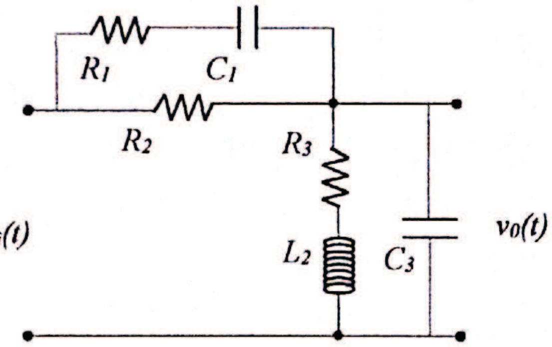
TEORÍA DE CIRCUITOS I

Facultad Regional De Buenos Aires. Departamento de Electrónica

Primer Examen Parcial Integrador. 8 de julio de 2017

Teniendo en cuenta el siguiente *circuito eléctrico*, se pide resolver los primeros 5 incisos del examen integrador, a saber:



1. Realice un *lugar geométrico* de la *impedancia total* del circuito, teniendo en cuenta para este inciso que $C_3 = 0$. La única variable del circuito es la frecuencia angular de la excitación $v_i(t) = V_p sin(\omega t + \theta_v)$, con $0 \leq \omega < \infty$. Tenga en cuenta en su gráfico cualitativo que debe presentarse al menos una frecuencia de resonancia en el circuito.

2. Verifique analíticamente lo obtenido en el inciso anterior, determinando la/s posibles *frecuencia/s angular/es* para las cuales el circuito presenta un factor de potencia unitario, así también, como la relación entre los componentes circuitales para que ello ocurra. Considere para sus cálculos son $R_1 = 10\Omega$, $R_2 = 1M\Omega$, $R_3 = 1K\Omega$, $L_2 = 10\ mHy$, $C_1 = 100\ \mu F$

3. Calcule las *ecuaciones de estado* del circuito eléctrico completo, considerando como entrada la tensión aplicada $v_i(t)$ y como vector de salida $Y(t)$ la tensión de salida $v_0(t)$, la corriente en la resistencia R_2, la corriente del capacitor C_1, la corriente en el inductor L_2 y la caída de potencial en L_2. El modelo obtenido debe contener las matrices de estado *A*, *B*, *C* y *D*.

4. Se aplica al circuito una señal senoidal $v_i(t) = V_0 + V_p sin(\omega t + \theta_v)$, siendo $V_0 = 10\ V$, $V_p = 100\sqrt{2}\ V$, $\omega = 1000\ r/s$ y $\theta_v = 30°$. Los componentes del circuito son $R_1 = 10\Omega$, $R_2 = 1M\Omega$, $R_3 = 1K\Omega$, $L_2 = 10\ mHy$, $C_1 = 100\ \mu F$ y $C_3 = 1\ \mu F$.

- *a)* Calcule la *potencia total disponible* en el circuito.
- *b)* Calcule la *potencia activa* y *reactiva total* del circuito.
- *c)* ¿La *potencia de deformación* es nula? Si no es así, calcule su valor.

5. Calcule la *ecuación diferencial* que relaciona la tensión de entrada $v_i(t)$ con la tensión de salida $v_0(t)$, considerando en este inciso que $L_2 = 0$. El resultado quedará en función de los componentes circuitales, es decir R_1, R_2, R_3, C_1 y C_3. Si la excitación de esta ecuación diferencial fuera $v_i(t) = Vu(t)$, considerando condiciones iniciales nulas, calcule los valores de $i_{R_2}(0)$, $i_{R_3}(0)$, $i_{R_1}(t \to \infty)$ y $v_0(t \to \infty)$.

6. A partir del siguiente *modelo de estado*, se pide *reconstruir el circuito eléctrico* que le dio origen:

$$\begin{cases} \dot{X}(t) = AX(t) + Bv_i(t) \\ v_0(t) = CX(t) + Dv_i(t) \end{cases}, \text{ siendo } A = \begin{bmatrix} \frac{-1}{RC} & \frac{-1}{C} \\ \frac{1}{L} & 0 \end{bmatrix}, B = \begin{bmatrix} \frac{1}{RC} \\ 0 \end{bmatrix}, C = [-1 \quad 0] \text{ y } D = [1].$$

1) (1.5 puntos)	*2)* (1.5 puntos)	*3)* (2.0 puntos)	*4)* (2.0 puntos)	*5)* (2.0 puntos)	*6)* (1.0 puntos)
Apellido y Nombres:				Nota:	

