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

# Semicondutores Aplicados a Conversores CC-CA

## *Módulos de Potência e Drivers*

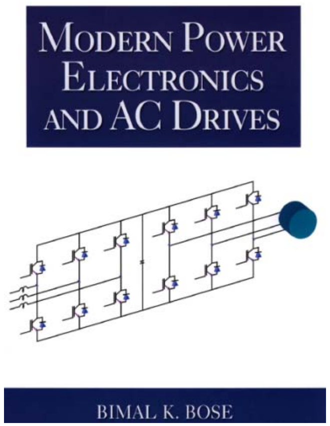
Prof. Clóvis Antônio Petry.

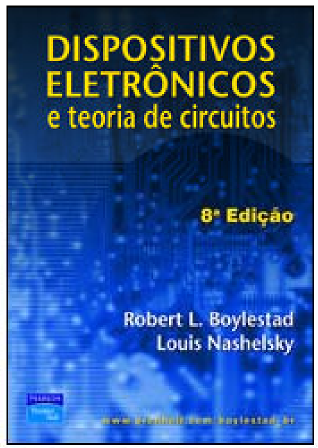
Florianópolis, junho de 2008.

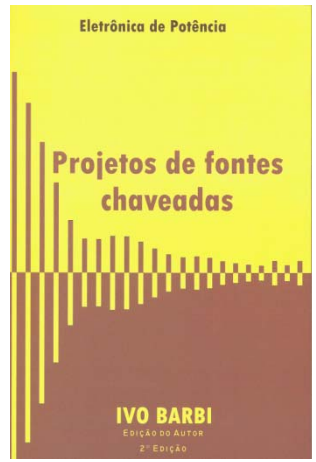
# Bibliografia para esta aula

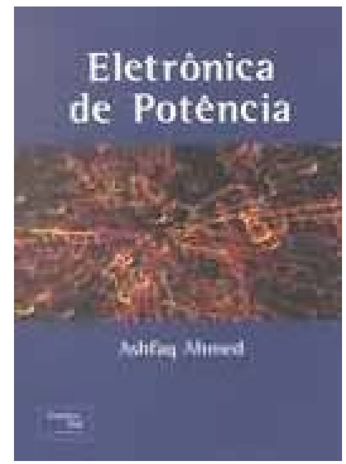
**Capítulo 10: Inversores**

1. Semicondutores aplicados aos conversores CC-CA.






www.cefetsc.edu.br/~petry

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

# Nesta aula

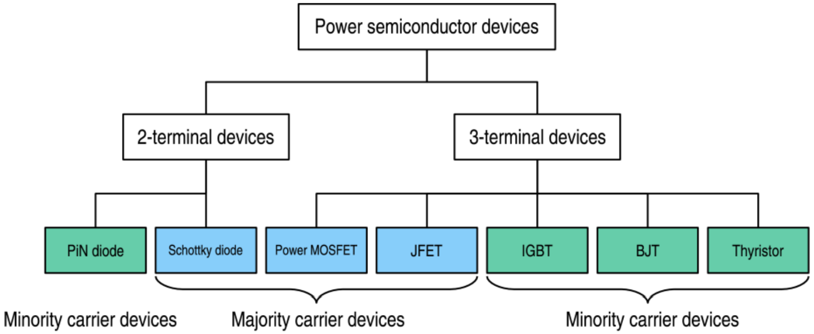
**Semicondutores aplicados a conversores CC-CA:**

1. Introdução;
2. MOSFET de potência;
3. IGBT;
4. Módulos de potência;
5. Driver de acionamento de MOSFET e IGBT;
6. Bootstrap.

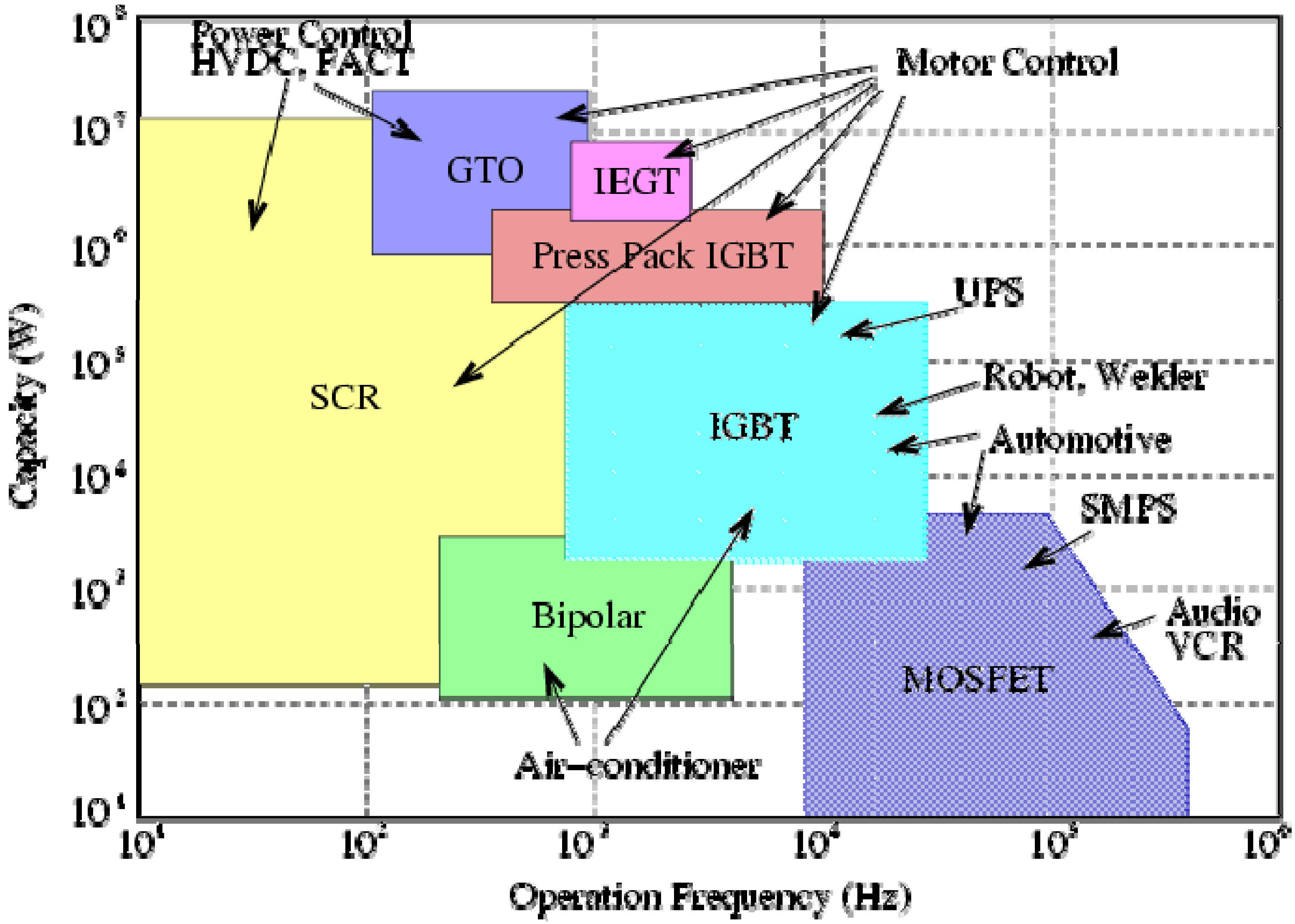
# Semicondutores para eletrônica de potência

## 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)

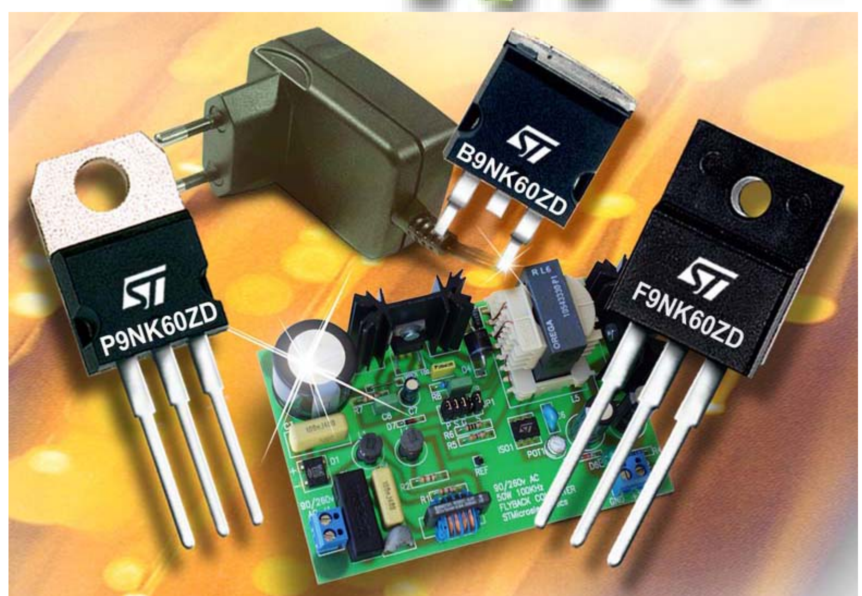


# Semicondutores para eletrônica de potência

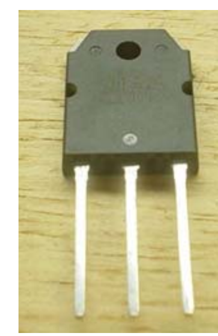


# Semicondutores para eletrônica de potência

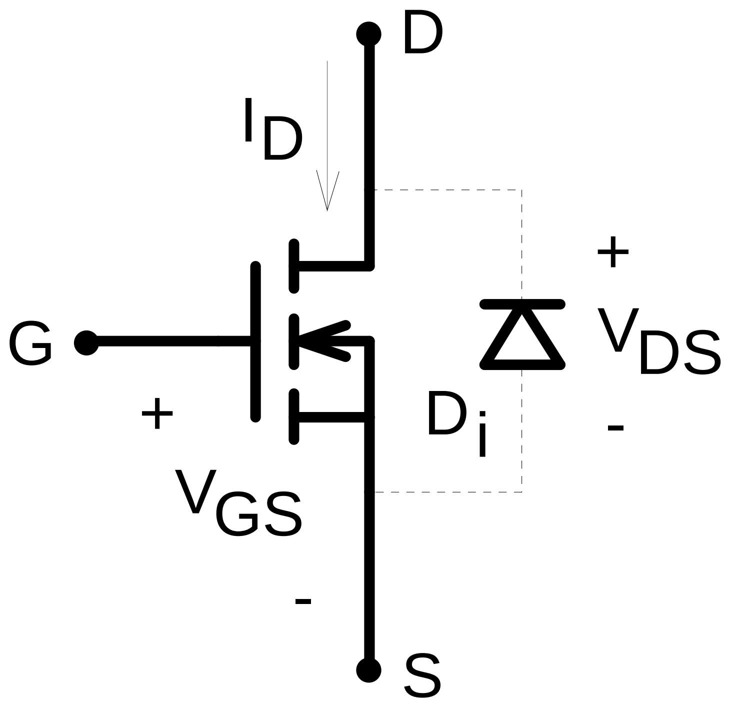


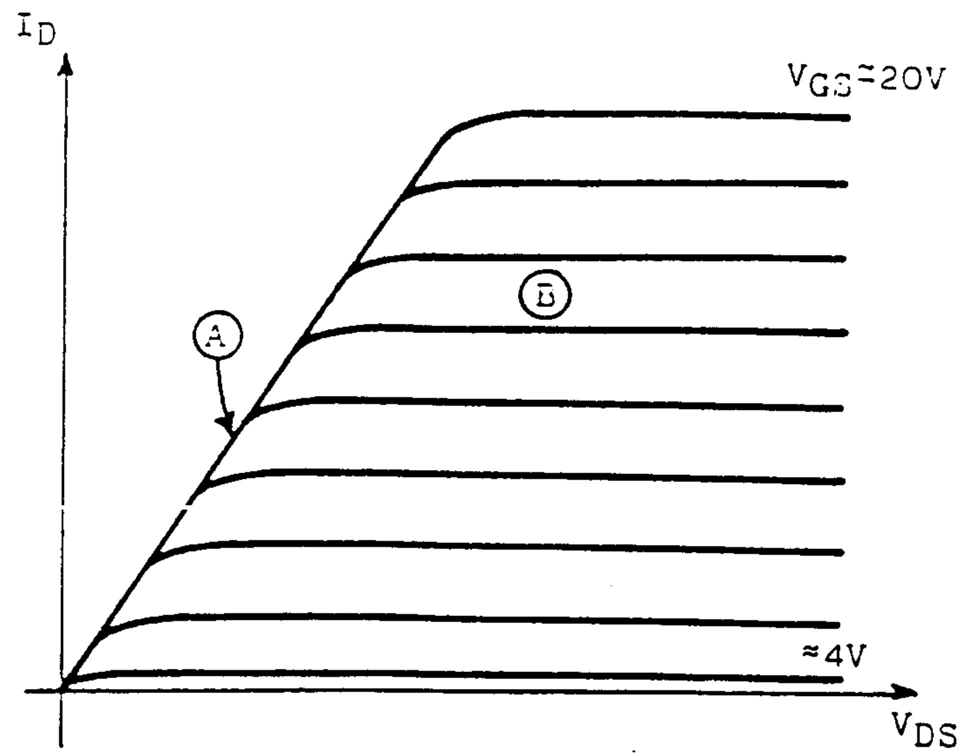






# MOSFET de potência



# MOSFET de potência

**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;

$$P_{com} = \frac{f}{2}\left(t_r + t_f\right) \cdot i_{d(on)} \cdot v_{ds(off)}$$

