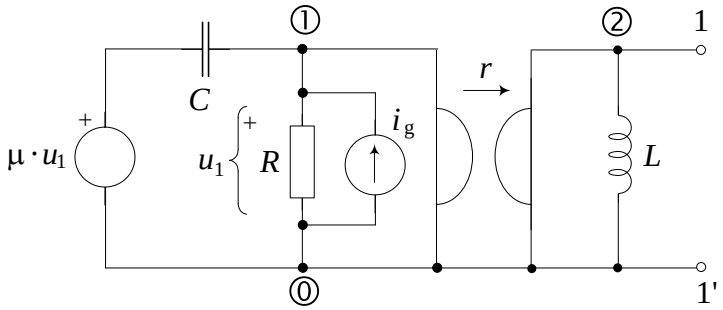
ZAVRŠNI ISPIT IZ ELEKTRIČNIH KRUGOVA – Rješenja – 2012-2013

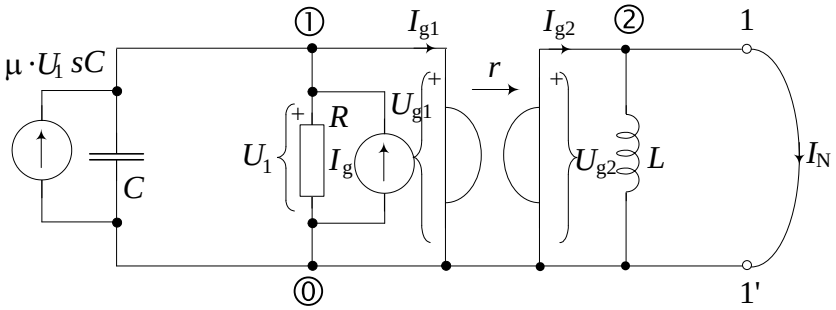
1. Za električni krug na slici zadane su normalizirane vrijednosti elemenata C=1, L=1, R=1 te μ=2, r=1, $i_g(t)=S(t)$. Odrediti nadomjesne parametre mreže po Northonu s obzirom na polove 1–1'. Koristiti metodu napona čvorišta. U zadatku je potrebno:

a) Nacrtati sklop za izračunavanje Nortonove struje, postaviti jednadžbe napona za čvorišta ① i ②;
b) Odrediti Nortonovu struju $I_N(s)$;
c) Nacrtati sklop za izračunavanje Nortonove admitancije, postaviti jednadžbe napona za čvorišta ① i ②;
d) Odrediti Nortonovu admitanciju $Y_N(s)$.
e) Da li je električni krug recipročan? Zašto?



Rješenje:

a) Jednadžbe napona za čvorišta ① i ②:



1) $U_1\left(sC+\frac{1}{R}\right)=I_g(s)+\mu U_1 sC-I_{g1}$

2) $U_2\frac{1}{sL}=I_{g2}(s)-I_N(s)$

3) $I_{g2}=-\frac{1}{r}U_1$

4) $I_{g1}=-\frac{1}{r}U_2$

$U_2=0,\ I_{g1}=0$

1) $U_1\left(sC-\mu sC+\frac{1}{R}\right)=I_g(s)\Rightarrow U_1=\frac{I_g(s)}{sC(1-\mu)+1/R}$

2) $I_N(s)=I_{g2}(s)=-\frac{1}{r}U_1(s)$ (1 bod)

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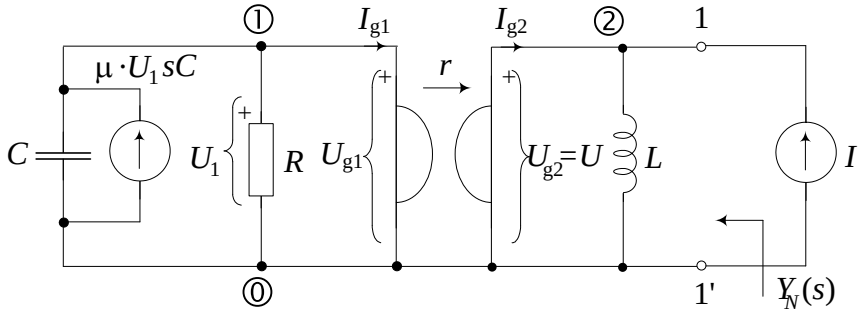
b) Nortonova struja $I_N(s)$:

$$1) \to 2) \Rightarrow I_N(s) = -\frac{1}{r} \cdot \frac{I_g(s)}{sC(1-\mu)+1/R}$$

