Universidad Politécnica de Valencia

Escuela Técnica Superior de Ingeniería de Diseño

· Diseño y simulación de un convertidor DC/DC para alimentación de un sistema de iluminación mediante LED ·

ANEXOS

Trabajo Fin de Grado

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Grado en Ingeniería Electrónica Industrial y Automática

Elección del programa de cálculo

Se elige Mathcad como programa de cálculo ya que permite modificar valores y fórmulas de forma instantánea agilizando así el proceso previo a la simulación del sistema. Además, permite graficar las diferentes funciones de transferencia y diagramas de Bode correspondientes.

Los cálculos realizados son los siguientes:

- Especificaciones del diseño:

$V_i := 30V$ $\quad V_o := 24V$ $\quad P := 30W$ $\quad f_s := 50kHz$

$R := 20\Omega$ $\quad L := 600\mu H$ $\quad C := 2200\mu F$ $\quad R_c := 52m\Omega$

$V_{ref} := 2.5V$

Modulador: $V_m := 3V$ $\quad F_m := \frac{1}{V_m}$ $\quad F_m = 0.333\frac{1}{V}$

- Cálculo Ciclo de Trabajo

$$D := \frac{V_o}{V_i} = 0.8$$

- Cálculo de la RCarga inicial

$$Rcarga := \frac{V_o^{\,2}}{P} = 19.2\,\Omega$$

- Cálculo del valor de la Bobina

$$Laprox := (1 - D)\frac{V_o}{2f_s \cdot 0.1A} = 4.8 \times 10^{-4}H$$

$$Laproxp := Laprox \cdot 0.25 = 1.2 \times 10^{-4}H$$

$$LFinal := Laprox + Laproxp = 6 \times 10^{-4}H$$

- Cálculo del valor del Condensador

$$\Delta V_o := \frac{20}{100 \cdot 4} = 0.05$$

$$Caprox := V_o \cdot \frac{(1 - D)}{8 \cdot L \cdot f_s^{\,2} \cdot 0.05V} = 8 \times 10^{-6}F$$

$$CFinal := 2200\mu F$$

- **Intensidades (Io, Iin)**

$$I_o := \frac{V_o}{Rcarga} = 1.25\,A \qquad I_i := D \cdot I_o = 1\,A$$

- **Potencias (Po, Pin)**

$$P_{in} := V_i \cdot I_i = 30\,W \qquad P_o := \frac{V_o^{\,2}}{Rcarga} = 30\,W$$

- **Rendimiento**

$$P_o := I_o \cdot V_o = 30\,W$$

$$\eta := \frac{P_o}{P_{in}} = 1$$

-**Modelizaión de la Etapa de potencia: FDT**

$$I_{L\_riz} := \frac{V_i - V_o}{L} \cdot D \cdot T_s \qquad I_{L\_riz} = 0.16 \cdot A \qquad \frac{I_{L\_riz}}{I_o} = 12.8 \cdot \%$$

$$I_{L\_riz} := \frac{(V_i - V_o) \cdot D}{L \cdot f_s} = 0.16\,A \qquad \frac{I_{L\_riz}}{8 \cdot f_s \cdot C} = 0.182 \cdot mV \qquad I_{L\_riz} \cdot R_c = 8.32 \cdot mV$$

$$V_{o\_riz\_ESR} := R_c \cdot I_{L\_riz} \qquad V_{o\_riz\_ESR} = 8.32 \cdot mV \qquad \frac{V_{o\_riz\_ESR}}{V_o} = 0.035 \cdot \%$$

$$V_{o\_riz\_C} := \frac{1}{8 \cdot C} \cdot I_{L\_riz} \cdot T_s \qquad V_{o\_riz\_C} = 0.182 \cdot mV$$

$$\omega_z := \frac{1}{R_c \cdot C} \qquad f_z := \frac{\omega_z}{2\pi} \qquad f_z = 1.391 \cdot kHz$$

$$f_z = \frac{1}{2\pi\, R_c \cdot C} = 7.958kHz \qquad \omega_z := \frac{1}{R_c \cdot C} = 8.741 \times 10^3 \cdot \frac{rad}{s}$$

