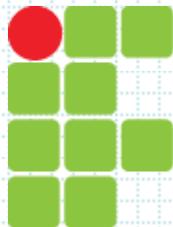
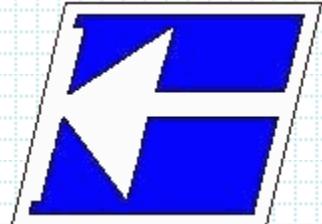


**Instituto Federal de Educação, Ciência e Tecnologia de Santa Catarina**  
**Departamento Acadêmico de Eletrônica**  
**Curso de Graduação em Engenharia Eletrônica**



INSTITUTO FEDERAL  
SANTA CATARINA



# **Metodologia de Projeto aplicada em conversores estáticos de potência**

**Prof. Joabel Moia.**

**Florianópolis, fevereiro de 2019.**

## Pontos Importantes que devem ser observados no Projeto Conversores Estáticos de Potência:

- Considerar a Potência Máxima de Saída para o projeto;
- Analisar as condições de entrada:
  - Variação de Tensão e de Corrente
- Analisar as questões térmicas e calcular dissipador(es) apropriados:
  - Analisar o melhor lugar para deixar o dissipador para não afetar outros componentes do circuito;
  - Considerar que o conversor vai estar em um gabinete e em algumas vezes acondicionado em um lugar com temperatura alta;

## Pontos Importantes que devem ser observados no Projeto Conversores Estáticos de Potência:

- Sempre fazer o projeto no pior caso:
  - Variação de tensão, frequência, potência e etc;
- Qualidade dos Componentes:
  - Adquirir componentes de fabricantes confiáveis;
- Desenhar o layout da Placa de Circuito Impresso de maneira adequada;
- Realizar testes adequados para a validação do conversor;

## Pré-Escolha dos Semicondutores:

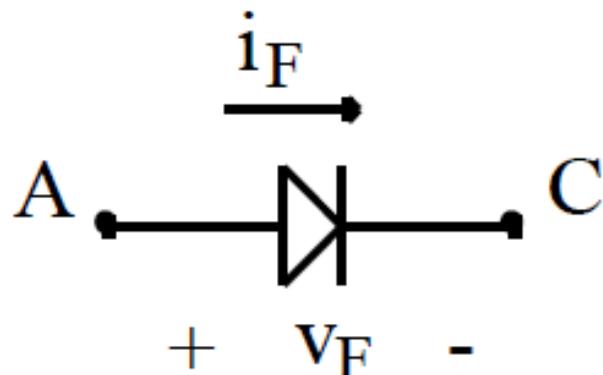
- A pré-escolha é feita com base no valor médio de corrente, corrente de pico e tensão máxima de bloqueio;
- Em seguida, com um número opções de modelos de semicondutores reduzidos, verifica-se as características Estáticas ( $R_{DS\_ON}$ ,  $V_F$ ,  $V_{CE}$ ,  $R_D$ , etc);
- Verifica-se também as características dinâmicas do semicondutor ( $t_r$ ,  $t_f$ ) e de recuperação reversa ( $Q_{rr}$ ,  $t_{rr}$ ), ou energia envolvidas nas comutações (*datasheet*) ;
- Por fim, realiza-se o cálculo térmico para escolher um dissipador, caso necessário, e analisar a viabilidade técnica do projeto, do ponto de vista de tamanho, peso, volume e etc;

## Pré-Escolha dos Semicondutores:

- O cálculo de perdas podem ser validados por simulação numérica, pois pode apresentar modelos mais completos;
- Se for necessário, podem ser utilizados semicondutores em paralelo ou série, porém deve se tomar cuidado. Normalmente, prefere-se utilizar outras soluções por meio de topologias (circuitos elétricos);
- Alguns fabricantes de semicondutores oferecem a opção de livre de chumbo (*Lead Free*);
- A escolha do semicondutores (BJT, MOSFET, IGBT, etc) deve ser realizado em função do parâmetros elétricos, custo facilidade de aquisição e etc;

## Diodo:

- Tensão máxima reversa;
- Cálculo da corrente média;
- Cálculo da corrente eficaz;
- Frequência de operação;
- Escolher um diodo disponível;
- Cálculo da corrente de pico;
- Calcular Perdas:
  - Condução
  - Comutação
  - Total
- Cálculo térmico



## Diodo:

- ▶ **Diodos standard:** transição > 0,5μs  
(baixa frequência)
- ▶ **Fast recovery** - transição < 250 ns
- ▶ **Soft-recovery** – transição  
amortecida sem pico de tensão  
(principalmente tecnologia Schottky)
- ▶ **ultrafast-recovery** transição < 100 ns
- ▶ **hyperfast-recovery** transição < 50 ns
- ▶ Zero recovery (Carbeto de silicio,  
(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

## Diodo – exemplos 1N400X

### MAXIMUM RATINGS ( $T_A = 25^\circ\text{C}$ unless otherwise noted)

PARAMETER	SYMBOL	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	UNIT
Maximum repetitive peak reverse voltage	$V_{RRM}$	50	100	200	400	600	800	1000	V
Maximum RMS voltage	$V_{RMS}$	35	70	140	280	420	560	700	V
Maximum DC blocking voltage	$V_{DC}$	50	100	200	400	600	800	1000	V
Maximum average forward rectified current 0.375" (9.5 mm) lead length at $T_A = 75^\circ\text{C}$	$I_{F(AV)}$				1.0				A
Peak forward surge current 8.3 ms single half sine-wave superimposed on rated load	$I_{FSM}$				30				A
Non-repetitive peak forward surge current square waveform $T_A = 25^\circ\text{C}$ (fig. 3)	$t_p = 1 \text{ ms}$ $t_p = 2 \text{ ms}$ $t_p = 5 \text{ ms}$	$I_{FSM}$			45				A
					35				
					30				
Maximum full load reverse current, full cycle average 0.375" (9.5 mm) lead length $T_L = 75^\circ\text{C}$	$I_{R(AV)}$				30				$\mu\text{A}$
Rating for fusing ( $t < 8.3 \text{ ms}$ )	$I^2t$ (1)				3.7				$\text{A}^2\text{s}$
Operating junction and storage temperature range	$T_J, T_{STG}$				- 50 to + 150				$^\circ\text{C}$

PARAMETER	TEST CONDITIONS	SYMBOL	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	UNIT
Maximum instantaneous forward voltage	1.0 A	$V_F$				1.1				V
Maximum DC reverse current at rated DC blocking voltage	$T_A = 25^\circ\text{C}$	$I_R$				5.0				$\mu\text{A}$
	$T_A = 125^\circ\text{C}$					50				
Typical junction capacitance	4.0 V, 1 MHz	$C_J$				15				pF

## Diodo – exemplos IDH10G65C5

Table 3 Maximum ratings

Parameter	Symbol	Values			Unit	Note/Test Condition
		Min.	Typ.	Max.		
Continuous forward current	$I_F$	–	–	10	A	$T_C < 140^\circ\text{C}$ , D=1
Surge non-repetitive forward current, sine halfwave	$I_{F,SM}$	–	–	82		$T_C = 25^\circ\text{C}$ , $t_p=10 \text{ ms}$
		–	–	71		$T_C = 150^\circ\text{C}$ , $t_p=10 \text{ ms}$
Non-repetitive peak forward current	$I_{F,max}$	–	–	431	$\text{A}^2\text{s}$	$T_C = 25^\circ\text{C}$ , $t_p=10 \mu\text{s}$
$i^2t$ value	$\int i^2 dt$	–	–	34		$T_C = 25^\circ\text{C}$ , $t_p=10 \text{ ms}$
		–	–	25		$T_C = 150^\circ\text{C}$ , $t_p=10 \text{ ms}$
Repetitive peak reverse voltage	$V_{RRM}$	–	–	650	V	$T_j = 25^\circ\text{C}$
Diode $dv/dt$ ruggedness	$dv/dt$	–	–	100	V/ns	$V_R=0.480 \text{ V}$
Power dissipation	$P_{tot}$	–	–	89	W	$T_C = 25^\circ\text{C}$
Operating and storage temperature	$T_j, T_{stg}$	-55	–	175	°C	
Mounting torque		–	–	70	Ncm	M3 screws

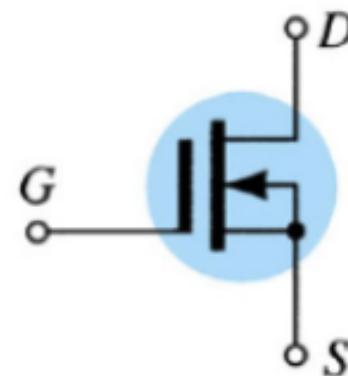
Table 4 Thermal characteristics TO-220-2

Parameter	Symbol	Values			Unit	Note/Test Condition
		Min.	Typ.	Max.		
Thermal resistance, junction-case	$R_{thJC}$	–	1.0	1.7	K/W	
Thermal resistance, junction-ambient	$R_{thJA}$	–	–	62		leaded
Soldering temperature, wavesoldering only allowed at leads	$T_{sold}$	–	–	260	°C	1.6mm (0.063 in.) from case for 10 s

## MOSFET:

### MOSFET

- Tensão máxima no interruptor;
- Cálculo da corrente média;
- Cálculo da corrente eficaz;
- Escolher um interruptor disponível;
- Observar a  $R_{DSon}$  e os tempos de operação;
- Cálculo da corrente de pico;
- Calcular Perdas:
  - Condução
  - Comutação
  - Total
- Cálculo térmico



## MOSFET:



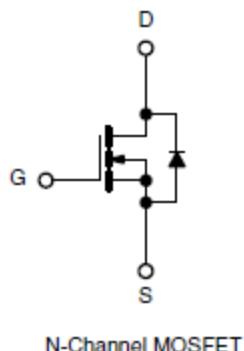
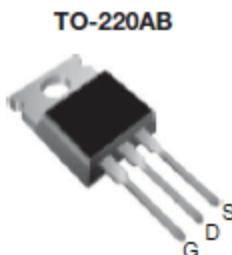
[www.vishay.com](http://www.vishay.com)

**IRF840, SiHF840**

Vishay Siliconix

## Power MOSFET

PRODUCT SUMMARY	
$V_{DS}$ (V)	500
$R_{DS(on)}$ ( $\Omega$ )	$V_{GS} = 10$ V      0.85
$Q_g$ max. (nC)	63
$Q_{gs}$ (nC)	9.3
$Q_{gd}$ (nC)	32
Configuration	Single



### FEATURES

- Dynamic dV/dt rating
- Repetitive avalanche rated
- Fast switching
- Ease of paralleling
- Simple drive requirements
- Material categorization: for definitions of compliance please see [www.vishay.com/doc?99912](http://www.vishay.com/doc?99912)



Available  
**RoHS\***

### Note

\* This datasheet provides information about parts that are RoHS-compliant and / or parts that are non-RoHS-compliant. For example, parts with lead (Pb) terminations are not RoHS-compliant. Please see the information / tables in this datasheet for details.

### DESCRIPTION

Third generation power MOSFETs from Vishay provide the designer with the best combination of fast switching, ruggedized device design, low on-resistance and cost-effectiveness.

The TO-220AB package is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 W. The low thermal resistance and low package cost of the TO-220AB contribute to its wide acceptance throughout the industry.

## MOSFET: IRF840

ORDERING INFORMATION				
Package		TO-220AB		
Lead (Pb)-free		IRF840PbF		
		SIHF840-E3		
SnPb		IRF840		
		SIHF840		
ABSOLUTE MAXIMUM RATINGS ( $T_C = 25^\circ\text{C}$ , unless otherwise noted)				
PARAMETER		SYMBOL	LIMIT	UNIT
Drain-Source Voltage		$V_{DS}$	500	V
Gate-Source Voltage		$V_{GS}$	$\pm 20$	V
Continuous Drain Current	$V_{GS}$ at 10 V	$T_C = 25^\circ\text{C}$	$I_D$	A
		$T_C = 100^\circ\text{C}$	5.1	
Pulsed Drain Current <sup>a</sup>		$I_{DM}$	32	
Linear Derating Factor			1.0	W/ $^\circ\text{C}$
Single Pulse Avalanche Energy <sup>b</sup>		$E_{AS}$	510	mJ
Repetitive Avalanche Current <sup>a</sup>		$I_{AR}$	8.0	A
Repetitive Avalanche Energy <sup>a</sup>		$E_{AR}$	13	mJ
Maximum Power Dissipation	$T_C = 25^\circ\text{C}$	$P_D$	125	W
Peak Diode Recovery $dV/dt$ <sup>c</sup>		$dV/dt$	3.5	V/ns
Operating Junction and Storage Temperature Range		$T_J, T_{stg}$	-55 to +150	$^\circ\text{C}$
Soldering Recommendations (Peak temperature) <sup>d</sup>	for 10 s		300	
Mounting Torque	6-32 or M3 screw		10	lbf · in
			1.1	N · m

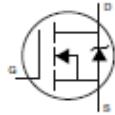
Notes:

## MOSFET: IRF840

SPECIFICATIONS ( $T_J = 25^\circ\text{C}$ , unless otherwise noted)								
PARAMETER	SYMBOL	TEST CONDITIONS		MIN.	TYP.	MAX.	UNIT	
<b>Static</b>								
Drain-Source Breakdown Voltage	$V_{DS}$	$V_{GS} = 0 \text{ V}$ , $I_D = 250 \mu\text{A}$		500	-	-	V	
$V_{DS}$ Temperature Coefficient	$\Delta V_{DS}/T_J$	Reference to $25^\circ\text{C}$ , $I_D = 1 \text{ mA}$		-	0.78	-	$^\circ\text{C}$	
Gate-Source Threshold Voltage	$V_{GS(\text{th})}$	$V_{DS} = V_{GS}$ , $I_D = 250 \mu\text{A}$		2.0	-	4.0	V	
Gate-Source Leakage	$I_{GSS}$	$V_{GS} = \pm 20 \text{ V}$		-	-	$\pm 100$	nA	
Zero Gate Voltage Drain Current	$I_{DSS}$	$V_{DS} = 500 \text{ V}$ , $V_{GS} = 0 \text{ V}$		-	-	25	$\mu\text{A}$	
		$V_{DS} = 400 \text{ V}$ , $V_{GS} = 0 \text{ V}$ , $T_J = 125^\circ\text{C}$		-	-	250		
Drain-Source On-State Resistance	$R_{DS(\text{on})}$	$V_{GS} = 10 \text{ V}$	$I_D = 4.8 \text{ A}^b$	-	-	0.85	$\Omega$	
Forward Transconductance	$g_{fs}$	$V_{DS} = 50 \text{ V}$ , $I_D = 4.8 \text{ A}^b$		4.9	-	-	S	
<b>Dynamic</b>								
Input Capacitance	$C_{iss}$	$V_{GS} = 0 \text{ V}$ , $V_{DS} = 25 \text{ V}$ , $f = 1.0 \text{ MHz}$ , see fig. 5		-	1300	-	pF	
Output Capacitance	$C_{oss}$			-	310	-		
Reverse Transfer Capacitance	$C_{rss}$			-	120	-		
Total Gate Charge	$Q_g$	$V_{GS} = 10 \text{ V}$	$I_D = 8 \text{ A}$ , $V_{DS} = 400 \text{ V}$ , see fig. 6 and 13 <sup>b</sup>	-	-	63	nC	
Gate-Source Charge	$Q_{gs}$			-	-	9.3		
Gate-Drain Charge	$Q_{gd}$			-	-	32		
Turn-On Delay Time	$t_{d(on)}$			-	14	-		
Rise Time	$t_r$	$V_{DD} = 250 \text{ V}$ , $I_D = 8 \text{ A}$ $R_g = 9.1 \Omega$ , $R_D = 31 \Omega$ , see fig. 10 <sup>b</sup>		-	23	-	ns	
Turn-Off Delay Time	$t_{d(off)}$			-	49	-		
Fall Time	$t_f$			-	20	-		
Internal Drain Inductance	$L_D$			-	4.5	-		
Internal Source Inductance	$L_S$	Between lead, 6 mm (0.25") from package and center of die contact		-	7.5	-	nH	
Gate Input Resistance	$R_g$			$f = 1 \text{ MHz}$ , open drain	0.6	-		

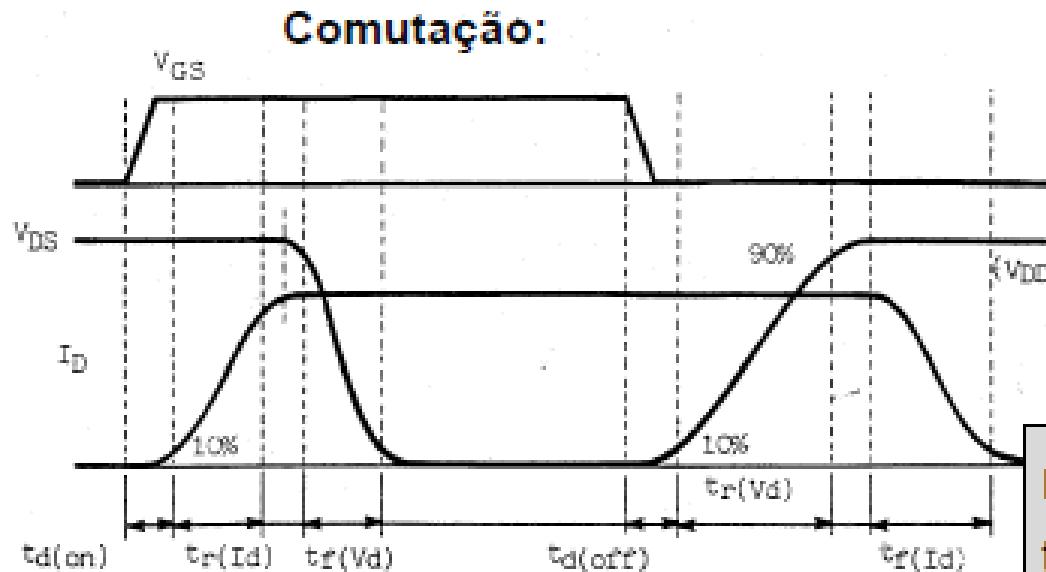


## MOSFET: IRF840

Drain-Source Body Diode Characteristics							
Continuous Source-Drain Diode Current	$I_S$	MOSFET symbol showing the integral reverse p - n junction diode 	-	-	8.0	A	
Pulsed Diode Forward Current <sup>a</sup>	$I_{SM}$		-	-	32		
Body Diode Voltage	$V_{SD}$	$T_J = 25 \text{ }^\circ\text{C}, I_S = 8 \text{ A}, V_{GS} = 0 \text{ V}$ <sup>b</sup>	-	-	2.0	V	
Body Diode Reverse Recovery Time	$t_{rr}$	$T_J = 25 \text{ }^\circ\text{C}, I_F = 8 \text{ A}, dI/dt = 100 \text{ A}/\mu\text{s}$ <sup>b</sup>	-	460	970	ns	
Body Diode Reverse Recovery Charge	$Q_{rr}$		-	4.2	8.9	$\mu\text{C}$	
Forward Turn-On Time	$t_{on}$	Intrinsic turn-on time is negligible (turn-on is dominated by $L_S$ and $L_D$ )					

## MOSFET: IRF840

### Dimensionamento do interruptores



$P_{\text{com}}$  = Perdas de comutação. [W]

$t_{\text{on}}$  = Tempo de entrada em condução

$V_{RM}$  = Tensão reversa

$f$  = frequência de comutação

$$P_{\text{com}} = \frac{f}{2} (t_{\text{on}} + t_{\text{off}}) i_d \cdot V_{ds}$$

