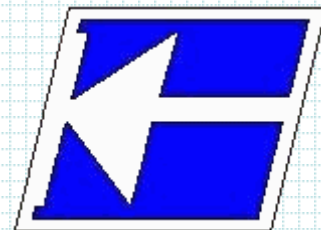


**Instituto Federal de Educação, Ciência e Tecnologia de Santa Catarina**  
**Departamento Acadêmico de Eletrônica**  
**Curso de Graduação em Engenharia Eletrônica**



# **Cálculo de Perdas em diodos, MOSFET e de dissipadores**

**Prof. Joabel Moia.**

**Florianópolis, março de 2025.**

# Bibliografia para esta aula

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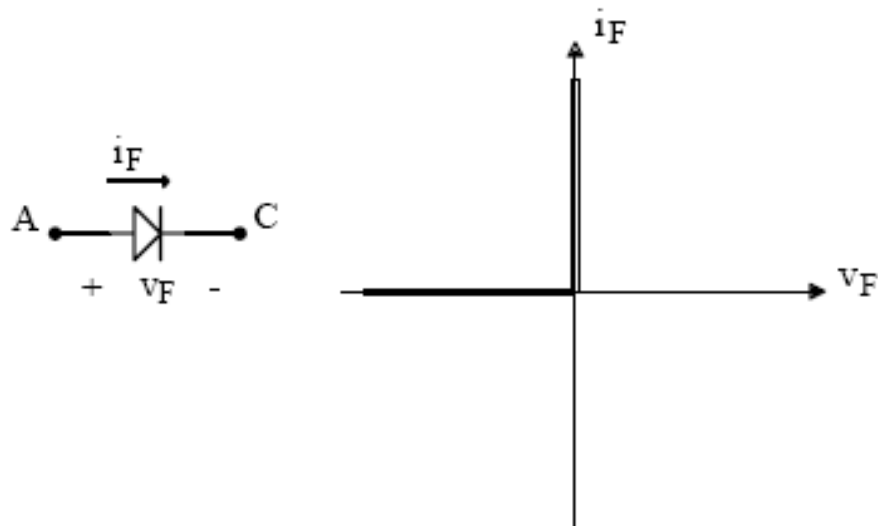
<http://www.hsdissipadores.com.br/default.asp>

<http://www.semikron.com/>

<https://www.onsemi.com/>

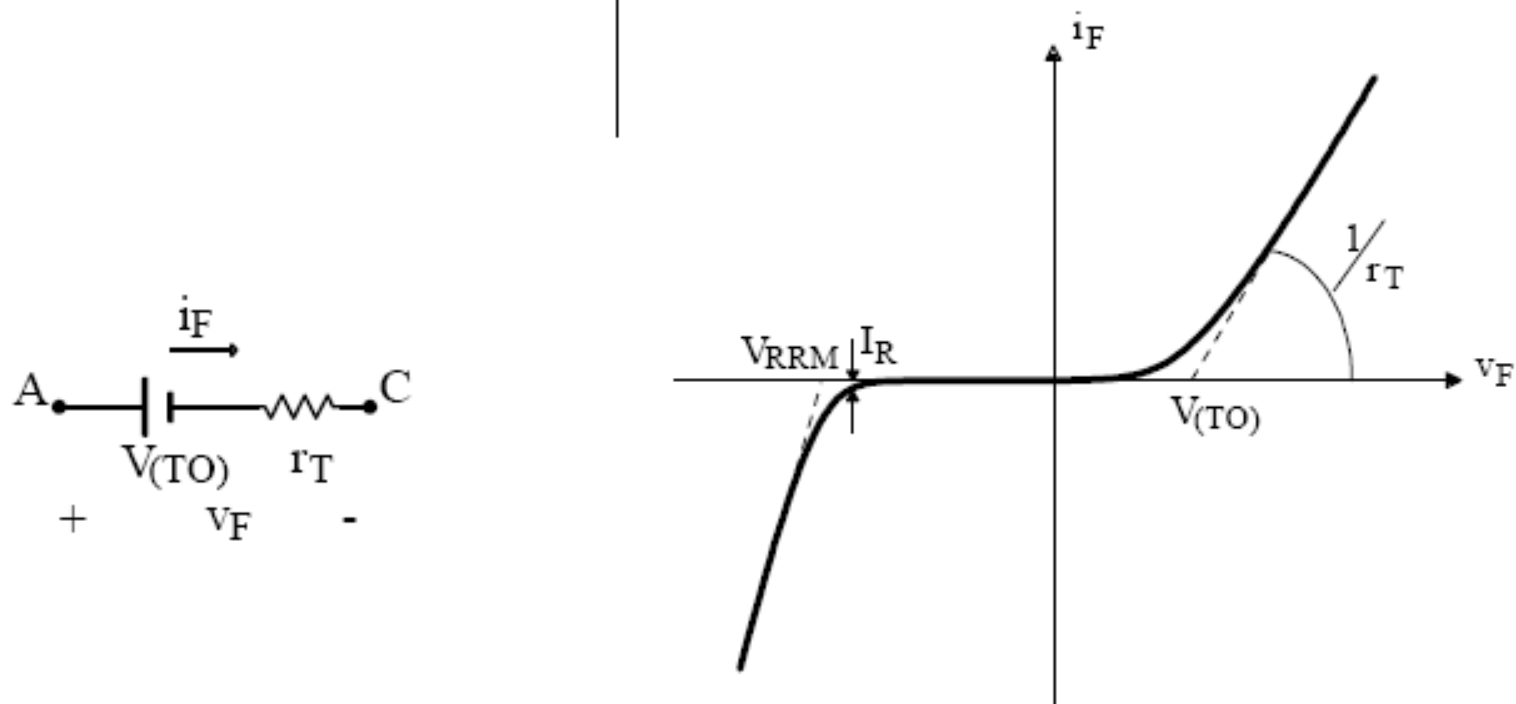
<http://www.irf.com/>

# Diodo ideal e real



## Exemplo: Diodo SKN20/08

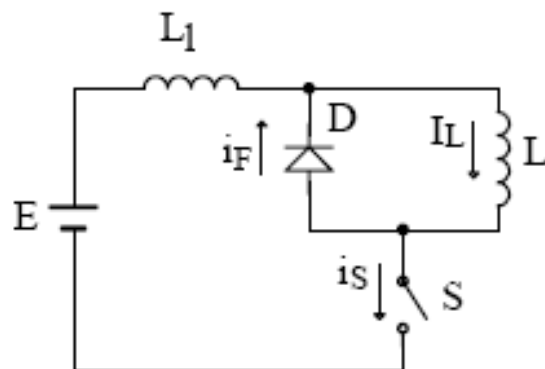
- $V_{RRM} = 800 \text{ V}$ ;
- $V_{(TO)} = 0,85 \text{ V}$ ;
- $r_T = 11 \text{ m}\Omega$ ;
- $I_{Dmed} = 20 \text{ A}$ ;
- $I_\sigma = 0,15 \text{ mA}$ .



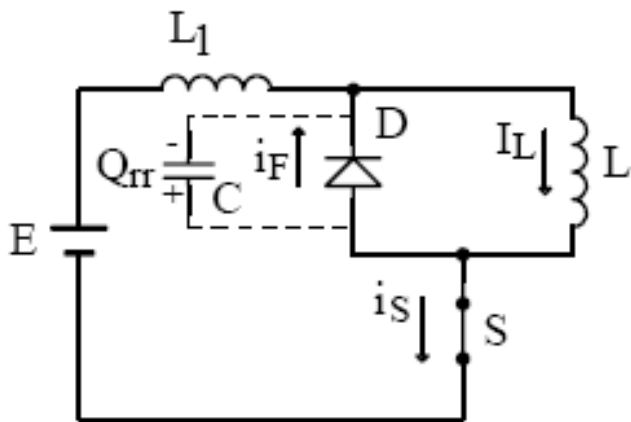
Característica estática

# Diodo real - comutação

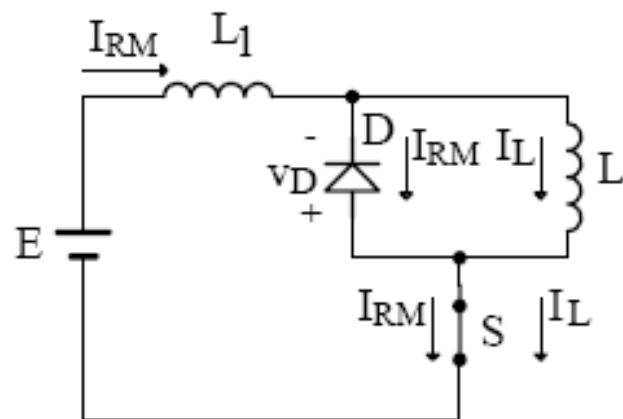
## Bloqueio



**Circuito para estudo da comutação**



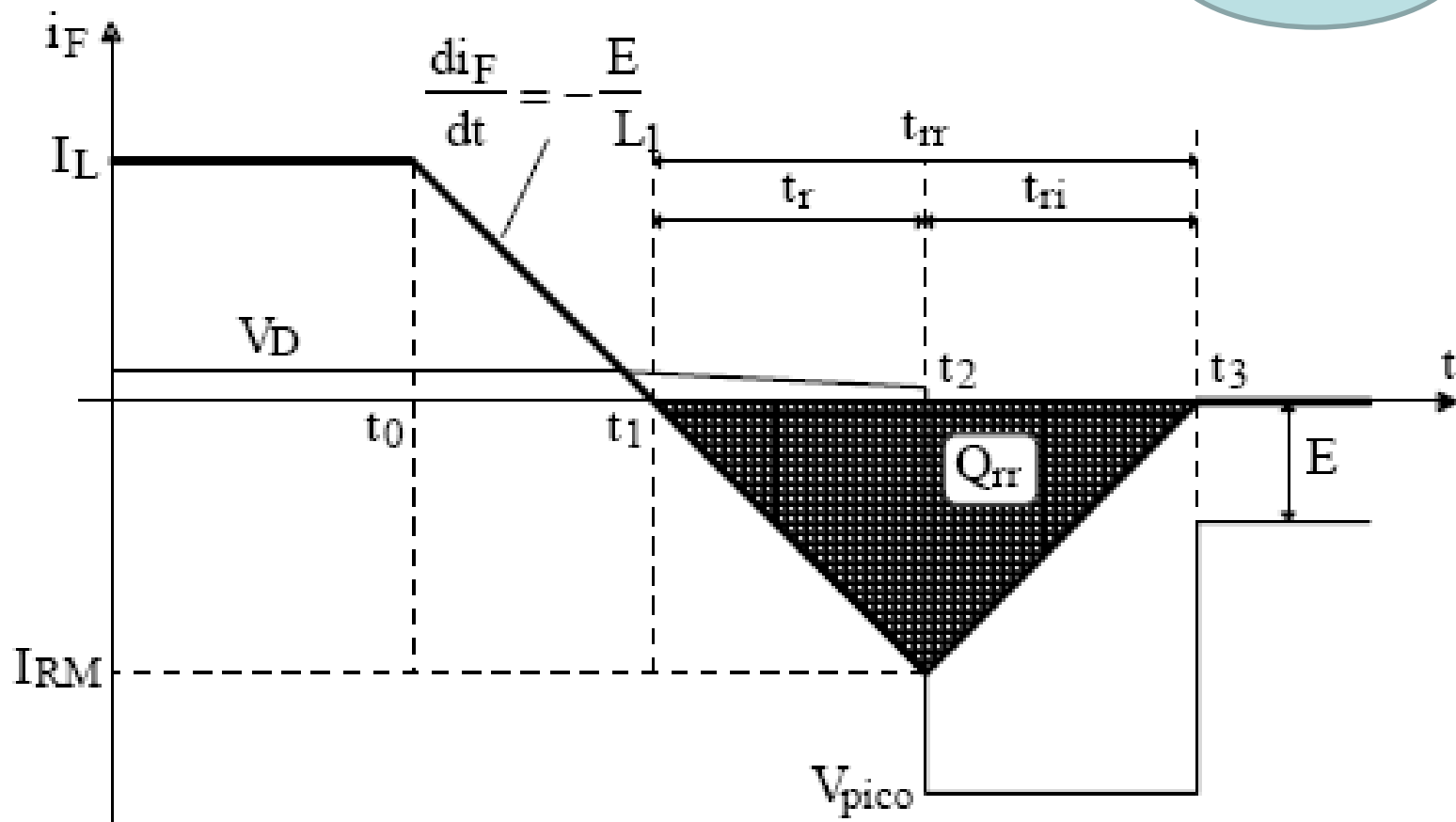
**Primeira etapa de comutação**



**Segunda etapa de comutação**

# Diodo real - comutação

Bloqueio



## Bloqueio

No bloqueio do diodo (comutação crítica):

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

Derivada da corrente depende da indutância

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

Tempo de recuperação reversa

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

Corrente máxima devido a recuperação reversa

## Classificação das perdas:

### 1. Condução;

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

### 1. Comutação:

- Entrada em condução;

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

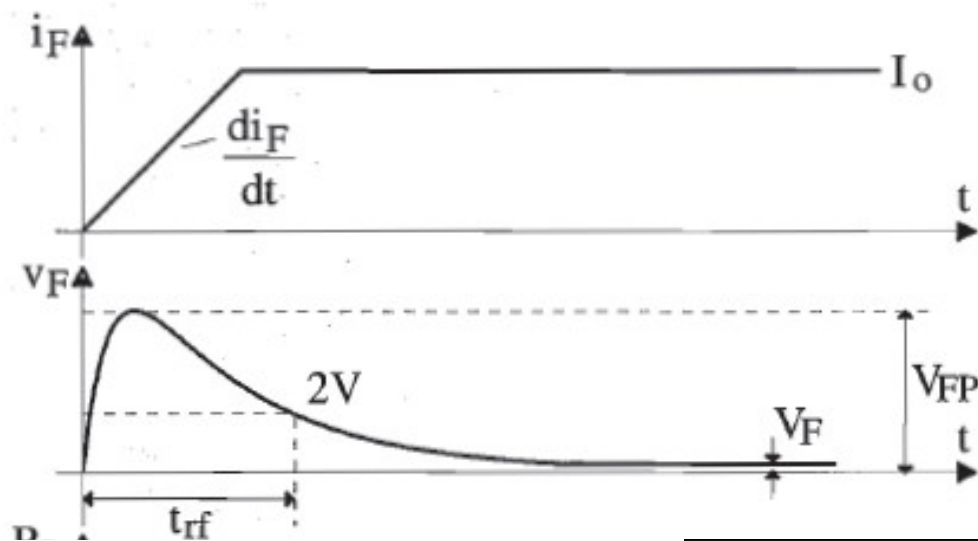
- Bloqueio.

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

# Perdas nos diodos

- Entrada em condução;

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



$P_1$  = Perdas na entrada em condução do diodo. [W]

$V_{FP}$  = Sobretensão direta na entrada em condução. [V]

$f$  = frequência de comutação do diodo. [Hz]

$t_{rf}$  = tempo de atraso na transição. [s]

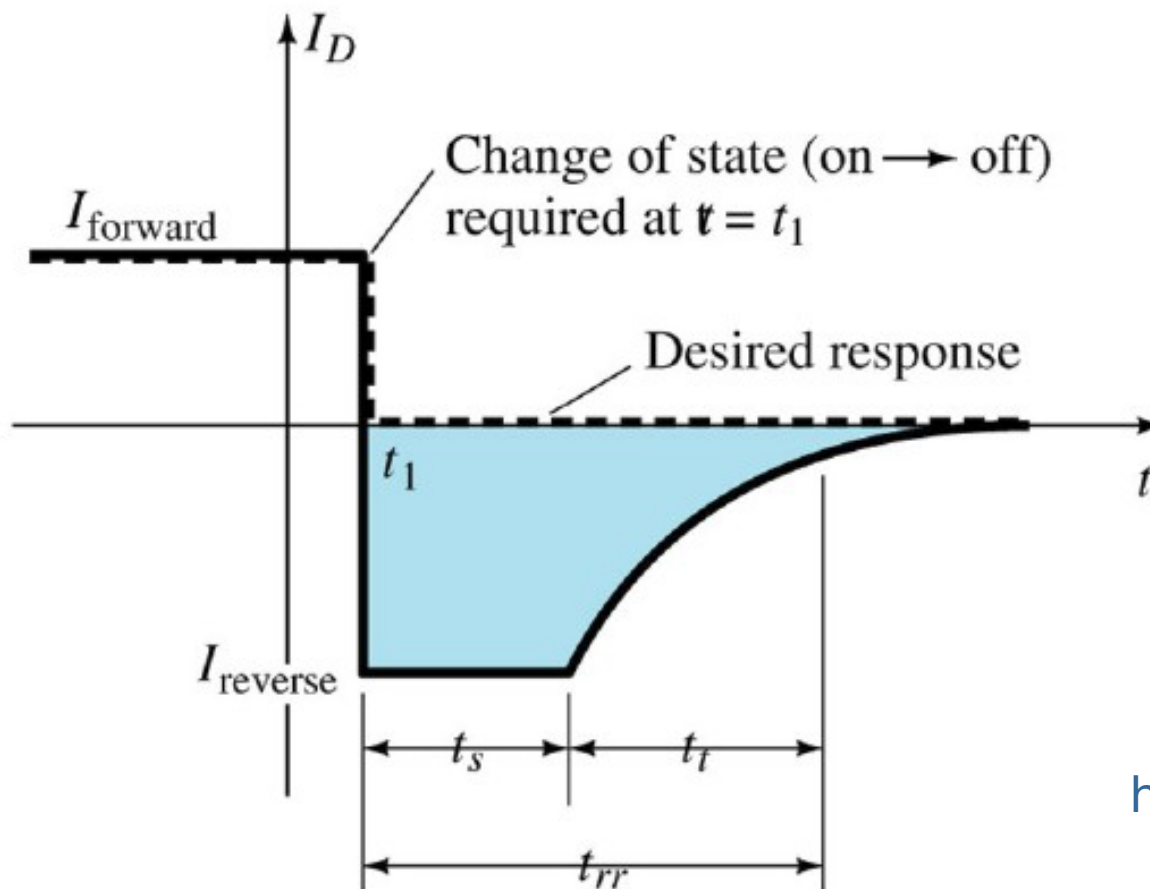
$I_o$  = Corrente em condução do diodo. [A]



# Diodo real - comutação

## Diodos de carbeto de s  cio (silicon carbide):

Diminuem acentuadamente o fen  meno da recupera  o reversa.



