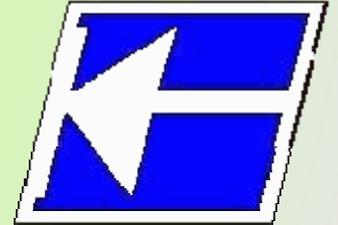


**Centro Federal de Educação Tecnológica de Santa Catarina**  
**Departamento Acadêmico de Eletrônica**  
**Conversores Estáticos**



# **Semicondutores Aplicados a Conversores CA-CC (tiristores)**

**Prof. Clóvis Antônio Petry.**

**Florianópolis, fevereiro de 2008.**

# Bibliografia para esta aula

## Capítulo 4: Dispositivos tiristores

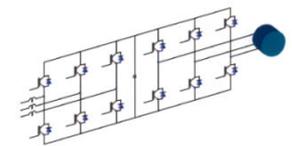
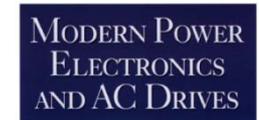
### 1. Semicondutores aplicados aos conversores CA-CC (tiristores).



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



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



BIMAL K. BOSE

[www.cefetsc.edu.br/~petry](http://www.cefetsc.edu.br/~petry)

# Nesta aula

## **Semicondutores aplicados a conversores CA-CC (tiristores):**

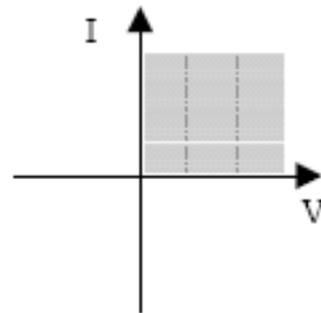
1. Introdução;
2. Características dos componentes ideais;
3. Características dos componentes reais;
4. Perdas no tiristor;
5. Cálculo de dissipador de calor.

# Quadrantes de condução de semicondutores

## Operações Básicas Desejadas

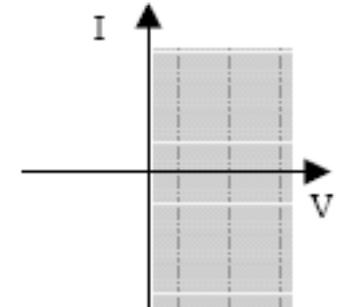
### Operação em um quadrante

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



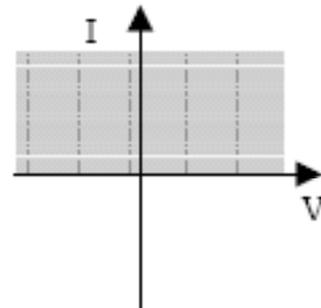
### Operação em dois quadrantes com corrente bidirecional

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



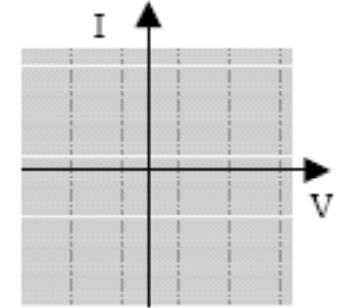
### Operação em dois quadrantes com tensão bidirecional

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



### Operação em quatro quadrantes

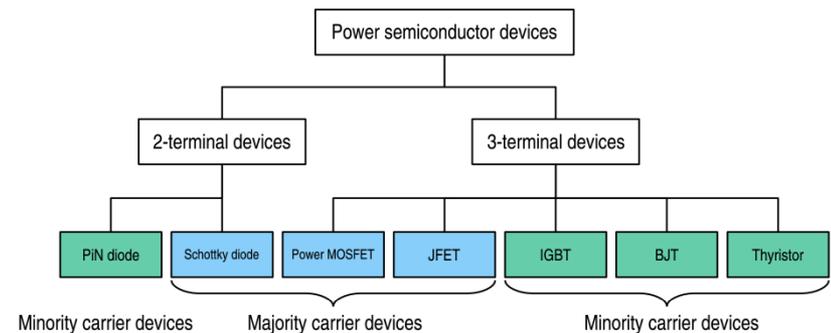
- ◆ Arranjo de diodos com transistores bipolares



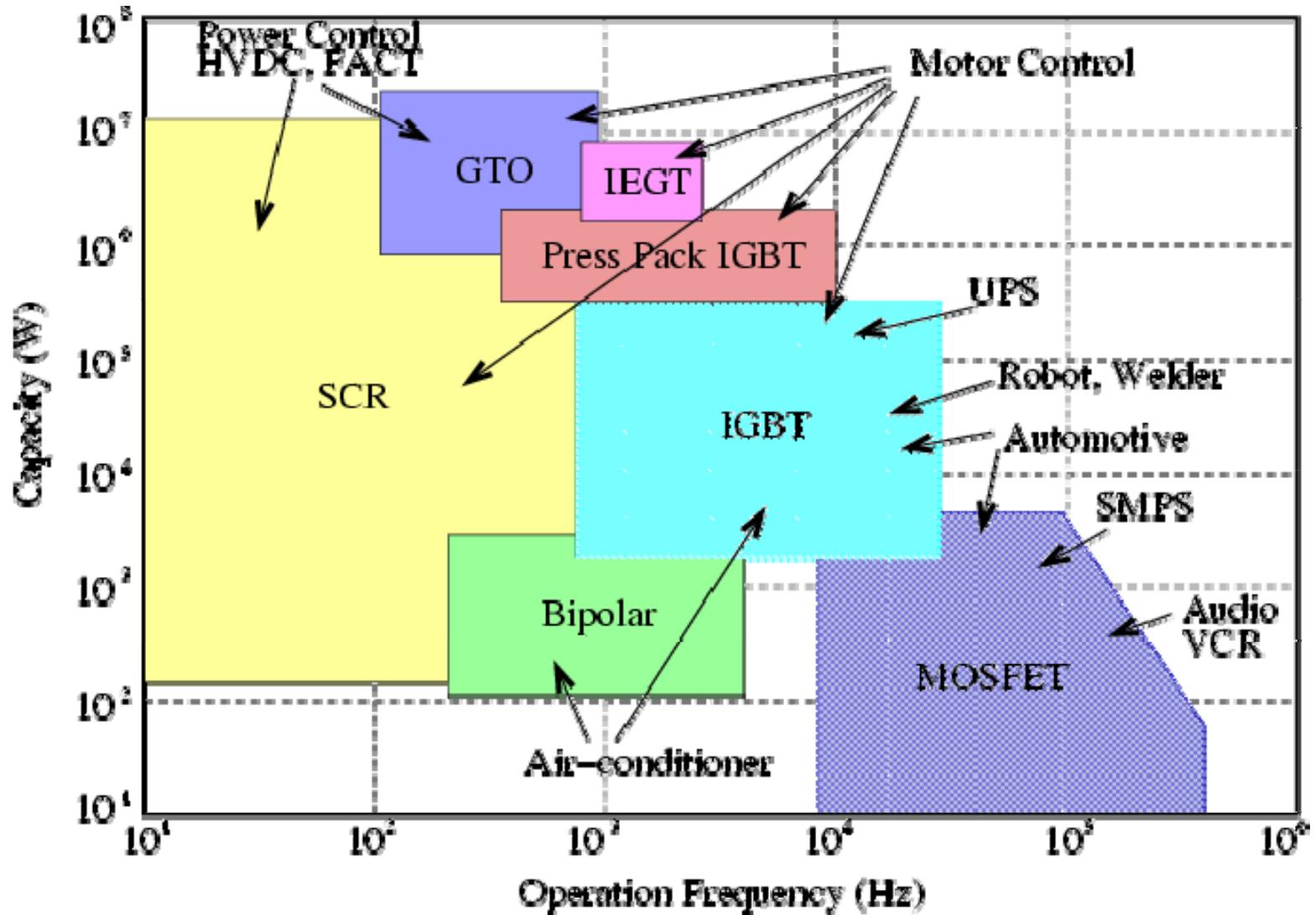
# Semicondutores para eletrônica de potência

