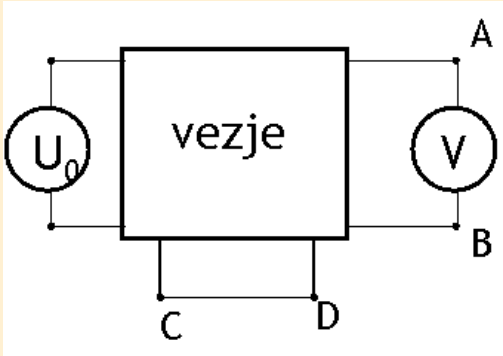
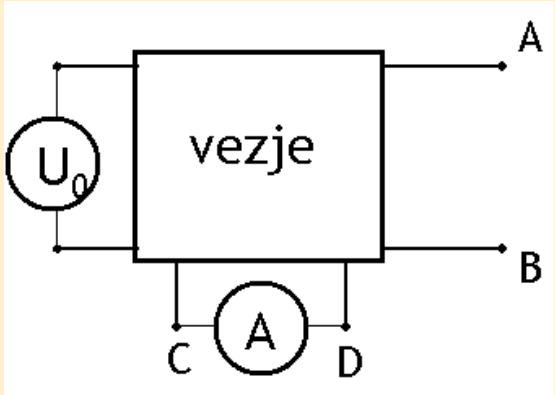
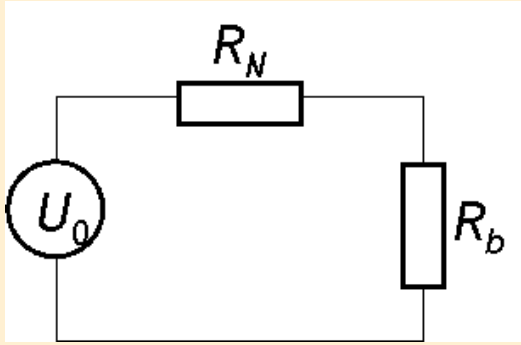
VAJA 1

Besedilo naloge

Ugotovite napetost med sponkama A-B in tok veje C-D danega linearnega vezja ter določite **sistematične pogreške** vključitve instrumentov v vezje! Določite tudi sistematske pogreške vključitve instrumentov pri merjenju napetosti, toka in moči na bremenu!

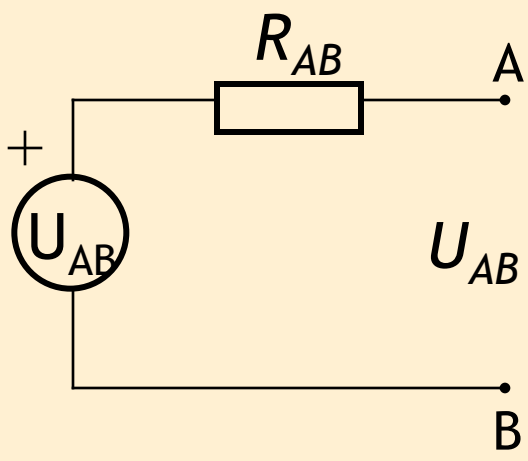






Merjenje napetosti

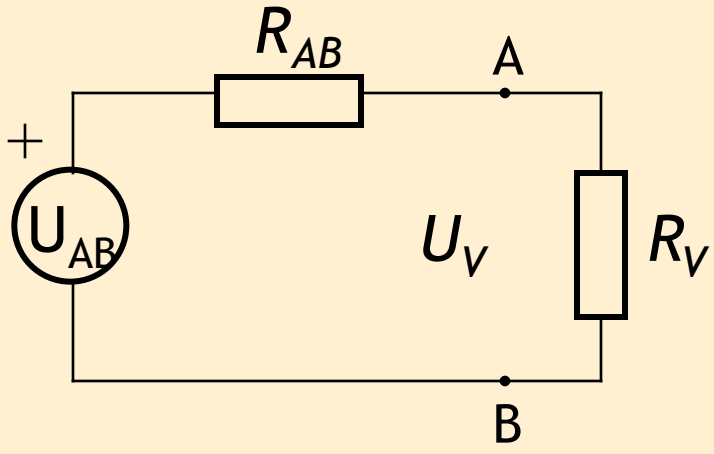
Theveninovo nadomestno vezje



Merjenje napetosti

Theveninovo nadomestno vezje

$$U_V = U_{AB} \frac{R_V}{R_V + R_{AB}}$$



Merjenje napetosti

Sistematski pogrešek (relativni)

