




Cálculo e Projeto de Dissipadores de Calor para Diodos e Tiristores


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Geração de Calor



Diodo: $P = V_{(TO)} \cdot I_{FAV} + r_T \cdot I_{FRMS}^2 + \frac{f}{2} \cdot t_{rr} \cdot I_{RM} \cdot V_D$



Tiristor: $P = V_{(TO)} \cdot I_{FAV} + r_T \cdot I_{FRMS}^2 + \frac{f}{2} \cdot t_{rr} \cdot I_{RM} \cdot V_D$

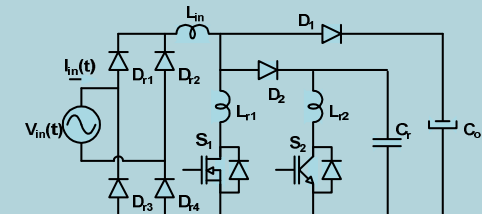
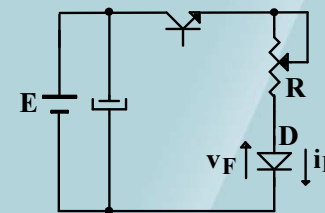
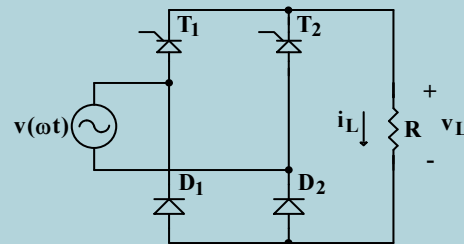
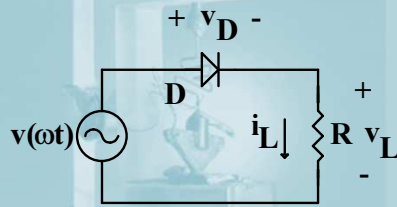
Simbologia
SEMIKRON


GTO: $P = V_{(TO)} \cdot I_{FAV} + r_T \cdot I_{FRMS}^2 + \text{Parcela não linear multi-parâmetros}$


BJT: $P = V_{CE(Sat)} \cdot I_{Cmed} + \left(\frac{f}{2} \cdot V_{CE(off)} \cdot I_{Cef} \cdot (t_{ri} + t_{fv} + t_{rv} + t_f) \right) + r_{CE(Sat)} \cdot I_{Cef}^2$



MOSFET: $P = (R_{DS(on)} \cdot I_{ef}^2 + V_{SD} \cdot \bar{I}_D) + \left(\frac{f}{2} \cdot V_{DS(off)} \cdot I_{ef} \cdot (t_{on} + t_{off}) \right)$


IGBT: $P = V_{CE(Sat)} \cdot I_{Cmed} + \left(\frac{f}{2} \cdot V_{CE(off)} \cdot I_{Cef} \cdot (t_{on} + t_{off}) \right) + r_{CE(Sat)} \cdot I_{Cef}^2$







Geração de Calor

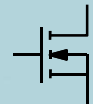

Diodo: $P = V_{(TO)} \cdot I_{FAV} + r_T \cdot I_{FRMS}^2 + \frac{f}{2} \cdot t_{rr} \cdot I_{RM} \cdot V_D$


Simbologia
SEMIKRON

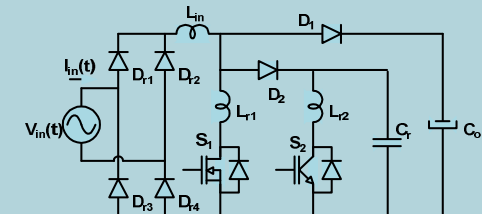
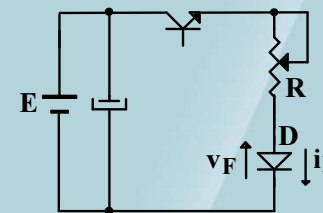
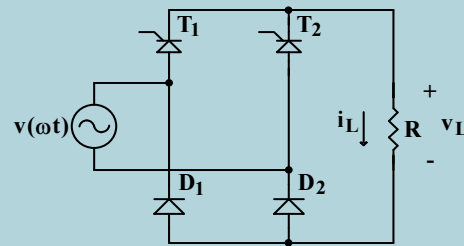
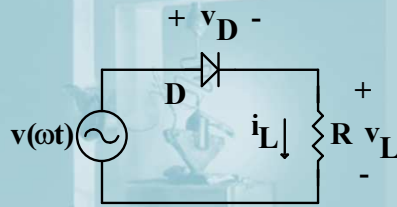

Tiristor: $P = V_{(TO)} \cdot I_{FAV} + r_T \cdot I_{FRMS}^2 + \frac{f}{2} \cdot t_{rr} \cdot I_{RM} \cdot V_D$


