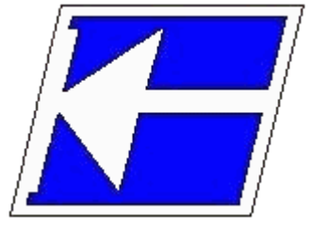
Instituto Federal de Educação, Ciência e Tecnologia de Santa Catarina
Departamento Acadêmico de Eletrônica

Eletrônica de Potência



Semicondutores de Potência
Diodos e Tiristores

Prof. Clovis Antonio Petry.

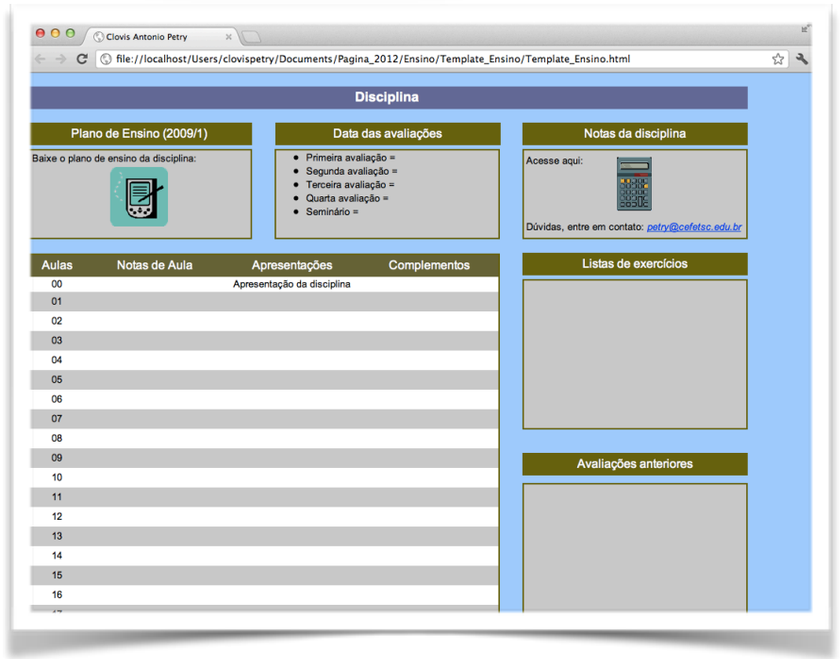
Florianópolis, agosto de 2018.

Biografia para Esta Aula

Capítulos 2 e 4:

- Diodos de potência;
- Dispositivos tiristores.

www.ProfessorPetry.com.br



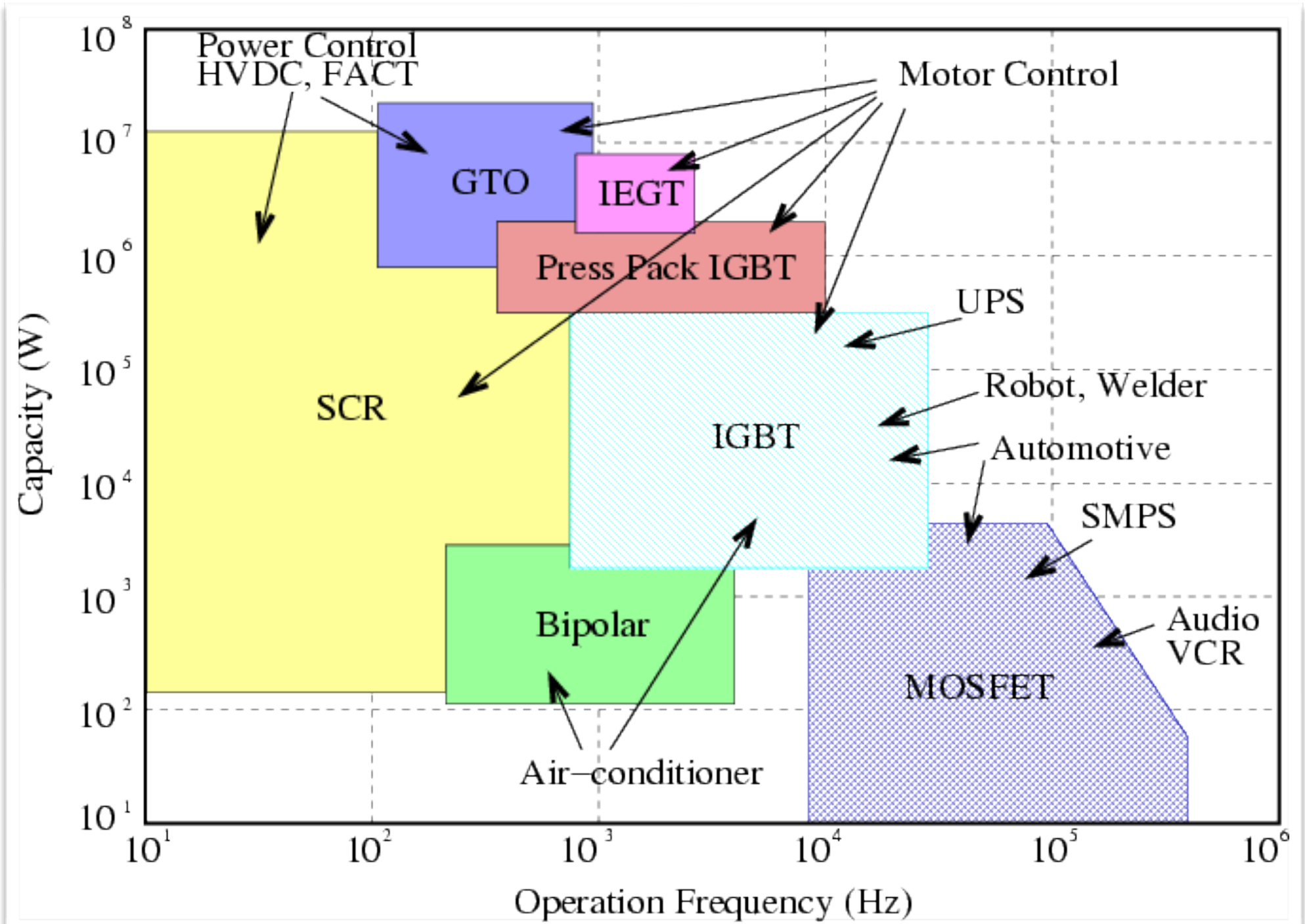
Nesta Aula

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

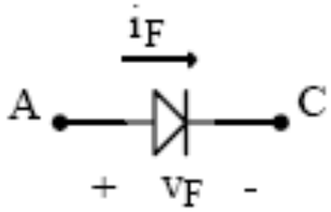
Semicondutores aplicados à eletrônica de potência:

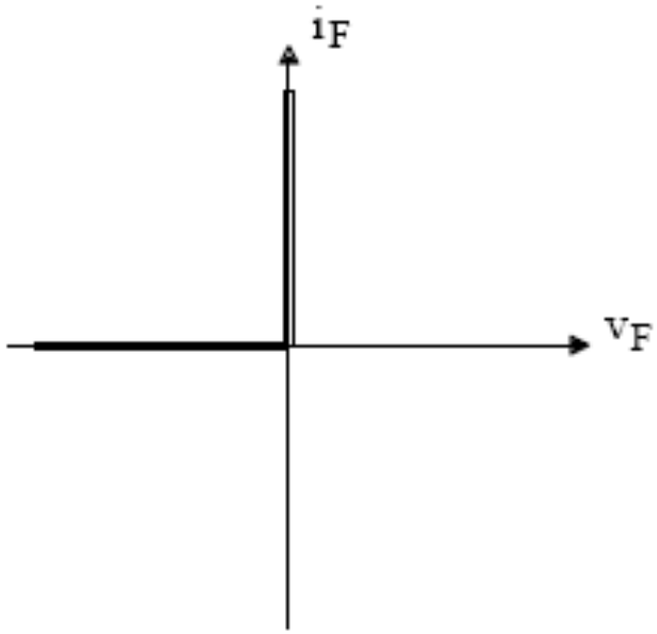


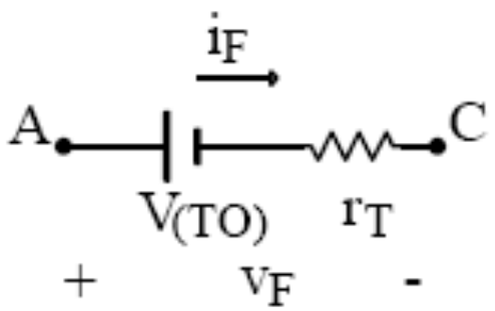
Diodo Ideal x Diodo Real

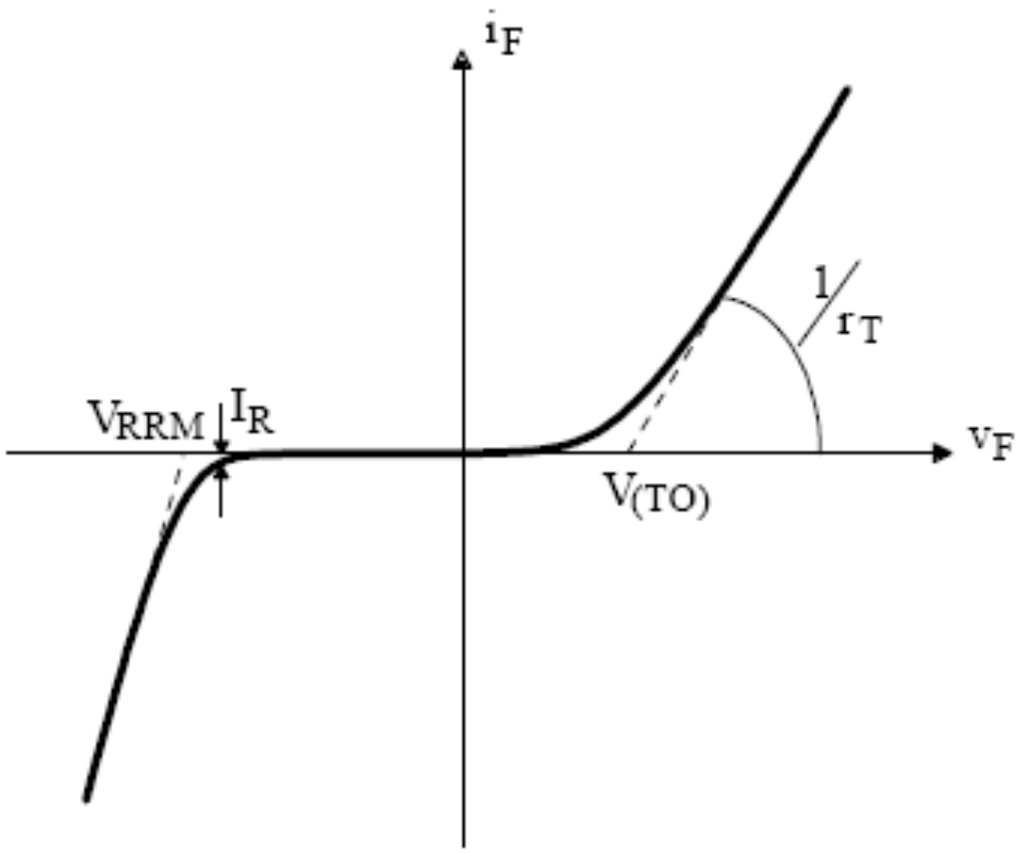
Exemplo: Diodo SKN20/08

- VRRM = 800 V;
- V(TO) = 0,85 V;
- rT = 11 mΩ;
- IDmed = 20 A;
- IR = 0,15 mA.