$$I_N(s) = -\frac{1}{1} \cdot \frac{\frac{1}{s}}{-s+1} = -\frac{1}{s(1-s)} = \frac{1}{s(s-1)} \Rightarrow I_N(s) = \frac{1}{s(s-1)} \quad \text{(1 bod)}$$

c) Izračunavanje Nortonove admitancije pomoću jednadžbi napona čvorišta ① i ②



$$\Rightarrow Y_N(s) = \frac{I(s)}{U(s)}$$

1) $U_1\left(sC + \frac{1}{R}\right) = \mu U_1 sC - I_{g1}$

2) $U_2 \frac{1}{sL} = I_{g2}(s) + I(s)$

3) $I_{g2} = -\frac{1}{r} U_1$

4) $I_{g1} = -\frac{1}{r} U_2$, $U_2 = U$

$$1) \; U_1\left[sC(1-\mu) + \frac{1}{R}\right] = \frac{1}{r} U_2 \Rightarrow U_1 = \frac{1}{r} \cdot \frac{U_2}{sC(1-\mu)+1/R}$$

$$2) \; U_2 \frac{1}{sL} = -\frac{1}{r} U_1 + I(s) \Rightarrow U_2 \frac{1}{sL} = -\frac{1}{r^2} \cdot \frac{U_2}{sC(1-\mu)+1/R} + I(s) \quad \text{(1 bod)}$$

d) Nortonova admitancija $Y_N(s)$:

$$I(s) = U(s)\left[\frac{1}{sL} - \frac{1}{r^2} \cdot \frac{1}{sC(1-\mu)+1/R}\right] \Rightarrow Y_N(s) = \frac{I(s)}{U(s)} = \frac{1}{sL} - \frac{1}{r^2} \cdot \frac{1}{sC(1-\mu)+1/R}$$

$$Y_N(s) = \frac{I(s)}{U(s)} = \frac{1}{s} - \frac{1}{-s+1} = \frac{1}{s} + \frac{1}{s-1} = \frac{s-1+s}{s(s-1)} = \frac{2s-1}{s(s-1)} \quad \text{(1 bod)}$$

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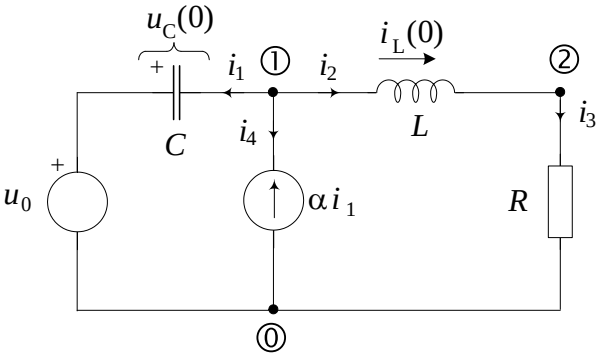
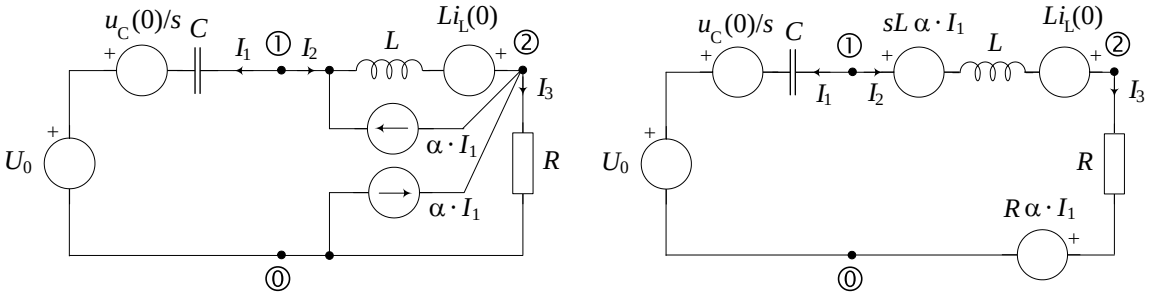
e) Da li je električni krug recipročan? Zašto?
NE, električni krug nije recipročan jer sadrži ovisni izvor i girator. (1 bod)

2. Za električni krug prikazan slikom i pridruženim orijentacijama grana te čvorovima (grane stabla: 1, 2) treba odrediti temeljni sustav jednadžbi petlji primjenom grafova. a) Na usamljeni strujni izvor u grani 4 treba primijeniti postupak posmicanja strujnog izvora (pritom grana 4 nestaje). b) Nacrtati orijentirani graf i napisati spojnu matricu **S**. Napisati: c) matricu impedancija grana $\mathbf{Z}_b$ i vektor početnih uvjeta i nezavisnih izvora grana $\mathbf{U}_{0b}$, d) matricu impedancija petlji $\mathbf{Z}_p$ i e) vektor početnih uvjeta i nezavisnih izvora petlji $\mathbf{U}_{0p}$.