GTO: $P = V_{(TO)} \cdot I_{FAV} + r_T \cdot I_{FRMS}^2 + \text{Parcela não linear multi-parâmetros}$


BJT: $P = V_{CE(Sat)} \cdot I_{Cmed} + \left(\frac{f}{2} \cdot V_{CE(off)} \cdot I_{Cef} \cdot (t_{on} + t_{off}) \right) + \text{Parâmetros Normalmente Inexistentes}$


MOSFET: $P = (R_{DS(on)} \cdot I_{ef}^2 + V_{SD} \cdot \bar{I}_D) + \left(\frac{f}{2} \cdot V_{DS(off)} \cdot I_{ef} \cdot (t_{on} + t_{off}) \right)$


IGBT: $P = V_{CE(Sat)} \cdot I_{Cmed} + \left(\frac{f}{2} \cdot V_{CE(off)} \cdot I_{Cef} \cdot (t_{on} + t_{off}) \right) + \text{P.N.I.}^2_{Cef}$





IGBT

▶ Diodo

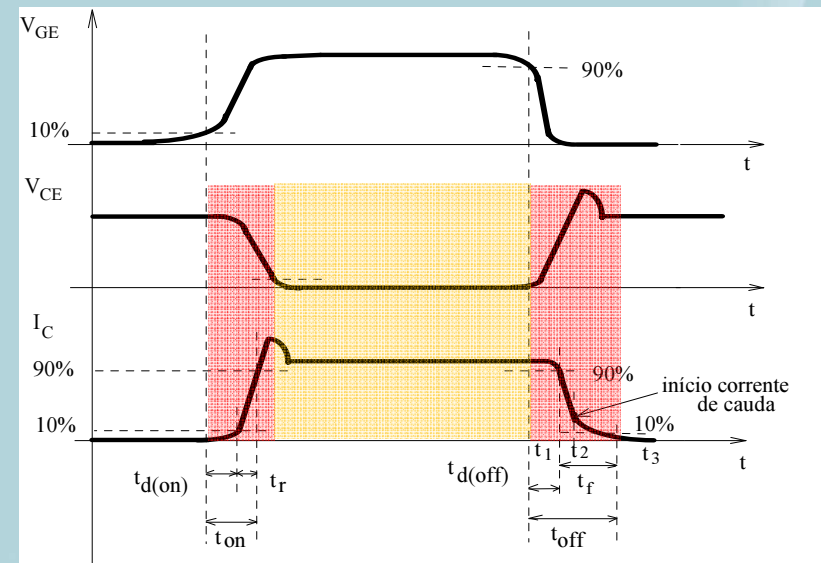
▶ Tiristor

▶ GTO

▶ BJT

▶ MOSFET

▶ **IGBT:**



Perdas em Condução

Perdas na Comutação

$$P = V_{CE(Sat)} \cdot I_{Cmed} + \left(\frac{f}{2} \cdot V_{CE(off)} \cdot I_{Cef} \cdot (t_{on} + t_{off}) \right)$$

MOSFET



‡ Diodo

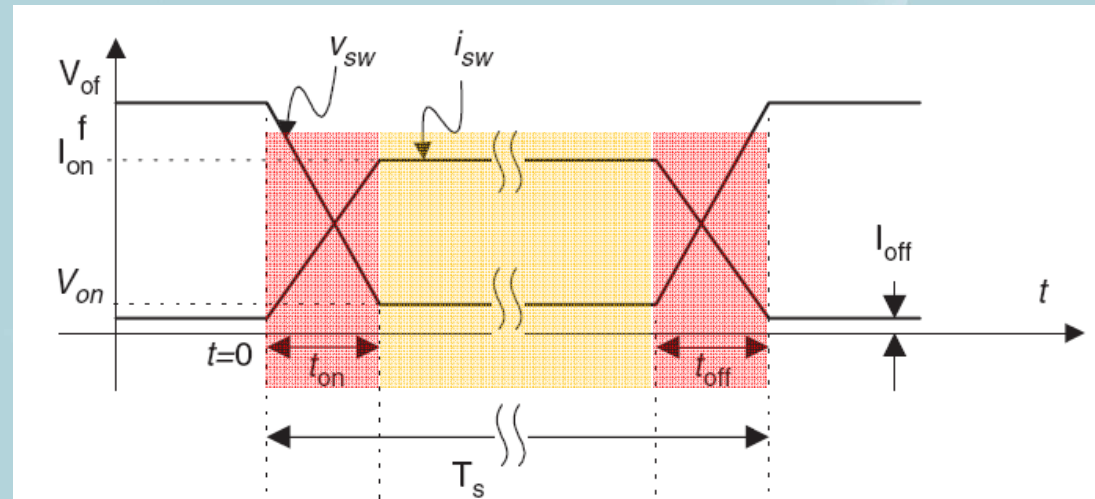
‡ Tiristor

‡ GTO

‡ BJT

‡ **MOSFET**

‡ IGBT



Perdas em Condução

Perdas na Comutação

$$P = \left(R_{DS(on)} \cdot I_{ef}^2 + V_{SD} \cdot \bar{I}_D \right) + \left(\frac{f}{2} \cdot V_{DS(off)} \cdot I_{ef} \cdot (t_{on} + t_{off}) \right)$$