$$\omega_n := \frac{1}{\sqrt{L \cdot C}} \qquad f_n := \frac{\omega_n}{2\pi} \qquad f_n = 0.139 \cdot kHz$$

$$f_n = \frac{1}{2\pi\sqrt{L \cdot C}} = 1.592kHz \qquad \omega_n = 870.388 \cdot \frac{rad}{s}$$

$$Q := \frac{\omega_n}{\frac{1}{R \cdot C} + \frac{R_c}{L}} \qquad Q = 7.956$$

Diseño del lazo de corriente

Para hallar el valor de Ai, primero hay que saber el valor de Gid que se halla de la siguiente forma: Consultar si es correcto.

Valor de Gid

$$G_{id}(\omega) := V_i \cdot \frac{1 + (R + R_c) \cdot C \cdot j \cdot \omega}{R + (R \cdot R_c \cdot C + L) \cdot j \cdot \omega - (R + R_c) \cdot L \cdot C \cdot \omega^2}$$

R >> Rc

$$G_{id}(\omega) := V_i \cdot \frac{1 + R \cdot C \cdot j \cdot \omega}{R + (R \cdot R_c \cdot C + L) \cdot j \cdot \omega - R \cdot L \cdot C \cdot \omega^2}$$

$$G_{id}(\omega) := \frac{V_i}{R} \cdot \frac{1 + R \cdot C \cdot j \cdot \omega}{1 + \frac{R \cdot R_c \cdot C + L}{R} \cdot j \cdot \omega - L \cdot C \cdot \omega^2}$$

$$\omega_n := \frac{1}{\sqrt{L \cdot C}} \qquad \omega_n = 870.388 \cdot \frac{rad}{s}$$

$$\omega_z := \frac{1}{R \cdot C} \qquad \omega_z = 22.727 \cdot \frac{rad}{s}$$

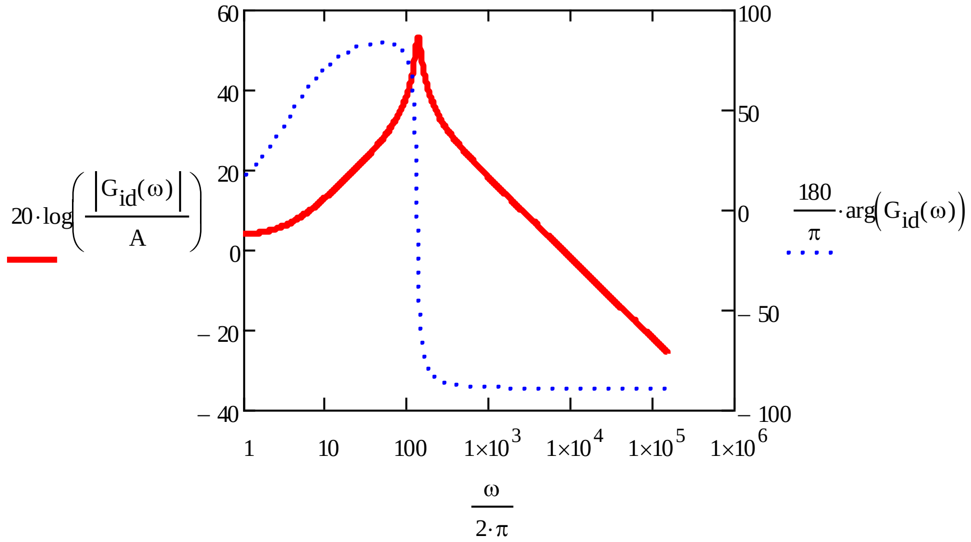
$$\zeta := \frac{1}{2 \cdot \omega_n} \cdot \left(\frac{1}{R \cdot C} + \frac{R_c}{L} \right) \qquad \zeta := \frac{\sqrt{L \cdot C}}{2} \cdot \left(\frac{1}{R \cdot C} + \frac{R_c}{L} \right) \qquad \zeta = 0.063$$