$$e = \frac{U_V - U_{AB}}{U_{AB}}$$

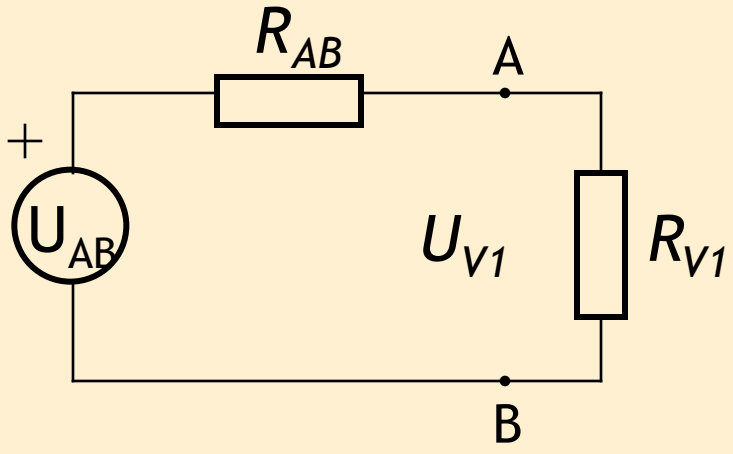
$$= \frac{U_V}{U_{AB}} - 1 = \frac{R_V}{R_V + R_{AB}} - 1 = \frac{R_{AB}}{R_V + R_{AB}} = -\frac{1}{1 + R_V / R_{AB}}$$

$$\frac{R_V}{R_{AB}} \to \infty \quad \Rightarrow \quad e \to 0$$

Merjenje napetosti

Če hočemo določiti U_{AB} (*in* R_{AB}), potrebujemo 2 meritvi...

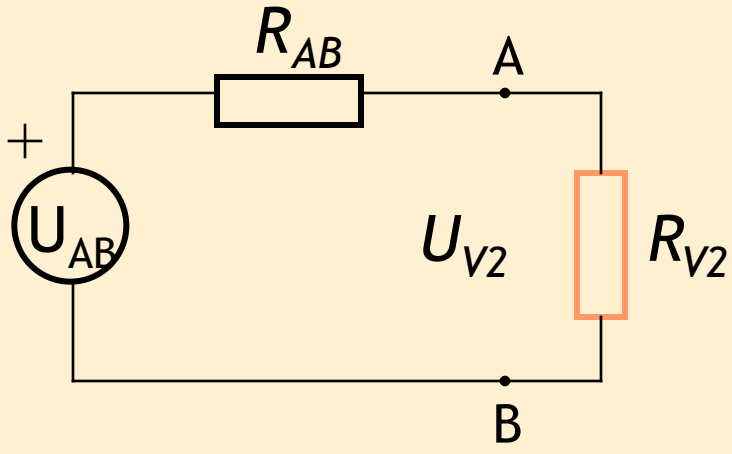
$$U_{V1} = U_{AB} \frac{R_{V1}}{R_{V1} + R_{AB}}$$



Merjenje napetosti

Če hočemo določiti U_{AB} (*in* R_{AB}), potrebujemo 2 meritvi...