Rješenje:

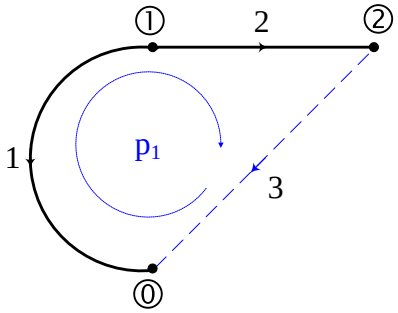
a) Primjena Laplaceove transformacije i posmicanje strujnog izvora:



(1 bod)

b) Orijentirani graf i spojna matrica:

Orijentirani graf:



Spojna matrica:

$$\mathbf{S} = \begin{bmatrix} -1 & 1 & 1 \end{bmatrix}$$

(1 bod)

c) Naponsko – strujne relacije grana: $\mathbf{U}_b = \mathbf{Z}_b \cdot \mathbf{I}_b + \mathbf{U}_{0b}$

(1) $U_1 = \dfrac{1}{sC} \cdot I_1 - \dfrac{u_C(0)}{s} + U_0$

(2) $U_2 = sL \cdot I_2 + sL\alpha \cdot I_1 - Li_L(0)$

(3) $U_3 = R \cdot I_3 + R \cdot \alpha \cdot I_1$

$$\mathbf{Z}_b = \begin{bmatrix} \dfrac{1}{sC} & 0 & 0 \\ sL\alpha & sL & 0 \\ R\alpha & 0 & R \end{bmatrix}, \quad \mathbf{U}_{0b} = \begin{bmatrix} -\dfrac{u_C(0)}{s} + U_0(s) \\ -Li_L(0) \\ 0 \end{bmatrix}$$

(1 bod)

Matrica $\mathbf{Z}_b$ je regularna.

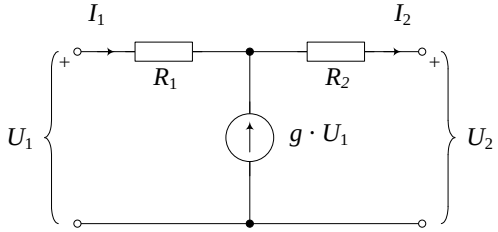
d) i e) Temeljni sustav jednadžbi petlji u matričnom obliku: $\mathbf{Z}_p \cdot \mathbf{I}_p = \mathbf{U}_{0p}$

$$\mathbf{S} \cdot \mathbf{Z}_b = \begin{bmatrix} -1 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{sC} & 0 & 0 \\ sL\alpha & sL & 0 \\ R\alpha & 0 & R \end{bmatrix} = \begin{bmatrix} -\frac{1}{sC} + sL\alpha + R\alpha & sL & R \end{bmatrix}$$

$$\mathbf{Z}_p = \mathbf{S} \cdot \mathbf{Z}_b \cdot \mathbf{S}^T = \begin{bmatrix} -\frac{1}{sC} + sL\alpha + R\alpha & sL & R \end{bmatrix} \cdot \begin{bmatrix} -1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{sC} - (sL + R)\alpha + sL + R \end{bmatrix}$$ (1 bod)

$$\mathbf{U}_{0p} = -\mathbf{S} \cdot \mathbf{U}_{0b} = -\begin{bmatrix} -1 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} -\frac{u_C(0)}{s} + U_0(s) \\ -Li_L(0) \\ 0 \end{bmatrix} = \begin{bmatrix} -\frac{u_C(0)}{s} + U_0(s) + Li_L(0) \end{bmatrix}$$ (1 bod)

3. Za četveropol na slici izračunati: a) [*a*]-parametre. Zadano je R_1=2, R_2=1, g=1/2. b) Da li je četveropol: recipročan, simetričan ? Obrazložiti odgovore. Ako je izlazni prilaz (2–2') zaključen otporom R_L=1 pomoću [*a*]-parametara izračunati: c) ulaznu impedanciju $Z_{ul1}(s)=U_1(s)/I_1(s)$; d) ako je uz to na ulaz priključen generator ulaznog otpora R_g=1 izračunati prijenosnu funkciju napona $H(s)=U_2(s)/U_g(s)$.