<http://www.infineon.com>

<http://www.cree.com>

# Diodo real - comutação

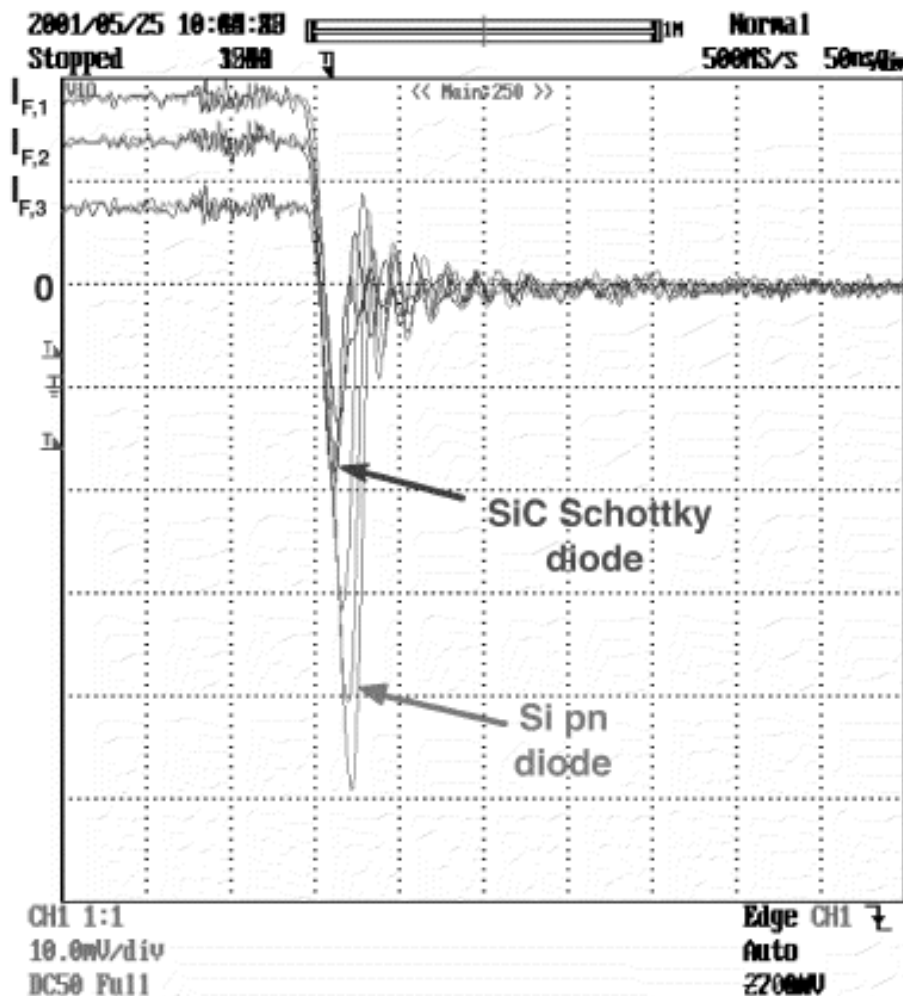


Fig. 5. Typical reverse recovery waveforms of the Si pn and SiC Schottky diode for three different forward currents (2 A/div.).

[http://powerelec.ece.utk.edu/pubs/pels\\_letters\\_SiC\\_june\\_2003.pdf](http://powerelec.ece.utk.edu/pubs/pels_letters_SiC_june_2003.pdf)

# Diodo real - comutação

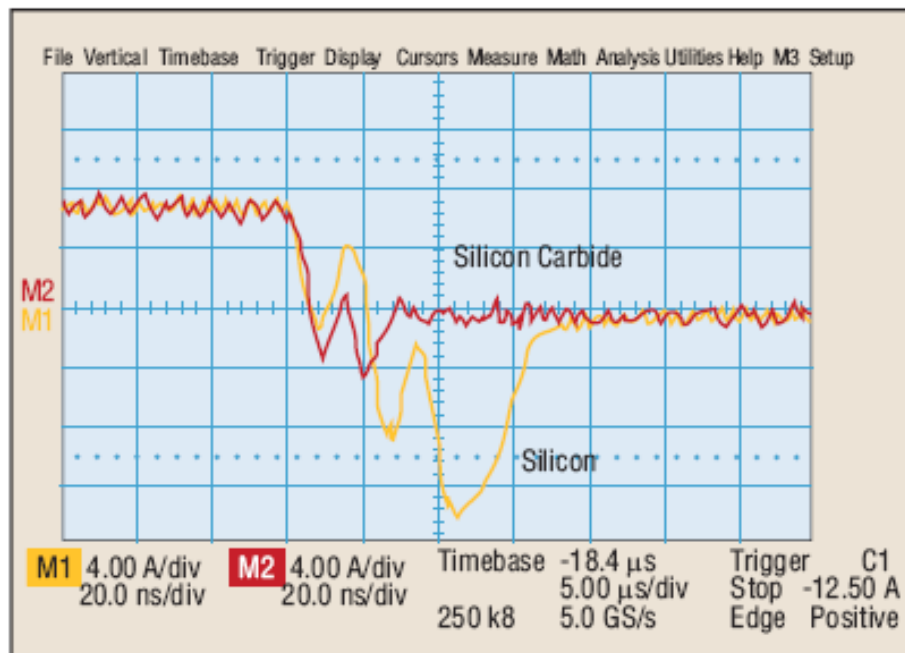


Fig. 4. Low-line diode recovery currents in PFC front-end converter.

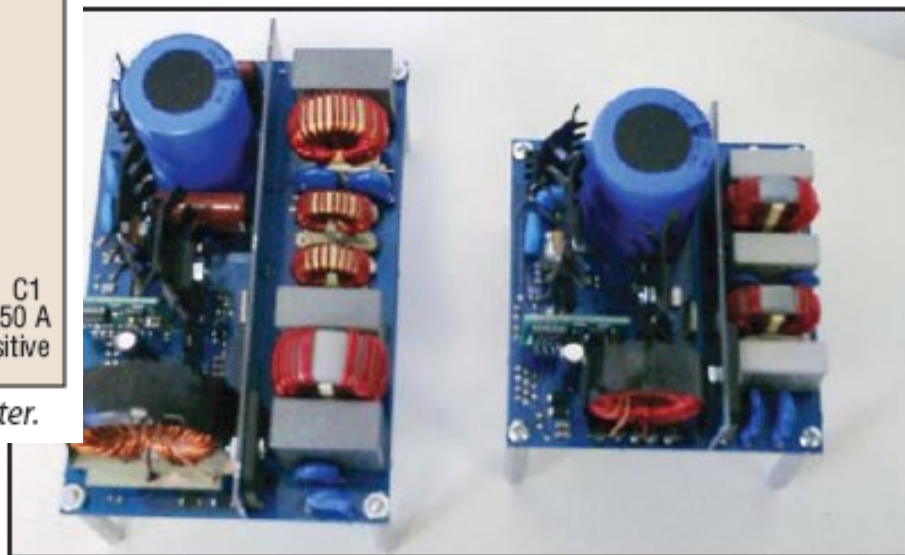
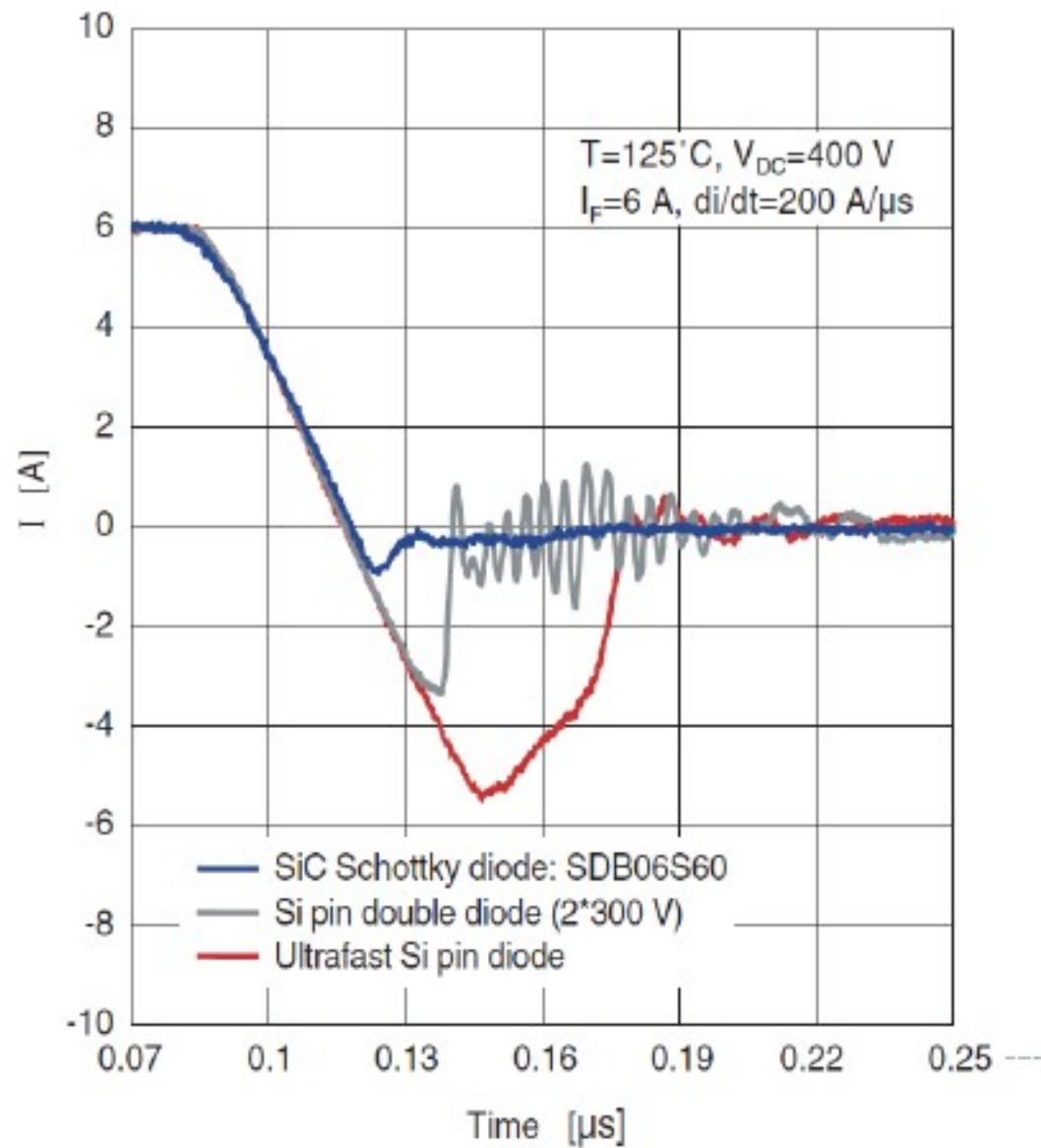


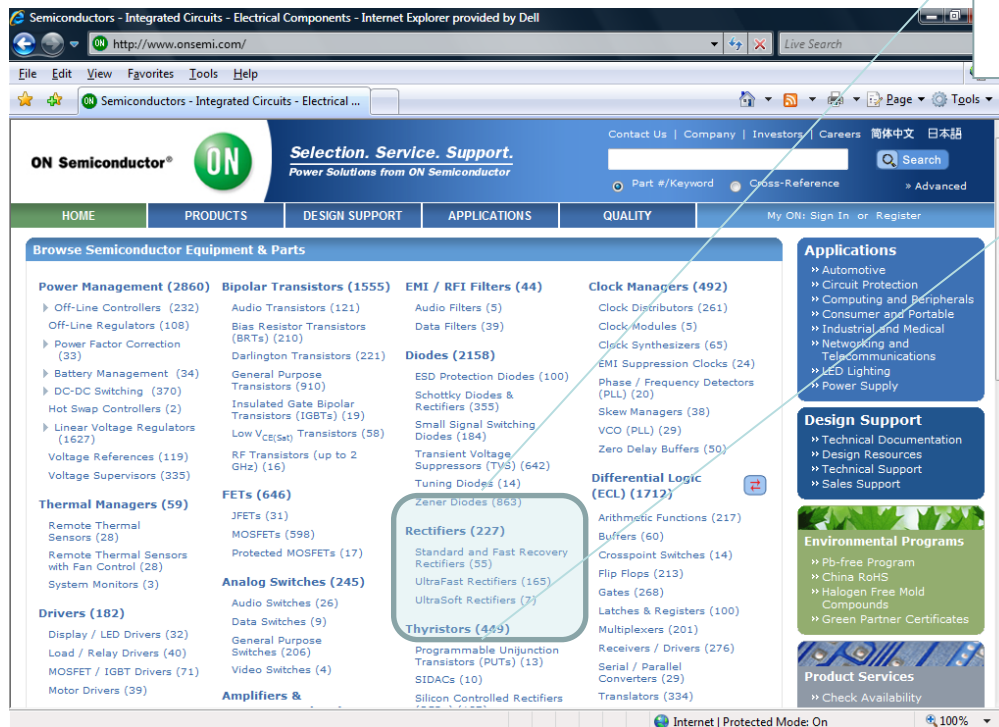
Fig. 8. A size comparison of an 80-kHz PFC front-end built with Si rectifiers (left) and a 200-kHz PFC front-end with SiC rectifiers.

# Diodo real - comutação



## Tipos de diodos de potência:

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



### Rectifiers (227)

Standard and Fast Recovery Rectifiers (55)

UltraFast Rectifiers (165)

UltraSoft Rectifiers (7)

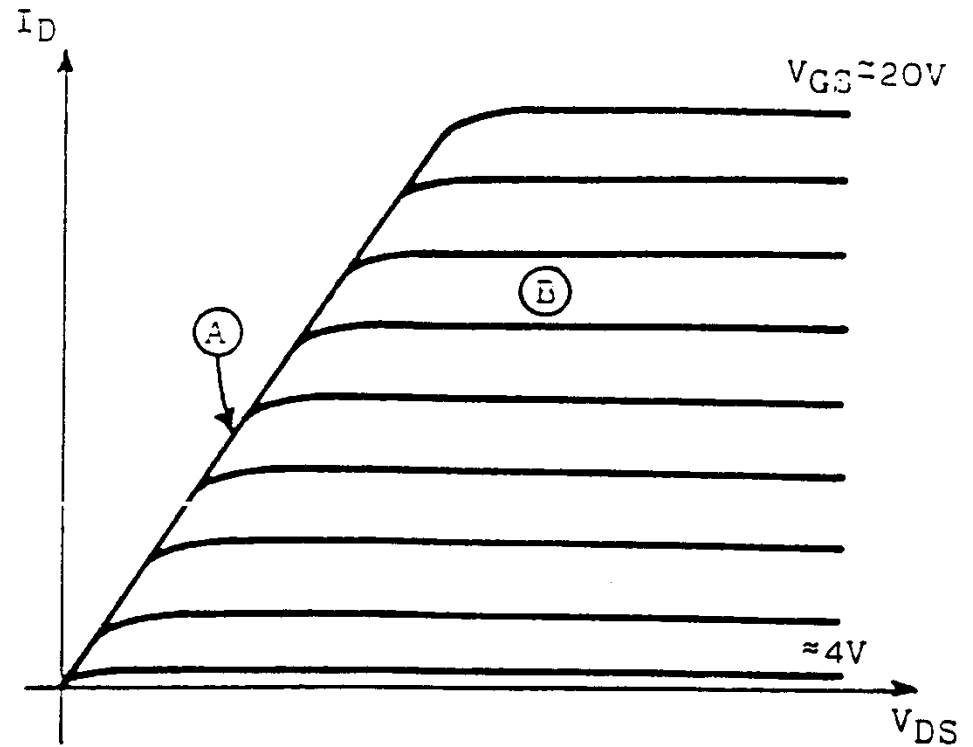
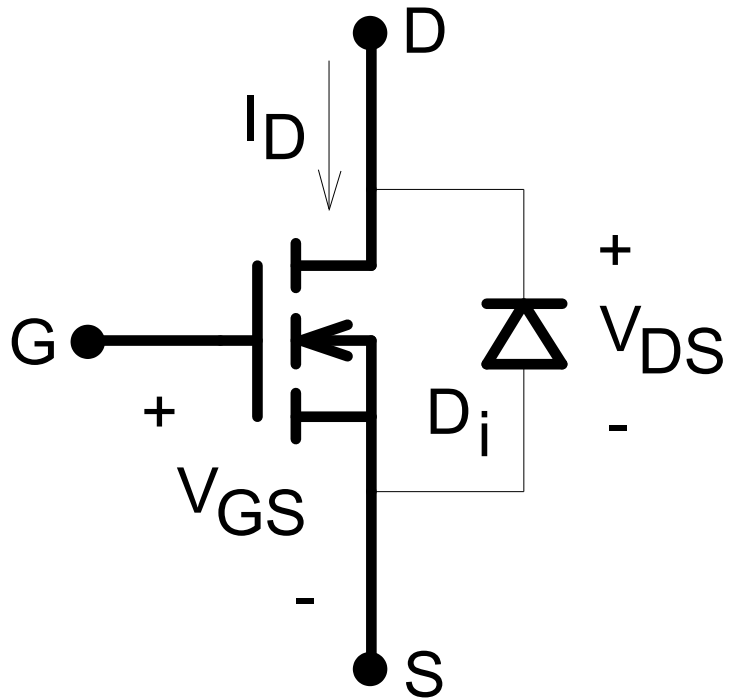
## Tipos de diodos de potência:

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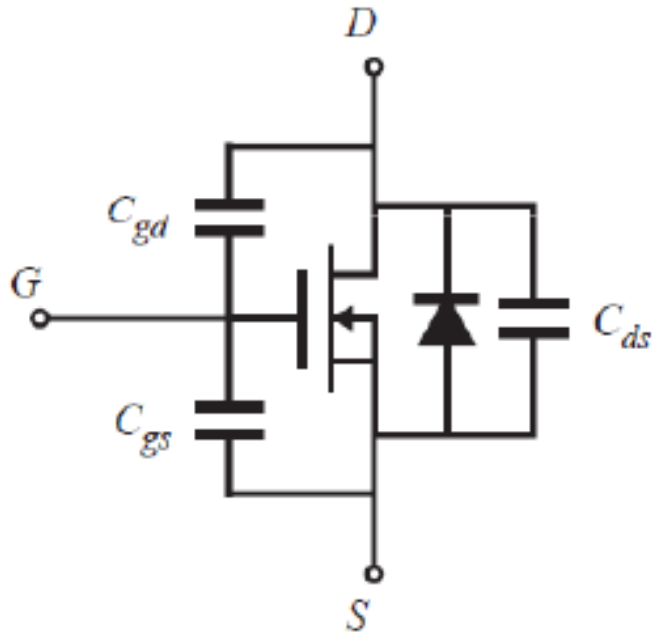
- ▶ **Diodos standard:** transição  $> 0,5\mu\text{s}$  (baixa frequência)
- ▶ **Fast recovery** - transição  $< 250\text{ ns}$
- ▶ **Soft-recovery** – transição *amortecida sem pico de tensão* (principalmente tecnologia Schottky)
- ▶ **ultrafast-recovery** transição  $< 100\text{ ns}$
- ▶ **hyperfast-recovery** transição  $< 50\text{ ns}$
- ▶ Zero recovery (Carbeto de silício, (SiC) – Silicon Carbide) transição em tempo desprezível.

- **Fast:**
  - 50V/50ns – 5000V/5us;
- **Ultra Fast:**
  - 200V/25ns – 600V/40ns
- **Hyper Fast:**
  - 200V/30ns – 600V/16ns;
- **Zero-recovery:**
  - 100-200V/1ns

# MOSFET de potência



# MOSFET de potência



$C_{gd}$  : Pequena e altamente não linear.

