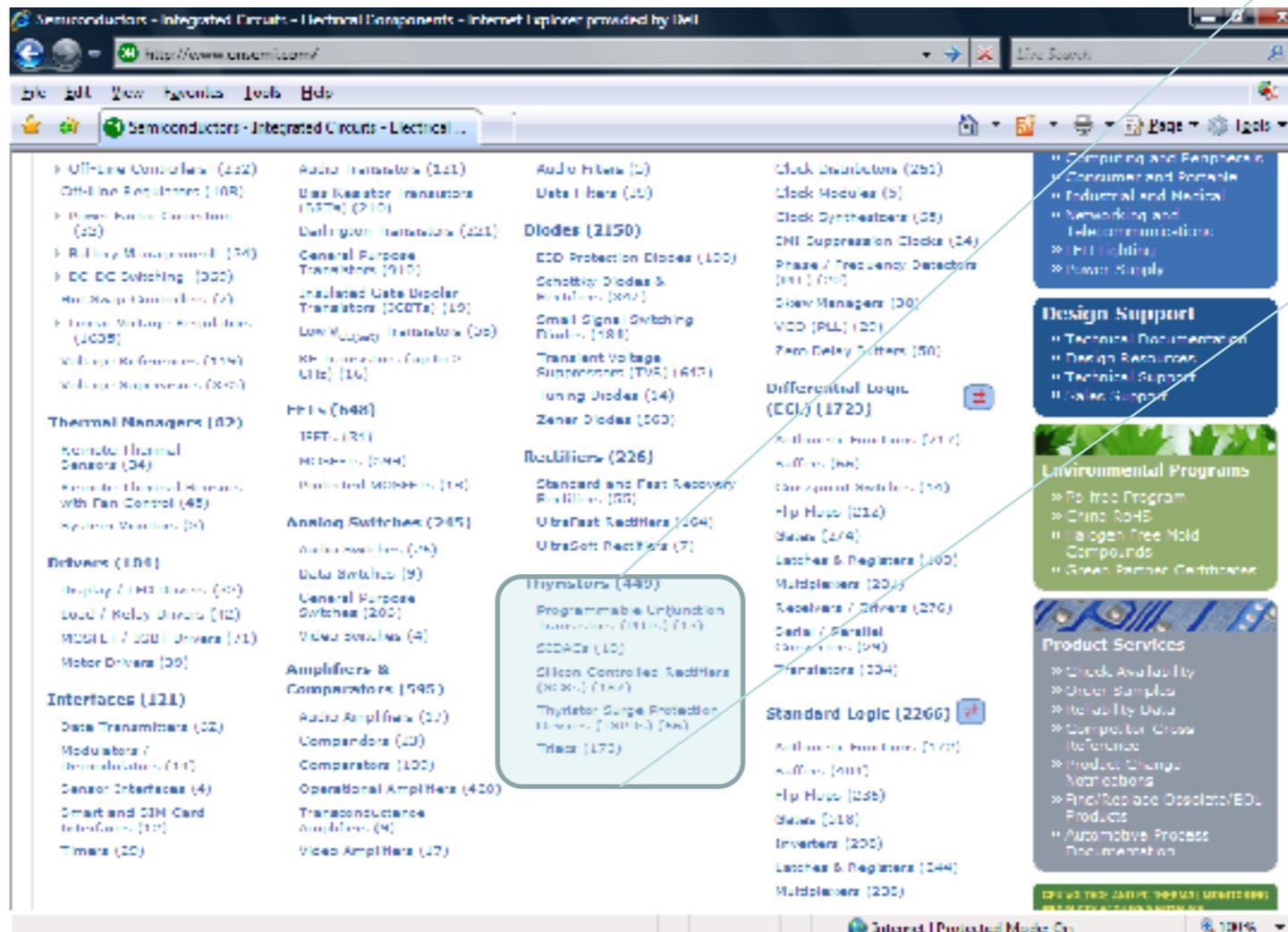
Características de Tiristores Comerciais

Tipos de tiristores de potência:

1. SCR;
2. Triac;
3. Sidac;
4. Para proteção, etc.

Thyristors (449)

- Programmable Unijunction Transistors (PUTs) (13)
- SIDACs (10)
- Silicon Controlled Rectifiers (SCRs) (187)
- Thyristor Surge Protection Devices (TSPDs) (66)
- Triacs (173)