- Onde:

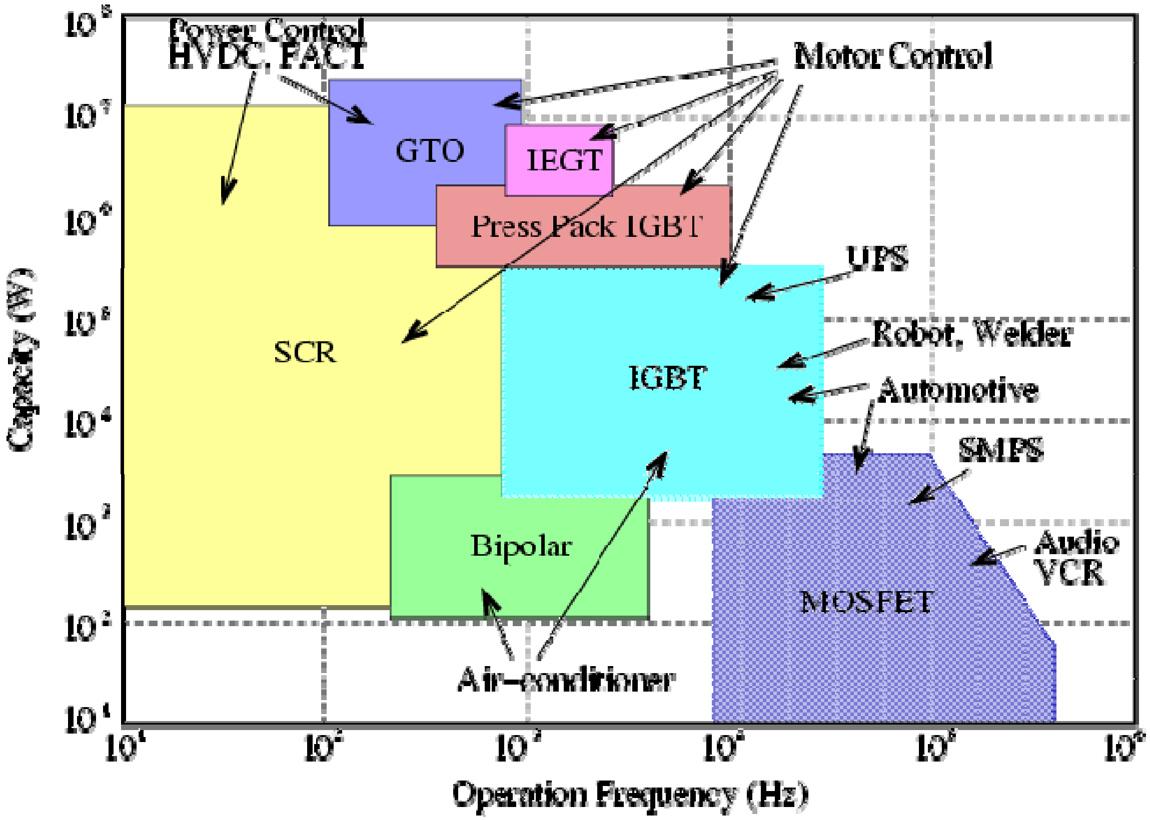
$$t_f \cong t_{on}$$

$$t_r \cong t_{off}$$

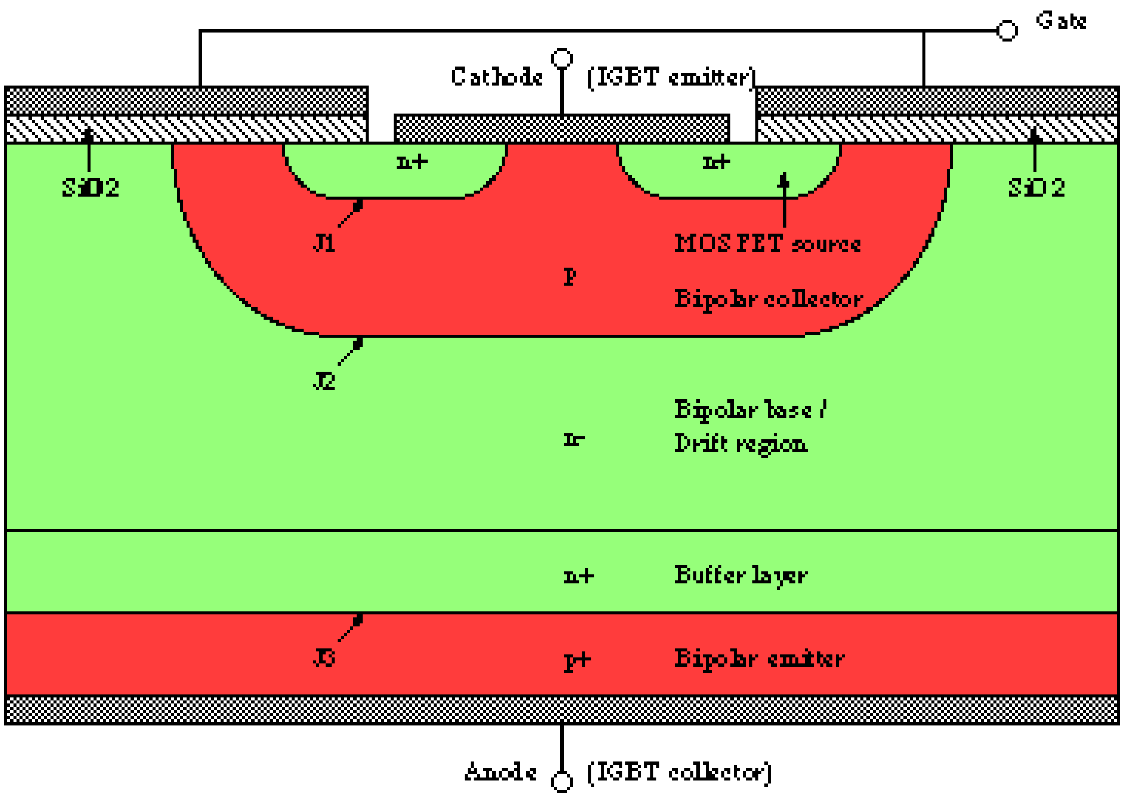
# MOSFET de potência

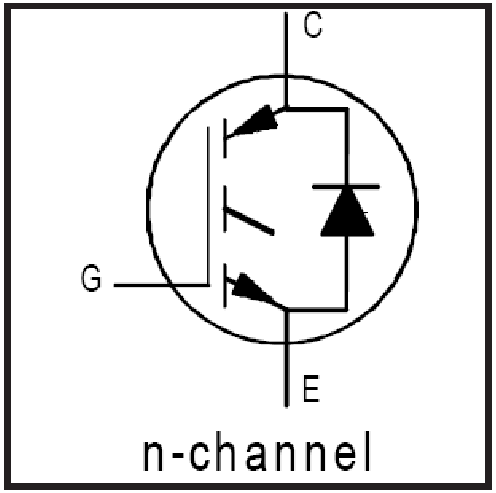
**Quando usar MOSFET:**

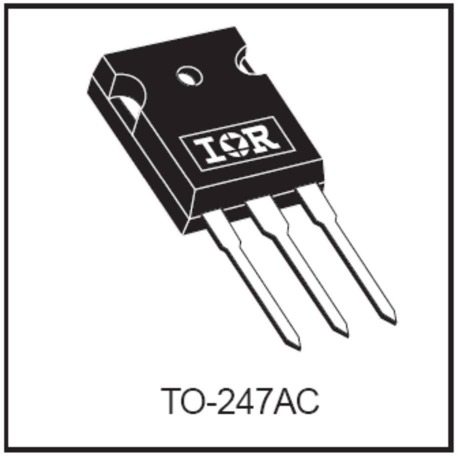
1. Freqüências altas (acima de 50 kHz);
2. Tensões muito baixas (< 500 V);
3. Potências baixas (< 1 kW).



# IGBT




**Características de BJT e MOSFET**

IGBT – Insulated Gate Bipolar Transistor

# IGBT

**Classificação das perdas:**

1. Condução;

0

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

2. Comutação:
   - Entrada em condução e bloqueio;

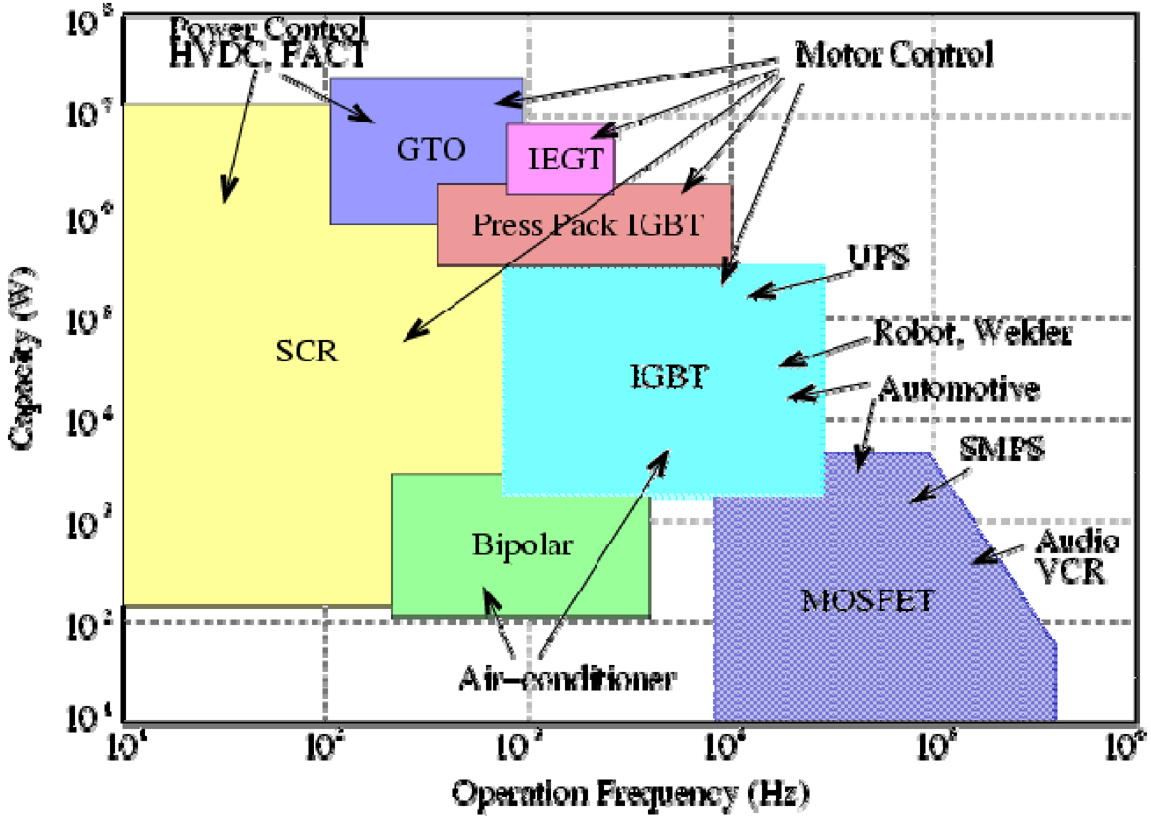
$$P_{com} = \frac{1}{2}\left(t_r + t_f\right) \cdot I \cdot E \cdot f$$

**Detalhamento do cálculo de perdas**

# IGBT

**Quando usar IGBT:**

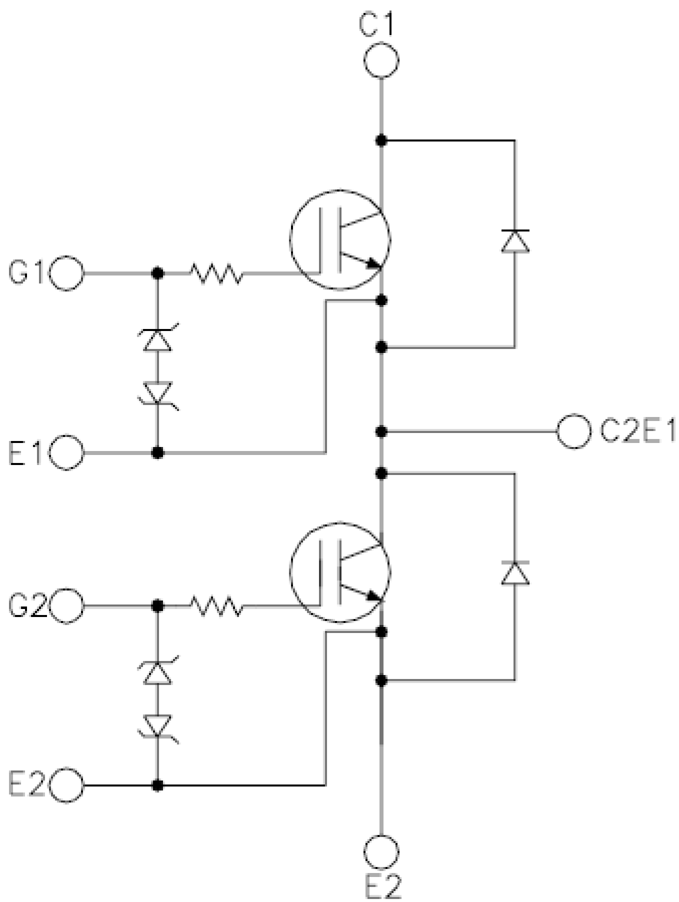
1. Freqüências baixas (menor que 50 kHz);
2. Tensões altas (> 500 V);
3. Potências altas (> 1 kW).