## MOSFET: Safe Operating Area (SOA)

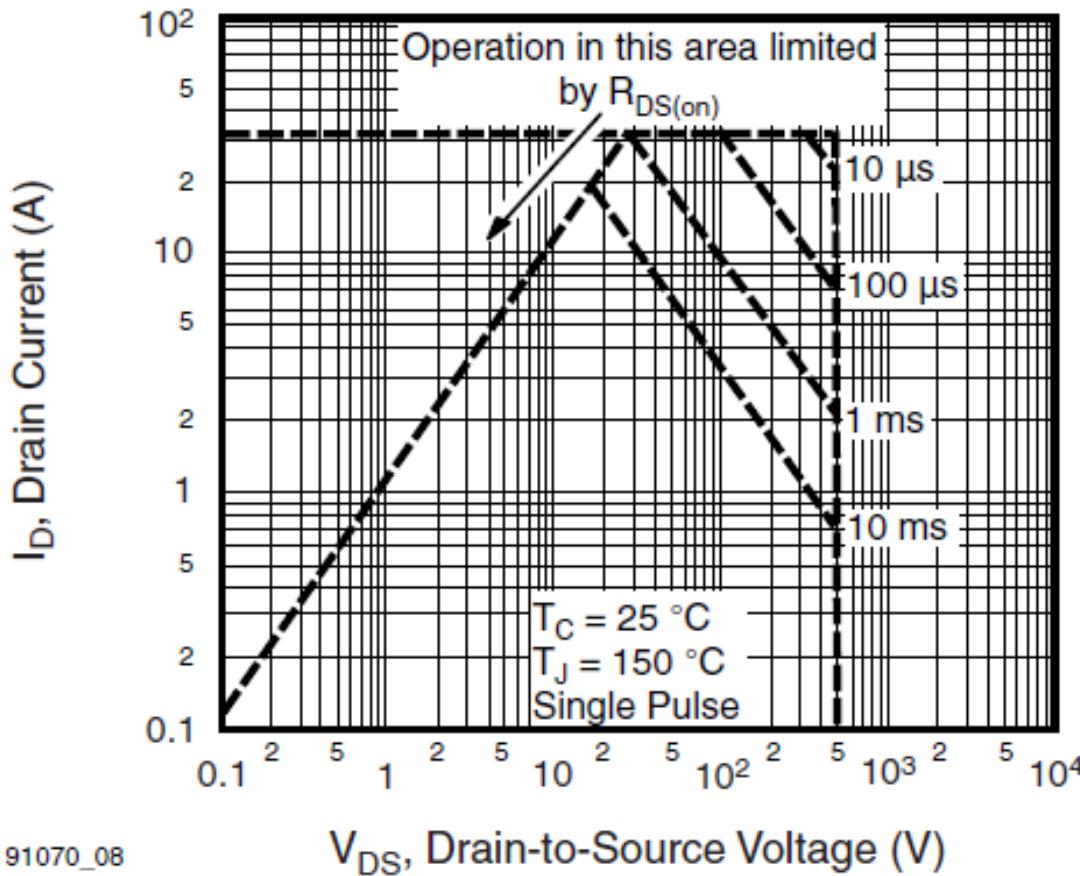
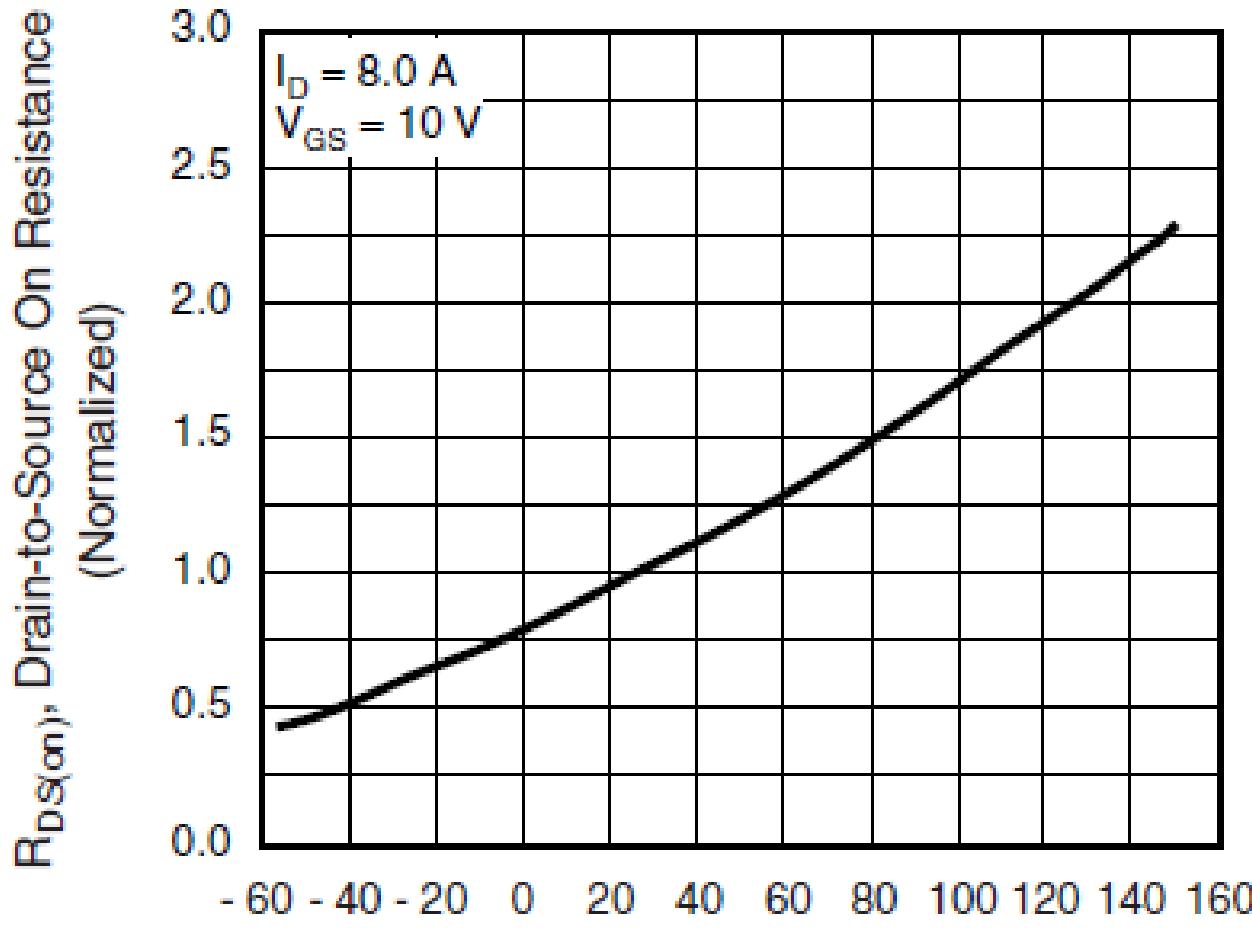


Fig. 8 - Maximum Safe Operating Area

# Metodologia de Projetos



$$P_{con} = \frac{t_{on}}{T} i_d^2 r_{ds}$$

91070\_04

$T_J$ , Junction Temperature (°C)

$P_{con}$  = Perdas em condução. [W]  
 $t_{on}$  = tempo em condução. [s]  
 $i_d$  = corrente em condução. [A]  
 $r_{ds}$  = resistência em condução. [Ω]  
 $T$  = Período de chaveamento

## MOSFET:

$$P_{mosfet} = P_{com} + P_{con}$$

$P_{mosfet}$  = Perdas totais no mosfet. [W]

$P_{com}$  = Perdas de comutação. [W]

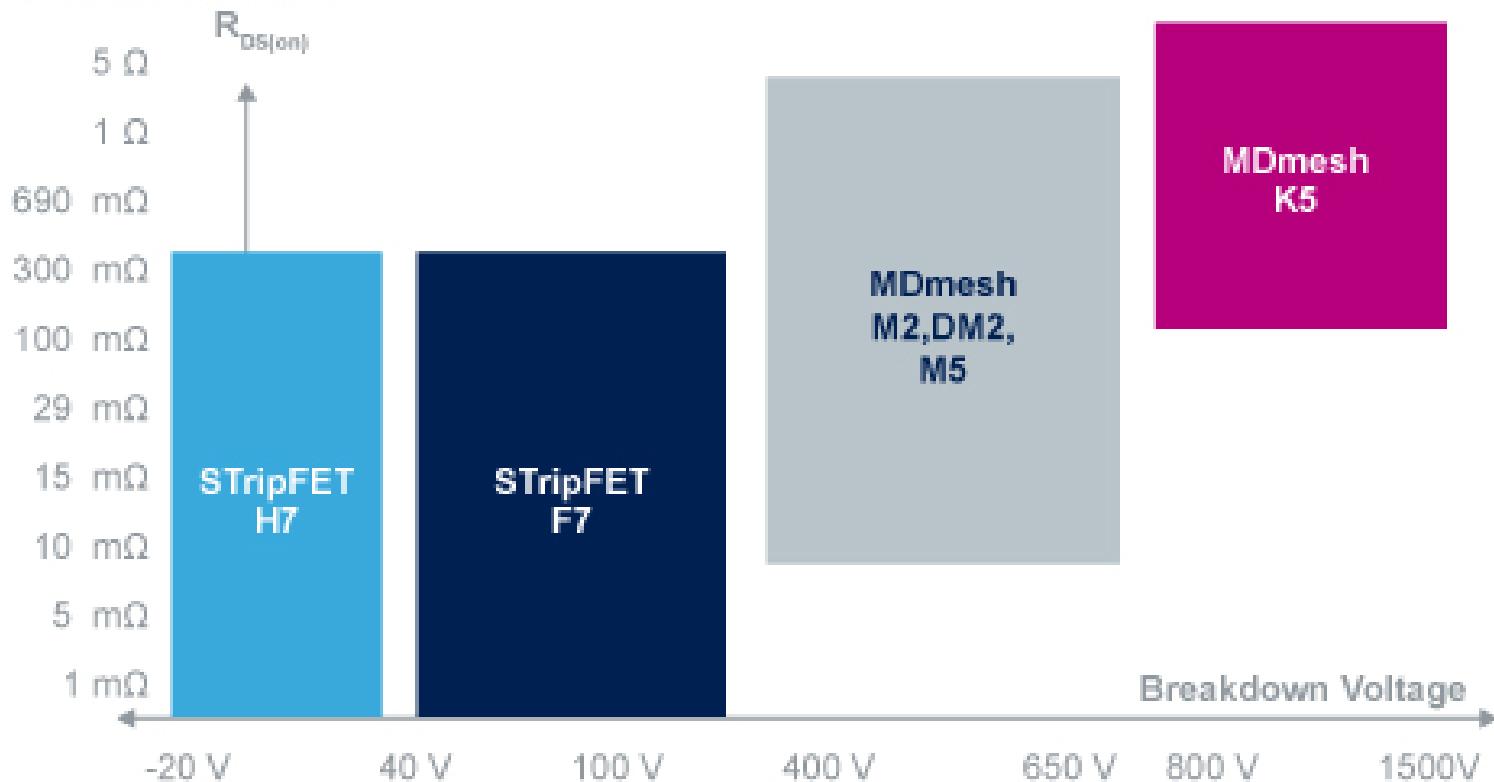
$P_{con}$  = Perdas em condução. [W]

### Considerações importantes para MOSFETs:

- Apresentam diodo intrínseco entre os terminais Source e Drain.
- Com terminal de gate aberto é normalmente fechado entre Drain-Source.

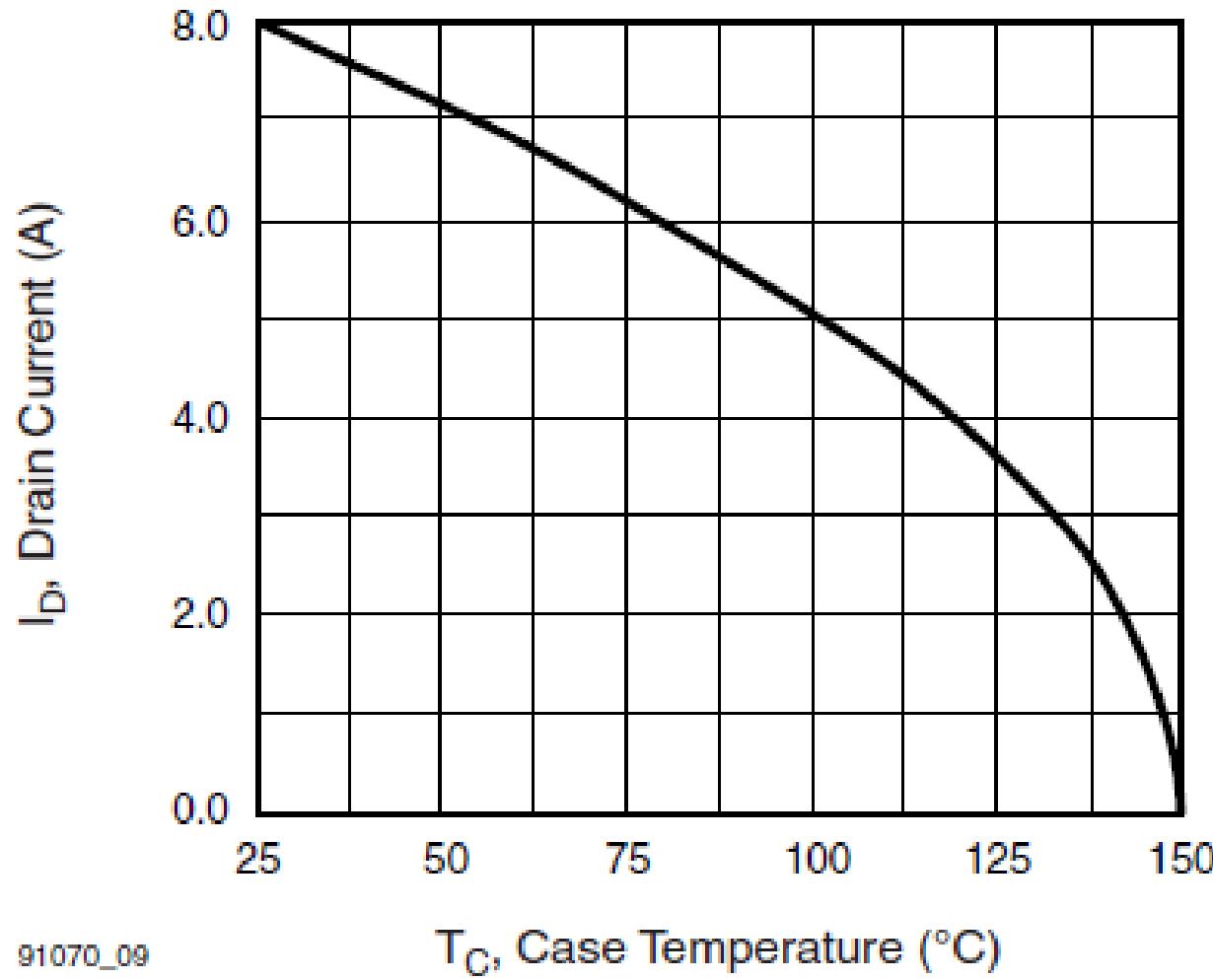
# Metodologia de Projetos

Main MOSFET series

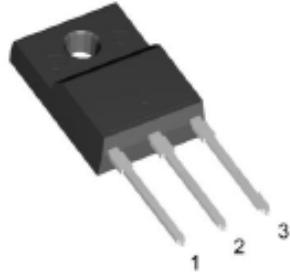


Fonte: [http://www.st.com/content/st\\_com/en/products/power-transistors/power-mosfets.html](http://www.st.com/content/st_com/en/products/power-transistors/power-mosfets.html)

## MOSFET:



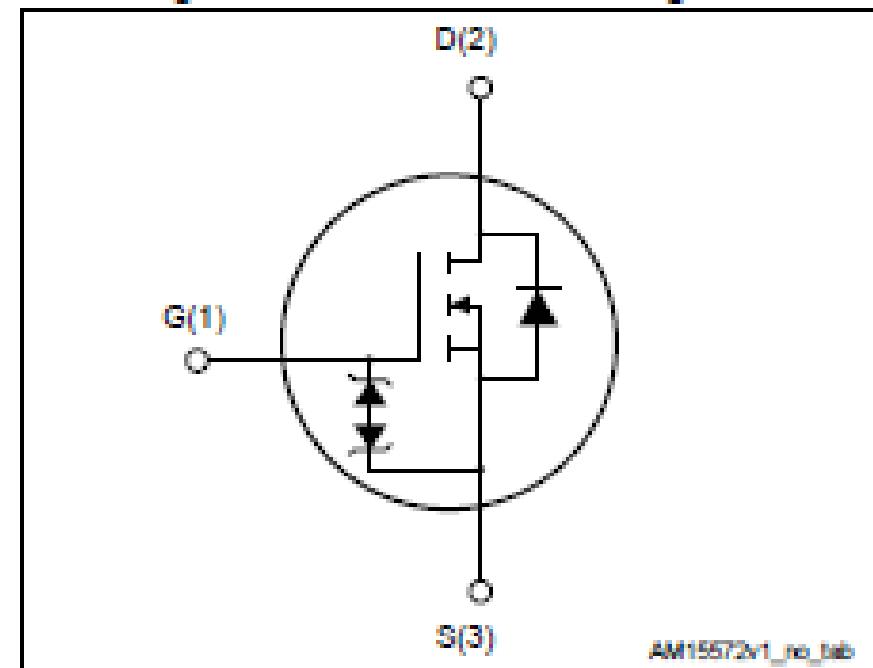
## Diodos Zener Interno:



TO-220FP wide creepage

Figure 1: Internal schematic diagram

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
$T_{Storage}$	Storage temperature range	-55 to 150	°C
$T_J$	Operating junction temperature range		



STFH24N60M2

N-channel 600 V, 0.168 Ω typ., 18 A MDmesh™ M2  
Power MOSFET in a TO-220FP wide creepage package

## Principais Fabricantes de Semicondutores de Potência:

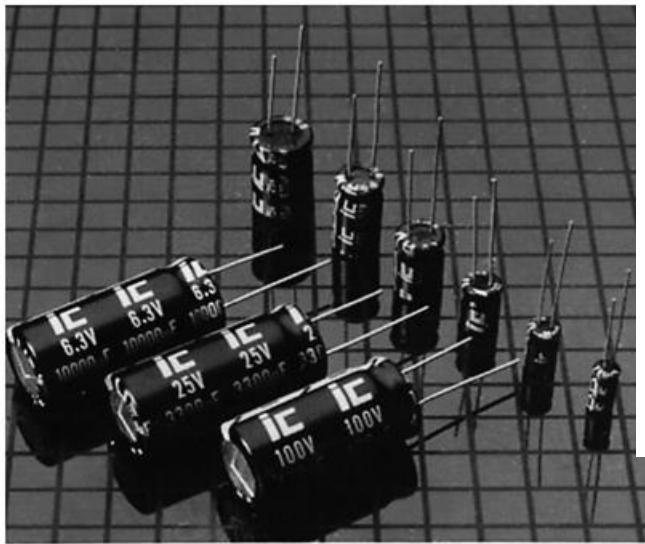
- Powerex;
- Infineon Technologies;
- ST Microelectronics;
- Ixys Corporation;
- Semikron;
- Fairchild;
- On Semiconductor;
- Microsemi;
- Vishay;
- Intersil;
- Cree Inc;
- International Rectifier (Infineon/Vishay);



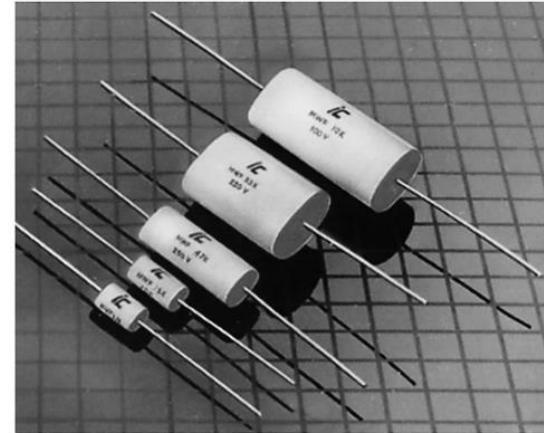
## Principais Fabricantes de Semicondutores no Brasil:

- HT Micron (São Leopoldo/RS):
  - Smart Cards;
  - DRAM;
  - Memória NAND: cartões micro SD, pen drives e SSD;
  - Multi-chip Package, CI para celulares;
- Ceitec/MCTI (Porto Alegre/RS):
  - Chips para controle de gado
  - Rastreamento de produto
- Smart Modular Technologies:
  - Drives SSD;
  - CI para memórias Flash e DRAM;
- Unitec (Ribeirão das Neves/MG):
  - IoT devices;
  - Smart Parking Systems;
  - Wearable Electronics;

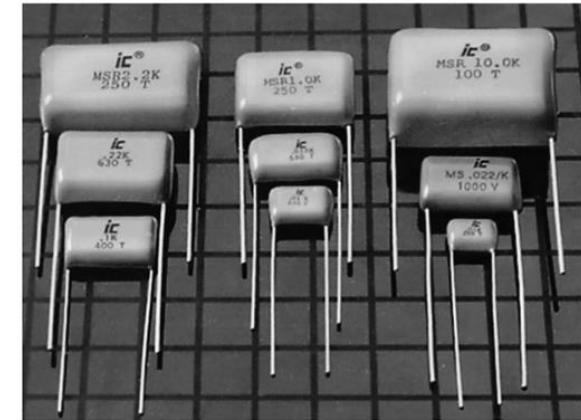
## Capacitores:



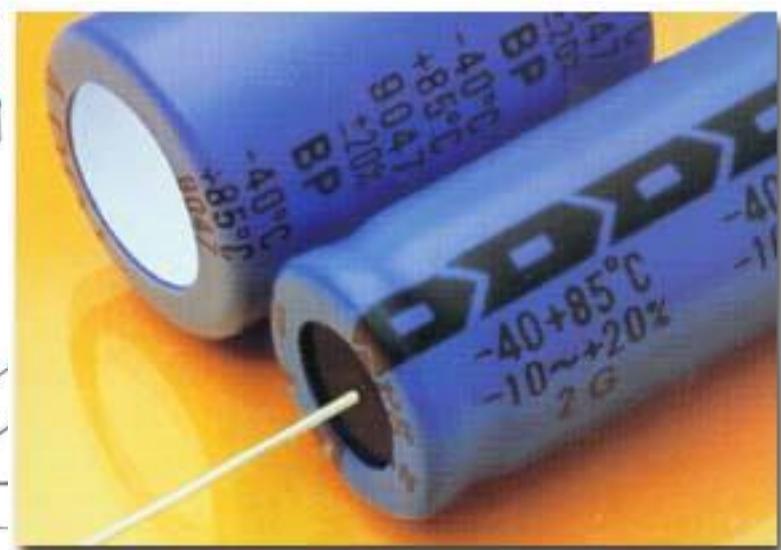
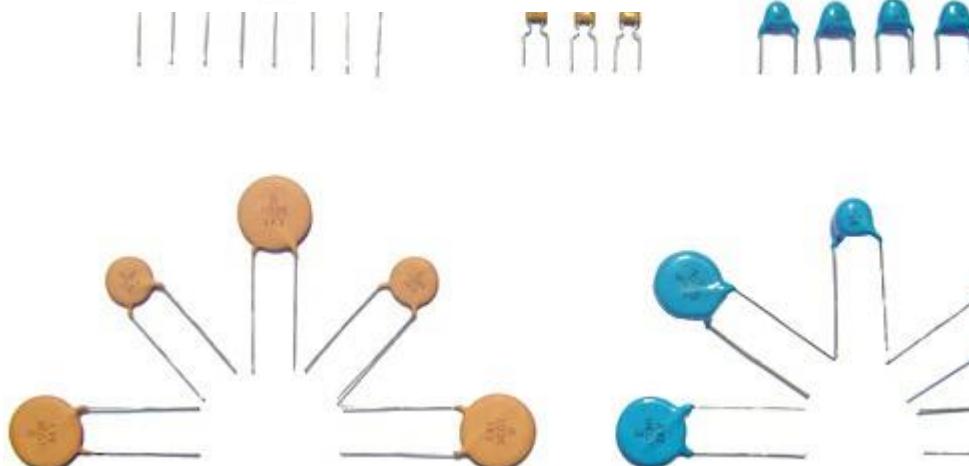
(a)



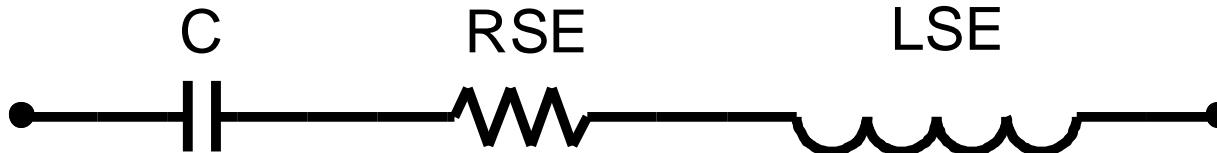
(a)



(b)



## Capacitores:



Modelo equivalente do capacitor

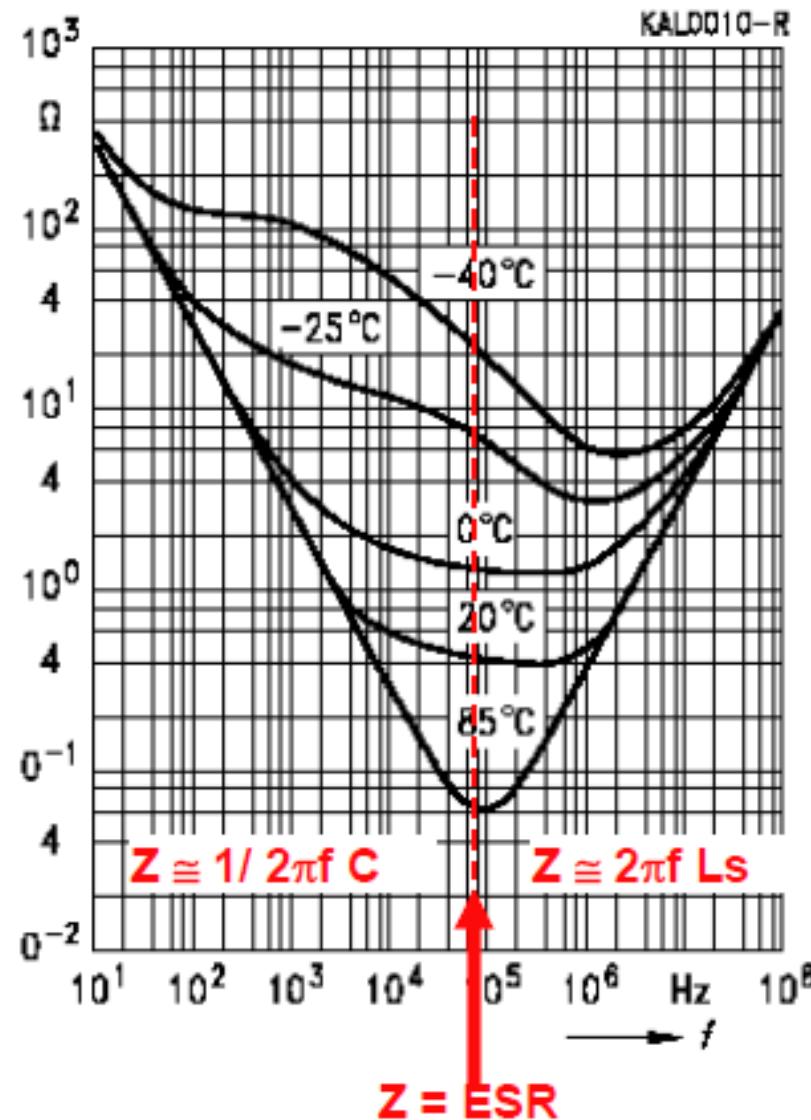
Onde:

- C = Capacitância;
- RSE = Resistência série equivalente;
- LSE = Indutância série equivalente.

Perdas devido à RSE:

$$P = RSE \cdot I_{ef}^2$$

## Curva de Impedância do Capacitor: ( $Z \times$ Frequência):



## Tipos de capacitores

- Eletrolíticos de Alumínio;
- Cerâmicos Multicamada;
- Filme Metalizado;
- Eletrolíticos de Tântalo;
- Capacitores de Potência;
- Ultra Capacitores;

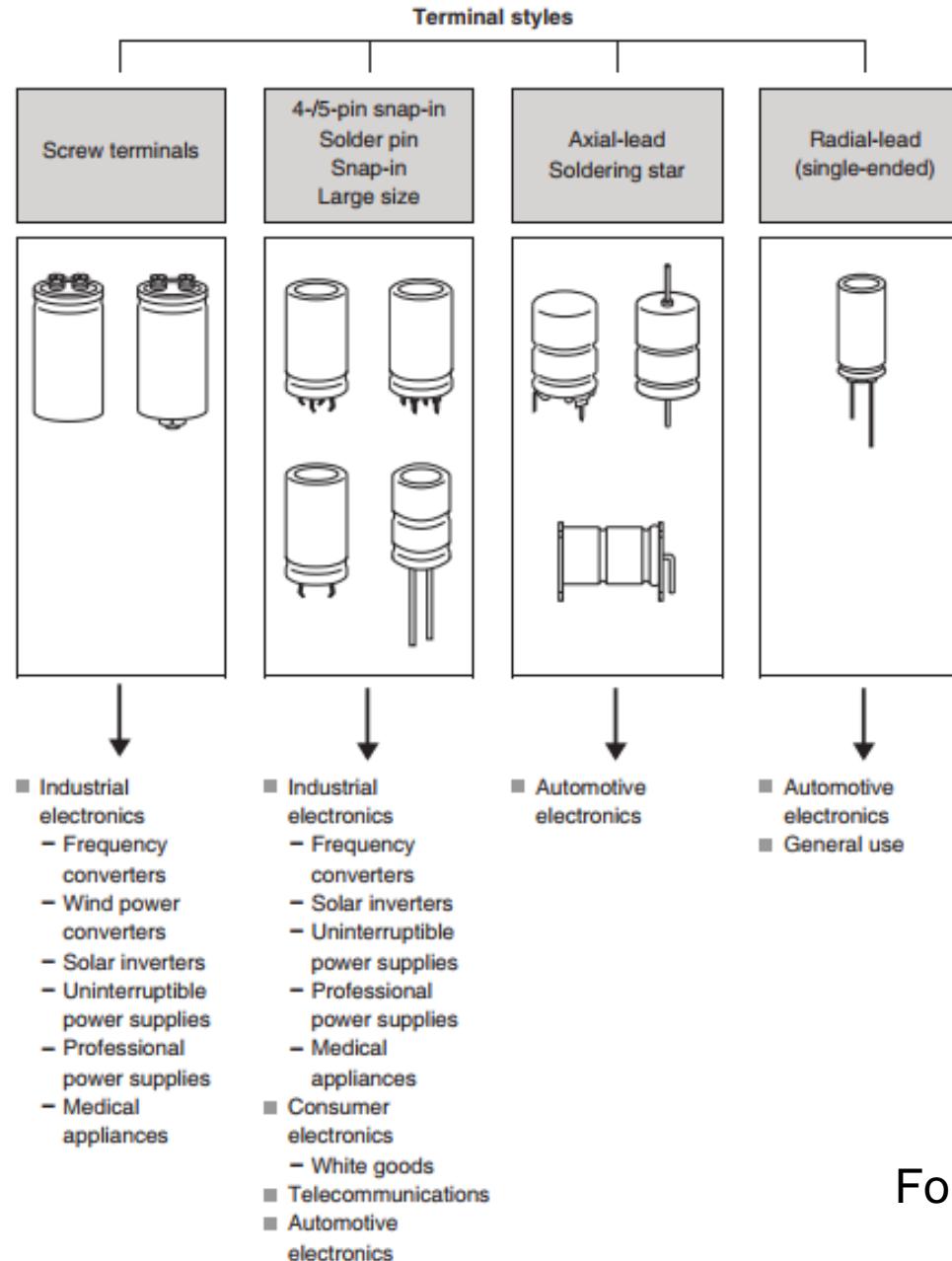
## Mais usados em eletrônica de potência:

- **Em filtros de conversores CC-CC e CA-CC** – São empregados capacitores eletrolíticos (maior densidade de potência);
- **Circuitos de auxiliares de comutação ou grampeamento:** Capacitores de polipropileno ou similares.
- **Circuitos de controle:** Cerâmicos (boa resposta em alta frequência)

## Tecnologias de capacitores:

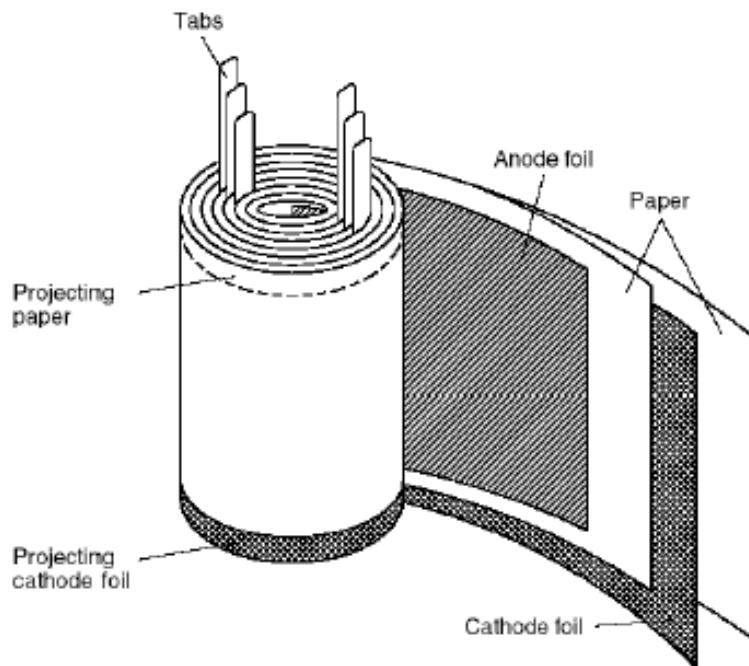
- Filtro do retificador de entrada – São empregados capacitores Eletrolíticos de alta tensão e grandes capacidades;
- Filtro de saída dos conversores – Empregam-se capacitores Eletrolíticos alumínio com baixa RSE;
- Circuitos de grampeamento (snubber) – São utilizados capacitores com dielétricos de polipropileno para regime intermitente de funcionamento.

# Metodologia de Projetos



Fonte: EPCOS

## Capacitores Eletrolítico



- Lâmina de alumínio recoberta por uma camada de óxido (dielétrico) e uma tira de papel impregnado com um líquido condutor eletrólito, sobreposto por uma outra lâmina de alumínio em contato com o papel.

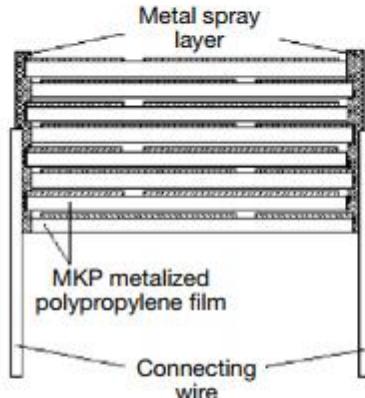
## Capacitores de Filme - Polipropileno



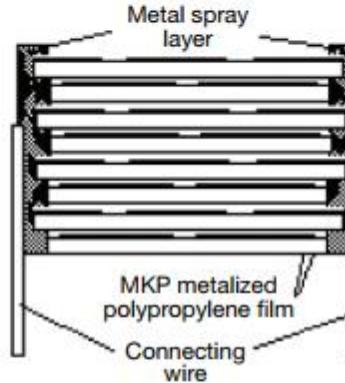
[www.vishay.com](http://www.vishay.com)

### General Technical Information

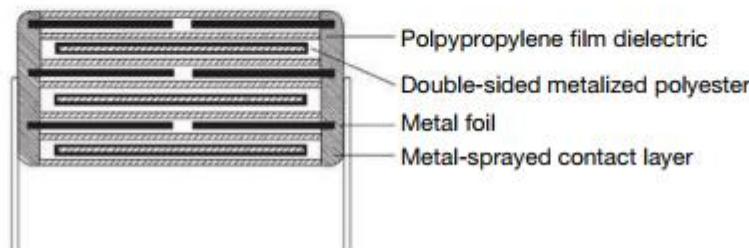
Vishay Roederstein



MKP385 (1600 V to 2000 V)  
Extended metallized film with internal series connections  
(3 sections) design



MKP385 (2500 V) Extended metallized film with  
internal series connections (4 sections) design



## Capacitores Eletrolítico: Marcação e Tolerância

	Manufacturer (company logo)
<b>EPCOS</b>	LL Grade (only on LL grade capacitors)
B43511-A9108-M	Part number (ordering code)
1000 µF (M)	Rated capacitance, tolerance (in coded form)
400 V-	Rated voltage, climatic category (to IEC or coded as explained below)
40/085/56	
11.12	Month and year of production

KAL1399-7-E

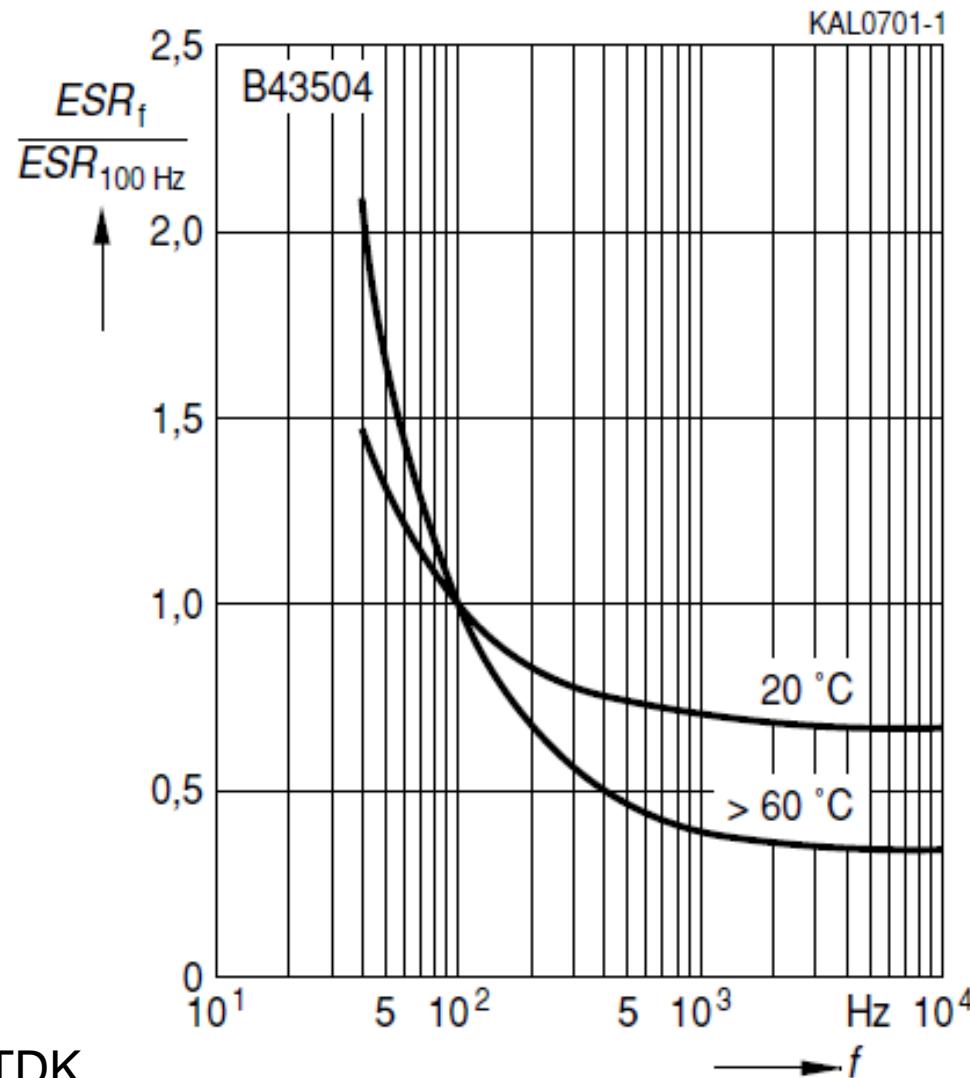
### Figure

#### Marking example

Capacitance tolerances are coded to IEC 60062 using the codes shown below:

Code letter	Capacitance tolerance	Code letter	Capacitance tolerance
A	Tolerances to which no other code applies	R	-20%/+30%
K	±10%	S	-20%/+50%
M	±20%	T	-10%/+50%
N	±30%	V	-10%/+100%
Q	-10%/+30%	Y	0%/+50%
		Z	-20%/+80%

## Capacitores Eletrolíticos: Variação da RSE com a frequência



B34504 EPCOS/TDK

## Capacitores Eletrolíticos: Dados

$U_R$ VDC	$C_R$ 100 Hz 20 °C $\mu\text{F}$	Case dimensions $d \times l$ mm	$ESR_{\text{typ}}$ 100 Hz 20 °C mΩ	$Z_{\max}$ 10 kHz 20 °C mΩ	$I_{\sim\max}$ 100 Hz 40 °C A	$I_{\sim\max}$ 100 Hz 85 °C A	$I_{\sim R}^1)$ 100 Hz 105 °C A
200	220	22 × 25	580	700	2,6	1,7	0,84
	270	22 × 25	480	570	2,8	1,9	0,93
	330	22 × 30	390	470	3,3	2,2	1,1
	390	22 × 30	330	400	3,6	2,4	1,2
	470	22 × 35	280	330	4,2	2,8	1,4
	470	30 × 25	280	330	4,5	3,0	1,5
	560	25 × 35	230	280	5,0	3,4	1,6
	680	25 × 40	190	230	5,8	3,9	1,9
	680	35 × 25	190	230	6,0	4,0	2,0
	820	25 × 45	160	190	6,6	4,5	2,2
	820	35 × 30	160	190	6,9	4,7	2,3
	1 000	30 × 35	130	160	7,3	4,9	2,4
	1 200	30 × 40	110	130	8,4	5,6	2,7
	1 500	35 × 40	90	110	10	6,9	3,4
	1 800	35 × 45	80	90	12	7,9	3,9
	2 200	35 × 50	60	70	14	9,1	4,4

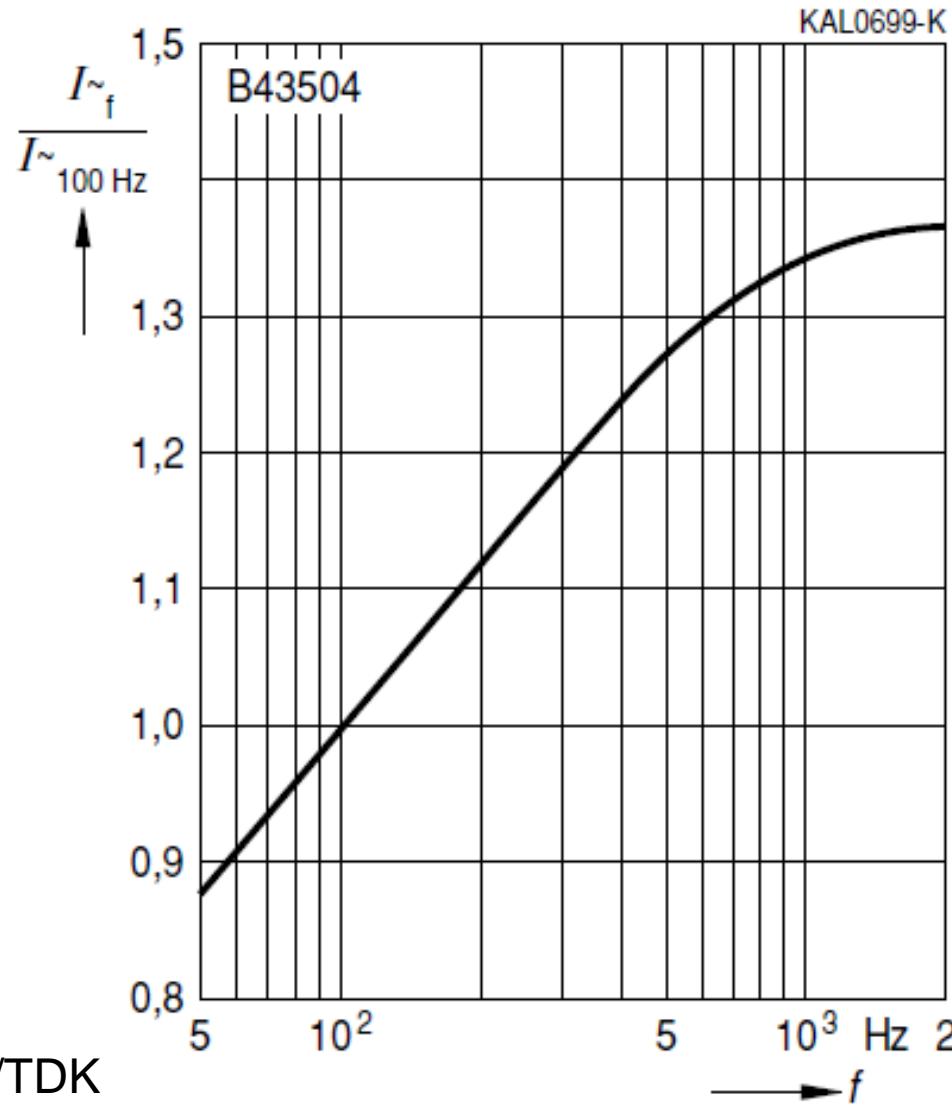
B34504 EPCOS/TDK

## Capacitores Eletrolíticos: Dados

$U_R$ VDC	$C_R$ 100 Hz 20 °C $\mu\text{F}$	Case dimensions $d \times l$ mm	$ESR_{\text{typ}}$ 100 Hz 20 °C	$Z_{\max}$ 10 kHz 20 °C	$I_{\sim\max}$ 100 Hz 40 °C	$I_{\sim\max}$ 100 Hz 85 °C	$I_{\sim R}^{1)}$ 100 Hz 105 °C	Ordering code <sup>2)</sup>
250	220	22 × 30	580	700	2,7	1,8	0,89	B43504A2227M000
	270	22 × 35	480	570	3,2	2,2	1,1	B43504A2277M000
	330	22 × 40	390	470	3,7	2,5	1,2	B43504B2337M000
	330	25 × 30	390	470	3,6	2,4	1,2	B43504C2337M000
	390	25 × 35	330	400	4,2	2,8	1,4	B43504A2397M000
	470	22 × 50	280	330	4,9	3,3	1,6	B43504A2477M000
	470	30 × 30	280	330	4,7	3,2	1,6	B43504B2477M000
	560	25 × 45	230	280	5,5	3,7	1,8	B43504A2567M000
	680	25 × 50	190	230	6,3	4,2	2,1	B43504A2687M000
	680	30 × 40	190	230	6,3	4,2	2,1	B43504B2687M000
	820	30 × 45	160	190	7,2	4,9	2,4	B43504B2827M000
	1 000	35 × 40	130	160	8,4	5,7	2,8	B43504A2108M000
	1 200	35 × 45	110	130	9,6	6,5	3,2	B43504A2128M000

B34504 EPCOS/TDK

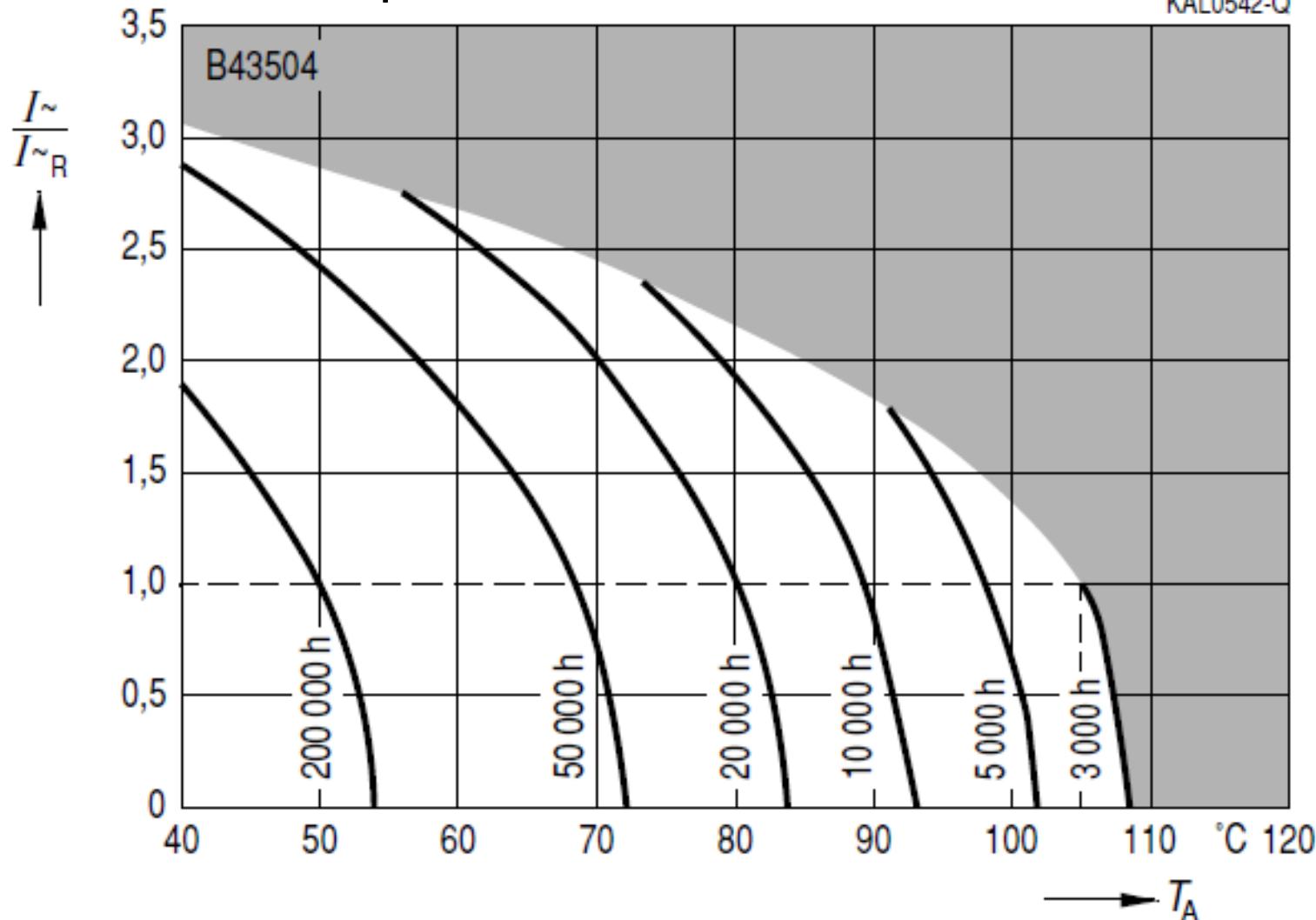
## Capacitores Eletrolíticos: Variação da corrente com a frequência



B34504 EPCOS/TDK

## Capacitores Eletrolíticos: Vida Útil

KAL0542-Q



B34504 EPCOS/TDK

$I_{\text{acR}}$  = Corrente ca nominal a 105 graus Celsius  
 $I_{\text{ac}}$  = Corrente ca que circula pelo capacitor

## Capacitores Eletrolíticos: Vida Útil

### Useful life

105 °C;  $U_R$ ;  $I_{\text{~R}}$

85 °C;  $U_R$ ;  $I_{\text{~max}}$

40 °C;  $U_R$ ;  $1,9 \cdot I_{\text{~R}}$

> 3 000 h

> 6 500 h

> 200 000 h

### Requirements:

$\Delta C/C \leq \pm 30\%$  of initial value

$\tan \delta \leq 3$  times initial specified limit

$I_L \leq$  initial specified limit

Failure percentage:  $\leq 1\%$

Failure rate:  $\leq 40 \text{ fit} (\leq 40 \cdot 10^{-9}/\text{h})$

(for definiton "fit", refer to chapter "Quality", page 62)

B34504 EPCOS/TDK

$I_{\text{acR}}$  = Corrente ca nominal a 105 graus Celsius

$I_{\text{ac}}$  = Corrente ca que circula pelo capacitor

$U_R$  = tensão nominal

## Capacitores Eletrolíticos: Vida Útil

### Aluminum Electrolytic Capacitors

#### Life expectancy

Aluminum electrolytic capacitors slowly degrade over time and once the capacitor has degraded beyond a specified amount, the capacitor is considered to have failed. Most capacitors are considered a failure when the capacitance has changed by 20 to 25% of its initial value.

Aluminum electrolytic Capacitors load life's ratings are generally expressed between 1000 and 10000 hours at their rated voltage, maximum temperature rating and with maximum ripple current applied to the capacitor. This means that the capacitance of the capacitor will not change by more than the amount indicated under the load life rating when the capacitor is operated at the stated conditions. Although the life expectancies appear be a short amount of time the following can increase them.

When the capacitor is operated at temperatures other than the maximum rated temperature for the capacitor the expected life of the capacitor will increase. The rate of increase in operating life is for the life to double for every 10°C decrease in temperature (Arrhenius's law).

Fonte: Illinois Capacitor, Inc.

## Capacitores Eletrolíticos: Tensão Máxima

B34504 EPCOS/TDK

### Specifications and characteristics in brief

Rated voltage $U_R$	200 ... 450 VDC
Surge voltage $U_S$	$1,15 \cdot U_R$ (for $U_R \leq 250$ VDC) $1,10 \cdot U_R$ (for $U_R \geq 400$ VDC)
Rated capacitance $C_R$	47 ... 2 200 $\mu\text{F}$
Capacitance tolerance	$\pm 20 \% \triangleq M$

### 3.1.3 Surge voltage $V_S$

The surge voltage is the maximum voltage which may be applied to the capacitor for short periods of time, i.e. up to 5 times for 1 minute per hour. IEC 60384-4 specifies the surge voltage as follows:

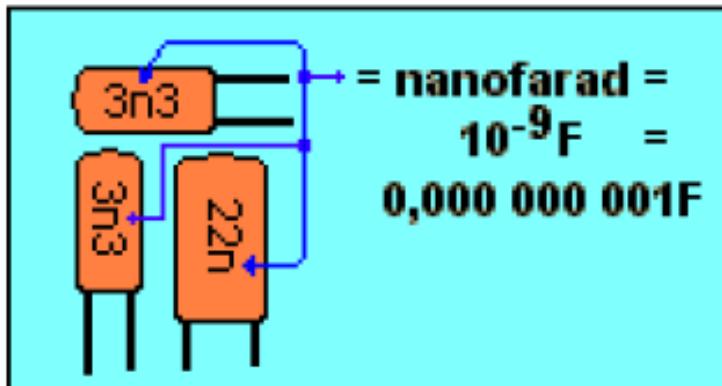
for  $V_R \leq 315$  V:  $V_S = 1.15 \cdot V_R$

for  $V_R > 315$  V:  $V_S = 1.10 \cdot V_R$

## Capacitores

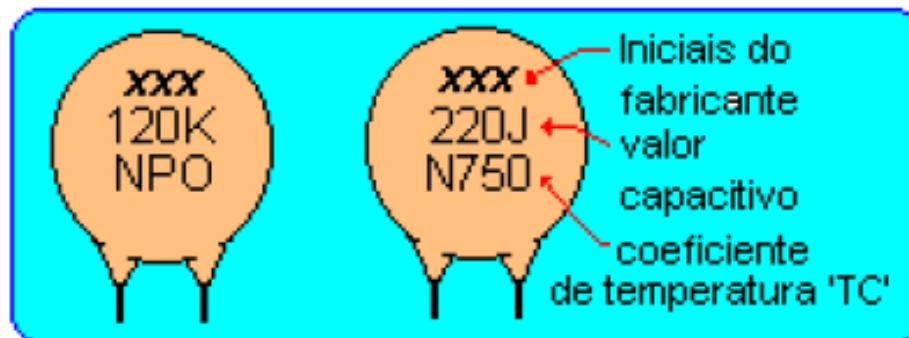
### Leitura dos valores:

- ▶ Polipropileno, polister e policarbonato



- ▶ Cerâmico:

120  
12x10<sup>0</sup> pF



220  
22x10<sup>0</sup> pF

## Capacitores

Leitura dos valores:

- ▶ Eletrolítico

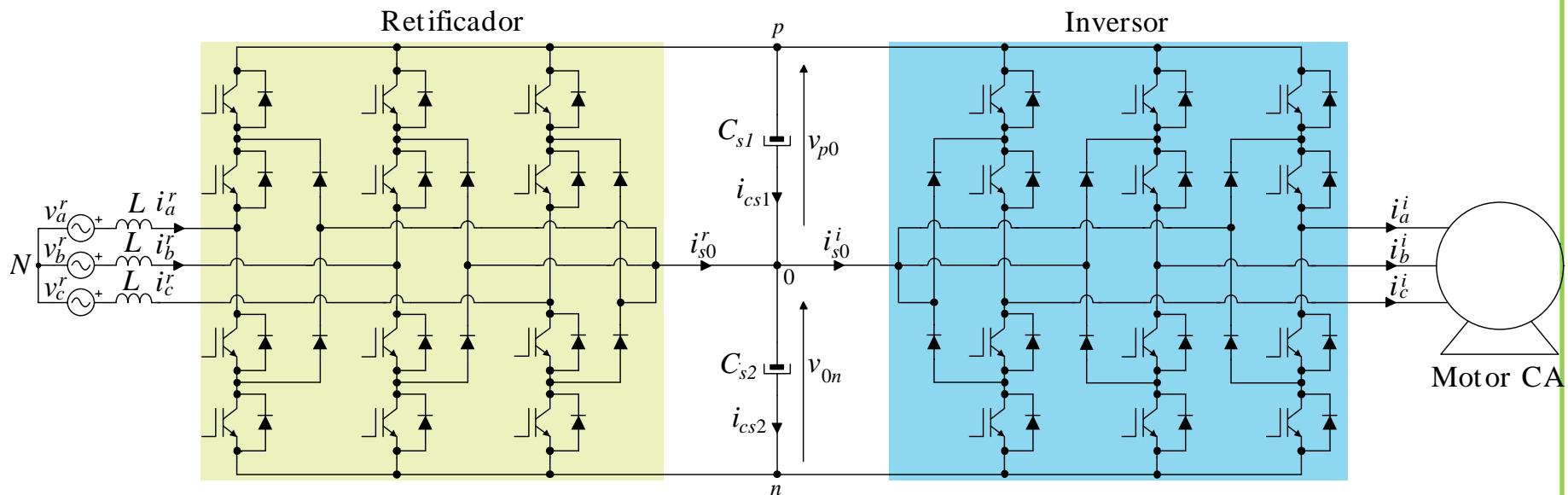


## Comparativo Capacitor Filme x Eletrolítico:

- Capacitores de Filme apresentam menor resistência série equivalente (Redução de Perdas);
- Capacitores de Filme suportam tensão maiores (até 1.600 Vdc);
- Capacitores de Filme apresentam maior vida útil:
  - Capacitores eletrolíticos têm vida útil típica de 6,5 kh com operação nominal
  - Capacitores de filme têm vida útil típica de 100 kh com operação nominal
- Capacitores de Filme suportam alta ondulações de corrente;
- Capacitores de Filme apresentam baixa capacidade por unidade;
- Capacitores de Filme apresentam alto volume (farad x volume);
- Capacitores de Filme apresentam custo relativo maior por farad;