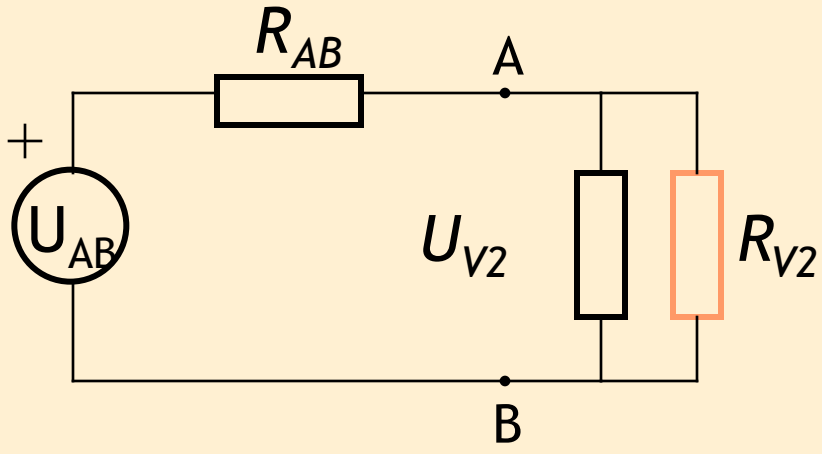
$$U_{V2} = U_{AB} \frac{R_{V2}}{R_{V2} + R_{AB}}$$



Merjenje napetosti

Če hočemo določiti U_{AB} (*in* R_{AB}), potrebujemo 2 meritvi...

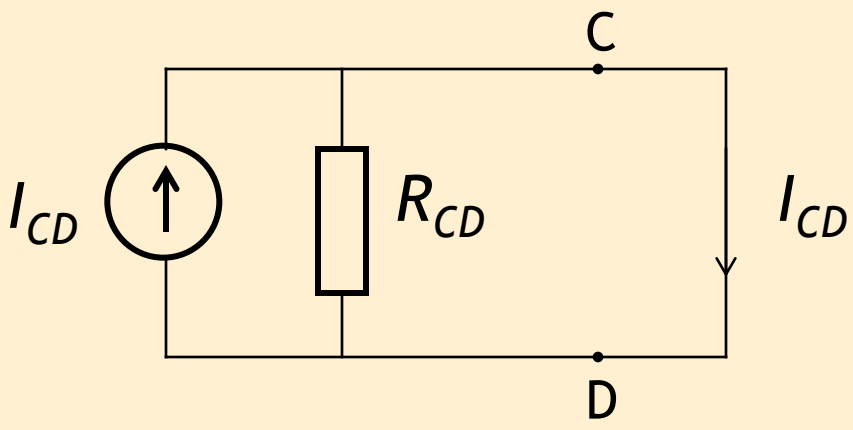
$$U_{V2} = U_{AB} \frac{R_{V2}}{R_{V2} + R_{AB}}$$



$$U_{AB} = U_{V1} U_{V2} \frac{R_{V2} - R_{V1}}{R_{V2} U_{V1} - R_{V1} U_{V2}}$$

Merjenje toka

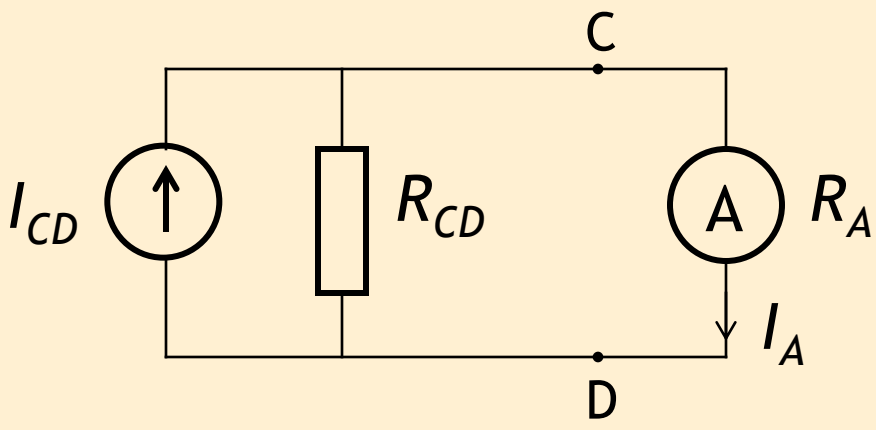
Nortonovo nadomestno vezje



Merjenje toka

Nortonovo nadomestno vezje

$$I_A = I_{CD} \frac{R_{CD}}{R_{CD} + R_A}$$



Merjenje toka

Sistematski pogrešek (relativni)