$$Q := \frac{\sqrt{L \cdot C}}{\frac{L}{R} + R_c \cdot C} \qquad Q = 7.956$$

$$\frac{R \cdot r \cdot C + L}{R} := 2\zeta \cdot \omega_n \cdot L \cdot C$$

$$G_{id}(\omega) := \frac{V_i}{R} \cdot \frac{1 + j \cdot \frac{\omega}{\omega_z}}{1 + j \cdot \frac{1}{Q} \cdot \frac{\omega}{\omega_n} - \left(\frac{\omega}{\omega_n} \right)^2}$$

$$G_{id}(j\omega) = \frac{V_i}{R_L} \cdot \frac{1 + j \cdot \frac{\omega}{\omega_z}}{1 + j \cdot \frac{1}{Q} \cdot \frac{\omega}{\omega_n} - \left(\frac{\omega}{\omega_n} \right)^2}$$



Hallamos también los valores de Ri y de Fm para completar la ecuación de Ti

Valor de Ri

$R_i := 1\Omega$

Valor de Fm

$F_m := \frac{1}{V_m}$ $\qquad F_m = 0.333\,\frac{1}{V}$

Por último, se saca el valor de Ai con el método del factor K

1. Diseño del controlador por el método del Factor K:

10% fs < fci < 20% fs $\qquad$ fci > 10 fn
40º < MFi < 70º
MG > 10º

$f_s = 50 \cdot kHz$ $\qquad \omega_s := 2\pi f_s$ $\qquad \omega_s = 3.142 \times 10^5 \cdot \frac{rad}{s}$

$10\% \cdot f_s = 5 \cdot kHz$ $\qquad$ < fci < $\qquad 20\% \cdot f_s = 10 \cdot kHz$

$f_n := \frac{\omega_n}{2\pi}$ $\qquad f_n = 138.527 \cdot Hz$ $\qquad 10 \cdot f_n = 1.385 \cdot kHz$ $\qquad$ < fc

Valores de diseño $\qquad f_{ci} := 7kHz$ $\qquad MFi := 70°$

$\omega_{ci} := 2\pi f_{ci}$

$-\arg(G_{id}(\omega_{ci})) = 89.887 \cdot °$ $\qquad |G_{id}(\omega_{ci})| = 1.137\,A$

Compensador tipo 2: $A_i(j\omega) = \frac{\omega_{p0c}}{j\cdot\omega}\cdot\frac{1 + j\cdot\frac{\omega}{\omega_{zc}}}{1 + j\cdot\frac{\omega}{\omega_{pc}}}$

Paso 1) $\arg(G_{id}(\omega_{ci})) - 90° + AUFA_i = -180° + MFi$

$AUFA = MFi - \arg(G_{id}(\omega_{ci})) - 90°$

$AUFA_i := (MFi - \arg(G_{id}(\omega_{ci})) - 90°)$ $\qquad AUFA_i = 69.887\cdot°$

Paso 2) $K_i := \tan\left(45° + \frac{AUFA_i}{2}\right)$ $\qquad K_i = 5.639$ $\qquad K_i = \tan\left(45° + \frac{AUFA_i}{2}\right)$

$\omega_{zci} := \frac{\omega_{ci}}{K_i}$ $\qquad \omega_{zci} = 7.8\cdot\frac{krad}{s}$ $\qquad \omega_{zci} = \frac{\omega_{ci}}{K_i}$

$\omega_{pci} := K_i\cdot\omega_{ci}$ $\qquad \omega_{pci} = 248.006\cdot\frac{krad}{s}$ $\qquad \omega_{pci} = K_i\cdot\omega_{ci}$