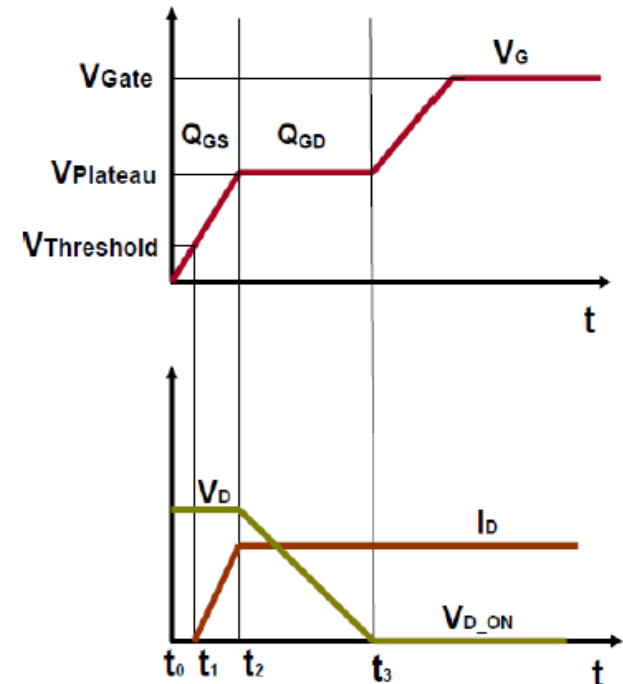
$C_{gs}$ : Elevada e praticamente constante.

$C_{ds}$  : Média e altamente não linear

Os tempos de comutação são determinados pelas taxas de carga e descarga de  $C_{gs}$  e  $C_{gd}$  ( $C_{iss}$ ):

$$C_{iss} = C_{dg} + C_{gs}$$

$$C_{oss} = C_{gd} + C_{ds}$$





## Classificação das perdas:

### 1. Condução;

$$P_{cond} = \frac{t_{on}}{T} \cdot r_{ds(on)} \cdot i_{d(on)}^2 = r_{ds(on)} \cdot i_{d(on)_{rms}}^2$$

### 1. Comutação:

- Entrada em condução e bloqueio;

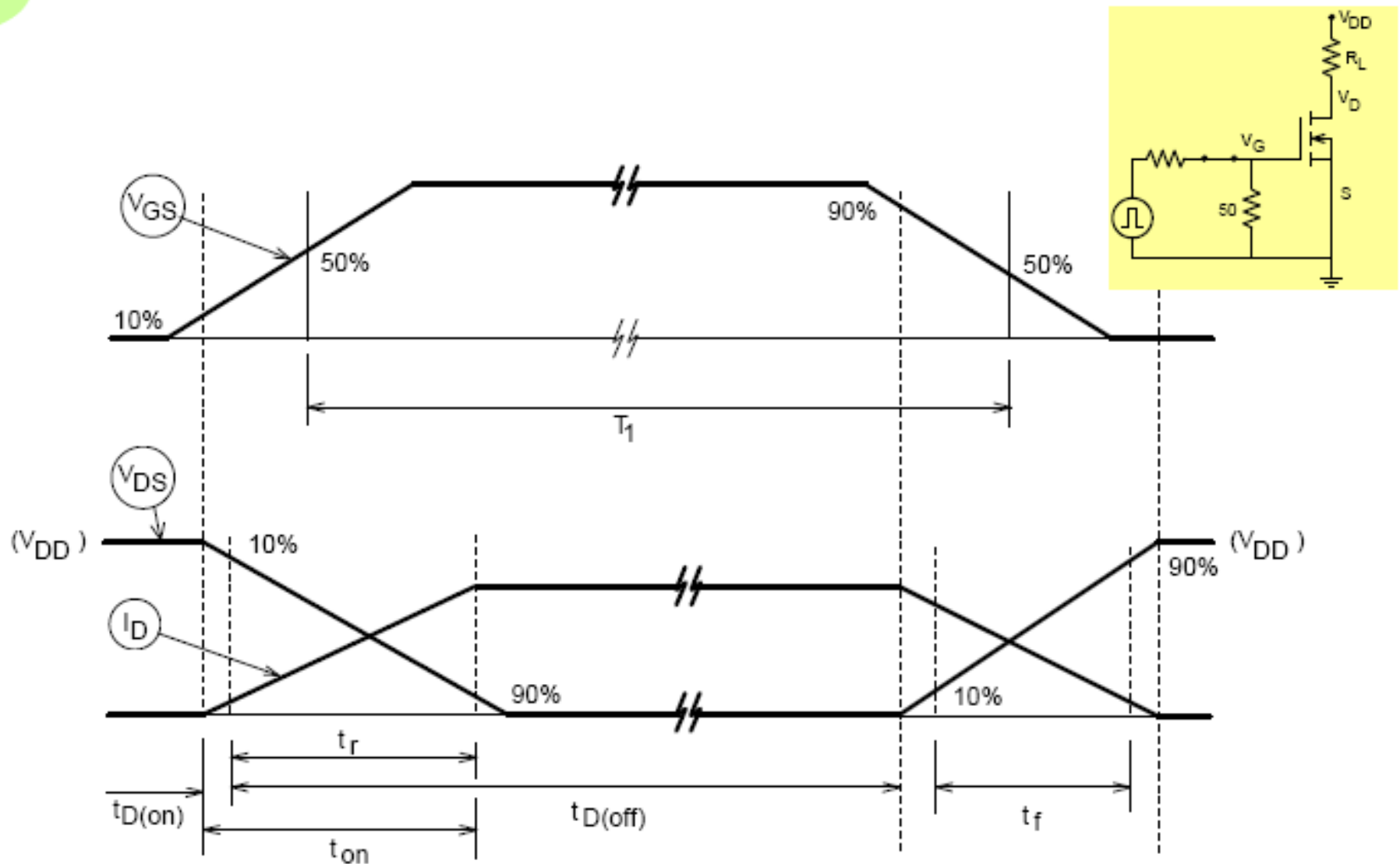
$$P_{com} = \frac{f}{2} (t_r + t_f) \cdot i_{d(on)} \cdot v_{ds(off)}$$

- Onde:

$$t_f \cong t_{on}$$

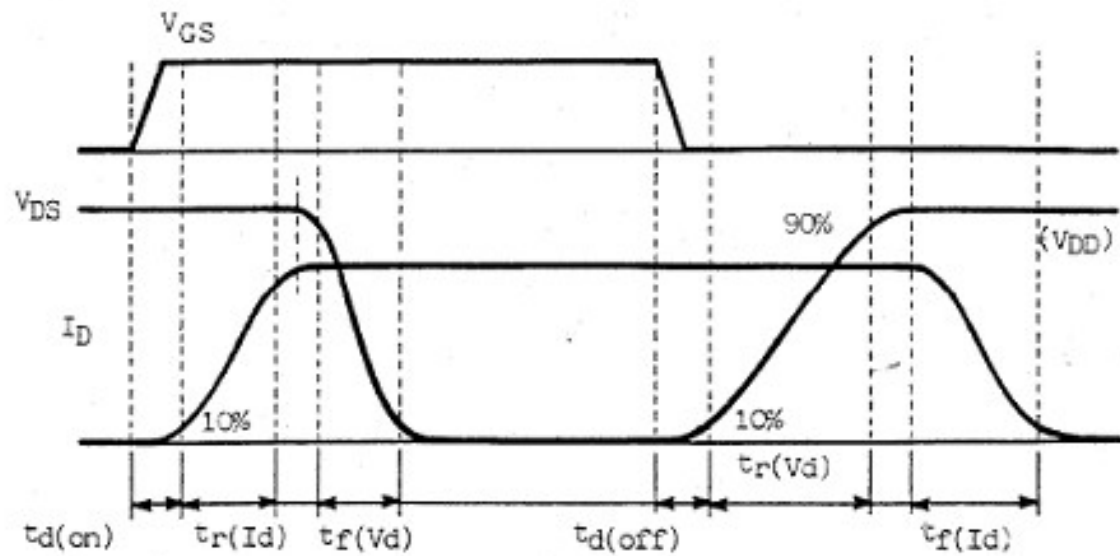
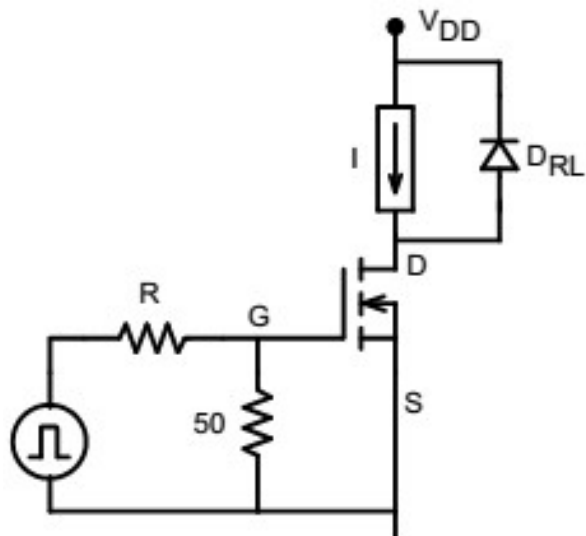
$$t_r \cong t_{off}$$

# MOSFET de potência

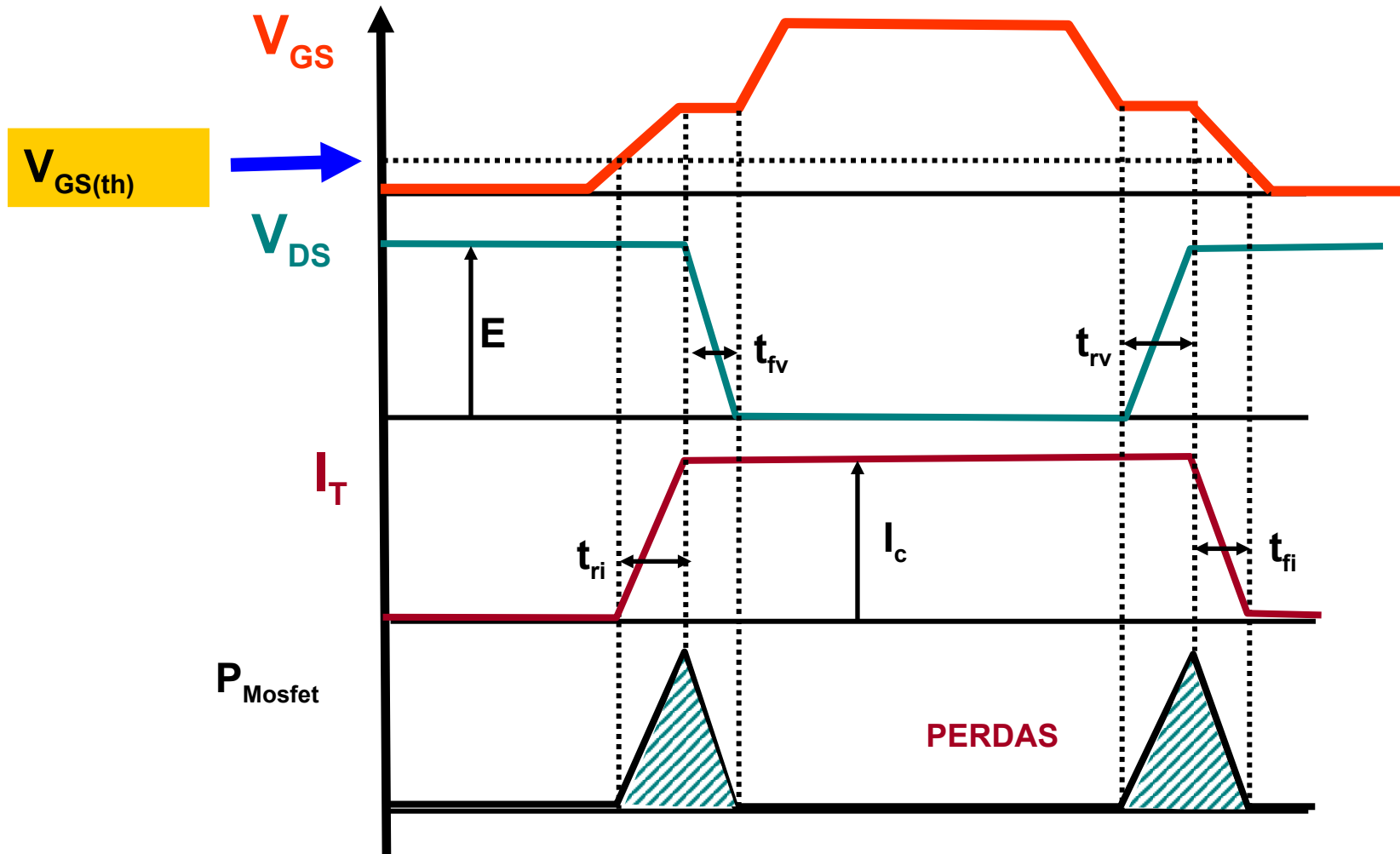


Comutação do MOSFET com carga resistiva

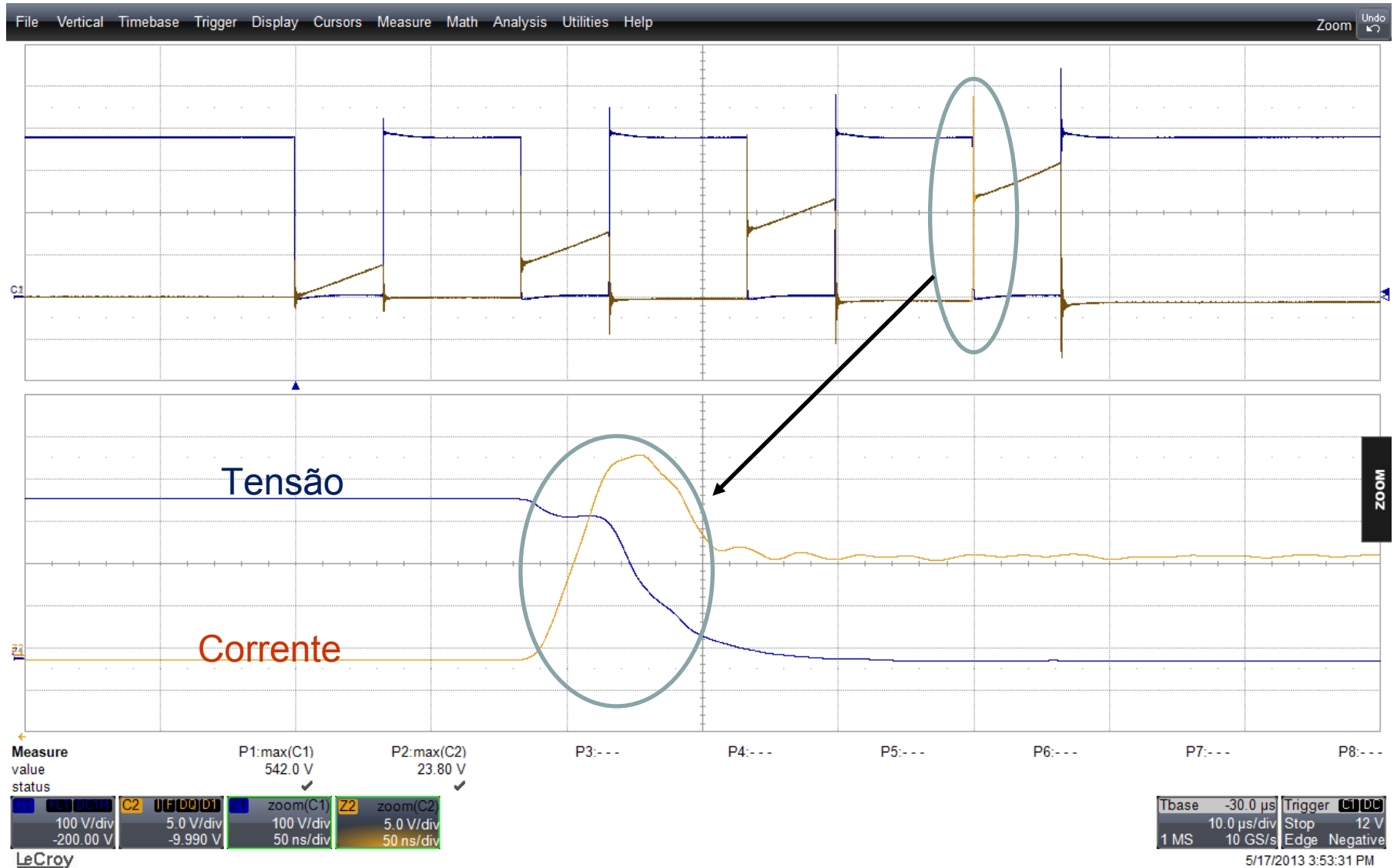
# Perdas em MOSFET



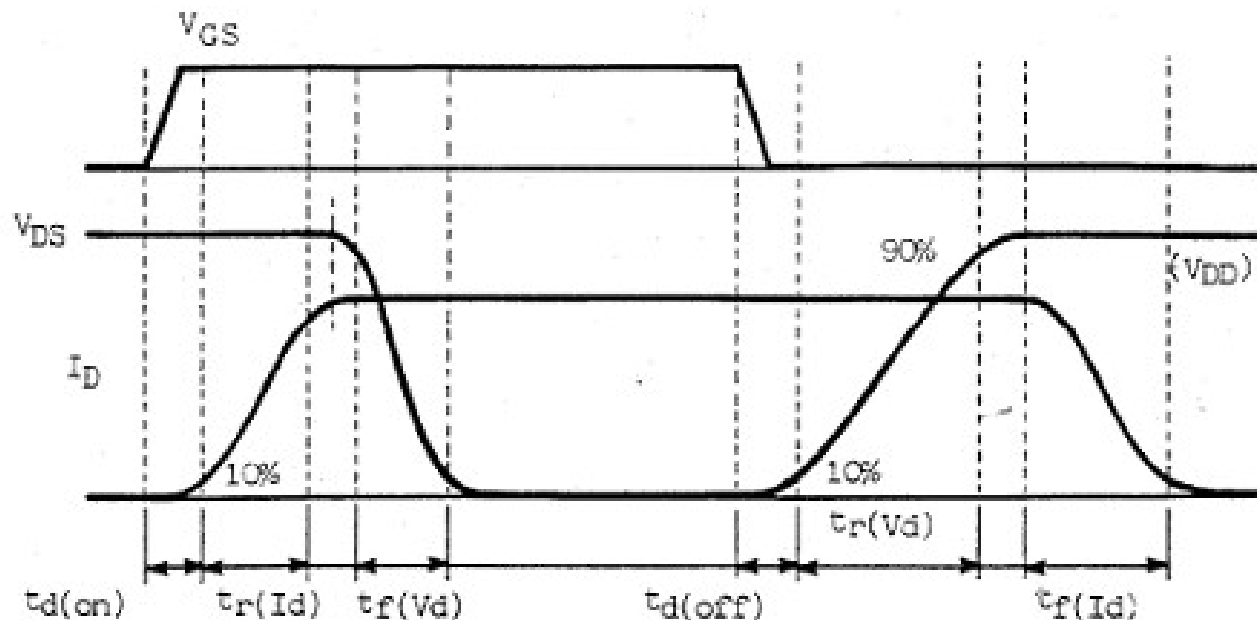
## Transistor Mosfet / IGBT – Características dinâmicas Carga indutiva



