Teorie ke zkoušce

SUS:

Rezistory → sériově : $R_1 + R_2 \dots = R$

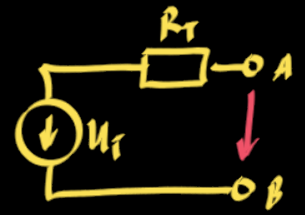
paralelně : $\frac{R_1 R_2}{R_1 + R_2} = R$

Dělič napětí → $U_{R_1} = \frac{R_1}{R_1 + R_2} U$

Dělič proudu → $I_{R_1} = \frac{R_2}{R_1 + R_2} I$

Thevenin: U_T = napětí naprázdno mezi A-B

R_T = celk. odpor obvodu



Norton: I_N = proud mezi zkratovanými A-B

$R_N = R_T$

Superpozice → pokud nemáme řízené zdroje

zdroje napětí ⇒ zkrat, proudu ⇒ rozpojení

→ spočítám "příspěvky" od zdrojů, které pak sečtu

Obvodové rovnice:

MUN: $v = d - z_U =$

$=$ uzl. póly − zdroje U

↳ **postup:** referenční uzel, 1. KCL → např. "$\frac{U_1 - 0}{R_1} + \frac{U_1 - U_2}{R_2} - I = 0$"

MSP: $s = v - d - z_I =$

$=$ proky − uzl. póly − zdroje I

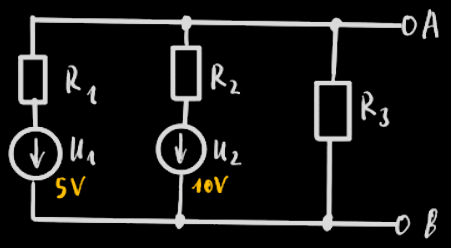
↳ **postup:** pro z_I neděláme smyčku

(pokud součástkou prochází více smyček, je potřeba je ± podle orientace.

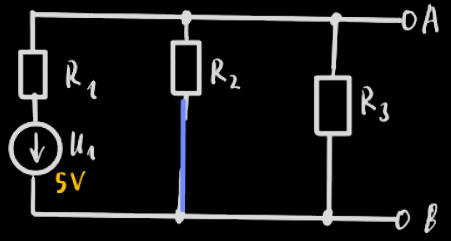
2. KCL → např. "$-U + R_3(I_1 + I_2) + R_2(I_1 + I) = 0$

Smyčky nesmí procházet z_I a jeho smyčkou

Thevenin:



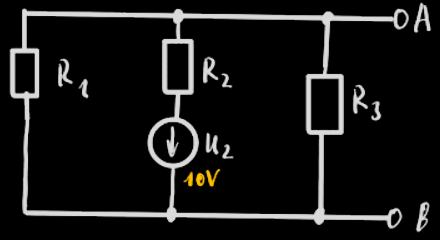
U_1:



$R_{23} = 1200\,\Omega$

$U_{R23} = U_{AB1} = U_1 \frac{R_{23}}{R_1 + R_{23}} = \underline{2{,}73\,V}$

U_2:



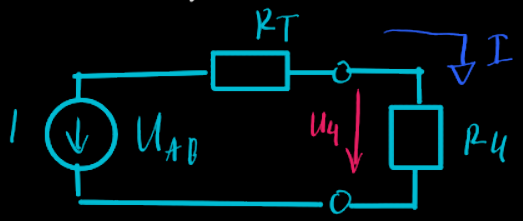
$R_{13} = 750\,\Omega$

$U_{R13} = U_{AB2} = U_2 \frac{R_{13}}{R_2 + R_{13}} = \underline{2{,}73\,V}$

$U_{AB} = U_T = \underline{5{,}455\,V}$

$R_{123} = \underline{545{,}455\,\Omega}$

$R_4 = 1000\,\Omega$

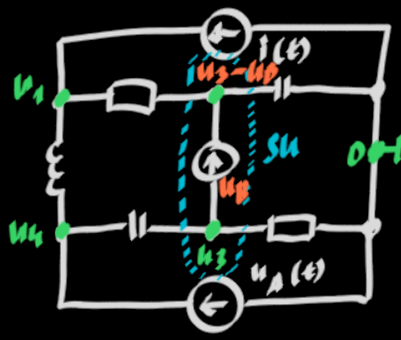


$U_4 = U_T \frac{R_4}{R_T + R_4} = \underline{3{,}53\,V}$ | $P_4 = U_4 \cdot I = 0{,}0125\,W = 12\,mW$

$I = \frac{U_T}{R_T + R_4} = \underline{3{,}53\,mA}$

Problém plovoucích zdrojů:

pokud zdroj není přímo připojený na referenci (plave), vytvoříme „superuzel"



$u_4 = -u_A(t)$

$u_1 = ?$

$u_2 = ?$

$u_3 = ?$

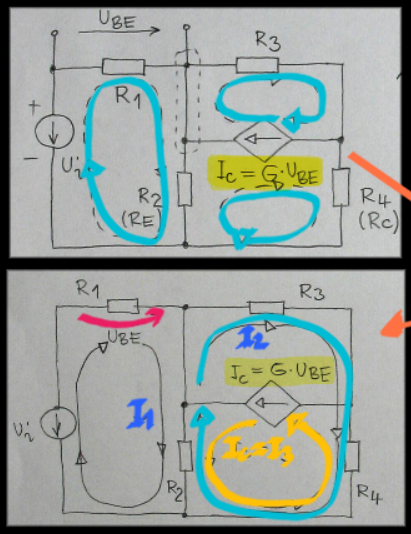
Superuzel → 2. KCL → $u_2(t) - u_3(t) + u_B(t) = 0$

$u_2(t) = u_3(t) - u_B(t)$

u_1: $-i + \frac{u_1 - (u_3 - u_B)}{R_1} + \frac{1}{L}\int (u_1 + u_A)\,dx + i_L(0)$

Superuzel: $\frac{u_3}{R_2} + C_2\frac{d[u_3 + u_A]}{dt} + C_1\frac{d[u_3 - u_B]}{dt} + \frac{u_3 - u_B - u_1}{R_1} = 0$

Řešení řízených zdrojů: MSP



uzly = 4, $d = 4 - 1 = 3$

prvky = 6, $s = 6 - 3$

$x_{MSP} = s - 2i = 2$ rovnice

nesmíme ale vést > 1 smyčkou zdrojem proudu, je potřeba úprava abychom se „vyhnuli" I_C.

I_1: $-U_1 + R_1 I_1 + R_2(I_1 + I_C - I_2) = 0$

I_2: $R_3 I_2 + R_4(I_2 - I_C) + R_2(I_2 - I_C - I_1) = 0$

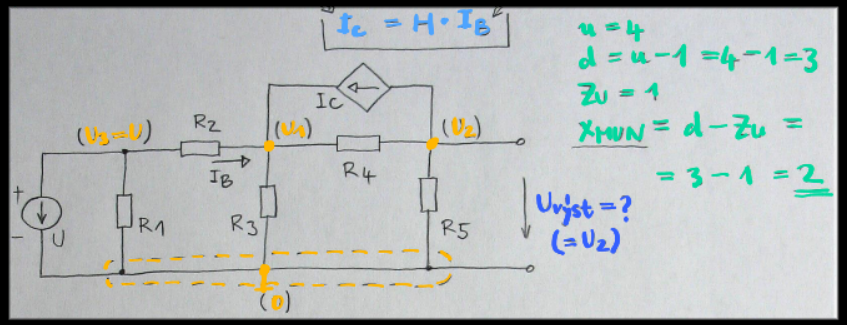
Musíme vyjádřit I_C: $I_C = G \cdot U_{BE}$

→ vyjádřit smyč. proudy $U_{BE} = R_1 I_1 \Rightarrow$ **$I_C = G \cdot R_1 I_1$**