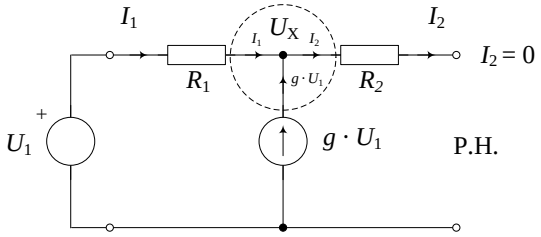


Rješenje:

a) [*a*]-parametri: (2 boda)

$$U_1 = A\cdot U_2 + B\cdot I_2$$
$$I_1 = C\cdot U_2 + D\cdot I_2$$

$I_2 = 0$ $\qquad A = \left.\dfrac{U_1}{U_2}\right|_{I_2=0}$; $\quad C = \left.\dfrac{I_1}{U_2}\right|_{I_2=0}$

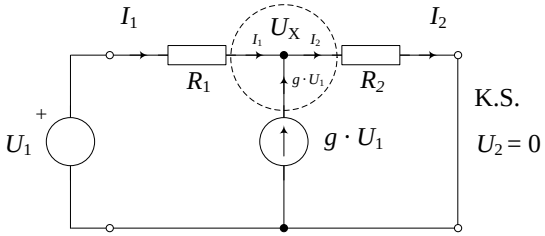


$$I_1 + g\cdot U_1 = 0 \Rightarrow I_1 = -g\cdot U_1$$
$$U_X = U_1 - I_1\cdot R_1$$

$$\Rightarrow U_2 = U_X = U_1 + g\cdot U_1\cdot R_1 = (1+gR_1)\cdot U_1 \qquad A = \left.\frac{U_1}{U_2}\right|_{I_2=0} = \frac{1}{1+gR_1} = \frac{1}{1+\frac{1}{2}2} = \frac{1}{2}$$

$$\Rightarrow U_1 = -\frac{I_1}{g},\ U_2 = (1+gR_1)\cdot U_1 = -\frac{1+gR_1}{g}\cdot I_1 \qquad C = \left.\frac{I_1}{U_2}\right|_{I_2=0} = -\frac{g}{1+gR_1} = \frac{-\frac{1}{2}}{1+1} = -\frac{1}{4}$$

$U_2 = 0$ $\qquad B = \left.\dfrac{U_1}{I_2}\right|_{U_2=0}$; $\quad D = \left.\dfrac{I_1}{I_2}\right|_{U_2=0}$



(1) $I_1 + g\cdot U_1 = I_2$

(2) $U_X = I_2\cdot R_2 = U_1 - I_1\cdot R_1$

$$(1) \Rightarrow U_1 = \frac{I_2}{g} - \frac{I_1}{g}$$

$$(2) \Rightarrow I_1 = \frac{1}{R_1}\cdot U_1 - I_2\frac{R_2}{R_1},\ I_2 = \frac{U_1}{R_2} - I_1\frac{R_1}{R_2}$$

$$\frac{1}{R_1}\cdot U_1 - I_2\frac{R_2}{R_1} + g\cdot U_1 = I_2$$

$$U_1\left(\frac{1}{R_1}+g\right) = I_2\left(1+\frac{R_2}{R_1}\right) \qquad B = \left.\frac{U_1}{I_2}\right|_{U_2=0} = \frac{1+R_2/R_1}{1/R_1+g} = \frac{R_1+R_2}{1+gR_1} = \frac{2+1}{1+(1/2)\cdot 2} = \frac{3}{2}$$

$$(1)\rightarrow(2) \Rightarrow I_2 = I_2\frac{1}{gR_2} - I_1\frac{1}{gR_2} - I_1\frac{R_1}{R_2}$$

$$I_2\left(\frac{1}{gR_2}-1\right) = I_1\left(\frac{1}{gR_2}+\frac{R_1}{R_2}\right) \quad D = \left.\frac{I_1}{I_2}\right|_{U_2=0} = \frac{\frac{1}{gR_2}-1}{\frac{1}{gR_2}+\frac{R_1}{R_2}} = \frac{1-gR_2}{1+gR_1} = \frac{1-\frac{1}{2}}{1+\frac{1}{2}2} = \frac{\frac{1}{2}}{2} = \frac{1}{4}$$

Uvrstimo vrijednosti elemenata R_1=2, R_2=1, g=1/2:

$$[a] = \begin{bmatrix} 1/2 & 3/2 \\ -1/4 & 1/4 \end{bmatrix}$$

b) Da li je četveropol recipročan, simetričan? (1bod)

Za recipročnost vrijedi: $\Delta = AD - BC = 1$

$$\Delta = \frac{1}{2}\cdot\frac{1}{4} + \frac{3}{2}\cdot\frac{1}{4} = \frac{1}{8}+\frac{3}{8} = \frac{4}{8} = \frac{1}{2} \quad \Rightarrow \text{ Čeveropol nije recipročan.}$$

Za simetričnost vrijedi: A=D $\Rightarrow \frac{1}{2} \neq \frac{1}{4}$ $\Rightarrow$ Četveropol nije simetričan