# Perdas em IGBT - Caso Real



# Perdas em MOSFET

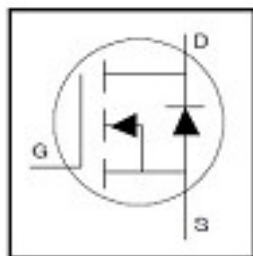


$$P_{\text{cond}} = \frac{t_{\text{on}}}{T} r_{\text{ds(on)}} i_{\text{d(on)}}^2$$

$$P = P_{\text{cond}} + P_{\text{com}}$$

$$P_{\text{com}} = \frac{f}{2} (t_r + t_f) i_{\text{d(on)}} V_{\text{ds(off)}}$$

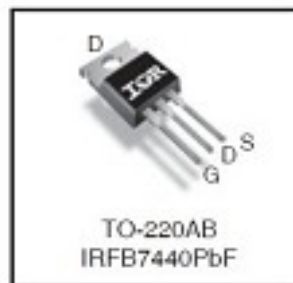
# Perdas em MOSFET



HEXFET® Power MOSFET

$V_{DS}$		40V
$R_{DS(on)}$	typ.	2.0mΩ
	max.	2.5mΩ
$I_D$		172A①
$I_D$ (Package Limited)		120A

International  
**IR** Rectifier



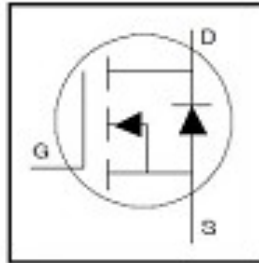
$$P_{cond} = \frac{t_{on}}{T} r_{ds(on)} i_{d(on)}^2$$

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

$t_{d(on)}$	Turn-On Delay Time	—	24	—	ns	$V_{DD} = 20V$
$t_r$	Rise Time	—	68	—		$I_D = 30A$
$t_{d(off)}$	Turn-Off Delay Time	—	115	—		$R_G = 2.7\Omega$
$t_f$	Fall Time	—	68	—		$V_{GS} = 10V$ ②

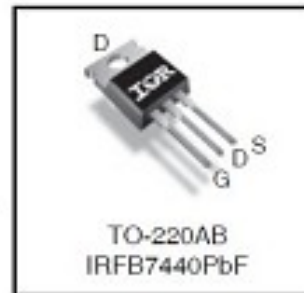
# Perdas em MOSFET

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max.	2.5mΩ
$I_D$	172A①
$I_D$ (Package Limited)	120A

International  
**IOR** Rectifier



$$P_{cond} = \frac{t_{on}}{T} r_{ds(on)} i_{d(on)}^2$$

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

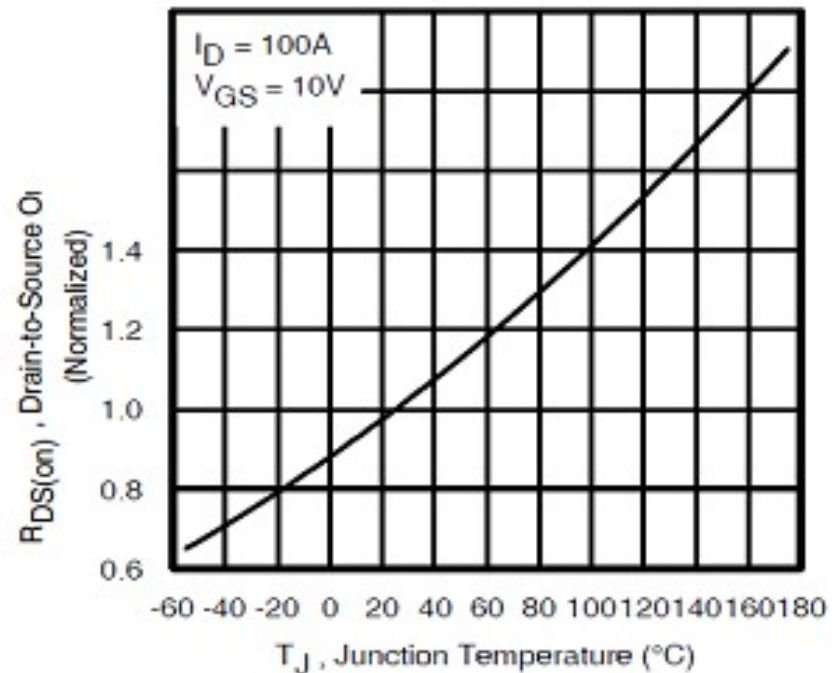
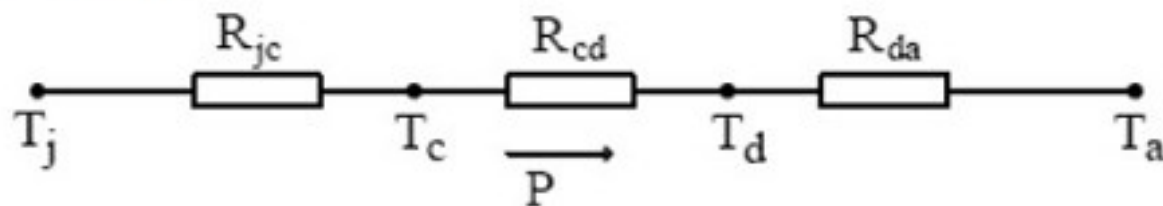


Fig 6. Normalized On-Resistance vs. Temperature



# Cálculo Térmico

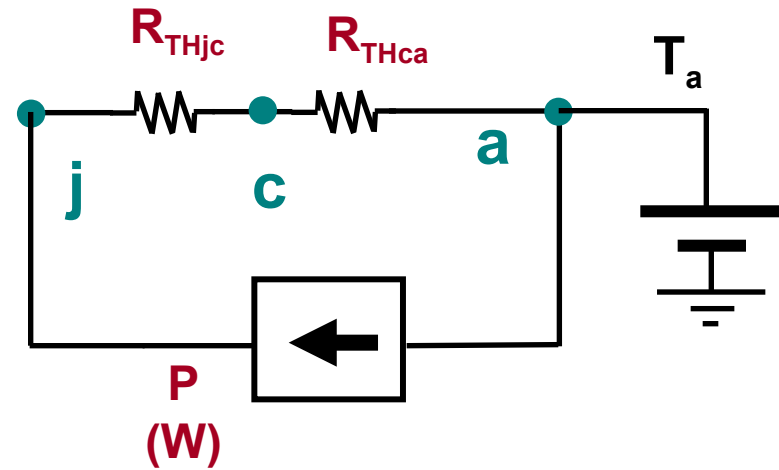
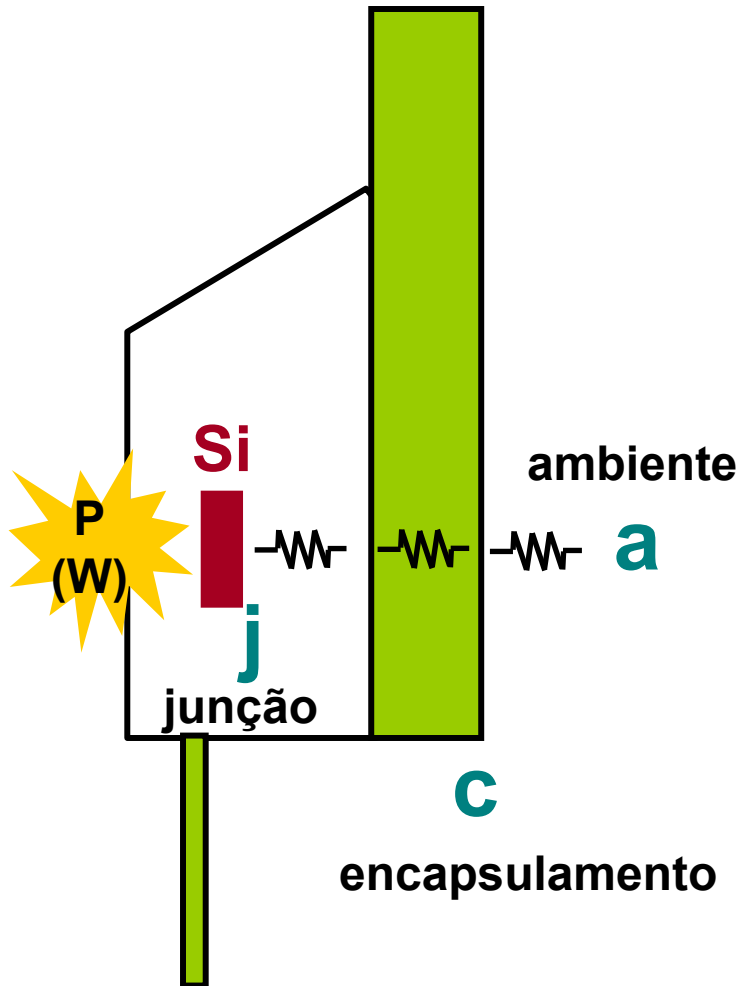
- Objetivo de verificar a necessidade de uso de dissipador de calor ou não.
- Modelo térmico:



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



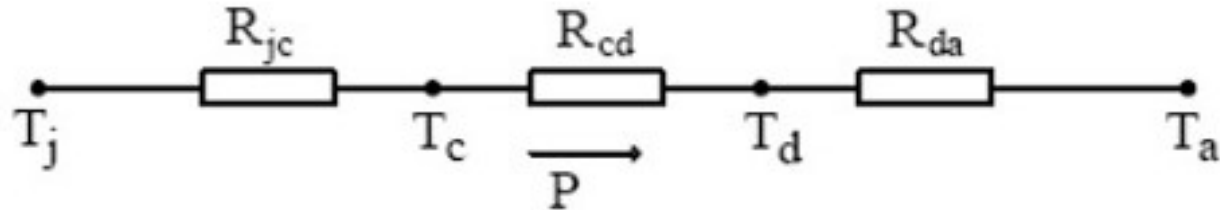
## Dissipação de calor



$T_a$  : Temperatura ambiente

Tensões = Temperaturas

Corrente = Perdas (W)



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

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













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

← → ↻ ⓘ www.changpuak.ch/electronics/calc\_23.php

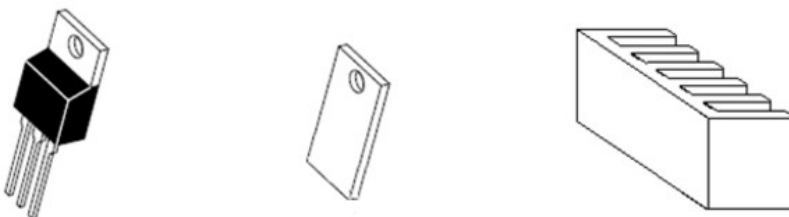
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- Micro Projects • Tools
- Arduino Projects / Shields
- Arduino Knowledgebase
- Power Supply
- Amplifier Design • Amplifiers
- Opamp Calculations
- Doctoral hat electronics
- Antenna Design
- Filter Designer (Audio, AF)
- Filter Designer (Radio, RF)
- Components • Networks
- Software
- Datasheets, Manuals
- PLL, VCO, DDS, Oscillators
- Tutorials
- Troubleshooting • Repair
- Conversions
- misc. Calculations

**STATISTICS**

 101,358	 14,422	 7,853
 43,048	 13,644	 7,708
 36,256	 12,839	 7,061
 28,502	 10,024	 6,955

## ONLINE HEATSINK CALCULATOR



**TRANSISTOR**

$T_j$   °C

$R_{th,j-a}$   °C/W

$P_{diss}$   W

**CALCULATE**

**THERMAL PAD**

$R_{th}$   °C/W



**HEATSINK**

$T_a$   °C


$R_{th}$   °C/W

**17 10**







**FURTHER READING**

-  [Berechnung Kühlkörper](#)
-  [Heatsink Calculation](#)


**YOUR VALUABLE OPINION :**



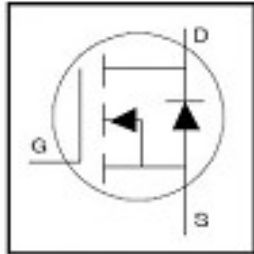
Avg. 3.93 from 75 votes.

 1  2  3  4  5 

**RATE**



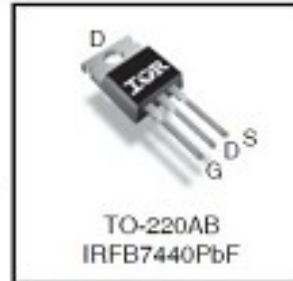
Changpuak electronics: [http://www.changpuak.ch/electronics/calc\\_23.php](http://www.changpuak.ch/electronics/calc_23.php)



HEXFET® Power MOSFET

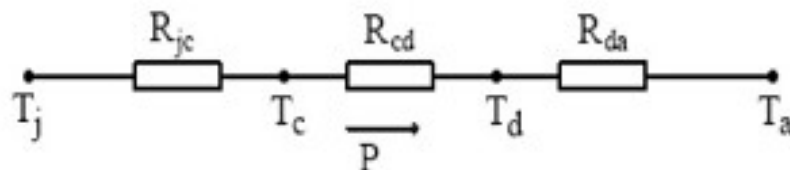
$V_{DS}$	40V
$R_{DS(on)}$ typ.	2.0m $\Omega$
max.	2.5m $\Omega$
$I_D$	172A①
$I_D$ (Package Limited)	120A

International  
**IOR** Rectifier



## Thermal Resistance

Symbol	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case ③	—	1.05	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat Greased Surface	0.50	—	
$R_{\theta JA}$	Junction-to-Ambient	—	62	





HS 3542



HS 3818



HS 4225



HS 4262

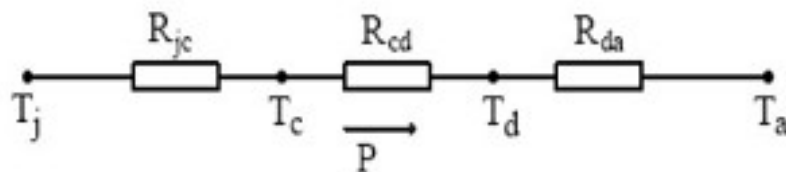


HS 4320



HS 4425

[www.hsdissipadores.com.br](http://www.hsdissipadores.com.br)



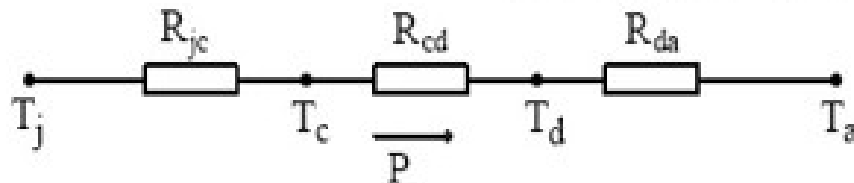
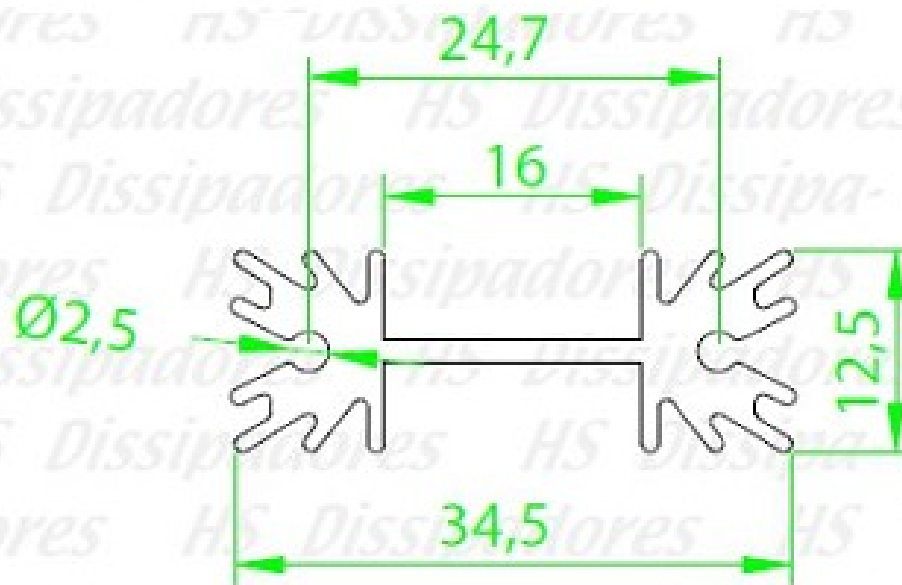


**Código : HS 3512**

Dimensões aproximadas: 35 x 12 mm

Perímetro: 183 mm

Resistência Térmica: 8,35 °C / W / 4"



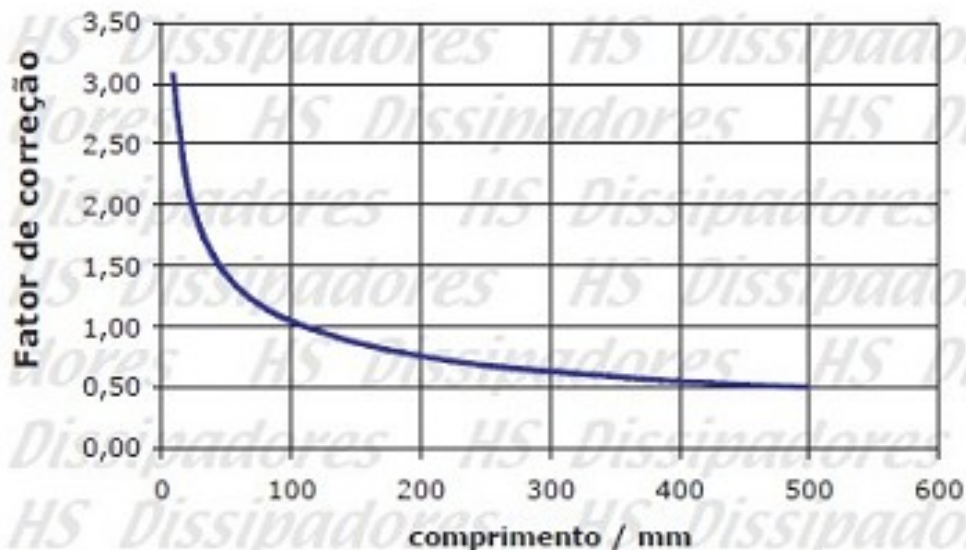
## Fatores que afetam a $R_{th}$

Para melhorar a capacidade de evacuação de calor é possível utilizar ventilação forçada. Isto permite reduzir a resistência térmica.