The screenshot shows the onsemi.com website's navigation menu. The 'Thyristors (449)' category is highlighted with a blue box. The menu lists various semiconductor products and their counts:

- Off-Line Converters (222)
- Off-Line Regulators (108)
- Power Factor Correction (22)
- Power Management (134)
- DC-DC Switching (300)
- Power MOSFETs (2)
- Linear Voltage Regulators (1005)
- Voltage References (119)
- Voltage Supervisors (200)
- Thermal Managers (87)
- Smart Thermal Sensors (34)
- Smart Thermal Sensors with Fan Control (45)
- System Monitors (3)
- Drivers (104)
- Display / LED Drivers (4)
- Load / Relay Drivers (10)
- MOSFET / IGBT Drivers (11)
- Motor Drivers (30)
- Interfaces (121)
- Data Transmitters (22)
- Modulators / Demodulators (11)
- Sensor Interfaces (4)
- Smart and SIM Card Interfaces (11)
- Timers (20)
- Audio Transistors (141)
- Voice Keypad Transistors (MPTs) (210)
- Ballpoint Transistors (221)
- General Purpose Transistors (910)
- Insulated Gate Bipolar Transistors (IGBTs) (19)
- Low Voltage Transistors (20)
- RF Transistors (Capacitance Multiplier) (16)
- HETs (448)
- TRFETs (13)
- MOSFETs (244)
- Power MOSFETs (18)
- Analog Switches (245)
- Audio Switches (16)
- Data Switches (9)
- General Purpose Switches (200)
- Video Switches (4)
- Amplifiers & Comparators (595)
- Audio Amplifiers (17)
- Comparators (20)
- Comparators (100)
- Operational Amplifiers (410)
- Transconductance Amplifiers (4)
- Video Amplifiers (17)
- Audio Filters (2)
- Data Filters (10)
- Diodes (2150)
- ESD Protection Diodes (100)
- Schottky Diodes & Rectifiers (207)
- Small Signal Switching Diodes (188)
- Transient Voltage Suppressors (TVS) (417)
- Tuning Diodes (14)
- Zener Diodes (203)
- Rectifiers (226)
- Standard and Fast Recovery Rectifiers (55)
- UltraFast Rectifiers (104)
- UltraSoft Rectifiers (7)
- Thyristors (449)
- Programmable Unijunction Transistors (PUTs) (13)
- SIDACs (10)
- Silicon Controlled Rectifiers (SCRs) (187)
- Thyristor Surge Protection Devices (TSPDs) (66)
- Triacs (173)
- Clock Dividers (261)
- Clock Modules (5)
- Clock Synthesizers (25)
- EMI Suppression Clocks (24)
- Phase / Frequency Detectors (11) (10)
- Clock Managers (30)
- VCO (PLL) (20)
- Zero Delay Drivers (50)
- Differential Logic (ECJ) (1720)
- Arithmetic Functions (117)
- Buffers (66)
- Combinational (14)
- Flip Flops (214)
- Glues (474)
- Latches & Registers (100)
- Multiplexers (20)
- Receivers / Drivers (276)
- Serial / Parallel Converters (24)
- Translators (104)
- Standard Logic (2266)
- Arithmetic Functions (117)
- Buffers (66)
- Flip Flops (214)
- Glues (474)
- Inverters (200)
- Latches & Registers (104)
- Multiplexers (20)

MCR12DCM, MCR12DCN

Preferred Device

Silicon Controlled Rectifiers

Reverse Blocking Thyristors

Designed for high volume, low cost, industrial and consumer applications such as motor control; process control; temperature, light and speed control.

Features

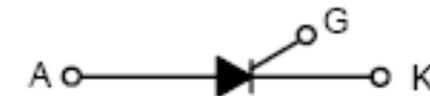
- Small Size
- Passivated Die for Reliability and Uniformity
- Low Level Triggering and Holding Characteristics
- Epoxy Meets UL 94 V-0 @ 0.125 in
- ESD Ratings: Human Body Model, 3B > 8000 V
Machine Model, C > 400 V
- Pb-Free Packages are Available



ON Semiconductor®

<http://onsemi.com>

SCRs
12 AMPERES RMS
600 – 800 VOLTS



Características de Tiristores Comerciais

2N6344A, 2N6348A, 2N6349A

Preferred Device

Triacs

Silicon Bidirectional Thyristors

Designed primarily for full-wave AC control applications, such as light dimmers, motor controls, heating controls and power supplies; or wherever full-wave silicon gate controlled solid-state devices are needed. Triac type thyristors switch from a blocking to a conducting state for either polarity of applied anode voltage with positive or negative gate triggering.