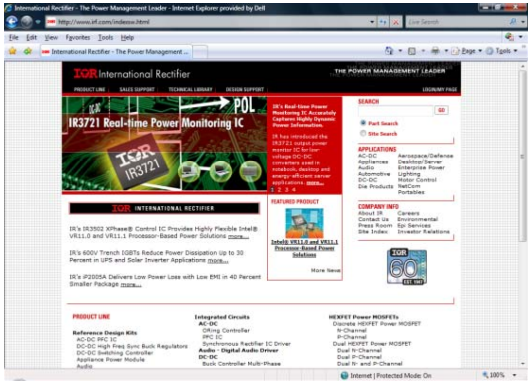


# BJT x MOSFET x IGBT

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

# Módulos de potência



www.irf.com

International Rectifier

## HiRel™ INT-A-Pak 2, PLASTIC HALF-BRIDGE IGBT MODULE

**Product Summary**

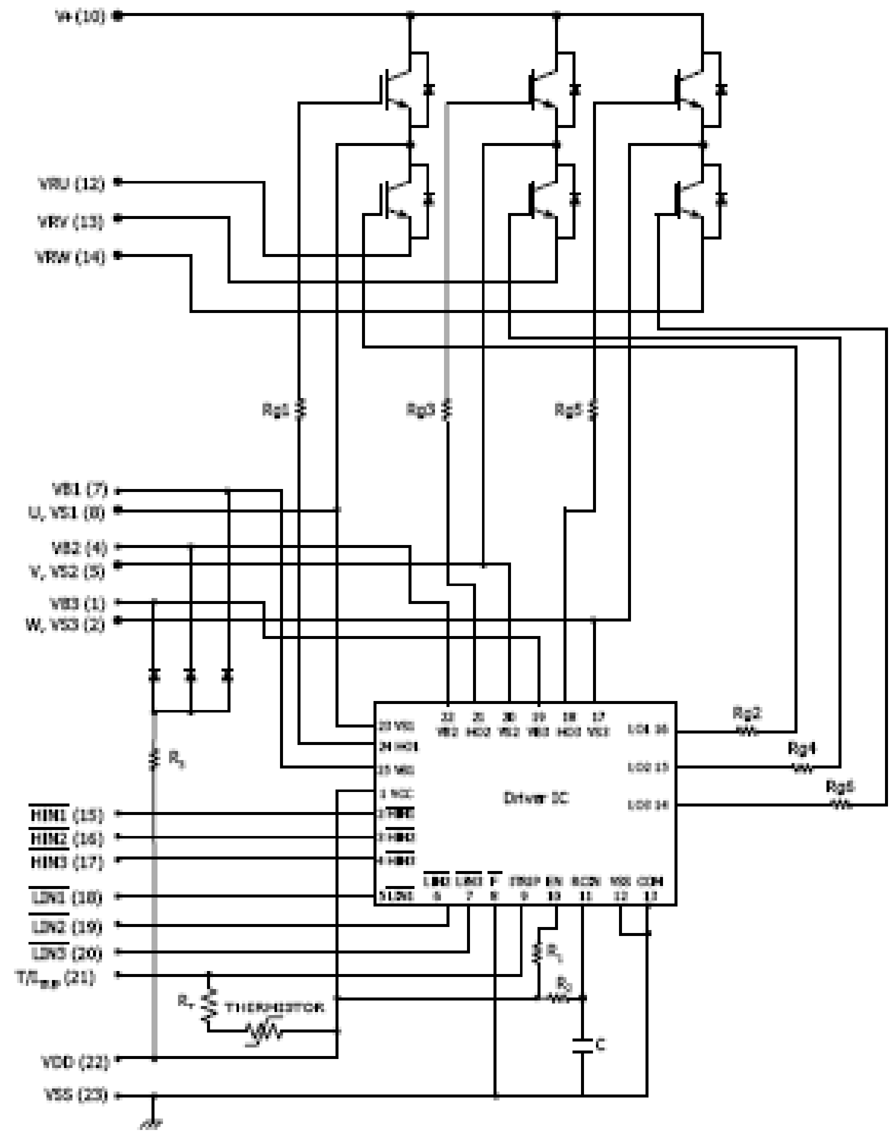
| Part Number | $V_{CE}$ | $I_C$ | $V_{CE(SAT)}$ |
|---|---|---|---|
| G450HHBK06P2 | 600V | 450A | 1.8 |

# Módulos de potência

IRAMS06UP60A

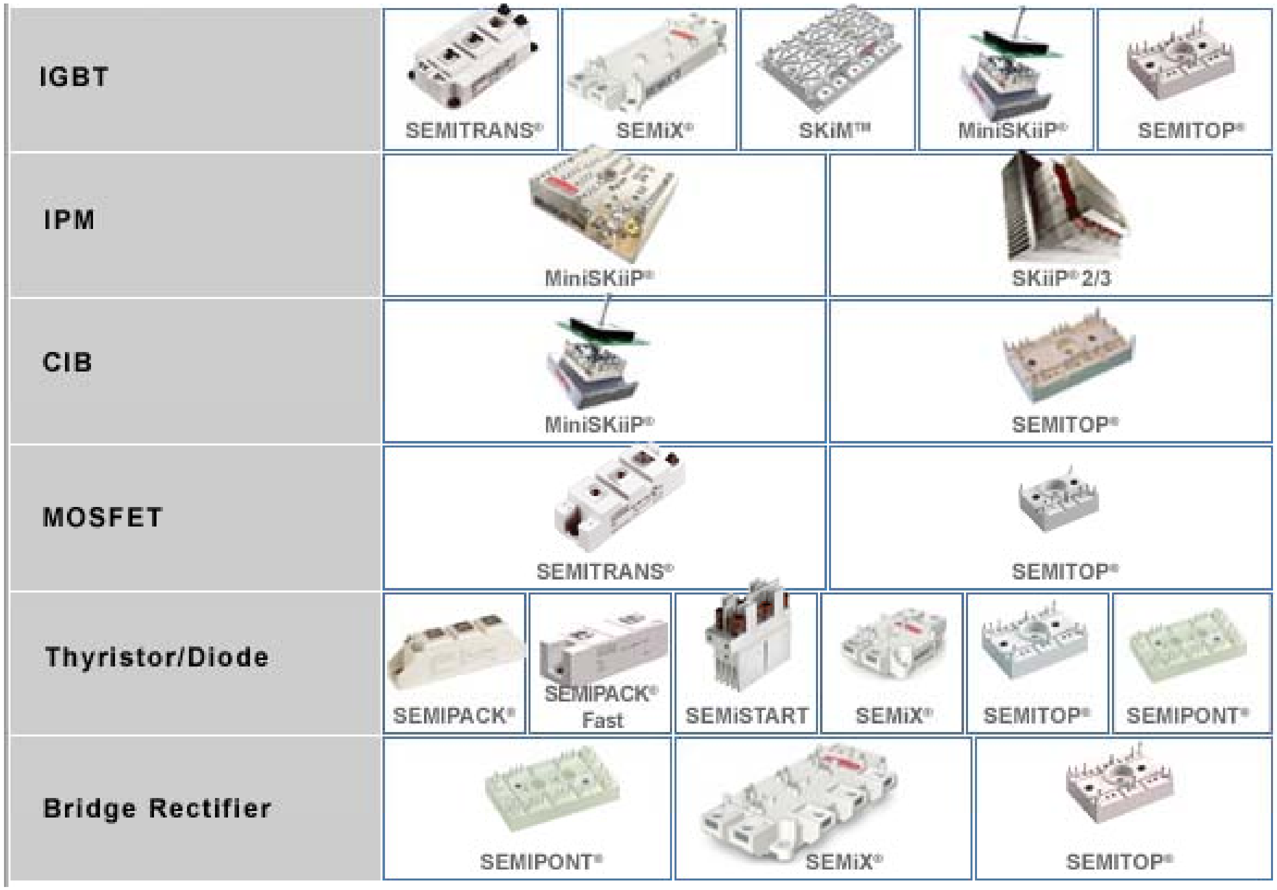
iMOTION™ Series

6A, 600V




www.irf.com

# Módulos de potência



| | | | | | | |
|---|---|---|---|---|---|---|
| IGBT | SEMITRANS® | SEMiX® | SKiM™ | MiniSKiiP® | SEMITOP® | |
| IPM | MiniSKiiP® | SKiiP® 2/3 | | | | |
| CIB | MiniSKiiP® | SEMITOP® | | | | |
| MOSFET | SEMITRANS® | SEMITOP® | | | | |
| Thyristor/Diode | SEMIPACK® | SEMIPACK® Fast | SEMiSTART | SEMiX® | SEMITOP® | SEMIPONT® |
| Bridge Rectifier | SEMIPONT® | SEMiX® | SEMITOP® | | | |


www.semikron.com.br

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# Módulos de potência

## SKM 50GB063D

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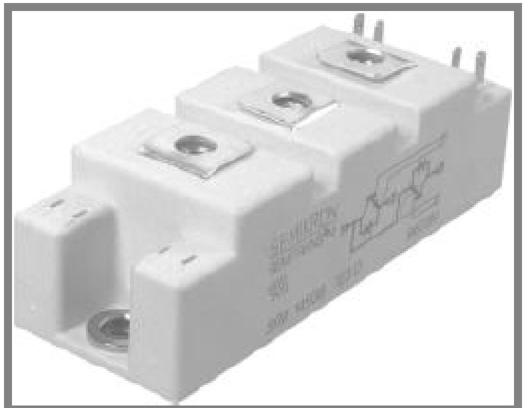
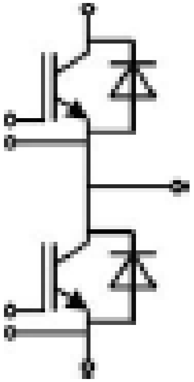
| Absolute Maximum Ratings | $T_c$ = 25 °C, unless otherwise specified | | | |
|---|---|---|---|---|
| **Symbol** | **Conditions** | | **Values** | **Units** |
| **IGBT** | | | | |
| $V_{CES}$ | $T_j$ = 25 °C | | 600 | V |
| $I_C$ | $T_j$ = 150 °C | $T_{case}$ = 25 °C | 70 | A |
| | | $T_{case}$ = 75 °C | 50 | A |
| $I_{CRM}$ | $I_{CRM}$=2x$I_{Cnom}$ | | 100 | A |
| $V_{GES}$ | | | ± 20 | V |
| $t_{psc}$ | $V_{CC}$ = 300 V; $V_{GE} \leq$ 20 V; $V_{CES}$ < 600 V | $T_j$ = 125 °C | 10 | µs |
| **Inverse Diode** | | | | |
| $I_F$ | $T_j$ = 150 °C | $T_{case}$ = 25 °C | 75 | A |
| | | $T_{case}$ = 80 °C | 50 | A |
| $I_{FRM}$ | $I_{FRM}$=2x$I_{Fnom}$ | | 100 | A |
| $I_{FSM}$ | $t_p$ = 10 ms; sin. | $T_j$ = 150 °C | 440 | A |
| **Module** | | | | |
| $I_{t(RMS)}$ | | | 200 | A |
| $T_{vj}$ | | | - 40 ... + 150 | °C |
| $T_{stg}$ | | | - 40 ... + 125 | °C |
| $V_{isol}$ | AC, 1 min. | | 2500 | V |



SEMITRANS® 2



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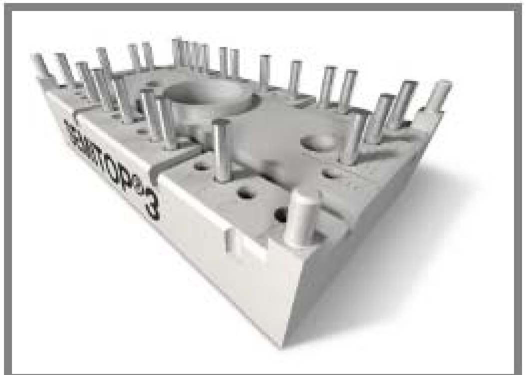
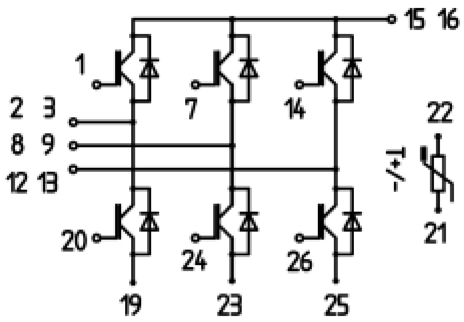
# Módulos de potência

## SK50GD066ET

| Absolute Maximum Ratings | $T_s$ = 25 °C, unless otherwise specified | | |
|---|---|---|---|
| **Symbol** | **Conditions** | **Values** | **Units** |
| **IGBT** | | | |
| $V_{CES}$ | $T_j$ = 25 °C | 600 | V |
| $I_C$ | $T_j$ = 175 °C; $T_s$ = 25 °C | 57 | A |
| | $T_s$ = 70 °C | 45 | A |
| $I_{CRM}$ | $I_{CRM}$= 2 x $I_{Cnom}$ | 100 | A |
| $V_{GES}$ | | ± 20 | V |
| $t_{psc}$ | $V_{CC}$ = 360 V; $V_{GE} \leq$ 20 V; VCES < 600 V; $T_j$ = 125 °C | 6 | µs |
| **Inverse Diode** | | | |
| $I_F$ | $T_j$ = 175 °C; $T_s$ = 25 °C | 56 | A |
| | $T_s$ = 70 °C | 44 | A |
| $I_{FRM}$ | $I_{FRM}$= 2 x $I_{Fnom}$ | 60 | A |
| **Module** | | | |
| $I_{t(RMS)}$ | | | A |
| $T_{vj}$ | | -40 ... +150 | °C |
| $T_{stg}$ | | -40 ... +125 | °C |
| $V_{isol}$ | AC, 1 min. | 2500 | V |