I_1: $-U_1 + R_1 I_1 + R_2(I_1 + GR_1 I_1 - I_2) = 0$

I_2: $R_3 I_2 + R_4(I_2 - GR_1 I_1) + R_2(I_2 - GR_1 I_1 - I_1) = 0$

Řízený zdroj č.2 — MUN



$u = 4$
$d = u - 1 = 4 - 1 = 3$
$z_U = 1$
$x_{MUN} = d - z_U = 3 - 1 = 2$

$U_1: \quad \frac{U_1 - U}{R_2} + \frac{U_1}{R_3} + \frac{(U_1 - U_2)}{R_4} - I_C = 0$

$U_2: \quad I_C + \frac{(U_2 - U_1)}{R_4} + \frac{U_2}{R_5} = 0$

$I_C = H \cdot I_B = H \frac{U - U_1}{R_2}$ ✓

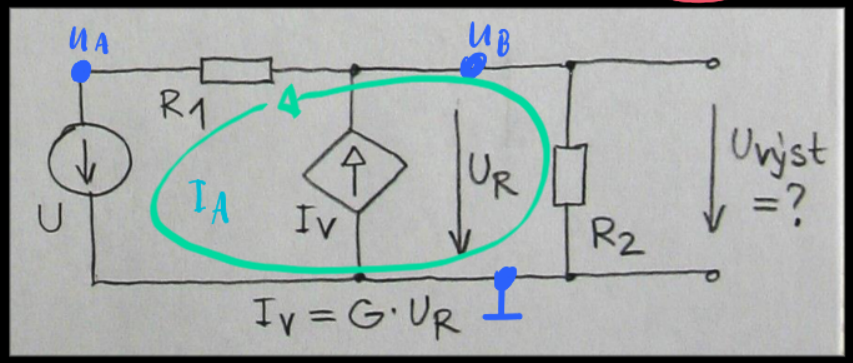
$I_B = \frac{U - U_1}{R_2}$

$U_1: \quad \frac{U_1 - U}{R_2} + \frac{U_1}{R_3} + \frac{U_1 - U_2}{R_4} - H\frac{U - U_1}{R_2} = 0$

$U_2: \quad H\frac{U - U_1}{R_2} + \frac{U_2 - U_1}{R_4} + \frac{U_2}{R_5} = 0$

✓

Řízený zdroj č.3 — MUN + MSP



$x_{MUN} = d - z_U = 2 - 1 - 1 = 1$

$x_{MSP} = p - d - z_I = 4 - 2 - 1 = 1$

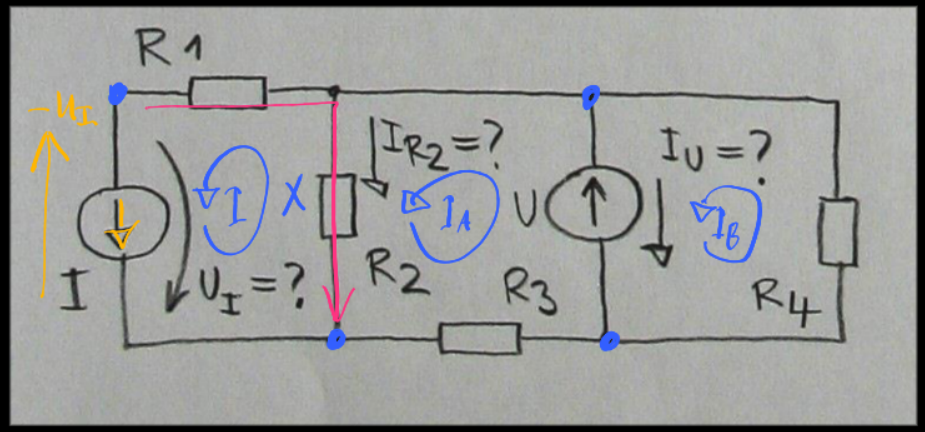
MSP: $I_A: \quad U + R_2 I_A + R_1 I_A = 0$

$I_V = G \cdot U_R = G \cdot R_2 I_A$

MUN: $U_A = U$

$U_B: \quad \frac{U_B - U_A}{R_1} - G \cdot U_B + \frac{U_B}{R_2} = 0$

Obvodové rovnice příklad



MUN: $r = d - z_u = 3 - 1 = 2$

✕ superuzel, eh...

MSP: $p = 6$, $d = 3$

$s = p - d - z_i = 6 - 3 - 1 = 2$

I_A: $R_2(I_A - I) + R_3(I_A) + U - I_B = 0$ ①

I_B: $U - I_A + R_4 I_B = 0$

$I_{R_2} = I_A - I$, $I_U = I_B - I_A$ ②

$-[R_1 \cdot I + R_2(I - I_A)] = U_I$

HUS

- impedance a fázory napětí/proudů se vyjadřují komplexními čísly
- přepnout kalkulačku do **RADIÁNŮ**.

$\omega = 2\pi f = \frac{2\pi}{T}$

6.1:

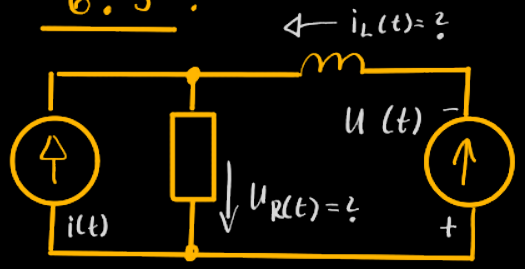
$u_S(t) = 325 \sin(\omega t + \pi/3)$

$u_T(t) = 325 \sin(\omega t + \pi)$

$(162{,}5 - 281{,}5j) + (-325 + 0j) =$

$= -162{,}5 - 281{,}5j =$

6.3:



$R = 3200\,\Omega$

$L = 0{,}8\,H$

$i(t) = 5 \sin(4000t + \pi/2)\,[mA] = 0{,}005\, e^{j\pi/2}$

$u(t) = 10 \sin(4000t + 0)\,[V] =$

$= \underline{10\,V}$

Superpozice: Příspěvek I:

- $\hat{Z}_I = \frac{3200 \cdot 3200 e^{j\pi/2}}{3200\sqrt{2}\, e^{j\pi/4}} = \underline{2262{,}7\, e^{j\pi/4}\ [\Omega]}$
- $\hat{U}_{Z_I} = \hat{Z}_I \cdot \hat{i} = 2262{,}7 e^{j\pi/4} \cdot 0{,}005\, e^{j\pi/2} = \underline{11{,}31\, e^{j\frac{3}{4}\pi}}$

$\hat{I}_{LI} = \frac{-\hat{U}_{ZI}}{\hat{Z}_L} = \frac{-1 \cdot 11{,}31 e^{j3/4\,\pi}}{3200\ e^{j\pi/4}} = \underline{3{,}53\, e^{j(-\pi + \frac{1}{2}\pi)}\,[mA]}$

$= \underline{3{,}53\, e^{-\frac{3}{4}\pi}\,[mA]}$

Příspěvek U:

- $\hat{Z}_u = 3200 + 3200j = \underline{4525{,}5\, e^{j\frac{\pi}{4}}\ [\Omega]}$
- $\hat{I}_{Lu} = -\frac{\hat{U}}{\hat{Z}_u} = \frac{10\, e^{\pm j\pi}}{4525{,}5\, e^{j\pi/4}} = \underline{2{,}21\ e^{j\frac{3\pi}{4}}\,[mA]}$

$\hat{U}_R = R \cdot \hat{I}_{Lu} = 3200 \cdot \hat{I}_{Lu} = \underline{7{,}07\ e^{j\frac{3\pi}{4}}}$

$\hat{I}_L = 3{,}53\, e^{-j\frac{3}{4}\pi} + 2{,}21\, e^{j\frac{3\pi}{4}} =$

$= (-2{,}5 - 2{,}5j) - 1{,}56 + 1{,}56j =$

$= -4{,}06 - 0{,}94j\ [mA] = \underline{4{,}16\, e^{j0{,}227}\,[mA]}$

$\hat{U}_L = 7{,}07 e^{j3\pi/4} + 11{,}31\, e^{j\frac{3\pi}{4}} =$

$= -5 + 5j - 8 + 8j = -13 + 13j =$

$= \underline{18{,}38\, e^{-j\pi/4}}$ ✓

HUS č.2

- **Činný** $P = \frac{1}{2} U_m I_m \cos(\varphi_u - \varphi_i)\ [W] = U_{ef} \cdot I_{ef} \cos(\varphi_u - \varphi_i)$

  zdánlivý $S = \frac{1}{2} U_m \hat{I}_m\ [VA] = U_{ef} \cdot I_{ef}$

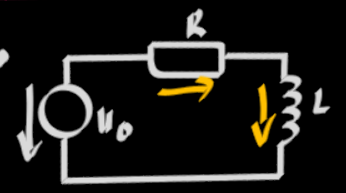
  komplexní: $\underline{S} = \frac{1}{2} U_m I_m^*\ [VA] = P + Q\,j$