Features

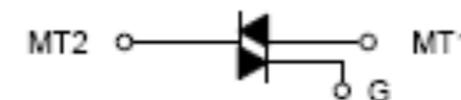
- Blocking Voltage to 800 V
- All Diffused and Glass Passivated Junctions for Greater Parameter Uniformity and Stability
- Small, Rugged, Thermowatt Construction for Low Thermal Resistance, High Heat Dissipation and Durability
- Gate Triggering Guaranteed in all Four Quadrants
- For 400 Hz Operation, Consult Factory
- 8.0 A Devices Available as 2N6344 thru 2N6349
- Pb-Free Packages are Available*



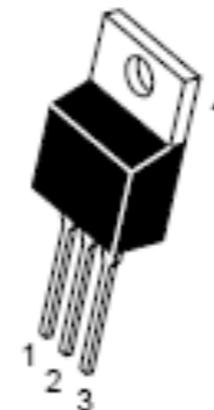
ON Semiconductor®

<http://onsemi.com>

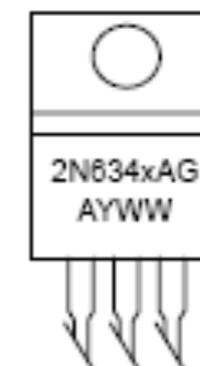
TRIACS
12 AMPERES RMS
600 thru 800 VOLTS



**MARKING
DIAGRAM**



TO-220AB
CASE 221A
STYLE 4



Características de Tiristores Comerciais

SEMIKRON, leading manufacturer of diode thyristor power semiconductor modules, (IGBT, Mosfet, c Internet Explorer provided by

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Silicon Controlled Rectifier... SEMIKRON, leading ma...

	MiniHüP®	SEMITOP®
MOSFET	SEMI TRANS™	SEMITOP®
Thyristor/Diode	SEMI PACK®	SEMI PACK® Fast
	SEMI START	SEMI X®
	SEMI TOP®	SEMI PONT®
Bridge Rectifier	SEMI PONT®	SEMI X®
		SEMI TOP®