Transistor de Junção Bipolar

BJT



‡ Diodo

‡ Tiristor

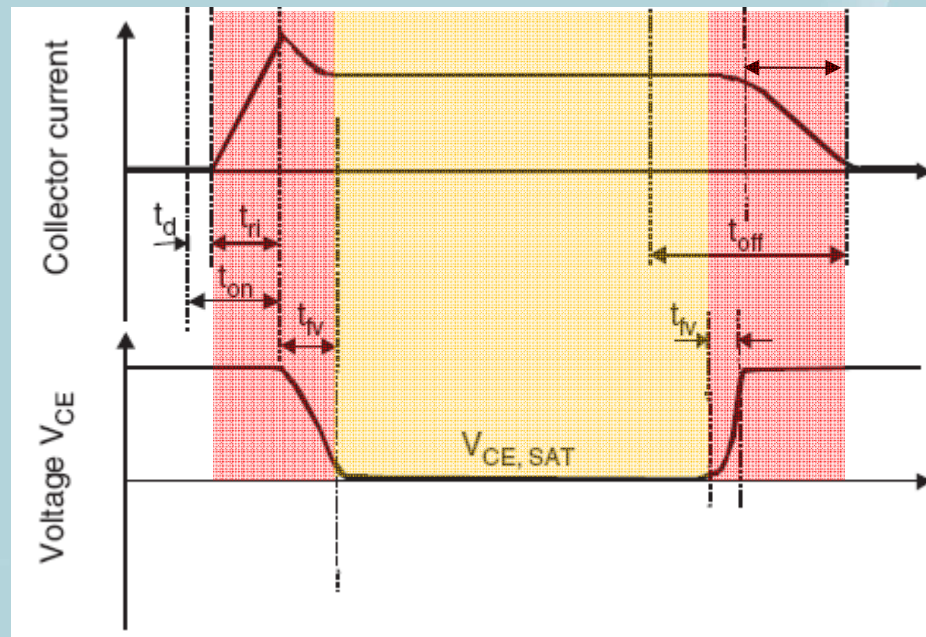
‡ GTO

‡ **BJT**

‡ MOSFET

‡ IGBT

Parcelas Normalmente Insignificantes



$$P = V_{CE(Sat)} \cdot I_{Cmed} + \left(\frac{f}{2} \cdot V_{CE(off)} \cdot I_{Cef} \cdot (t_{ri} + t_{fv} + t_{rv} + t_f) \right)$$