## Correção do Comprimento



comprimento	fator de correção
10 mm	3,05
20 mm	2,21
30 mm	1,82
40 mm	1,59
50 mm	1,43
70 mm	1,22
100 mm	1,04
150 mm	0,86
200 mm	0,75
250 mm	0,67
300 mm	0,62
400 mm	0,54
500 mm	0,49

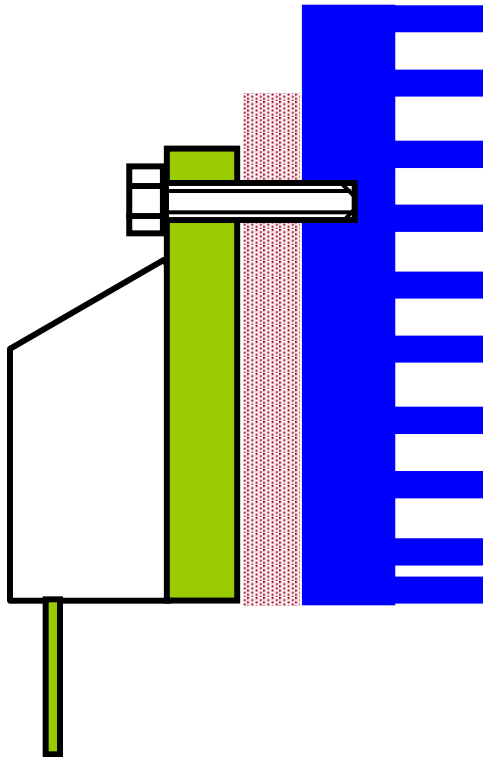
## Montagem do dispositivo sobre o radiador

Nos semicondutores, a parte metálica costuma ser o catodo ou o dreno (coletor) de um transistor MosFet (IGBT).

Se o semicondutor é montado diretamente sobre o radiador, o mesmo se encontra conectado ao mesmo potencial do dispositivo.

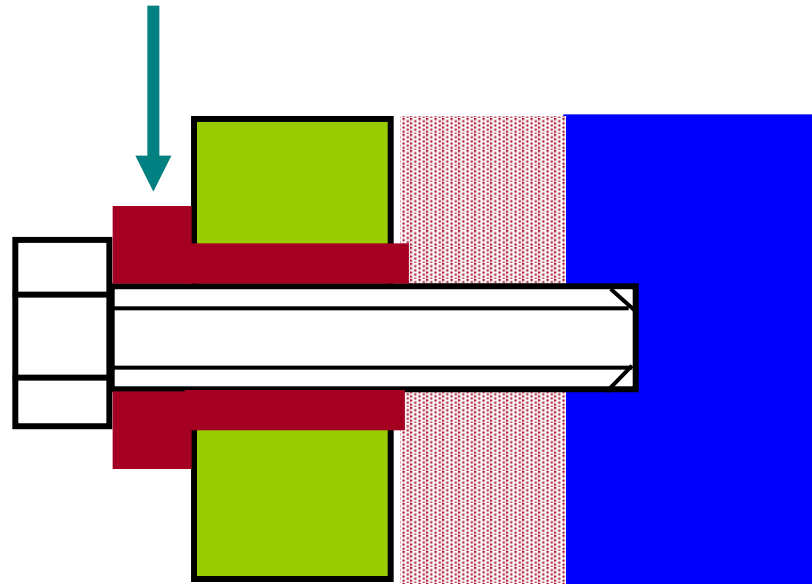


## Montagem do dispositivo sobre o radiador



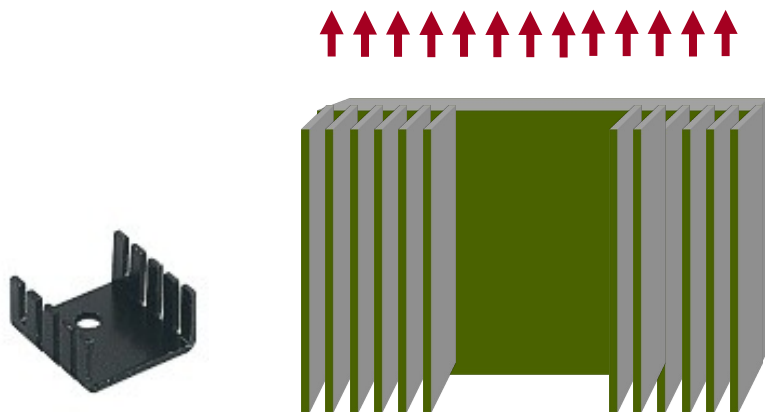
Um parafuso metálico é um conexão elétrica e acaba com o isolamento.

Utilizam-se arruelas de plástico para evitar o contato elétrico.

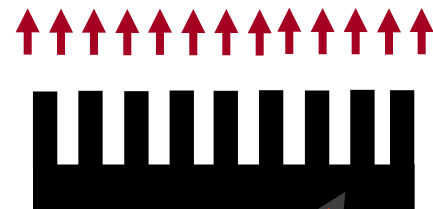


## Montagem do radiador

A  $R_{TH}$  fornecida pelo fabricante é válida para radiador montado na posição vertical. Na posição horizontal a evacuação do calor fica comprometida. Na posição vertical ocorre o “efeito chaminé” no qual o próprio calor gerado pelo aquecimento do radiador cria uma corrente de ar ascendente que melhora a refrigeração.



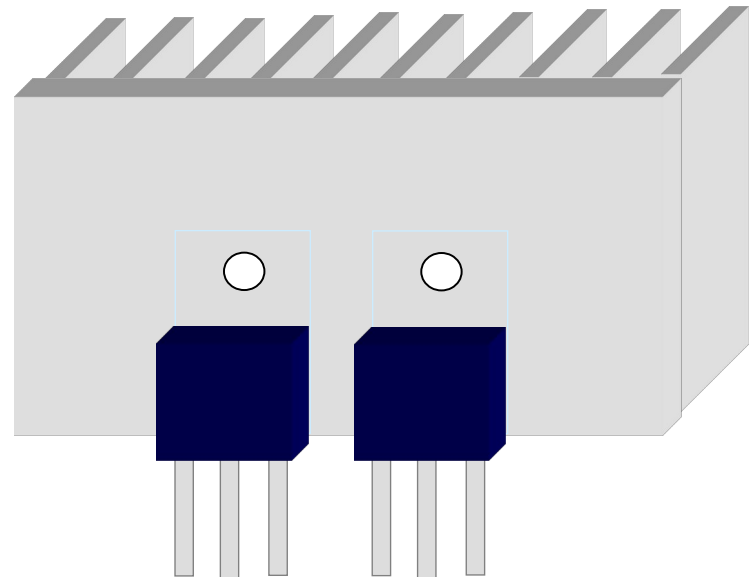
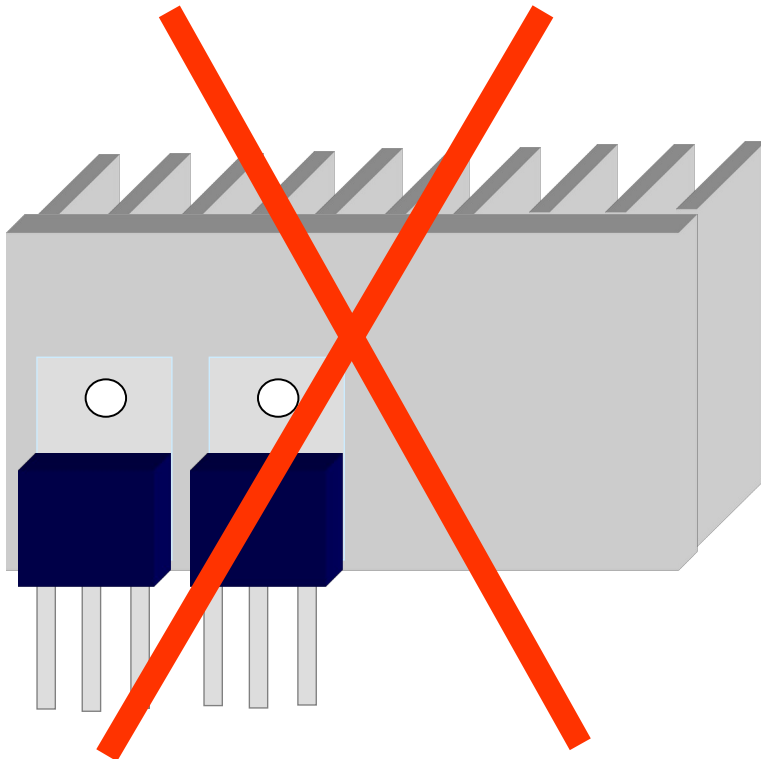
**MELHOR**



**PIOR**

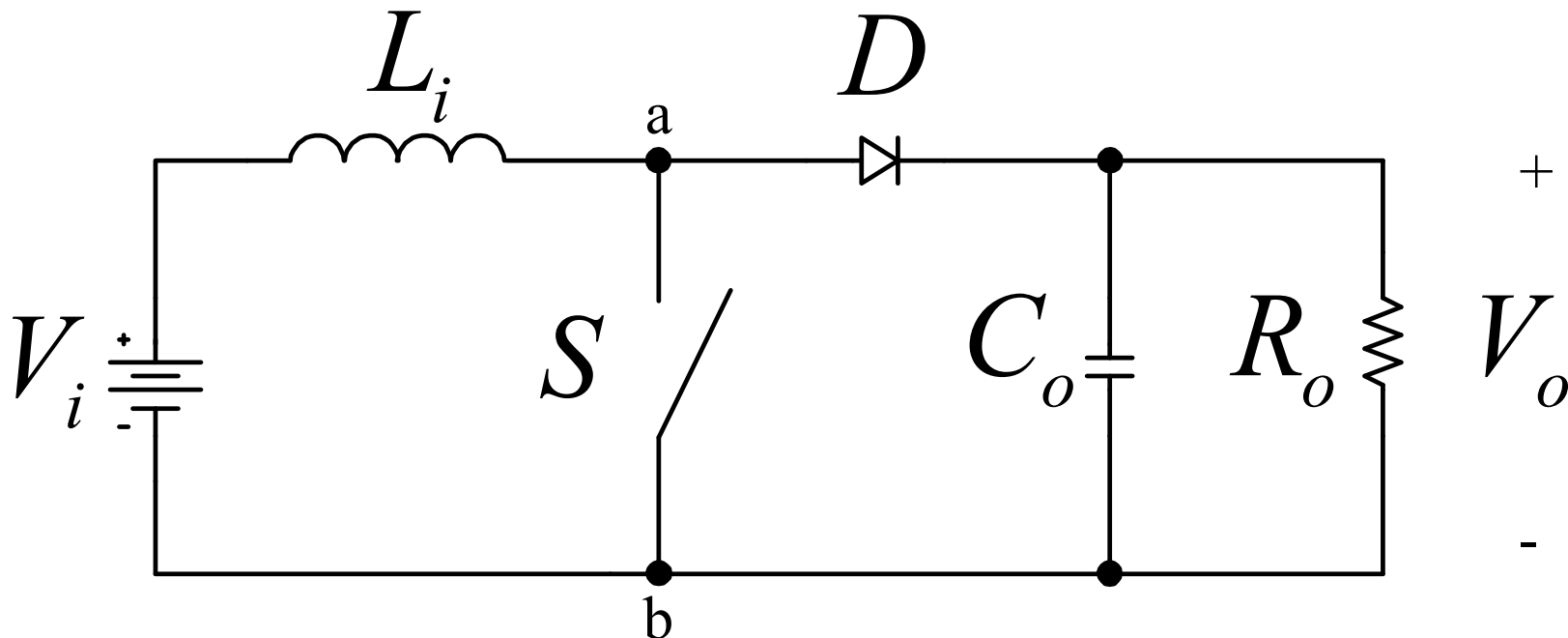
## Dimensionamento estático de radiadores

1. Podem ser colocados vários dispositivos no mesmo dissipador
2. Centralizar o dispositivo semicondutor no dissipador.



# Exemplo Cálculo Térmico

Conversor Boost CC-CC modo de condução Contínua (MCC):



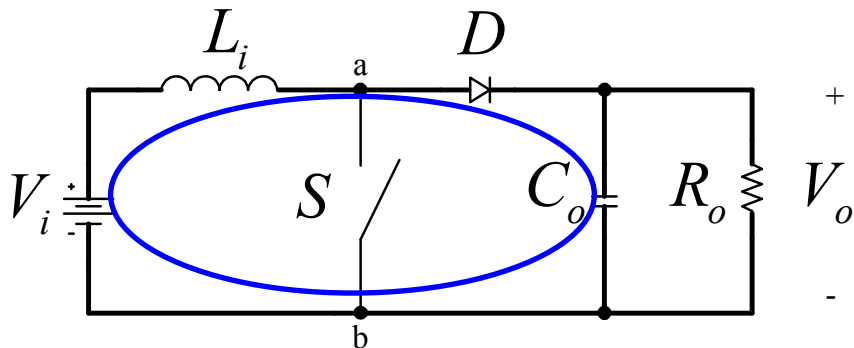
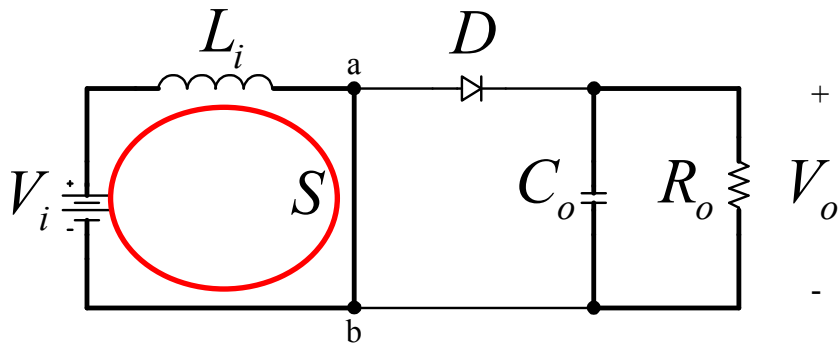
Especificação:

- Tensão de Entrada: 25 V;
- Tensão de Saída: 50 V;
- Potência de Saída: 100 W;
- Frequência de Comutação: 20 kHz;
- Indutância de Entrada ( $L_i$ ): 800  $\mu$ H;

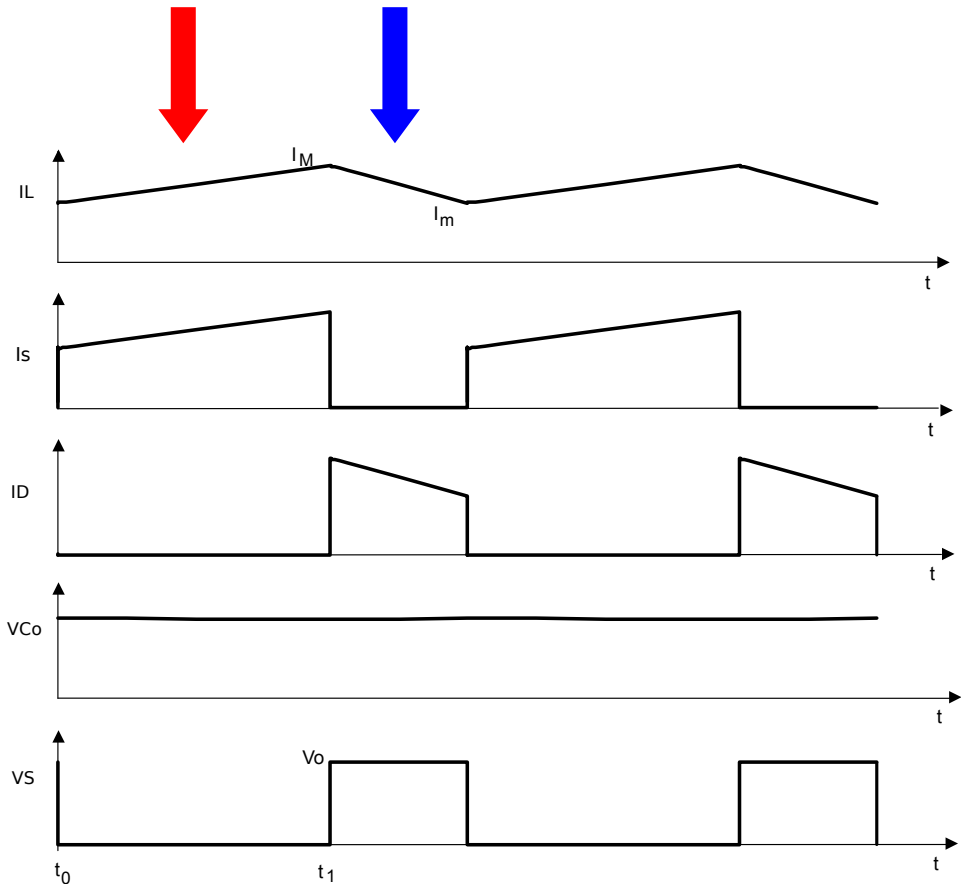
# Exemplo Cálculo Térmico

## Conversor Boost CC-CC modo de condução Contínua (MCC):

### Etapas de operação - MCC



### Formas de onda

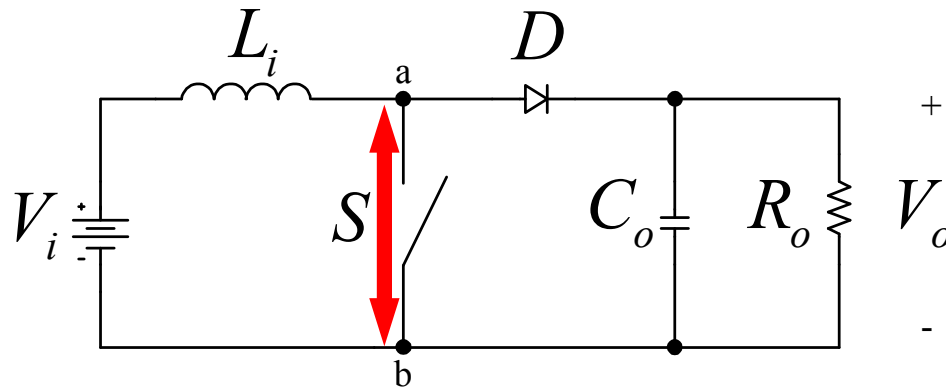


# Exemplo Cálculo Térmico

Conversor Boost CC-CC modo de condução Contínua (MCC):