$$e = \frac{I_A - I_{CD}}{I_{CD}}$$

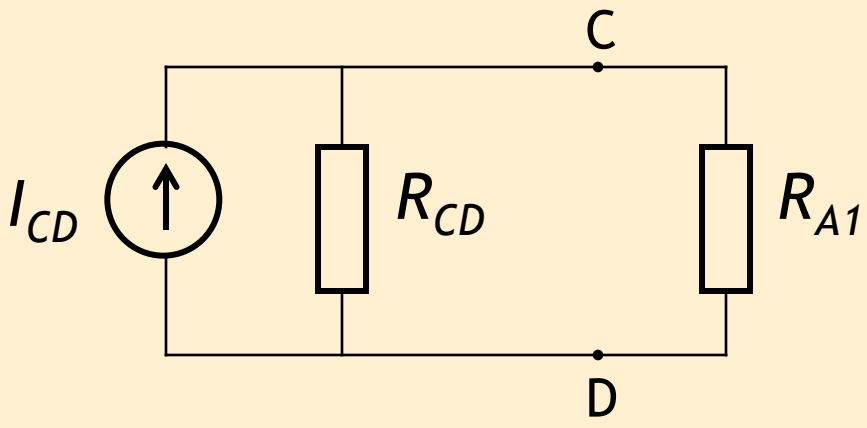
$$= \frac{I_A}{I_{CD}} - 1 = \frac{R_{CD}}{R_{CD} + R_A} - 1 = \frac{R_A}{R_{CD} + R_A} = -\frac{1}{1 + R_{CD}/R_A}$$

$$R_A \to 0 \quad \Rightarrow \quad e \to 0$$

Merjenje toka

Če hočemo določiti I_{CD} (*in* R_{CD}), potrebujemo 2 meritvi...

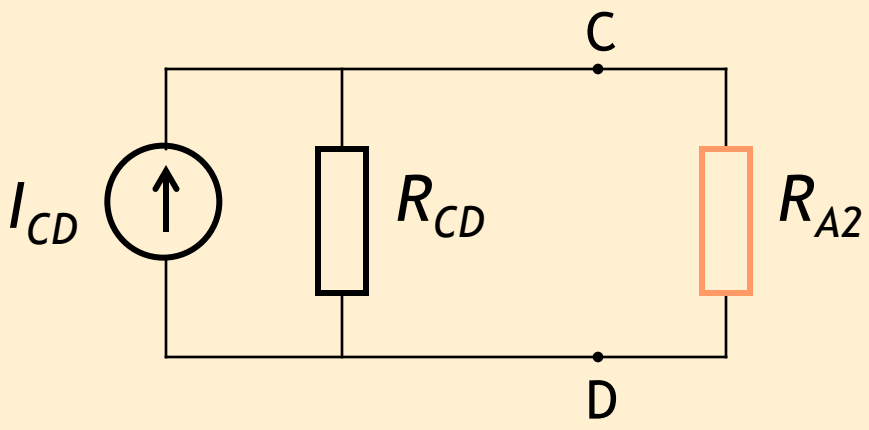
$$I_{A1} = I_{CD} \frac{R_{CD}}{R_{CD} + R_{A1}}$$



Merjenje toka

Če hočemo določiti I_{CD} (*in* R_{CD}), potrebujemo 2 meritvi...

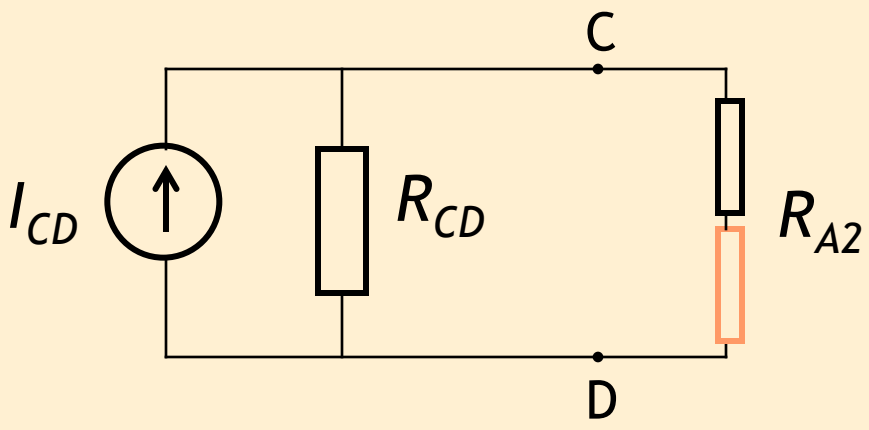
$$I_{A2} = I_{CD} \frac{R_{CD}}{R_{CD} + R_{A2}}$$