SEMITOP® 3

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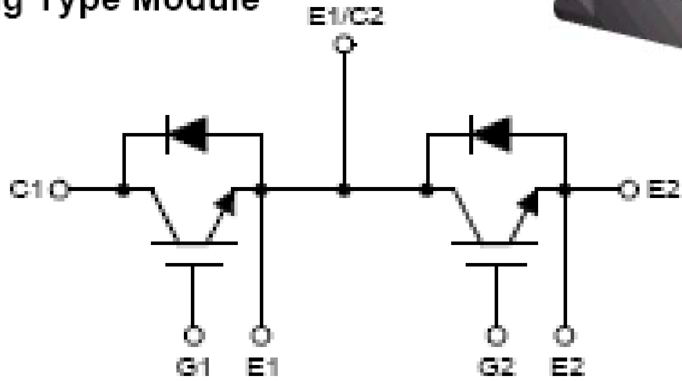
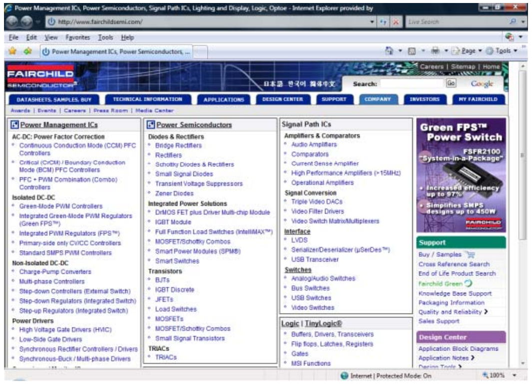
# Módulos de potência

## FMG2G50US60

**Molding Type Module**



www.fairchildsemi.com

### Absolute Maximum Ratings

$T_C$ = 25°C unless otherwise noted

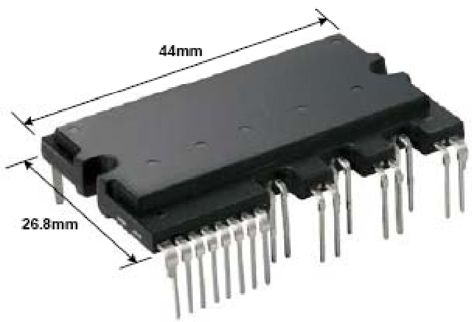
| Symbol | Description | | FMG2G50US60 | Units |
|---|---|---|---|---|
| $V_{CES}$ | Collector-Emitter Voltage | | 600 | V |
| $V_{GES}$ | Gate-Emitter Voltage | | ± 20 | V |
| $I_C$ | Collector Current | @ $T_C$ = 25°C | 50 | A |
| $I_{CM\,(1)}$ | Pulsed Collector Current | | 100 | A |
| $I_F$ | Diode Continuous Forward Current | @ $T_C$ = 100°C | 50 | A |
| $I_{FM}$ | Diode Maximum Forward Current | | 100 | A |
| $T_{SC}$ | Short Circuit Withstand Time | @ $T_C$ = 100°C | 10 | us |
| $P_D$ | Maximum Power Dissipation | @ $T_C$ = 25°C | 250 | W |
| $T_J$ | Operating Junction Temperature | | -40 to +150 | °C |
| $T_{stg}$ | Storage Temperature Range | | -40 to +125 | °C |
| $V_{iso}$ | Isolation Voltage | @ AC 1minute | 2500 | V |
| Mounting Torque | Power Terminals Screw : M5 | | 2.0 | N.m |
| | Mounting Screw : M5 | | 2.0 | N.m |

# Módulos de potência

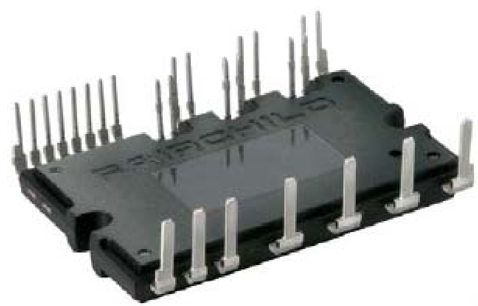
FAIRCHILD SEMICONDUCTOR

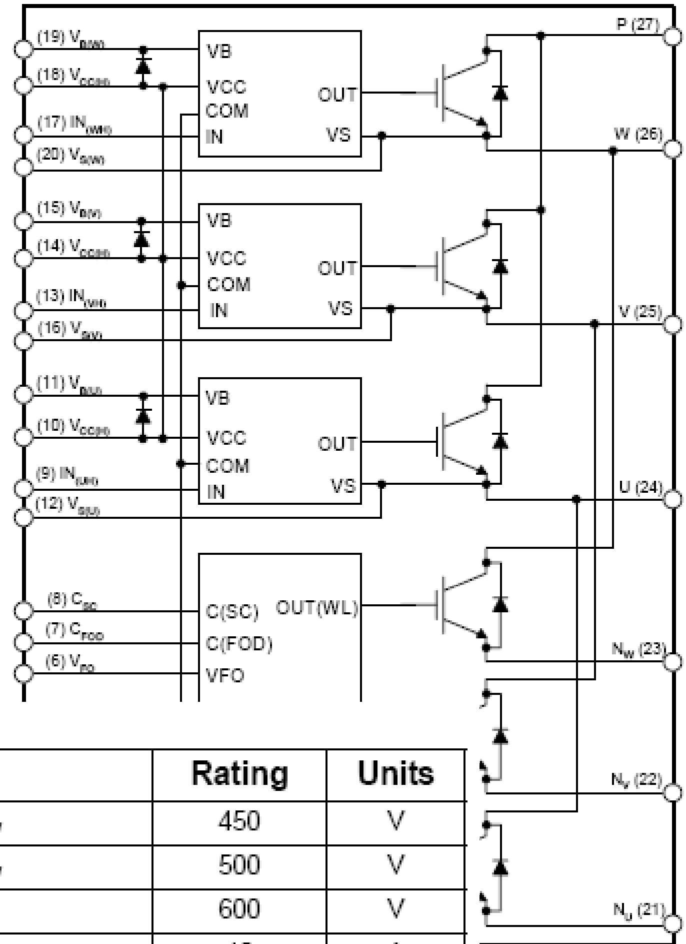
## FSBF10CH60BT
## Smart Power Module

Top View




Bottom View






### Inverter Part

| Symbol | Parameter | Conditions | Rating | Units |
|---|---|---|---|---|
| $V_{PN}$ | Supply Voltage | Applied between P- $N_U$, $N_V$, $N_W$ | 450 | V |
| $V_{PN(Surge)}$ | Supply Voltage (Surge) | Applied between P- $N_U$, $N_V$, $N_W$ | 500 | V |
| $V_{CES}$ | Collector-emitter Voltage | | 600 | V |
| $\pm I_C$ | Each IGBT Collector Current | $T_C$ = 25°C | 10 | A |
| $\pm I_{CP}$ | Each IGBT Collector Current (Peak) | $T_C$ = 25°C, Under 1ms Pulse Width | 20 | A |
| $P_C$ | Collector Dissipation | $T_C$ = 25°C per One Chip | 20 | W |
| $T_{J(Power\ chips)}$ | Operating Junction Temperature | (Note 1) | -40 ~ 150 | °C |

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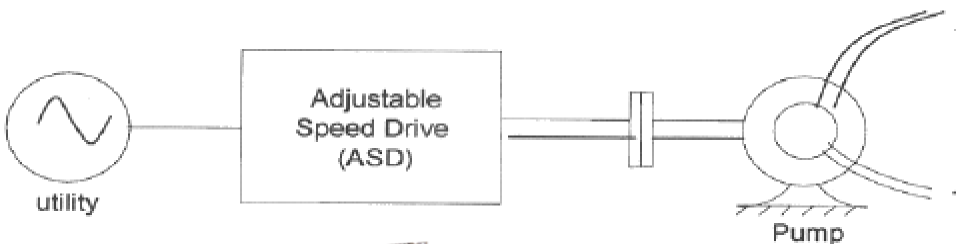
# Driver ou Drive

**Drive**

Para acionamento de motores

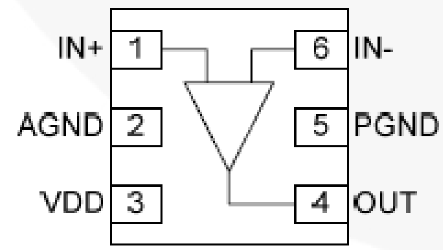


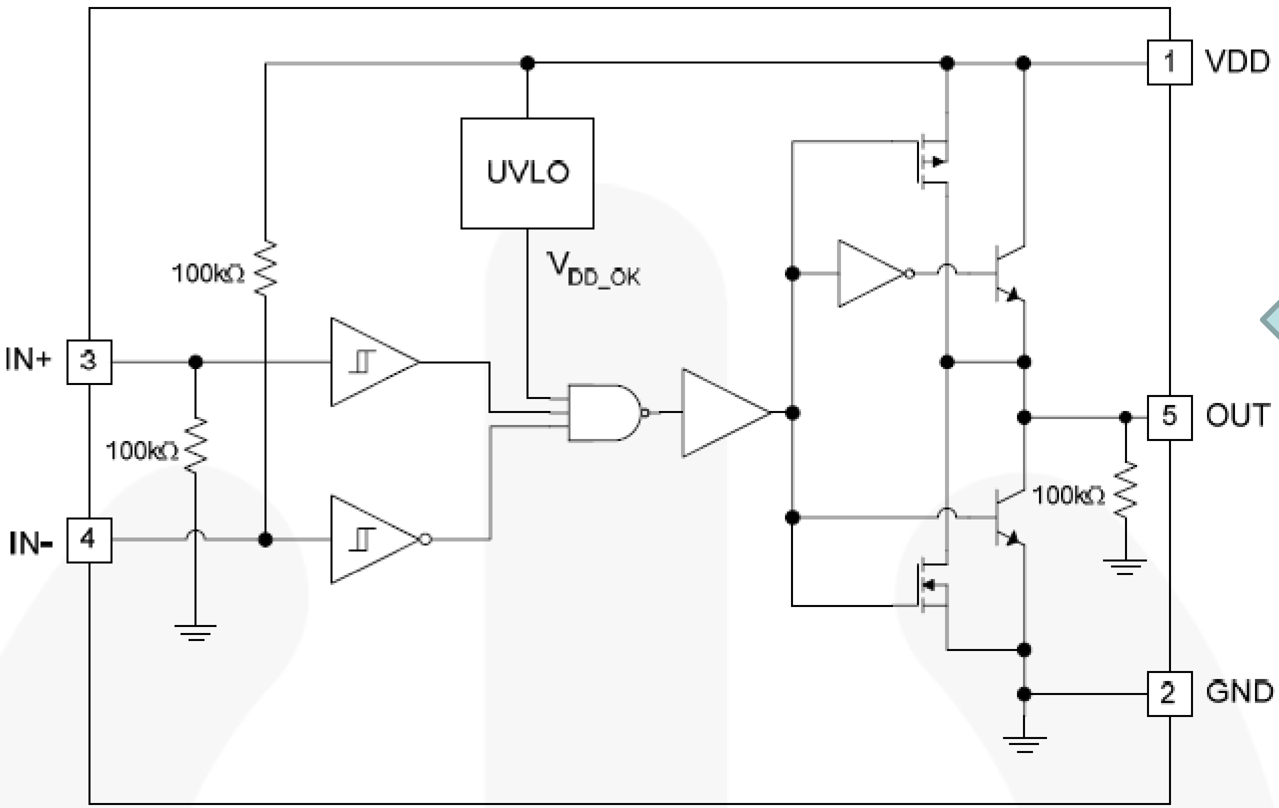

**Driver**

Para acionamento semicondutores

# Driver

**FAN3100**
**Single 2A High-Speed, Low-Side Gate Driver**



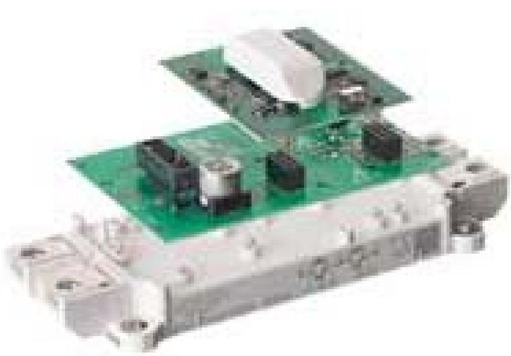




PWM??