Discretes

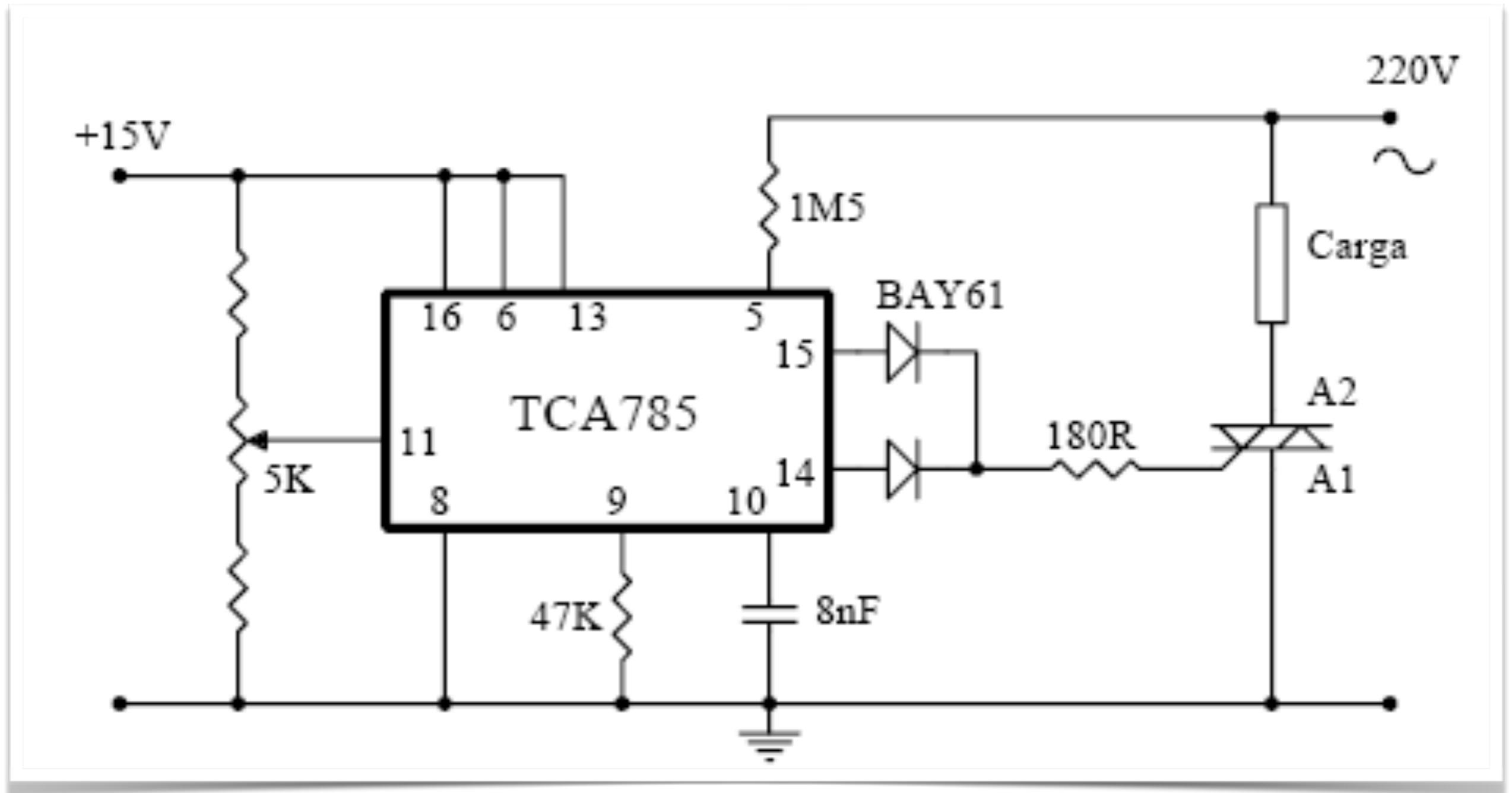
Diode	Leaded	Surface Mount	Stud Screw Fit	Capsule
Thyristor	Stud Screw Fit	Capsule		
Miniature Bridge Rectifier	Leaded	Fast-on		
Chips	Frontloading Diodes	Rectifiers	Thyristors	

Top

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Acionamento de Tiristores



FAIRCHILD
SEMICONDUCTOR



6-Pin DIP Zero-Cross Optoisolators Triac Driver Output (600 Volts Peak)

The MOC3061, MOC3062 and MOC3063 devices consist of gallium arsenide infrared emitting diodes optically coupled to monolithic silicon detectors performing the functions of Zero Voltage Crossing bilateral triac drivers.

They are designed for use with a triac in the interface of logic systems to equipment powered from 115/240 Vac lines, such as solid-state relays, industrial controls, motors, solenoids and consumer appliances, etc.

- Simplifies Logic Control of 115/240 Vac Power
- Zero Voltage Crossing
- dV/dt of 1500 V/μs Typical, 600 V/μs Guaranteed
- To order devices that are tested and marked per VDE 0884 requirements, the suffix "V" must be included at end of part number. VDE 0884 is a test option.

Recommended for 115/240 Vac(rms) Applications:

- Solenoid/Valve Controls
- Lighting Controls
- Static Power Switches
- AC Motor Drives
- Temperature Controls
- E.M. Contactors
- AC Motor Starters
- Solid State Relays

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
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INFRARED EMITTING DIODE

Reverse Voltage	V_{RR}	6	Volts
Forward Current — Continuous	I_F	80	mA
Total Power Dissipation @ $T_A = 25^\circ\text{C}$ Negligible Power in Output Driver Derate above 25°C	P_D	120	mW
		1.41	mW/°C

OUTPUT DRIVER

Off-State Output Terminal Voltage	V_{DRM}	600	Volts
Peak Repetitive Surge Current (PW = 100 μs, 120 pps)	I_{TSM}	1	A
Total Power Dissipation @ $T_A = 25^\circ\text{C}$ Derate above 25°C	P_D	150	mW
		1.78	mW/°C