Konačno iz jednadžbi $\underline{\begin{aligned} U_1 &= A\cdot U_2 + B\cdot I_2 \\ I_1 &= C\cdot U_2 + D\cdot I_2 \end{aligned}}$, $R_L = \frac{U_2}{I_2}$, $U_g = I_1R_g + U_1$ slijede:

c) Ulazna impedancija u četveropol:

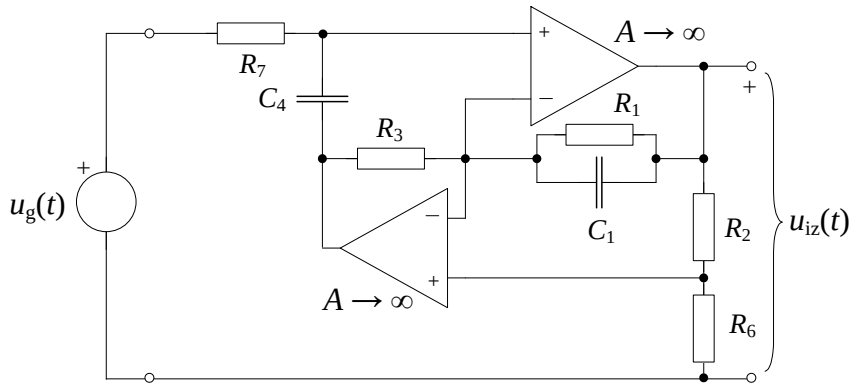
$$Z_{ul1}(s) = \frac{U_1}{I_1} = \frac{AU_2+BI_2}{CU_2+DI_2} = \frac{A\frac{U_2}{I_2}+B}{C\frac{U_2}{I_2}+D} = \frac{AR_L+B}{CR_L+D} \Rightarrow Z_{ul1}(s) = \frac{\frac{1}{2}\cdot 1+\frac{3}{2}}{-\frac{1}{4}\cdot 1+\frac{1}{4}} = \frac{2}{0} = \infty \text{ (1 bod)}$$

d) Prijenosna funkcija napona:

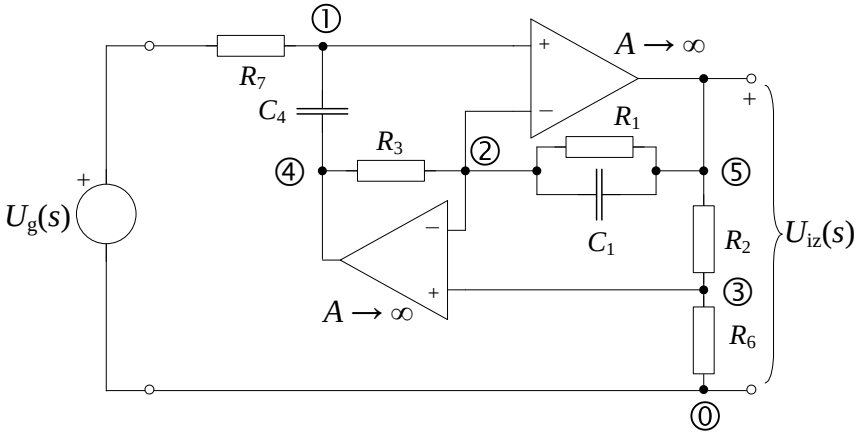
$$U_g = I_1R_g + U_1 = \left(CU_2 + D\frac{U_2}{R_L}\right)R_g + AU_2 + B\frac{U_2}{R_L}$$

$$\Rightarrow H(s) = \frac{U_2}{U_g} = \frac{R_L}{AR_L + B + R_g(CR_L+D)} \Rightarrow H(s) = \frac{1}{\frac{1}{2}\cdot 1+\frac{3}{2}+1\cdot\left[-\frac{1}{4}\cdot 1+\frac{1}{4}\right]} = \frac{1}{2} \text{ (1 bod)}$$

4. Zadan je aktivni-RC električni filtar prikazan slikom s normaliziranim vrijednostima elemenata C_1=1/2, C_4=2, te R_1=3, R_2=R_3=R_6=R_7=1. a) Izračunati njegovu naponsku prijenosnu funkciju $T(s)=U_{iz}(s)/U_g(s)$. O kojem se tipu filtra radi (NP, VP, PP ili PB)? b) Usporedbom s odgovarajućim općim oblikom prijenosne funkcije filtra 2. stupnja izračunati parametre k, ω_0, Q. c) Prikazati raspored polova i nula u kompleksnoj ravnini. d) Nacrtati amplitudno-frekvencijsku karakteristiku.