Trabalhando de Forma Chaveada

GTO



‡ Diodo

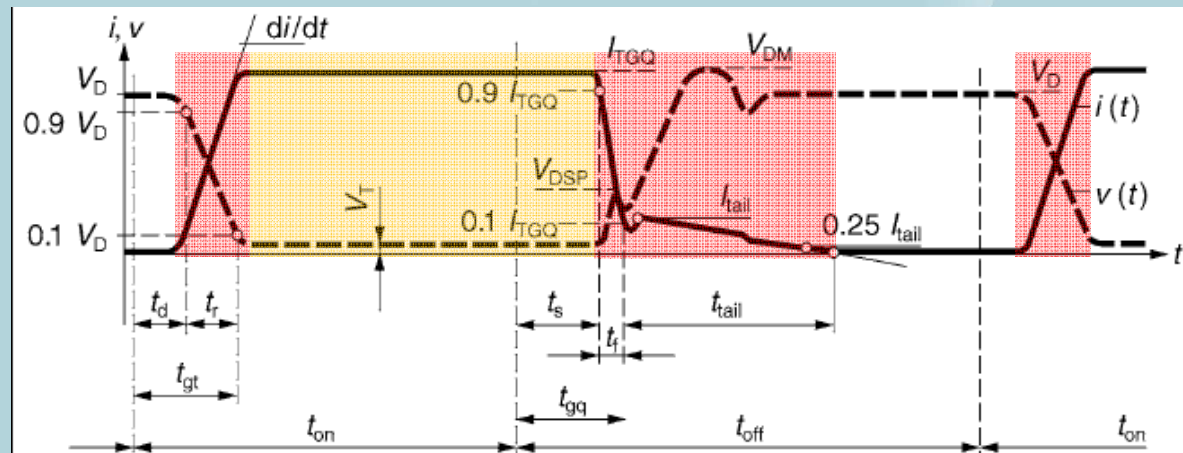
‡ Tiristor

‡ **GTO**

‡ BJT

‡ MOSFET

‡ IGBT



Perdas em Condução

Perdas na Comutação

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

Gráficos e Equações mais elaboradas



Diodo e Tiristor

 **Diodo**

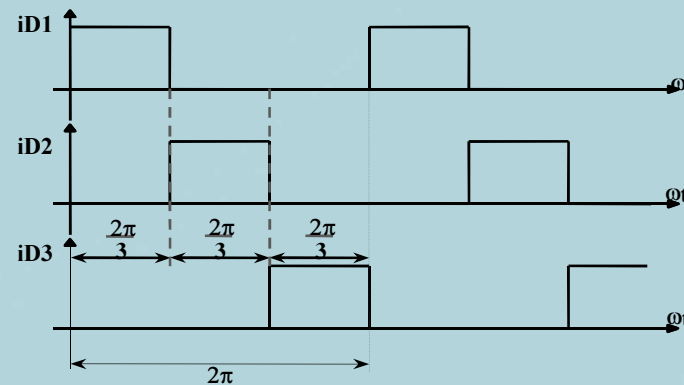
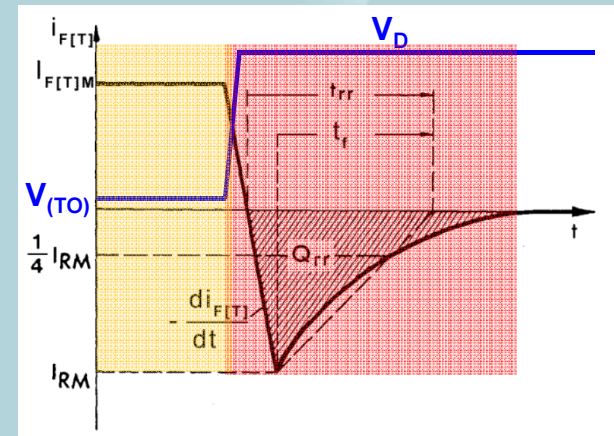
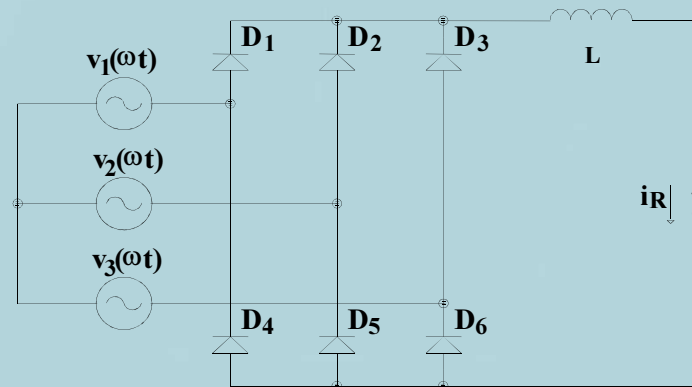
 **Tiristor**

 **GTO**

 **BJT**

 **MOSFET**

 **IGBT**



Perdas em Condução

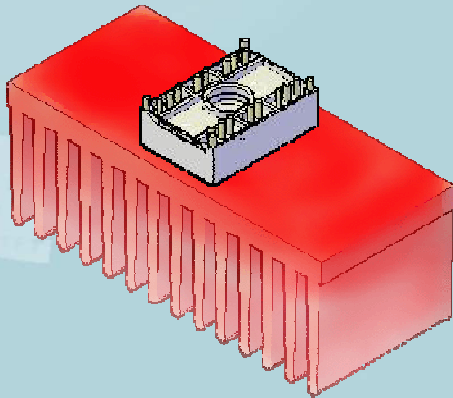
Perdas na Comutação

$$P = V_{(TO)} \cdot I_{FAV} + r_T \cdot I_{FRMS}^2 + \frac{f}{2} \cdot t_{rr} \cdot I_{RM} \cdot V_D$$