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08/07/17

Primer examen Parcial de
Teoría de Circuitos I

(3) ent: V_i

$Y(t) = [\, V_0(t) \;\; i_{R2} \;\; i_{C1} \;\; i_{L2} \;\; V_{L2} \,]^T$

$$\begin{cases} \dot{X}(t) = A X(t) + B\, V_i(t) \\ Y(t) = C X(t) + D\, V_i(t) \end{cases}$$

$V_0 = V_{C3} = V_{R3} + V_{L2}$

$i_{R1} = i_{C1}$

$i_{R3} = i_{L2}$

$X_1 = V_{C1}, \; X_2 = i_{L2}, \; X_3 = V_{C3}$

$i_{R1} + i_{R2} = i_{R3} + i_{C3}$

$i_{C1} + i_{R2} = i_{L2} + i_{C3}$

$i_{C1} + i_{R2} = i_{L2} + i_{C3}$

$i_{R1} + \frac{(V_i - V_{C3})}{R_2} = i_{L2} + C_3 \frac{dV_{C3}}{dt}$

$V_i = V_{R2} + V_0$

$V_i = V_{R2} + V_{C3}$

$= V_{R2} + V_{R3} + V_{L2}$

$\frac{(V_{R2} - V_{C1})}{R_1} + \frac{V_i}{R_2} - \frac{V_{C3}}{R_2} = i_{L2} + C_3 \frac{dV_{C3}}{dt}$

$\frac{(V_i - V_{C3})}{R_1} - \frac{V_{C1}}{R_1} + \frac{V_i}{R_2} - \frac{V_{C3}}{R_2} = i_{L2} + C_3 \dot{V}_3$

$\frac{V_i}{R_1} - \frac{X_3}{R_1} - \frac{X_1}{R_1} + \frac{V_i}{R_2} - \frac{X_3}{R_2} = X_2 + C_3 \dot{X}_3$

$V_i\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - X_3\left(\frac{1}{R_1} - \frac{1}{R_2}\right) - \frac{X_1}{R_1} - X_2 = C_3 \dot{X}_3$

$$\boxed{\dot{X}_3 = V_i\left(\frac{1}{R_1C_3} + \frac{1}{R_2C_3}\right) - X_3\left(\frac{1}{R_1C_3}\;\frac{1}{R_2C_3}\right) - \frac{X_1}{R_1C_3} - \frac{X_2}{C_3}}$$

$X_2 = i_{L2} = \frac{1}{L_2}\int V_{L2}\, dt \qquad L_2 \frac{di_{L2}}{dt} = V_{C3} - V_{R3} = V_{C3} - i_{R3} \cdot R_3 = V_{C3} - i_{L2} R_3$

$L_2 \cdot \dot{X}_2 = X_3 - X_2 \cdot R_3$

$X_1 = V_{C1} \Rightarrow C_1 \frac{dV_{C1}}{dt} = i_{R1}$

$$\boxed{\dot{X}_2 = -\frac{X_2 R_3}{L_2} + \frac{X_3}{L_2}}$$

$C_1 \frac{dV_{C1}}{dt} = \frac{(V_i - V_{C3} - V_{C1})}{R_1}$

$C_1 \dot{X}_1 = \frac{V_i}{R_1} - \frac{X_3}{R_1} - \frac{X_1}{R_1} \Rightarrow$

$$\boxed{\dot{X}_1 = \frac{V_i}{R_1C_1} - \frac{X_3}{R_1C_1} - \frac{X_1}{R_1C_1}}$$

$\Rightarrow$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} -1/R_1C_1 & 0 & -1/R_1C_1 \\ 0 & -R_3/L_2 & 1/L_2 \\ -1/R_1C_3 & -1/C_3 & -\frac{1}{R_1C_3} - \frac{1}{R_2C_3} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 1/R_1C_1 \\ 0 \\ \frac{1}{R_1C_3} + \frac{1}{R_2C_3} \end{bmatrix} V_i(t)$$

$V_0 = V_{C3} = X_3$

$$\begin{bmatrix} V_0(t) \\ i_{R2} \\ i_{C1} \\ i_{L2} \\ V_{L2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & -1/R_2 \\ -1/R_1 & 0 & -1/R_1 \\ 0 & 1 & 0 \\ 0 & -R_3 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 1/R_2 \\ -1/R_1 \\ 0 \\ 0 \end{bmatrix} V_i(t)$$