  $\Rightarrow Re\{\underline{S}\} = P$

  $\Rightarrow Im\{\underline{S}\} = Q$

  jalový: $Q = \frac{1}{2} U_m I_m \sin(\varphi_u - \varphi_i) = \frac{1}{2} U I \sin(\varphi_u - \varphi_i)\ [VAr]$

Přechodové děje



$$iR + L\frac{di}{dt} = u_0 \quad /:R$$

$$\frac{L}{R}\frac{di}{dt} + i = \frac{u_0}{R}$$

#YOLO

$$i(t) = k_1 e^{-t/\tau} + k_2$$

$$\tau = L/R = RC$$

$t \to \infty$: $i(\infty) = k_2$ (sus) $\Rightarrow$ $i(\infty) = \frac{u_0}{R}$

Poč. podm.: $i(0) - i(\infty) = k_1 \Rightarrow 0 - \frac{u_0}{R} = -\frac{u_0}{R}$

λ: $\frac{L}{R}\lambda + 1 = 0 \quad \lambda = -\frac{R}{L}$ $\qquad \tau = \frac{L}{R}$

hom: $i_h(t) = k_1 e^{\lambda t} = k_1 e^{-R/L\,t} = k_1 e^{-t/\tau}$

part.: sus v ∞ $\quad i_p(t \to \infty) = \frac{u_0}{R}$

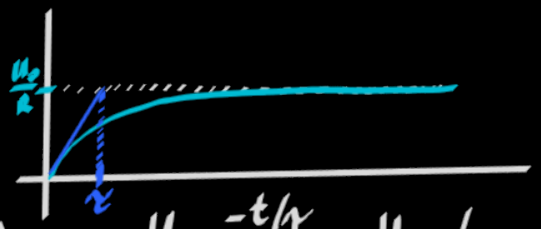
$$i(t) = i_h + i_p = k_1 e^{-t/\tau} + \frac{u_0}{R}$$

$k_1 = ?$, $\Rightarrow t = 0$

$i(0) = k_1 e^0 + \frac{u_0}{R}$

$0 = k + \frac{u_0}{R}$

$k = -\frac{u_0}{R}$

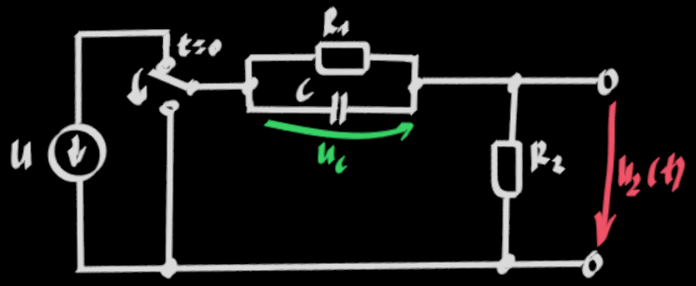


$$i(t) = -\frac{u_0}{R} e^{-t/\tau} + \frac{u_0}{R}$$

$$i(t) = \frac{u_0}{R}\left(1 - e^{-t/\tau}\right)\,[A]$$

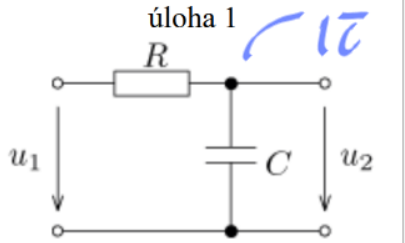
Vzorec: $\tau \to$ čas. konst.

- $u_C(t) = (u_0 - u_\infty)\, e^{-t/\tau} + u_\infty$
- $i_L(t) = (i_0 - i_\infty)\, e^{-t/\tau} + i_\infty$