Merjenje toka

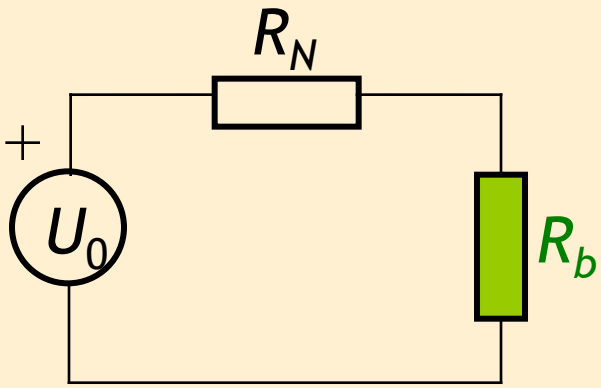
Če hočemo določiti I_{CD} (*in* R_{CD}), potrebujemo 2 meritvi...

$$I_{A2} = I_{CD} \frac{R_{CD}}{R_{CD} + R_{A2}}$$



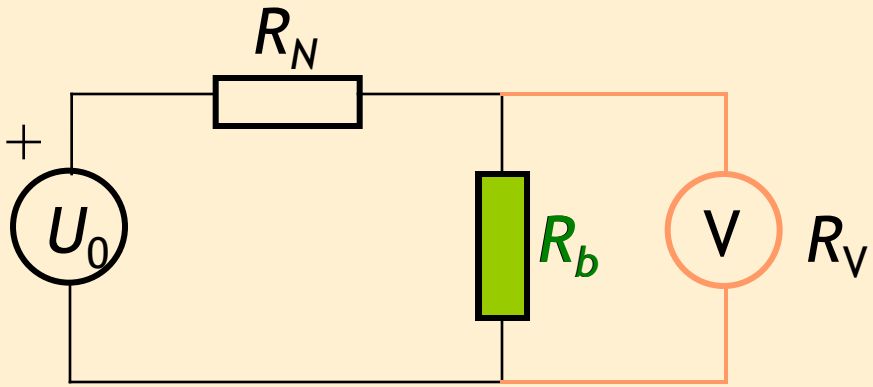
$$I_{CD} = I_{A1} I_{A2} \frac{R_{A2} - R_{A1}}{I_{A2} R_{A2} - I_{A1} R_{A1}}$$