## Semicondutores utilizados em eletrônica de potência:

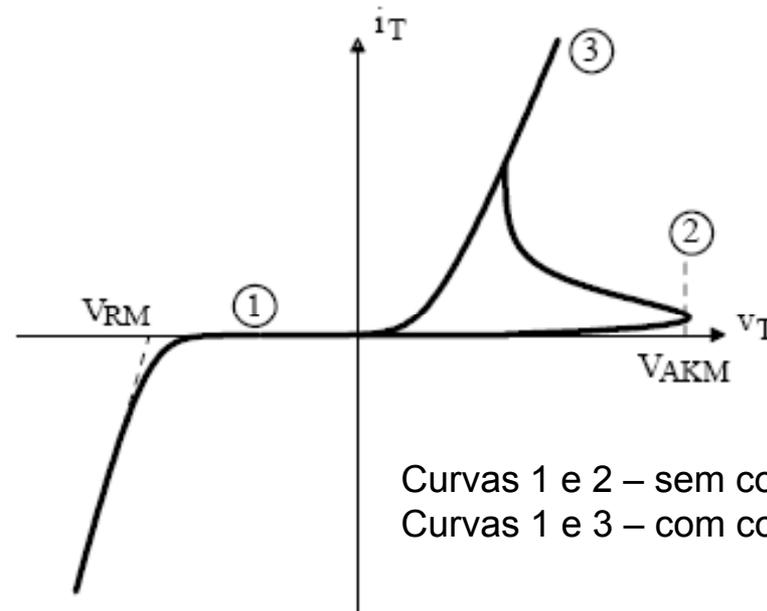
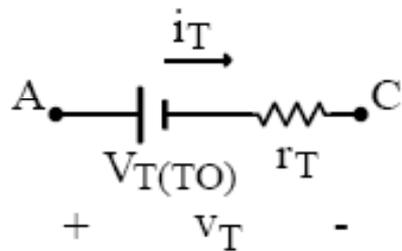
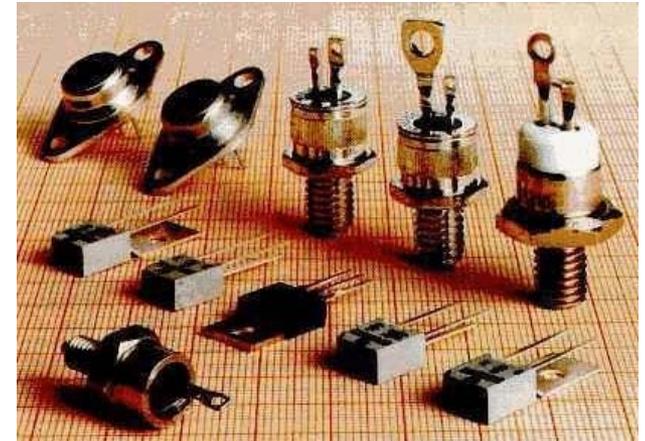
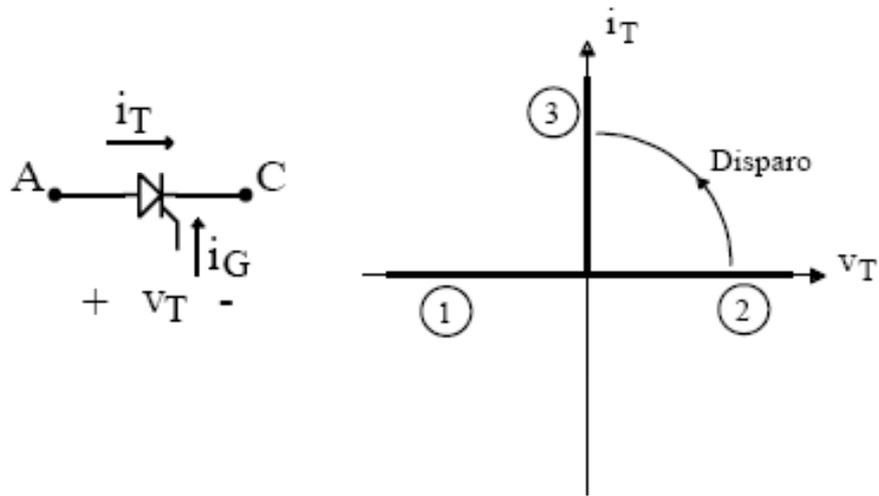
- Diode
- Thyristor or silicon-controlled rectifier (SCR)
- Triac
- Gate turn-off thyristor (GTO)
- Bipolar junction transistor (BJT or BPT)
- Power MOSFET
- Static induction transistor (SIT)
- Insulated gate bipolar transistor (IGBT)
- MOS-controlled thyristor (MCT)
- Integrated gate-commutated thyristor (IGCT)



# Semicondutores para eletrônica de potência



# Tiristor ideal e real

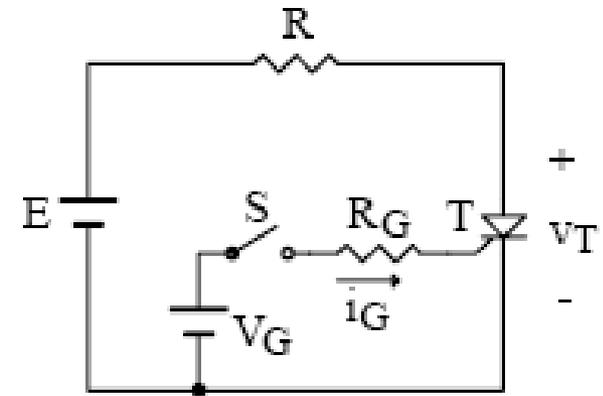
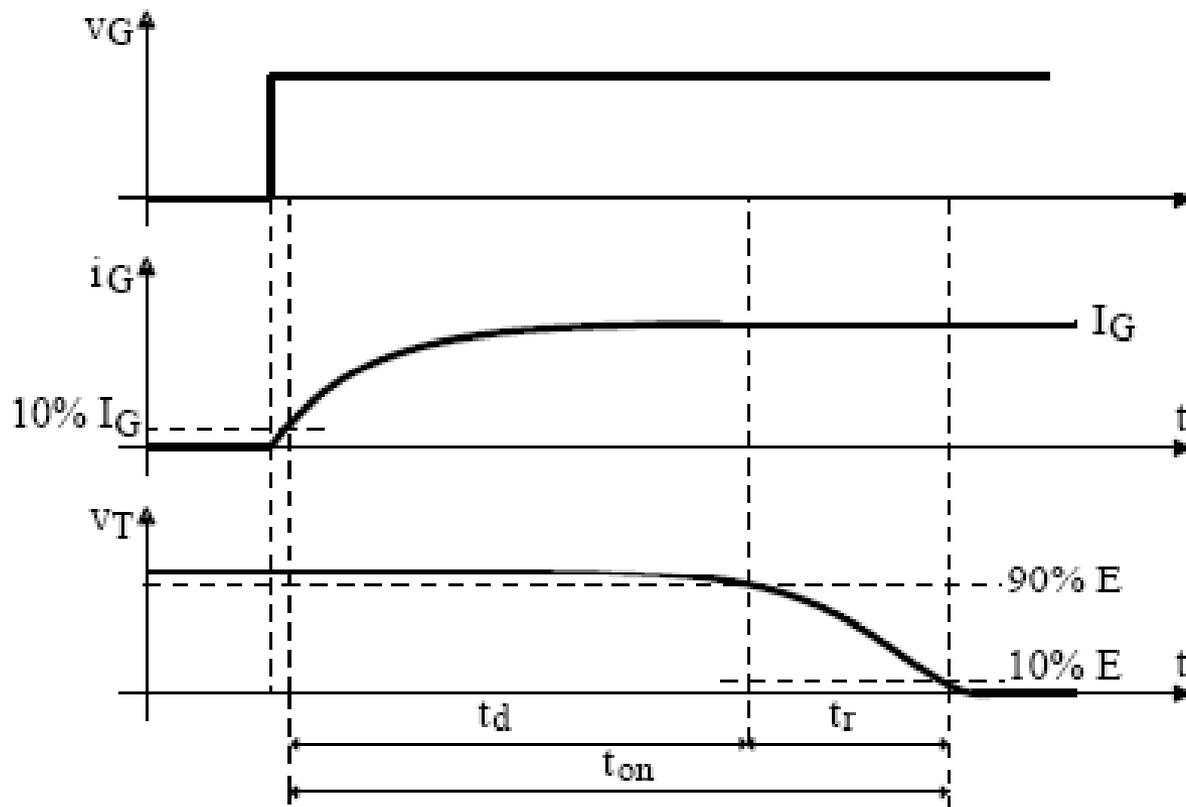