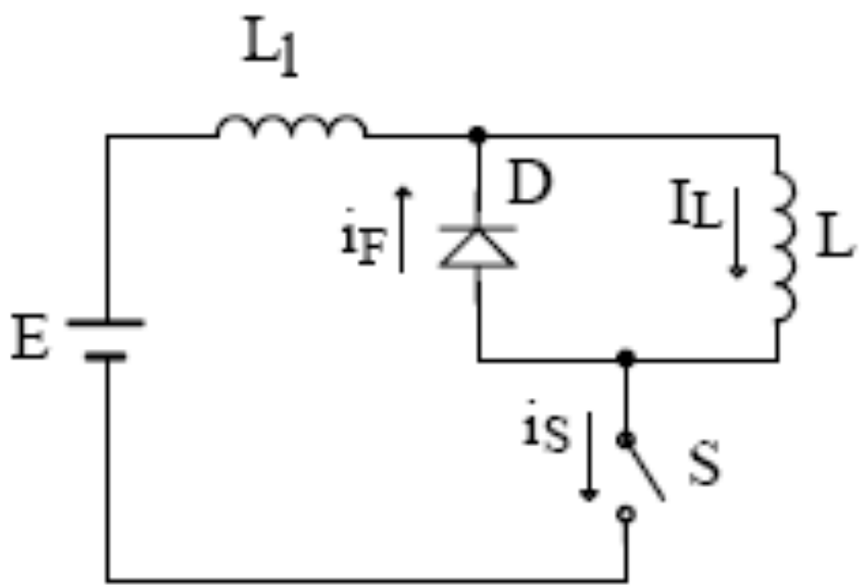




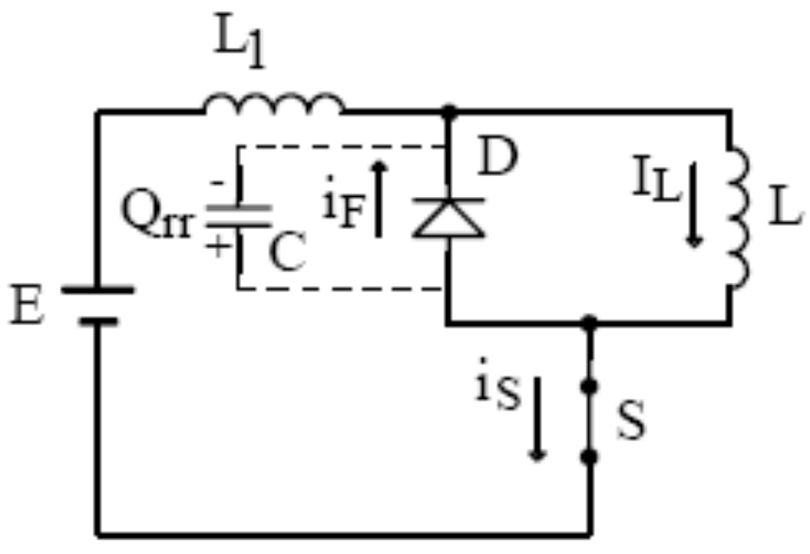
Característica estática

Comutação de Diodos

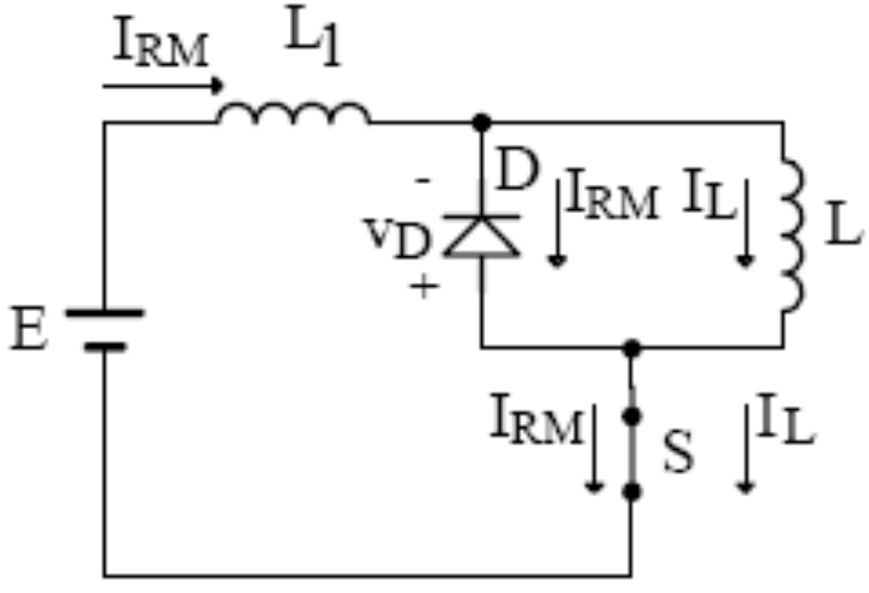
Bloqueio:



Circuito para estudo da comutação



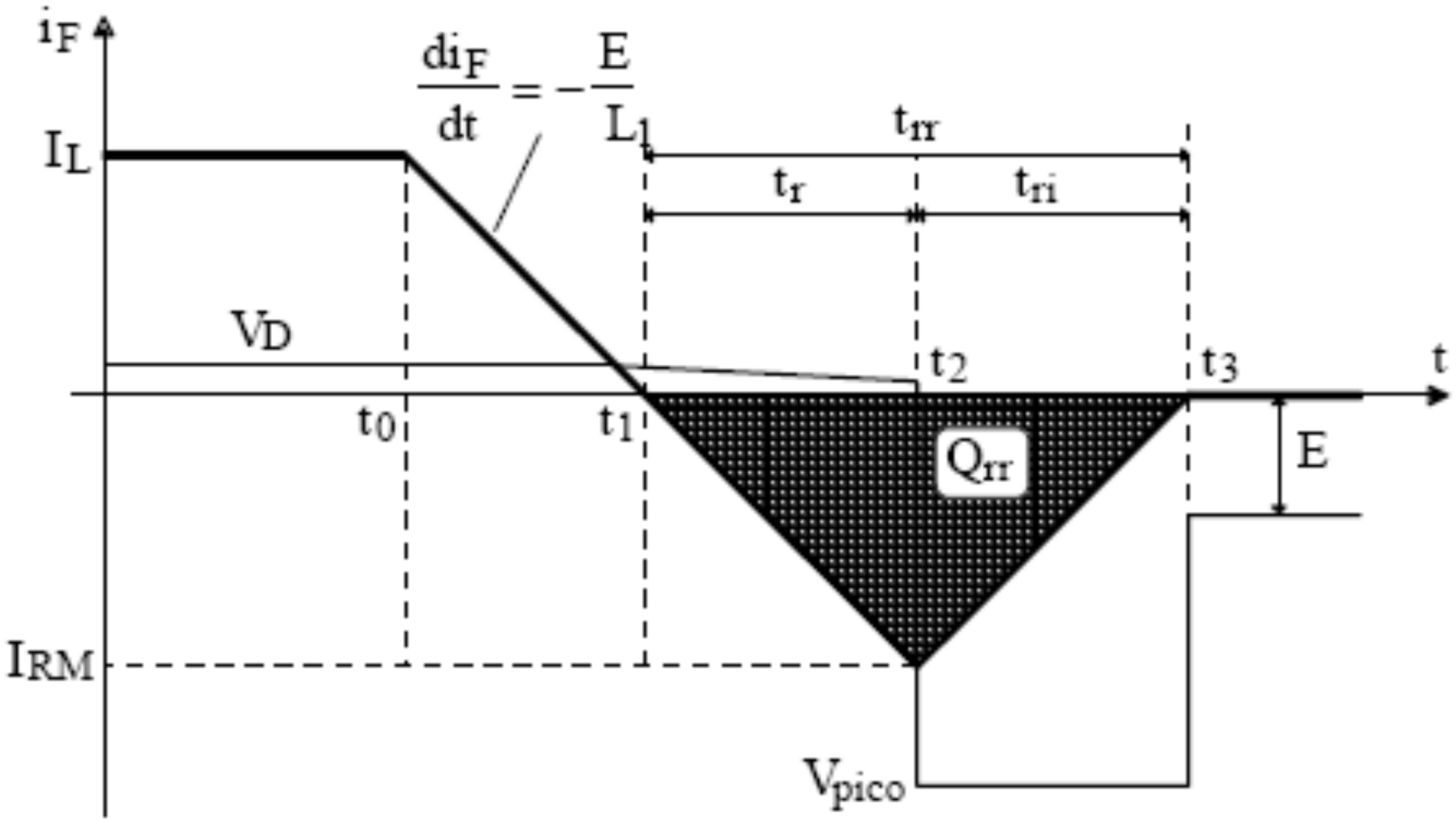
Primeira etapa de comutação



Segunda etapa de comutação

Comutação de Diodos

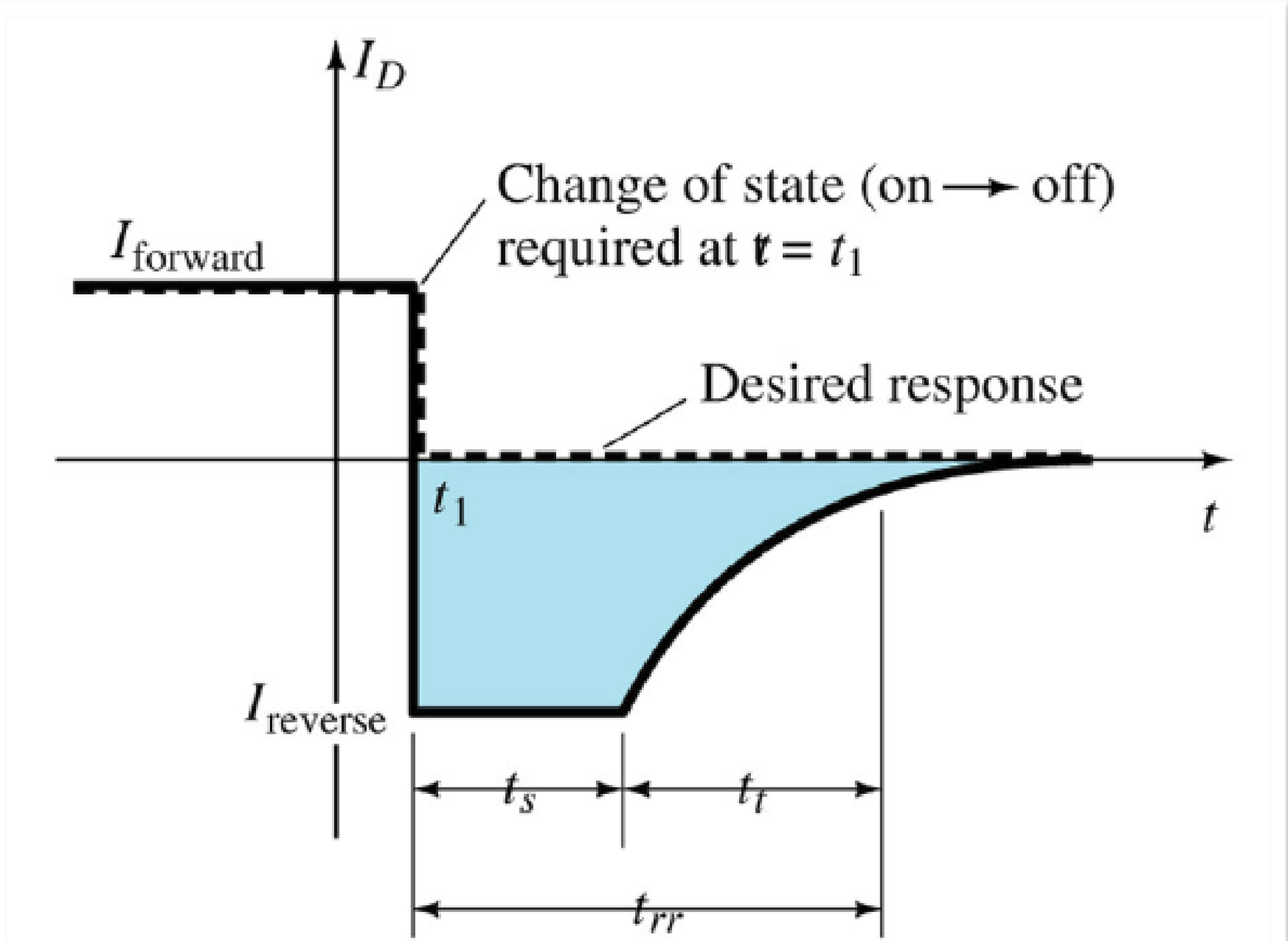
Bloqueio:



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

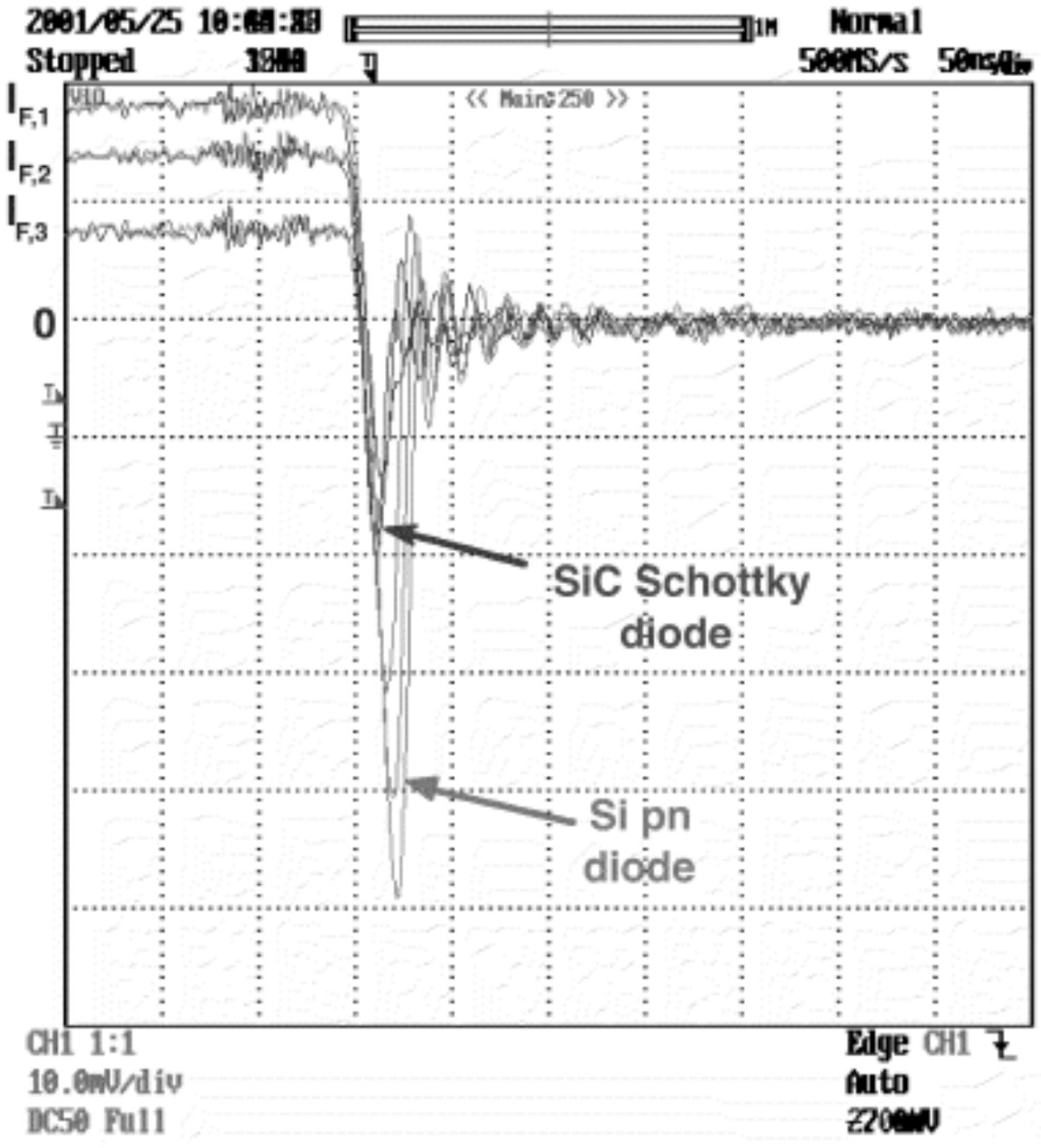


Fig. 5. Typical reverse recovery waveforms of the Si pn and SiC Schottky diode for three different forward currents (2 A/div.).

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

Comutação de Diodos

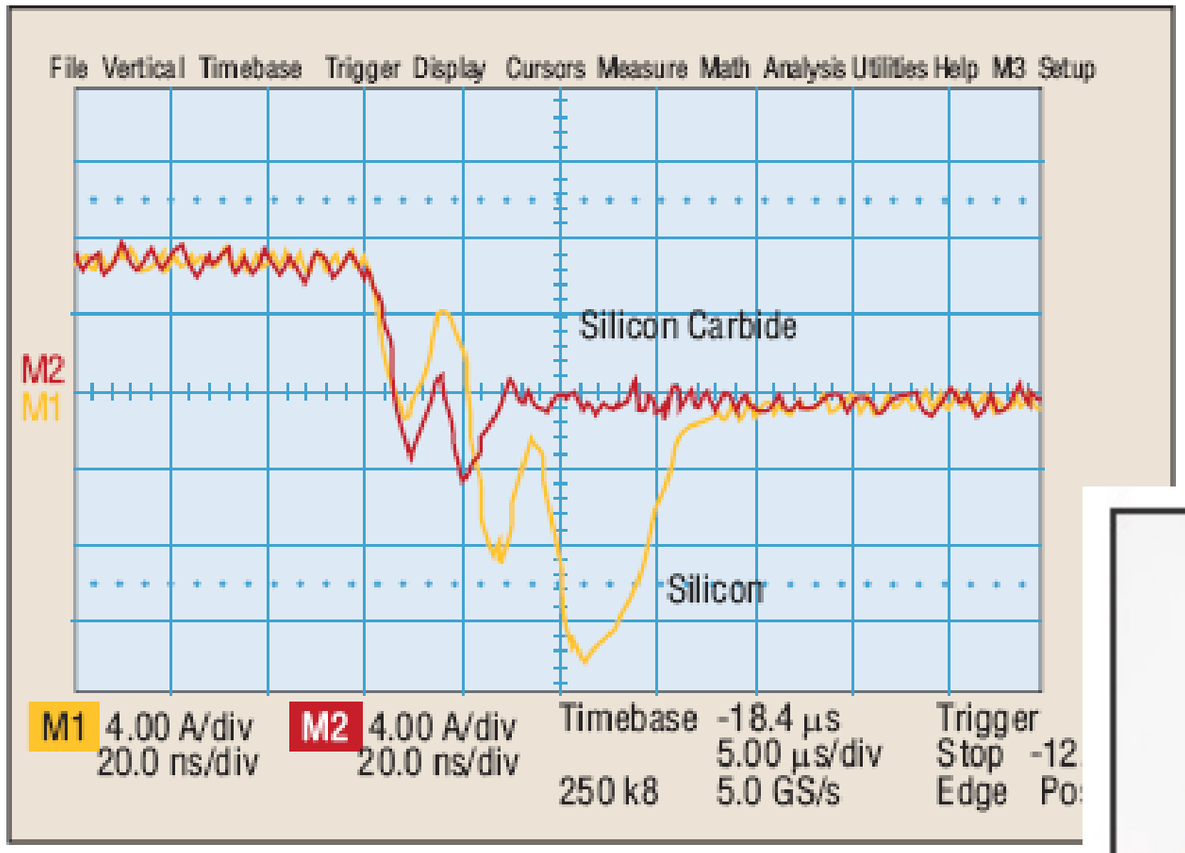


Fig. 4. *Low-line diode recovery currents in PFC front-end conver*

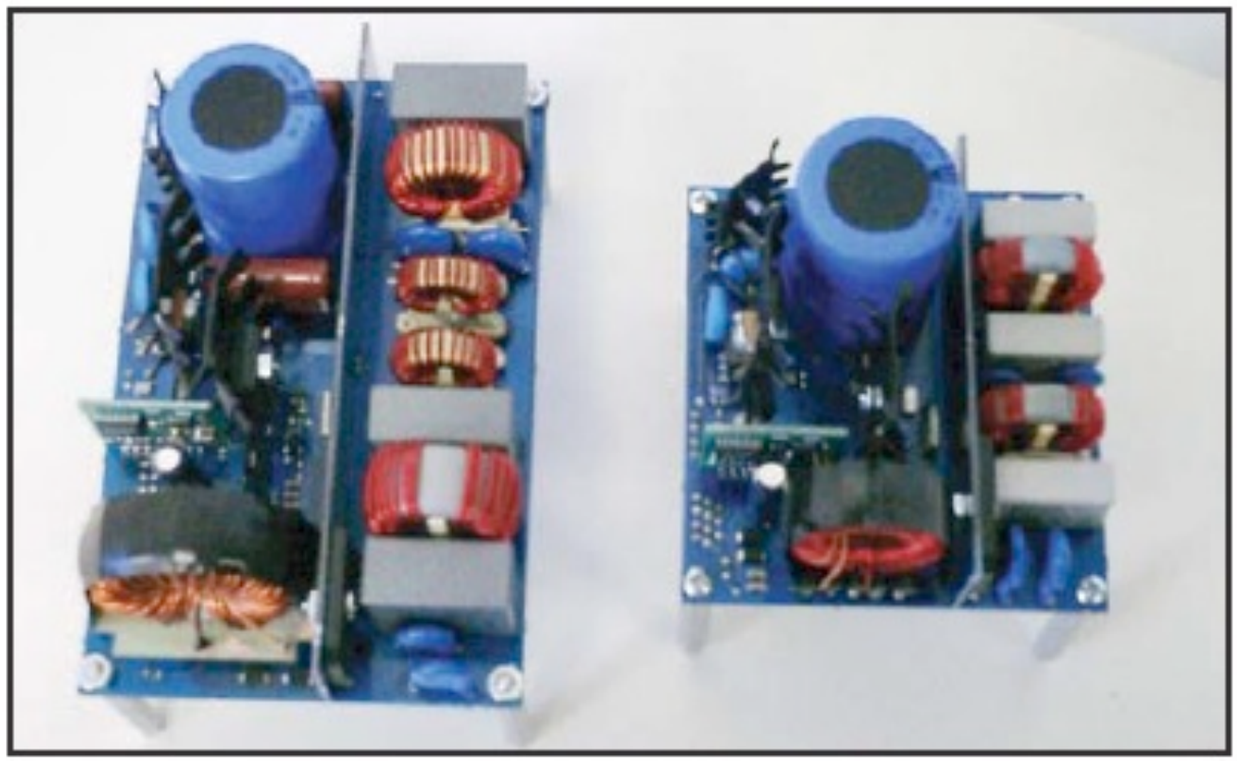


Fig. 8. *A size comparison of an 80-kHz PFC front-end built with Si rectifiers (left) and a 200-kHz PFC front-end with SiC rectifiers.*

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

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

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

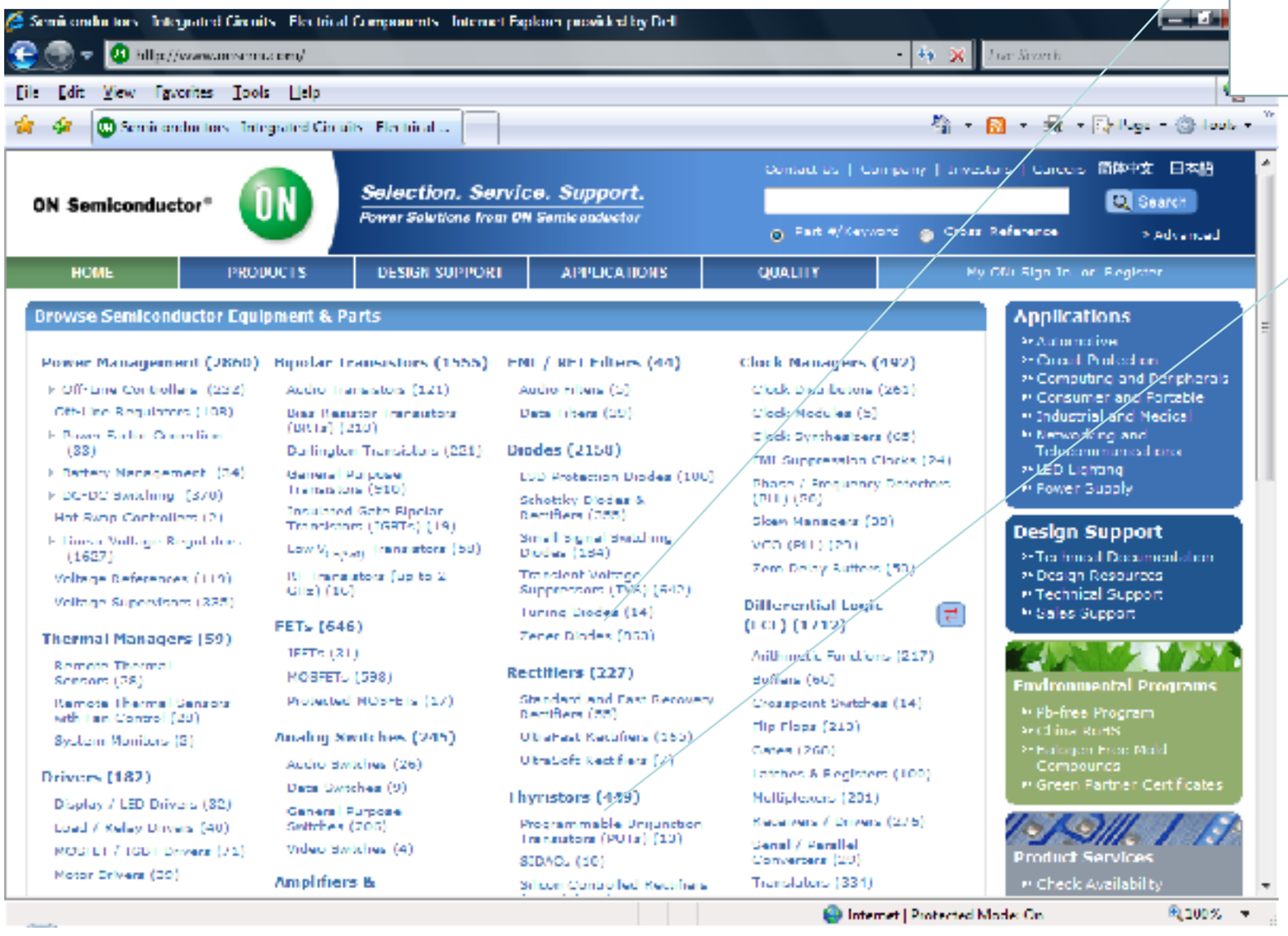
ELECTRICAL CHARACTERISTICS

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:

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



www.onsemi.com

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

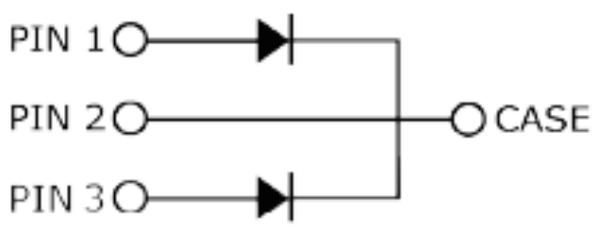
Package

TO-247-3

www.cree.com

Benefits

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



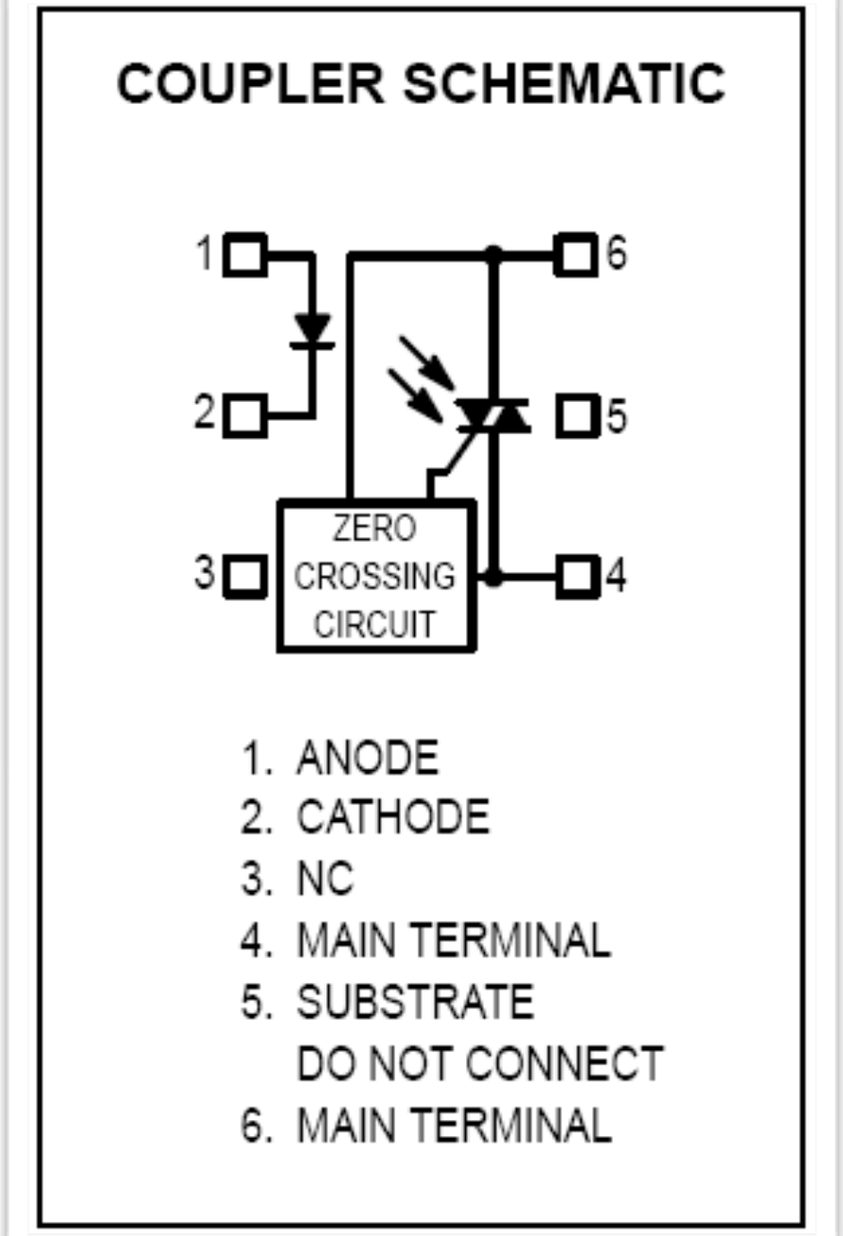
Características de Diodos Comerciais

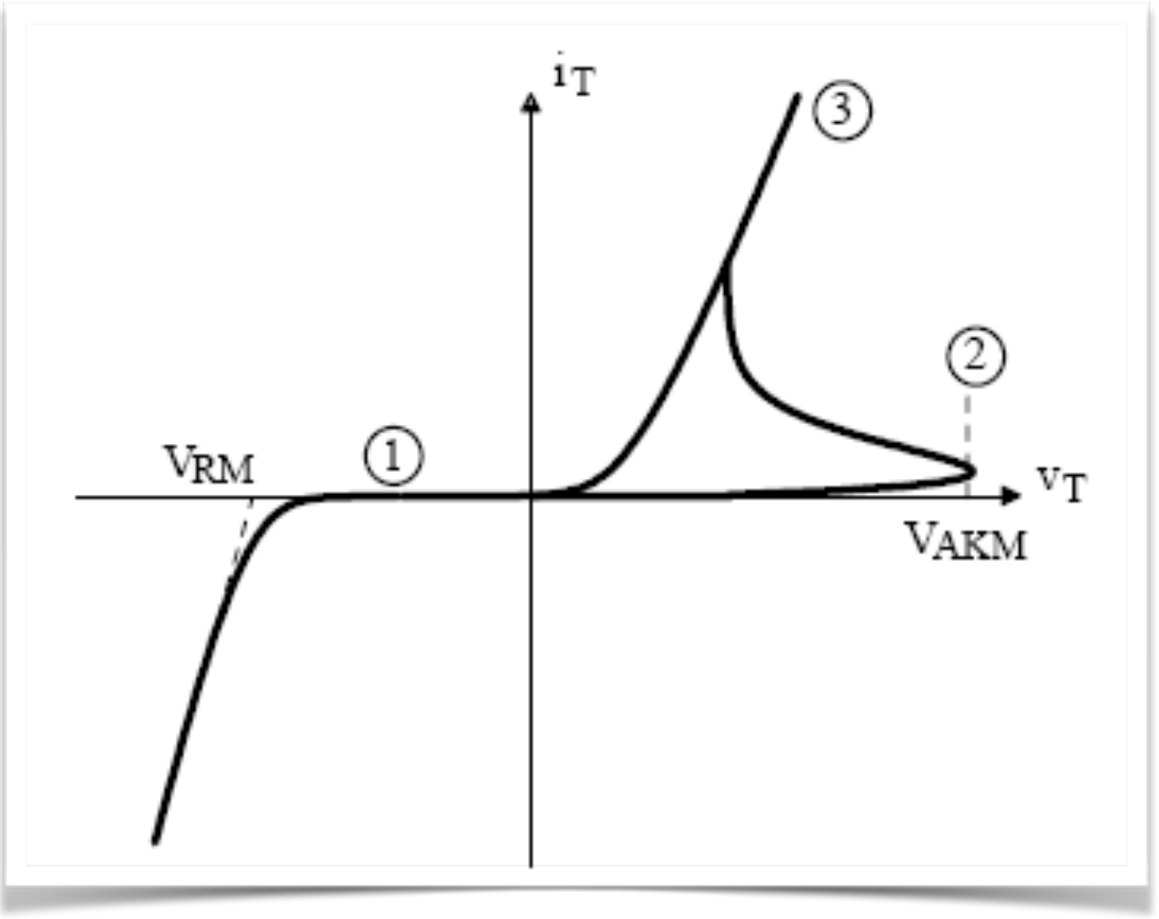
Demonstração

Demo

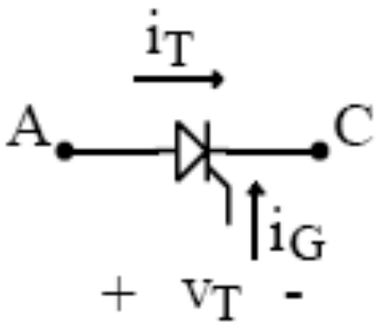
- Testes de diodos com multímetro.

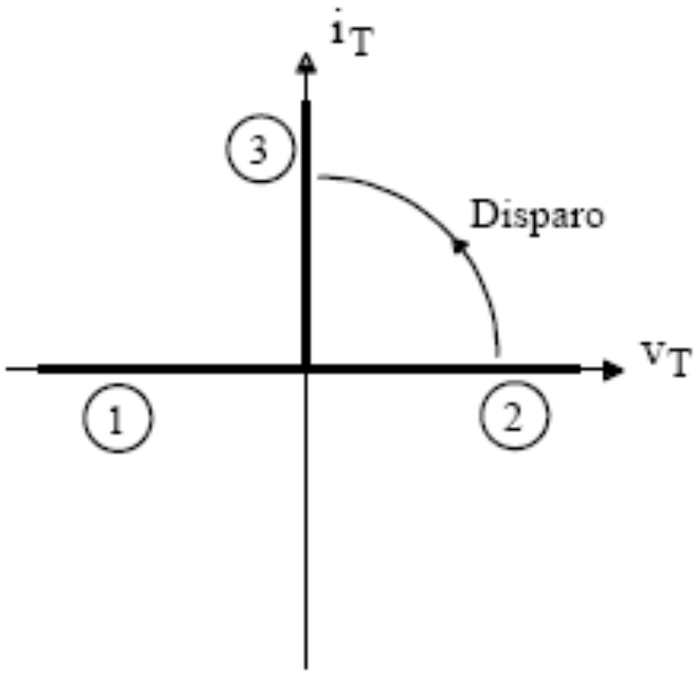
Tiristores

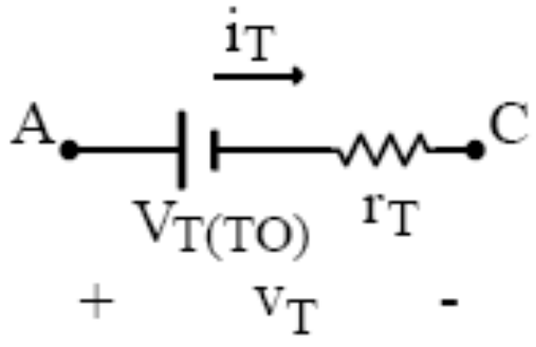

COUPLER SCHEMATIC
1
2
3
6
5
4
ZERO
CROSSING
CIRCUIT
1. ANODE
2. CATHODE
3. NC
4. MAIN TERMINAL
5. SUBSTRATE
DO NOT CONNECT
6. MAIN TERMINAL