$i_{R2} = \frac{V_i - V_{C3}}{R_2}$

$i_{C1} = i_{R1} = \frac{V_i - V_{C3} - V_{C1}}{R_1}$

$i_{L2} = X_2$

$V_{L2} = V_{C3} - V_{R3} = V_{C3} - i_{L2}R_3$

$$\begin{cases} V_0 = X_3 \\ i_{R2} = -\frac{V_{C3}}{R_2} + \frac{V_i}{R_2} \end{cases}$$

$i_{C1} = -\frac{V_{C1}}{R_1} - \frac{V_{C3}}{R_1} - \frac{V_i}{R_1}$

$i_{L2} = X_2$

$V_{L2} = V_{C3} - i_{L2}R_3$

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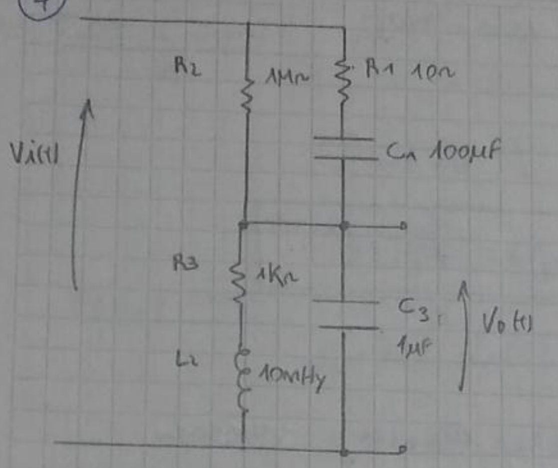


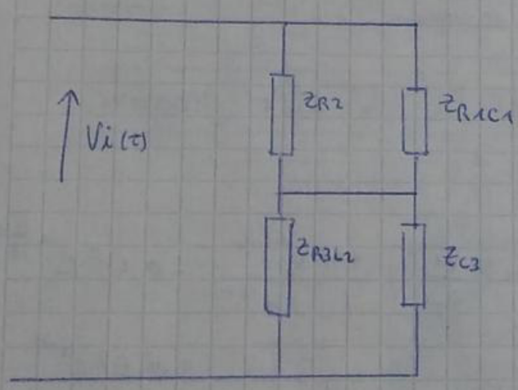
$V_i(t) = 10V + 100\sqrt{2}V \operatorname{sen}(1000t + \pi/6)$

$\omega_{C1} = 0,1$

$\omega_{C3} = \frac{1}{1000}$

$\omega_{L2} = 10$

→ Calculo impedancias: (para $100\sqrt{2} \operatorname{sen}(1000t + \pi/6)$ V)



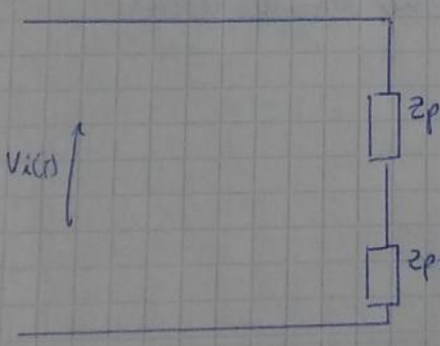
$Z_{R1C1} = Z_{C1} + R_1 = -j\frac{1}{\omega C_1} + R_1$

$Z_{R1C1} = \left(-j\frac{1}{0,1} + 10\right)\Omega$

$Z_{R1C1} = (10 - 10j)\Omega = 10\sqrt{2}e^{-j\pi/4}\,[\Omega]$

$Z_{R2} = R_2 = 1M\Omega$

$\frac{1}{Z_{p1}} = \frac{1}{R_2} + \frac{1}{Z_{R1C1}} \Rightarrow \frac{R_2 \cdot Z_{R1C1}}{R_2 + Z_{R1C1}} = Z_{p1}$



$Z_{p1} = \frac{1M\Omega \cdot 10\sqrt{2}e^{-j\pi/4}\Omega}{(\underbrace{1M\Omega + (10 - 10j)\Omega}_{\simeq 1.10^6})} = \frac{1.10^7\sqrt{2}e^{-j\pi/4}\Omega^2}{1.10^6\Omega}$

$\boxed{Z_{p_1} \simeq 10\sqrt{2}e^{-j\pi/4}\Omega = (10 - 10j)\Omega}$

$Z_{C3} = C3 = -j\frac{1}{\omega C_3} = -j\frac{1}{1000^{-1}}\Omega =$

$Z_{R3L2} = R3 + Z_{L2} = R3 + j\omega L_2$

$Z_{R3L2} = (1000 + j10)\Omega \simeq 1000,05e^{j0,57°}$

$Z_{p_2} = \frac{\left(-\frac{1}{\omega C_3}\right)j \cdot (1000 + j10)}{-j\frac{1}{\omega C_3} + 1000 + j10}$

$$\begin{bmatrix} \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} -1/R_1C_1 & 0 & -1/R_{f1} \\ 0 & -R_3/L_2 & 1/L_2 \\ -1/RC_3 & -1/C_2 & \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1/R_1C_1 \\ 0 \end{bmatrix} V_{i(t)}$$