$u_c(0) =$

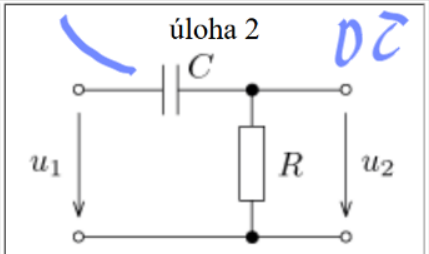
úloha 1



$R = 1\,\mathrm{k\Omega}$, $C = 1\,\mu\mathrm{F}$, $U_1 = 5\,\mathrm{V}$

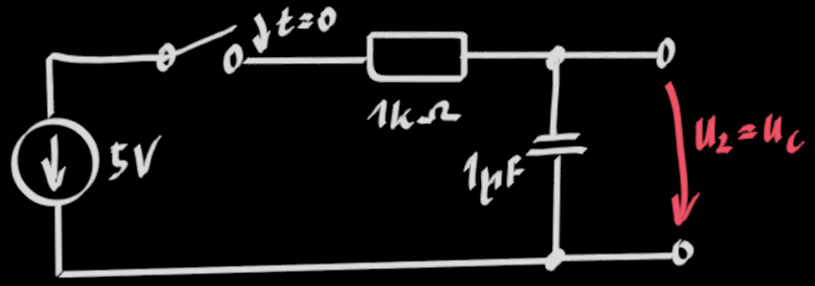
výsledek

úloha 2



$R = 1\,\mathrm{k\Omega}$, $C = 1\,\mu\mathrm{F}$, $U_1 = 5\,\mathrm{V}$

výsledek



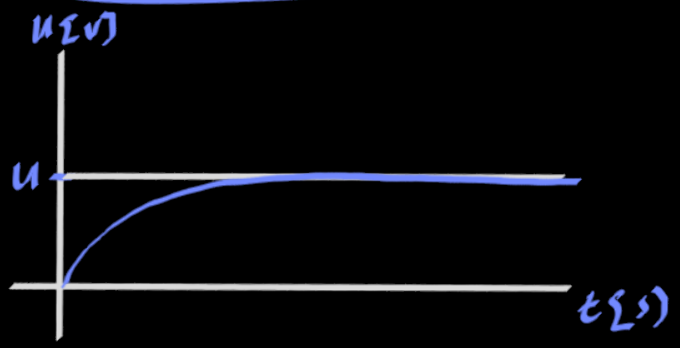
$k_1 = u_C(0) - u_C(\infty)$

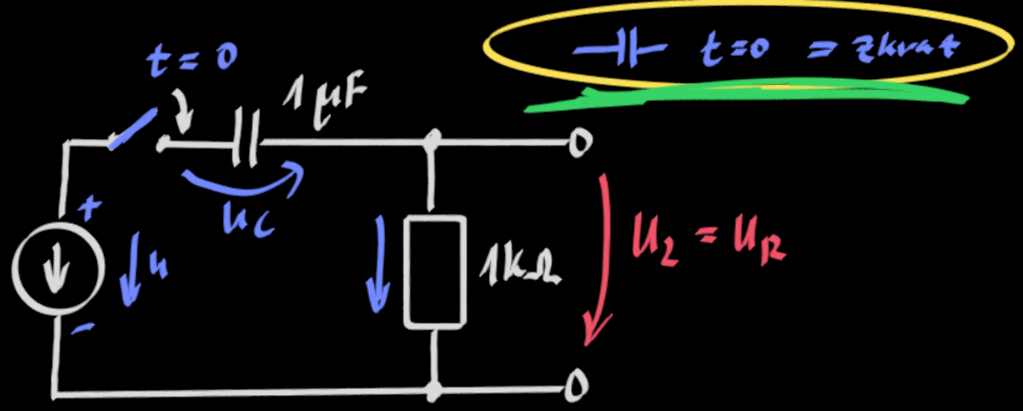
$\tau = RC$

$u_C(t) = K_1 e^{-t/\tau} + k_2$

$t(0)^-$ (0), $t(\infty)$

$u_C(t) = -U e^{-t/\tau} + U$





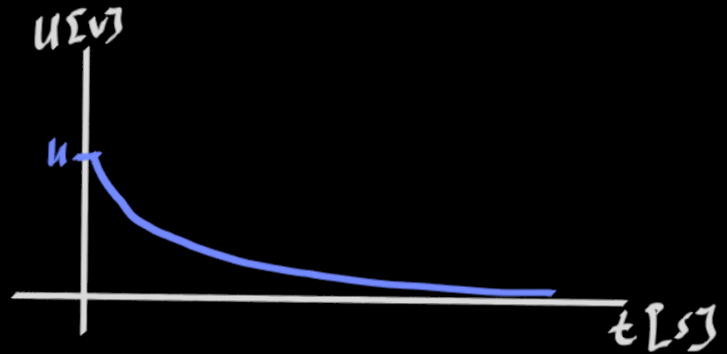
⊣⊢ t=0 = zkrat

$u_R(0) =$ nabíjet $= U$

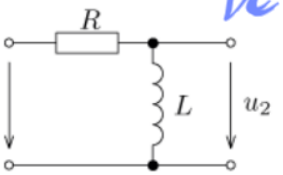
$u_R(\infty) = 0$

$u_R(t) = K_1 e^{-t/\tau} + k_2$

$u_R(t) = U e^{-t/\tau} + 0$



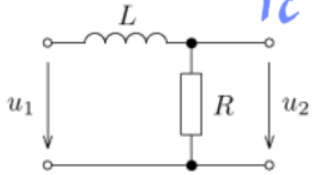
úloha 3 DČ



$R = 1\,\mathrm{k\Omega}$, $L = 1\,\mathrm{H}$, $U_1 = 5\,\mathrm{V}$

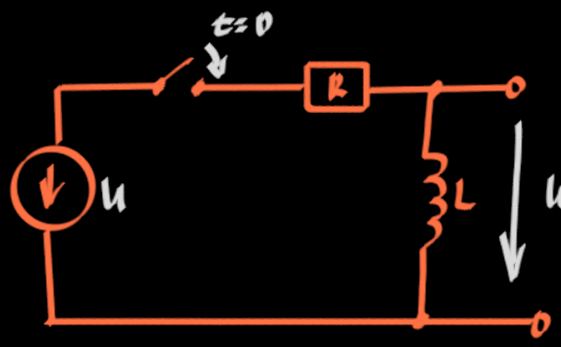
výsledek

úloha 4 IČ



$R = 1\,\mathrm{k\Omega}$, $L = 1\,\mathrm{H}$, $U_1 = 5\,\mathrm{V}$

výsledek



v $t=0$ = zkrat

$Z_L = j\omega L$

$Z_R = R$

$\tau = \frac{L}{R}$

$i_L(0) = 0$

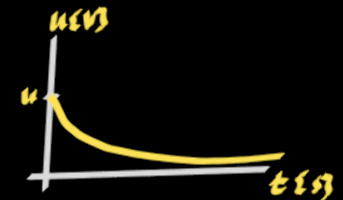
$i_L(\infty) = \frac{U}{R}$

$$\hat{i}_L(t) = -\frac{U}{R} e^{-t/\tau} + \frac{U}{R}$$

$$\hat{u}_L(t) = L \frac{di_L}{dt} = L \frac{\left(-\frac{U}{R} e^{-t/\tau} + \overset{0}{\frac{U}{R}}\right)}{dt} =$$

$$= L \left(\frac{R}{L} \cdot \frac{U}{R} e^{-t/\tau} + 0\right) =$$

$$= U e^{-t/\tau}$$

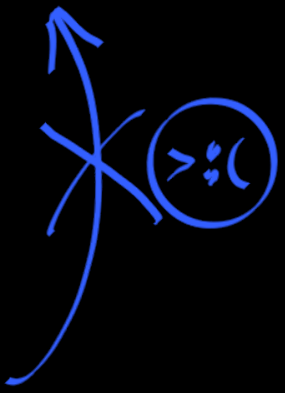


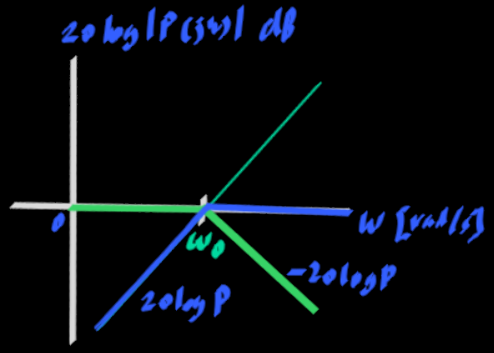
Thur vstup a frekvence

$$\hat{P}_r = \frac{\hat{U}_2}{\hat{U}_1} \Rightarrow \hat{U}_2 = \hat{U}_1 \frac{Z_L}{Z_R + Z_L} = \hat{U}_1 \cdot \frac{j\omega L}{R + j\omega L}$$

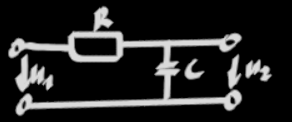
$$\hat{P} = \frac{Z_L}{Z_R + Z_L} = \frac{j\omega L}{R + j\omega L} = j\omega L \frac{1}{R + j\omega L} \cdot \frac{1/R}{1/R} = \frac{j\omega L}{R} \cdot \frac{1}{1 + \frac{j\omega L}{R}} = j\omega \frac{L}{R} \cdot \frac{1}{1 + j\omega \frac{L}{R}} =$$

$R/L = \omega_0 = \omega_p$





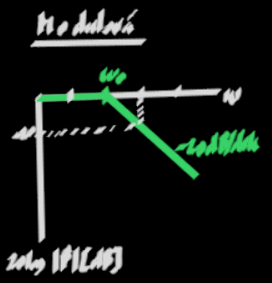
Havlík - frek. char.

1.) 

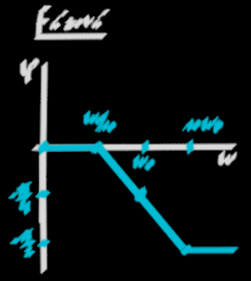
$$\hat{P}(j\omega) = \frac{\hat{U}_2}{\hat{U}_1} = \frac{\frac{1}{j\omega C}}{R + \frac{1}{j\omega C}} = \frac{1}{Rj\omega C + 1} = \frac{1}{1 + j\frac{\omega}{\omega_0}}$$

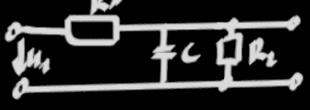
$$\omega_0 = \frac{1}{RC}$$

Modulová



Fázová



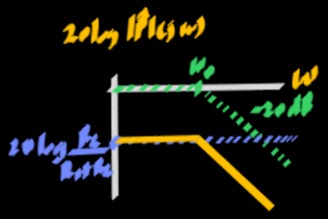
2.) 

$$\hat{P}(j\omega) = \frac{\hat{U}_2}{\hat{U}_1} = \frac{\frac{R_2 \cdot \frac{1}{j\omega C}}{R_2 + \frac{1}{j\omega C}}}{R_1 + \frac{\frac{R_2 \cdot \frac{1}{j\omega C}}{R_2 + \frac{1}{j\omega C}}}{R_2 + \frac{1}{j\omega C}}} = \frac{\frac{R_2}{1 + j\omega R_2 C}}{R_1 + \frac{R_2}{1 + j\omega R_2 C}} = \frac{R_2}{R_1 + R_2 + j\omega R_1 R_2 C} = \frac{R_2}{R_1 + R_2} + \frac{1}{1 + j\omega \frac{R_1 R_2}{R_1 + R_2} C}$$

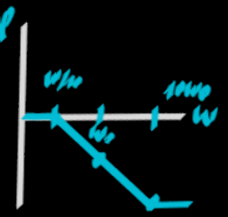
$$= \frac{R_2}{R_1 + R_2} + \frac{1}{1 + j\frac{\omega}{\omega_0}}$$

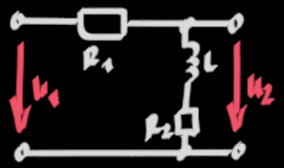
$$\omega_0 = \frac{R_1 + R_2}{R_1 R_2 C}$$

Modulová



Fázová



3.) 