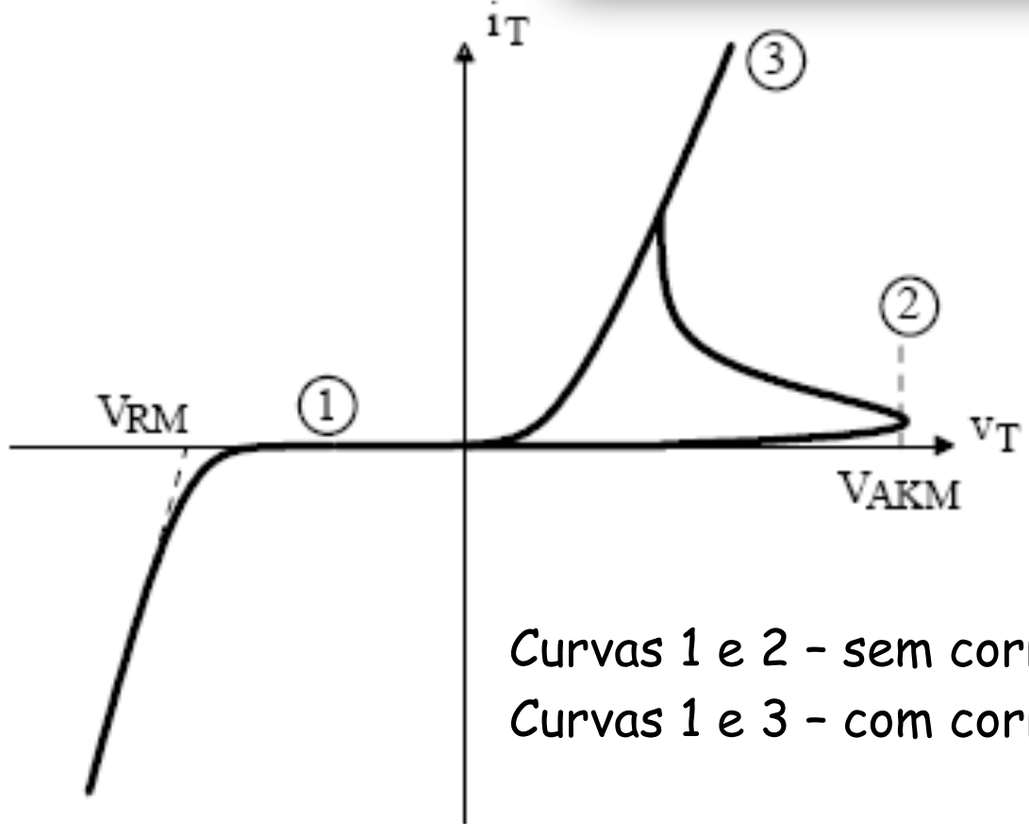

iT
3
2
1
VRM
vT
VAKM

Tiristor Ideal e Tiristor Real





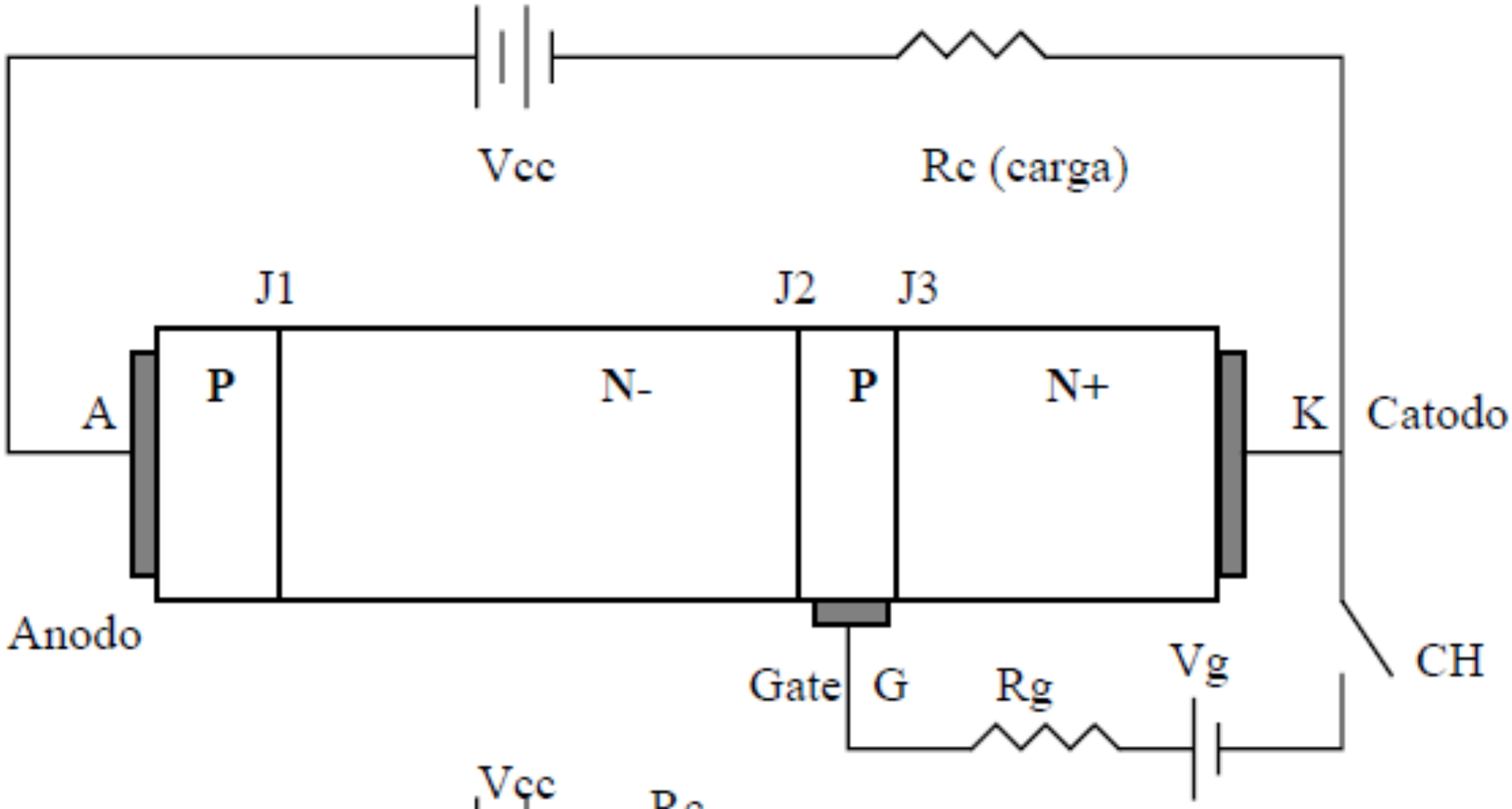


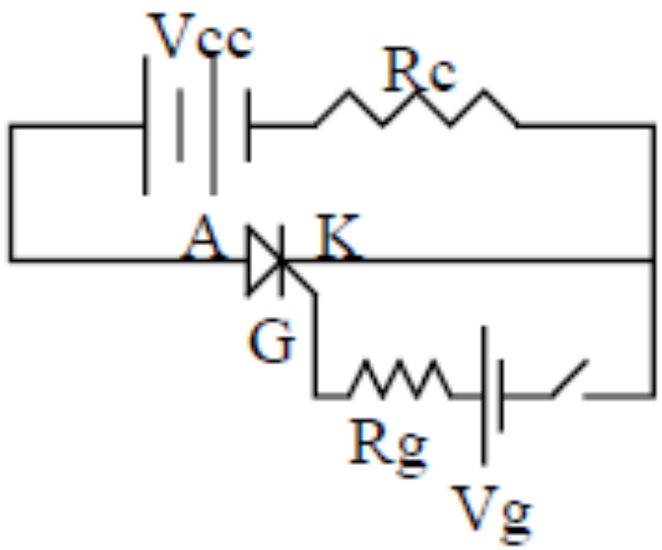


Curvas 1 e 2 – sem corrente de gatilho
Curvas 1 e 3 – com corrente de gatilho

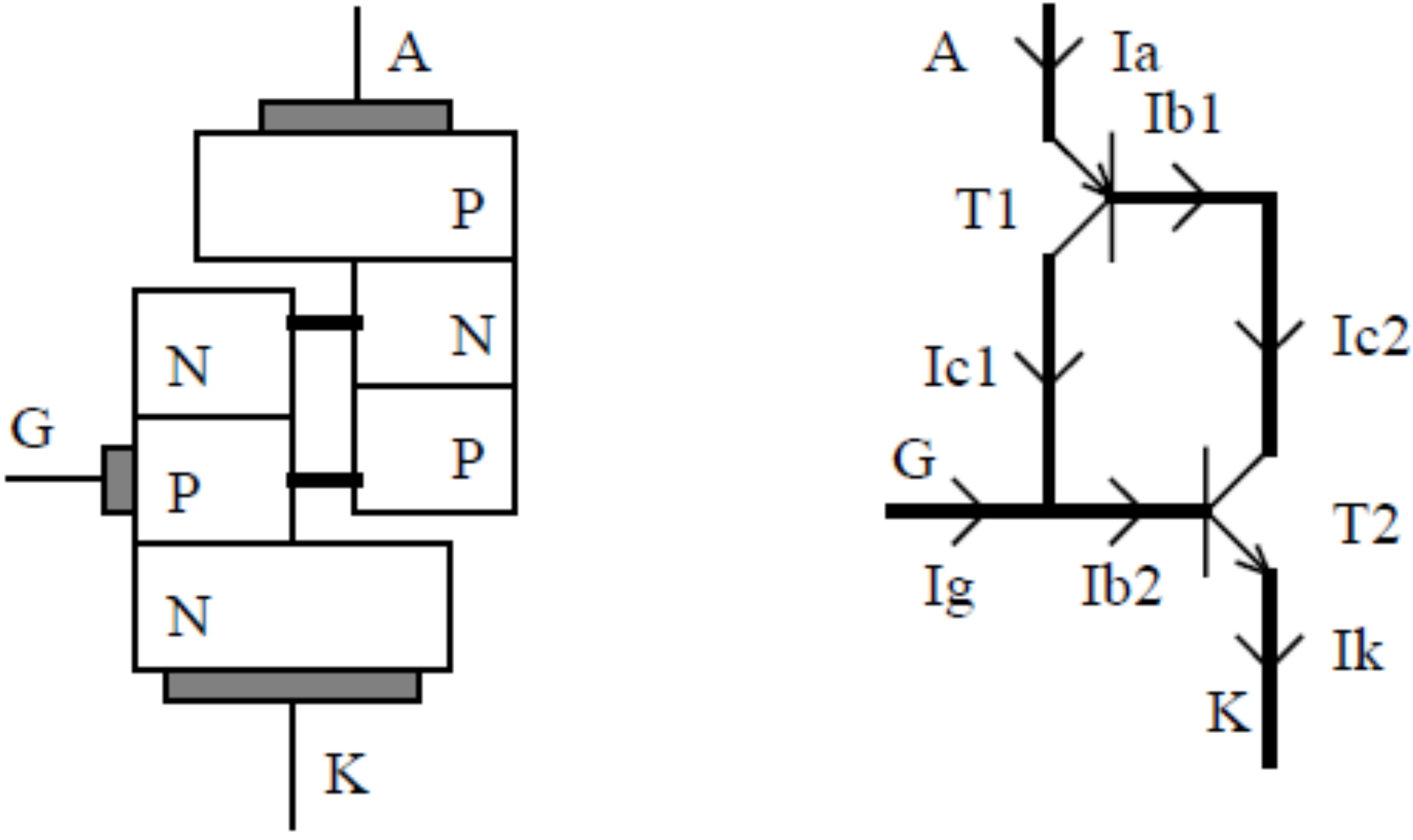
Característica estática

Funcionamento do Tiristor



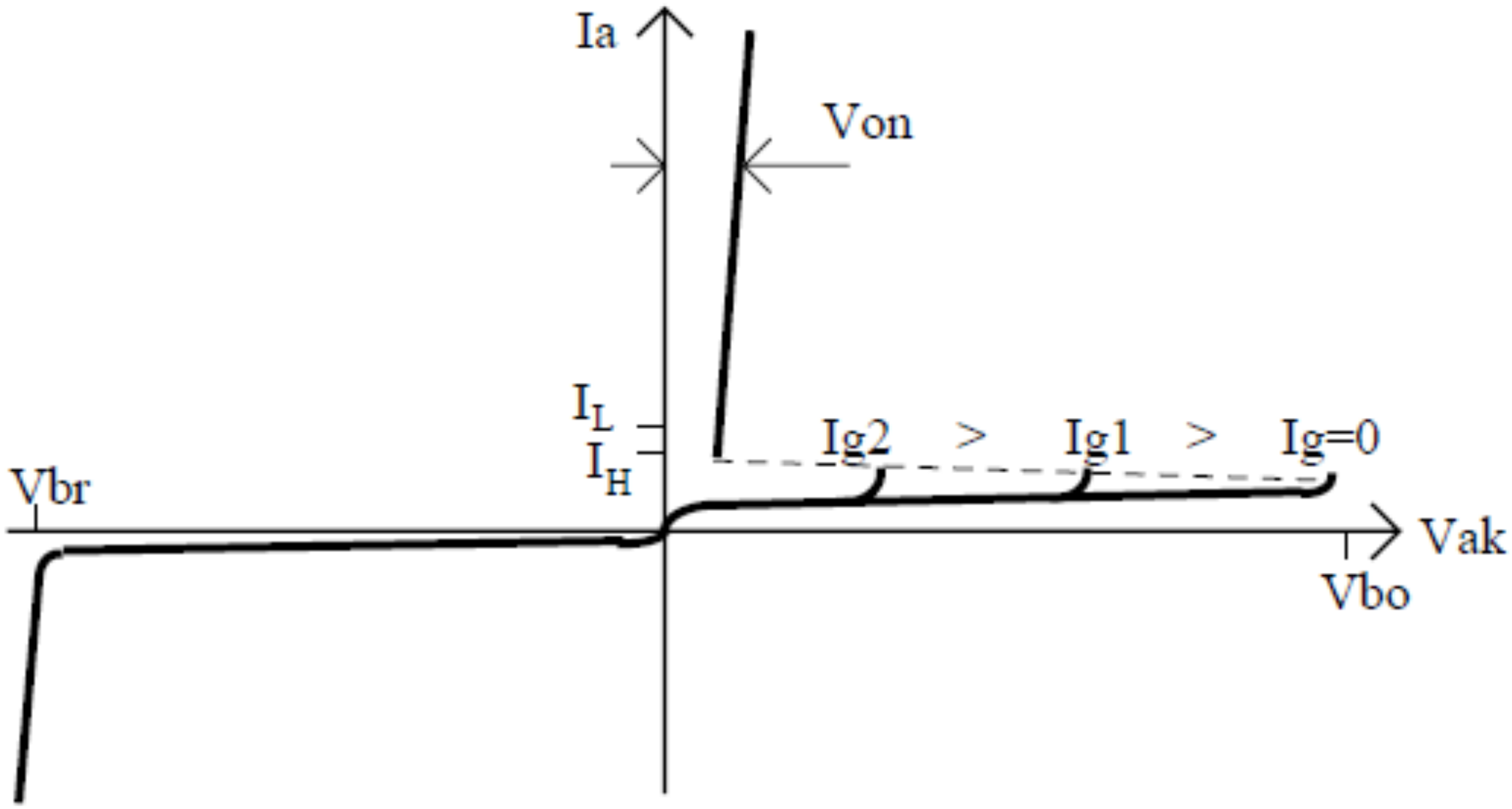


Funcionamento do Tiristor