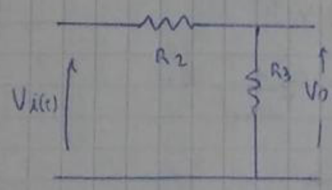
$$Z_{p2} = \frac{\left(-j\frac{1}{1000}\right)(1000+10j)}{j\left(10-\frac{1}{1000}\right)+1000} = \frac{(10000-1.10^6 j)}{1000-990j} \cong \underbrace{505-500j}_{Z_{p2}} \cong \overset{710{,}68}{710}\, e^{-i\pi/4}\ [\Omega]$$

$\Rightarrow Z_T = Z_{p1} + Z_{p2} \quad \Rightarrow Z_T = (10-10j)\Omega + (505-500j)\Omega$

$$\boxed{Z_T = (515-510j)\Omega \cong 724{,}8\, e^{-i\pi/4}}$$

$V_0 = 10V$, $w=0$

→ el circuito para continua: $\Rightarrow R_T = R_2 + R_3 = 1M\Omega + 1K\Omega = 1001000\Omega$



$$I_0 = \frac{V_0}{R_T} = \frac{10V}{1001000\Omega} = 9{,}9\mu A \cong \underline{10\mu A}$$

Luego: $\boxed{P_0 = V_0 I_0 = 10V \cdot 10\mu A = 100\mu W}$

$w = 1000$

$V_1 = 100V$, $Z_T = (515-510j)$ $\Rightarrow$ $\bar{I}_1 = \frac{V_1}{Z_T} = \frac{100e^{i\pi/6}}{724{,}8\, e^{-i\pi/4}} = 0{,}138\, e^{i\frac{5}{12}\pi}$

↑
eficaz

$= 0{,}138 e^{i75}$

$I_1 = 0{,}138\ A$

↑
coef. de la primer armónica (eficaz)

Luego

$\cancel{Vef = (100)^2 + (0{,}138)^2}$

$Vef = \sqrt{(10)^2 + (100)^2}$

$Vef = 105\ V$

$Ief = \sqrt{(10\mu)^2 + (0{,}138)^2}$

$Ief = 0{,}138\ A$

$\boxed{P_s = 14{,}5\ V.A}$

↑
potencia aparente

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Potencia activa

$$P = P_0 + V_1 I_1 \cdot \cos(\varphi) \quad , \varphi = -\pi/4$$

$$P = 100\mu W + 100 \cdot 0{,}138 \cdot \frac{\sqrt{2}}{2} (W)$$

$$\boxed{P \cong 9{,}76\ W} \quad 9{,}75817$$

Potencia reactiva

$$P_q = V_1 I_1 \operatorname{sen}(\varphi)$$

$$P_q = 100 \cdot 0{,}138 \cdot \operatorname{sen}(-\pi/4)$$

$$\boxed{P_q \cong -9{,}76\ VAR} \quad 9{,}75807$$

Potencia de deformación

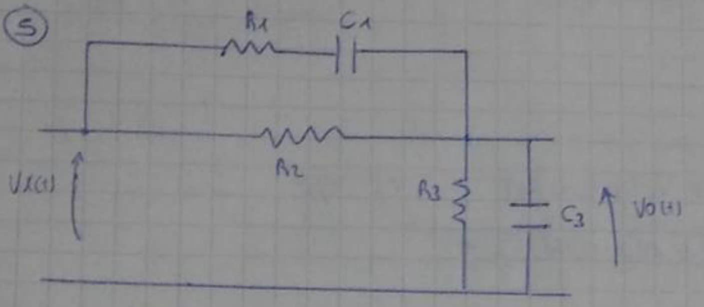
$$P_d = \sqrt{P_S^2 - P_q^2 - P^2}$$

$$P_d = \sqrt{(14{,}5)^2 - (9{,}75817)^2 - (9{,}75807)^2} \quad 4{,}45$$

$$\boxed{P_d = 4{,}45\ VAd}$$

NOTA

(5)