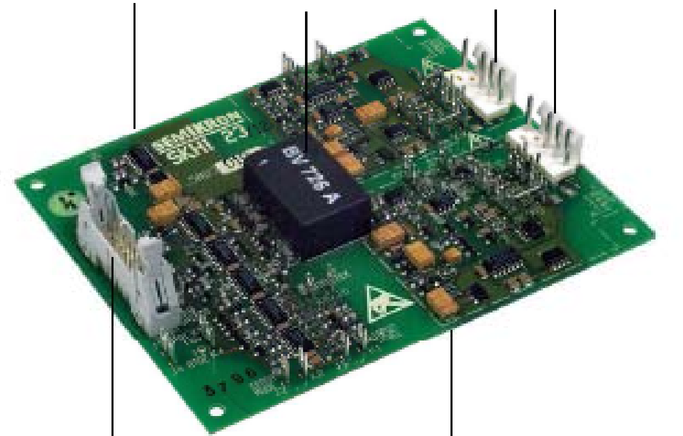
# Driver

## SEMIDRIVER™

| Type | Number of Channels | $V_{CE}$ max. V | Gate voltage V | Output peak current A | Output charge □C | Switching frequency kHz | Isolation voltage kV | dv/dt max. kV/□s |
|---|---|---|---|---|---|---|---|---|
| **SKYPER™ Driver Core** | | | | | | | | |
| SKYPER□32 (R) | 2 | 1700 | +15 / -7 | 15 | 2,5 | 50 | 4 | 50 |
| SKYPER□32PRO (R) | 2 | 1700 | +15 / -7 | 15 | 6,3 | 50 | 4 | 50 |
| **SKHI-DRIVER PCB-mountable** | | | | | | | | |
| SKHI□21A (R) | 2 | 1200 | +15 / 0 | 8 | 4 | 50 | 2,5 | 50 |
| SKHI□22□A□/□B (R) | 2 | 1200 | +15 / -7 | 8 | 4 | [illegible] | [illegible] | [illegible] |
| SKHI□22□A / B H4 (R) | 2 | 1700 | +15 / -7 | 8 | 4 | [illegible] | [illegible] | [illegible] |
| SKHI□24 (R) | 2 | 1700 | +15 / -8 | 15 | 5 | [illegible] | [illegible] | [illegible] |
| SKHI□61 (R) | 6 | 900 | +15 / -6,5 | 2 | 1 | [illegible] | [illegible] | [illegible] |
| SKHI□71 (R) | 7 | 900 | +15 / -6,5 | 2 | 1 | [illegible] | [illegible] | [illegible] |
| **SKHI-DRIVER Plug-and-Play** | | | | | | | | |
| SKHI□10/12 (R) | 1 | 1200 | +15 / -8 | 8 | 9,6 | [illegible] | [illegible] | [illegible] |
| SKHI□10/17 (R) | 1 | 1700 | +15 / -8 | 8 | 9,6 | [illegible] | [illegible] | [illegible] |
| SKHI□23/12 (R) | 2 | 1200 | +15 / -8 | 8 | 4,8 | [illegible] | [illegible] | [illegible] |
| SKHI□23/17 (R) | 2 | 1700 | +15 / -8 | 8 | 4,8 | [illegible] | [illegible] | [illegible] |
| SKHI□26W,□SKHI□26F * | 2 | 1600 | +15 / -8 | 8 | 10 | [illegible] | [illegible] | [illegible] |
| SKHI□27W * | 2 | 1700 | +15 / -8 | 30 | 30 | 10 | 4 | 75 |
| SKHIT□01 (R) | 3 | - | - | - | - | - | 2,5 | - |



# Driver

<table>
<tr><th>SKYPER® Driver Core</th><th>SKHI-DRIVER PCB-mountable</th><th>SKHI-DRIVER Plug-and-Play</th></tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>▪ Core technology<br>▪ PCB mountable driver<br>▪ Pins for PCB soldering & plug connection</td>
<td>▪ Hybrid technology<br>▪ PCB mountable driver<br>▪ Pins for PCB soldering<br>▪ Capsule housing</td>
<td>▪ SMT technology<br>▪ Complete driver solution<br>▪ Connectors for controller and IGBT connection<br>▪ Integrated turn-on and turn-off gate resistors</td>
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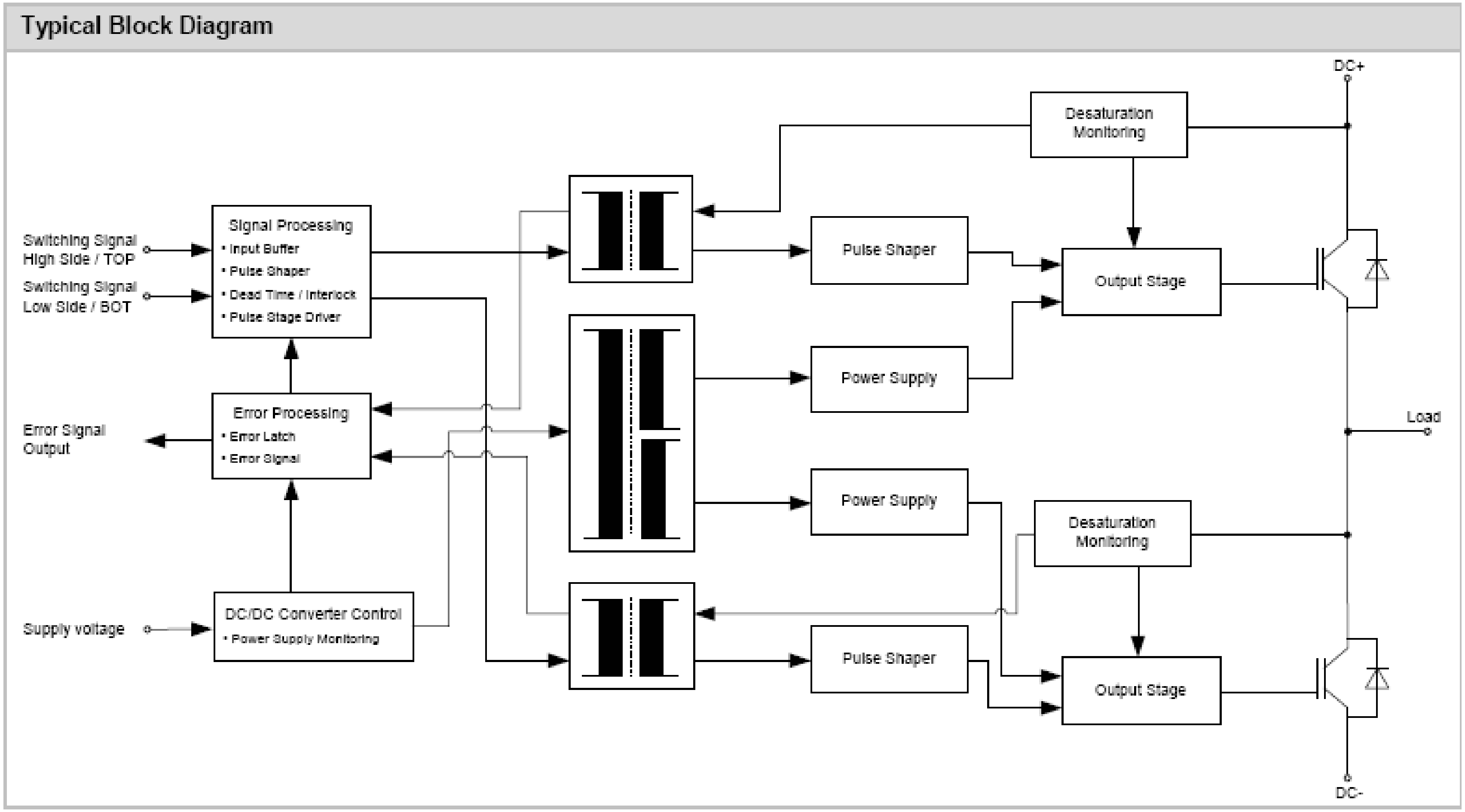
# Driver

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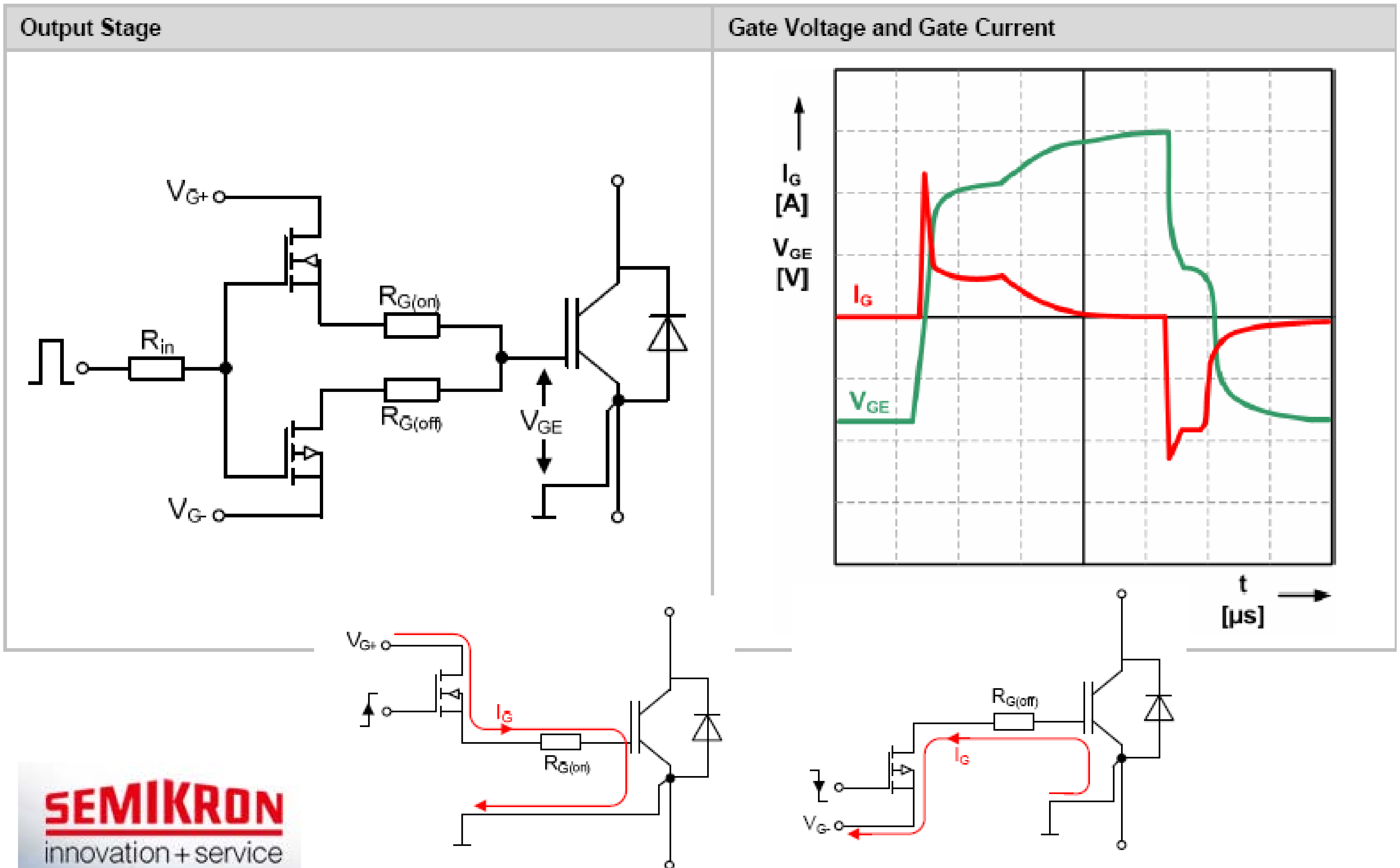
# Driver

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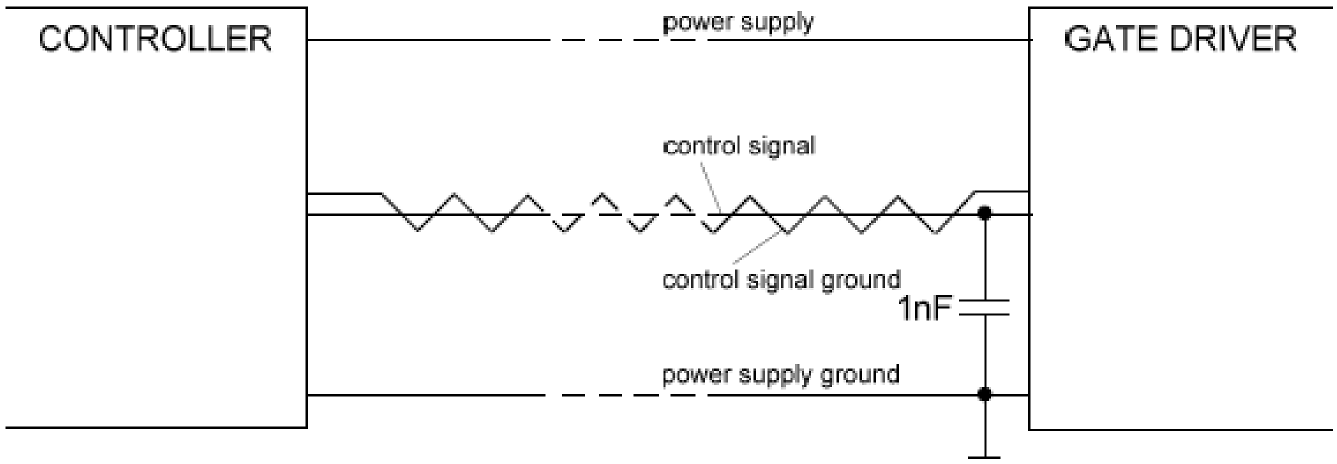
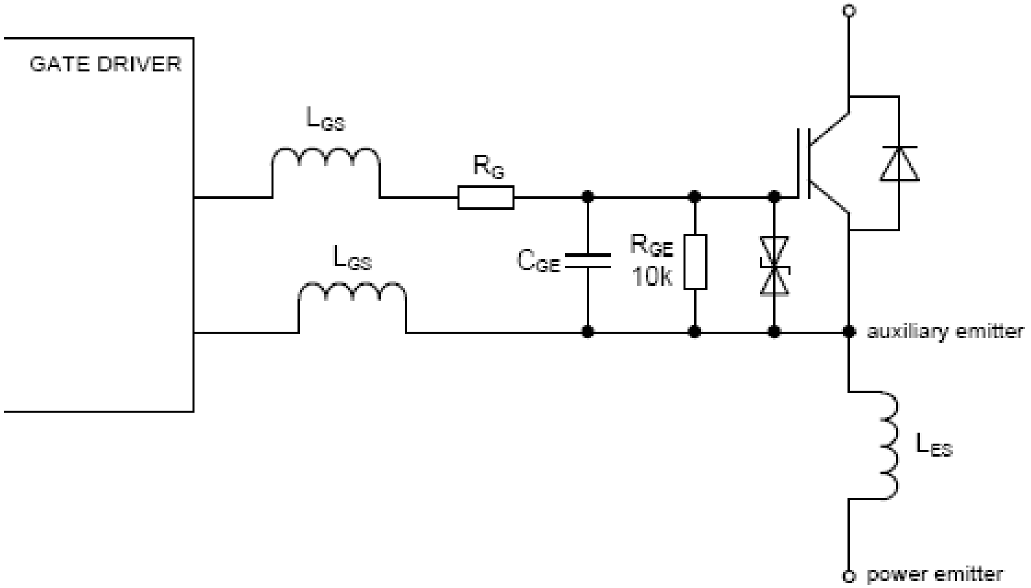
# Driver

