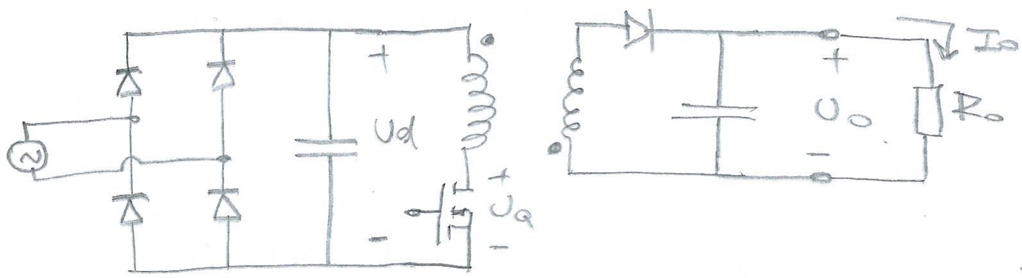
Examen de Electrónica de Potencia - Diciembre 2018

Solución Problema 2



$U_o = 24V$

$I_{omáx} = 5A$

$f = 100kHz$

$\delta \to 0{,}12 \to 0{,}60$

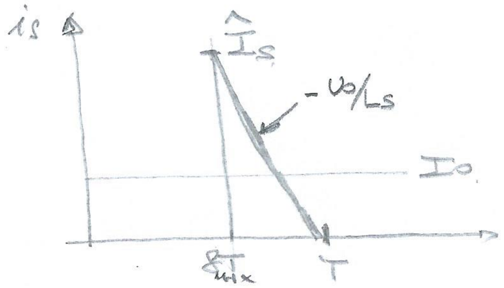
$T_{amáx} = 40C$

$U_{dmáx} = \sqrt{2} \cdot 230 \cdot 1{,}2 = 390{,}32V$

$U_{dmín} = \sqrt{2} \cdot 110 \cdot 0{,}8 = 124{,}45V.$

$\to$ Trabaja en MCD

1)

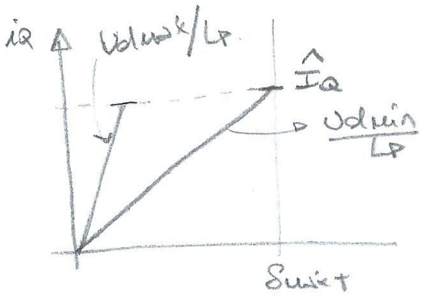


Para minimizar $\hat{I}_s$ asumo que a carga máxima con $U_d = U_{dmín}$ el convertidor está en el LCC

$$\left.\begin{array}{l} I_o = \frac{1}{\cancel{T}} \frac{1}{2} (1-\delta_{máx})\cancel{T} \cdot \hat{I}_s \\ \hat{I}_s = \frac{U_o}{L_s}(1-\delta_{máx})T \end{array}\right\} \Rightarrow I_o = \frac{(1-\delta_{máx})^2}{2} \cdot \frac{U_o T}{L_s}$$

$$\Rightarrow L_s = \frac{U_o (1-\delta_{máx})^2}{2 I_o \cdot f} = \frac{24(1-0{,}6)^2}{2 \cdot 5 \cdot 100 \times 10^3} \Rightarrow \boxed{L_s = 3{,}84\,\mu H}$$

2) Corriente de pico máxima por la llave:



$P_o = 24 \cdot 5 = 120W$

Como los componentes son ideales:

$P_o = P_{in} = \frac{1}{2} \cdot L_P \cdot \hat{I}_Q^2 \cdot f$

$\hat{I}_Q = \frac{U_{dmín}}{L_P} \cdot \delta_{máx} T$

$L_P = \frac{U_{dmín} \cdot \delta_{máx} \cdot T}{\hat{I}_Q} \Rightarrow P_o = \frac{1}{2} \frac{U_{dmín} \cdot \delta_{máx} \cdot}{\cancel{\hat{I}_Q} \cdot \cancel{f}} \cdot \hat{I}_Q^{\cancel{2}} \cdot \cancel{f}$

$$\hat{I}_Q = \frac{2 P_o}{U_{dmín} \cdot \delta_{máx}} = \frac{2 \cdot 120}{124{,}45 \cdot 0{,}6} = \boxed{3{,}21A < I_D = 7{,}8A} \checkmark$$

Tensión máxima sobre la llave:

$U_Q = U_d + \frac{n_P}{n_S} \cdot U_o \Rightarrow U_{Qmáx} = U_{dmáx} + \frac{n_P}{n_S} \cdot U_o$

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Solución Problema 2 (cont.)