$$i_{R1} + i_{R2} = i_{R3} + i_{C3}$$

$$V_{R1} + V_{C1} + V_o = V_i$$

$$V_{C1} = V_i - V_o - V_{R1}$$

$$\frac{V_i - V_{C3} - V_{C1}}{R_1} + \frac{V_i - V_{C3}}{R_2} = \frac{V_{C3}}{R_3} + C_3 \frac{d}{dt} V_{C3}$$

$$i_{R3} + i_{C3} - i_{R2}$$
$$\downarrow \quad \downarrow \quad \downarrow$$
$$\frac{V_o}{R_3} \quad C_3\frac{dV_o}{dt} \quad \frac{(V_i - V_o)}{R_2}$$

$$\frac{V_i}{R_1} - \frac{V_o}{R_1} - \frac{V_{C1}}{R_1} + \frac{V_i}{R_2} - \frac{V_o}{R_2} = \frac{V_o}{R_3} + C_3 \frac{dV_o}{dt}$$

$$V_i\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - V_o\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{1}{R_1}\frac{1}{C_1}\int i_{C1}\,dt = \frac{V_o}{R_3} + C_3\frac{dV_o}{dt}$$

$$V_i\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{1}{R_1C_1}\int (i_{R3} + i_{C3} - i_{R2})\,dt = V_o\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) + C_3\frac{dV_o}{dt}$$

$$\frac{dV_i}{dt}\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{1}{R_1C_1}(i_{R3} + i_{C3} - i_{R2}) = \frac{dV_o}{dt}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) + C_3\frac{d^2V_o}{dt^2}$$

$$\frac{dV_i}{dt}\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{1}{R_1C_1R_3}\cdot V_o - \frac{C_3 dV_o}{R_1C_1 dt} + \frac{V_i}{R_2} - \frac{V_o}{R_2} = \frac{dV_o}{dt}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) + C_3\frac{d^2V_o}{dt^2}$$

> Falta multiplicar por R

$$\dot{V_i}\left(\frac{1}{R_1} + \frac{1}{R_2}\right) + V_i \cdot \frac{1}{R_2} = \ddot{V_o}C_3 + \dot{V_o}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{C_3}{R_1C_1}\right) + V_o\left(\frac{1}{R_1C_1R_3} + \frac{1}{R_2}\right)$$

$$\dot{V_i}\left(\frac{R_1+R_2}{R_1R_2}\right) + V_i\frac{1}{R_2} = \ddot{V_o}C_3 + \dot{V_o}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{C_3}{R_1C_1}\right) + V_o\left(\frac{R_2R_3C_1 + 1}{R_1R_2R_3C_1}\right)$$

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(b) (1) $\overset{\circ}{X_1} = \dfrac{-X_1}{RC} - \dfrac{X_2}{C} + \dfrac{V_i}{RC}$, $\dot{X_2} = \dfrac{X_1}{L}$ (2)

(3) $V_0(t) = -X_1 + V_i(t)$

de (1):

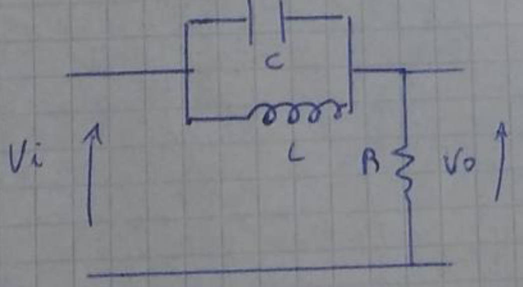
$$C \cdot \overset{\circ}{X_1} = -\frac{X_1}{R} - X_2 + \frac{V_i}{R}$$

Si $X_1 = V_C$, $X_2 = i_L$

$$C \frac{dV_C}{dt} = -\frac{V_C}{R} - i_L + \frac{V_i}{R}$$

$$i_L + \frac{V_C}{R} + i_C = \frac{V_i}{R}$$

$$i_L + i_C = \frac{(V_i - V_C)}{R} \quad i_R$$

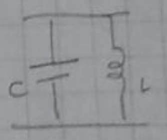


de (2):

$$L \dot{X_2} = X_1$$

$\downarrow$

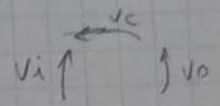
$$L \frac{di_L}{dt} = V_C = V_L$$



de (3)