Curvas 1 e 2 – sem corrente de gatilho  
Curvas 1 e 3 – com corrente de gatilho

Característica estática

# Comutação – Características dinâmicas

Disparo

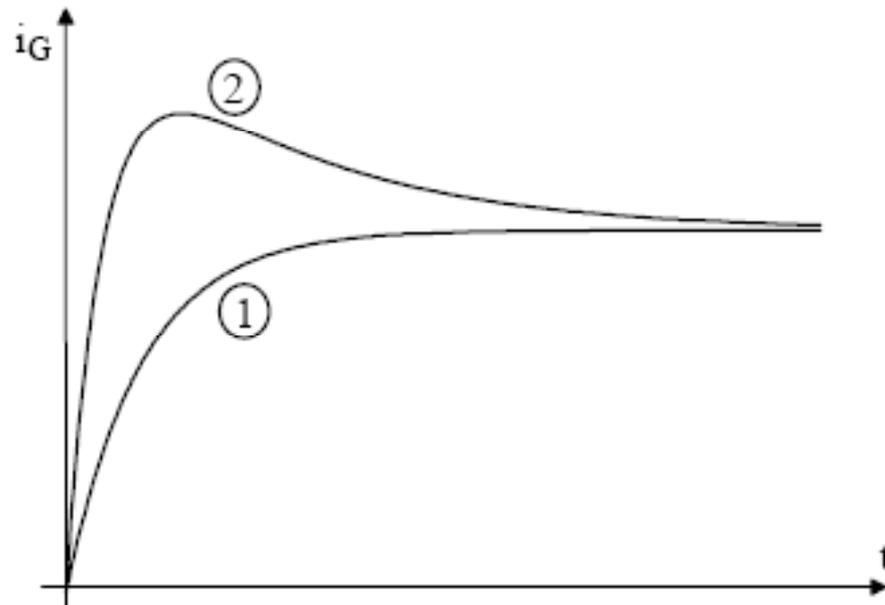


# Comutação – Características dinâmicas

## Disparo

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

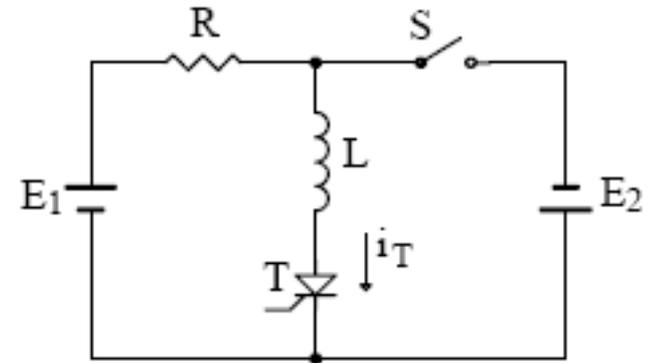
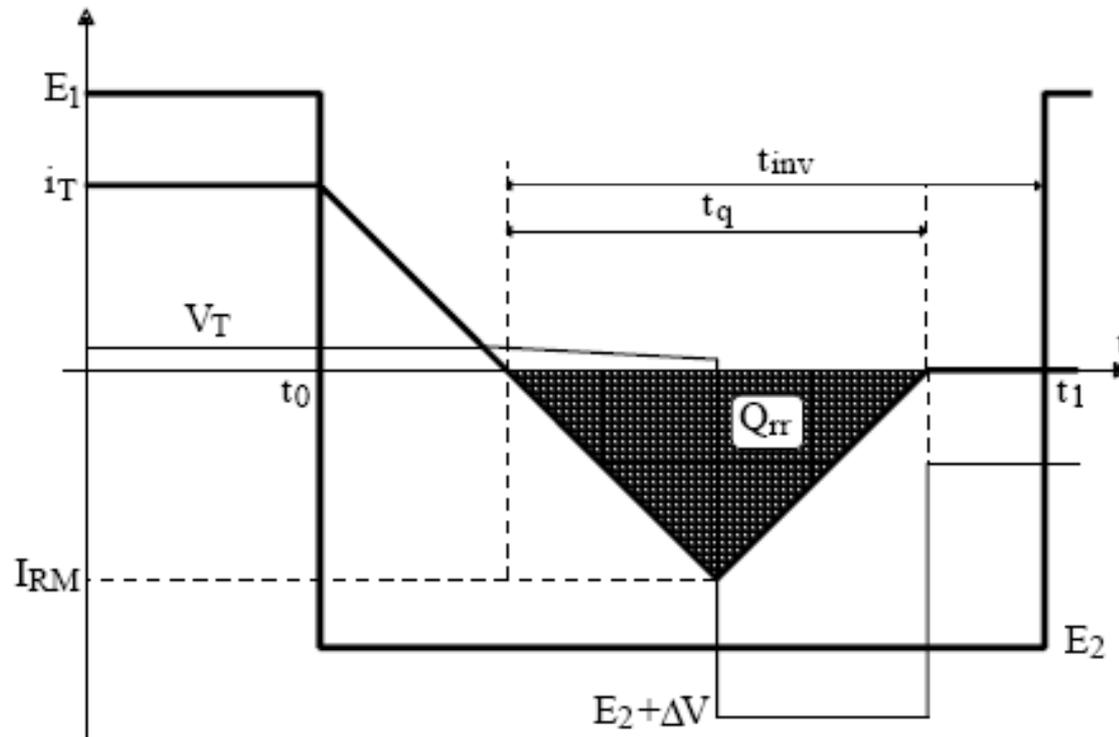
$$t_{on} = t_d + t_r$$



Influência da corrente de gatilho no tempo de retardo

# Comutação – Características dinâmicas

## 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;

**Simulação**

- Bloqueio.

**Simulação**

# 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.

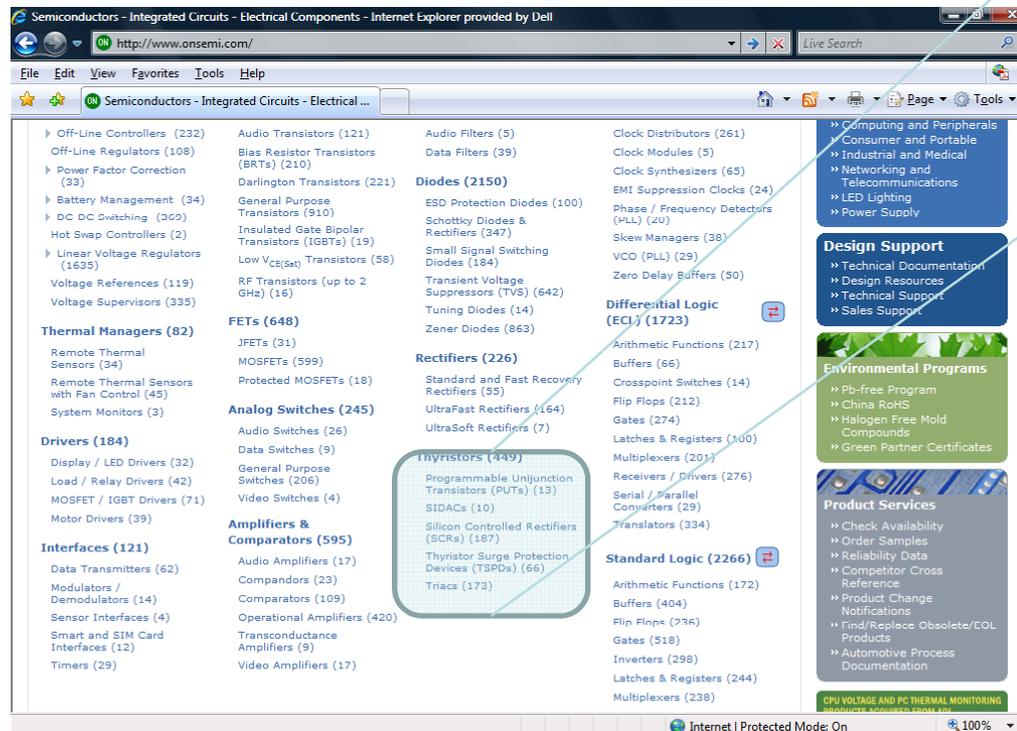
# Características de tiristores comerciais

## 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)



# 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



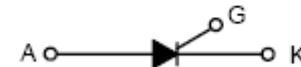
**ON Semiconductor®**

<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>

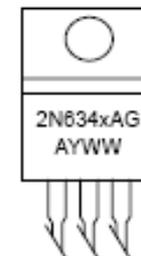
**TRIACS**  
**12 AMPERES RMS**  
**600 thru 800 VOLTS**



**MARKING  
DIAGRAM**



**TO-220AB**  
**CASE 221A**  
**STYLE 4**



# Características de tiristores comerciais

The screenshot displays the SEMIKRON website's product catalog, organized into a grid of categories and sub-categories. The browser window shows the URL <http://www.semikron.com/internet/index.jsp?sekId=289&sekNav=228> and the page title "Silicon Controlled Rectifier...".