Análise das grandezas envolvidas

Tensão média na saída



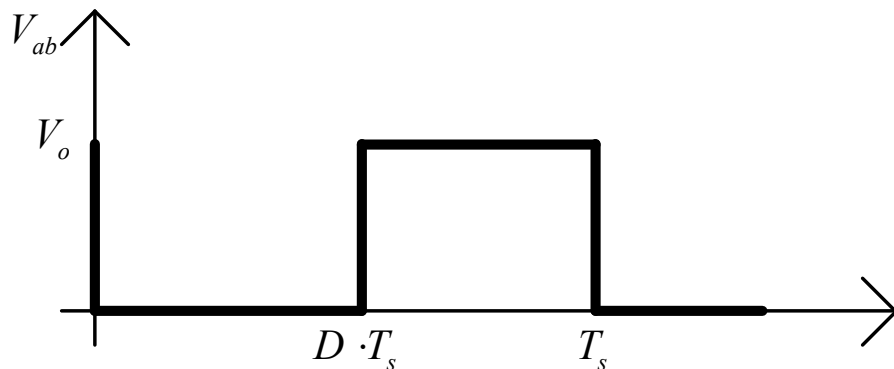
$$V_{ab} = \frac{1}{T_s} \int_{D T_s}^{T_s} V_o \cdot dt = V_o \frac{(T_s - D \cdot T_s)}{T_s}$$

$$V_{ab} = V_o (1 - D)$$

$$V_{ab} = V_i$$

$$V_o = \frac{V_i}{1 - D}$$

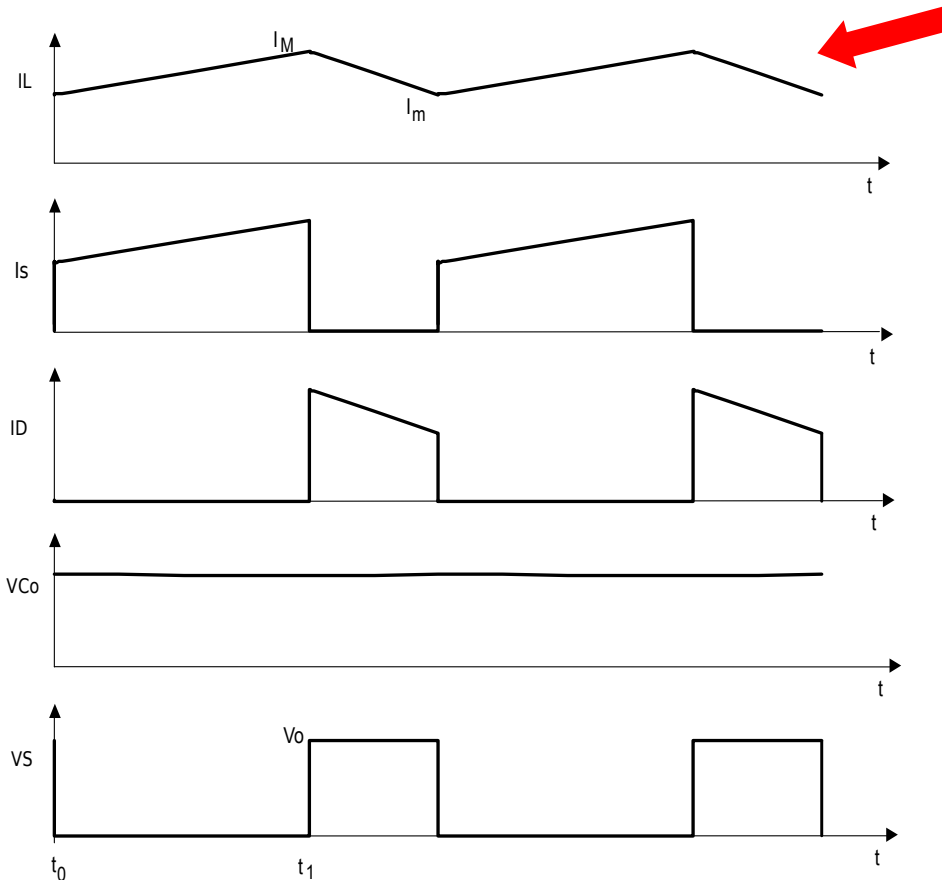
$$D = 1 - \frac{V_i}{V_o}$$





# Conversor CC-CC elevador - Boost

## Análise das grandezas envolvidas



## Corrente no Indutor

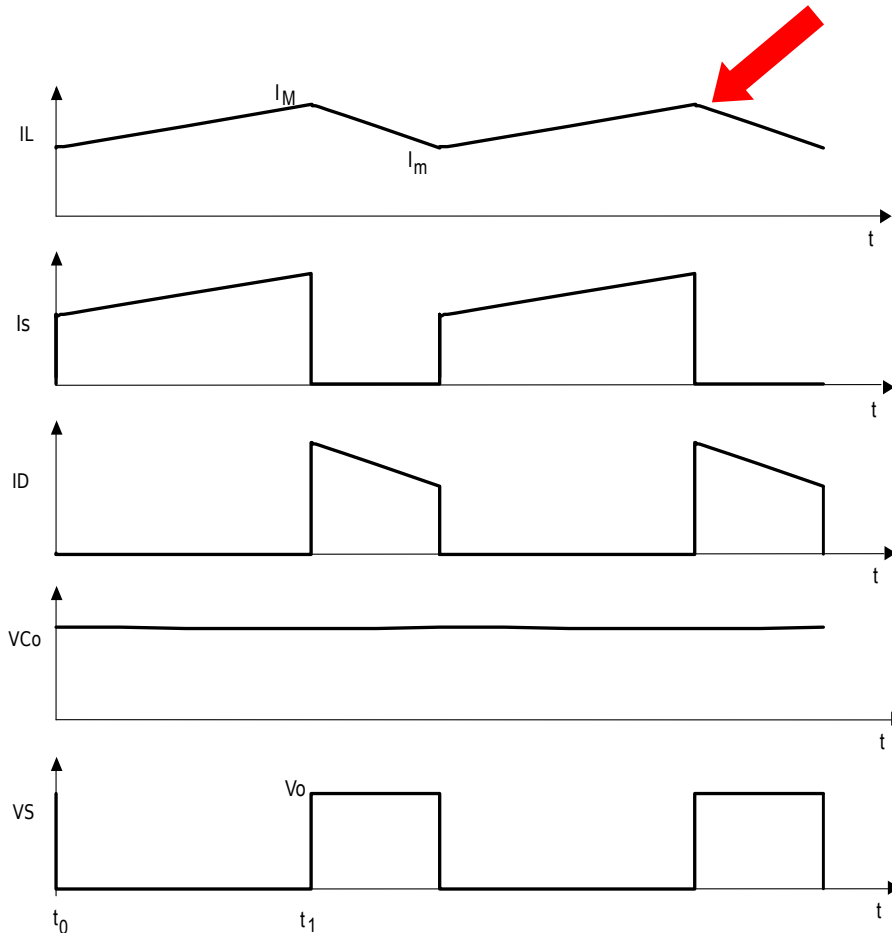
$$\Delta i_L = \frac{V_{in}}{L} T_1 \quad \Delta i_L = \frac{V_{in} \cdot D}{L \cdot f}$$

Valor Médio da Corrente no Indutor

$$I_{Li} = \frac{V_i}{R_o} \cdot \frac{1}{(1 - D)^2}$$

# Conversor CC-CC elevador - Boost

## Análise das grandezas envolvidas



## Corrente de pico no Indutor

$$I_P = i_{in} + \frac{\Delta i_L}{2}$$

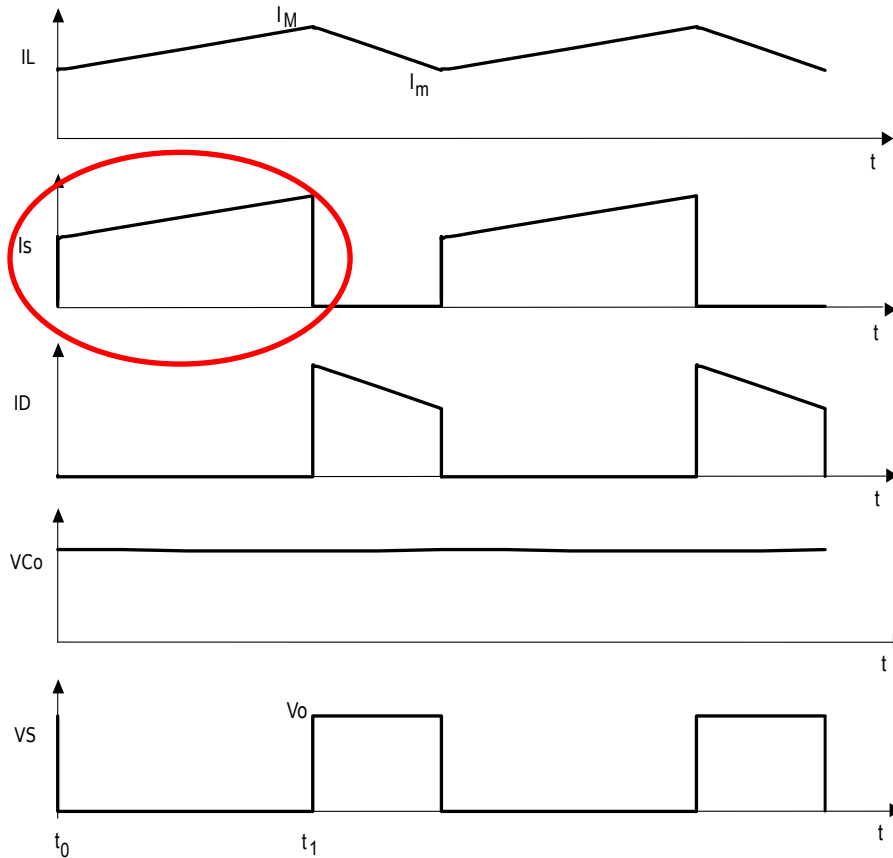
$$I_P = \frac{V_i}{R_o} \cdot \frac{1}{(1-D)^2} + \frac{V_{in} \cdot D}{2 \cdot L \cdot f}$$

## Corrente de pico no transistor e no diodo

$$I_{TP} = I_{DP} = I_P$$

# Conversor CC-CC elevador - Boost

## Análise das grandezas envolvidas



## Correntes no transistor

### Corrente média

$$I_{Tmd} = \frac{1}{T} \int_0^{D \cdot T} i_L dt$$

$$I_{Tmd} = D \cdot I_L$$

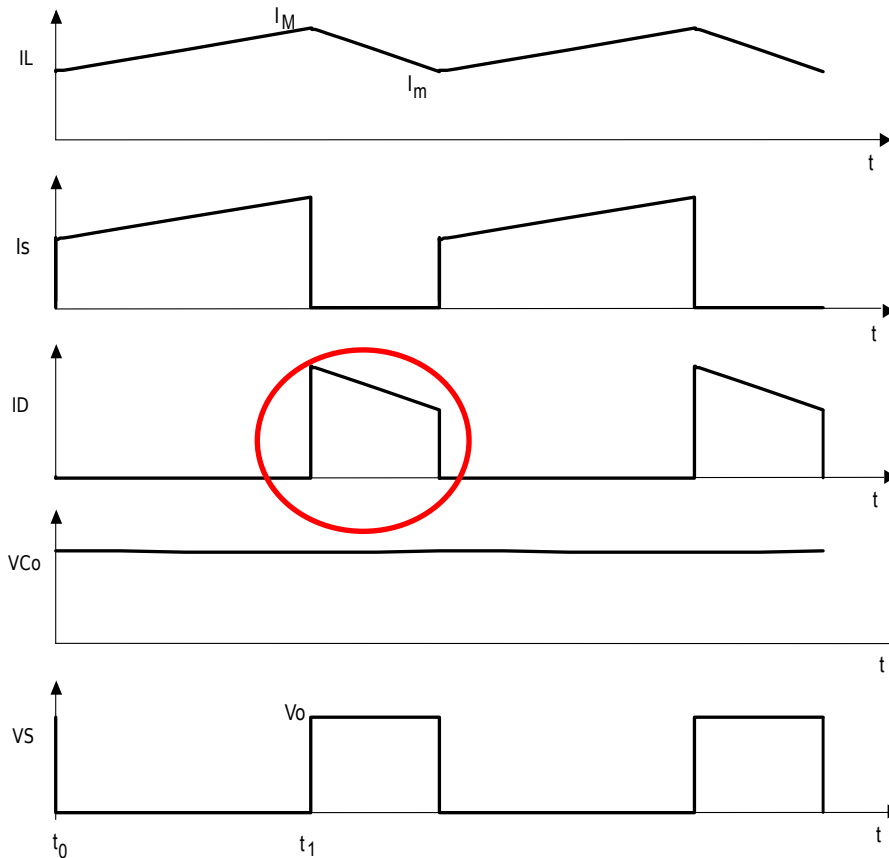
### Corrente eficaz

$$I_{Tef} = \sqrt{\frac{1}{T} \int_0^{D \cdot T} i_L^2 dt}$$

$$I_{Tef} = \sqrt{D} \cdot I_L$$

# Conversor CC-CC elevador - Boost

## Análise das grandezas envolvidas



## Correntes no diodo

### Corrente média

$$I_{Dmd} = \frac{1}{T} \int_0^T i_L dt$$

$$I_{Dmd} = (1 - D) \cdot I_L$$

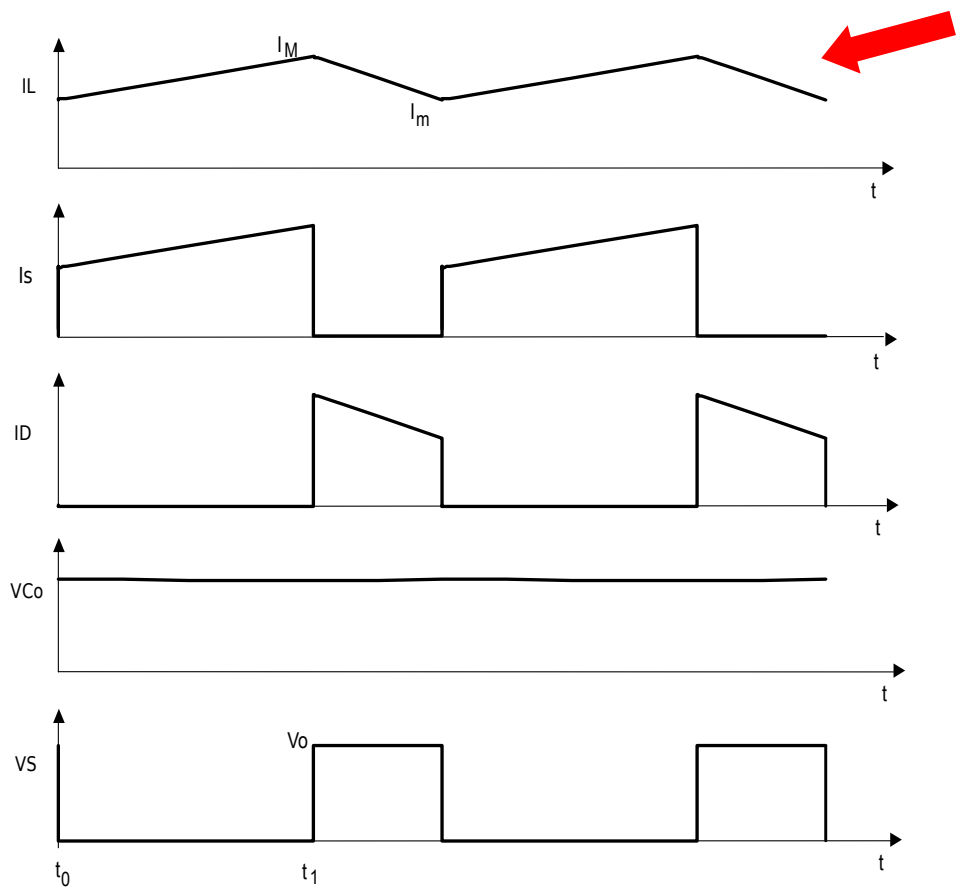
### Corrente eficaz

$$I_{Def} = \sqrt{\frac{1}{T} \int_0^T i_L^2 dt}$$

$$I_{Def} = \sqrt{1 - D} \cdot I_L$$

# Conversor CC-CC elevador - Boost

## Análise das grandezas envolvidas

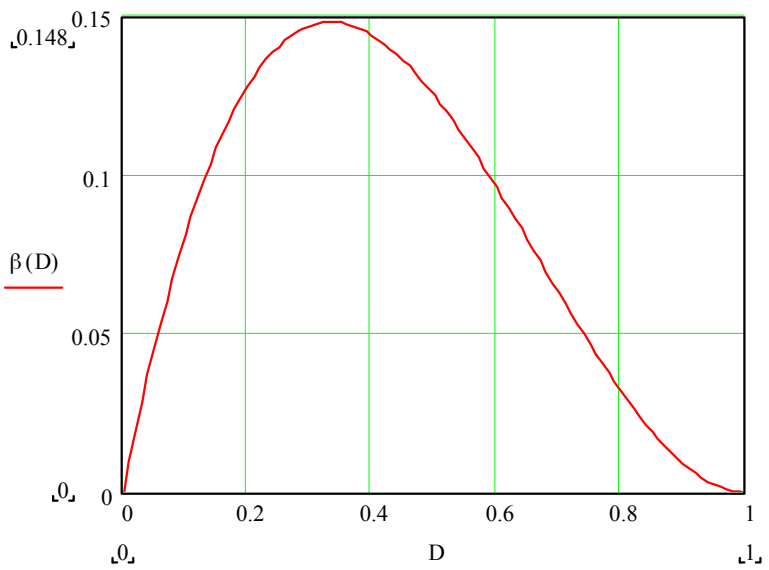


## Corrente no Indutor

$$\Delta i_L = \frac{V_{in}}{L} T_1 \qquad \Delta i_L = \frac{V_{in} \cdot D}{L \cdot f}$$