Modelos para Cálculo Térmico de Semicondutores

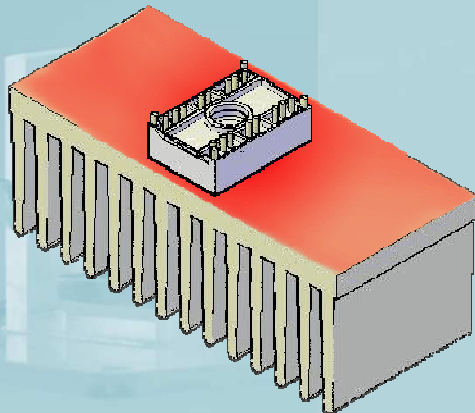


Modelo para Regime Permanente



Temperatura no conjunto semiconductor
+ dissipador **não varia.**

Modelo para Regime Transitório

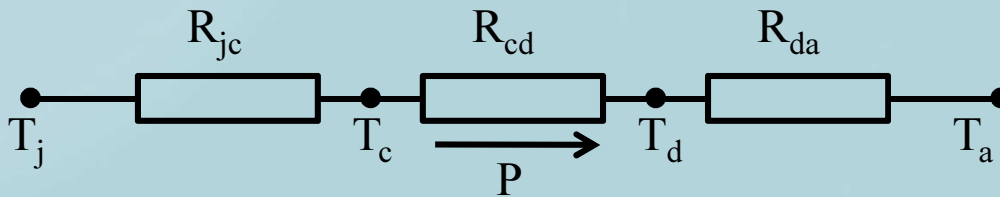


Temperatura no conjunto semiconductor
+ dissipador **varia.**

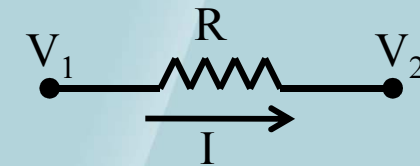
Modelo para Regime Permanente



Modelo utilizando analogia à circuitos elétricos



$$T_j - T_a = (R_{jc} + R_{cd} + R_{da}) \cdot P$$



$$V_1 - V_2 = R \cdot I$$

T_j : Temperatura de junção (°C) – **Dado do fabricante Usualmente 125°C**;

T_c : Temperatura da cápsula (°C);

T_d : Temperatura do dissipador (°C);

T_a : Temperatura ambiente (°C);

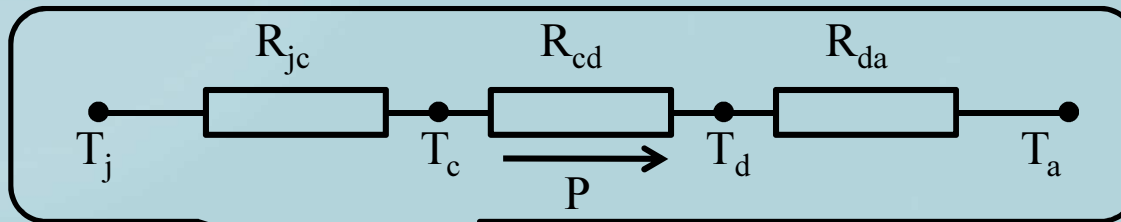
R_{jc} : Resistência térmica junção-cápsula (°C/W);

R_{cd} : Resistência térmica cápsula-dissipador (°C/W);

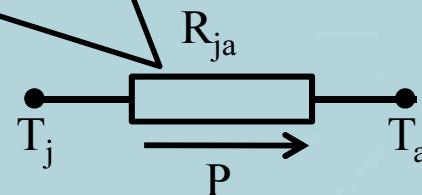
R_{da} : Resistência térmica dissipador-ambiente (°C/W);

P : Potência térmica que flui da junção para o ambiente (W).

Modelo para Regime Permanente



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

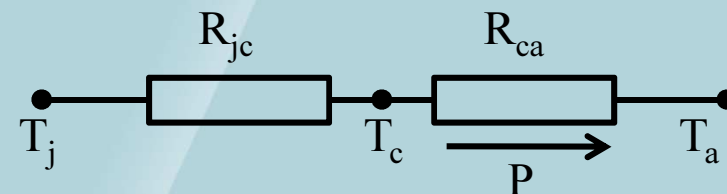
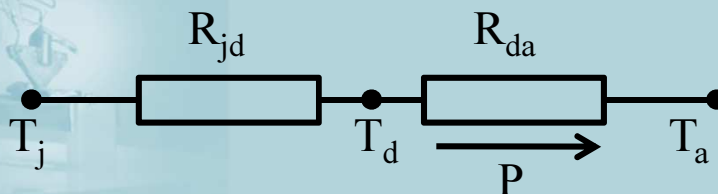


$$R_{ja} = R_{jc} + R_{cd} + R_{da}$$

R_{ja} : Resistência térmica junção-ambiente ($^{\circ}\text{C}/\text{W}$);

R_{jd} : Resistência térmica junção-dissipador ($^{\circ}\text{C}/\text{W}$);