Paso 3) Ganancia del regulador ω_{p0ci}

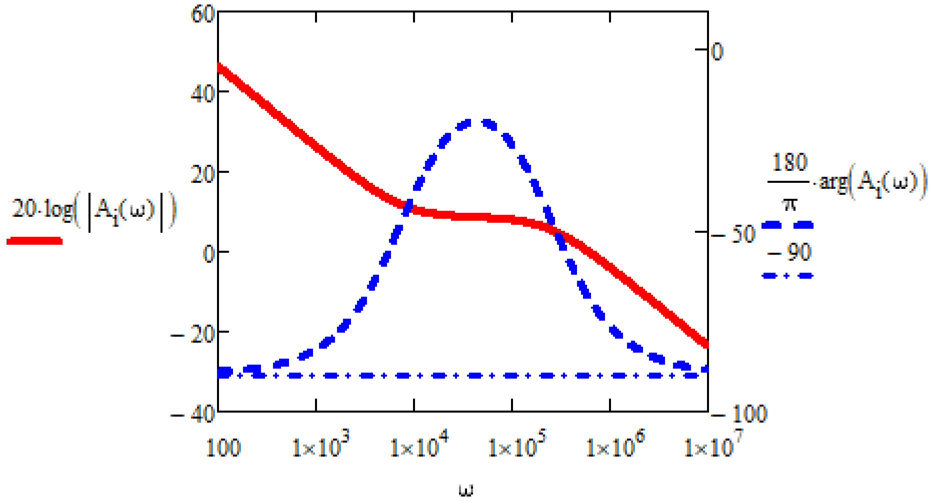
$T_i(\omega) = G_{id}(\omega)\cdot A_i(\omega)\cdot F_m\cdot R_i$ $\qquad |T_i(\omega_{ci})| = 1$

$$|G_{id}(\omega_{ci})|\cdot\left|\frac{\omega_{p0ci}}{j\cdot\omega_c}\cdot\frac{\left(1 + j\cdot\frac{\omega_{ci}}{\omega_{zc}}\right)}{\left(1 + j\cdot\frac{\omega_{ci}}{\omega_{pc}}\right)}\right|\cdot F_m\cdot R_i = 1$$

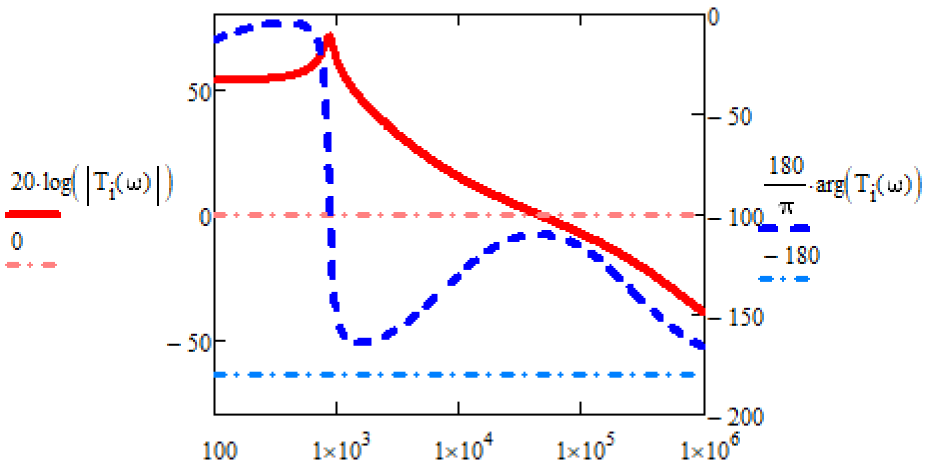
$$\omega_{p0ci} := \frac{\omega_{ci}}{F_m\cdot R_i\cdot|G_{id}(\omega_{ci})|}\cdot\frac{\left|\left(1 + j\cdot\frac{\omega_{ci}}{\omega_{pci}}\right)\right|}{\left|\left(1 + j\cdot\frac{\omega_{ci}}{\omega_{zci}}\right)\right|}$$

$\omega_{p0ci} = 20.576\cdot\frac{krad}{s}$

$$A_i(\omega) := \frac{\omega_{p0ci}}{j\cdot\omega}\cdot\frac{\left(1 + j\cdot\frac{\omega}{\omega_{zci}}\right)}{\left(1 + j\cdot\frac{\omega}{\omega_{pci}}\right)}$$