$V_0(t) = -V_C + V_i$

$V_i = V_0 + V_C$



NOTA

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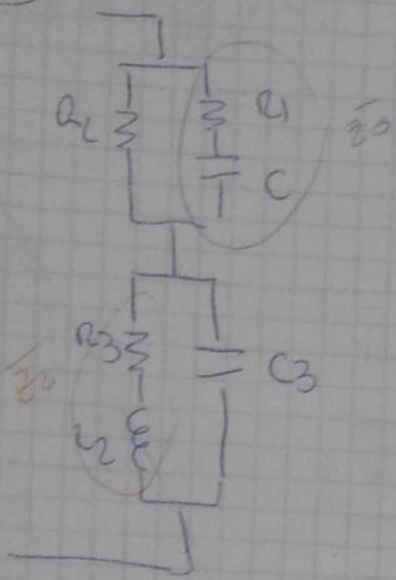


$v_i(t) = v_0 + v_p \operatorname{sen}(\omega t + \theta_v)$

$v_0 = 10\,V \qquad v_p = 100\sqrt{2}\,V$

$\omega = 1000\ r/s \qquad \theta_v = 30°$

$R_1 = 10\,\Omega$

$R_2 = 1\ 10^{6}\,\Omega$

$R_3 = 1\,k\Omega$

$L_2 = 10\ 10^{-3}\,Hy$

$C_1 = 100\ 10^{-6}\,F$

$C_3 = 1\ 10^{-6}\,F$

a) $P_S = \bar{V} \cdot I^{*}$

$\overline{Y_{C3}} = j\omega C = j\,1000 \cdot 1\,10^{-6} = j\,1\,10^{-3}$

$\overline{Z_S} = R_1 - j\frac{1}{\omega C} = 10\,\Omega - j\frac{1}{1000 \cdot 100\,10^{-6}}$

$\overline{Z_S} = 10\,\Omega - j\,10 = 9{,}85\ e^{-j45°}$

$\overline{Z_{R2}} = R_2 = 1\ 10^{6}\,\Omega$

$\overline{Y_1} = \frac{1}{R_2} + \frac{1}{\overline{Z_S}} = \frac{1}{1\,10^{6}\,\Omega} + \frac{1}{9{,}85\,e^{-j45}}$

$\overline{Y_1} = 1\,10^{-6} + \underbrace{0{,}10\ e^{j45°}}_{0{,}07 + j\,0{,}07}$

$\overline{Y_1} = (70\ 10^{-3} + j\,0{,}07)\,\Omega$

$\overline{Z_2} = R_3 + j\omega L = 1\,10^{3}\,\Omega + j\,1000\,1/s\ 10\,10^{-3}\,Hy$

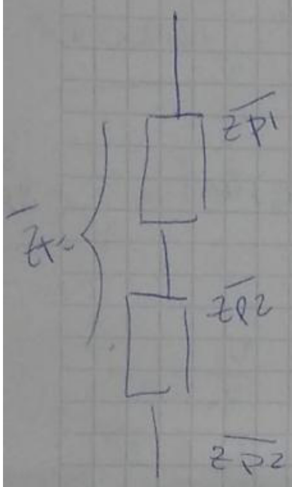
$\overline{Z_2} = 1\,10^{3}\,\Omega + j\,10 = 1\,10^{3}\ e^{j0{,}57°}$

$$\overline{Y_2} = \frac{1}{\overline{Z_2}} + \overline{Y_3} = \frac{1}{1\,10^{3} e^{j0,57°}} + j\,1\,10^{-3}$$

$$= 1\,10^{-3} e^{-j0,57°} + j\,1 \cdot 10^{-3}$$

$$= 0,99\,10^{-3} - j\,9,9\,10^{-6} + j\,1\,10^{-3}$$

$$\overline{Y_2} = 0,99\,10^{-3} - j\,9,9\,10^{-4}$$



$$\boxed{\overline{Y_2} = 1,4\,10^{-3}\, e^{-j45°}} \;\Omega$$

$$\overline{Z_{P2}} = \frac{1}{1,4\,10^{-3} e^{-j45°}}$$

$$\overline{Z_{P2}} = 714,29\, e^{j45°} \;\Omega$$

$$\overline{Z_{P2}} = 505,1 + j\,505,1$$

$$\overline{Y_{P1}} = (70 \cdot 10^{-3} + j\,0,07)\;\Omega$$

$$\overline{Y_{P1}} = 0,099\, e^{j45°} \;\Omega$$

$$\overline{Z_{P1}} = \frac{1}{0,099\, e^{j45°}} \;\Omega$$

$$\boxed{\overline{Z_{P1}} = 10\, e^{-j45°} \;\Omega}$$

$$\overline{Z_{P1}} = 7,07 - j\,7,07$$

$$\overline{Z_T} = \overline{Z_{P1}} + \overline{Z_{P2}} = 505,1 + j\,505,1 + 7,07 - j\,7,07$$

$$\boxed{\overline{Z_T} = 512,17 + j\,498,03 \;\Omega}$$

$\bar{Z} = (512,17 \; (-) \; j\,498,03)\ \Omega = 714,39\, e^{(-)j\,44,2^\circ}$

a)