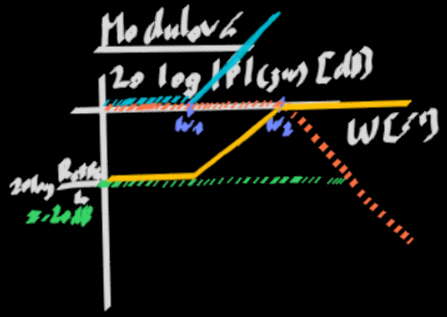
$R_1 = 9\,k\Omega$
$R_2 = 1\,k\Omega$
$L = 0{,}1\,H$

$$\hat{P}(j\omega) = \frac{j\omega L + R_2}{R_1 + j\omega L + R_2} = \frac{R_2}{R_1 + R_2} + \frac{1 + j\omega\frac{L}{R_2}}{1 + j\omega\frac{L}{R_1 + R_2}} = \frac{R_2}{R_1 + R_2} \cdot \frac{1 + j\frac{\omega}{\omega_1}}{1 + j\frac{\omega}{\omega_2}}$$

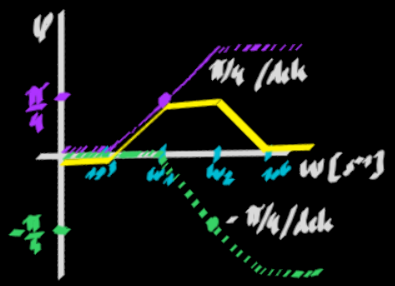
$$\omega_1 = \frac{R_2}{L} = 10^4\ s^{-1}$$

$$\omega_2 = \frac{R_1 + R_2}{L} = 10^5\ s^{-1}$$

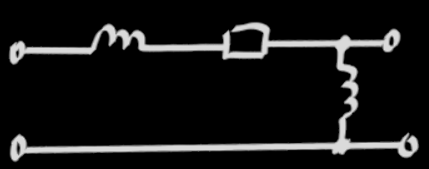
Modulová



Fázová



4.)



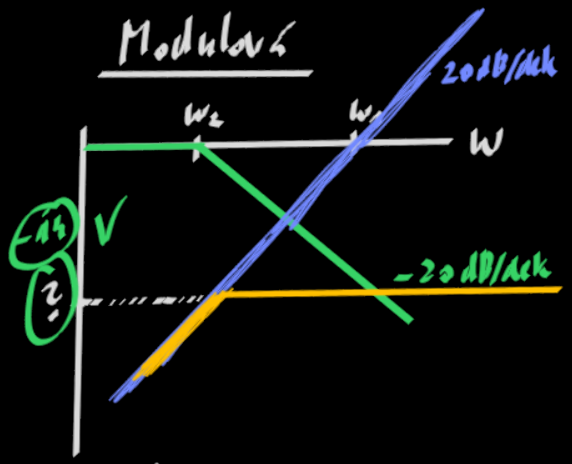
$L_1 = 0{,}8\ H$
$L_2 = 0{,}2\ H$
$R = 1800\ \Omega$

$$\hat{P}(j\omega) = \frac{\hat{U}_2}{\hat{U}_1} = \frac{j\omega L_2}{j\omega L_1 + R + j\omega L_2} = \frac{j\omega L_2}{R + j\omega(L_1+L_2)} \overset{(*)}{=} \frac{j\omega(L_2/R)}{1 + j\omega\left(\frac{L_1+L_2}{R}\right)} = \frac{j\frac{\omega}{\omega_1}}{1 + j\frac{\omega}{\omega_2}}$$

$$\omega_1 = R/L_2 = \underline{9\,000\ s^{-1}}$$

$$\omega_2 = \frac{R}{L_1+L_2} = \underline{1800\ s^{-1}}$$

Modulová



$20 \log|\hat{P}(j\omega)|$ [dB]

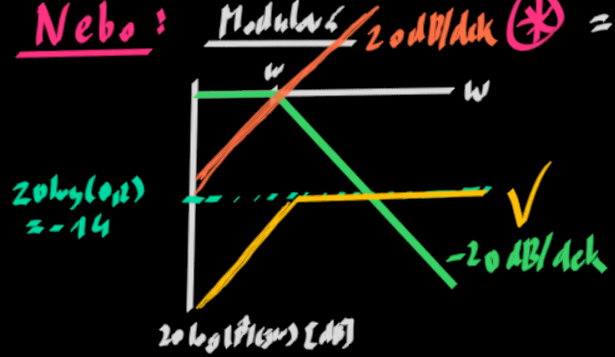
$$\lim_{\omega\to\infty} |\hat{P}(j\omega)| = \lim_{\omega\to\infty} \frac{j\frac{\omega}{\omega_1}}{1 + j\frac{\omega}{\omega_2}} = \frac{j\frac{\omega}{\omega_1}}{j\frac{\omega}{\omega_2}} = \frac{\omega_2}{\omega_1} = \underline{0{,}2}$$

$20 \log(0{,}2) \doteq \underline{-14}$

Pouze 1 spolužák mezní frekvence.

Nebo:

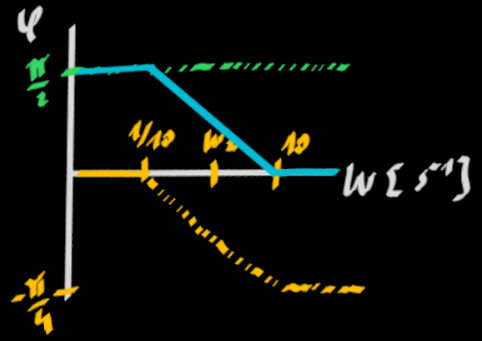
Modulová



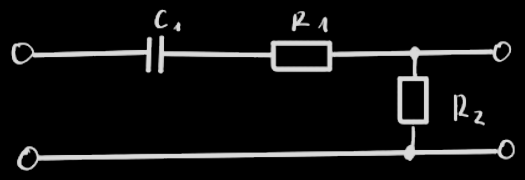
$20 \log|\hat{P}(j\omega)|$ [dB]

$$\overset{(*)}{=} \frac{j\omega(L_2/R)}{1 + j\omega\left(\frac{L_1+L_2}{R}\right)} = \underbrace{\frac{L_2}{L_1+L_2}}_{0{,}2} \cdot \frac{j\omega\left(\frac{L_1+L_2}{R}\right)}{1 + j\omega\left(\frac{L_1+L_2}{R}\right)} \quad \left\{ \omega_0 = \frac{R}{L_1+L_2} = 1800\ s^{-1} \right.$$

Fázová



5.)