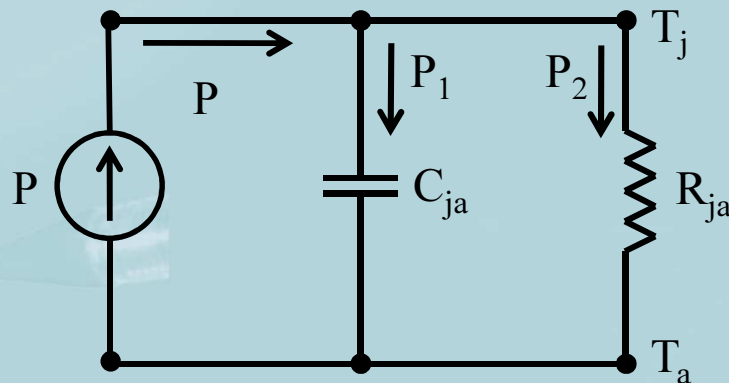
R_{ca} : Resistência térmica cápsula-ambiente ($^{\circ}\text{C}/\text{W}$);



Modelo para Regime Transitório



Modelo utilizando analogia à circuitos elétricos



$$P = P_1 + P_2$$

$$R_{ja} \cdot P_2 = \frac{1}{C_{ja}} \int P_1 \cdot dt = T_j - T_a = \Delta T$$

$$\frac{P}{R_{ja} \cdot C_{ja}} = \frac{dP_2}{dt} + \frac{P_2}{R_{ja} \cdot C_{ja}}$$

Fornecido pelo fabricante

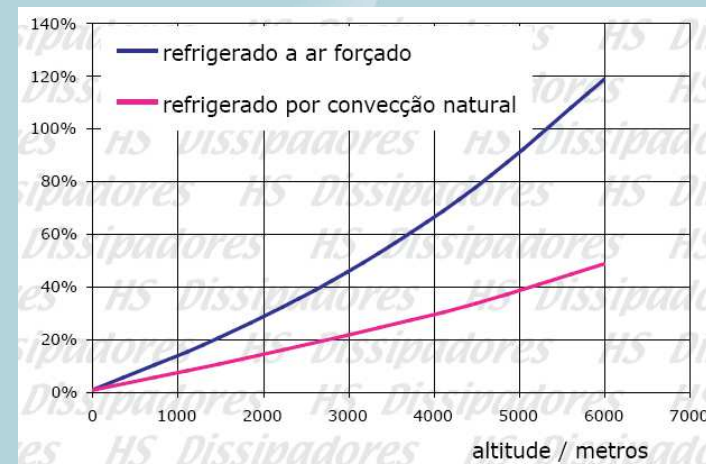
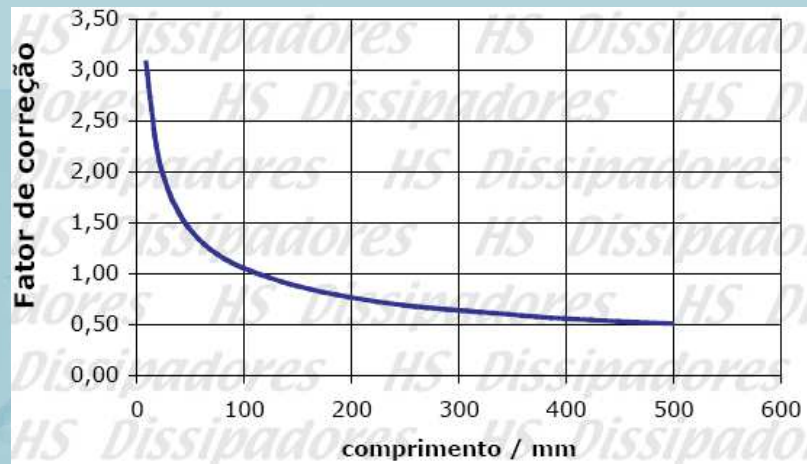
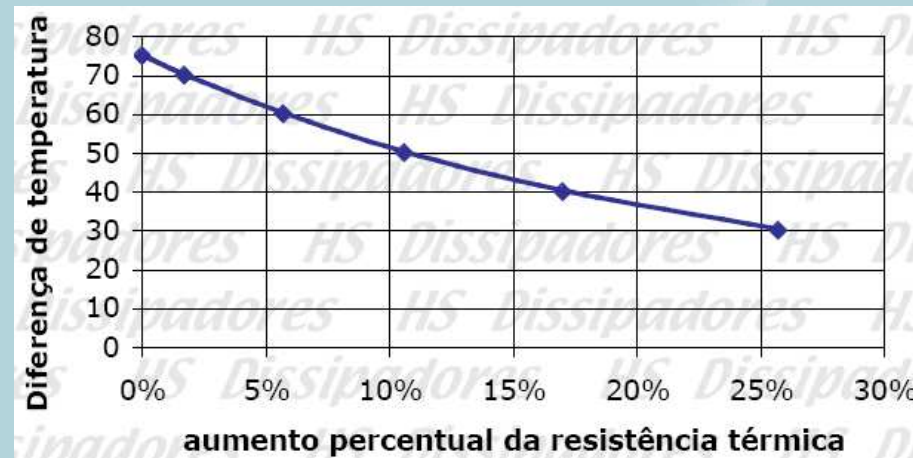
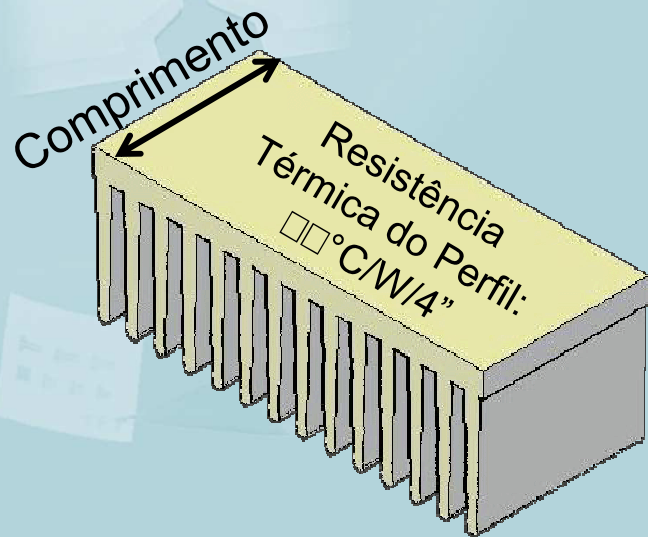
Z_t : Impedância térmica ($^{\circ}\text{C}/\text{W}$);