	MiniSKiiP®	SEMITOP®		
<b>MOSFET</b>	SEMITRANS™	SEMITOP®		
<b>Thyristor/Diode</b>	SEMIACK® Fast	SEMIACK® SEMISTART SEMIK® SEMITOP® SEMIKONT®		
<b>Bridge Rectifier</b>	SEMIKONT®	SEMIK® SEMITOP®		
<b>Discretes</b>				
<b>Diode</b>	Leaded	Surface Mount	Stud Screw Fit	Capsule
<b>Thyristor</b>	Stud Screw Fit	Capsule		
<b>Miniature Bridge Rectifier</b>	Leaded	Fast-on		
<b>Chips</b>	Freewheeling Diodes	Rectifiers	Thyristors	

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Internet | Protected Mode: On 100%

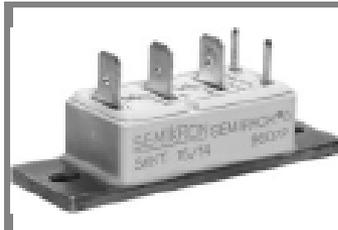
<http://www.semikron.com>

# Características de tiristores comerciais

Modules - Thyristor / Diode											
Type	$V_{RRM}$	$V_{DRM}$	$I_{TAV}$	$I_{FAV}$	$T_c$	$I_{TSM}@T_j=25^\circ C$	$I_{FSM}$	$T_{vj}$	$R_{th(j-c)}$ cont.	Cases	Circuit
	V		A		°C	A		°C	KW		
SKKT 15	600-1600		15		75	320		- 40 ... + 125	1,6	A 1	
SKKT 20	800-1600		20		80	320		- 40 ... + 125	1,2	A 46	
SKKT 27	800-1800		27		82	550		- 40 ... + 125	0,9	A 46	
SKKT 42	800-1800		40		85	1000		- 40 ... + 125	0,65	A 46	
SKKT 57	800-2200		55		80	1500		- 40 ... + 125	0,57	A 46	
SKKT 72	800-2200		70		85	1600		- 40 ... + 125	0,35	A 46	
SKKT 92	800-1800		95		85	2000		- 40 ... + 125	0,28	A 46	
SKKT 106	800-1800		106		85	2250		- 40 ... + 130	0,28	A 46	
SKKT 122	800-1800		122		88	3600		- 40 ... + 125	0,2	A 21	
SKKT 132	800-1800		130		87	4700		- 40 ... + 125	0,18	A 21	
SKKT 162	800-1800		160		83	5400		- 40 ... + 125	0,17	A 21	
SKKT 172	1400-1800		172		86	5400		- 40 ... + 125	0,16	A 21	
SKKT 250	800-1800		250		85	9000		- 40 ... + 130	0,14	A 73b	
SKKT 273	1200-1800		273		85	9000		- 40 ... + 130	0,1	A 43a	
SKKT 280	2000-2200		280		79	8500		- 40 ... + 125	0,11	A 73b	
SKKT 323	1200-1600		323		84	9500		- 40 ... + 130	0,09	A 43a	
SKKT 330	800-1800		330		80	9500		- 40 ... + 130	0,11	A 73b	
*SKKT 430	1600-2200		430		86	15000		- 40 ... + 125	0,06	A 60 a	
*SKKT 500	800-1800		500		89	17000		- 40 ... + 130	0,06	A 60 a	
SKKT 570	1200-1800		570		85	19000		- 40 ... + 135	0,07	A 60b	
SKKT 132 H4	2000-2200		132		84	4500		- 40 ... + 125	0,17	A 21	
SKKT 162 H4	2000-2200		162		77	5200		- 40 ... + 125	0,16	A 21	
SKKT 106B	800-1800		106		85	2250		- 40 ... + 130	0,28	A 46	
SKKT 20B	800-1600		20		80	320		- 40 ... + 125	1,2	A 46	
SKKT 27B	800-1800		27		82	550		- 40 ... + 125	0,9	A 46	
SKKT 42B	800-1800		40		85	1000		- 40 ... + 125	0,65	A 46	
SKKT 57B	800-2200		55		80	1500		- 40 ... + 125	0,57	A 46	
SKKT 72B	800-2200		70		85	1600		- 40 ... + 125	0,35	A 46	
SKKT 92B	800-1800		95		85	2000		- 40 ... + 125	0,28	A 46	

# Características de tiristores comerciais

## SKKT 15, SKKH 15



SEMIPACK<sup>®</sup> 0

Thyristor / Diode Modules

SKKT 15

SKKH 15

### Features

- Heat transfer through aluminium oxide ceramic isolated metal baseplate
- Hard soldered joints for high reliability
- UL recognized, file no. E 63 932

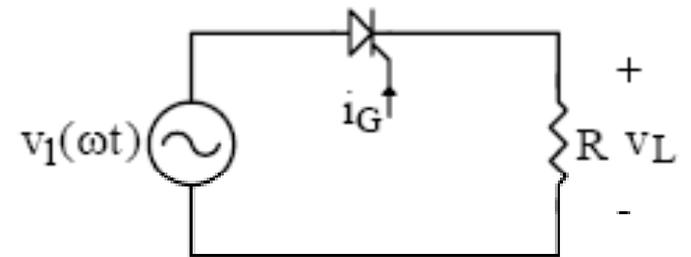
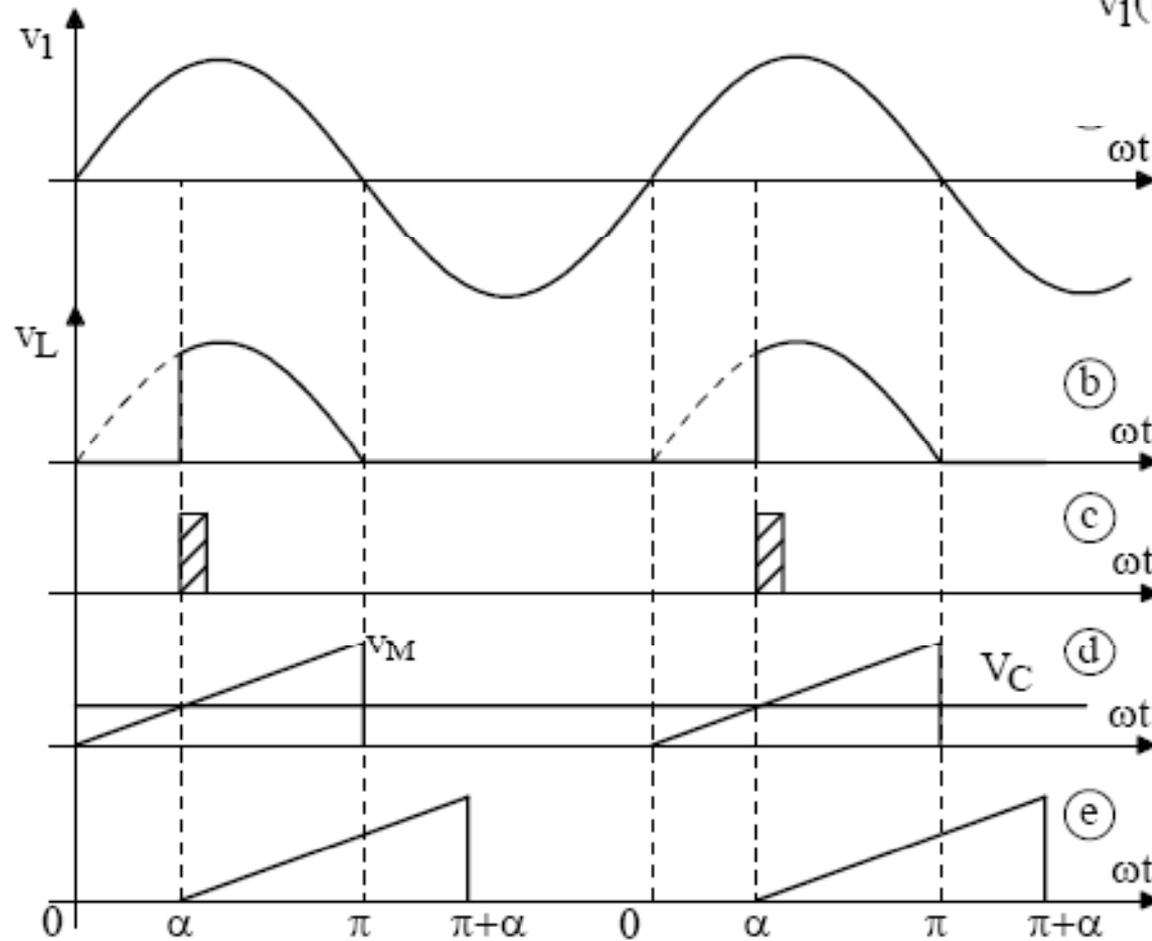
### Typical Applications