$R_1 = 9k\Omega$
$R_2 = 1k\Omega$
$C = 10nF$

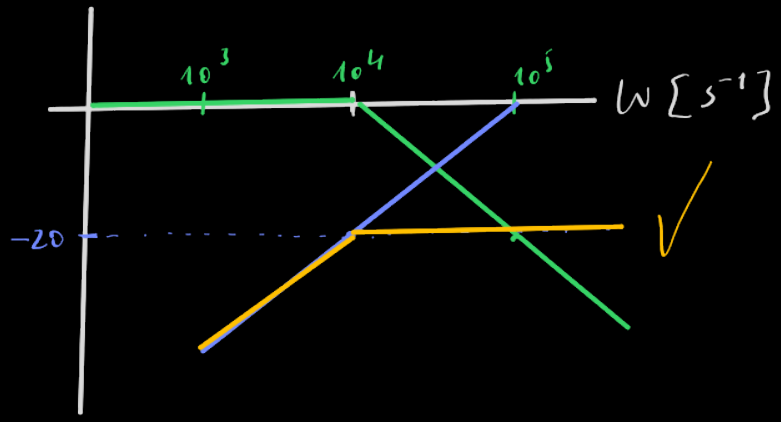
$$\hat{P}(jw) = \frac{\hat{u}_2}{\hat{u}_1} = \frac{R_2}{\frac{1}{jwC} + R_1 + R_2} = \frac{jwCR_2}{1 + jwC(R_1+R_2)} = \frac{R_2}{R_1+R_2} \cdot \frac{jwC(R_1+R_2)}{1+jwC(R_1+R_2)}$$

$$w_0 = \frac{1}{C(R_1+R_2)} = 10^4$$

$\frac{1}{10} = 0,1$

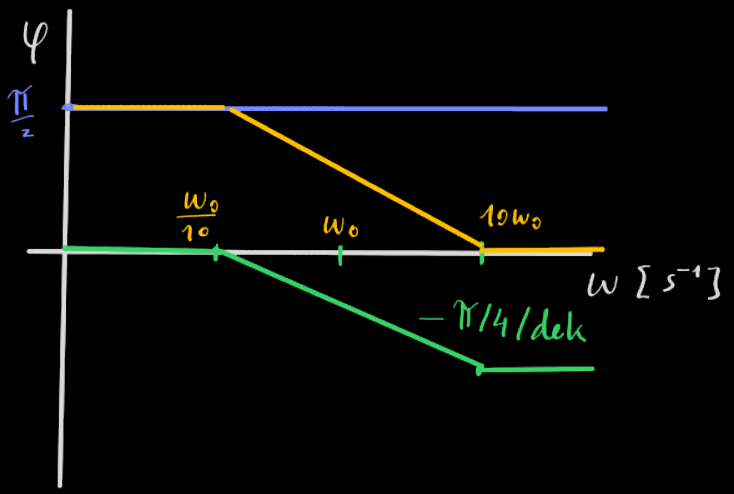
$20\log(0,1) = -20$

Modulová

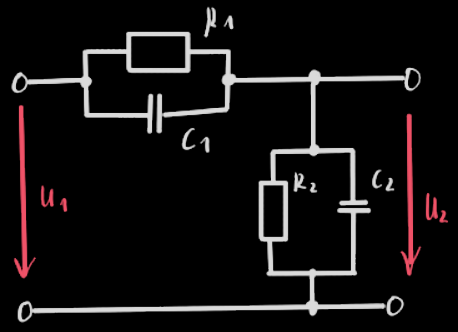


$20\log|\hat{P}(jw)|$ [dB]

Fázová



Havlík video č.2



$$\frac{R\,\frac{1}{j\omega C}}{R+\frac{1}{j\omega C}} = \frac{R}{1+j\omega RC}$$

$R_1 = 5\,k\Omega$

$R_2 = 1\,k\Omega$

$C_1 = 0{,}8\,\mu F$

$C_2 = 0{,}1\,\mu F$

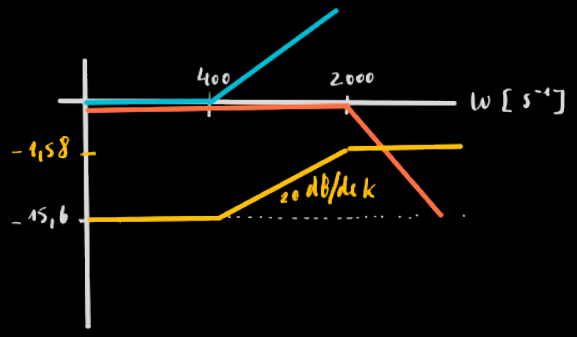
$$\hat{P}(j\omega) = \frac{\hat{U}_2}{\hat{U}_1} = \frac{\frac{R_2}{1+j\omega R_2 C_2}}{\frac{R_1}{1+j\omega R_1 C_1} + \frac{R_2}{1+j\omega R_2 C_2}} = \frac{\frac{R_2}{1+j\omega R_2 C_2}}{\frac{R_1 + j\omega R_1 R_2 C_2 + R_2 + j\omega R_1 R_2 C_1}{(1+j\omega R_1 C_1)(1+j\omega R_2 C_2)}} =$$

$$= \frac{R_2 (1+j\omega R_1 C_1)}{R_1 + j\omega R_1 R_2 C_2 + R_2 + j\omega R_1 R_2 C_1} =$$

$$= \frac{R_2}{R_1+R_2} \cdot \frac{1+j\omega R_1 C_1}{1+j\omega\left(\frac{R_1 R_2}{R_1+R_2}\right)(C_1+C_2)} =$$

$$= \frac{R_2}{R_1+R_2} \cdot \frac{1+j\omega/\omega_1}{1+j\omega/\omega_2}$$

Modulová



$20\log|\hat{P}(j\omega)|$ [dB]

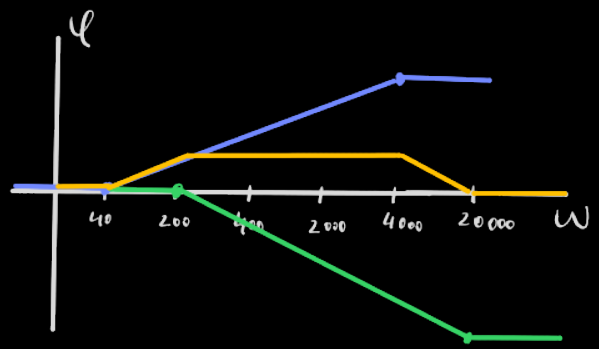
$$\lim_{\omega\to\infty} \frac{R_1}{R_1+R_2} \cdot \frac{1+j\frac{\omega}{\omega_1}}{1+j\frac{\omega}{\omega_2}} = \frac{1}{6} \cdot \frac{\omega_2}{\omega_1} = \frac{5}{6}$$

$$\omega_1 = \frac{1}{R_1 C_1} = 400\ s^{-1}$$

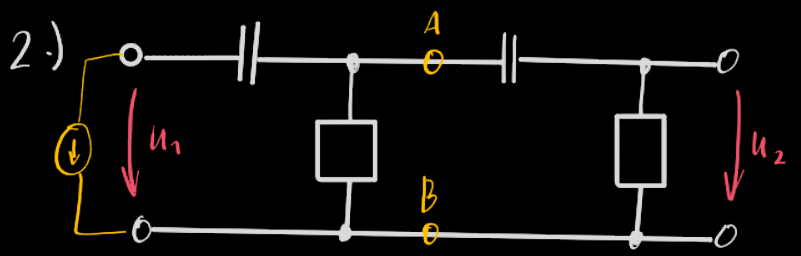
$$\omega_2 = \left(\frac{R_1+R_2}{R_1 R_2}\right)\left(\frac{1}{C_1+C_2}\right) = 2000\ s^{-1}$$

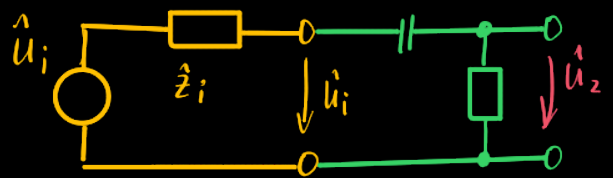
$$\frac{R_2}{R_1+R_2} = \frac{1}{6}$$

Fázová



2.)





$$\hat{Z}_i = \frac{R_1 \cdot 1/j\omega C}{R_1 + 1/j\omega C_1} = \frac{R}{1 + j\omega C R_1}$$

$$\hat{U} = U_1 \frac{R_1}{R_1 + 1/j\omega C_1} = U_1 \frac{j\omega C_1 R_1}{1 + j\omega C_1 R_1}$$

$$\hat{P}(j\omega) = \frac{j\omega C_1 R_1}{1 + j\omega C_1 R_1} \cdot \frac{R_2}{Z_i + \frac{1}{j\omega C} + R_2} =$$

$$= \frac{j\omega C_1 R_1}{1 + j\omega C_1 R_1} \cdot \frac{R_2}{\frac{R_1}{1 + j\omega C_1 R_1} + \frac{1}{j\omega C_2} + R_2} =$$