Rješenje: Laplaceova transformacija:



a) Metoda čvorišta:

$$(1)\quad U_1\left(\frac{1}{R_7}+sC_4\right)-U_4sC_4=U_g\frac{1}{R_7}$$

$$(2)\quad -U_4\frac{1}{R_3}+U_2\left(\frac{1}{R_1}+\frac{1}{R_3}+sC_1\right)-U_5\left(\frac{1}{R_1}+sC_1\right)=0$$

$$(3)\quad -U_5\frac{1}{R_2}+U_3\left(\frac{1}{R_2}+\frac{1}{R_6}\right)=0$$

$$(4)\quad A\to\infty\Rightarrow U_1=U_2=U_3$$

$$(1)\quad U_1\left(\frac{1}{R_7}+sC_4\right)-U_4sC_4=U_g\frac{1}{R_7}$$

$$(2)\quad -U_4\frac{1}{R_3}+U_1\left(\frac{1}{R_1}+\frac{1}{R_3}+sC_1\right)-U_5\left(\frac{1}{R_1}+sC_1\right)=0$$

$$(3)\quad -U_5\frac{1}{R_2}+U_1\left(\frac{1}{R_2}+\frac{1}{R_6}\right)=0$$

$$(1) \Rightarrow U_4 = -U_g \frac{1}{sR_7C_4} + U_1\left(\frac{1}{sR_7C_4}+1\right)$$

$$(2) \Rightarrow U_4 = U_1\left(\frac{R_3}{R_1}+1+sR_3C_1\right) - U_5\left(\frac{R_3}{R_1}+R_3sC_1\right)$$

$$(3) \Rightarrow U_1 = \frac{R_6}{R_2+R_6}U_5; \quad U_5 = U_{iz} = \left(\frac{R_2}{R_6}+1\right)U_1$$

(1), (3) $\rightarrow$ (2) $\Rightarrow$

$$-U_g \frac{1}{sR_7C_4} + U_1\left(\frac{1}{sR_7C_4}+1\right) = U_1\left(\frac{R_3}{R_1}+sR_3C_1+1\right) - U_1\left(\frac{R_2}{R_6}+1\right)\left(\frac{R_3}{R_1}+sR_3C_1\right)$$

$$-U_g \frac{1}{sR_7C_4} + U_1\frac{1}{sR_7C_4} + U_1 = U_1\left(\frac{R_3}{R_1}+sR_3C_1\right) + U_1 - U_1\frac{R_2}{R_6}\left(\frac{R_3}{R_1}+sR_3C_1\right) - U_1\left(\frac{R_3}{R_1}+sR_3C_1\right)$$

$$U_g \frac{1}{sR_7C_4} = U_1\frac{1}{sR_7C_4} + U_1\frac{R_2}{R_6}\left(\frac{R_3}{R_1}+sR_3C_1\right) \Big/ \cdot sR_7C_4$$

$$U_g = U_1\left(1+\frac{R_3}{R_1}\frac{R_2}{R_6}sR_7C_4 + s\frac{R_2}{R_6}R_3C_1sR_7C_4\right)$$

$$U_g = U_1\left(1+s\frac{R_2R_3R_7C_4}{R_1R_6} + s^2\frac{R_2R_3R_7C_1C_4}{R_6}\right)$$

$$U_g = \frac{R_6}{R_2+R_6}U_{iz}\left(1+s\frac{R_2R_3R_7C_4}{R_1R_6} + s^2\frac{R_2R_3R_7C_1C_4}{R_6}\right)$$

$$T(s) = \frac{U_{iz}(s)}{U_g(s)} = \frac{\frac{R_2+R_6}{R_6}}{1+s\frac{R_2R_3R_7C_4}{R_1R_6}+s^2\frac{R_2R_3R_7C_1C_4}{R_6}} = \frac{\left(\frac{R_2}{R_6}+1\right)\frac{R_6}{R_2R_3R_7C_1C_4}}{s^2+s\frac{1}{R_1C_1}+\frac{R_6}{R_2R_3R_7C_1C_4}} = \frac{2}{s^2+\frac{2}{3}s+1}$$

(2 boda)

-o kojem se tipu filtra radi (NP, VP, PP ili PB)? $\Rightarrow$ NP

b) Usporedbom s odgovarajućim općim oblikom prijenosne funkcije filtra 2. stupnja izračunati parametre k, ω_0, Q.

$$T(s) = \frac{k\cdot\omega_0^{\,2}}{s^2+\frac{\omega_0}{Q}\cdot s+\omega_0^{\,2}}$$ Opći oblik NP (niski propust)