Como se impuso LCC para carga máxima y $U_d = U_{d\,min}$

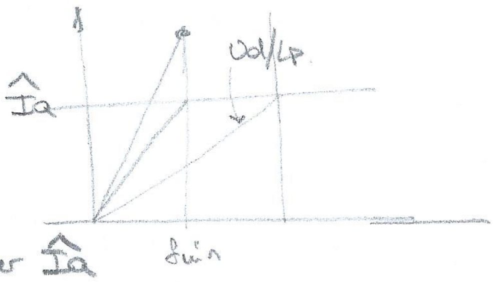
$$\Rightarrow \frac{U_o}{U_{d\,min}} = \frac{n_s}{n_p} \cdot \frac{\delta_{max}}{1-\delta_{max}} \Rightarrow \frac{n_s}{n_p} = \frac{(1-\delta_{max})}{\delta_{max}} \frac{U_o}{U_{d\,min}}$$

$$\frac{n_s}{n_p} = \frac{0{,}4}{0{,}6} \frac{24}{124{,}45} \Rightarrow \boxed{\frac{n_s}{n_p} = 0{,}129}$$

$$U_{a\,máx} = 390{,}32 + \frac{24}{0{,}129} \Rightarrow \boxed{U_{a\,máx} = 577V < V_{DSS} = 800V} \checkmark$$

3) Ahora $U_d = \sqrt{2} . 230 . 1{,}4 = 455{,}38V$.

$$L_p = L_s\left(\frac{n_p}{n_s}\right)^2 = \frac{3{,}84}{0{,}129^2} = 230{,}76 \mu H.$$



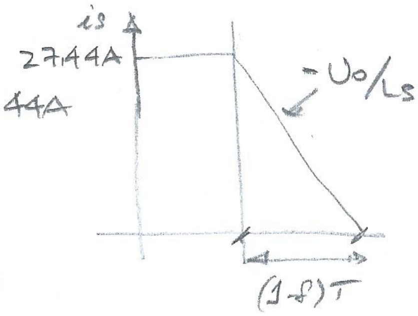
Asumo que el control puede mantener $\hat{I}_a$

$$\hat{I}_a = \frac{U_d}{L_p} . \delta T \Rightarrow \delta = \frac{\hat{I}_a . L_p . f}{U_d} = \frac{3{,}21 . 230{,}76 \times 10^{-6} . 100 \times 10^3}{455{,}38}$$

$\delta = 0{,}163 < \delta_{min} = 0{,}18$.

$$\Rightarrow \hat{I}_a = \frac{U_d}{L_p} . \delta T = \frac{455{,}38 . 0{,}18}{230{,}76 \times 10^{-6} . 100 \times 10^3} = 3{,}54 A < I_D = 7{,}8 \checkmark$$

Ahora $\hat{I}_s = \frac{n_p}{n_s} . \hat{I}_a = \frac{3{,}54}{0{,}129} \Rightarrow \hat{I}_s = 27{,}44A$



$$\hat{I}_s = \frac{U_o}{L_s}(1-\delta).T$$

$$(1-\delta) = \frac{\hat{I}_s . L_s . f}{U_o} = \frac{27{,}44 . 3{,}84 \times 10^{-6} . 100 \times 10^3}{24}$$

$(1-\delta) = 0{,}439 \Rightarrow$ continúa en MCD

$$\frac{U_o}{U_d} = \sqrt{\frac{RT}{2L_p}} . \delta$$

Carga en condiciones nominales: $U_o = R . I_o \Rightarrow R = \frac{24}{5} = 4{,}8\Omega$

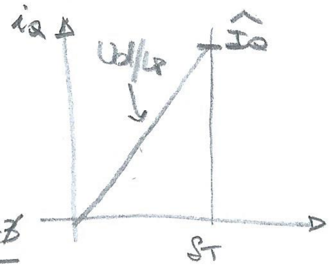
$$U_o = U_d . \delta \sqrt{\frac{RT}{2L_p}} = 455{,}38 . 0{,}18 \sqrt{\frac{4{,}8}{2 . 230{,}76 \times 10^{-6} . 100 \times 10^3}}$$

$$\Rightarrow \boxed{U_o = 26{,}43V}$$

Solución Problema 2 (cont.)

$$U_Q = 455{,}38 + \frac{26{,}43}{0{,}129} = 660{,}3\ V < V_{DSS} = 800\ V \checkmark$$