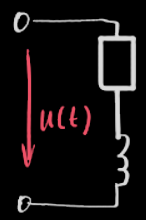
$$= \frac{j\omega C_1 R_1}{1 + j\omega C_1 R_1} \cdot \frac{R_2}{\dfrac{j\omega C_2 R_1 + 1 + j\omega C_1 R_1 + j\omega C_2 R_2 (1 + j\omega C_1 R_1)}{(1 + j\omega C_1 R_1)(j\omega C_2)}} =$$

$$= \frac{j\omega (C_1 R_1) \cdot j\omega (C_2 R_2)}{1 + j\omega (C_2 R_1 + C_1 R_1 + C_2 R_2) + (j\omega)^2 (R_1 R_2 C_1 C_2)} =$$

$\neq -1$

$$= \text{lol, hl.}$$

PNHS Havlík video



$R = 50\,\Omega$, $L = 0{,}12\,H$

$$i(t) = 0{,}8 + 2{,}5\sin(\omega_0 t) + 0{,}5\sin\left(2\omega_0 t + \frac{\pi}{12}\right) + 1{,}5\sin\left(3\omega_0 t - \frac{\pi}{6}\right)[A]$$

$\omega_0 = 314\ s^{-1}$

$I_{ss} = 0{,}8\,A$

$\hat{I}_1 = 2{,}5\,A$

$\hat{I}_2 = 0{,}5\,e^{j\pi/12}$

$\hat{I}_3 = 1{,}5\,e^{-j\pi/6}$

"Superpozice":

$U_{ss} = R \cdot I_{ss} = \underline{40\,V}$

$\hat{U}_1 = (R + Z_L)\cdot\hat{I}_1 = (R + j\omega_0 L)\cdot\hat{I}_1 = (50 + 37{,}68j)\,2{,}5 = \underline{156{,}5\,e^{j0{,}65}\,V}$

$\hat{U}_2 = (R + j2\omega_0 L)\cdot\hat{I}_2 = (50 + 75{,}36j)\cdot 0{,}5\,e^{j\pi/12} = 90{,}4\,e^{j0{,}985}\cdot 0{,}5\,e^{j\pi/12} = \underline{45{,}2\,e^{j1{,}25}\,V}$

$\hat{U}_3 = (R + j3\omega_0 L)\cdot\hat{I}_3 = (50 + 113{,}04j)\cdot 1{,}5\,e^{-j\pi/6} = 123{,}6\,e^{j1{,}154}\cdot 1{,}5\,e^{-j\pi/6} = \underline{185{,}4\,e^{j0{,}63}\,V}$

$$u(t) = 40 + 156{,}5\left(\omega_0 t + 0{,}65\right) + 45{,}2\sin(2\omega_0 t + 1{,}25) + 185{,}4\sin(3\omega_0 t + 0{,}63)$$

Efektivní hodnoty + výkon v obvodu

- $\underline{I_{ef}} = \sqrt{I_{ss}^2 + \left(\frac{I_{m1}}{\sqrt{2}}\right)^2 + \left(\frac{I_{m2}}{\sqrt{2}}\right)^2 + \dots} = \sqrt{0{,}8^2 + \frac{1}{2}\left(2{,}5^2 + 0{,}5^2 + 1{,}5^2\right)} = \underline{2{,}24\,A}$
- $\underline{U_{ef}} = \sqrt{U_{ss}^2 + \left(\frac{U_{m1}}{\sqrt{2}}\right)^2 + \left(\frac{U_{m2}}{\sqrt{2}}\right)^2 + \dots} = \sqrt{40^2 + \frac{1}{2}\left(156{,}5^2 + 45{,}2^2 + 185{,}4^2\right)} = \underline{179{,}04\,V}$
- $\underline{\text{Činný výkon:}}$ $P = I_m \cdot U_m + \frac{1}{2}\sum_k \hat{I}_k \cdot \hat{U}_k \cos(\varphi_{uk} - \varphi_{ik}) =$ mělo by...

PNUS Havlík video č.2

- $u(t) = 50 + 100\sin(\omega_0 t) + 60\sin\left(2\omega_0 t - \frac{\pi}{6}\right) + 40\sin\left(3\omega_0 t - \frac{\pi}{4}\right)$ [V]

  $i(t) = 1\sin(\omega_0 t) + 0{,}5\sin(2\omega_0 t - \pi/3) + 0{,}2\sin(3\omega_0 t + \pi/2)$ [A]

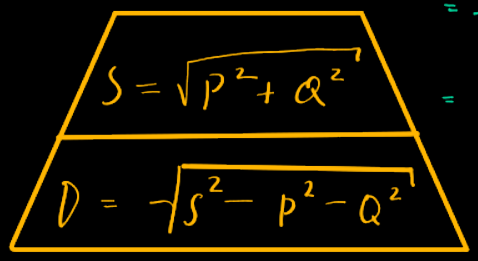
- $P = I_0 U_0 + \frac{1}{2}\sum_k \hat{I}_{mk} \cdot \hat{U}_{mk} \cos(\varphi_{uk} + \varphi_{Ik}) = 0 + \frac{1}{2}\left(100\cos(0) + 30\cos(\pi/3) + 8\cos\left(-\frac{3\pi}{4}\right)\right) = \underline{54{,}7\,W}$

  $Q = \frac{1}{2}\sum_k I_{mk} \cdot U_{mk} \sin(\varphi_{uk} + \varphi_{Ik}) = \ldots$ HMH?, prý $4{,}67$ VAr

  $S = I_{ef} \cdot U_{ef} = \sqrt{I_0^2 + \frac{1}{2}\sum_k I_{mk}^2} \cdot \sqrt{U_0^2 + \frac{1}{2}\sum_k U_{mk}^2} =$

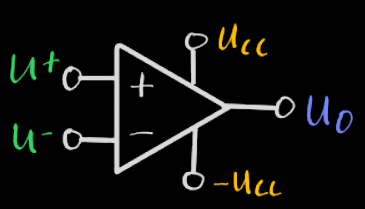
  $= \sqrt{\left[0^2 + \frac{1}{2}(1^2 + 0{,}15^2 + 0{,}12^2)\right]} \cdot \sqrt{\left[50^2 + \frac{1}{2}(100^2 + 60^2 + 40^2)\right]} =$

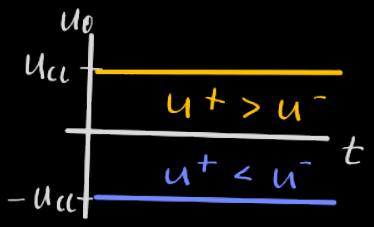
  $= 0{,}5385 \cdot 100{,}4988 = \underline{54{,}12\,VA}$



Operační zesilovače

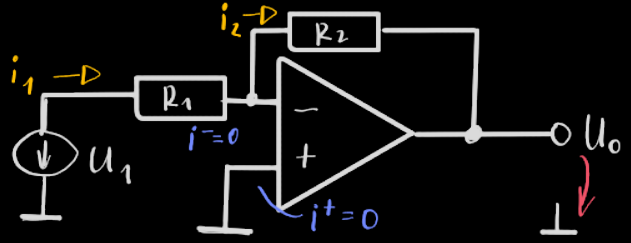
- aktivní součástka, vlastnosti: $R_{in} = \infty \Rightarrow i^+ \text{ a } i^- = 0$
  $U_d = u^+ - u^- = 0$





Základní zapojení

- Invertující zesilovač:



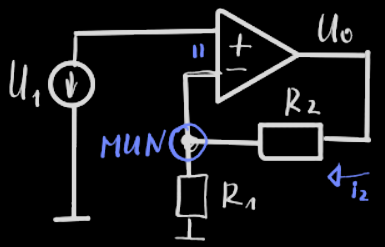
$i_1 = i_2$

$i_1 = \frac{u_1}{R_1}$, $i_2 = \frac{-u_0}{R_2}$

$\frac{u_1}{R_1} = \frac{-u_0}{R_2}$

$$U_0 = -U_1 \cdot \frac{R_2}{R_1}$$

- Neinvertující zesilovač:



$u^+ = u^-$

$u^+ = u_1 = u^-$

$U_0 = f(u_1)$

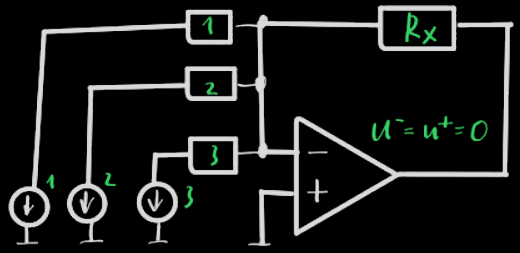
MUN:

$\frac{u_1}{R_1} + \frac{u_1 - u_0}{R_2} = 0$

$u_1 \left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{u_0}{R_2}$

$$U_0 = \left(1 + \frac{R_2}{R_1}\right) u_1$$

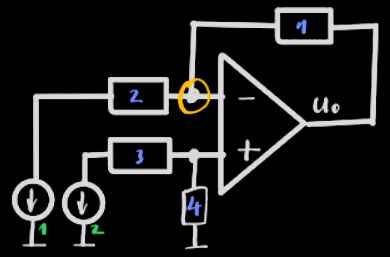
- Sumační zesilovač:



$\frac{u_1}{R_1} + \frac{u_2}{R_2} + \frac{u_3}{R_3} = -\frac{u_0}{R_x}$

$$U_0 = R_x \sum_i \frac{u_i}{R_i}$$

Rozdílový zesilovač:



MUN:

$\frac{u^- - u_1}{R_1} + \frac{u^- - u_0}{R_2} = 0$

$U_0 = u^- \frac{R_2}{R_1} - u_1 \frac{R_2}{R_1} = 0$

$U_0 = u^- \left(1 + \frac{R_2}{R_1}\right) - u_1 \frac{R_2}{R_1}$

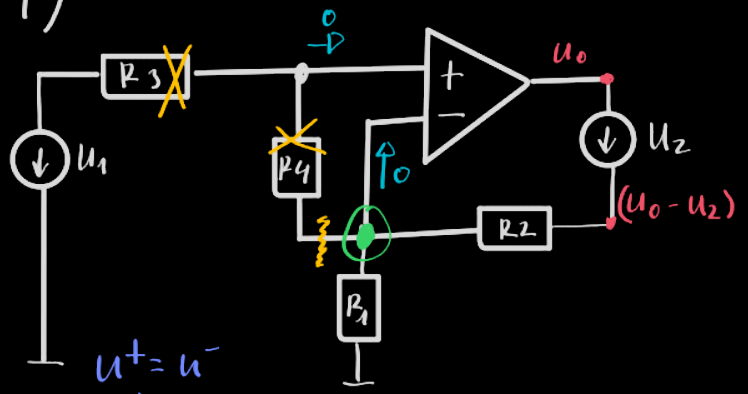
$u^- = u^+$

$u^+ = u_2 \frac{R_4}{R_3 + R_4} = u^-$

$$U_0 = u_2 \frac{R_4}{R_3 + R_4} \left(1 + \frac{R_2}{R_1}\right) - u_1 \frac{R_2}{R_1}$$

Cvičko příklady – Šimek

1.) Na R_3 a R_4 není úbytek.



$u^+ = u^-$

$u^+ = u_1 = u^-$

MUN

$$\frac{u^-}{R_1} + \frac{u^- - (u_0 - u_2)}{R_2} = 0$$

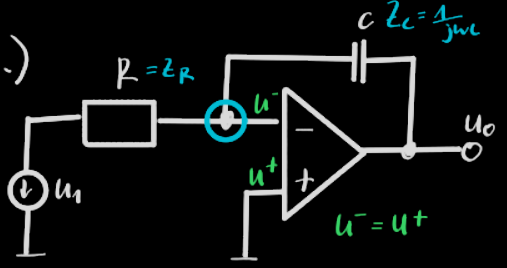
$$\frac{u_1}{R_1} + \frac{u_1}{R_2} + \frac{u_2}{R_2} = \frac{u_0}{R_2}$$

$$u_0 = \left(\frac{u_1}{R_1} + \frac{u_1}{R_2} + \frac{u_2}{R_2}\right) \cdot R_2$$

$$u_0 = \frac{u_1 R_2}{R_1} + u_1 + u_2$$

$$u_0 = u_2 + u_1\left(1 + \frac{R_2}{R_1}\right)$$

2.)



MUN:

$$-\frac{\hat{u}_1}{Z_R} + \frac{(-\hat{u}_0)}{Z_C} = 0$$

$$-\frac{\hat{u}_1}{R} - j\omega C \hat{u}_0 = 0$$

$$-\frac{\hat{u}_1}{j\omega C R} = \hat{u}_0$$

$$\hat{P}(j\omega) = \frac{\hat{u}_0}{\hat{u}_1} = -\frac{1}{j\omega RC}, \quad \omega_0 = \frac{1}{RC}$$

MUN:

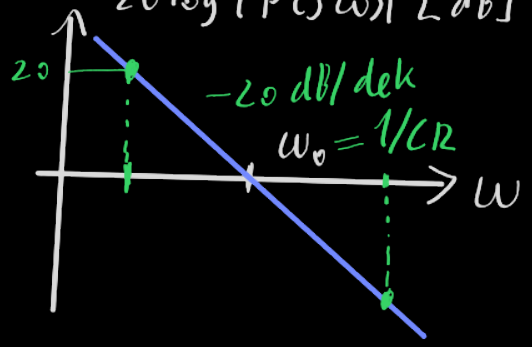
$$-\frac{u_1}{R} + C\frac{d(-u_0)}{dt} = 0$$

$$-\frac{u_1}{R} = C\frac{du_0}{dt} \Big| \int$$

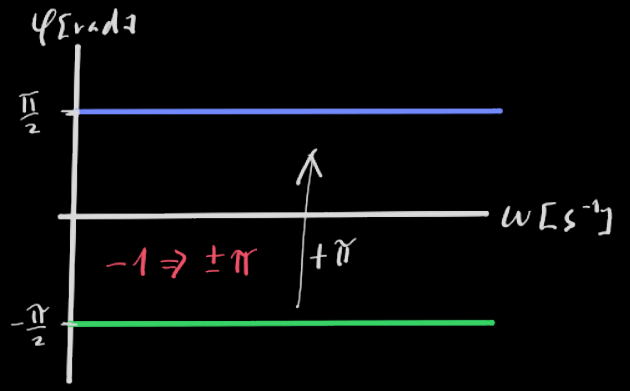
$$C u_0 = -\frac{1}{R}\int u_1 \, d\tau$$

$$u_0 = -\frac{1}{CR}\int_0^t u_1 \, d\tau$$

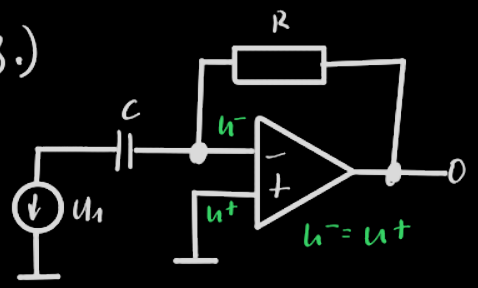
Modulová



Fázová



3.)

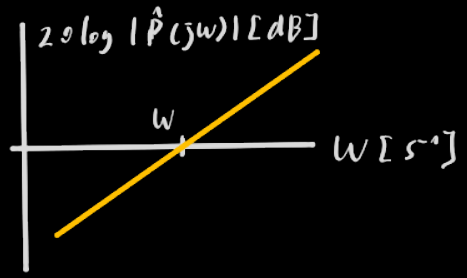


$$-\frac{\hat{u}_1}{Z_C} - \frac{\hat{u}_0}{Z_R} = 0$$

$$\hat{u}_0 = -\frac{\hat{u}_1}{Z_C} \cdot Z_R = -\hat{u}_1 \cdot jwCR$$

$$\hat{P}(jw) = \frac{\hat{u}_0}{\hat{u}_1} = -jwCR = j\frac{w}{w_0} \quad , \quad w_0 = \frac{1}{CR}$$

Modulová



Fázová