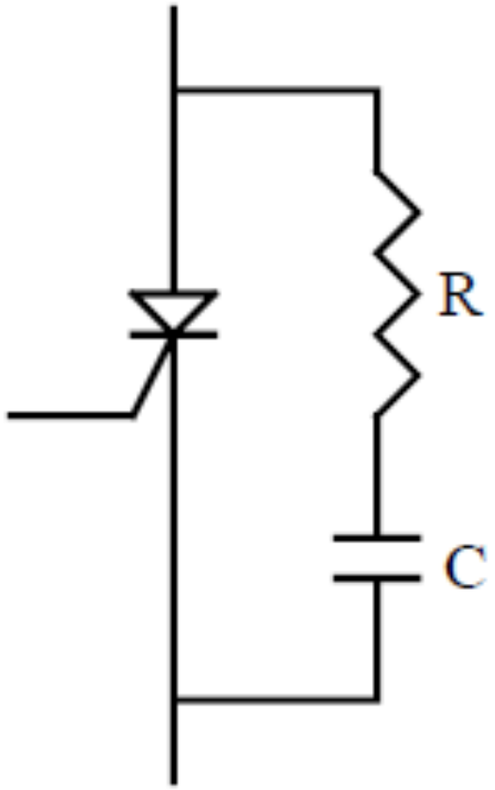
Estrutura interna e analogia com BJT

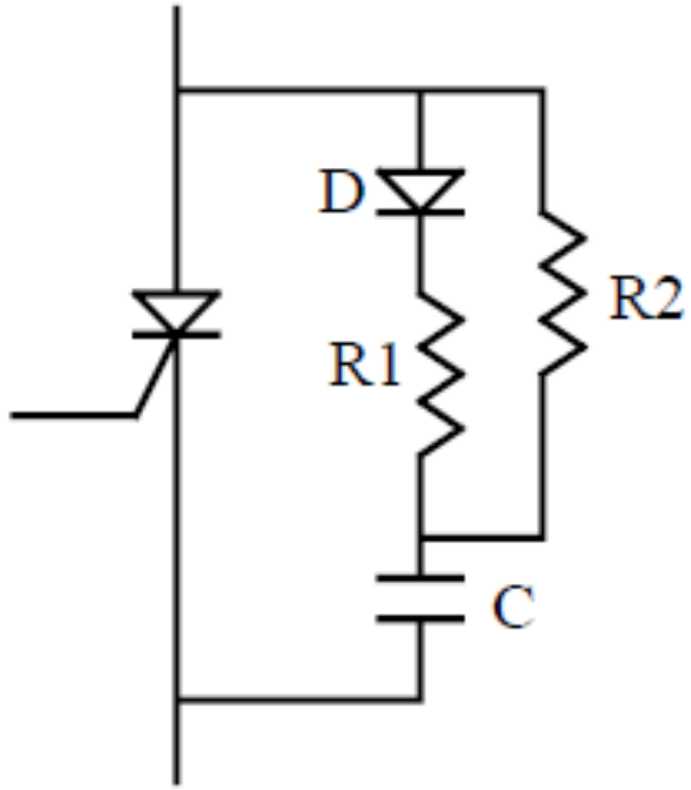
Funcionamento do Tiristor

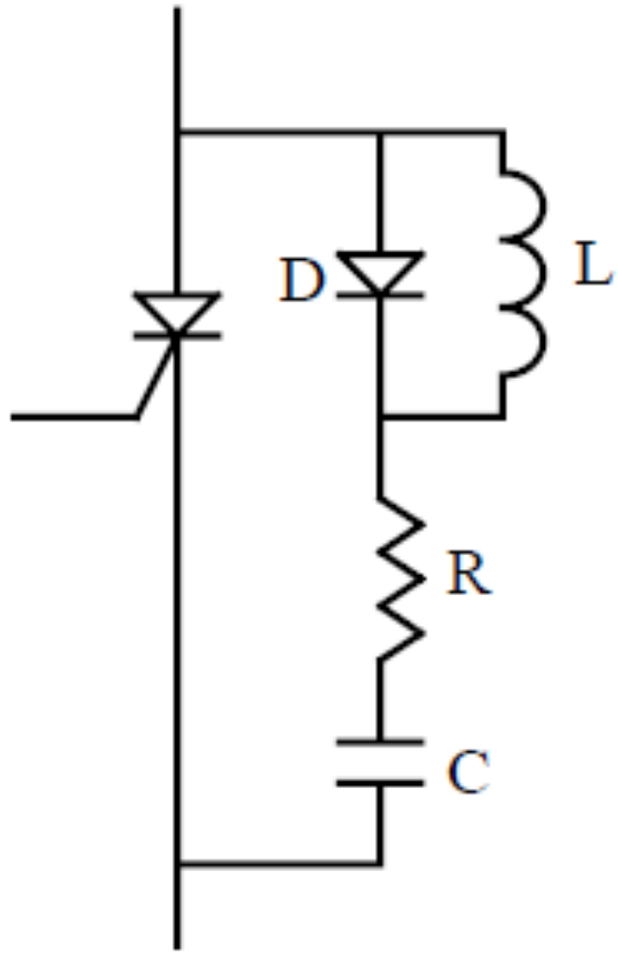


Curva característica V x I

Funcionamento do Tiristor



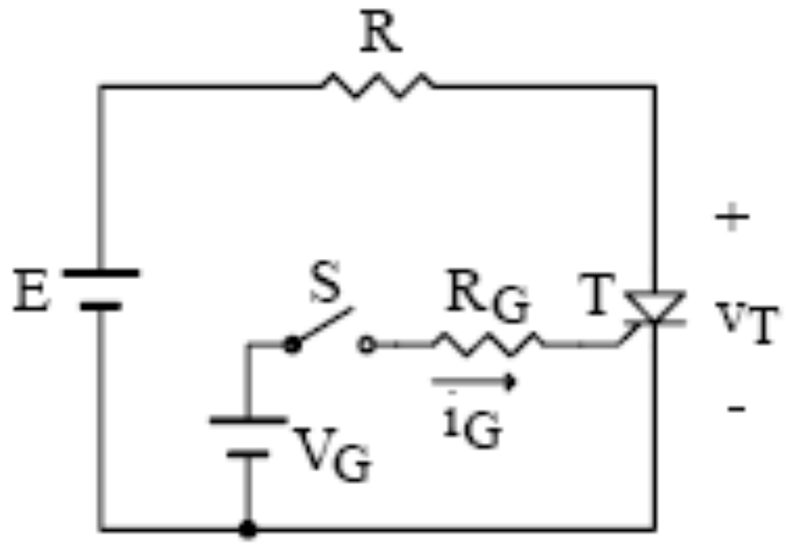


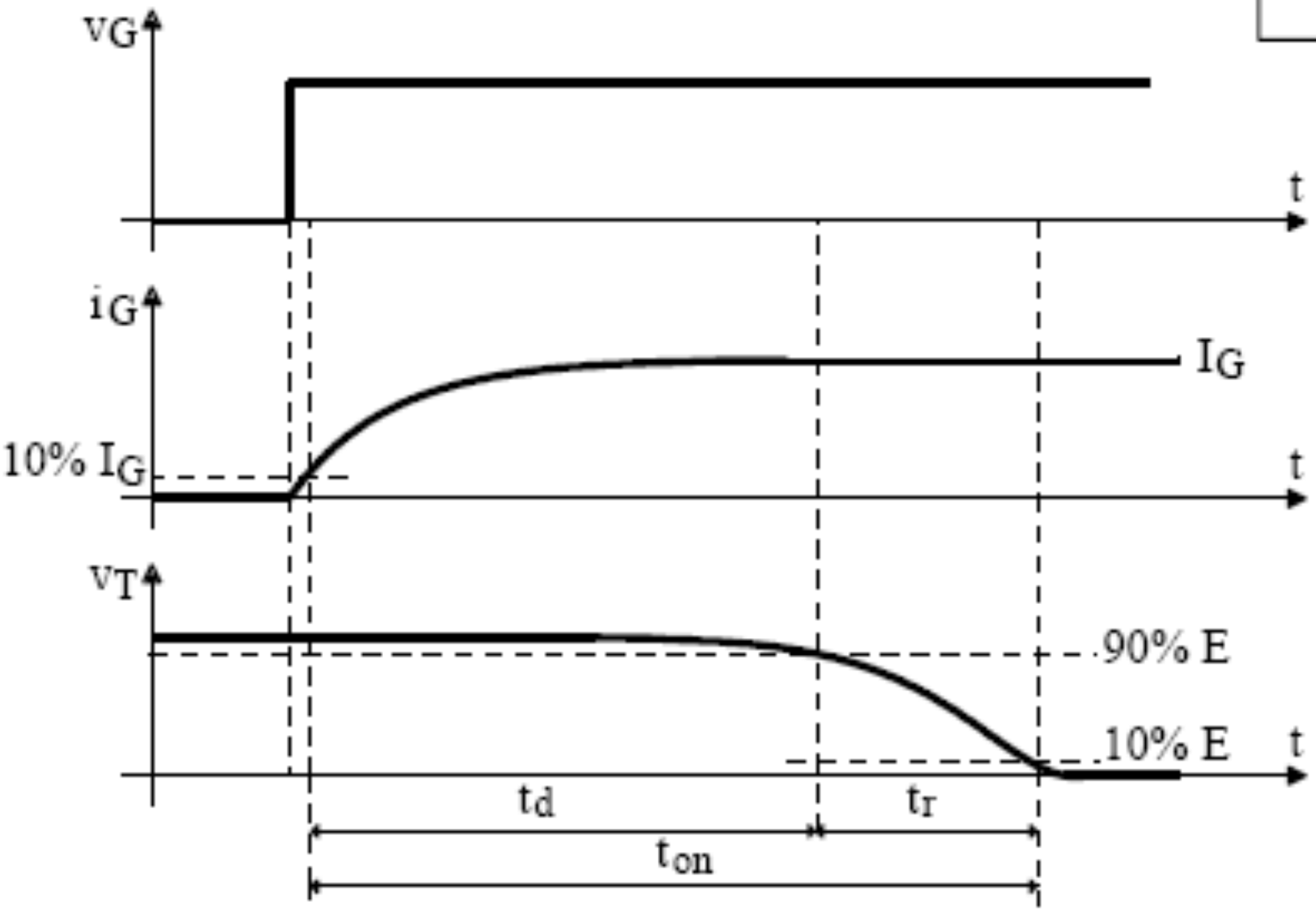


Circuitos para auxiliar na proteção de tiristores e
evitar disparos intempestivos