- DC motor control (e. g. for machine tools)
- Temperature control (e. g. for ovens, chemical processes)
- Professional light dimming (studios, theaters)

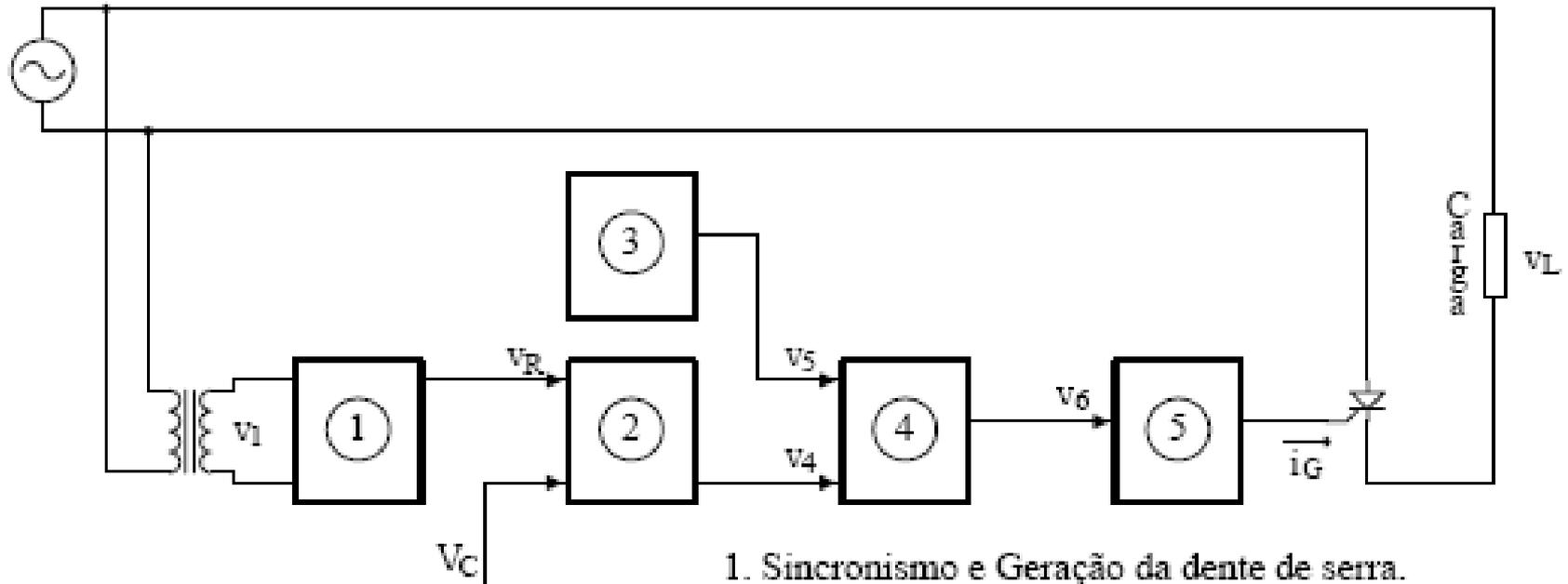
$V_{ORM}$ V	$V_{ORM} V_{ORM}$ V	$I_{T(RMS)} = 24$ A (maximum value for continuous operation) $I_{T(RMS)} = 15$ A (min. 180; $T_c = 75$ °C)	
700	600	SKKT 15A06E	SKKH 15A06E
900	600	SKKT 15A08E	SKKH 15A08E
1300	1200	SKKT 15I12E	SKKH 15I12E
1500	1400	SKKT 15I14E	SKKH 15I14E
1700	1600	SKKT 15I16E	SKKH 15I16E

Symbol	Conditions	Values	Units
$I_{T(RMS)}$	min. 180; $T_c = 85$ (100) °C;	13,5 (9,5)	A
$I_T$	P13A100; $T_c = 45$ °C; 82 / 88	14 / 17	A
$I_{T(RMS)}$	P13A100; $T_c = 45$ °C; W1 / W5	21 / 3 ± 12	A
$t_{rise}$	$T_c = 25$ °C; 10 ms	320	A
	$T_c = 125$ °C; 10 ms	380	A
$\rho_i$	$T_c = 25$ °C; 8,3 ... 10 ms	510	A $\mu$ s
	$T_c = 125$ °C; 8,3 ... 10 ms	390	A $\mu$ s
$V_T$	$T_c = 25$ °C; $I_T = 75$ A	max. 2,45	V
$V_{T(100)}$	$T_c = 125$ °C	max. 1,1	V
$r_T$	$T_c = 125$ °C	max. 20	m $\Omega$
$I_{T(100)} / I_{T(10)}$	$T_c = 125$ °C; $V_{T(100)} = V_{T(10)}$ ; $V_{T(100)} = V_{T(10)}$	max. 8	mA
$t_{gr}$	$T_c = 25$ °C; $I_T = 1$ A; $dI_T/dt = 1$ A/ $\mu$ s	1	$\mu$ s
$t_{gr}$	$V_D = 0,87 * V_{T(100)}$	1	$\mu$ s
$(dI_T/dt)_{cr}$	$T_c = 125$ °C	max. 100	A/ $\mu$ s
$(dV_D/dt)_{cr}$	$T_c = 125$ °C	max. 1000	V/ $\mu$ s
$t_{tr}$	$T_c = 125$ °C	80	$\mu$ s
$I_{T(10)}$	$T_c = 25$ °C; $I_T$ / max.	50 / 150	mA
$I_{T(10)}$	$T_c = 25$ °C; $R_{T(10)} = 33$ $\Omega$ ; $I_T$ / max.	150 / 300	mA
$V_{T(10)}$	$T_c = 25$ °C; d.c.	min. 3	V
$V_{T(10)}$	$T_c = 25$ °C; d.c.	min. 100	mA
$V_{T(10)}$	$T_c = 125$ °C; d.c.	max. 0,25	V
$I_{T(10)}$	$T_c = 125$ °C; d.c.	max. 5	mA
$P_{T(10-10)}$	cont.; per thyristor / per module	1,8 / 0,8	KW
$P_{T(10-10)}$	min. 180; per thyristor / per module	1,7 / 0,9	KW
$P_{T(10-10)}$	rec. 120; per thyristor / per module	1,8 / 0,9	KW
$P_{T(10-10)}$	per thyristor / module	0,2 / 0,1	KW
$T_c$		-40 ... + 125	°C
$T_{stg}$		-40 ... + 125	°C
$V_{max}$	a. c. 50 Hz; rms a.; 1 s / 1 min.	3800 / 3000	V-
$M_{th}$	to heatsink	1,5 ± 15 %	mm
$\alpha$		5 * 9,81	m/s <sup>2</sup>
$m$	approx.	50	g
Case	SKKT	A 1	
	SKKH	A 2	