ΔT : Variação de Temperatura ($^{\circ}\text{C}$);

Resolvendo por Laplace e Manipulando

$$\frac{\Delta T}{P} = R_{ja} \cdot \left(1 - e^{-\frac{t}{R_{ja} \cdot C_{ja}}} \right) = Z_t$$

Característica dos Dissipadores



Metodologia de Projeto



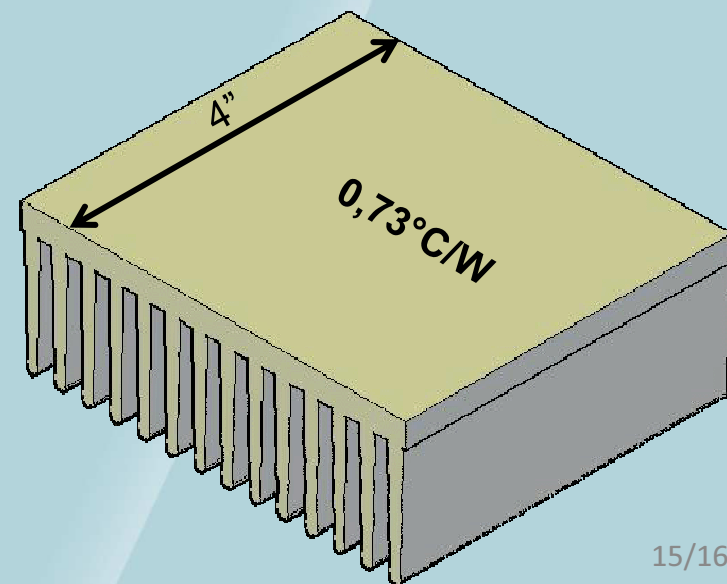
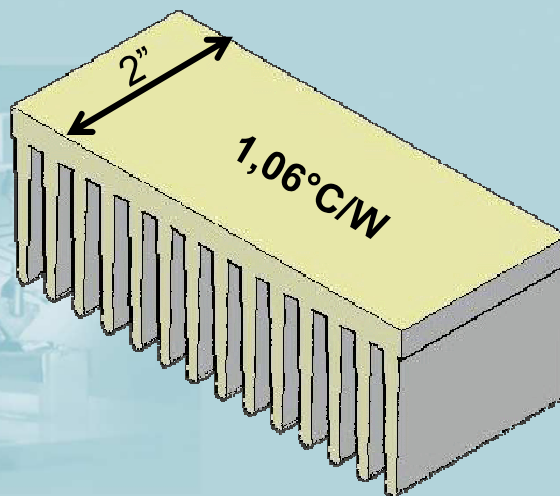
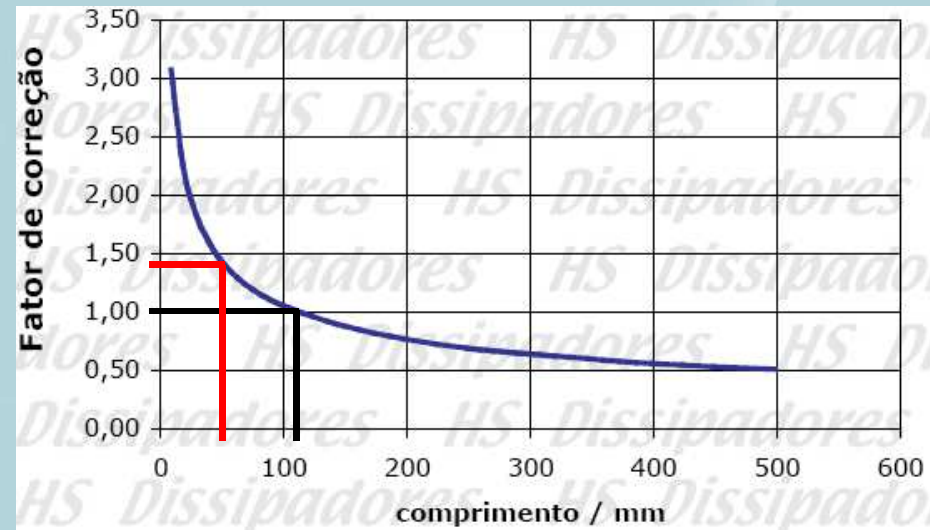
- Calcula-se a potência média dissipada no semicondutor;
- Em função dos parâmetros de catálogo fornecidos pelo fabricante, calcula-se a resistência térmica dissipador-ambiente para que a temperatura de junção não ultrapasse o valor desejado;
- **A resistência térmica do dissipador deve ser menor que a calculada.**
 - Calcula-se um R_{da} utilizando um dissipador com R_{da} exatamente igual: $T_j = (R_{jc} + R_{cd} + R_{da}) \cdot P + T_a$ **Obtém-se uma T_j .**
 - Com R_{da} maior (R_{da+}): $T_{j+} > T_j$
 - Com R_{da} menor (R_{da-}): $T_{j-} < T_j$