$PS = \sqrt{\sum_{n=0}^{+\infty} V_n^2}\ \sqrt{\sum_{n=0}^{+\infty} I_n^2} = \sqrt{10\,100V^2}\ \sqrt{0,02A^2} = 14,21$

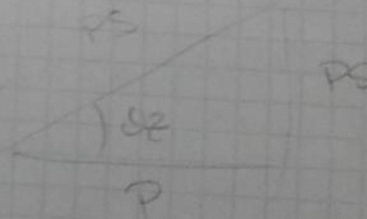
$\sum_{n=0}^{+\infty} V_n^2 = V_0^2 + V_1^2 = (10V)^2 + (100V)^2 = 10\,100\,V^2$

$\sum_{n=0}^{+\infty} I_n^2 = I_0^2 + I_1^2 = (0,014A)^2 + (0,14A)^2 = 0,02A^2$

$Z = \frac{V}{I} \Rightarrow \bar{I} = \frac{\bar{V}}{\bar{Z}} \Rightarrow \bar{I}_0 = \frac{V_0}{Z_1} \qquad \bar{I}_1 = \frac{\bar{V}_1}{Z_1}$

$\bar{I}_0 = \frac{10V}{714,39} = 0,014\ A.$

$\bar{I}_1 = \frac{100}{714,39} = 0,14\ A$



b)

$\cos\theta z = \frac{P}{PS} \Rightarrow P = 10\ W$

$PS = 14,21\ VA$

$\theta z = 44,2^\circ$

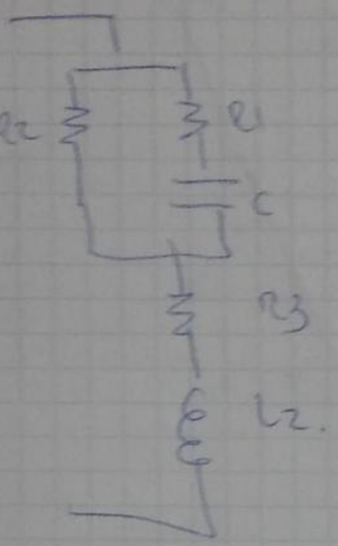
$\sin\theta z = \frac{PQ}{PS} \Rightarrow PQ = (-)\ 10\ VAR$