# Acionamento de tiristores

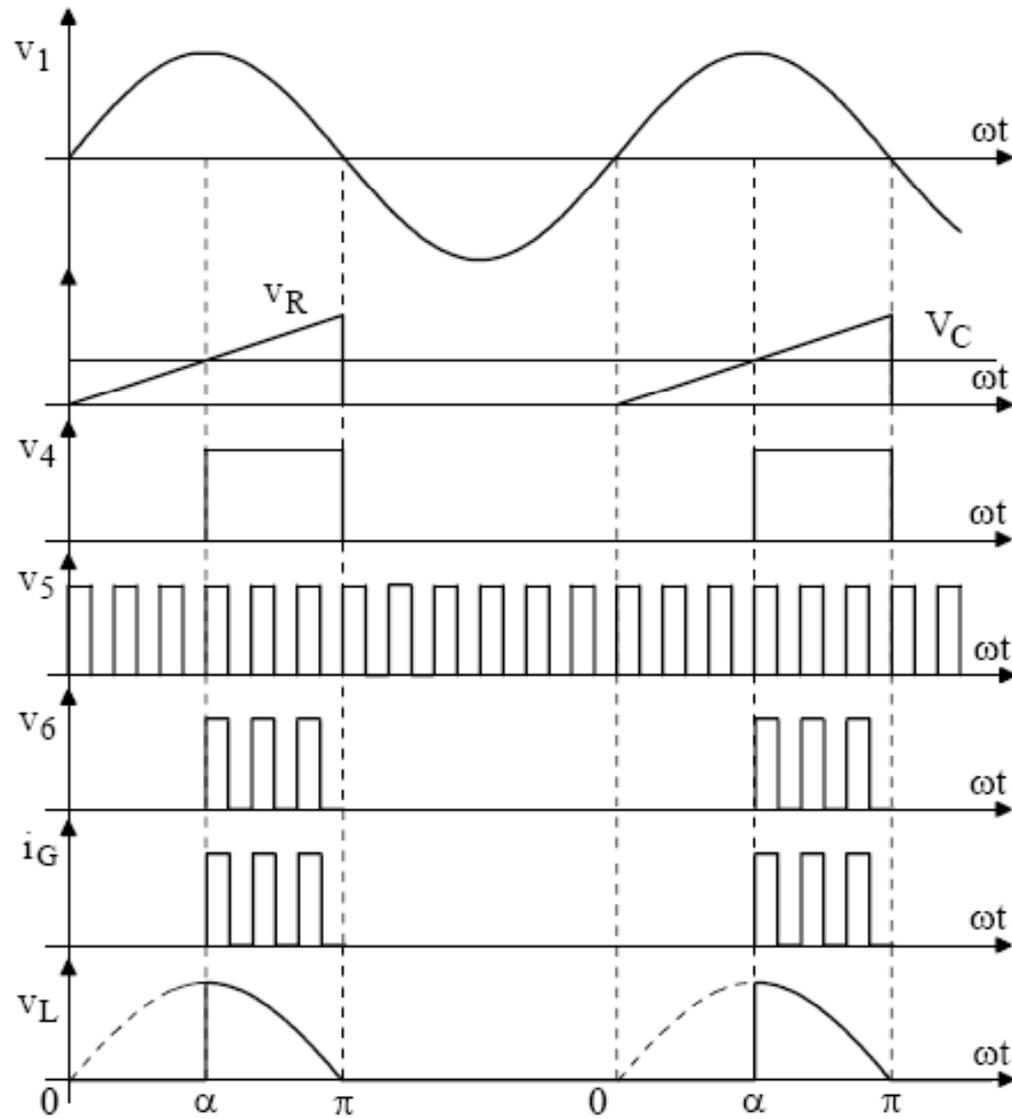


# Acionamento de tiristores

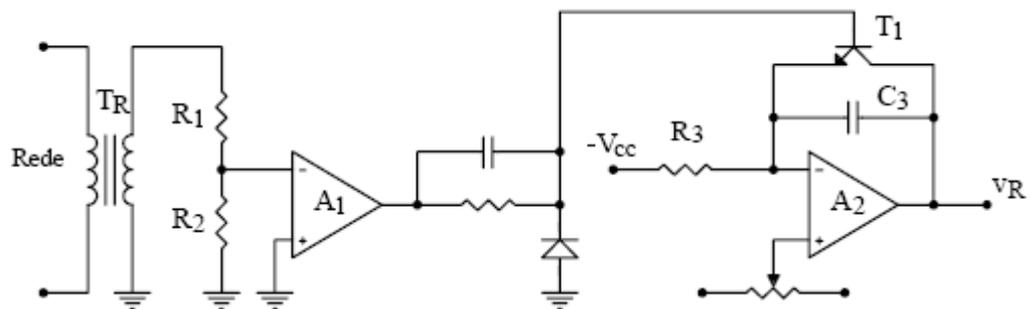
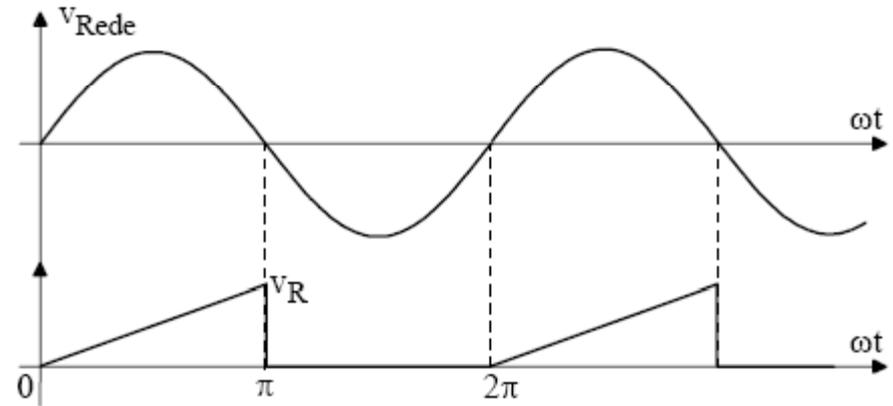
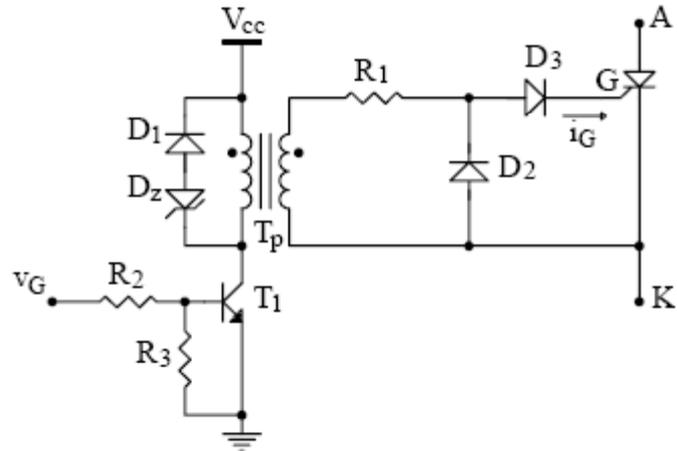


1. Sincronismo e Geração da dente de serra.
2. Comparador.
3. Oscilador.
4. Porta Lógica "E".
5. Amplificação, isolamento e ataque.