-parametri k, ω_0, Q:

$$k = \frac{R_2}{R_6}+1 = \left(\frac{1}{1}+1\right) = 2$$

$$\omega_0 = \sqrt{\frac{R_6}{R_2R_3R_7C_1C_4}} = \sqrt{\frac{1}{1\cdot1\cdot1\cdot\frac{1}{2}\cdot2}} = 1$$

$$\frac{\omega_0}{Q} = \frac{1}{R_1C_1} \Rightarrow Q = R_1C_1\omega_0 = R_1C_1\sqrt{\frac{R_6}{R_2R_3R_7C_1C_4}} = R_1C_1\cdot\omega_0 = \frac{3}{2}\cdot1 = 1.5\,.$$(1 bod)

c) raspored polova i nula u kompleksnoj ravnini: (1 bod)

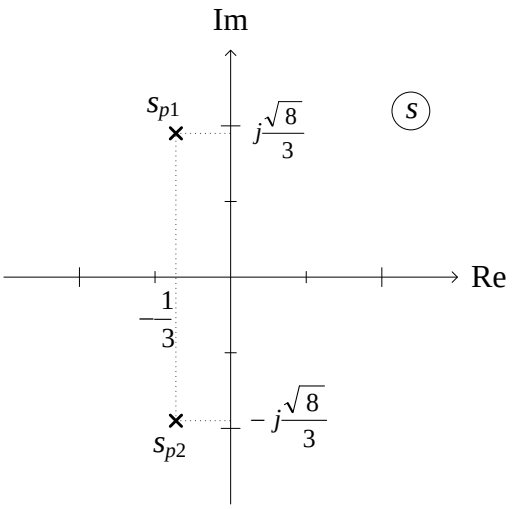
$$T(s)=\frac{2}{s^2+\frac{2}{3}s+1} \qquad \text{nule} \qquad s_{o1}=\infty, s_{o2}=\infty$$

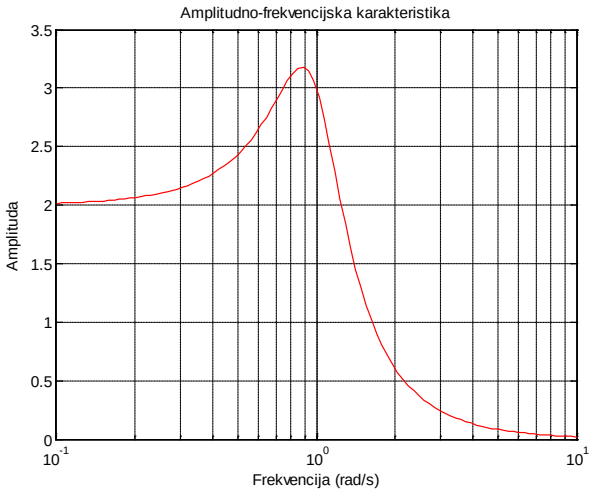
$$\text{polovi} \quad s^2+\frac{2}{3}s+1=0 \qquad \Rightarrow \qquad s_{p1,2}=-\frac{1}{3}\pm\sqrt{\frac{1}{9}-1}=-\frac{1}{3}\pm j\frac{\sqrt{8}}{3}=-\frac{1}{3}\pm j\frac{2\sqrt{2}}{3}$$

d) amplitudno-frekvencijska karakteristika: (1 bod)

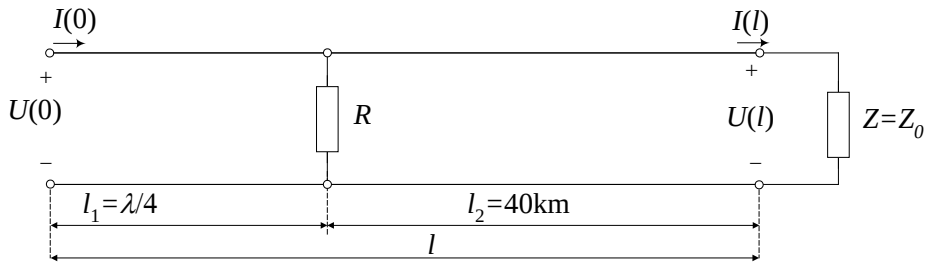
$s=j\omega \Rightarrow$

$$T(j\omega)=\frac{2}{-\omega^2+j\frac{2}{3}\omega+1} \qquad \Rightarrow \qquad |T(j\omega)|=\frac{2}{\sqrt{\left(1-\omega^2\right)^2+\left(\frac{2}{3}\omega\right)^2}}$$





5. Zadana je linija bez gubitaka s L=2 mH/km i C=6 nF/km, duljine $l=\lambda/4+40$km. Na kraj linije priključen je dvopol impedancije $Z=Z_0$, a na udaljenosti $l=\lambda/4$ od početka linije priključen je otpor R=100 Ω. Napon na ulazu linije je $u(0, t)=4\cdot\cos(10^4 t)$.
Odrediti:
a) karakterističnu impedanciju Z_0, koeficijent prijenosa γ i duljinu linije u km;
b) ulaznu impedanciju prve linije: Z_{ul1};
c) napon na kraju prve linije: $u(l_1, t)$;
d) napon na kraju linije: $u(l, t)$;
e) struju na kraju linije: $i(l, t)$.