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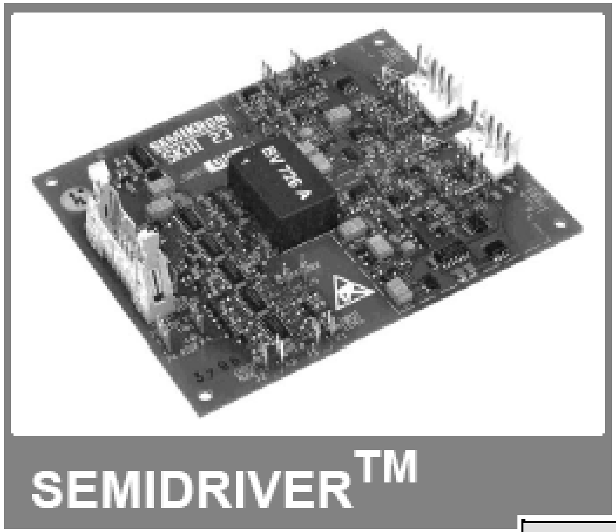
# Driver




Medium Power Double IGBT Driver

**SKHI 23/12 (R)**

SEMIKRON
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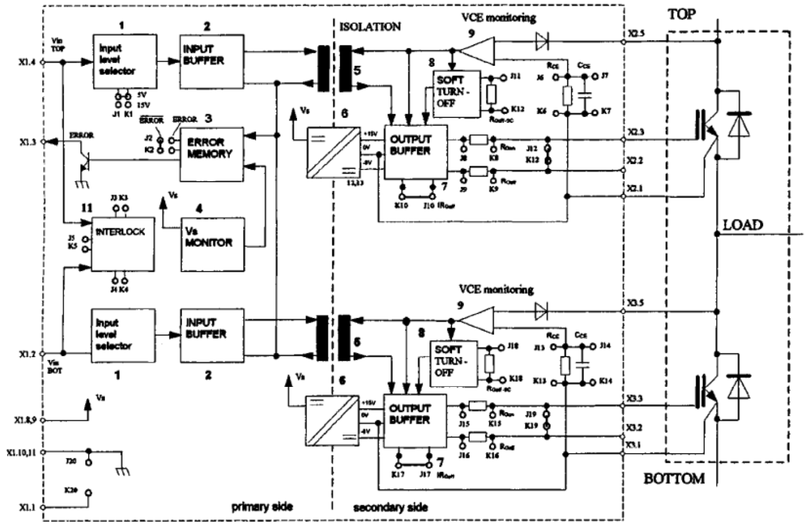
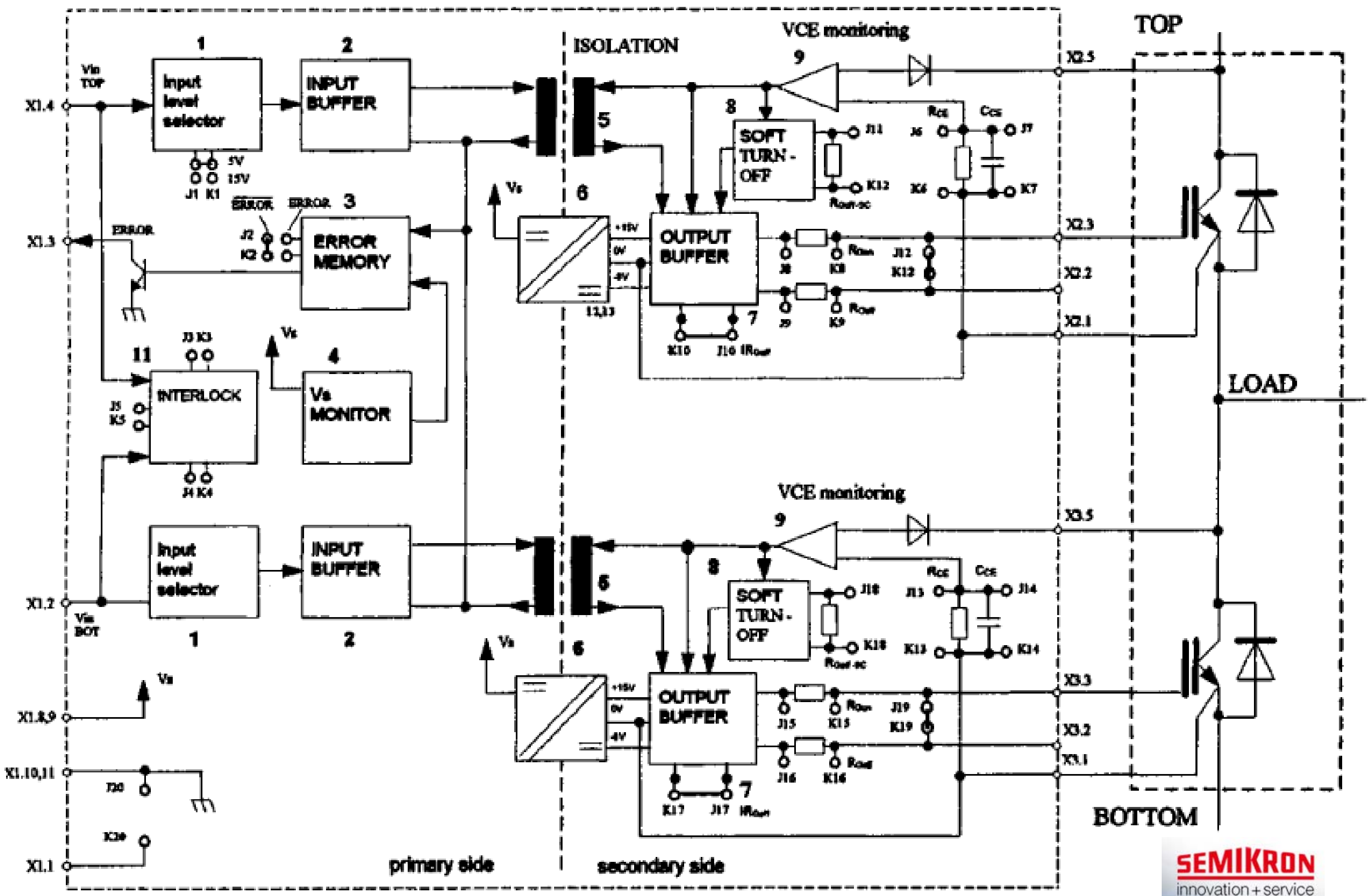



| Absolute Maximum Ratings | | $T_a$ = 25 °C, unless otherwise specified | |
|---|---|---|---|
| **Symbol** | **Conditions** | **Values** | **Units** |
| $V_S$ | Supply voltage primary | 18 | V |
| $V_{iH}$ | Input signal voltage (HIGH) (for 15 V and 5 V input level) | $V_S$ + 0,3 | V |
| $Iout_{PEAK}$ | Output peak current | ± 8 | A |
| $Iout_{AV}$ | Output average current | ± 50 | mA |
| $V_{CE}$ | Collector emitter voltage sense | 1200 | V |
| dv/dt | Rate of rise and fall of voltage (secondary to primary side) | 75 | kV/µs |
| $V_{isol\ IO}$ | Isolation test volt. IN-OUT (2 sec. AC) | 2500 | V |
| $R_{Gon\ min}$ | minimal $R_{Gon}$ | 2,7 | Ω |
| $R_{Goff\ min}$ | minimal $R_{Goff}$ | 2,7 | Ω |
| $Q_{out/pulse}$ | charge per pulse | 4,8 | µC |
| $T_{op}$ | Operating temperature | - 25 ... + 85 | °C |
| $T_{stg}$ | Storage temperature | - 25 ... + 85 | °C |