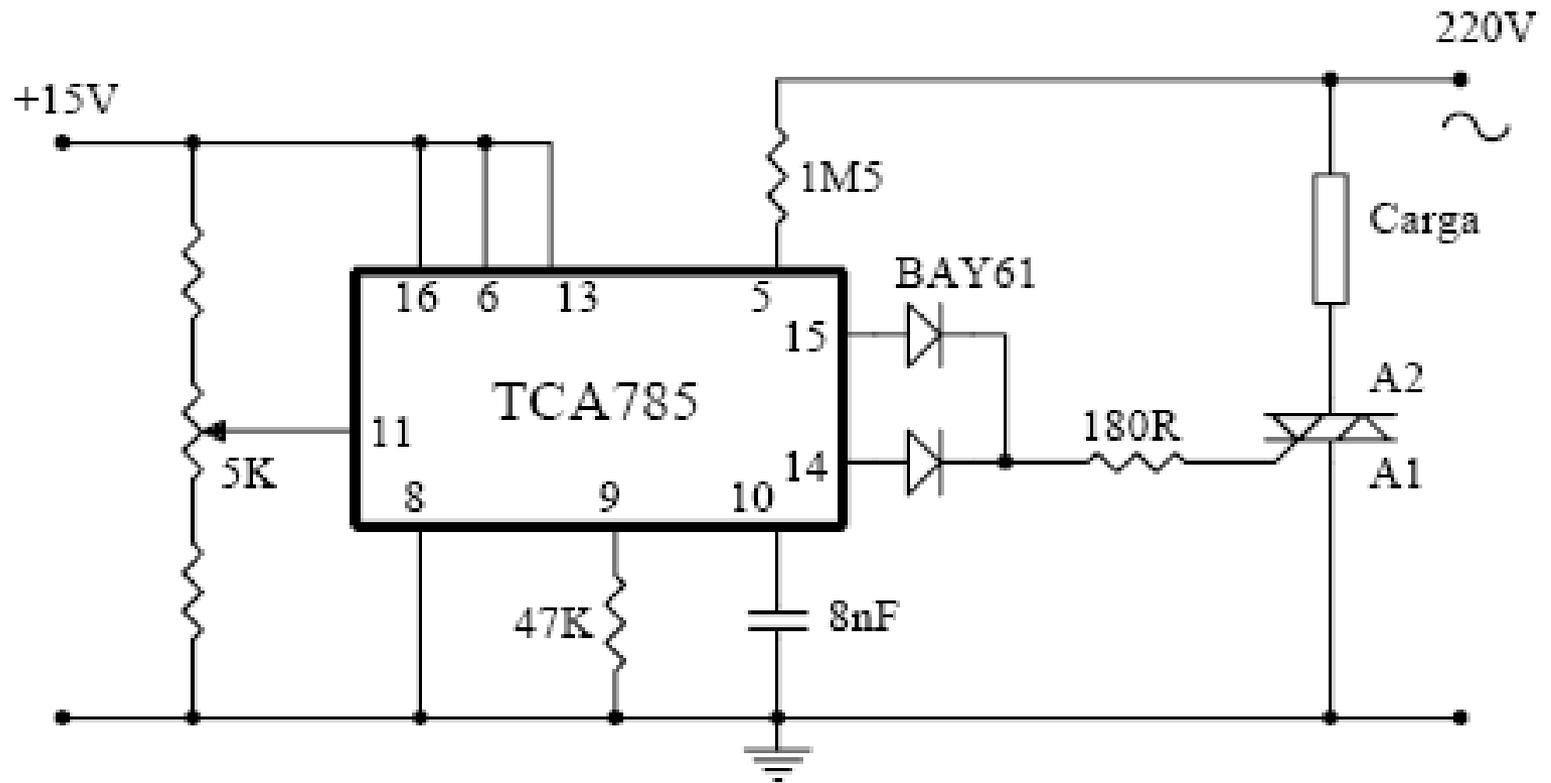
# Acionamento de tiristores



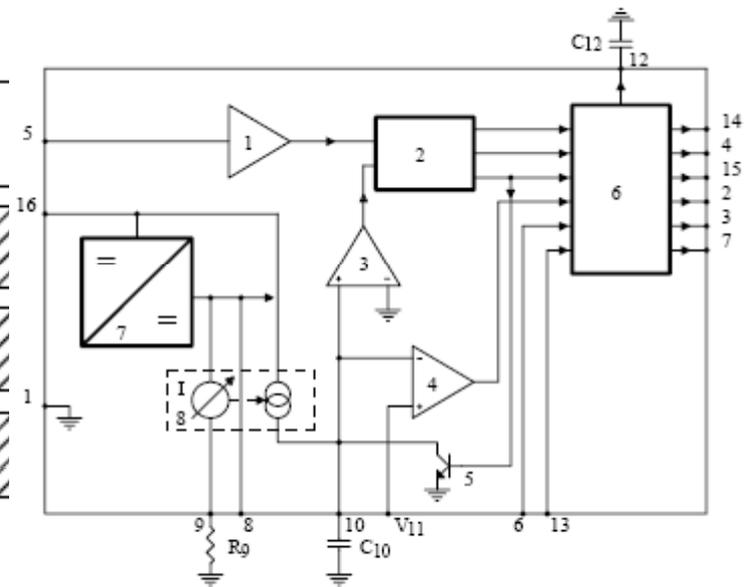
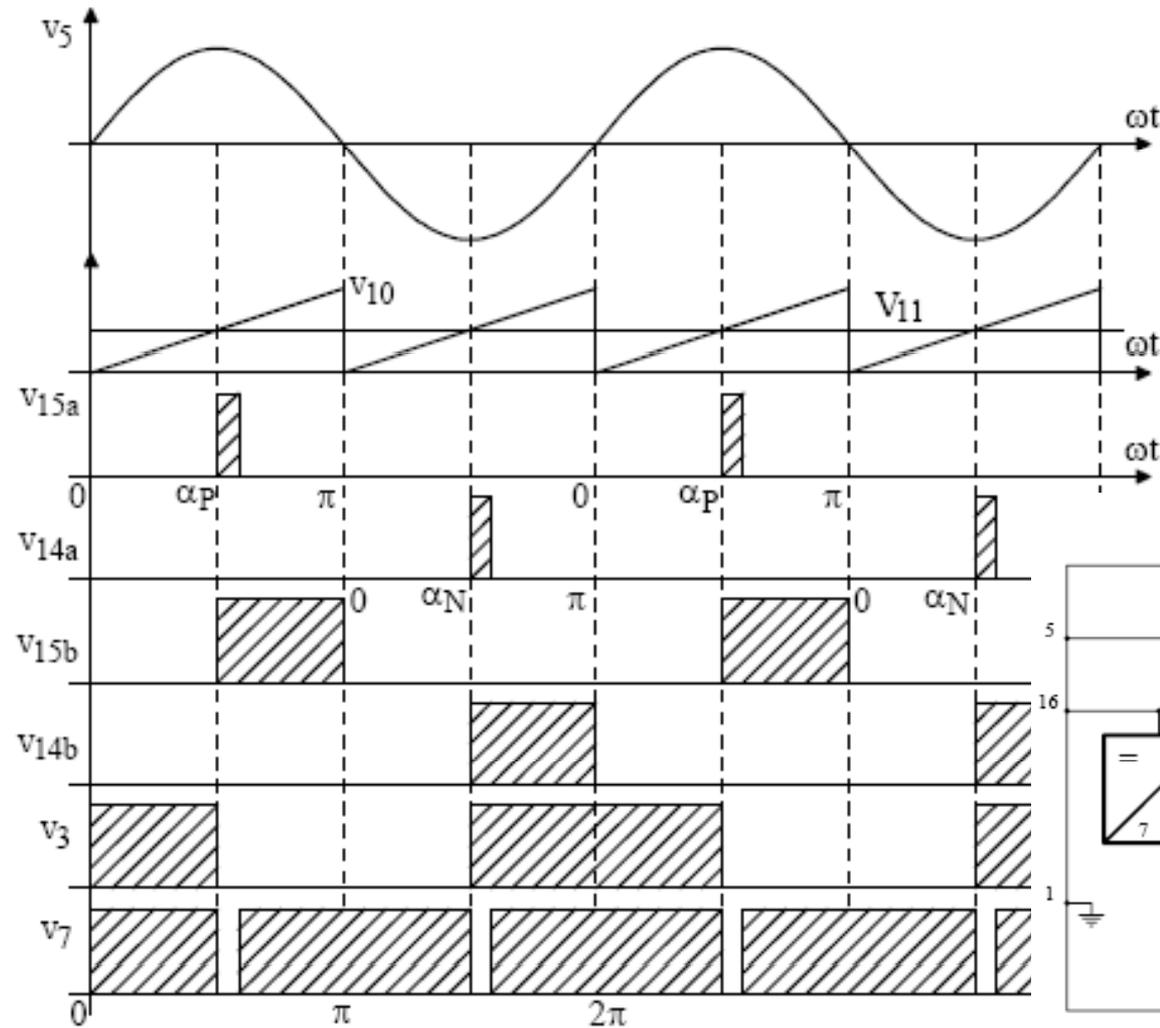
# Acionamento de tiristores