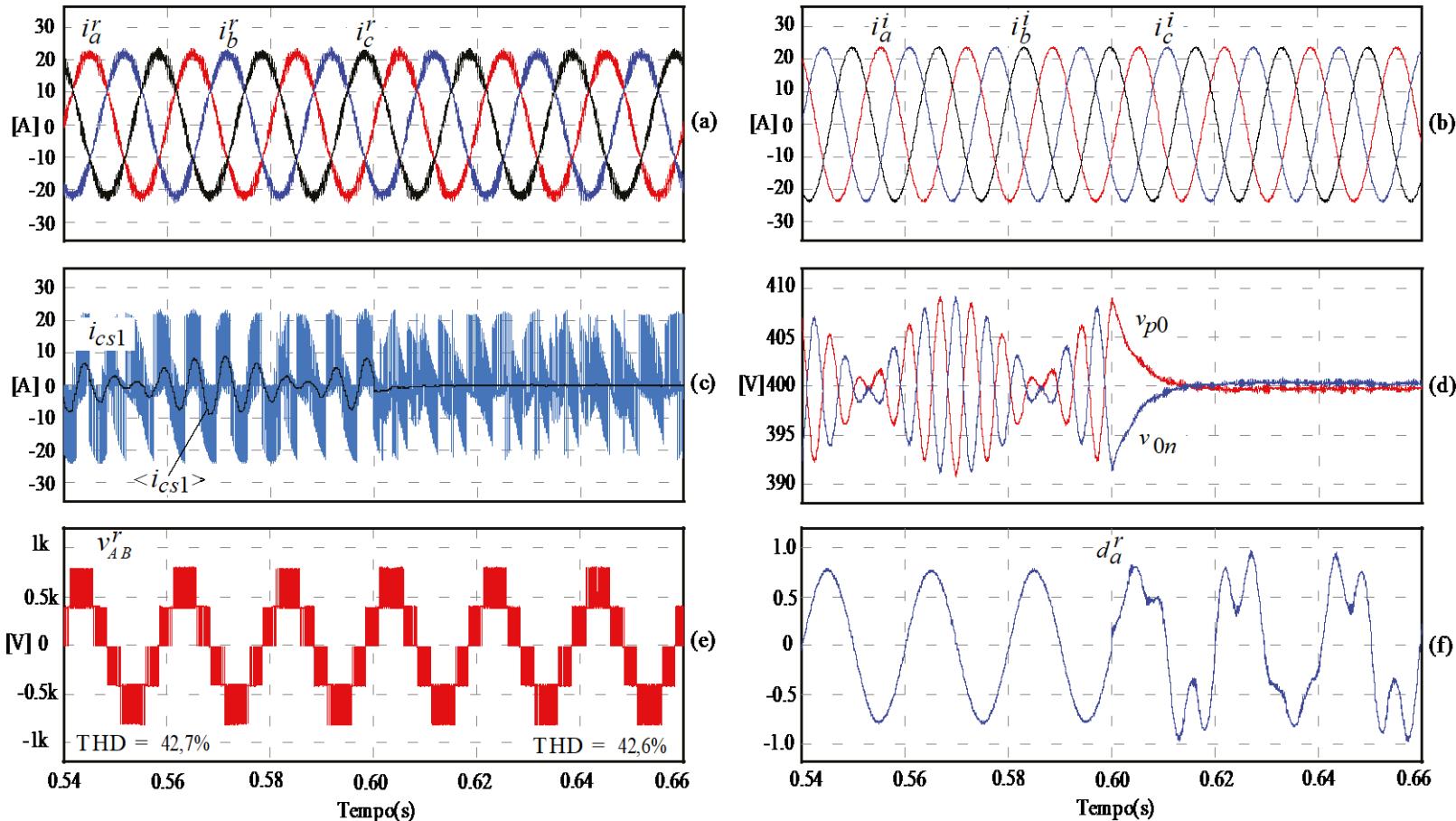
# Inversor Trifásico Bidirecional

- Sistema *Back-to-Back* (B2B) baseado no conversor NPC três fios/fases/níveis é amplamente utilizado:
  - Geração Eólica;
  - Sistemas de Energias Renováveis;
  - Propulsão Marinha;
  - Acionamento de Máquinas em Corrente Alternada (CA).



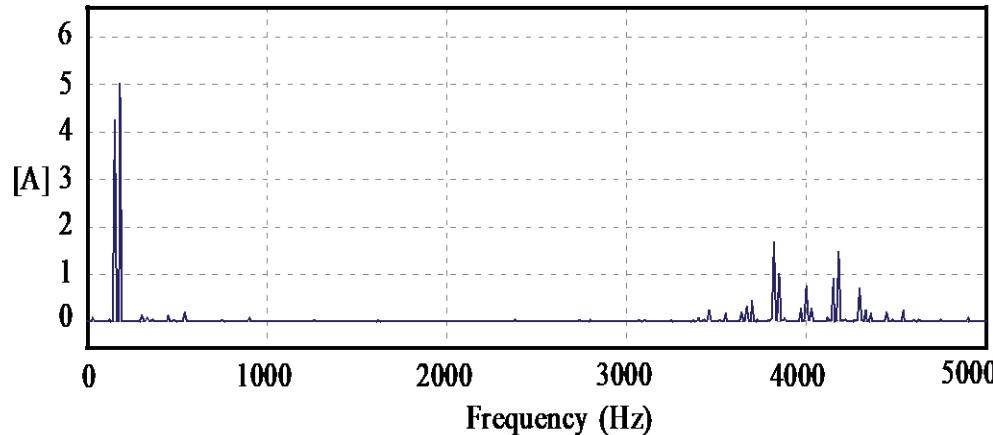
# Inversor Trifásico Bidirecional

- Apresentam componentes de corrente de baixa frequência (BF) nos barramentos parciais, ocasionando ondulações:
  - A causa se deve às correntes injetadas no ponto central do sistema, oriundas do retificador e do inversor, três vezes a frequência do sinal de modulação;

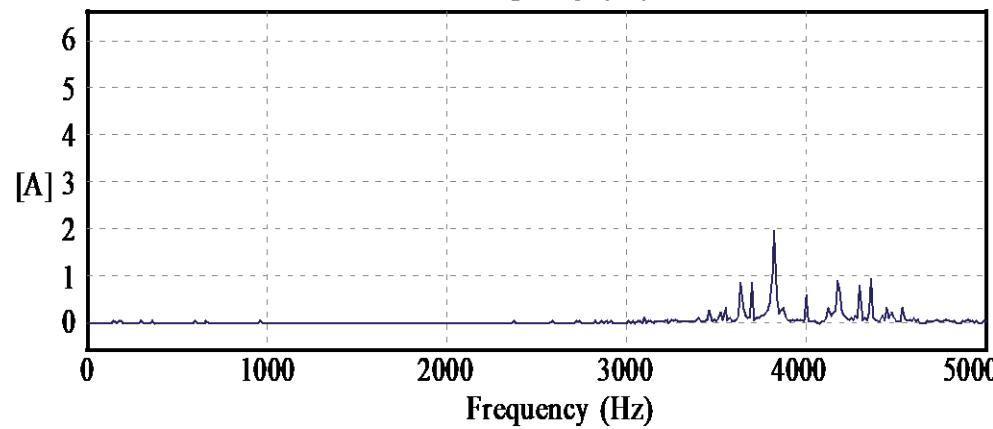


# Inversor Trifásico Bidirecional

- FFT da corrente do capacitor do barramento positivo:



(a) SPWM



(b) Modulação Proposta

## Exemplo: Fabricante EPCOS /TDK



B43504



B32778G

Parâmetro	B43504	B32778G
Capacitância	1000 uF	50 uF
Tensão CC máxima	250 V	800 V
Corrente eficaz máxima	5,7 A (85°C e 100 Hz)	16 A (80°C e 10 kHz)
ESR	140 mΩ (20°C e 100 Hz)	6,3 mΩ (70°C e 10 kHz)
Tolerância	20%	10%
Vida útil	6.500 horas	100.000 horas
Dimensional	35 x 40 mm (d x h)	30x45x57,5 mm (w x h x l)

# Inversor Trifásico Bidirecional

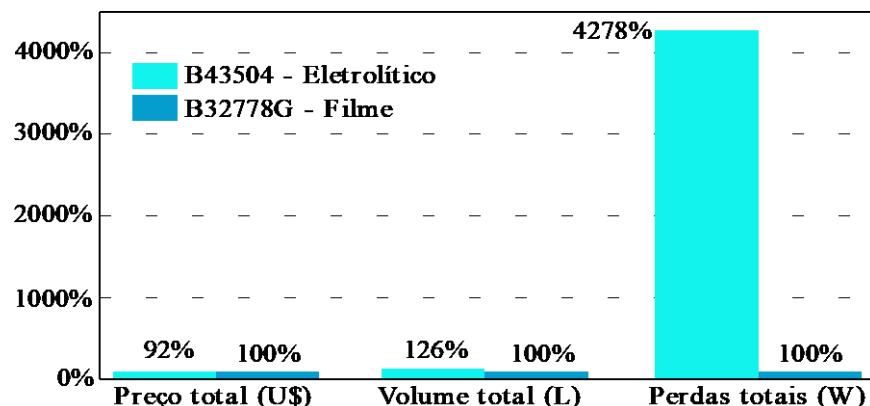
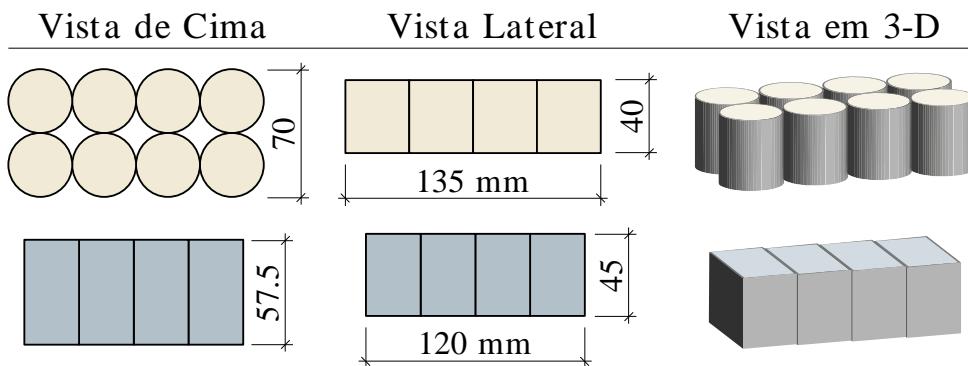


Parâmetros Motor Trifásico CA PMSM	Símbolo	Valor
Potência nominal mecânica	$P_m$	11,04 kW
Frequência nominal	$f_m$	60 Hz
Tensão de linha nominal	$V_{Lm}$	380 V
Torque nominal	$T_m$	57,86 N.m
Velocidade Nominal	$\omega_{rpm}$	1.800 rpm
Número de Polos	$p$	4

# Inversor Trifásico Bidirecional

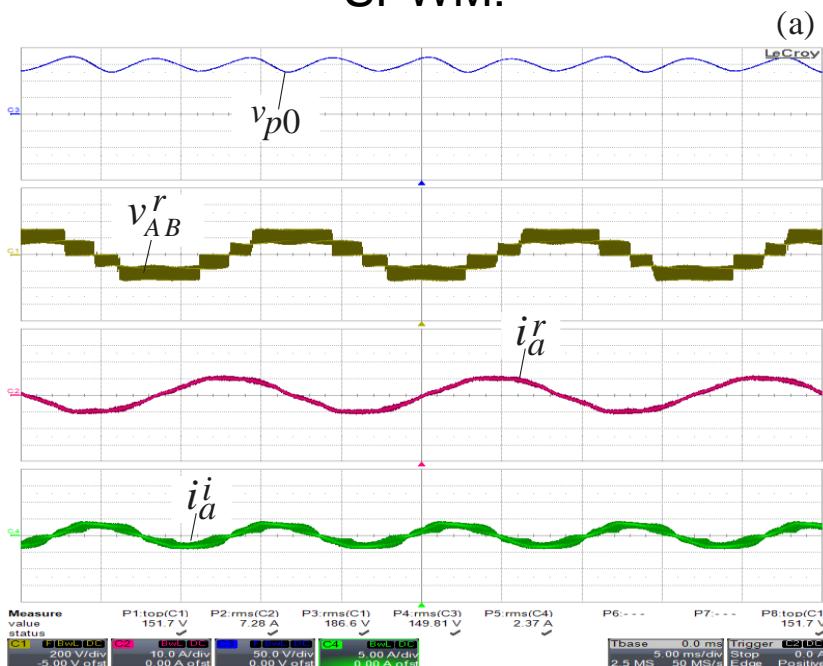
- Comparação entre os bancos de capacitores:

Parâmetro	B43504	B32778G
Preço total (U\$)	66,16	72,16
Volume total (L)	0,392	0,310
Perdas totais (W)	36,96	0,864

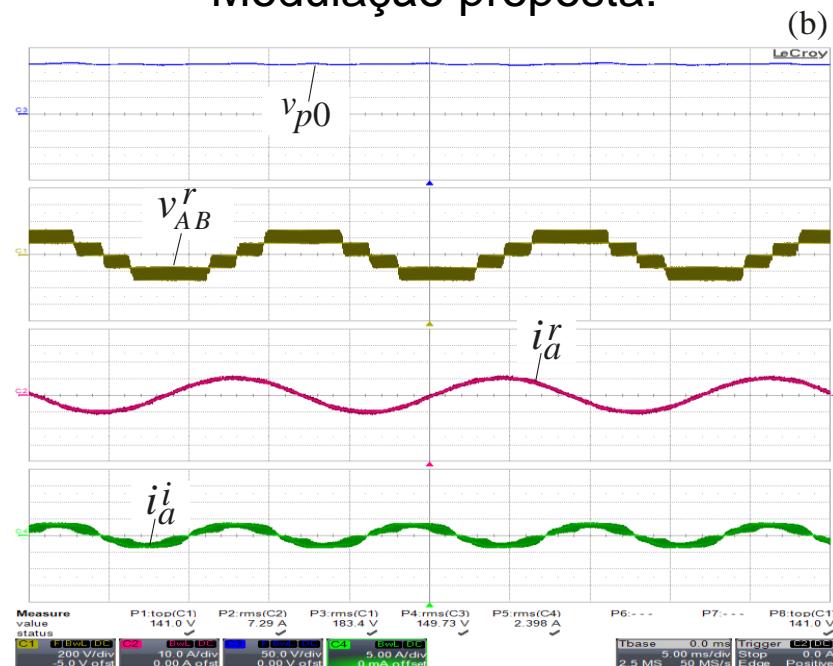


# Inversor Trifásico Bidirecional

SPWM:

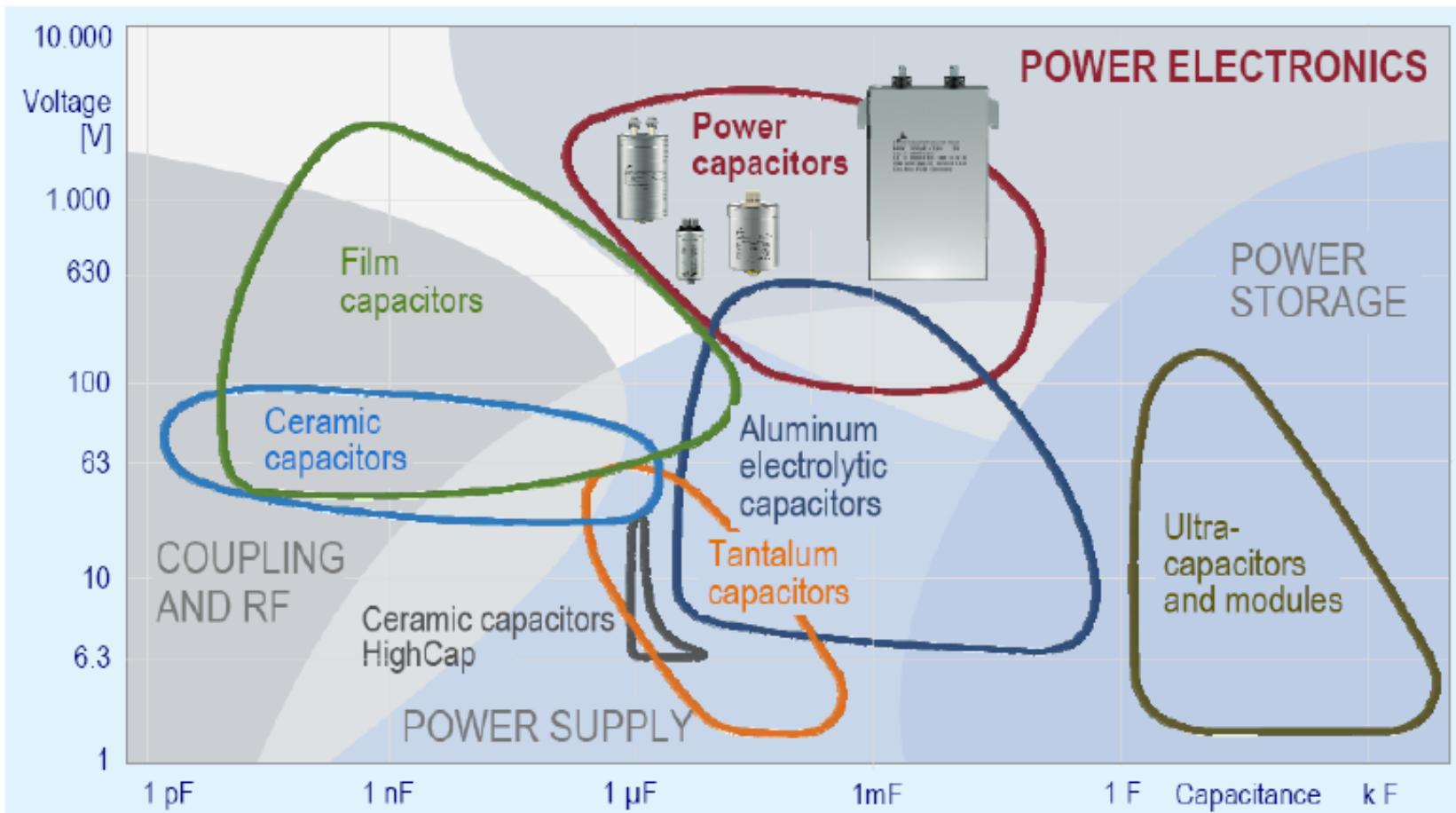


Modulação proposta:



- DSP =TMS320F28335 (TI): 150 MHz

## Capacitors



## Principais Fabricantes:

- EPCOS/TDK;
- United Chemi-Con
- Vishay;
- Nichicon;
- Kemet;
- Avx Corp;
- Murata;
- Panasonic;