# Driver




SEMIKRON
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# Driver

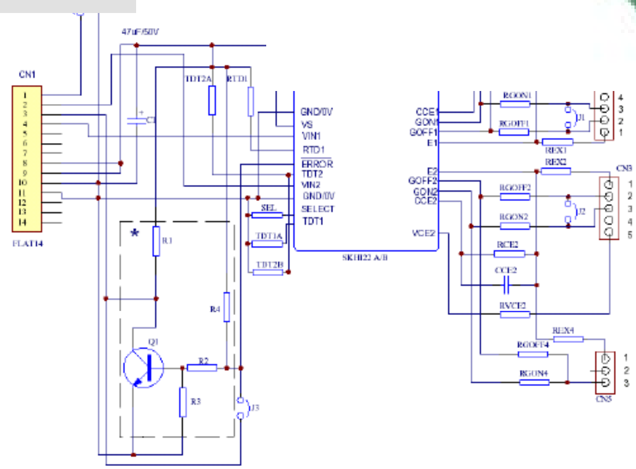
SEMIDRIVER™

Hybrid Dual MOSFET Driver

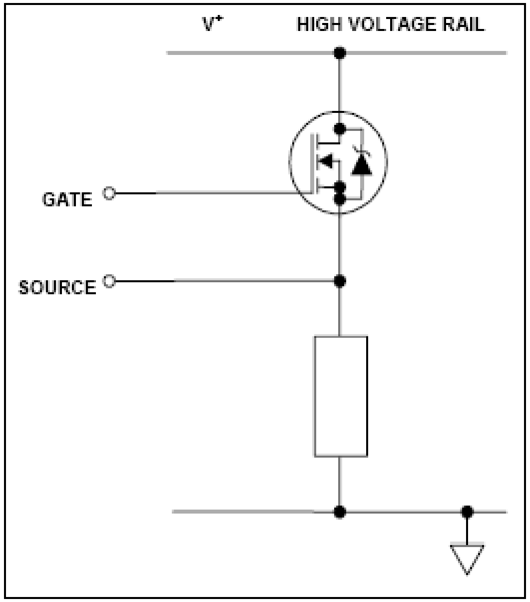
**SKHI 21A (R)**

Printed Circuit Board for SKHI 21A and SKHI 22A/B drivers

**SKPC 22/2**

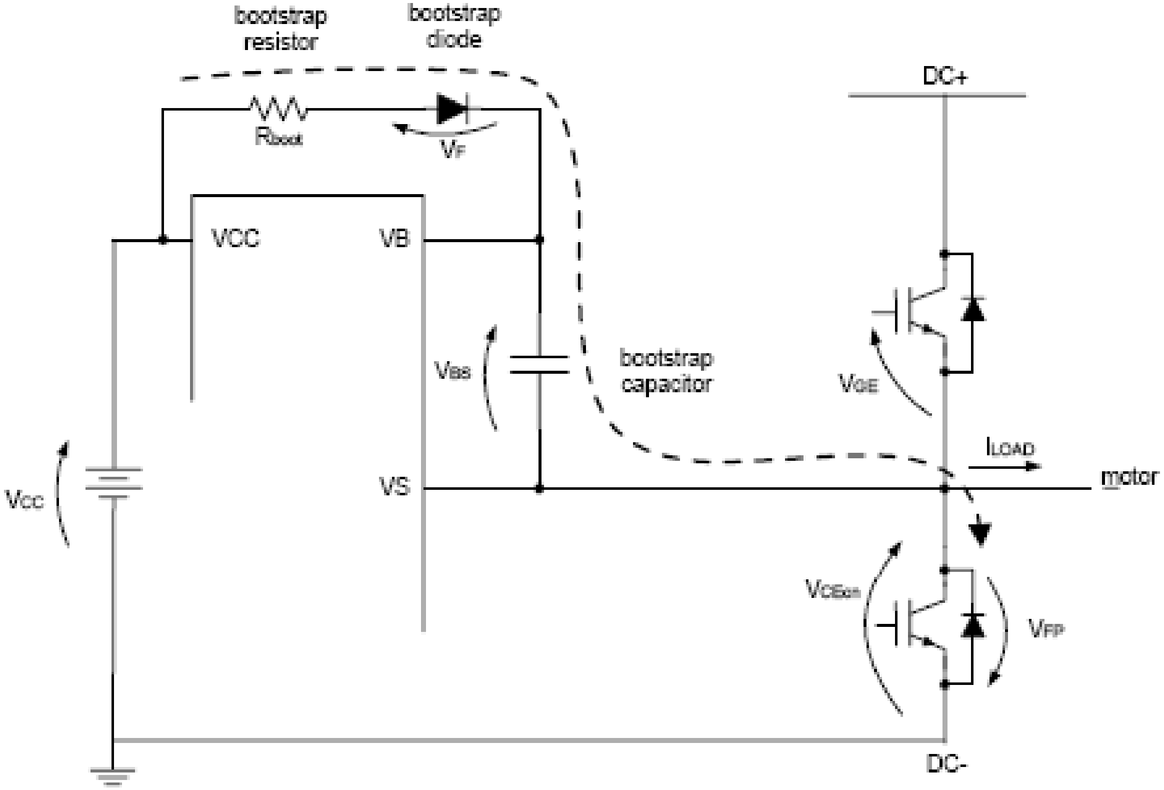


# Bootstrap




**Problema**

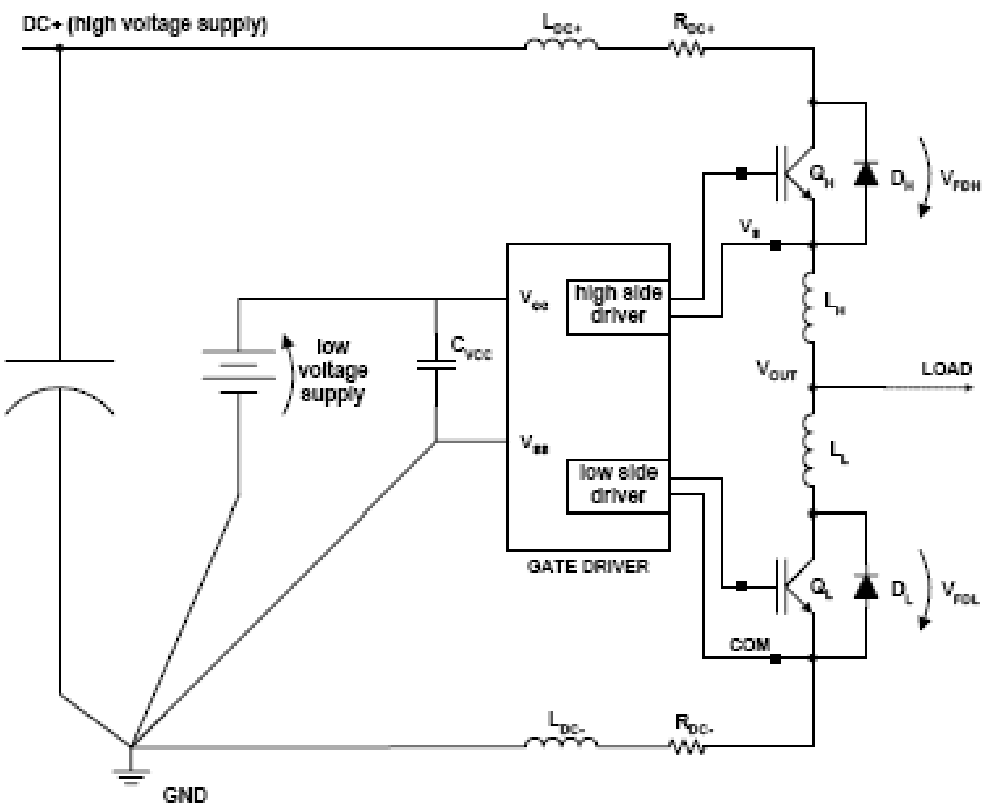
**Princípio do Bootstrap**

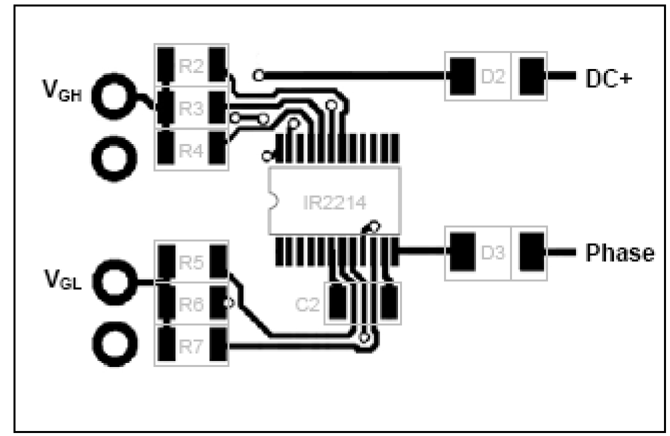


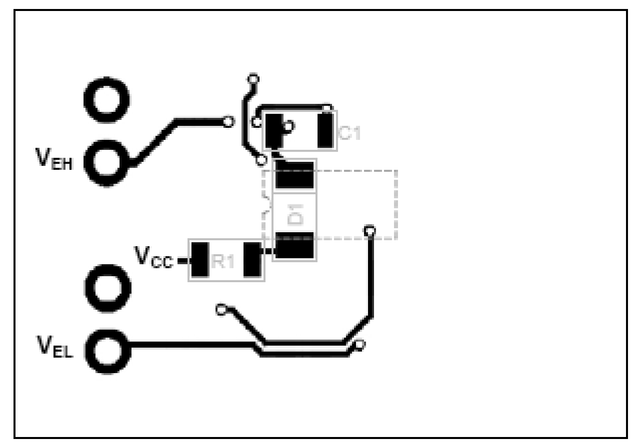

International Rectifier

www.irf.com

# Bootstrap


DC+ (high voltage supply)
L DC+
R DC+
Q H
D H
V FDH
V S
V cc
high side driver
L H
low voltage supply
C VCC
V OUT
LOAD
V SS
low side driver
L L
Q L
D L
V FDL
GATE DRIVER
COM
L DC-
R DC-
GND

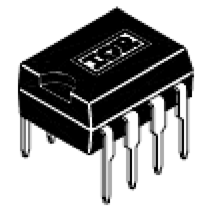

V GH
R2
R3
R4
D2
DC+
IR2214
V GL
R5
R6
R7
C2
D3
Phase


V EH
C1
D1
V CC
R1
V EL

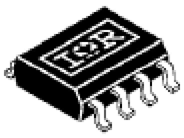
# Bootstrap

## IR2111(S)&(PbF)
## HALF-BRIDGE DRIVER

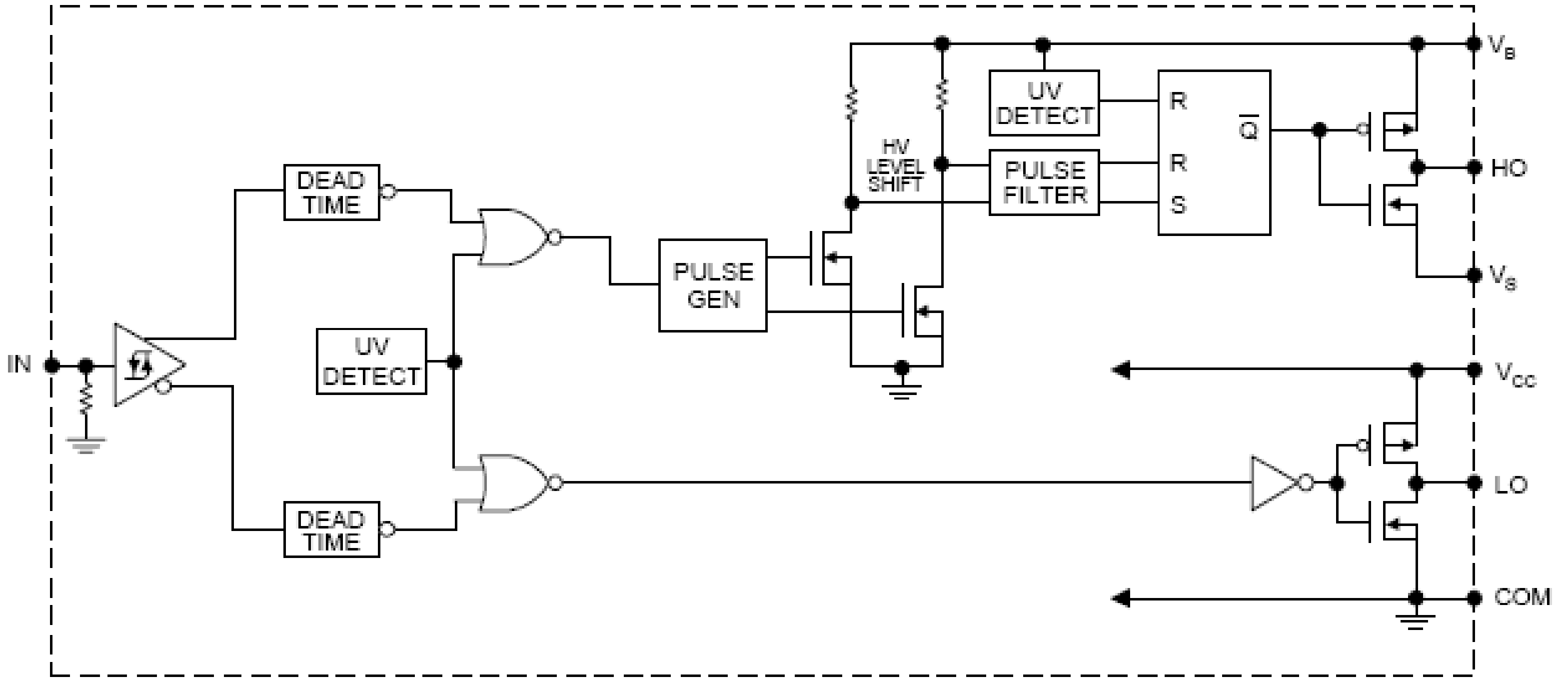
| | |
|---|---|
| $V_{OFFSET}$ | 600V max. |
| $I_O$+/- | 200 mA / 420 mA |
| $V_{OUT}$ | 10 - 20V |
| $t_{on/off}$ (typ.) | 750 & 150 ns |
| Deadtime (typ.) | 650 ns |