$$T_i(\omega) := G_{id}(\omega)\cdot A_i(\omega)\cdot F_m\cdot R_i$$

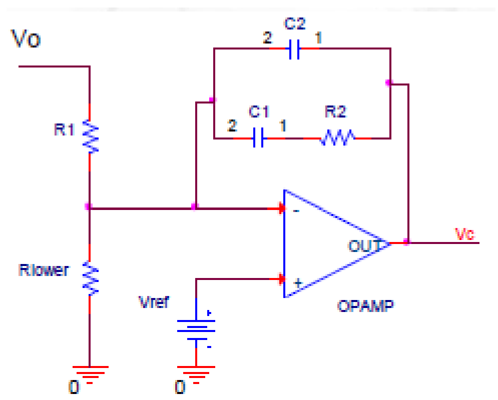


Dado $\omega_c := 1\frac{krad}{s}$ $\qquad |T_i(\omega_c)| = 1$

$\omega_{ci} := \text{Find}(\omega_c)$ $\qquad f_{ci} := \frac{\omega_{ci}}{2\pi} = 7\cdot kHz$

$MF_i := \arg(T_i(\omega_{ci})) + 180° = 70\cdot°$

Regulador tipo 2 con 1 AO:



$\omega_{zc} = 20.253 \cdot \frac{krad}{s}$

$\omega_{pc} = 95.513 \cdot \frac{krad}{s}$

$\omega_{p0c} = 464.042 \cdot \frac{krad}{s}$

$(C2 < C1)$ $\quad R_1 := 10k\Omega$ $\quad V_{ref} = 2.5\,V$

$$\omega_{p0c} := \frac{1}{R_1 \cdot (C_1 + C_2)} \qquad C_1 := \frac{1}{R_1 \cdot \omega_{p0ci}} = 4.86 \cdot nF$$

$$\omega_{zc} := \frac{1}{C_1 \cdot R_2} \qquad R_2 := \frac{1}{C_1 \cdot (\omega_{zci})} = 26.379 \cdot k\Omega$$

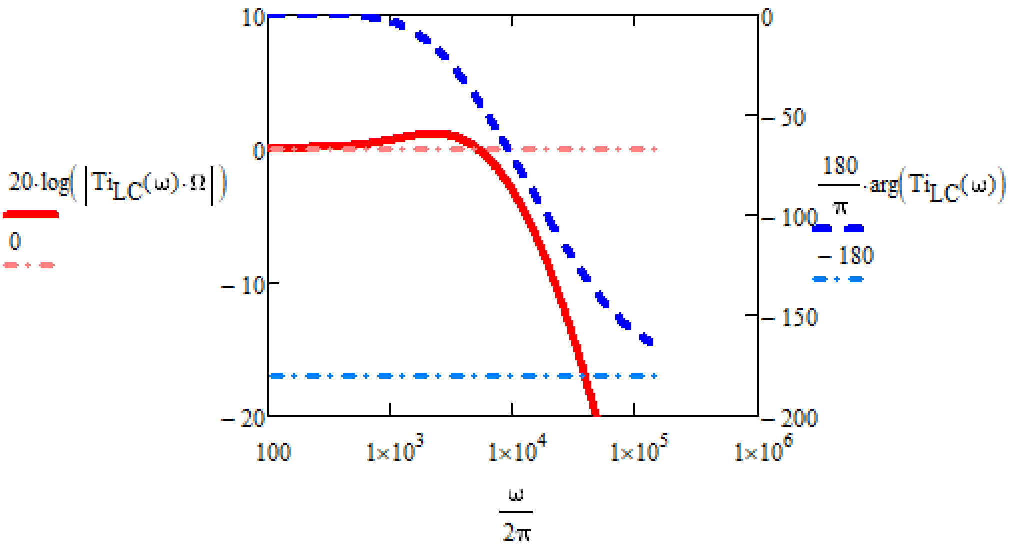
$$\omega_{pc} := \frac{(C_1 + C_2)}{R_2 \cdot C_1 \cdot C_2} \qquad C_2 := \frac{\omega_{zci}}{\omega_{pci} \cdot \omega_{p0ci} \cdot R_1} = 152.854 \cdot pF$$

$$RLOWER1 := V_{ref} \cdot \frac{R_1}{V_o - V_{ref}} = 1.163 \times 10^3\,\Omega$$