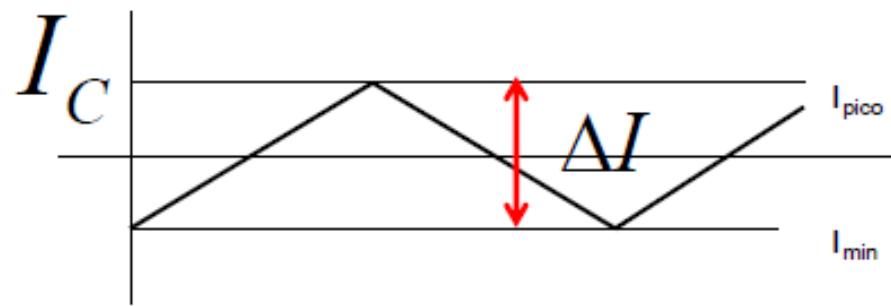
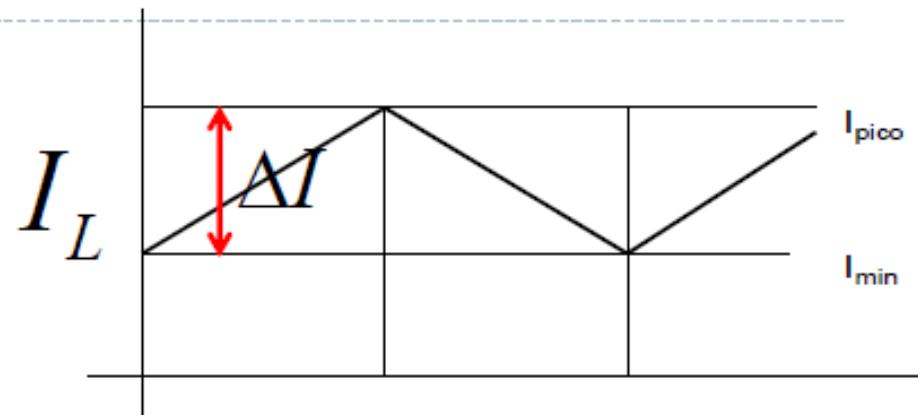
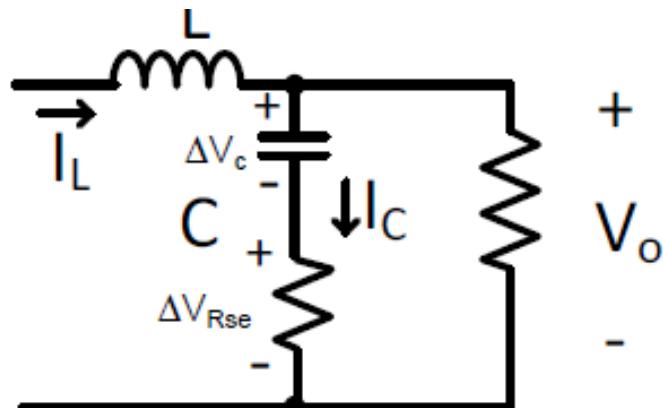
## Dimensionamento de Capacitor:

- Valor da Capacitância mínima para o projeto ( $\Delta V_c$  e  $\Delta I_c$ );
- Tensão Máxima;
- Corrente Eficaz Máxima;
- Perdas (observar a RSE corrente nas frequências);
- Custo, volume, espaço na PCI;

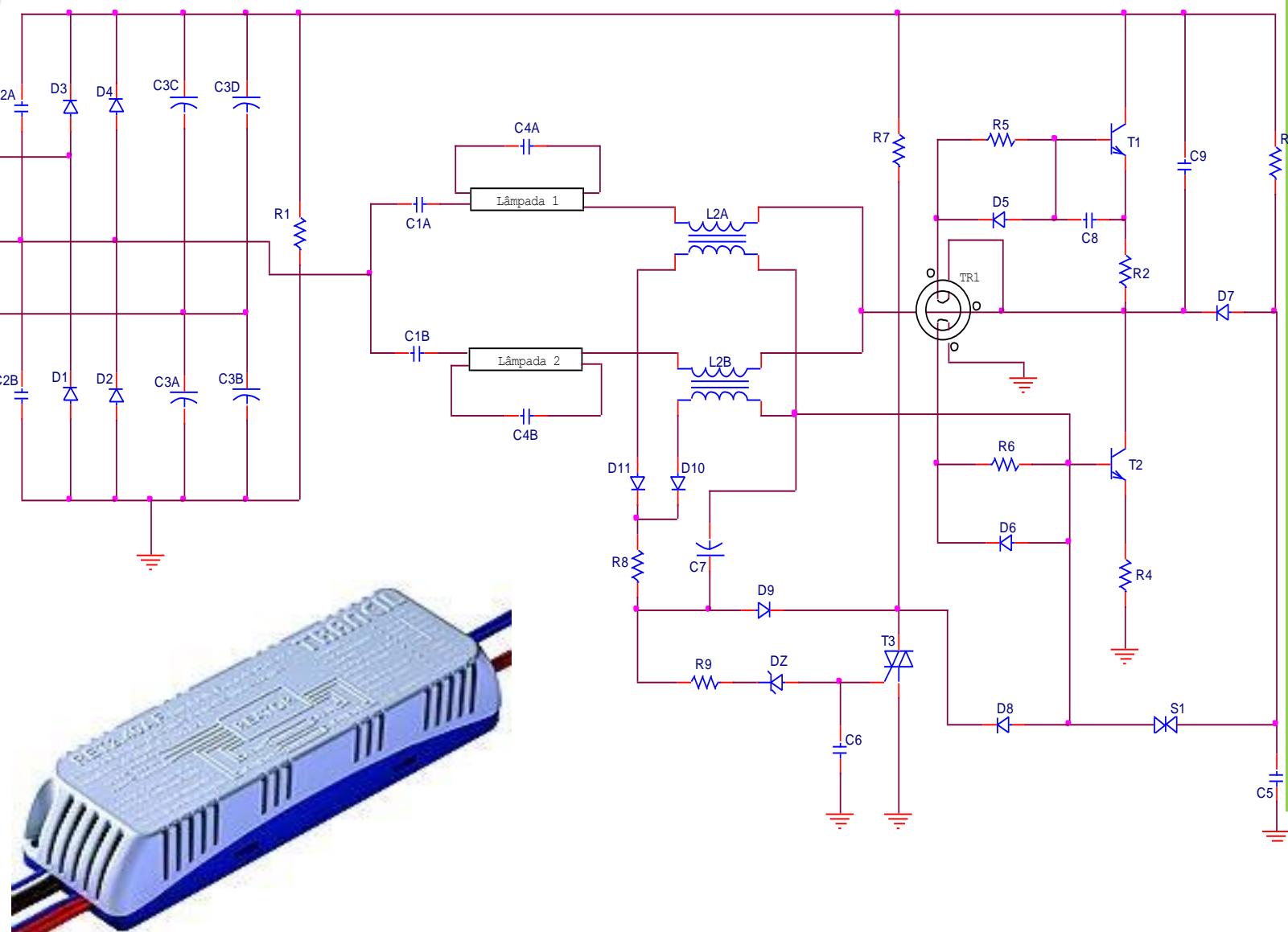
## Capacitores

### Dimensionamento:

- ▶ Cálculo da RSE;



**Importante:** Baixar custo com capacitores em série/paralelo



## Capacitores em série/paralelo: Indicação do fabricante

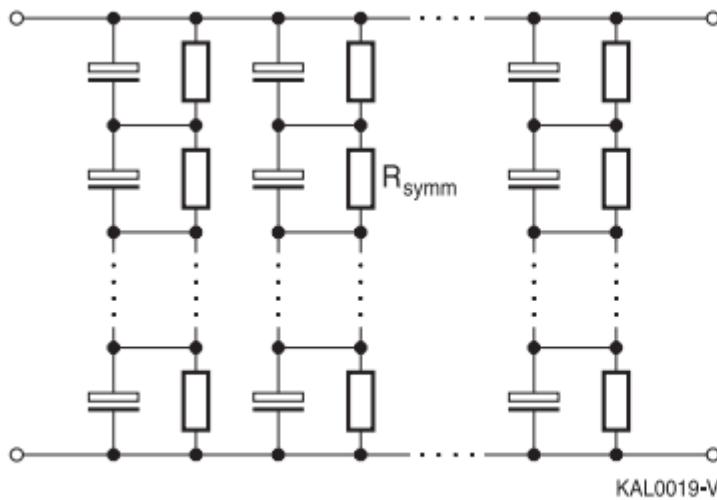


Figure 26  
Combined parallel / series connection  
(voltage balancing by shunt resistors)

The alternative solution, parallel connection of the series capacitors in the individual branch and the use of one balancing resistor for each capacitor group, is shown in figure 27.

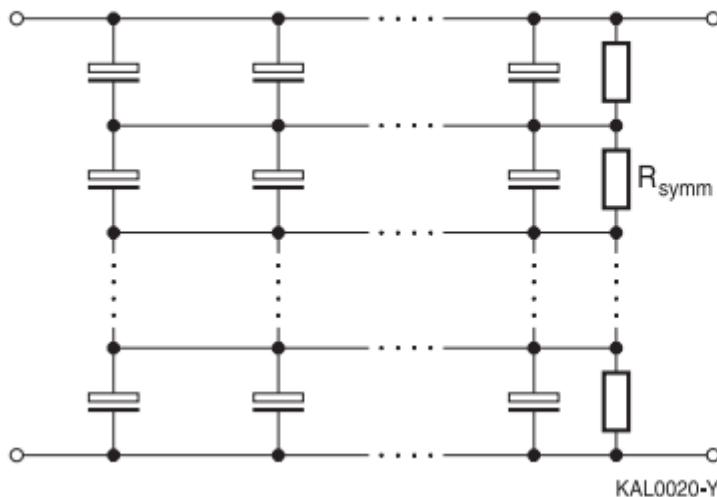


Figure 27  
Combined parallel / series connection (group voltage balancing)

## Capacitores Montagem: Indicação do fabricante

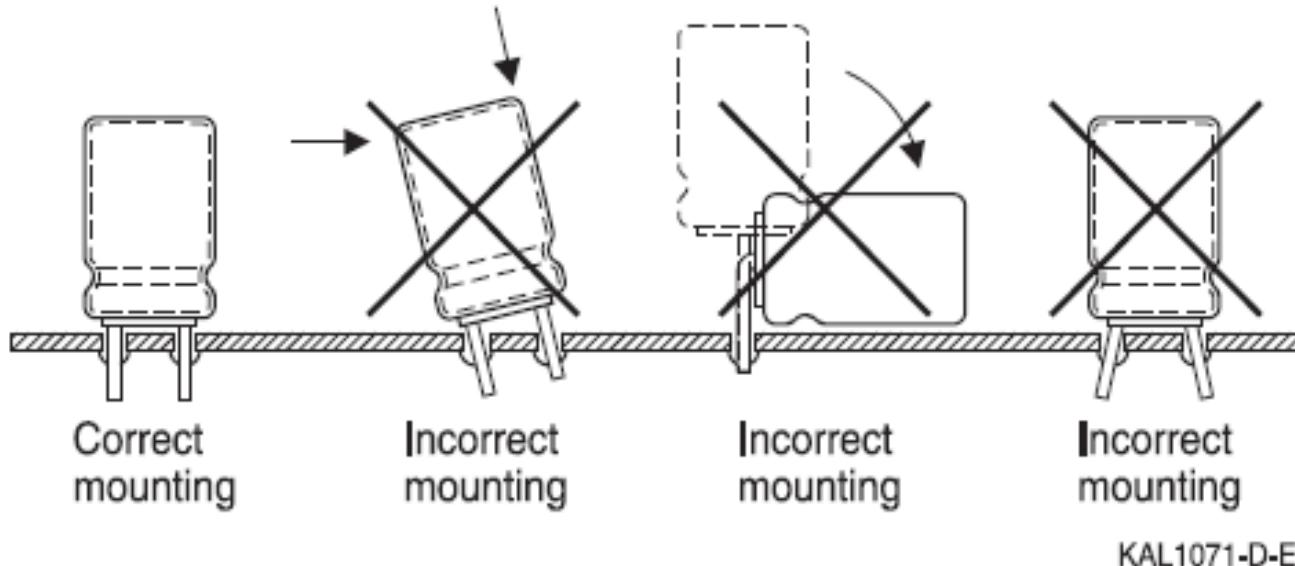


Figure 31  
Mounting considerations for single-ended capacitors

Fonte: EPCOS

## Exemplo de Softwares dedicados:

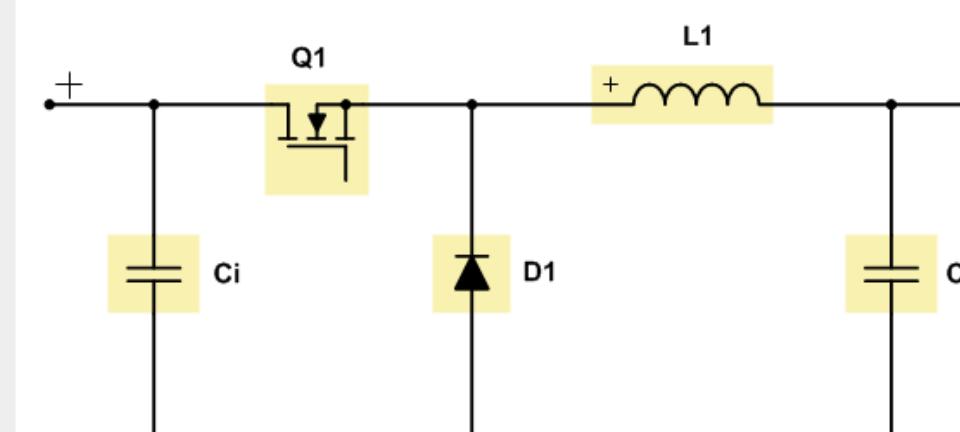
Power Stage Designer™ Tool - Version 3.0 - Buck

File Topology Help

**Design Values**

Minimum Input Voltage:	25 V
Maximum Input Voltage:	42 V
Output Voltage:	3.3 V
Output Current:	1.5 A
Switching Frequency:	500 kHz
Diode Voltage Drop:	0.7 V
Inductor Current Ripple:	25 %

**Circuit Diagram**



**Calculated Values at Input Voltage: 25.00 V**

Period:	2.00 µs	Input Power:	5.84 W	Input Current:	0.23 A
Duty Cycle:	15.56 %	Output Power:	4.95 W	Current Ripple:	0.31 A
On-Time:	0.31 µs	Diode Losses:	0.89 W		20.47 %
Off-Time:	1.69 µs				
Zero-Time:	0.00 µs				

[Check TIDesigns™ Reference Design Library](#)  
[Start WEBENCH® Design](#)

**Info**

**Recommended Value**

Calculated Inductance: 19.33 µH

**Choose Value**

Choose Inductance: 22 µH

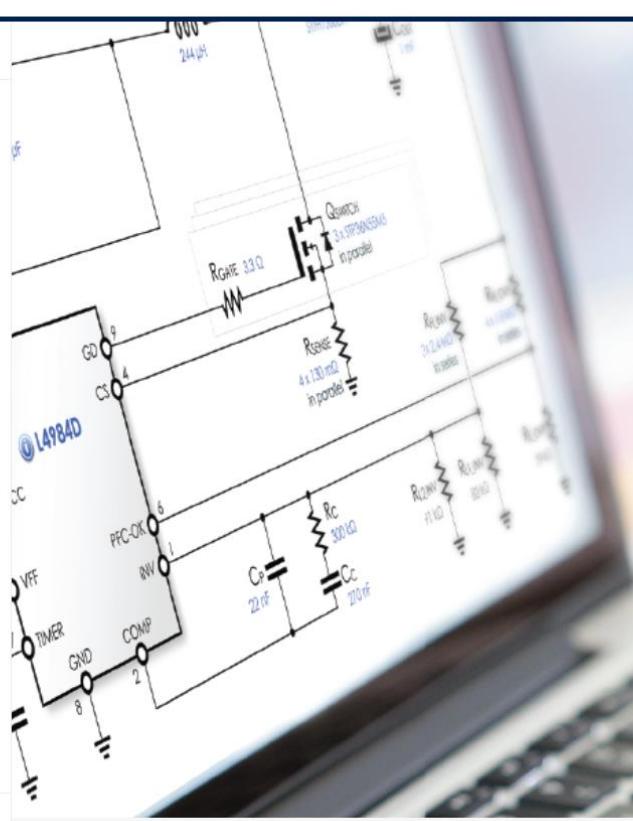
**Logos**



## Resumo do Projeto de Conversores Estáticos:

- ▶ Dimensionar semicondutores e elementos passivos para tolerar o pior situação de trabalho, especificações de projeto com menor custo.
- ▶ **Dimensionamento:**
- ▶ Interruptor: Máxima tensão, corrente média máxima e perdas térmicas.
- ▶ Diodos: Máxima tensão reversa, corrente média e perdas térmicas.
- ▶ Capacitores: Valor da capacitância, tensão máxima, corrente eficaz
- ▶ Indutor: Valor da indutância e corrente máxima eficaz.
- ▶ Transformador: relação de transformação, corrente eficaz no primário e no secundário, potência processada.

# Metodologia de Projetos



The screenshot shows the eDesignSuite software interface. At the top left is the ST logo with the tagline "life, augmented". To its right is the text "eDesignSuite". On the far right are icons for "Previous Version" and a user profile. Below the header is a navigation menu with the following items:

- Dashboard
- Converter
- Battery Charger
- LED Driver
- Photovoltaic
- Signal Conditioning
- RF Design
- AC Control
- Smart Selectors
- Configurators
- Help

The main area displays a detailed circuit diagram for a power converter, specifically an L4984D. The diagram includes various components like resistors (R<sub>GATE</sub> 33Ω, R<sub>SENSE</sub> 4.11Ω, R<sub>C</sub> 330Ω), capacitors (C<sub>G</sub> 22fF, C<sub>c</sub> 270fF), and inductors (L<sub>1</sub> 10μH). A hand is visible on the right side, pointing towards the keyboard of a laptop which is displaying the software interface.

**eDesignSuite**  
The smart design tool

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Fonte: <https://my.st.com/analogsimulator/html/#/home>

# Metodologia de Projetos

Power e SIM  
[www.poweresim.com](http://www.poweresim.com)

Login Eng 漢 汉

Better Than Real - Free Switch Mode Power Supply Circuit (SMPS) Design Software & Transformer Calculation / Simulation Tool.

| About | Free Account | Help Video | Support | Setting | Statistics | Testimonials | Custom Design | PowerEcal

**Start a Design Step by Step** Enter your specification below and press "Recommend Design"

AC Input Vin<sub>max</sub> 240.0 V<sub>rms</sub> Vo<sub>1</sub> 12.0 V  
DC Input Vin<sub>min</sub> 100.0 V<sub>rms</sub> Io<sub>1</sub> 0 A - 4.0 A  
O/P +

Power Supply Application: Adaptor  Recommend Design Recommend Products

**Start a Design from Topology** User can start a design from topologies below [More Topologies ...](#)

- Simple Flyback RCD
- Flyback PWM+S AC/DC
- Flyback Pri-Fb Quick Start
- Emitter Driven Flyback
- RCC Flyback AC/DC
- Pri. FB LED Bulb Driver
- LED Driver with PFC
- PFC CCM AC/DC
- PFC DCM AC/DC
- Interleaved PFC CCM
- Interleaved PFC DCM AC-DC
- Boost DC-DC
- Buck DC-DC
- Buck PNP
- Buck Boost DC-DC
- Buck Sync DC-DC
- Active Clamp AC/DC
- Resonate Reset Foward AC-DC
- Lossless Snubber Forward AC-DC
- LLC AC/DC
- LLC+SR AC/DC
- Full Bridge AC/DC
- Half Bridge AC/DC
- Asym Half Bridge AC/DC
- Phase Bridge AC/DC
- Push Pull AC/DC
- DC-AC H Bridge Inverter
- DC-AC Half Bridge Inverter
- Totem Pole PFC AC/DC
- Interleaved 2W Forward DC-DC
- VRM 1 Phase DC-DC
- Dual Vin Sync-Buck
- DC 1 Lamp Ballast HB Circuit
- DC 2 Lamp Ballast HB Circuit
- Standalone Xformer Design
- [More Topologies ...](#)

More Tools .....  
Transformer Design  
  
Magnetic Builder  


News Last update: 30/1/19 More...  
GET IT ON Google Play Download on the App Store  
• 2019-1-30: ★ New!  
  
New Infineon reference design for Infineon 60W 12V 5V SMPS ICE5QSAG is now open to public.