Merjenje napetosti bremena



$$U_b = U_0 \cdot \frac{R_b}{R_N + R_b}$$

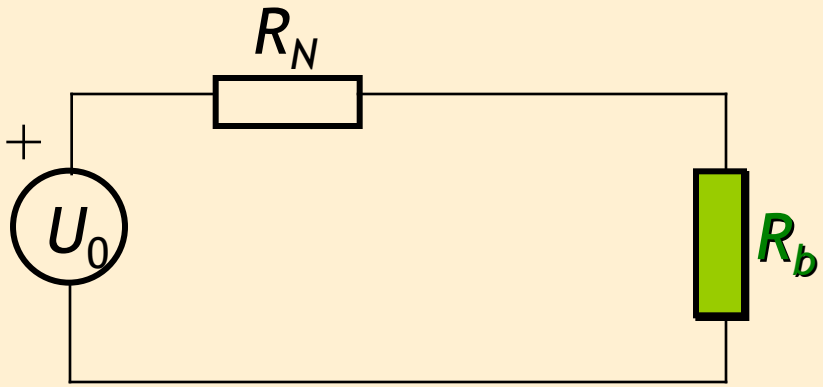
Merjenje napetosti bremena



$$U_V = U_0 \cdot \frac{R_b \| R_V}{R_N + R_b \| R_V}$$

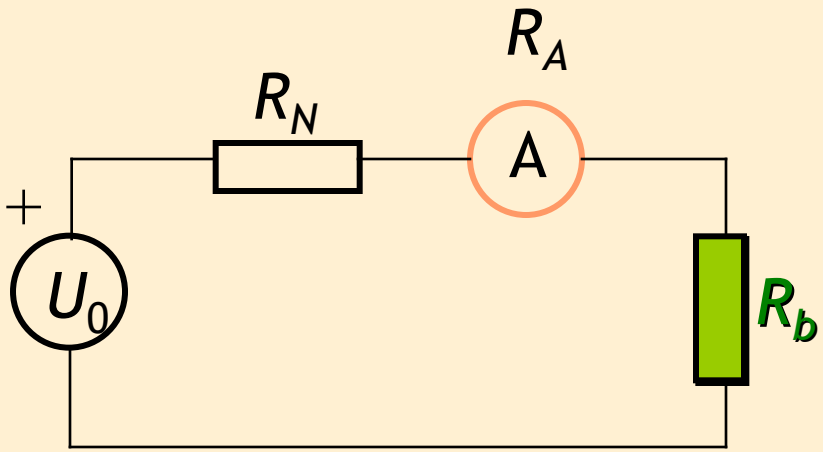
$$e_{U_b} = \frac{U_v - U_b}{U_b} = \ldots$$