c) $Pd^2 = Ps^2 - P^2 - PQ^2$

$Pd^2 = 1,9241$

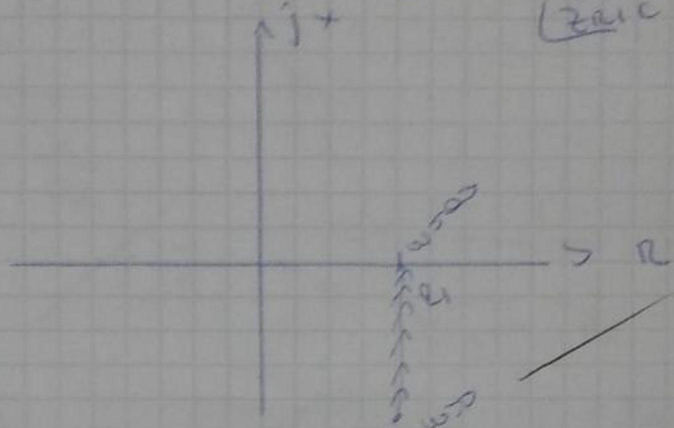
$\boxed{Pd = 1,38.}$

$0 \leq \omega < \infty$



$\overline{Z_{R_1C}} = R_1 - j\frac{1}{\omega C}$

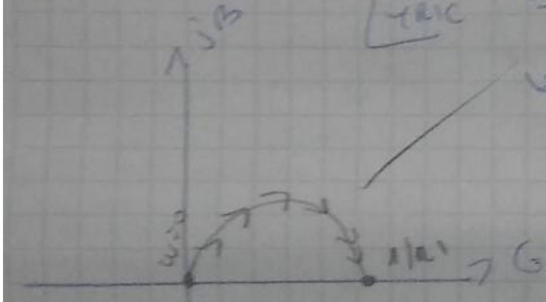
$\boxed{\overline{Z_{R_1C}}}$



$\boxed{\overline{Y_{R_1C}}}$

$\underline{\omega=0}$ $\overline{Z} = R_1 - j\infty$

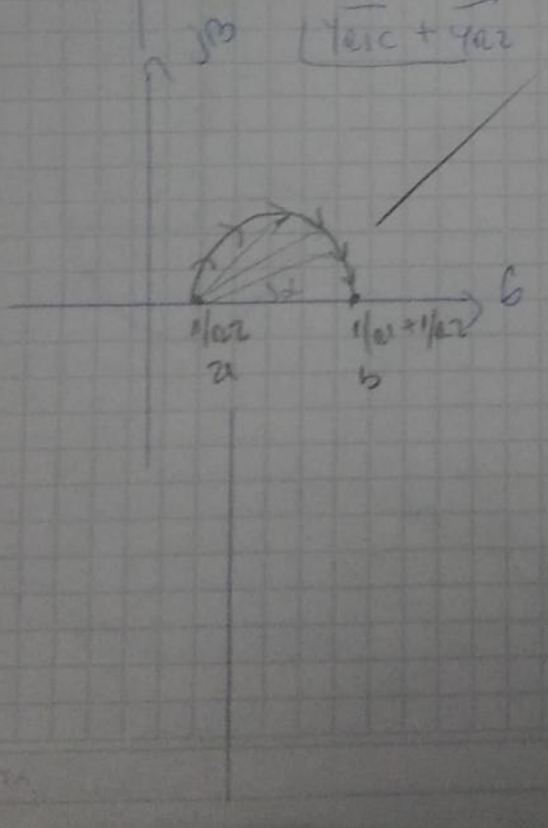
$\underline{\omega=\infty}$ $\overline{Z} = R_1 - j0$



$\overline{Y_{R_1C}} = \dfrac{1}{R_1 - j\frac{1}{\omega C}}$

$\underline{\omega=0}$ $\overline{Y} = \dfrac{1}{R_1 - j\infty}$

$\boxed{\overline{Y_{R_1C}} + \overline{Y_{R_2}}}$



$\underline{\omega=\infty}$ $\overline{Y} = \dfrac{1}{R_1 - j0}$

$\overline{Y_{R_1C}} + \overline{Y_{R_2}} = \dfrac{1}{R_1 - j\frac{1}{\omega C}} + \dfrac{1}{R_2}$

$\underline{\omega=0}$ $\overline{Y} = \dfrac{1}{R_1 - j\infty} + \dfrac{1}{R_2}$

$\underline{\omega=\infty}$ $\overline{Y} = \dfrac{1}{R_1 - j0} + \dfrac{1}{R_2}$

$\overline{Y_{R1C}} + \overline{Y_{R2}} = \frac{1}{R1 - j\frac{1}{\omega C}} + \frac{1}{R2}$

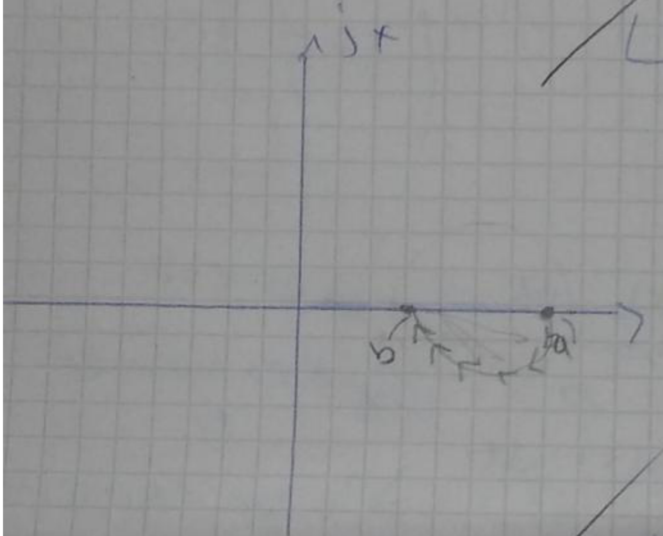
$$\overline{Z} = \frac{1}{\frac{1}{R1 - j\frac{1}{\omega C}} + \frac{1}{R2}} + R3$$

$\overline{Z}$

$\underline{\omega = 0}$ $\quad \frac{1}{\frac{1}{R_1 - j\infty} + \frac{1}{R2}} + R$

∞

$\frac{1}{\frac{1}{R2}} + R3$



$\underline{\omega = \infty}$

$\frac{1}{\frac{1}{R1 - j0} + \frac{1}{R1}} + R3$

$\overline{Z_4} = j\omega L_2$

$\overline{Z_T}$