8-Lead PDIP



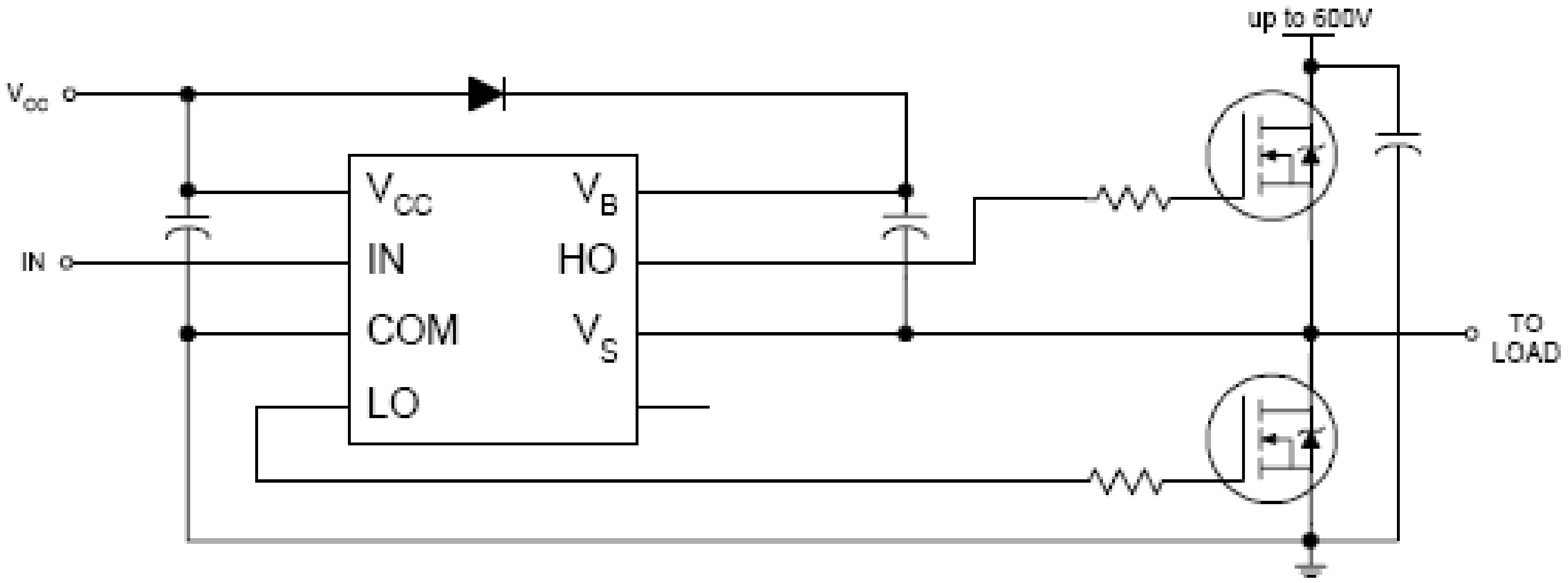
8-Lead SOIC



# Bootstrap

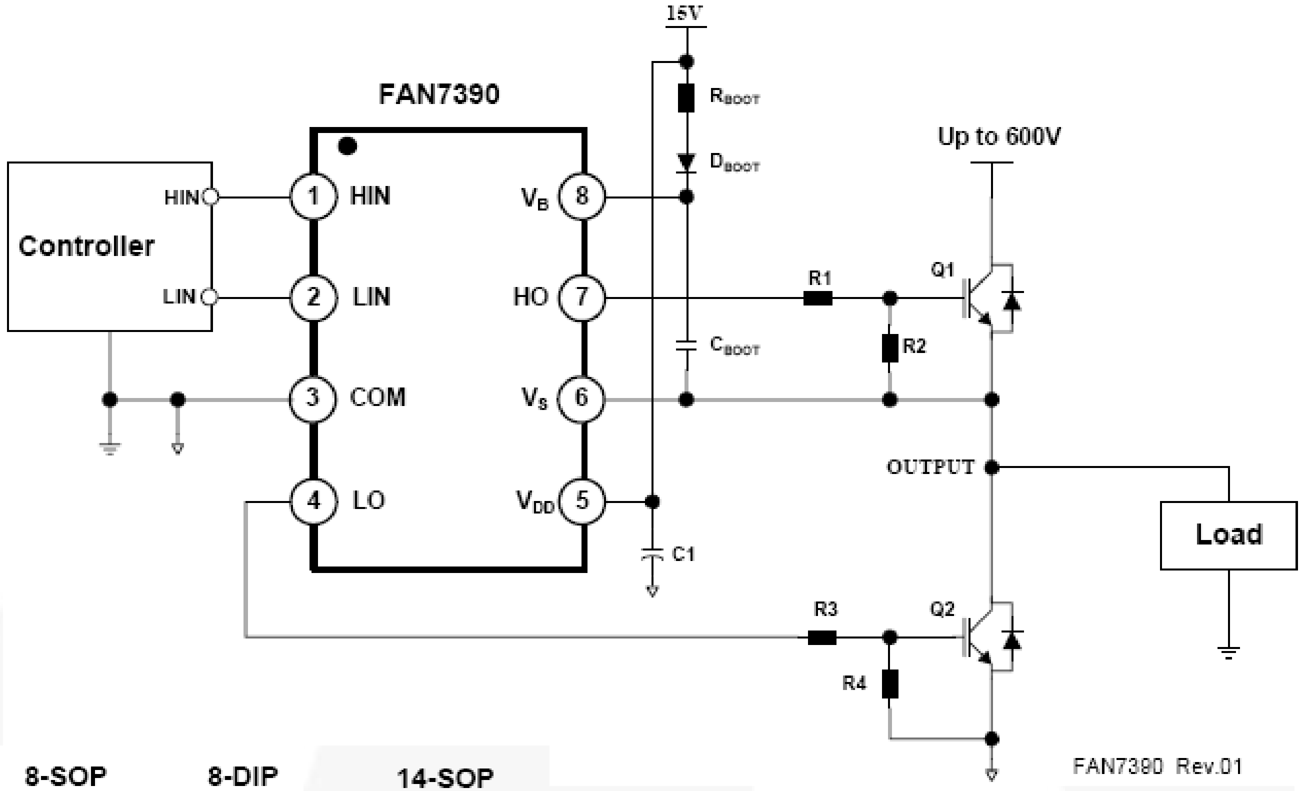
**IR2111(S)&(PbF)**

**HALF-BRIDGE DRIVER**



# Boostrap

## FAN7390
## High-Current, High & Low-Side, Gate-Drive IC

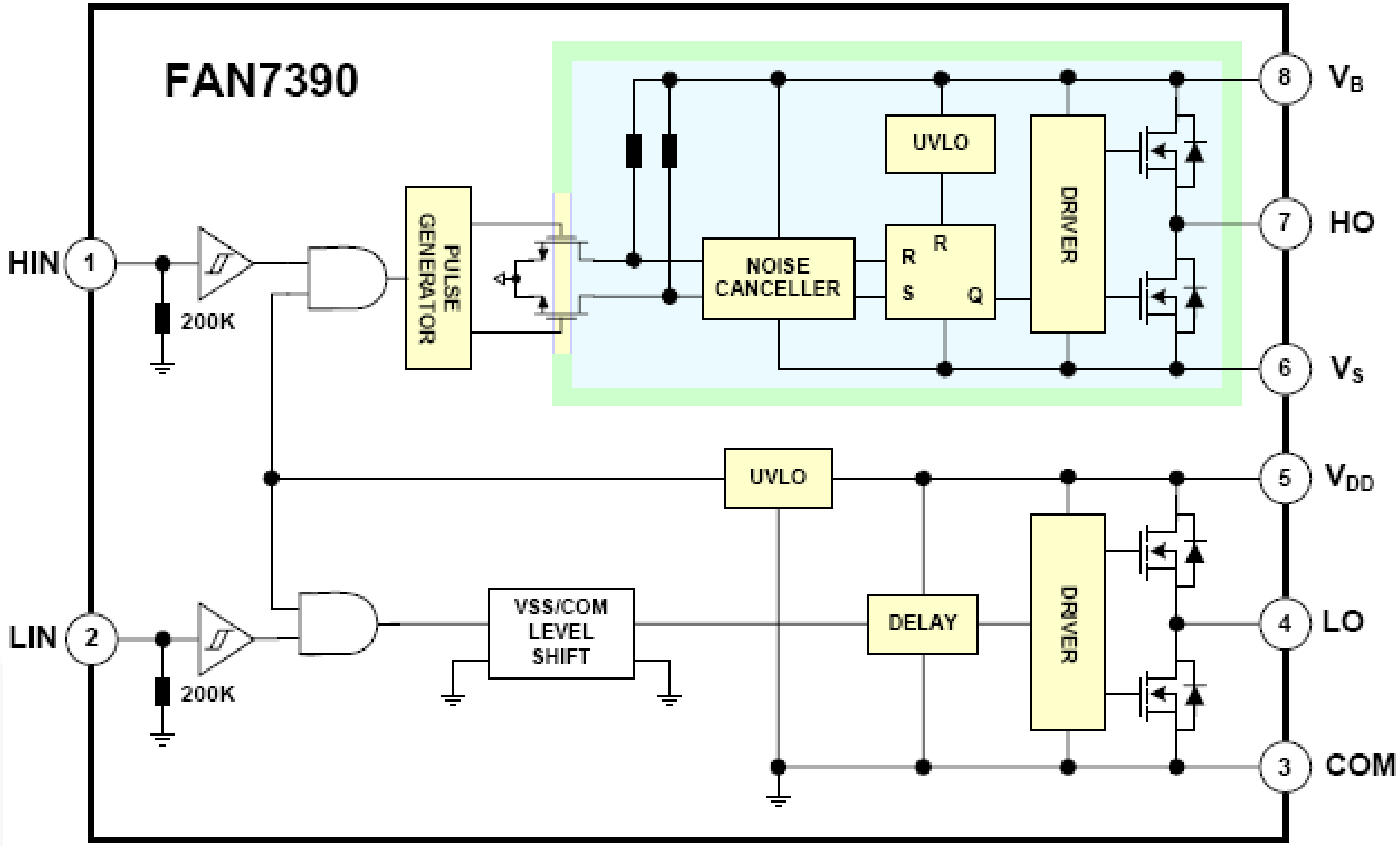



8-SOP 8-DIP 14-SOP

FAN7390 Rev.01

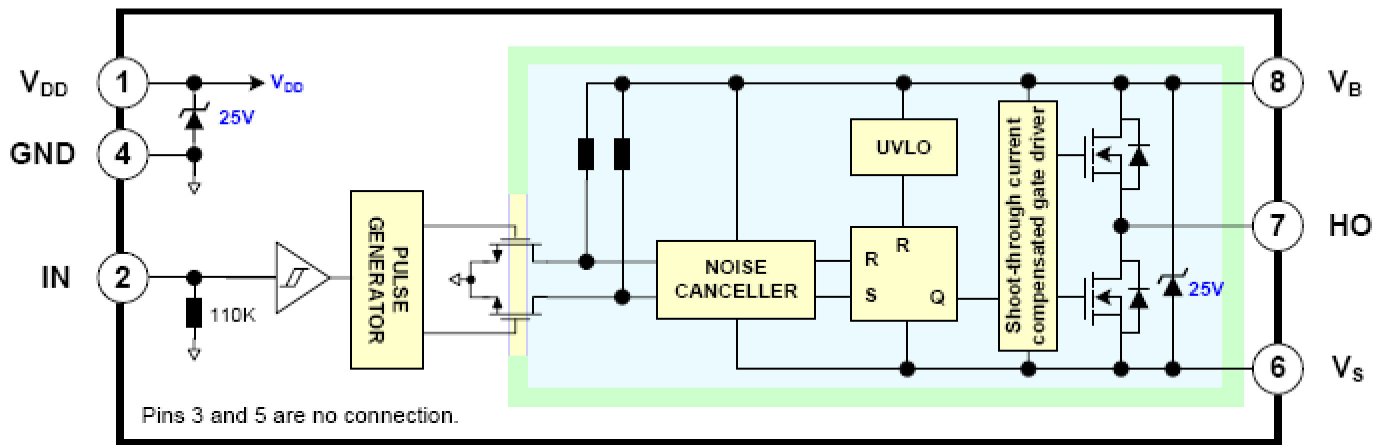
www.fairchildsemi.com

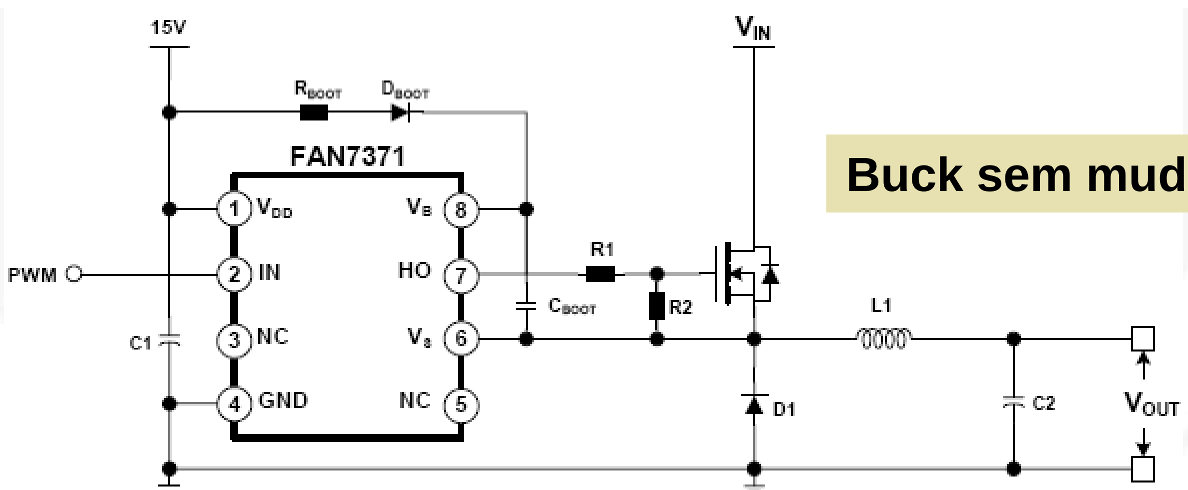
# Bootstrap


FAN7390
HIN 1
LIN 2
200K
200K
PULSE GENERATOR
NOISE CANCELLER
UVLO
R
R
S
Q
DRIVER
UVLO
VSS/COM LEVEL SHIFT
DELAY
DRIVER
8 $V_B$
7 HO
6 $V_S$
5 $V_{DD}$
4 LO
3 COM

# Bootstrap

## FAN7371
## High-Current High-Side Gate Drive IC




**Buck sem mudar chave de posição**

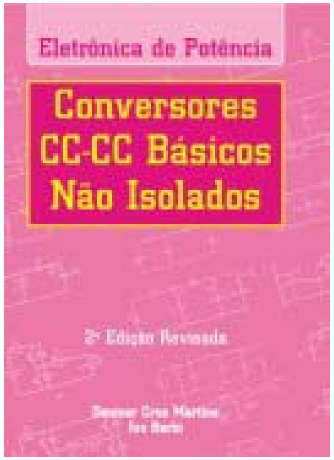
FAIRCHILD SEMICONDUCTOR

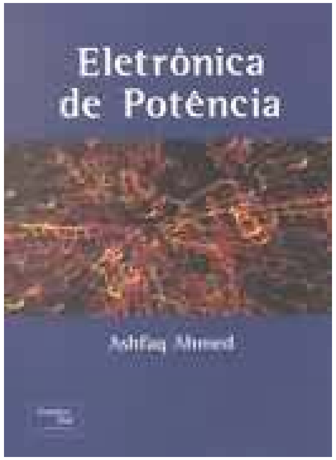
www.fairchildsemi.com

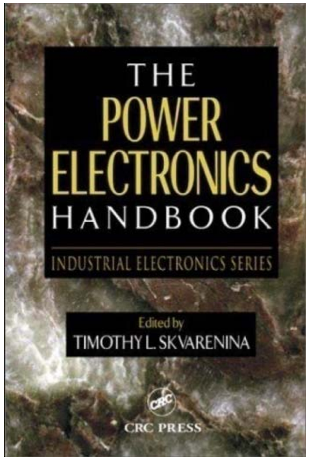
# Próxima aula

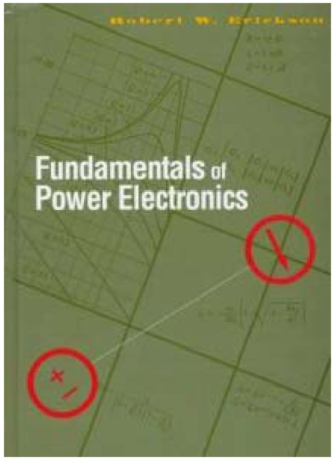
**Capítulo 10: Inversores**

1. Conversores CC-CA monofásicos.




www.cefetsc.edu.br/~petry