4) Pérdidas en el MOSFET: $P_M = \underbrace{P_{ON}}_{0 \text{ por MCD}} + P_{cond} + P_{OFF}$



$$P_{cond} = R_{DS(on)} \cdot I_{Qeff}^2$$

$$I_{Qeff}^2 = \frac{1}{T}\int_0^T i_Q^2(t)\,dt = \frac{1}{T}\int_0^{\delta T} \frac{\hat{I}_Q^2}{\delta^2 T^2}\, t^2\,dt = \frac{1}{\cancel{T}}\frac{\hat{I}_Q^2}{\cancel{\delta^2 T^2}}\frac{\delta^{\cancel{3}}\cancel{T^3}}{3}$$

$$P_{cond} = \frac{\hat{I}_Q^2 \cdot \delta}{3}$$

$$\left.\begin{aligned} P_{OFF} &= \frac{1}{2}\cdot U \cdot \hat{I}_Q \cdot t_f \cdot f \\ U &= U_d + \frac{n_P}{n_S} V_o \end{aligned}\right\} \Rightarrow P_{OFF} = \frac{1}{2}\left(U_d + \frac{n_P}{n_S} V_o\right)\cdot \hat{I}_Q \cdot t_f \cdot f$$

$$P_{MOSFET} = \frac{\hat{I}_Q^2 \cdot \delta}{3} + \frac{1}{2}\left(U_d + \frac{n_P}{n_S} V_o\right)\hat{I}_Q \cdot t_f \cdot f$$

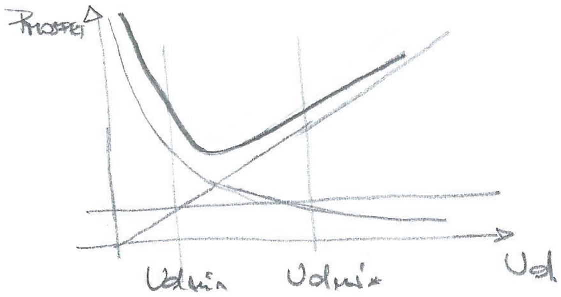
Expreso P_{MOSFET} en función de U_d para analizar su evolución:

$$\hat{I}_Q = \frac{U_d}{L_P}\cdot \delta T \Rightarrow \delta = \frac{L_P \cdot \hat{I}_Q}{U_d T}$$

$$P_{MOSFET} = \frac{\hat{I}_Q^3 \cdot L_P}{3\, U_d \cdot T} + \frac{1}{2} U_d \cdot \hat{I}_Q \cdot t_f \cdot f + \frac{1}{2}\frac{n_P}{n_S} V_o\, \hat{I}_Q \cdot t_f \cdot f$$

$$P_{MOSFET} = \frac{A}{U_d} + B \cdot U_d + K$$

El máximo se dará en $U_d = U_{d\,min}$ o $U_d = U_{d\,max}$.



De las hojas de datos:

$R_{DS(on)} = 1{,}2 \cdot 2{,}2 = 2{,}64\ \Omega$ $\quad t_f = 39\ ns.$

en condiciones nominales: $\hat{I}_Q = 3{,}21\ A.$

→ Para $U_d = U_{d\,max} = 390{,}32\ V$:

$$P_{MOSFET} = \frac{3{,}21^3 \cdot 23{,}76\times10^{-6} \cdot 100\times10^3}{3 \cdot 390{,}32} + \frac{1}{2}\left(390{,}32 + \frac{24}{0{,}129}\right) 3{,}21 \cdot 39\times10^{-9} \cdot 100\times10^3$$

$$P_{MOSFET} = 0{,}652 + 3{,}608 = \underline{4{,}26\ W}$$

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Solución Problema 2 (cont.)

→ Para $U_d = U_{d\,mín}$

$$P_{MOSFET} = \frac{3{,}21^3 \cdot 230{,}76\times10^{-6} \cdot 100\times10^3}{124{,}45} + \frac{1}{2}\left(124{,}45 + \frac{24}{0{,}129}\right) \cdot 3{,}21 \cdot 39\times10^{-9} \cdot 100\times10^3$$

$$P_{MOSFET} = 6{,}13 + 1{,}94 = \underline{8{,}07\ W} \leftarrow \text{peor caso}$$

$$T_j - T_a = P_{MOSFET}\left(R_{\theta jc} + R_{\theta cs} + R_{\theta sa}\right)$$

Hojas de datos:

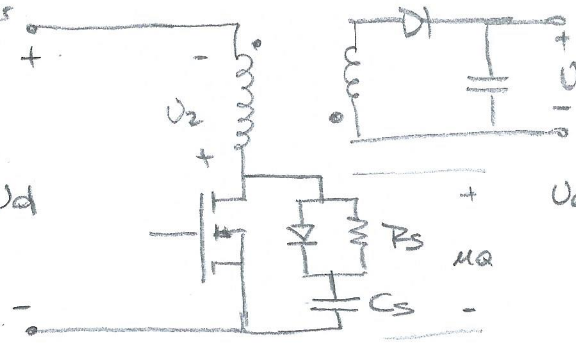
$R_{\theta jc} = 0{,}65\ °C/W$

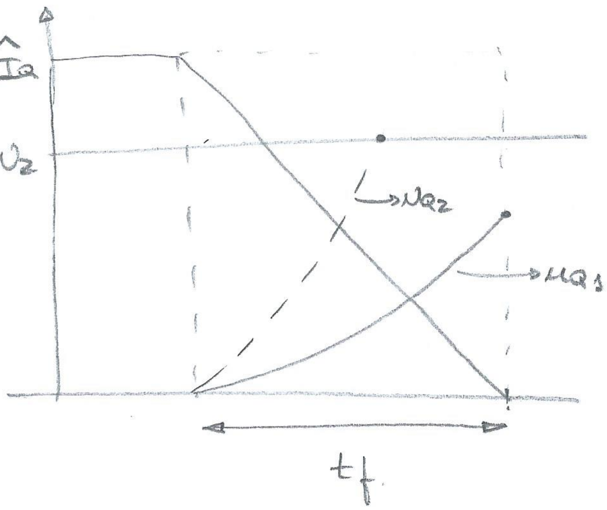
$R_{\theta cs} = 0{,}24\ °C/W$

$$R_{\theta sa} = \frac{T_j - T_a}{P_{MOSFET}} - R_{\theta jc} - R_{\theta cs}$$

$$R_{\theta sa} = \frac{120-40}{8{,}07} - 0{,}65 - 0{,}24 \Rightarrow \boxed{R_{\theta sa} = 9{,}02\ °C/W}$$

5) Snubber





$P_{off_s} = 0{,}5 \cdot P_{off}$ (en el peor caso) $U_d = U_{d\,máx}$

Ahora $P_{off} = \int_0^{t_f} u_Q \cdot i_Q$

$$i_Q = \hat{I}_Q - \frac{\hat{I}_Q\, t}{t_f}$$

$$u_Q(t) = \int_0^t \frac{i_c(\theta)\,d\theta}{C}$$

$$i_c(\theta) = \frac{\hat{I}_Q\, \theta}{t_f}$$

$$\Rightarrow u_Q(t) = \int_0^t \frac{\hat{I}_Q\, \theta}{t_f\, C}\, d\theta = \frac{\hat{I}_Q}{t_f \cdot C}\frac{t^2}{2}$$

$$P_{off} = \frac{1}{T}\int_0^{t_f} \frac{\hat{I}_Q\, t^2}{2 t_f \cdot C}\left(\hat{I}_Q - \frac{\hat{I}_Q\, t}{t_f}\right) = \left(\frac{\hat{I}_Q^2\, \cancel{t_f^3}^{\,2}}{2\cancel{t_f}\, C\, 3} - \frac{\hat{I}_Q^2\, \cancel{t_f^4}^{\,2}}{2\cancel{t_f^2}\, C\, 4}\right)\cdot f$$

$$P_{off} = \frac{\hat{I}_Q^2\, t_f^2\, f}{C}\left(\frac{1}{6} - \frac{1}{8}\right) = \frac{\hat{I}_Q^2 \cdot t_f^2 \cdot f}{24C}$$

Solución Problema 2 (cont.)

$$P_{off} = \frac{\hat{I}_Q^2 \cdot t_f^2 \cdot f}{24C} = 0{,}1 \cdot 3{,}608$$

$$C = \frac{3{,}21^2 \cdot (39\times10^{-9})^2 \cdot 100\times10^3}{24 \cdot 0{,}1 \cdot 3{,}608} = 181\ pF$$

Verifico: $u_Q(t_f) = \frac{\hat{I}_Q \cdot t_f^{\cancel{2}}}{2C\cancel{t_f}} = \frac{3{,}21 \cdot 39\times10^{-9}}{2 \cdot 181\times10^{-12}} = 345{,}8V < 577V$ ✓

$$3RC \leq \delta T \Rightarrow R \leq \frac{\delta T}{3C}$$

$$\delta = \frac{L_p \hat{I}_Q f}{U_d} = \frac{230{,}76\times10^{-6} \cdot 3{,}21 \cdot 100\times10^3}{390{,}32} = 0{,}19$$

$$R \leq \frac{0{,}19}{3 \cdot 181\times10^{-12} \cdot 100\times10^3} = 3{,}5k\Omega \Rightarrow \boxed{R \leq 3{,}5k\Omega}$$

$$P_R = \frac{E_C}{T} = \frac{1}{2} C \cdot V^2 \cdot f = \frac{1}{2} 181\times10^{-12} \cdot 577^2 \cdot 100\times10^3 = \underline{3W}$$