Comutação de Tiristores

Disparo:



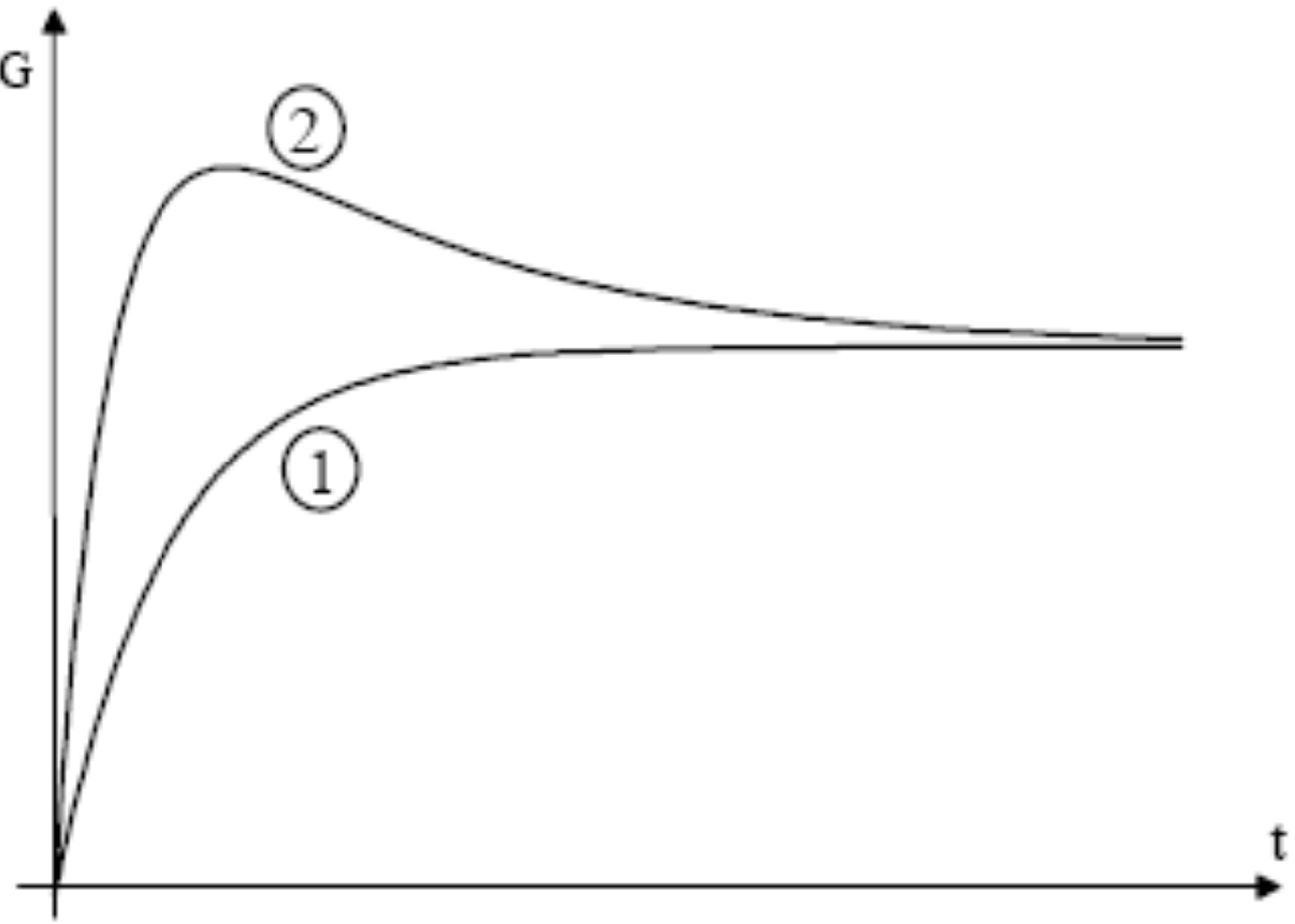


Comutação de Tiristores

Disparo:

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

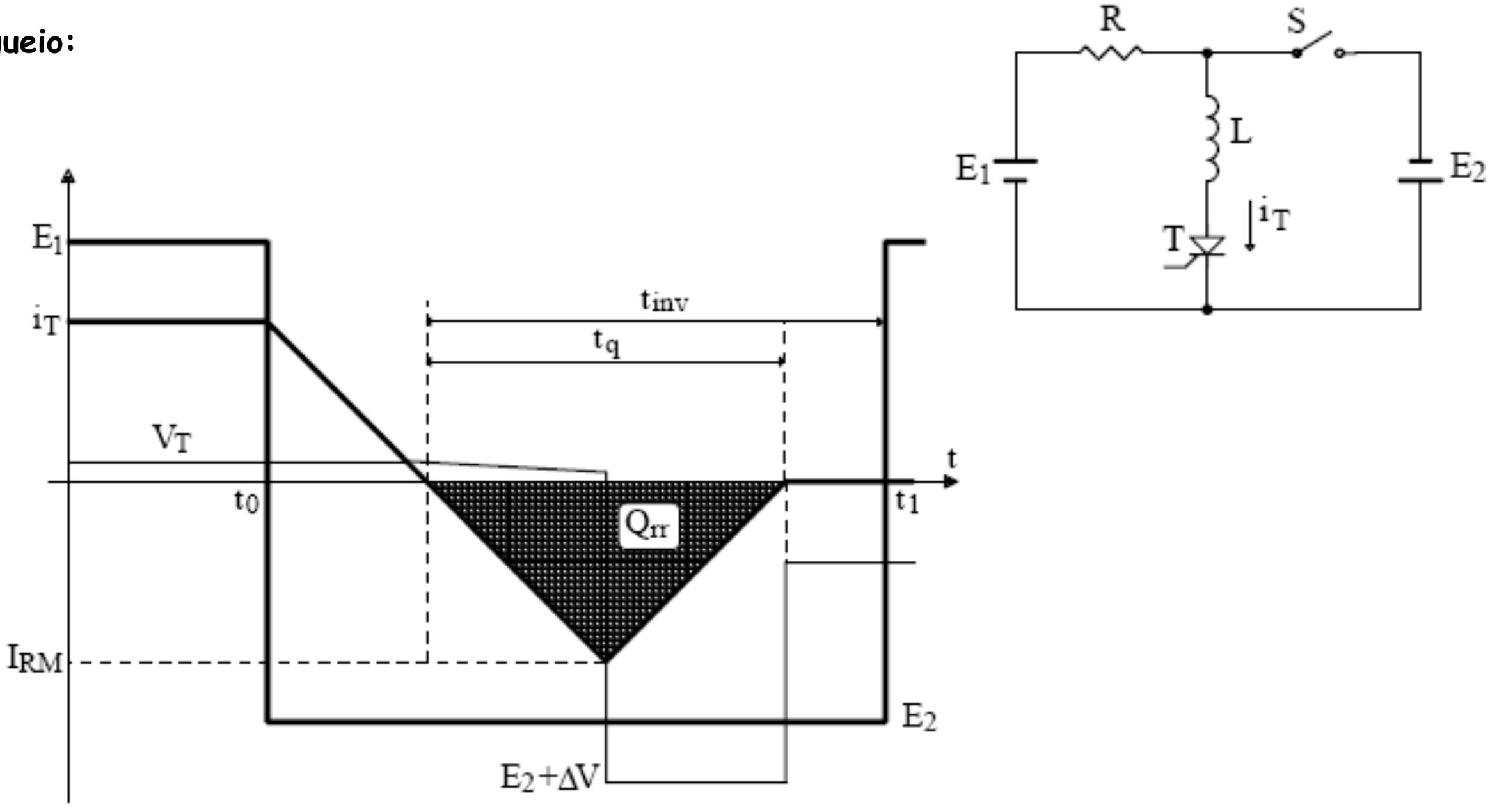
$$t_{on} = t_d + t_r$$



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 µs à 200 µs.

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.

www.onsemi.com

Características de Tiristores Comerciais

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.