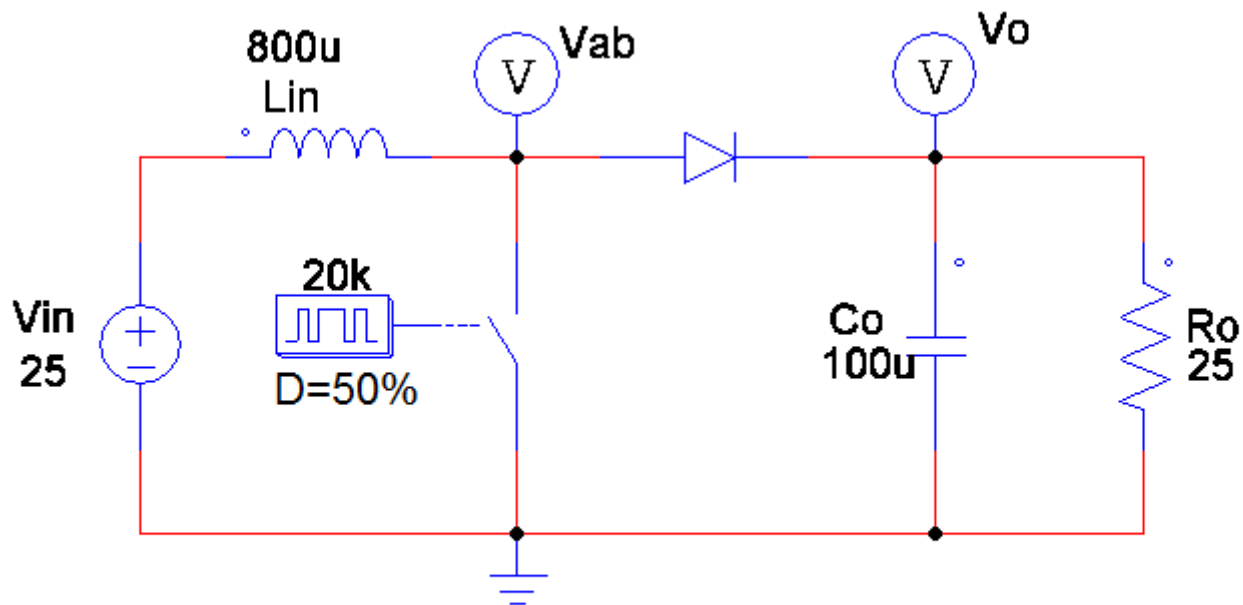
$$I_{Li} = \frac{V_i}{R_o} \cdot \frac{1}{(1 - D)^2}$$

$$\frac{\Delta i_L}{I_{Li}} = \frac{R_o \cdot D \cdot (1 - D)^2}{L \cdot f}$$



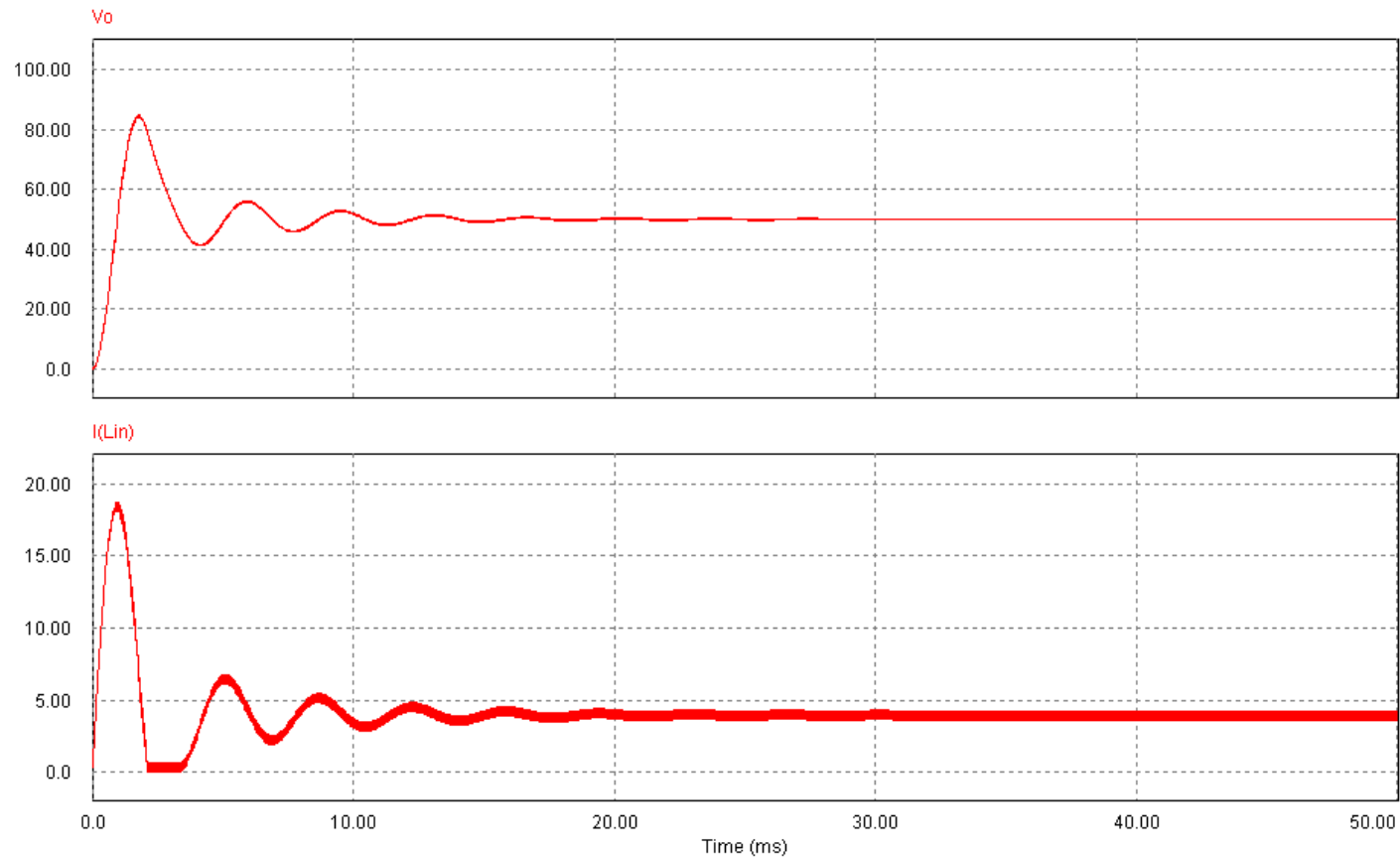
# Conversor CC-CC elevador - Boost

Principais formas de onda (circuito simulado):



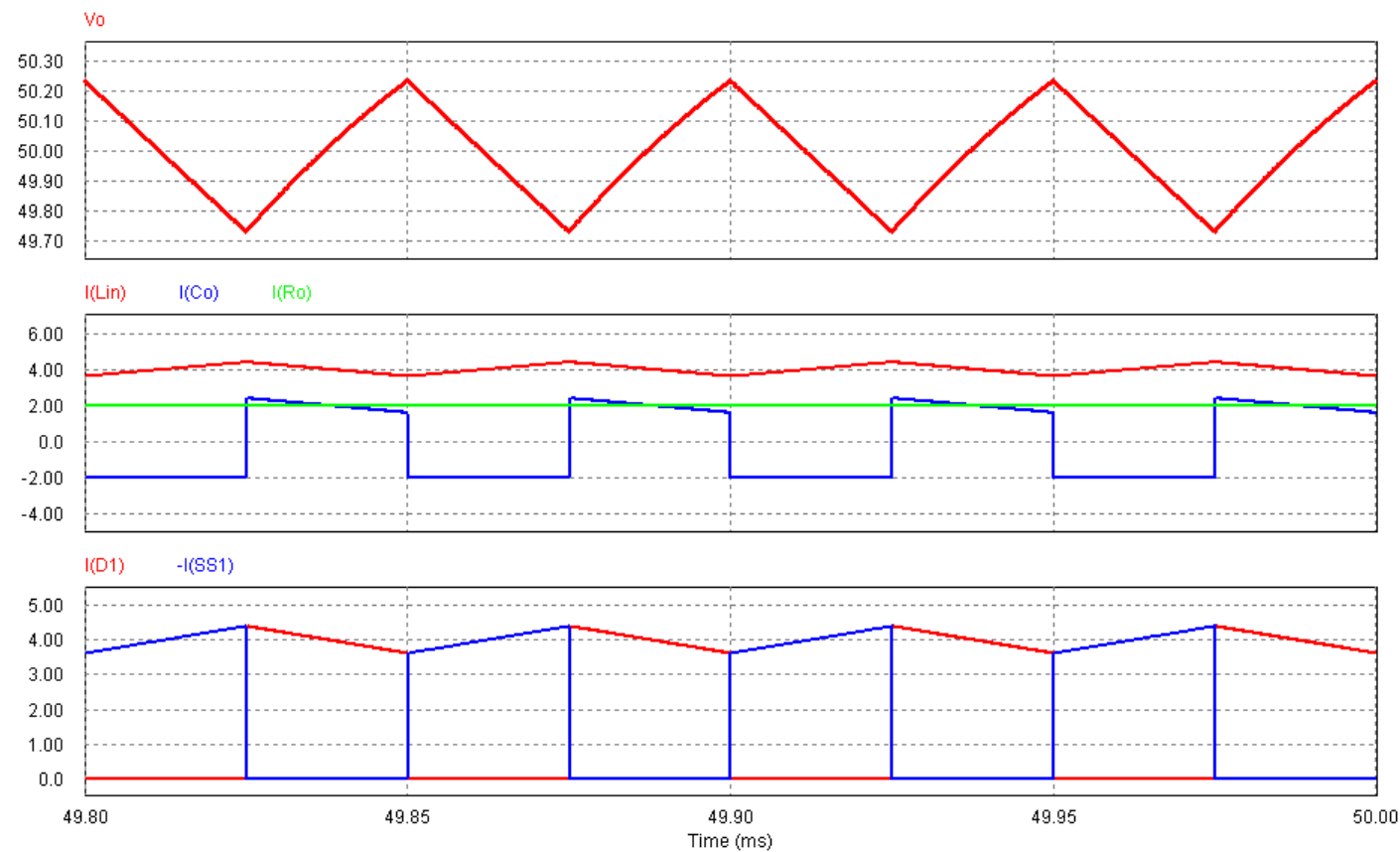
# Conversor CC-CC elevador - Boost

## Principais formas de onda (transitório de partida):



# Conversor CC-CC elevador - Boost

## Principais formas de onda (regime permanente):





**Razão Cíclica:**

$$D = 1 - \frac{V_{in}}{V_o} = 1 - \frac{25}{50} = 0,5$$

**Valor Médio da Corrente no Indutor:**

$$I_{L\_MED} = I_{in} = \frac{P}{V_{in}} = \frac{100}{25} = 4 \text{ A}$$

**Valor Médio e Eficaz da Corrente do Transistor:**

$$I_{S\_med} = D \cdot I_L = 0,5 \cdot 4 = 2 \text{ A}$$

$$I_{S\_ef} = \sqrt{D} \cdot I_L = \sqrt{0,5} \cdot 4 = 2,82 \text{ A}$$

**Tensão no Transistor bloqueado:**

$$V_{DS(OFF)} = V_o = 50 \text{ V}$$

**Ondulação da Corrente do Indutor:**

$$\Delta_{iL} = \frac{V_{in} \cdot D}{L \cdot f} = \frac{25 \cdot 0,5}{800 \cdot 10^{-6} \cdot 20 \cdot 10^3} = 0,78 \text{ A}$$

**Corrente de Pico no Transistor em Condução:**

$$I_{DS(ON)} = I_{L\_MAX} = I_{L\_MED} + \frac{\Delta_{iL}}{2} = 4 + \frac{0,78}{2} = 4,39 \text{ A}$$

International  
**IOR** Rectifier

PD -97140

## IRFP4668PbF

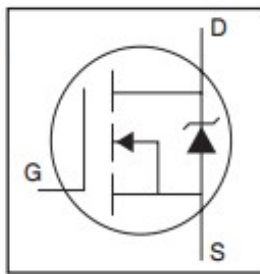
HEXFET® Power MOSFET

**Applications**

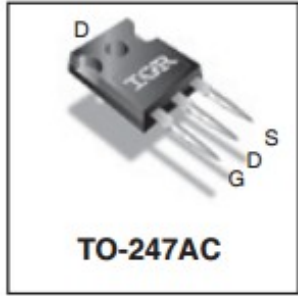
- High Efficiency Synchronous Rectification in SMPS
- Uninterruptible Power Supply
- High Speed Power Switching
- Hard Switched and High Frequency Circuits

**Benefits**

- Improved Gate, Avalanche and Dynamic dV/dt Ruggedness
- Fully Characterized Capacitance and Avalanche SOA
- Enhanced body diode dV/dt and dI/dt Capability
- Lead-Free



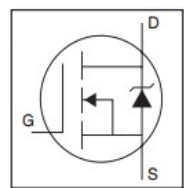
$V_{DSS}$	200V
$R_{DS(on)}$ typ. max	8.0mΩ
	9.7mΩ
$I_D$	130A



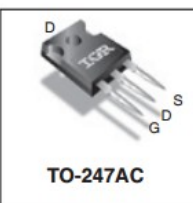
# Escolha do Transistor

## IRFP4668PbF

HEXFET® Power MOSFET



$V_{DS}$	200V
$R_{DS(on)}$ typ.	8.0m $\Omega$
max	9.7m $\Omega$
$I_D$	130A



TO-247AC

Symbol	Parameter	Min.	Typ.	Max.	Units	Conditions
gfs	Forward Transconductance	150	—	—	S	$V_{DS} = 50V, I_D = 81A$
$Q_g$	Total Gate Charge	—	161	241	nC	$I_D = 81A$
$Q_{gs}$	Gate-to-Source Charge	—	54	—		$V_{DS} = 100V$
$Q_{gd}$	Gate-to-Drain ("Miller") Charge	—	52	—		$V_{GS} = 10V$ ④
$Q_{sync}$	Total Gate Charge Sync. ( $Q_g - Q_{gd}$ )	—	109	—		$I_D = 81A, V_{DS} = 0V, V_{GS} = 10V$
$t_{d(on)}$	Turn-On Delay Time	—	41	—	ns	$V_{DD} = 130V$
$t_r$	Rise Time	—	105	—		$I_D = 81A$
$t_{d(off)}$	Turn-Off Delay Time	—	64	—		$R_G = 2.7\Omega$
$t_f$	Fall Time	—	74	—		$V_{GS} = 10V$ ④
$C_{iss}$	Input Capacitance	—	10720	—	pF	$V_{GS} = 0V$
$C_{oss}$	Output Capacitance	—	810	—		$V_{DS} = 50V$
$C_{rss}$	Reverse Transfer Capacitance	—	160	—		$f = 1.0MHz$
$C_{oss \text{ eff. (ER)}}$	Effective Output Capacitance (Energy Related)⑥	—	630	—		$V_{GS} = 0V, V_{DS} = 0V \text{ to } 160V$ ⑥
$C_{oss \text{ eff. (TR)}}$	Effective Output Capacitance (Time Related)⑤	—	790	—		$V_{GS} = 0V, V_{DS} = 0V \text{ to } 160V$ ⑤

Parâmetros Elétricos do Transistor Escolhido:

$$R_{DS(ON)} = 9,7 \text{ m}\Omega \text{ (max)}$$

$$t_r = 105 \text{ ns}$$

$$t_f = 74 \text{ ns}$$

$$V_{DS(OFF)} = 50 \text{ V}$$

Perdas por Condução:

$$P_{\text{cond}} = R_{DS(ON)} \cdot I_{S_{\text{ef}}}^2 = 0,0097 \cdot 2,82^2 = 0,077 \text{ W}$$

Perdas por Comutação:

$$P_{\text{com}} = \frac{f}{2} (t_r + t_f) \cdot I_{\text{DS(ON)}} \cdot V_{\text{DS(OFF)}} =$$
$$= \frac{20 \cdot 10^3}{2} (105 \cdot 10^{-9} + 74 \cdot 10^{-9}) \cdot 4,39 \cdot 50 = 0,39 \text{ W}$$

Perdas Totais do Transistor:

$$P = P_{\text{cond}} + P_{\text{com}} = 0,077 + 0,39 = 0,467 \text{ W}$$

Cálculo Térmico:

$$P = 0,467 \text{ W}$$

$$T_a = 50 \text{ }^{\circ}\text{C}$$

$$T_j(\text{max}) = 125 \text{ }^{\circ}\text{C}$$

$$R_{jc} = 0,29 \text{ }^{\circ}\text{C/W}$$

$$R_{cd} = R_{cs} = 0,24 \text{ }^{\circ}\text{C/W}$$

$$R_{ja} = 40 \text{ }^{\circ}\text{C/W} \text{ (sem dissipador)}$$

$$R_{da} = ? \text{ (dissipador)}$$

Resistência Térmica:

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

Resistência Máxima Junção-Ambiente:

$$R_{ja} = \frac{T_j - T_a}{P} = \frac{125 - 50}{0,467} = 160 \text{ } ^\circ\text{C}/\text{W}$$

$$R_{ja} = 40 \text{ } ^\circ\text{C}/\text{W} \text{ (sem dissipador)}$$



Aumento da frequência de Comutação para 200 kHz:

Perdas por Comutação:

$$P_{\text{com}} = \frac{f}{2} (t_r + t_f) \cdot I_{\text{DS(ON)}} \cdot V_{\text{DS(OFF)}} =$$
$$= \frac{200 \cdot 10^3}{2} (105 \cdot 10^{-9} + 74 \cdot 10^{-9}) \cdot 4,39 \cdot 50 = 3,92 \text{ W}$$

Perdas Totais do Transistor:

$$P = P_{\text{cond}} + P_{\text{com}} = 0,077 + 3,92 = 4,0 \text{ W}$$

Resistência Térmica:

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

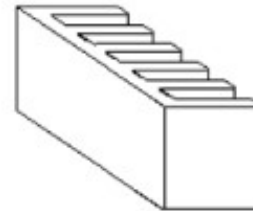
Resistência Térmica Máxima Junção Ambiente:

$$R_{ja} = \frac{T_j - T_a}{P} = \frac{125 - 50}{4,0} = 18^{\circ}\text{C}/\text{W}$$

Cálculo da Resistência Térmica do Dissipador:

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

$$R_{da} = 18 - 0,29 - 0,24 = 17,47^{\circ}\text{C}/\text{W}$$



TRANSISTOR	THERMAL PAD	HEATSINK
$T_j$ 125 °C		$T_a$ 50 °C
$R_{th,j-a}$ 0.53 °C/W	$R_{th}$ 0.0 °C/W	$R_{th}$ 18.22 °C/W
$P_{diss}$ 4 W		

CALCULATE

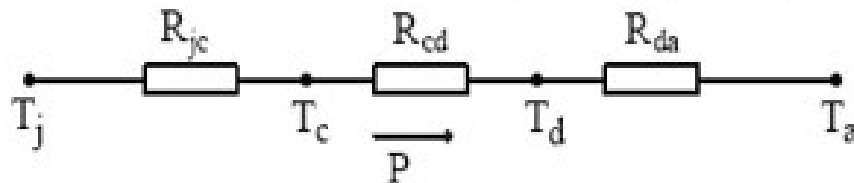
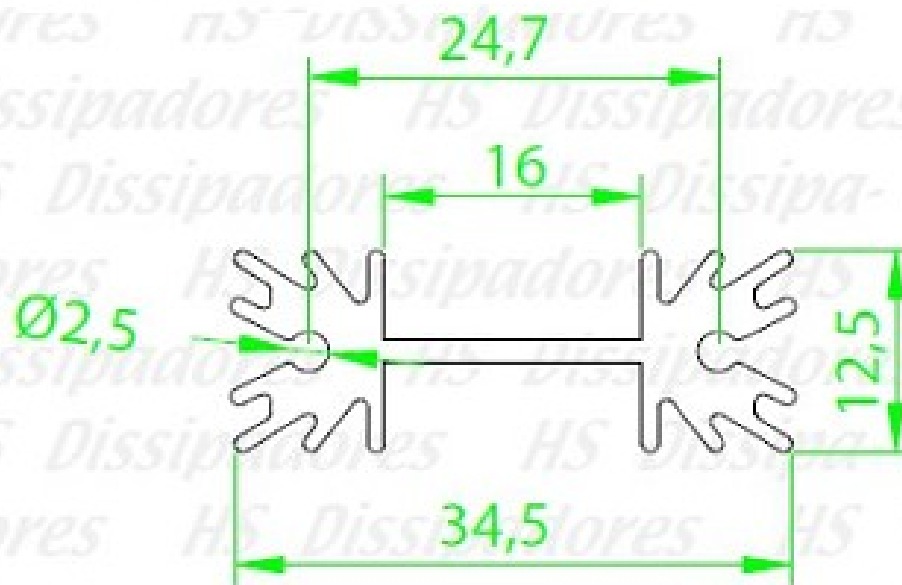
$T_j$	Temperature of the junction. Damage level for silicon is 175 °C
$R_{th,j-a}$	Thermal resistance of transistor. (Between junction and ambient)
$P_{diss}$	Dissipated Power.
$R_{th}$	Thermal resistance of pad/heatsink.
$T_a$	Ambient temperature. If greater than 60 °C, you should prevent user from touching it.