Metodologia de Projeto



Resistência Térmica do Perfil:
 $0,73^{\circ}\text{C/W/4}''$

$$R_{da} \cong \sim 1,45 \cdot 0,73 = 1,06^{\circ}\text{C/W}$$



Exemplo de Projeto



$$v(\omega t) = \sqrt{2} \cdot 220 \cdot \text{sen}(\omega t)$$

$$f = 60\text{Hz}$$

$$R = 10\Omega$$

$$D = \text{SKN20/04}$$

$$R_{jc} = 2^\circ\text{C/W} (R_{thjc})$$

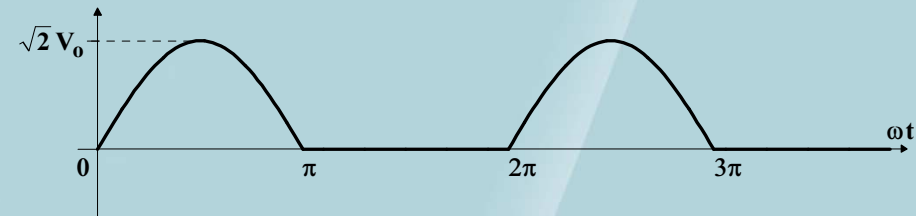
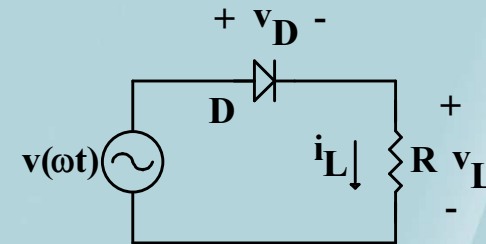
$$R_{cd} = 1^\circ\text{C/W} (R_{thcs})$$

$$T_j = 180^\circ\text{C}$$

$$V_{(TO)} = 0,85\text{V}$$

$$r_T = 11\text{m}\Omega$$

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



$$I_{Dmed} = \frac{0,45V_o}{R} = \frac{0,45 \cdot 220}{10} = 9,9\text{A}$$

$$I_{Def} = \frac{0,707V_o}{R} = \frac{0,707 \cdot 220}{10} = 15,55\text{A}$$

$$P = V_{(TO)} I_{Dmed} + r_T I_{Def}^2 \Rightarrow P = 0,85 \cdot 9,9 + 11 \cdot 10^{-3} \cdot (15,55)^2 = 11,07\text{W}$$

$$\Delta T = P(R_{jc} + R_{cd} + R_{da}) \Rightarrow R_{da} = \frac{130}{11} - 3 \cong 8,82^\circ\text{C/W}$$

$$R_{da} (\text{dissipador}) < 8,82^\circ\text{C/W}$$

Exercícios