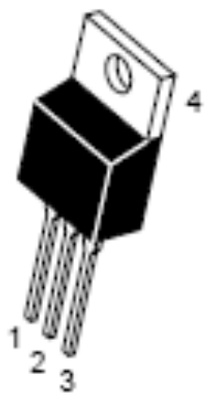
Features

- 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®

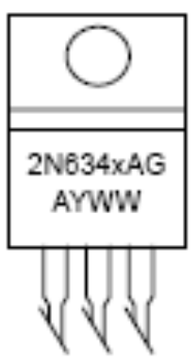
http://onsemi.com

TRIACS
12 AMPERES RMS
600 thru 800 VOLTS

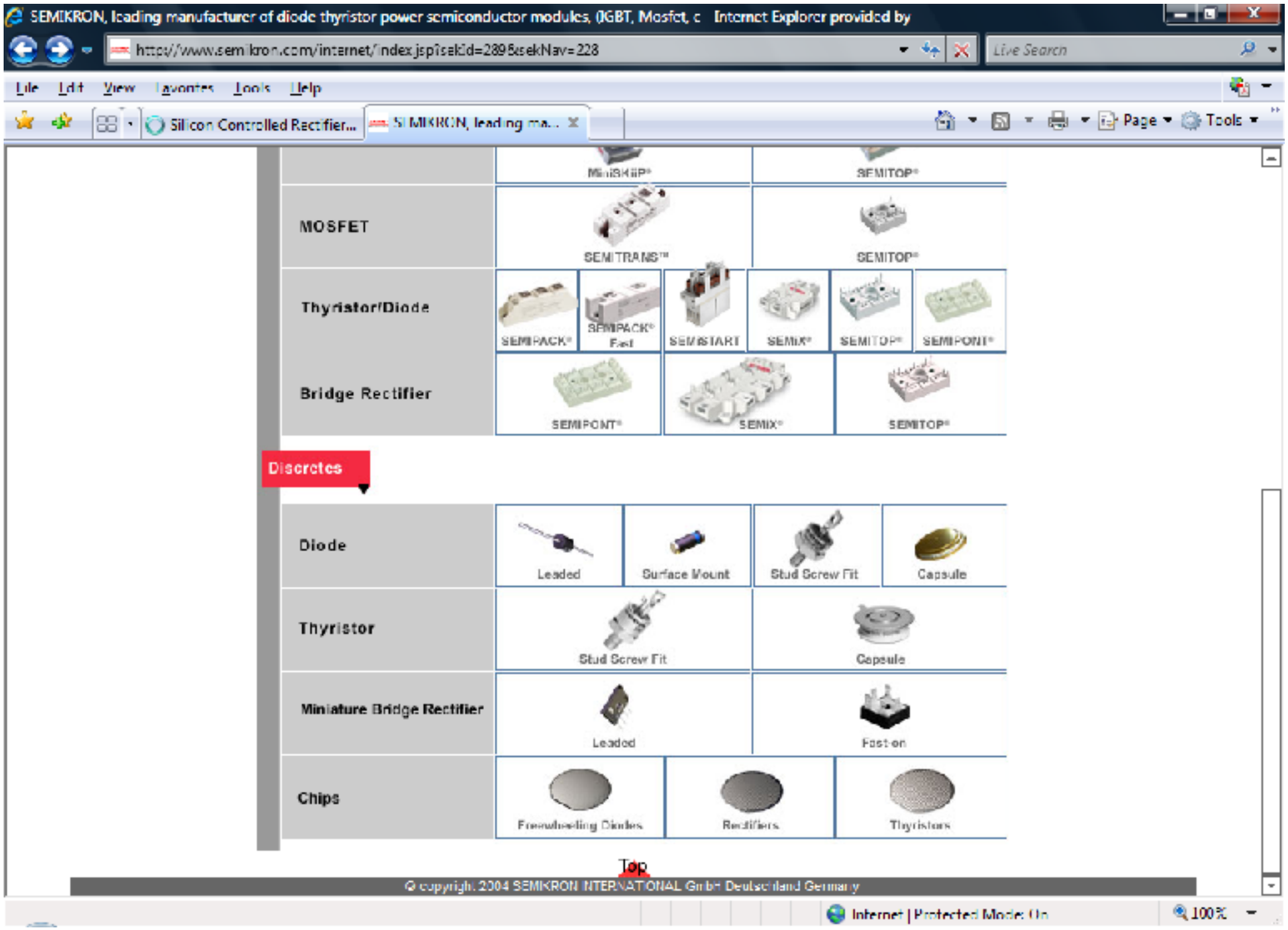


TO−220AB
CASE 221A
STYLE 4

MARKING DIAGRAM

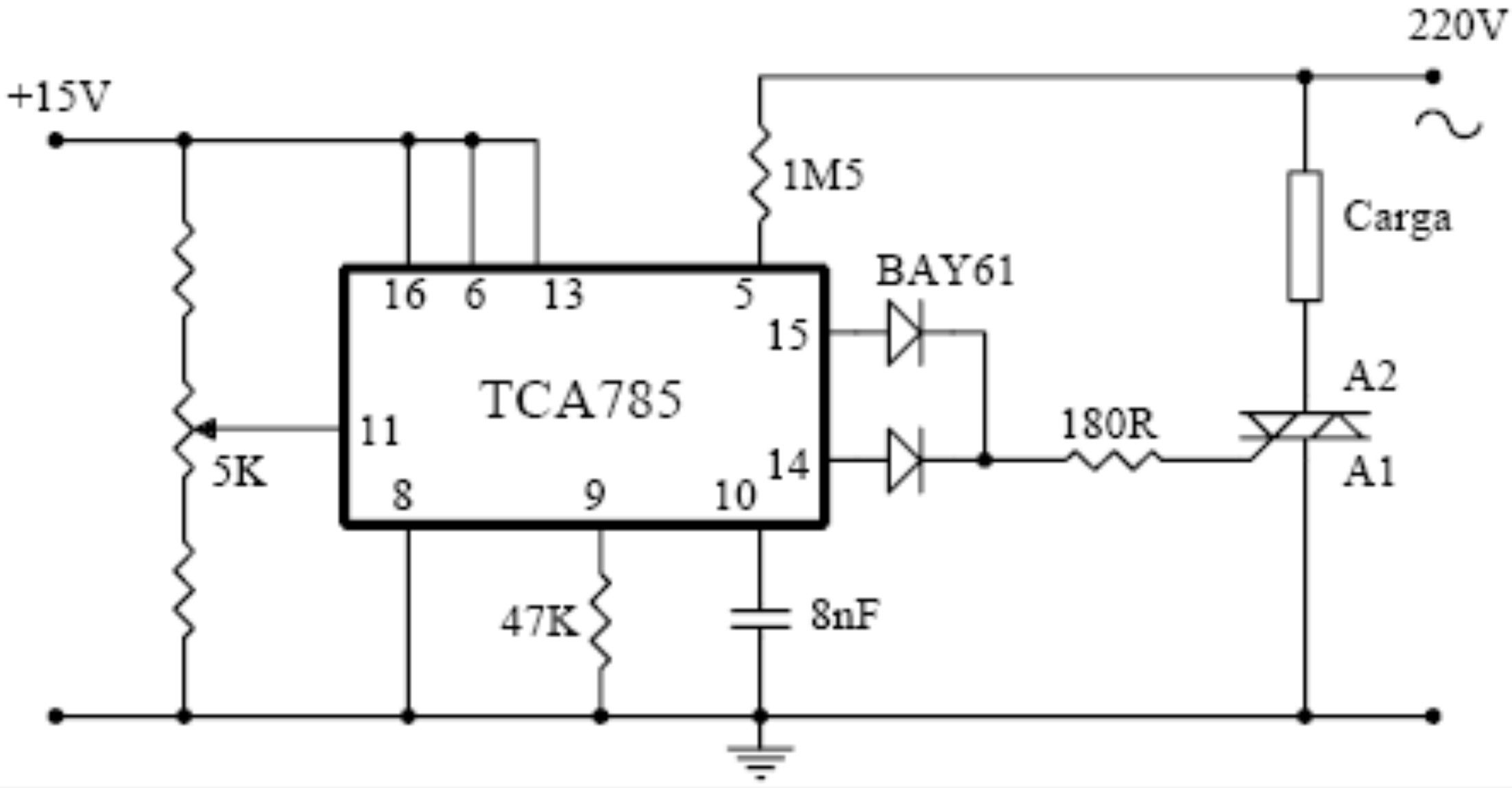


Características de Tiristores Comerciais



www.semikron.com

Acionamento de Tiristores



Acionamento de Tiristores

FAIRCHILD
SEMICONDUCTOR

GlobalOptoisolator™

VDE | UL | CSA | SPT | SRMKD | DRMKD | NRMKD | IMNT

MOC3061
MOC3062
MOC3063

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.

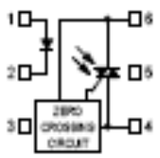
- Simplifies Logic Control of 115/240 Vac Power
- Zero Voltage Crossing
- dv/dt of 1500 V/µs Typical, 600 V/µs Guaranteed
- *To order devices that are tested and marked per VDE 0884 requirements, the suffix "V" must be included at end of part number. VDE 0884 is a test option.*

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

STANDARD THRU HOLE

COUPLER SCHEMATIC

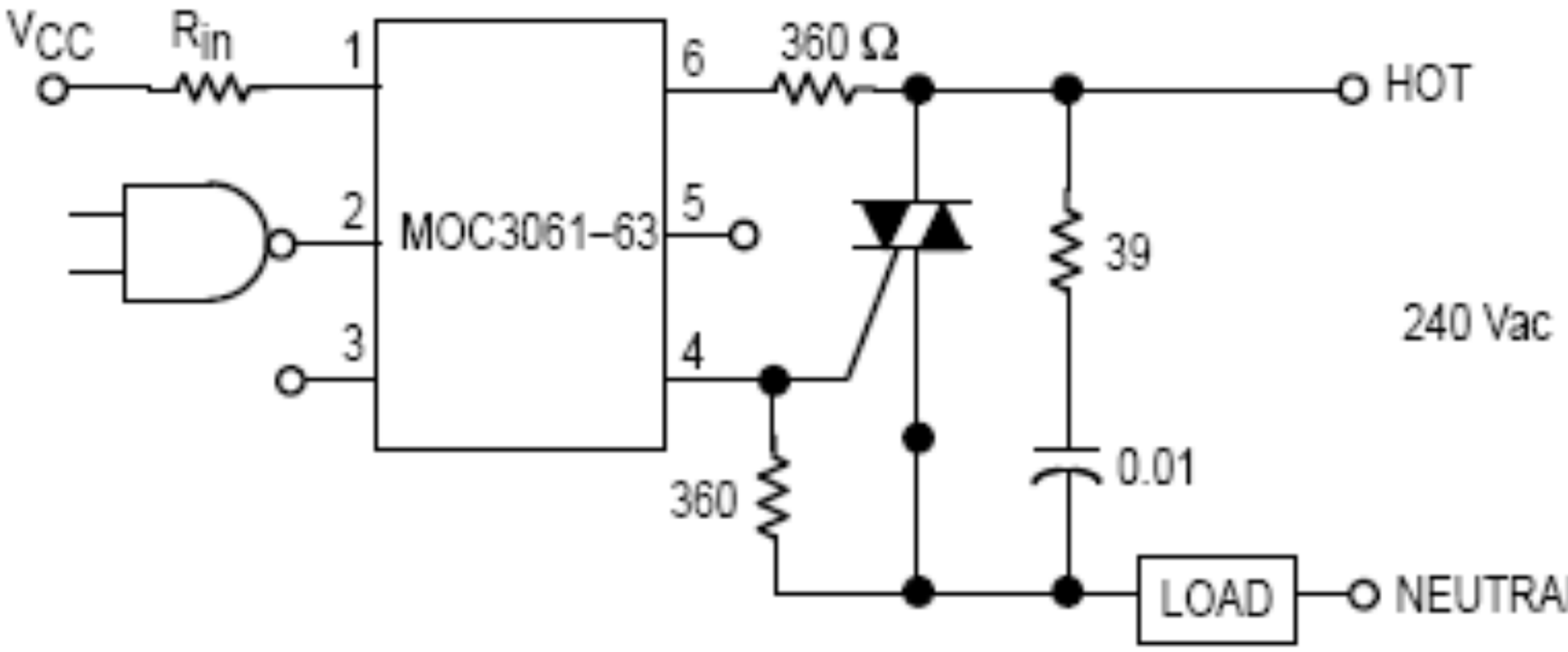


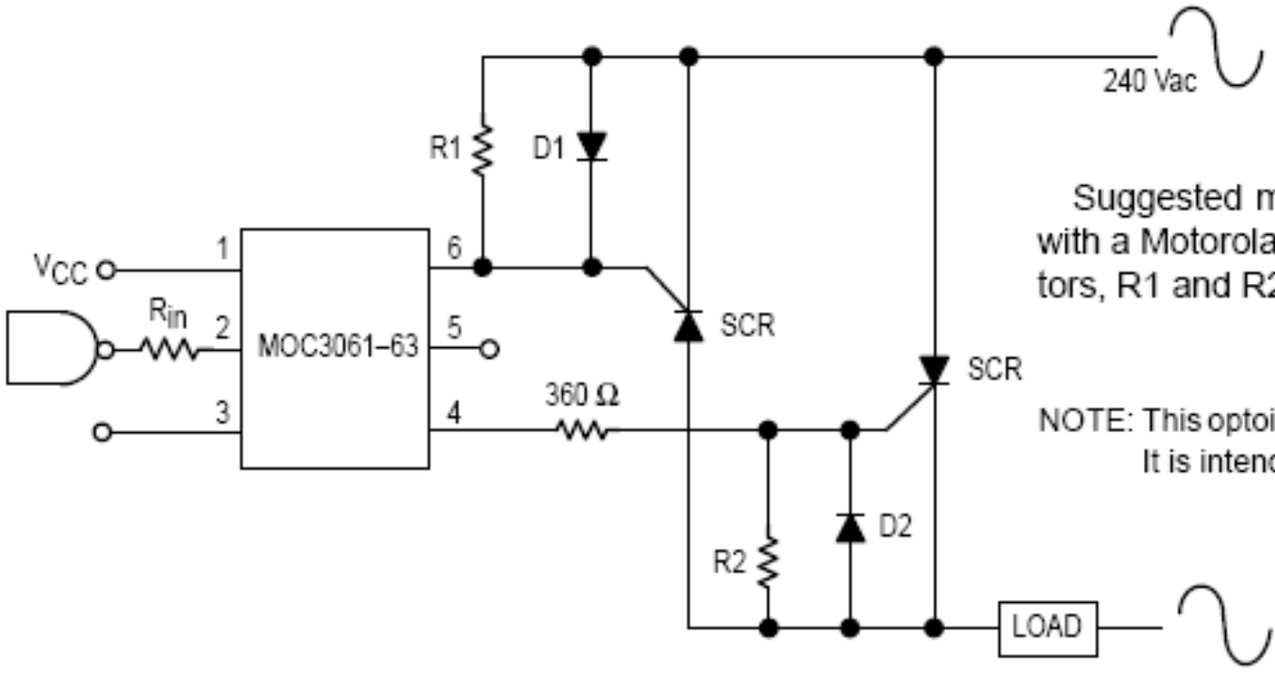
1. ANODE
2. CATHODE
3. NC
4. MAIN TERMINAL
5. SUBSTRATE
   DO NOT CONNECT
6. MAIN TERMINAL

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE			
Reverse Voltage	V_R	6	Volts
Forward Current — Continuous	I_F	60	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Output Driver Derate above 25°C	P_D	120 1.41	mW 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°C Derate above 25°C	P_D	150 1.76	mW 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°C Derate above 25°C	P_D	250 2.94	mW 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_L	260	°C

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.