# Acionamento de tiristores



# Acionamento de tiristores



# Acionamento de tiristores



## 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
- divd of 1500 V/us Typical, 600 V/us 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
--------	--------	-------	------

### INFRARED EMITTING DIODE

Reverse Voltage	$V_R$	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 $25^\circ\text{C}$	$P_D$	120	mW
		1.41	mW/°C

### OUTPUT DRIVER

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

### TOTAL DEVICE

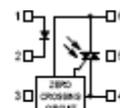
Isolation Surge Voltage(1) (Peak ac Voltage, 60 Hz, 1 Second Duration)	$V_{ISO}$	7500	Vac(p4)
Total Power Dissipation @ $T_A = 25^\circ\text{C}$ Derate above $25^\circ\text{C}$	$P_D$	250	mW
		2.94	mW/°C
Junction Temperature Range	$T_J$	-40 to +100	°C
Ambient Operating Temperature Range	$T_A$	-40 to +85	°C
Storage Temperature Range	$T_{STG}$	-40 to +150	°C
Soldering Temperature (10 s)	$T_L$	260	°C

**MOC3061  
MOC3062  
MOC3063**



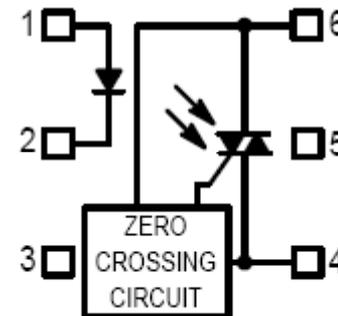
STANDARD THRU HOLE

### COUPLER SCHEMATIC



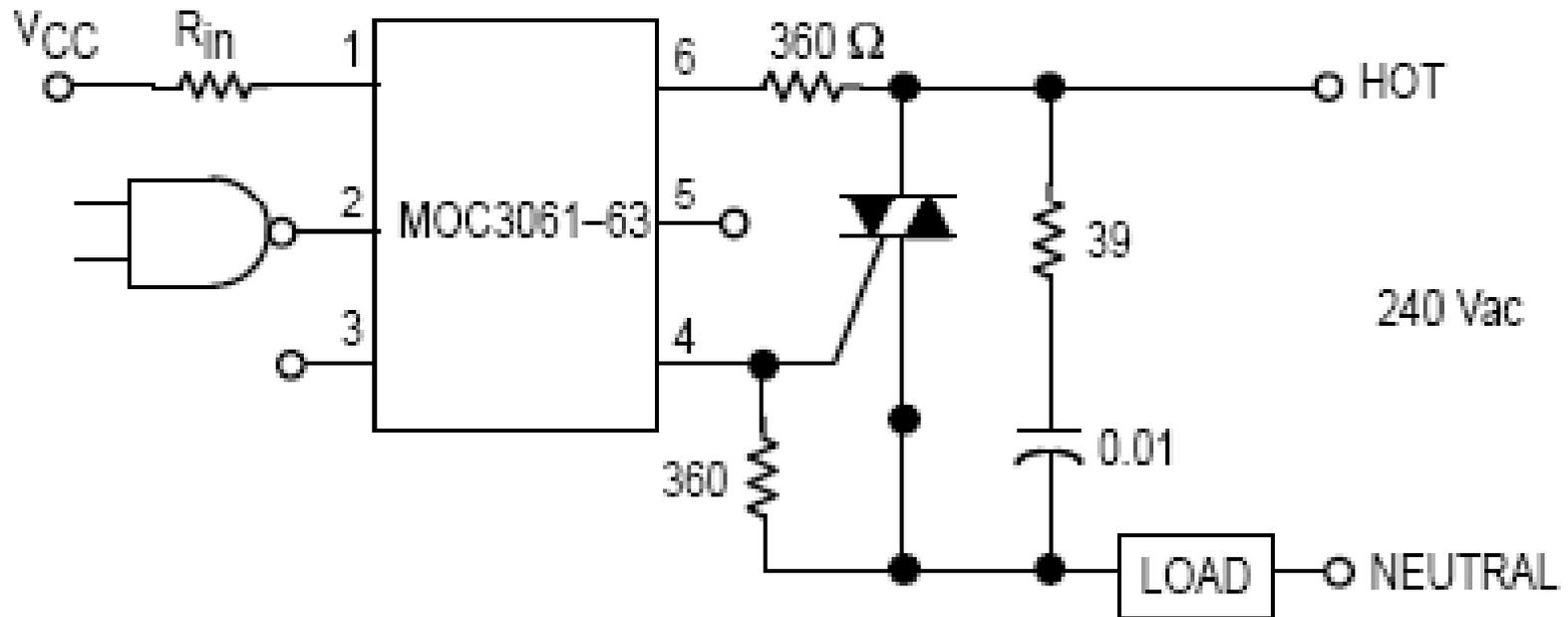
1. ANODE
2. CATHODE
3. NC
4. MAIN TERMINAL
5. SUBSTRATE  
DO NOT CONNECT
6. MAIN TERMINAL

## COUPLER SCHEMATIC

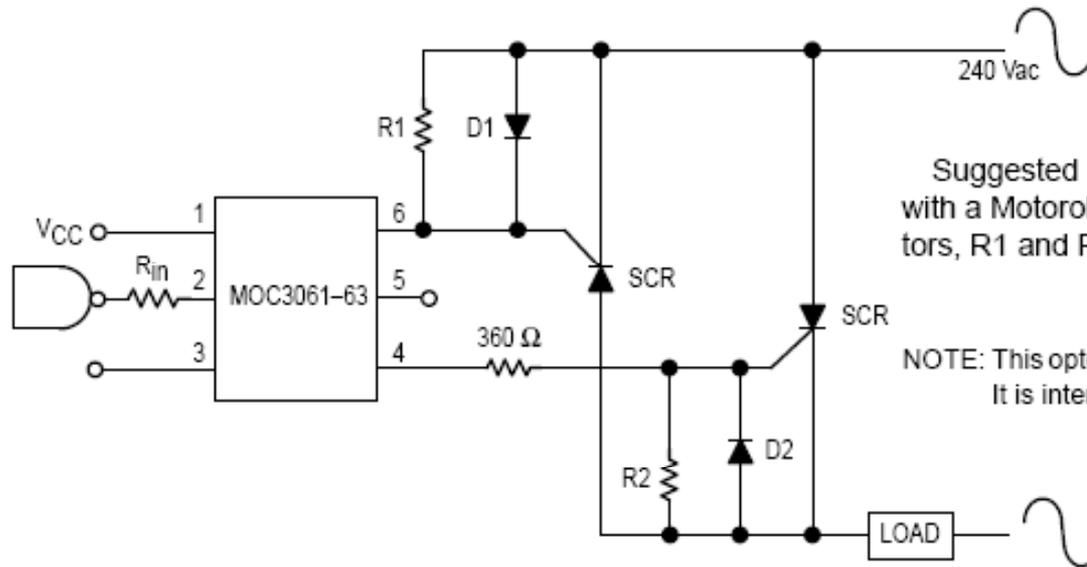


1. ANODE
2. CATHODE
3. NC
4. MAIN TERMINAL
5. SUBSTRATE  
DO NOT CONNECT
6. MAIN TERMINAL

# Acionamento de tiristores



# Acionamento de tiristores



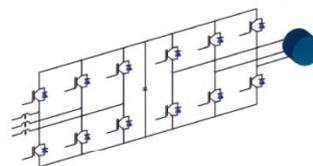
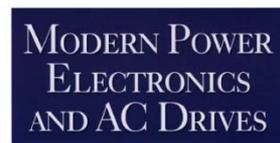
Suggested method of firing two, back-to-back SCR's, with a Motorola triac driver. Diodes can be 1N4001; resistors, R1 and R2, are optional 330 ohms.

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

# Próxima aula

## Conversores CA-CC:

1. Retificadores monofásicos controlados.



BIMAL K. BOSE