TOTAL DEVICE

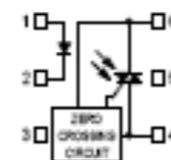
Isolation Surge Voltage(1) (Peak ac Voltage, 60 Hz, 1 Second Duration)	V_{ISO}	7500	Vac(pk)
Total Power Dissipation @ $T_A = 25^\circ\text{C}$ Derate above 25°C	P_D	250	mW
		2.94	mW/°C
Junction Temperature Range	T_J	-40 to +100	°C
Ambient Operating Temperature Range	T_A	-40 to +85	°C
Storage Temperature Range	T_{stg}	-40 to +150	°C
Soldering Temperature (10 s)	T_s	260	°C

MOC3061
MOC3062
MOC3063



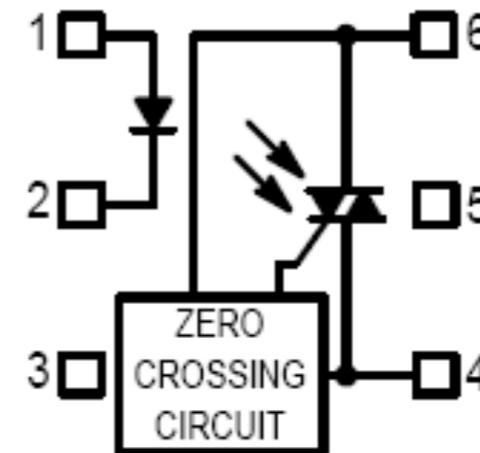
STANDARD THRU HOLE

COUPLER SCHEMATIC

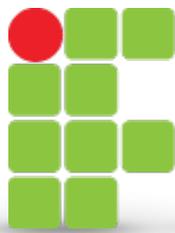


1. ANODE
2. CATHODE