**Código : HS 3512**

Dimensões aproximadas: 35 x 12 mm

Perímetro: 183 mm

Resistência Térmica: 8,35 °C / W / 4"



## Código : HS 1509

Dimensões aproximadas: 15 x 09 mm

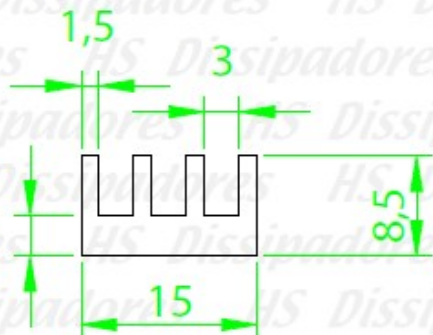
Perímetro: 78 mm

Resistência Térmica: 19,8 °C / W / 4"

- retornar ao índice com desenhos
- visualizar perfis similares



ESCALA 1:1



## Código : HS 1920

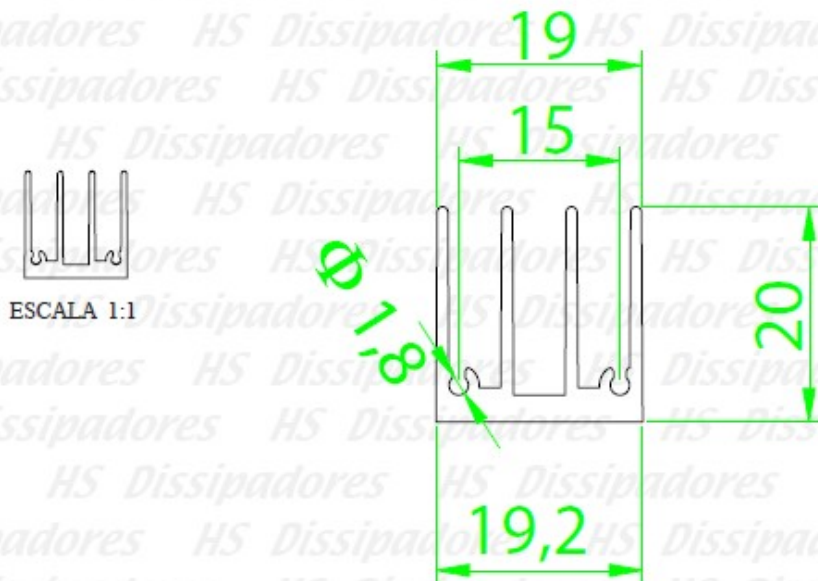
página ..... 25

Dimensões aproximadas: 19 x 20 mm

Perímetro: 134 mm

Resistência Térmica: 8,31 °C / W / 4"

- visualizar perfis similares
- retornar ao índice com desenhos



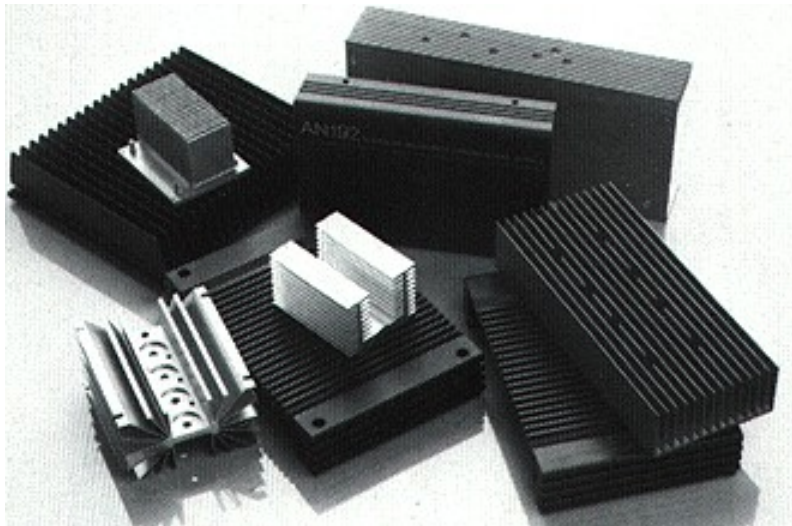
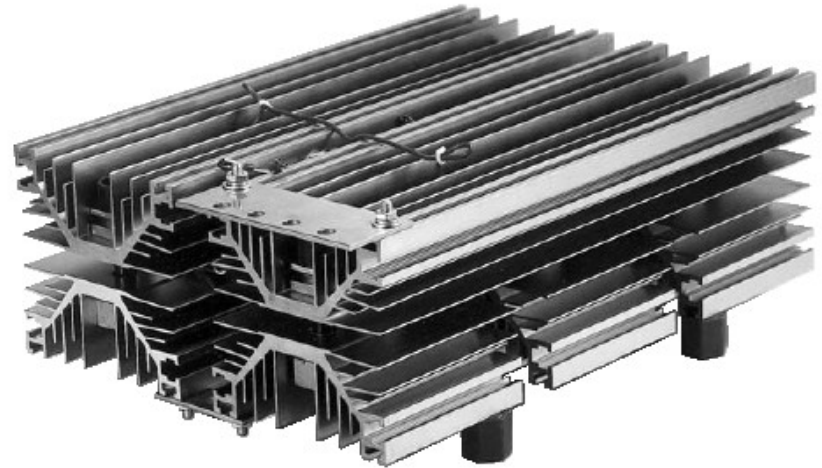
comprimento	fator de correção
10 mm	3,05
20 mm	2,21
30 mm	1,82
40 mm	1,59
50 mm	1,43
70 mm	1,22
100 mm	1,04
150 mm	0,86
200 mm	0,75
250 mm	0,67
300 mm	0,62
400 mm	0,54
500 mm	0,49

30 mm de comprimento

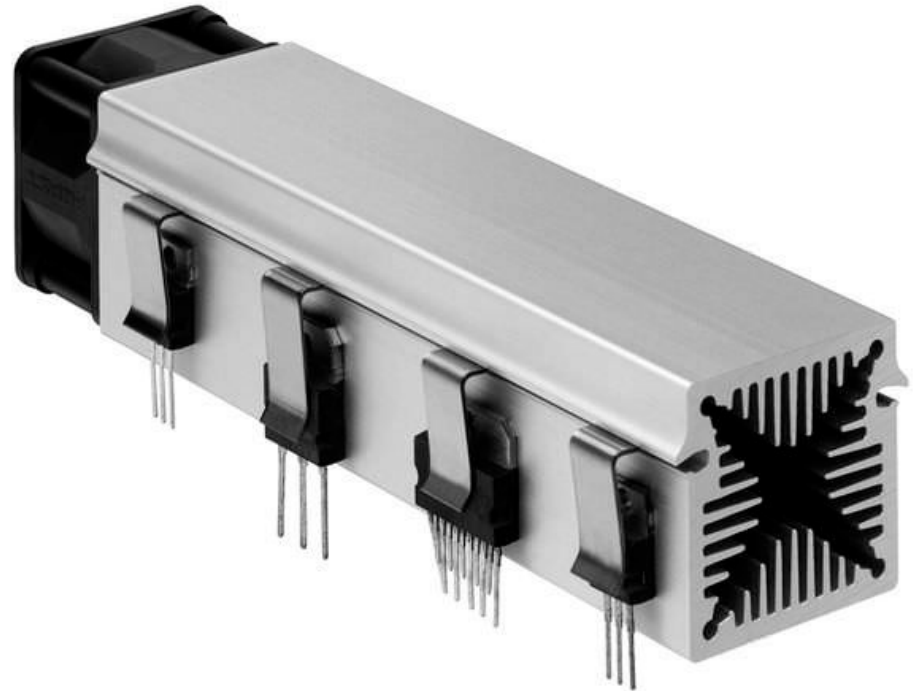
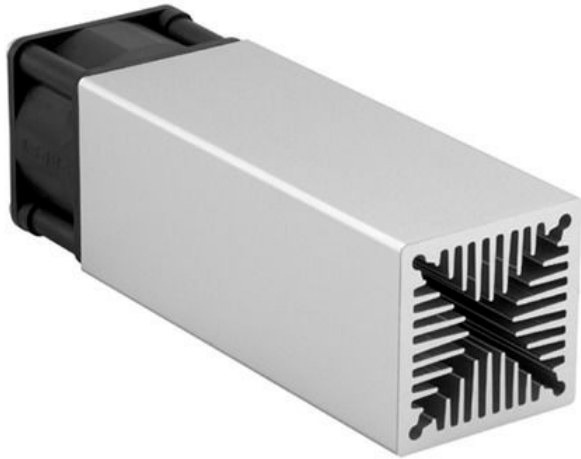




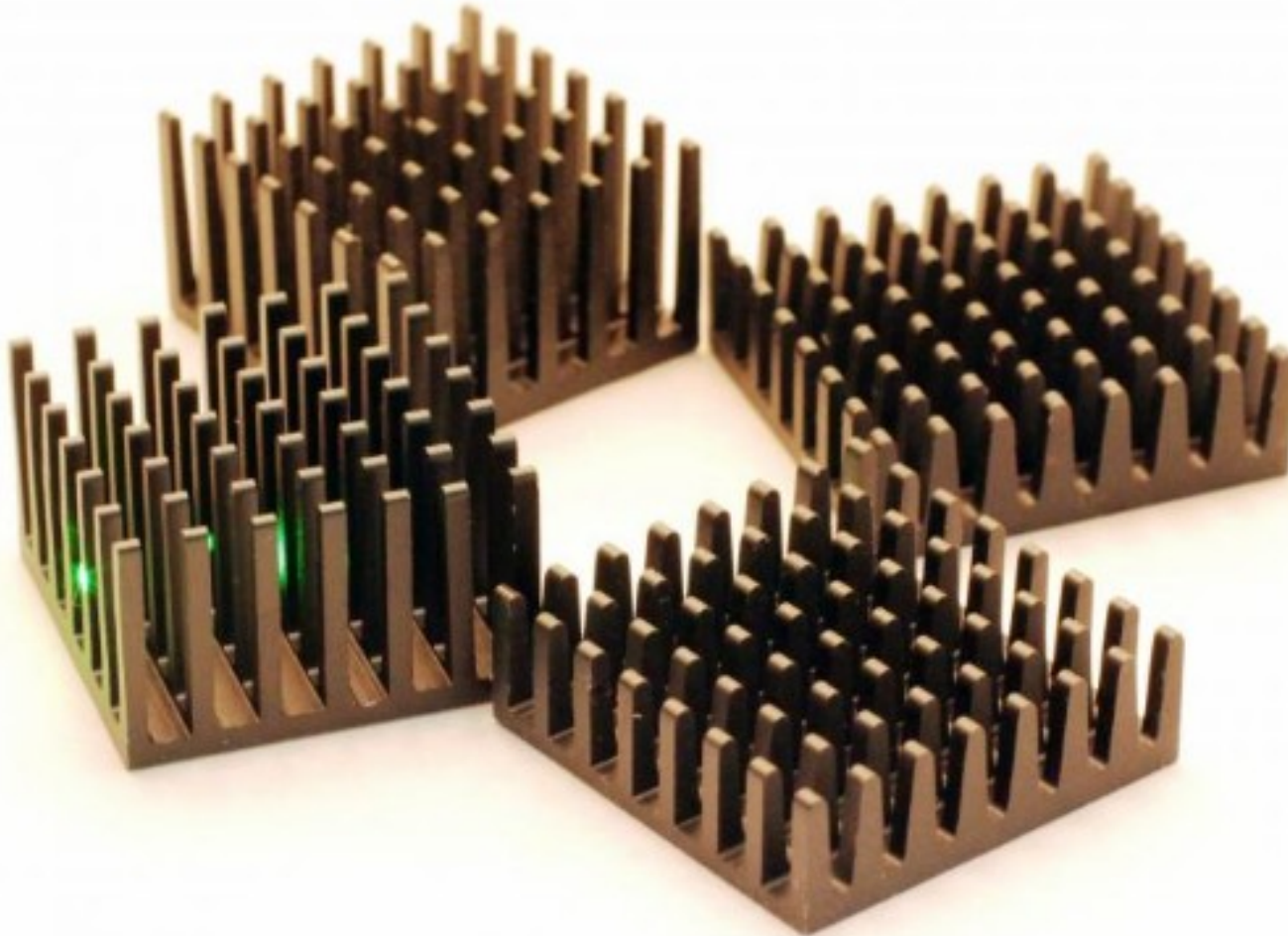
# Dissipadores



# Dissipadores







Novos Modelos: Pin Fin Heat Sinks  
Baixa resistência térmica: 2,5 graus/W

# Simulação de Perdas no PSIM

PSIM - [untitled1\*]

File Edit View Subcircuit Elements Simulate Options Utilities Window Help

PcdEditor

File Device View Help

File Name

C:\Program Files (x86)\Powersim\PSIM9.0.3\_Trial\Device\diode.dev  
C:\Program Files (x86)\Powersim\PSIM9.0.3\_Trial\Device\IGBT.dev  
C:\Program Files (x86)\Powersim\PSIM9.0.3\_Trial\Device\MOSFET.dev  
C:\Program Files (x86)\Powersim\PSIM9.0.3\_Trial\Device\...

Manufacturer International Rectifiers Part Number New

Package

Table 2: Absolute maximum ratings

Symbol	Parameter	Value	Unit
$V_{GS}$	Gate-source voltage	$\pm 25$	V
$I_D$	Drain current (continuous) at $T_C = 25^\circ\text{C}$	18 <sup>(1)</sup>	A
$I_D$	Drain current (continuous) at $T_C = 100^\circ\text{C}$	12 <sup>(1)</sup>	A
$I_{DM}$ <sup>(2)</sup>	Drain current (pulsed)	72 <sup>(1)</sup>	A
$P_{TOT}$	Total dissipation at $T_C = 25^\circ\text{C}$	30	W
$dv/dt$ <sup>(3)</sup>	Peak diode recovery voltage slope	15	V/ns
$dv/dt$ <sup>(4)</sup>	MOSFET $dv/dt$ ruggedness	50	V/ns
$V_{ISO}$	Insulation withstand voltage (RMS) from all three leads to external heat sink ( $t = 1\text{ s}$ ; $T_C = 25^\circ\text{C}$ )	2500	V
$T_{stg}$	Storage temperature range	- 55 to 150	$^\circ\text{C}$
$T_J$	Operating junction temperature range		

Device Type [All Types] Manufacturer [All Manufacturers]

Part Number	Voltage	Current
150EBU04	400	150
CM1000HA-24H	1200	1000
CM100TU-12H	600	100
CM600DU-24F	1200	600
CN240610	600	100
CS240650	600	50
FCD7N60	600	7
HGTG20N60A4D	600	40
IRF1010EZ	60	75
IRF1404S	40	162
IRF3805S	55	75
IRF7380	80	3.6
IRF744	450	8.8
IRFP460	500	20
ISL9R3060G2	600	30
IXGH40N60C2	600	40
MURS160	600	1
New	0	0
New	0	0
PS21A79	600	50

Electrical Characteristics - Diode

Vd vs. IF Edit

Test Conditions:

$t_{rr}$  (ns):  IF (A):   
 $Q_{rr}$  (nC):   $di/dt$  (A/μs):   
TJ (°C):

Thermal Characteristics

$R_{th(j-c)}$ :   $R_{th(j-s)}$ :   
(all in  $^\circ\text{C/W}$ )

Dimensions and Weight

Length (mm):  Width (mm):   
Height (mm):  Weight (g):

100% 10s

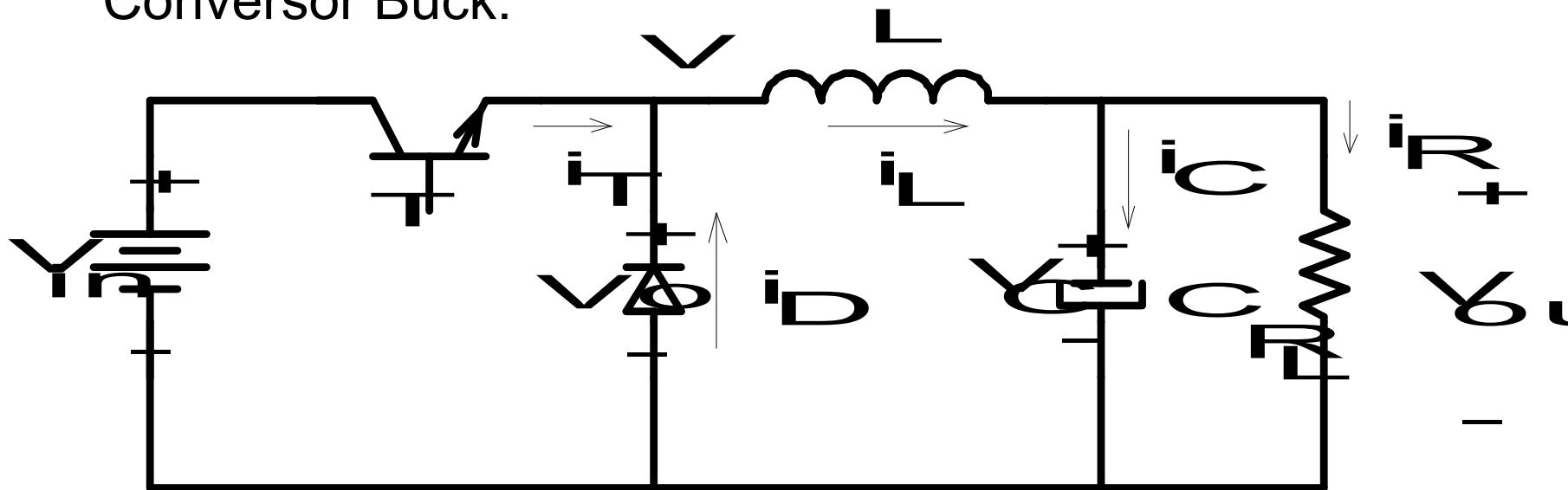
## Cálculo térmico – considerações finais

### Regras práticas:

- Impedir que a temperatura da junção ultrapasse o valor de 80% o valor máximo permissível (aumenta o MTDF do dispositivo)
- $T_a \rightarrow$  deve ser considerado o valor de 40° para instalação em ambiente ventilado ou um valor maior para conversor instalado em ambiente enclausurado
- Caso seja preciso isolar o dispositivo do dissipador, usar isolante (mica, teflon, mylar). Considerar sua resistência térmica
- Recomenda-se usar pasta térmica para evitar bolhas de ar entre o dispositivo e o dissipador

# Tarefa 1 para entregar

## Conversor Buck:



### Especificação:

Tensão de Entrada: 36 V

Tensão de Saída: 12 V

Freq. de comutação: 100 kHz;

Indutância  $L$ : 100  $\mu$ H

Capacitância  $C$ : 100  $\mu$ F;

Potência: 100 W;

Transistor: IRLZ44N (TO-220AB)

Diodo: MUR860 e MBR20100 (TO-220)

### Apresentar:

- Principais Formas de Ondas Teóricas;
  - Resultados de Simulação;
  - Esforços de Corrente no Transistor (T) e no Diodo (D);
  - Obter o dissipador para que o transistor e o diodo funcionem de maneira adequada no conversor Buck.
- Obs: HS Dissipadores e um outro fabricante de dissipadores.