Rješenje: Liniju ćemo analizirati kao dvije linije s istim primarnim parametrima, spojene u kaskadu

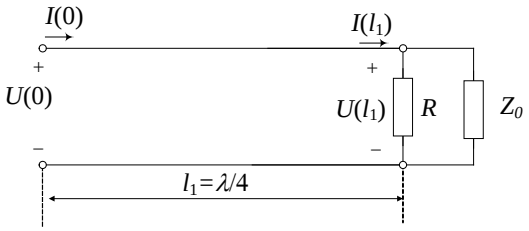
a) Linija bez gubitaka$\rightarrow Z_0 = \sqrt{\frac{L}{C}} = \sqrt{\frac{2\cdot 10^{-3}}{6\cdot 10^{-9}}} = \frac{10^3}{\sqrt{3}} = 577{,}35\Omega$

$$\gamma = j\beta = j\omega\sqrt{LC} = j2\cdot\sqrt{3}\cdot 10^{-2} = j0{,}0346/\text{km}$$

Duljina linije: $l = \frac{\lambda}{4} + 40 = \frac{2\pi}{4\beta} + 40 = \frac{2\pi}{4\cdot 2\cdot\sqrt{3}\cdot 10^{-2}} + 40 = 45{,}345 + 40 = 85{,}345\text{km}$ (1bod)

b) Ulazna impedancija linije.

Ulazna impedancija druge linije: $Z_{ul2} = Z_0$



Ukupna impedancija na kraju prve linije: $Z_2 = \frac{R\cdot Z_{ul2}}{R + Z_{ul2}} = \frac{R\cdot Z_0}{R + Z_0} = 85{,}25\Omega$

Ulazna impedancija prve linije: $Z_{ul1} = \frac{U(0)}{I(0)} = \frac{U(l_1)ch(\gamma l_1) + I(l_1)Z_0 sh(\gamma l_1)}{\frac{U(l_1)}{Z_0}sh(\gamma l_1) + I(l_1)Z_0 ch(\gamma l_1)}$

$$\gamma\cdot l_1 = j\beta\cdot l_1 = j\beta\frac{\lambda}{4} = j\frac{\pi}{2}$$

$$Z_{ul1} = \frac{U(l_1)\cos(\beta l_1) + jI(l_1)Z_0\sin(\beta l_1)}{j\frac{U(l_1)}{Z_0}\sin(\beta l_1) + I(l_1)Z_0\cos(\beta l_1)} = Z_0^2\frac{I(l_1)}{U(l_1)} = \frac{Z_0^2}{Z_2} = 3910\Omega$$

(1bod)

c) Napon na kraju prve linije (prva linija je zaključena sa $Z_2 \neq Z_0$):

$$U(l_1) = U(0)\cos(\beta l_1) - jI(0)Z_0\sin(\beta l_1) = -j\frac{U(0)}{Z_{ul1}}Z_0 = -j0.59$$

$$U(l_1) = 0{,}59\cdot e^{-j\pi/2}$$

$$u(l_1,t) = 0{,}59\cdot\cos(10^4 t - 1{,}57) = 0{,}59\cdot\cos(10^4 t - \pi/2)$$

(1bod)

d) Napon na kraju druge linije (druga linija je zaključena sa Z_0):

$$U(l) = U(l_2) = U(l_1)e^{-\gamma l_2} = U(l_1)e^{-j\beta\cdot 40} = U(l_1)e^{-j1{,}386} = 0{,}59\cdot e^{-j\pi/2}\cdot e^{-j1{,}386}$$

$$U(l) = 0{,}59\cdot e^{-j2{,}95}$$

$$u(l,t) = 0{,}59\cdot\cos(10^4 t - 2{,}95) = 0{,}59\cdot\cos(10^4 t - 0{,}94\pi)$$

(1bod)

e) Struja na kraju druge linije:

$$i(l,t) = \frac{u(l,t)}{Z_0} = 1{,}02\cdot 10^{-3}\cos(10^4 t - 2{,}95) = 1{,}02\cdot 10^{-3}\cdot\cos(10^4 t - 0{,}94\pi)$$

(1bod)