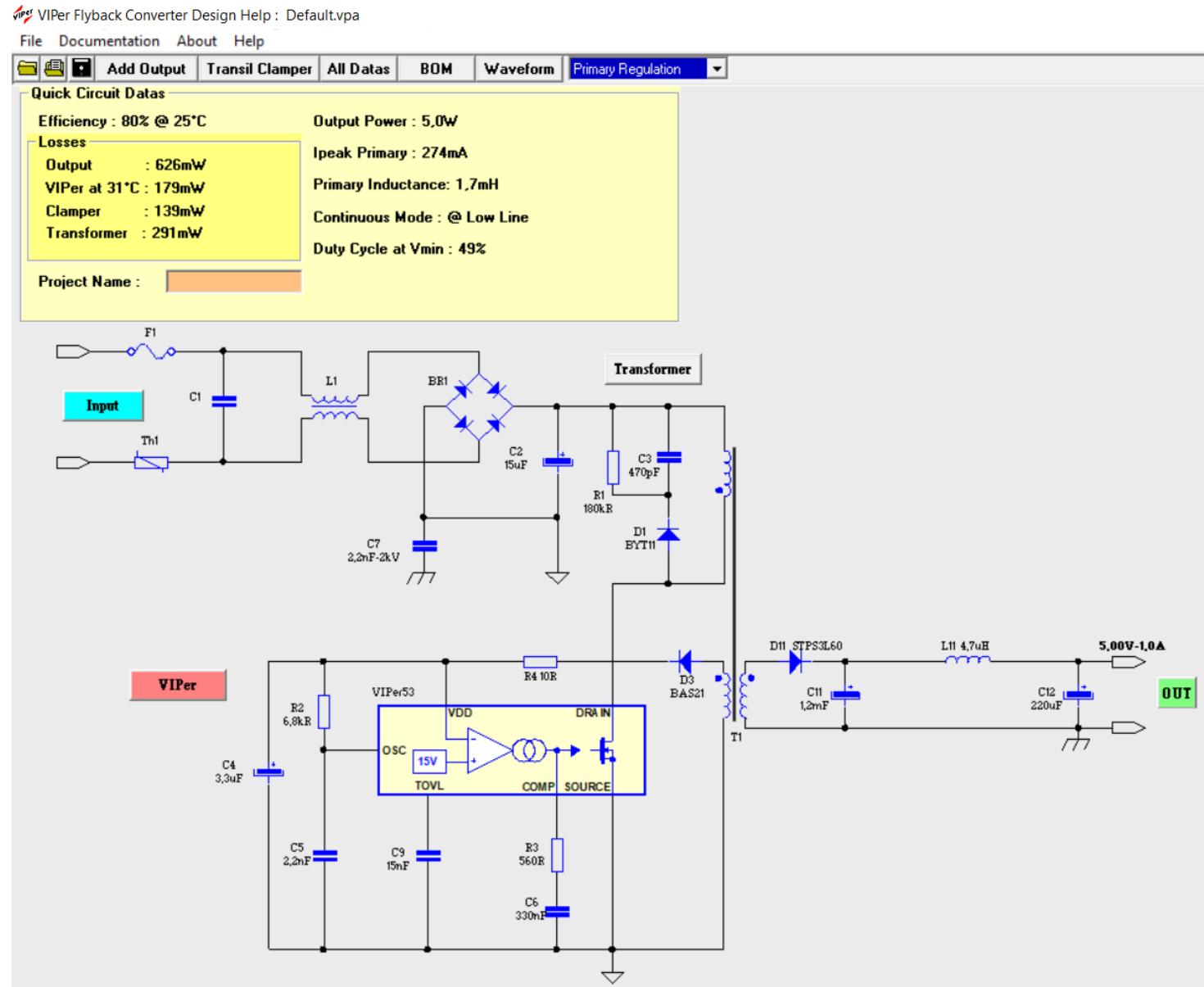
• 2019-1-11: New Interface for waveform monitor.

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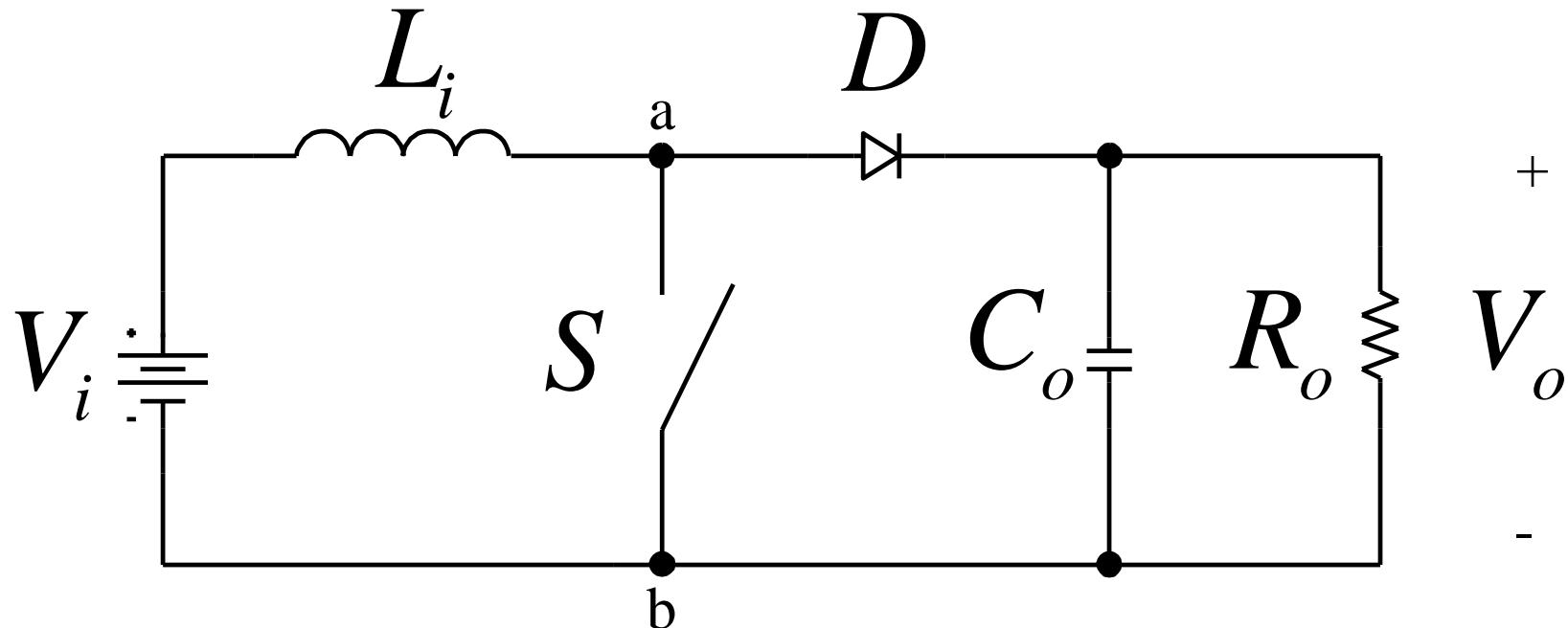
Simulation & Design Counter  
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# Metodologia de Projetos



VIPER - ST

## 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 uH;

# Cálculos Preliminares

---

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:

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

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

# Cálculos Preliminares

---

**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:**

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

# Escolha do transistor



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Automotive System IC	> IGBT
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HIREl	> Linear Voltage Regulator
Microcontroller	> DC-DC Converter
RF & Wireless Control	> Lighting ICs
Security & smart card solutions	> Silicon Carbide (SiC)
Sensor	> High Power Diodes & Thyristors
Interface	> Motor Control & Gate Driver ICs
Transistor & Diode	> AC-DC Power Conversion
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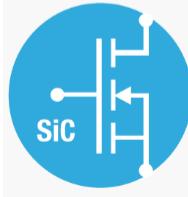
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Home > Power Transistors

## Power Transistors

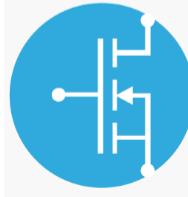
Leading-edge power technologies for both high-voltage and low-voltage applications combined with a full package range and innovative die bonding technologies exemplify ST's innovation in power transistors. Our portfolio includes **MOSFETs** ranging from -500 to 1700 V, **silicon carbide (SiC) MOSFETs** featuring the industry's highest temperature rating of 200 °C, **IGBTs** with breakdown voltages ranging from 300 to 1250 V and a wide range of **power bipolar transistors**.

### Wide bandgap transistors



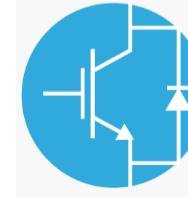
650 and 1200 V SiC MOSFETs featuring the

### Power MOSFETs



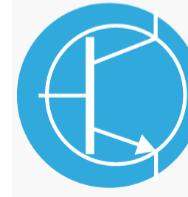
Broad range of breakdown voltages from -500 V to 1700

### IGBTs



Breakdown voltages from 300 to 1250 V. Low V<sub>CE(on)</sub>

### Power Bipolar



The range includes Darlington transistors and

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## Discretes

Fairchild's discrete portfolio spans from high voltage to small signal devices addressing system needs from the smallest mobile devices to full scale industrial applications. Our discrete products include field effect (FET) and bipolar (BJT) transistors, IGBTs, and a broad selection of diodes and rectifiers and circuit protection devices.

Fairchild has had a long history of innovation and leadership in both low voltage and high voltage MOSFET technologies. We are currently on our 10th generation of PowerTrench® devices with industry leading R<sub>DS(on)</sub> and power density. With a focus on switch mode power supplies, our IGBTs and diodes are specifically designed to be the fastest and most efficient in the market.

Our unique position of providing both a full range of discrete products and leading edge power management ICs allows Fairchild to address a wide variety of critical application requirements and provide a total solution.

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[Bipolar Transistors \(579\)](#)

[Diodes & Rectifiers \(1044\)](#)

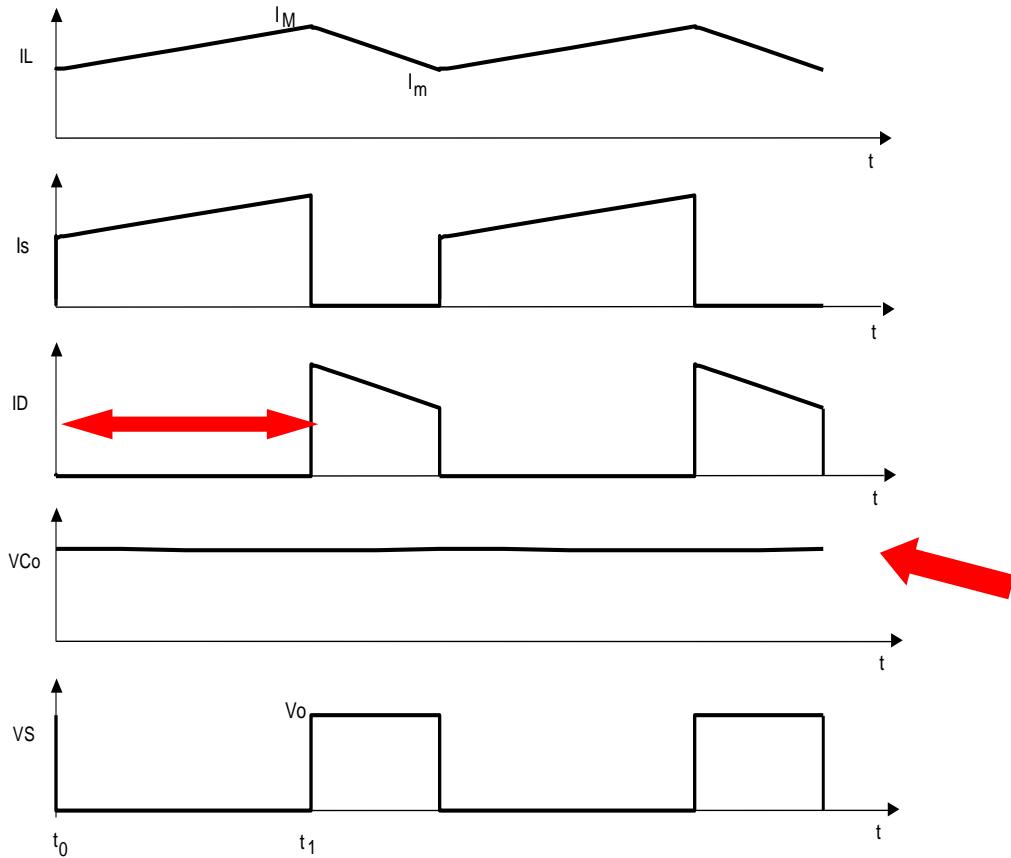
[IGBTs \(152\)](#)

[FETs \(1609\)](#)

[Circuit Protection \(345\)](#)

# Conversor CC-CC elevador - Boost

## Análise das grandezas envolvidas



## Tensão no capacitor

$i_C \approx I_{out}$  p/ primeira etapa

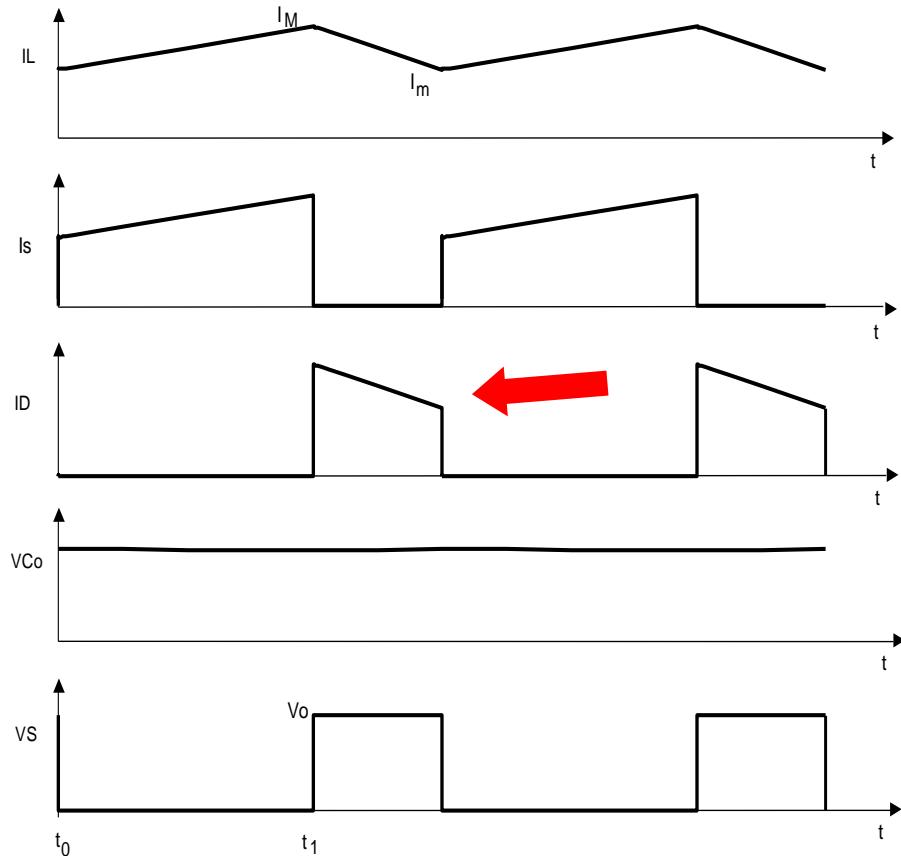
$$I_{out} = Co \cdot \frac{\Delta V_{Co}}{\Delta t}$$

$$\Delta V_{Co} = \frac{I_{out} \cdot \Delta t}{Co} = \frac{I_{out} \cdot D}{Co \cdot f}$$

$$\Delta V_{Co} = \frac{I_o}{C_o \cdot f} \cdot \frac{V_o - V_i}{V_o}$$

# Conversor CC-CC elevador - Boost

## Análise das grandezas envolvidas



## Tensão no capacitor Efeito da RSE

$$V_{RSE} = RSE \cdot i_{D_{CA}} = RSE \cdot i_{Co}$$

$$P_{RSE} = RSE \cdot i_{D_{CAef}}^2 = RSE \cdot i_{Co}^2$$

# Cálculos Preliminares

$$\Delta V_{Co} = \frac{I_o}{C_o \cdot f} \cdot \frac{V_o - V_i}{V_o}$$



$$C_o = \frac{I_o}{\Delta V_{Co} \cdot f} \cdot \frac{V_o - V_i}{V_o}$$

**Cálculo do capacitor mínimo:**

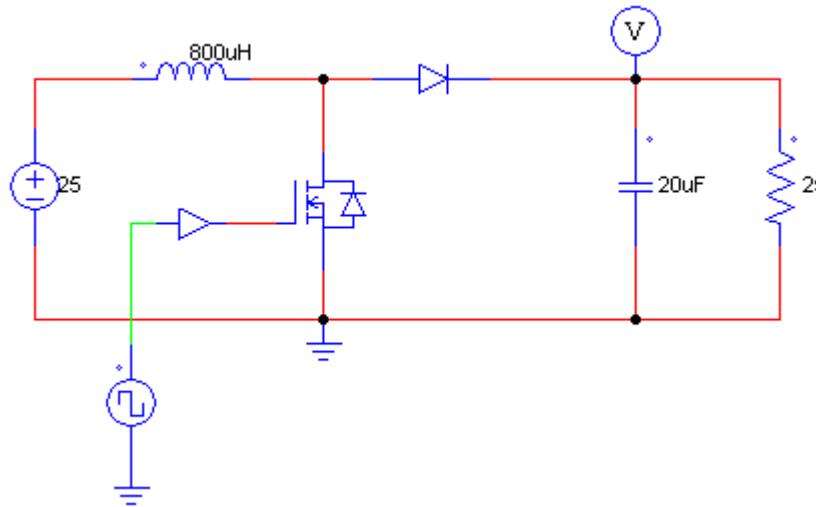
$$\Delta V_{Co} = 0,05 \cdot V_o = 0,05 \cdot 50 = 2,5 \text{ V}$$

$$C_o = \frac{I_o}{\Delta V_{Co} \cdot f} \cdot \frac{V_o - V_i}{V_o} = \frac{2}{2,5 \cdot 20k} \cdot \frac{50 - 25}{50} = 20 \mu F$$

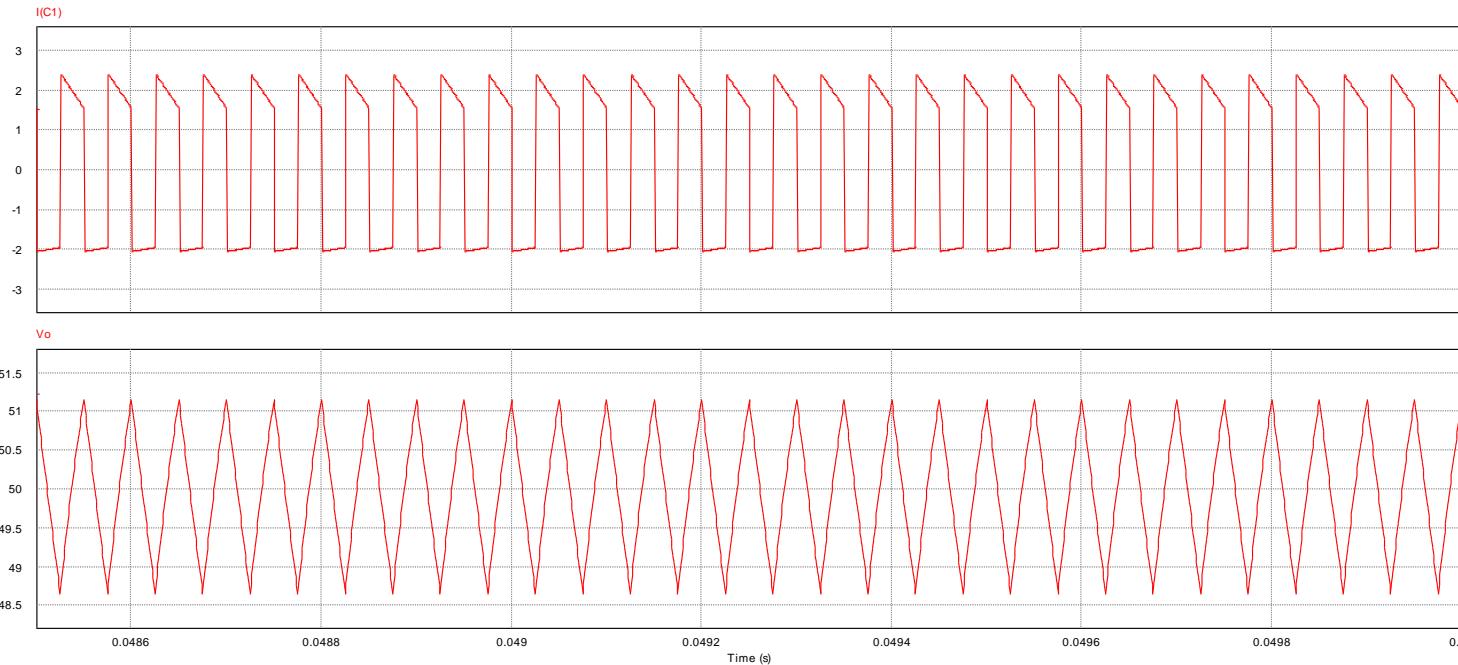
$$V_{Co} = V_o = 50 \text{ V}$$

$$I_{Co} = I_o \cdot \sqrt{\frac{D}{1-D}} = 2 \cdot \sqrt{\frac{0,5}{1-0,5}} = 2 \text{ A}$$