3. NC
4. MAIN TERMINAL
5. SUBSTRATE
DO NOT CONNECT
6. MAIN TERMINAL

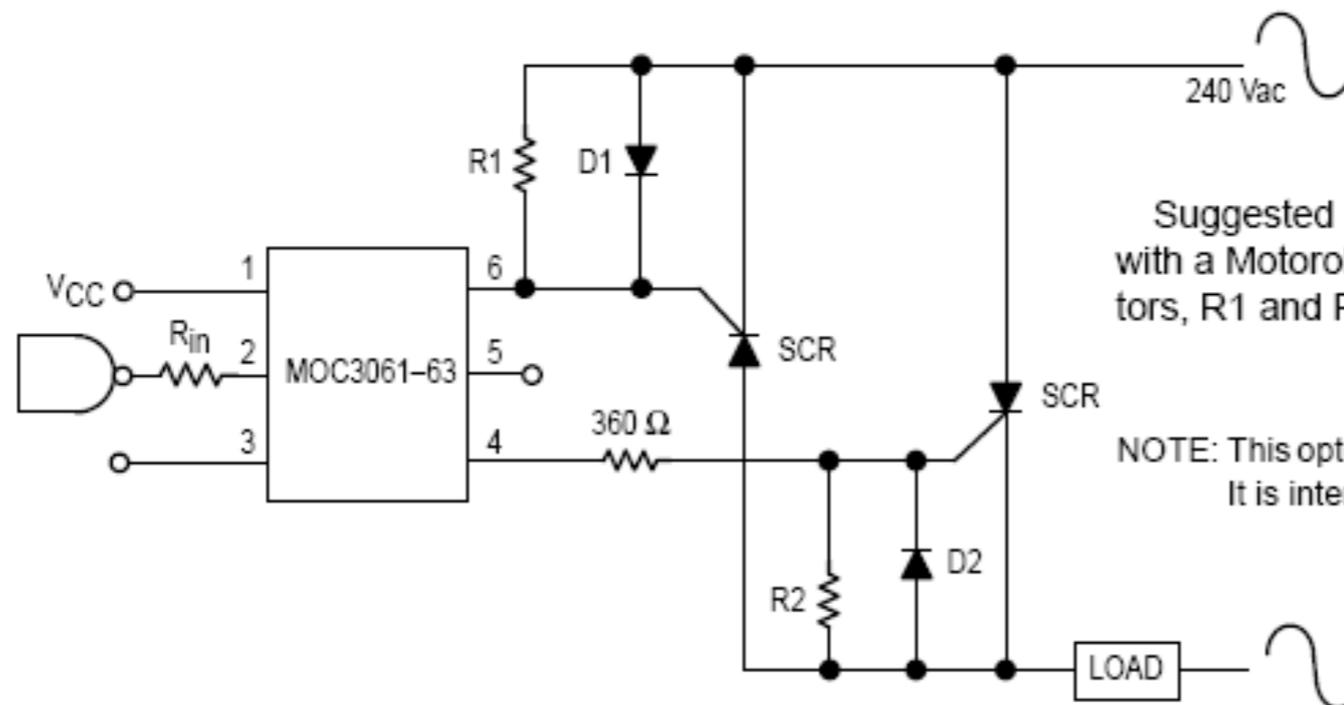
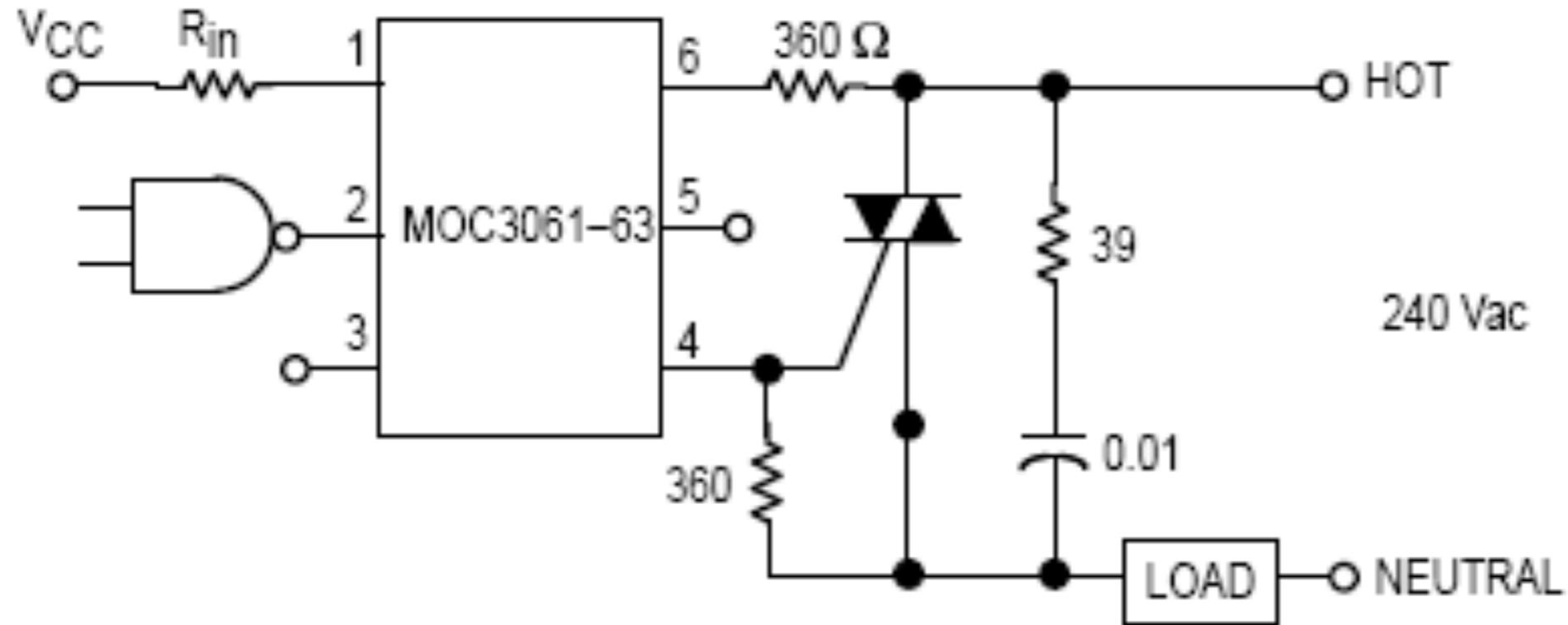
COUPLER SCHEMATIC



1. ANODE
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Acionamento de Tiristores



Suggested method of firing two, back-to-back SCR's, with a Motorola triac driver. Diodes can be 1N4001; resistors, R1 and R2, are optional 330 ohms.

NOTE: This optoisolator should not be used to drive a load directly. It is intended to be a trigger device only.

Próxima Aula

Componentes Semicondutores:

- BJT, MOSFET e IGBT.