Se saca el valor del lazo cerrado para asi seguir diseñando el lazo de tensión

Ganancia de corriente en lazo cerrado Ti(LC):

$$Ti_{LC}(\omega) := \frac{1}{R_i} \cdot \frac{T_i(\omega)}{1 + T_i(\omega)}$$



Diseño del lazo de tensión

Sabiendo que Gvi (jw) = Z (jw) hallamos el valor de Gvi y Gvc

Valor de Gvi

$$G_{vi}(\omega) := R \cdot \frac{1 + j \cdot R_c \cdot C \cdot \omega}{1 + j \cdot (R_c + R) \cdot C \cdot \omega}$$

Valor de Gvc

$$G_{vc}(\omega) := Ti_{LC}(\omega) \, G_{vi}(\omega)$$

Valor de Beta

$Beta := 1$

Por último, se saca el valor de Av con el método del factor K

1. Diseño del controlador por el método del Factor K:

10% fs < fc < 20% fs   fc > 10 fn
40º < MFv < 70º
MG > 10º

$f_s = 50 \cdot kHz$ $\omega_s := 2\pi f_s$ $\omega_s = 3.142 \times 10^5 \cdot \frac{rad}{s}$

$10\% \cdot f_s = 5 \cdot kHz$ < fcv < $20\% \cdot f_s = 10 \cdot kHz$

$f_n := \frac{\omega_n}{2\pi}$ $f_n = 138.527 \cdot Hz$ $10 \cdot f_n = 1.385 \cdot kHz$ < fcv

Valores de diseño $f_{cv} := \frac{f_{ci}}{5} = 1.4 \cdot kHz$ $MF_v := 70°$

$\omega_{cv} := 2\pi f_{cv} = 8.796 \cdot \frac{krad}{s}$

$-\arg(G_{vc}(\omega_{cv})) = 51.552 \cdot °$ $|G_{vc}(\omega_{cv})| = 0.081$

Compensador tipo 2: $A_v(j\omega) = \frac{\omega_{p0c}}{j \cdot \omega} \cdot \frac{\left(1 + j \cdot \frac{\omega}{\omega_{zc}}\right)}{\left(1 + j \cdot \frac{\omega}{\omega_{pc}}\right)}$

Paso 1) $\arg(G_{vc}(\omega_{cv})) - 90° + AUFA = -180° + MFv$

$AUFA = MFv - \arg(G_{vc}(\omega_{cv})) - 90°$

$AUFA_v := (MF_v - \arg(G_{vc}(\omega_{cv})) - 90°)$ $AUFA_v = 31.552 \cdot °$

Paso 2) $K_v := \tan\left(45° + \frac{AUFA_v}{2}\right)$ $K_v = 1.788$

$\omega_{zcv} := \frac{\omega_{cv}}{K_v}$ $\omega_{zcv} = 4.921 \cdot \frac{krad}{s}$

$\omega_{pcv} := K_v \cdot \omega_{cv}$ $\omega_{pcv} = 15.724 \cdot \frac{krad}{s}$

$\sqrt{\frac{\omega_{pcv}}{\omega_{zcv}}} = 1.788$

Paso 3) Ganancia del regulador ω_{p0c}:

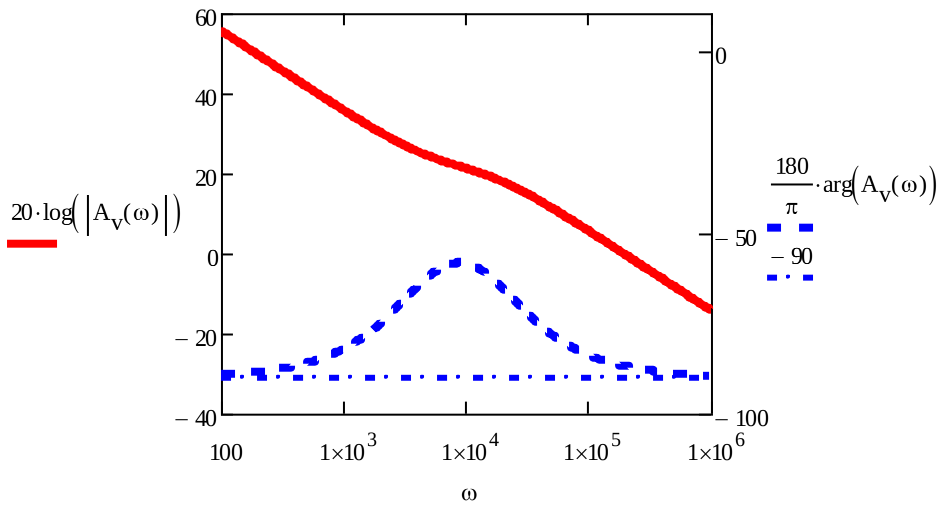
+

$$T_v(\omega) = G_{vc}(\omega)\cdot A_v(\omega)\cdot beta \qquad \left|T_v\left(\omega_{cv}\right)\right| = 1$$

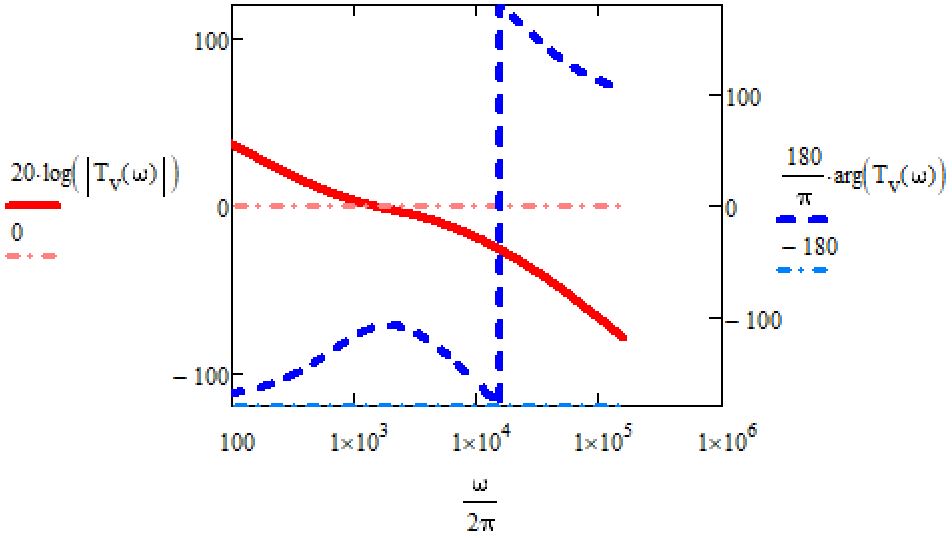
$$\left|G_{vc}\left(\omega_{cv}\right)\right|\cdot\left|\frac{\omega_{p0cv}}{j\cdot\omega_c}\cdot\frac{\left(1+j\cdot\frac{\omega_{cv}}{\omega_{zcv}}\right)}{\left(1+j\cdot\frac{\omega_{cv}}{\omega_{pcv}}\right)}\right| = 1$$

$$\omega_{p0cv} := \frac{\omega_{cv}}{\left|G_{vc}\left(\omega_{cv}\right)\right|}\cdot\frac{\left|\left(1+j\cdot\frac{\omega_{cv}}{\omega_{pcv}}\right)\right|}{\left|\left(1+j\cdot\frac{\omega_{cv}}{\omega_{zcv}}\right)\right|} \qquad \omega_{p0cv} = 60.929\cdot\frac{krad}{s}$$

$$A_v(\omega) := \frac{\omega_{p0cv}}{j\cdot\omega}\cdot\frac{\left(1+j\cdot\frac{\omega}{\omega_{zcv}}\right)}{\left(1+j\cdot\frac{\omega}{\omega_{pcv}}\right)}$$