# Simulação

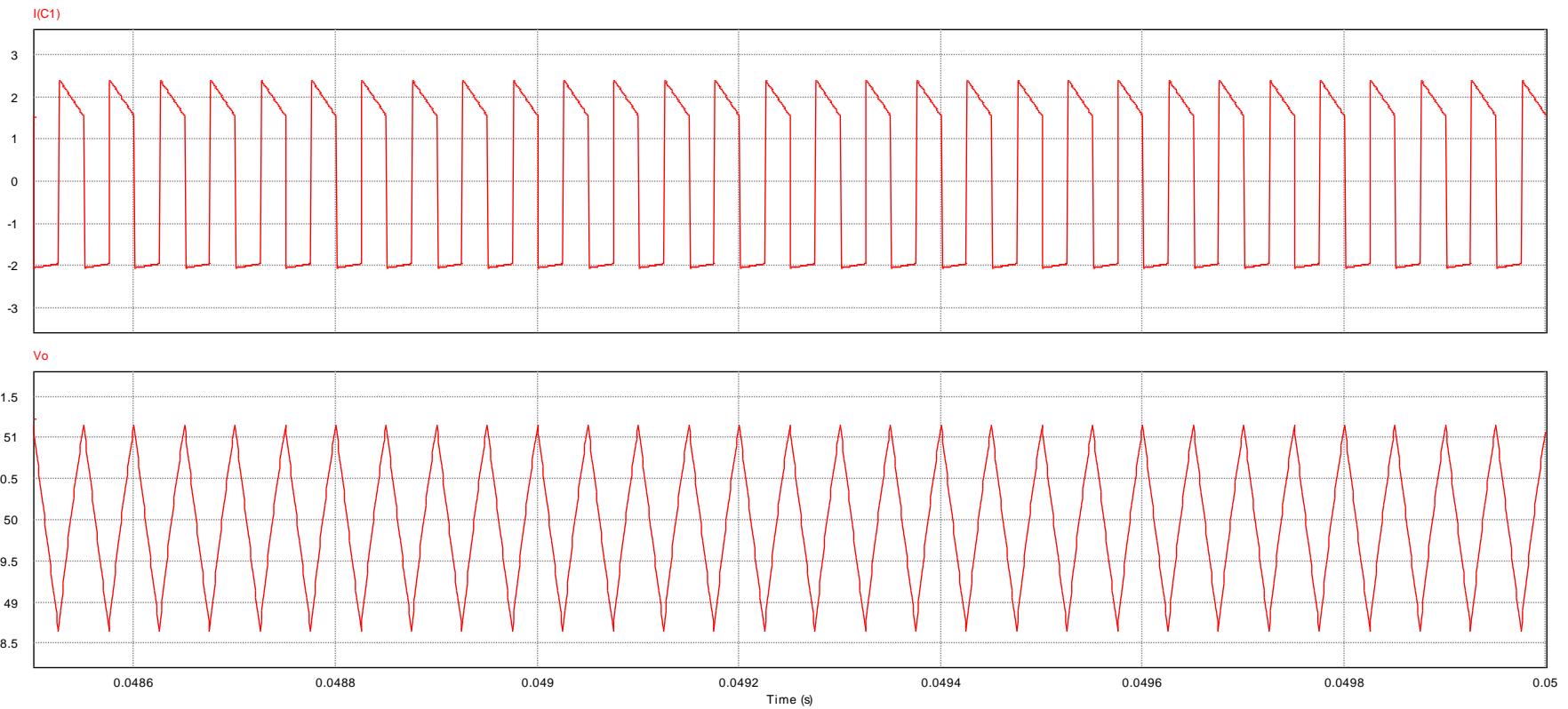


Corrente no Capacitor



Tensão no capacitor

# Simulação



$$RSE = 0 \Omega$$

Valor da Tensão Média de Saída

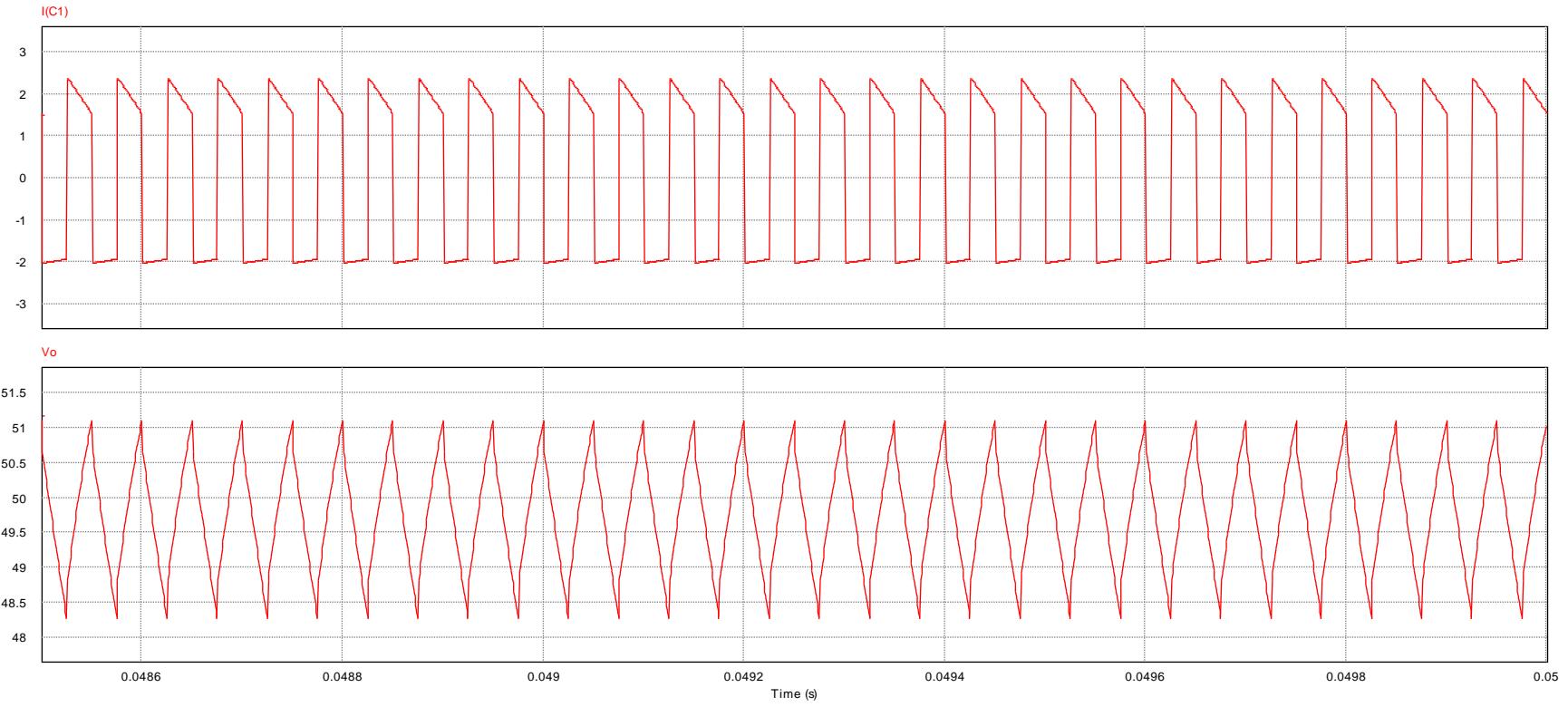
$$V_o = 50 \text{ V}$$

$$I_{Co} = 2 \text{ A (rms)}$$

$$\Delta I_{Co} = 4,5 \text{ A}$$

$$\Delta V_{Co} = 2,5 \text{ V}$$

# Simulação



$$RSE = 0,1\Omega$$

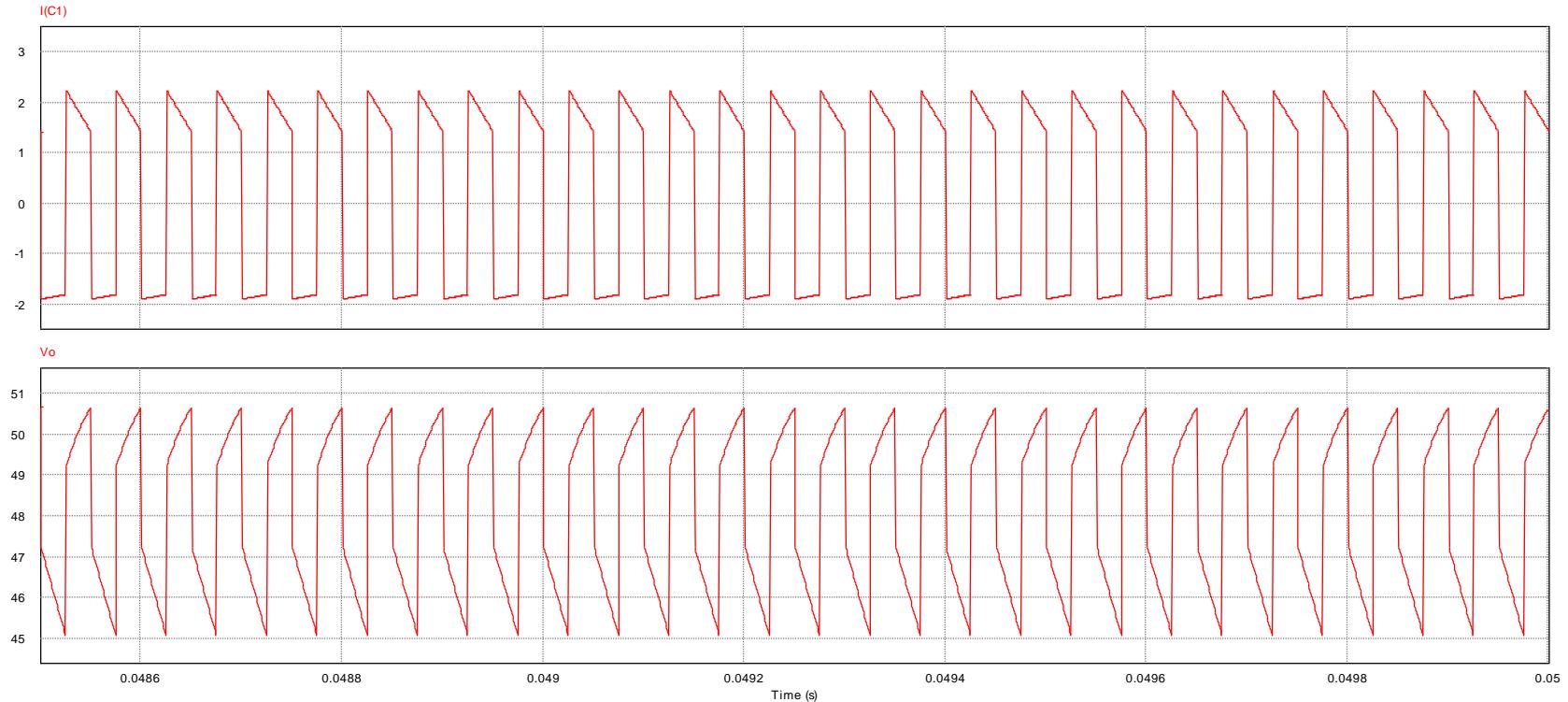
$$I_{Co} = 1,98 \text{ A (rms)}$$

Valor da Tensão Média de Saída

$$V_o = 49,75 \text{ V}$$

$$\Delta V_{Co} = 2,83 \text{ V}$$

# Simulação



$$RSE = 1\Omega$$

$$I_{Co} = 1,85 \text{ A (rms)}$$

Valor da Tensão Média de Saída

$$V_o = 48 \text{ V}$$

$$\Delta V_{Co} = 5,5 \text{ V}$$

# Escolha do Capacitor

$$I_{Co} = 2 \text{ A (rms)} \quad C_o = 20 \mu\text{F} \quad V_{Co} = 50 \text{ V} \quad f = 20 \text{ kHz}$$

$$\Delta V_{RSE} = RSE \cdot \Delta I_{Co}$$

RSE<sub>max</sub> =  $\frac{0,2 \cdot \Delta V_{Co}}{\Delta I_{Co}} = \frac{0,50}{4} = 0,125 \Omega$

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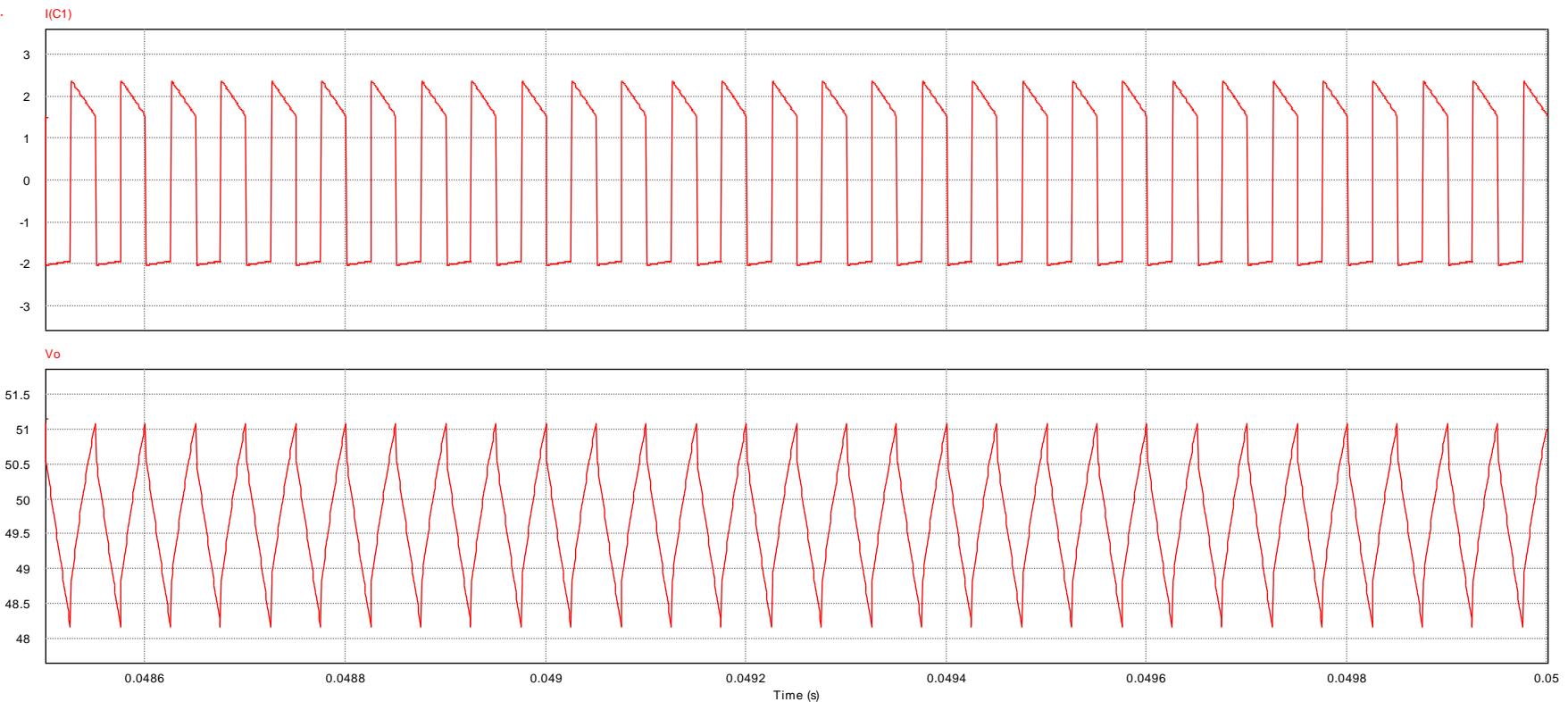
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# Simulação



$$RSE = 0,125 \Omega$$

$$I_{Co} = 1,975 \text{ A (rms)}$$

Valor da Tensão Média de Saída

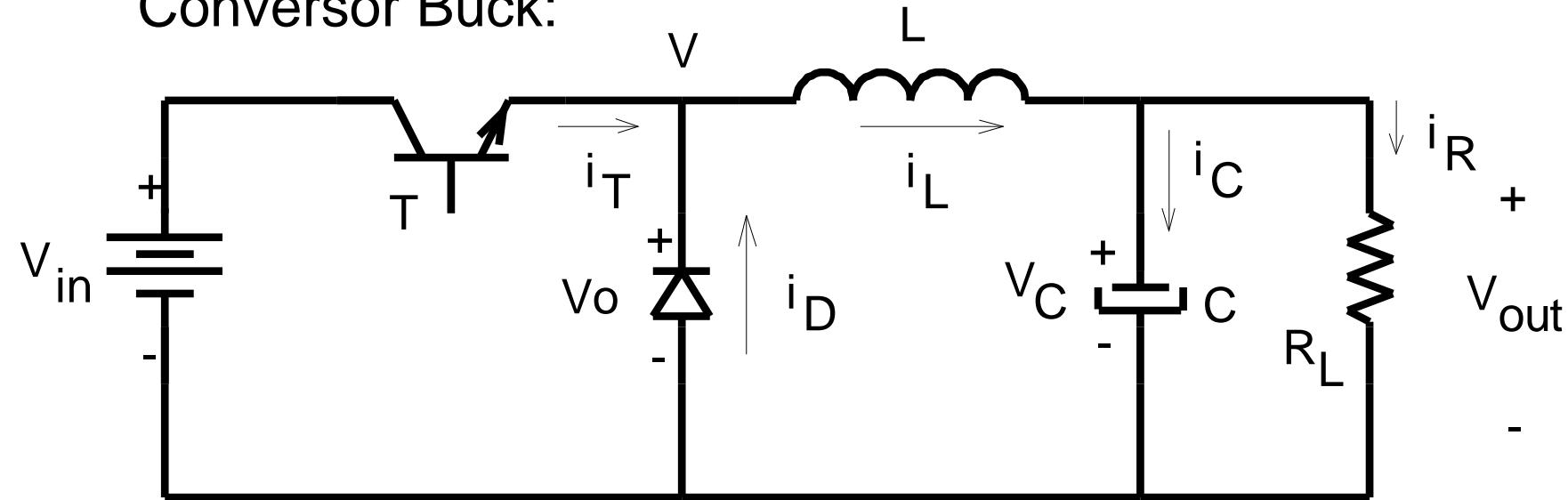
$$V_o = 49,7 \text{ V}$$

$$\Delta V_{Co} = 2,9 \text{ V}$$

$$\Delta I_{Co} = 4,39 \text{ A}$$

# Tarefa 2

## Conversor Buck:



### Especificação:

Tensão de Entrada: 36 V

Tensão de Saída: 12 V

Frequência de comutação: 50 kHz;

Indutância L: 100 uH

Potência: 100 W;

### Especificar:

- Díodo, transistor e capacitor
- Calcular Perdas no transistor
- Especificar um dissipador