$T_v(\omega) := G_{vc}(\omega) \cdot A_v(\omega) \cdot Beta$

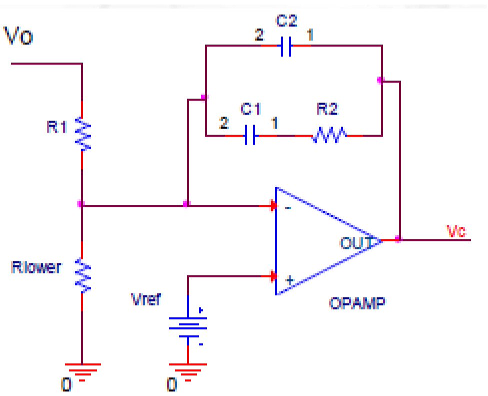


Dado $\omega_{cv} := 1 \frac{krad}{s}$ $|T_v(\omega_{cv})| = 1$

$\omega_{cv} := Find(\omega_{cv})$ $f_{cv} := \frac{\omega_{cv}}{2\pi} = 1.4 \cdot kHz$

$MF_v := arg(T_v(\omega_{cv})) + 180° = 70 \cdot °$

Regulador tipo 2 con 1 AO:



(C2 < C1) $R_{1v} := 10k\Omega$

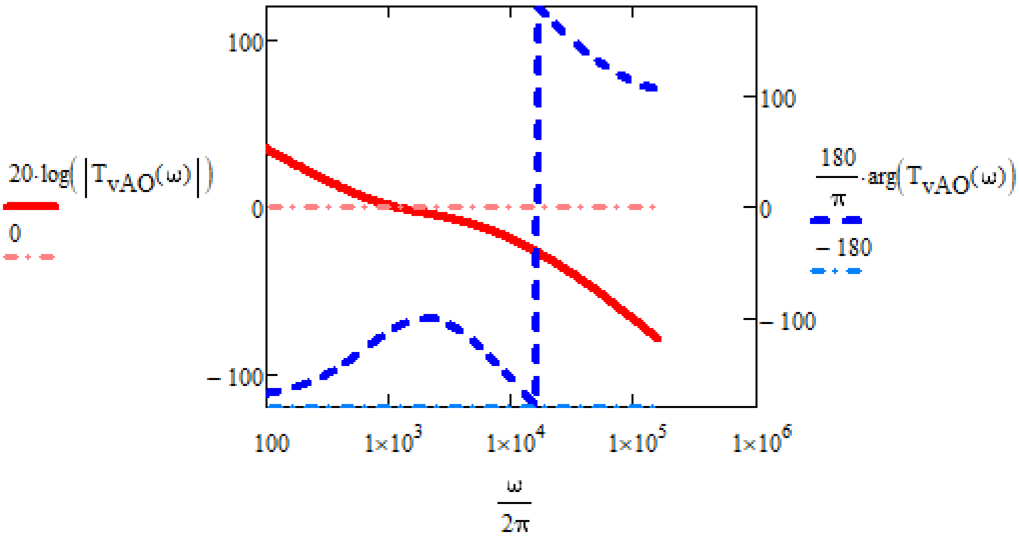
$$\omega_{p0cv} = \frac{1}{R_{1v} \cdot (C_{1v} + C_{2v})} \qquad C_{1v} := \frac{1}{R_{1v} \cdot \omega_{p0cv}} = 1.641 \cdot nF$$

$$\omega_{zcv} = \frac{1}{C_{1v} \cdot R_{2v}} \qquad R_{2v} := \frac{1}{C_{1v} \cdot (\omega_{zcv})} = 123.814 \cdot k\Omega$$

$$\omega_{pcv} = \frac{(C_{1v} + C_{2v})}{R_{2v} \cdot C_{1v} \cdot C_{2v}} \qquad C_{2v} := \frac{C_{1v}}{\omega_{pcv} \cdot R_{2v} \cdot C_{1v}} = 513.653 \cdot pF$$

$$RLOWER1 := V_{ref} \cdot \frac{R_{1v}}{V_o - V_{ref}} = 1.163 \times 10^3 \, \Omega$$

$T_{vAO}(\omega) := G_{vc}(\omega) \cdot A_{vAO}(\omega) \cdot Beta$



Dado $\omega_{cv} := 1 \frac{krad}{s}$ $|T_{vAO}(\omega_{cv})| = 1$

$\omega_{cv} := Find(\omega_{cv})$ $f_{cv} := \frac{\omega_{cv}}{2\pi} = 1.092 \cdot kHz$

$MF_v := arg(T_{vAO}(\omega_{cv})) + 180° = 70.198 \cdot °$