Merjenje toka bremena



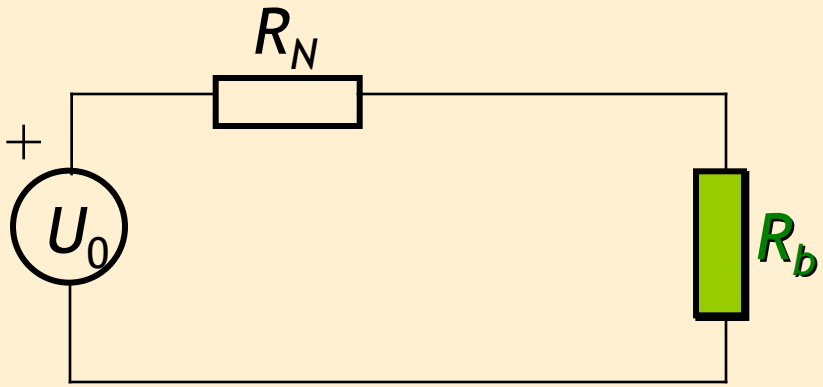
$$I_b = \frac{U_0}{R_N + R_b}$$

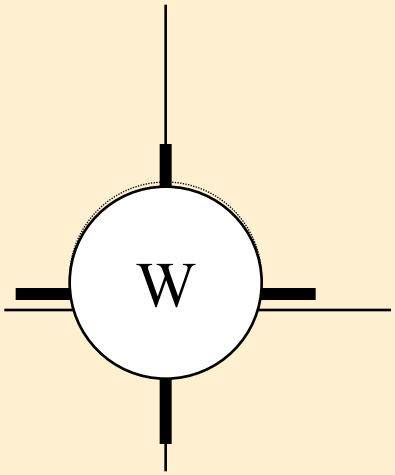
Merjenje toka bremena



$$I_A = \frac{U_0}{R_N + R_b + R_A} \quad \rightarrow e_{I_b}$$

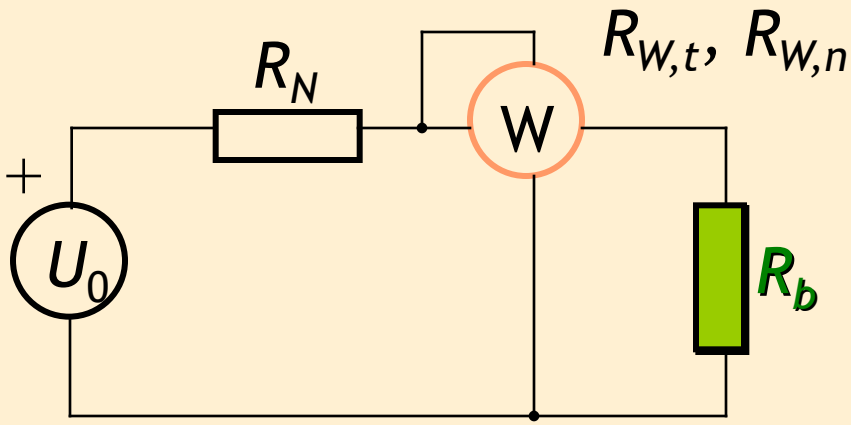
Merjenje moči bremena





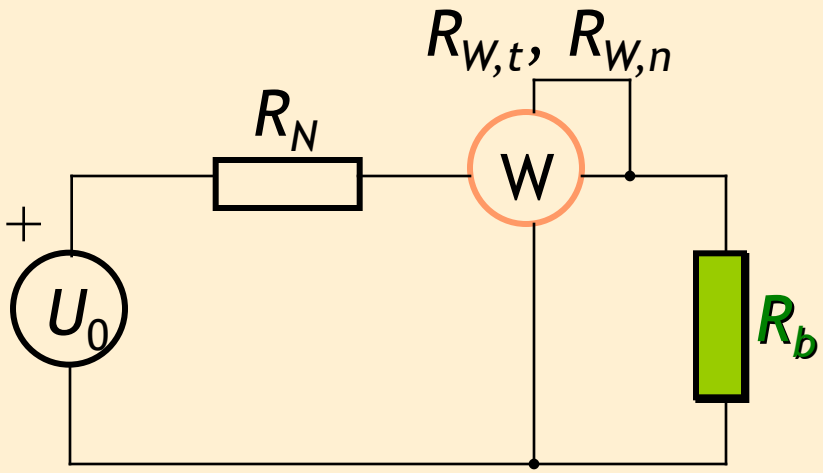
$$P_b = U_b I_b$$

Merjenje toka bremena



$$P_W = U_b I_b + I_b^2 \cdot R_{W,t} \qquad \rightarrow e_{P_b}$$

Merjenje toka bremena

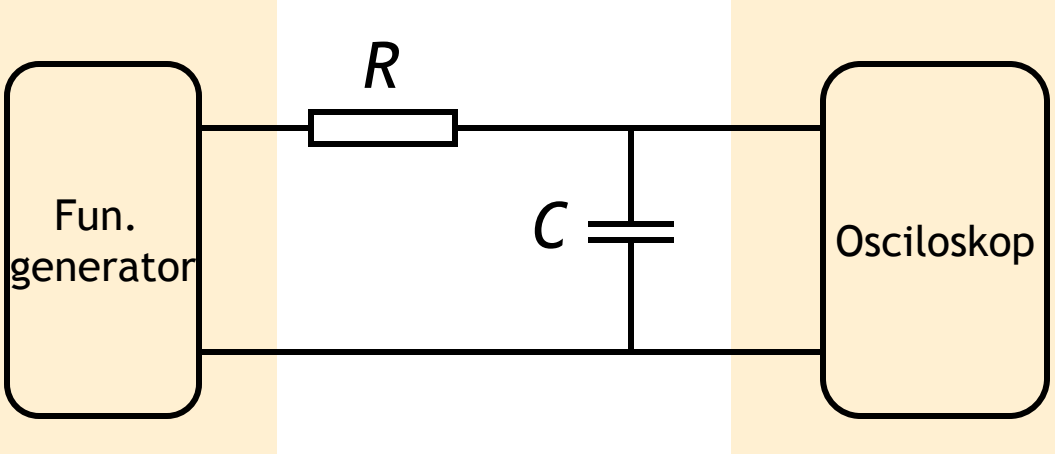


$$P_W = U_b I_b + \frac{U_b^2}{R_{W,n}} \qquad \rightarrow e_{P_b}$$

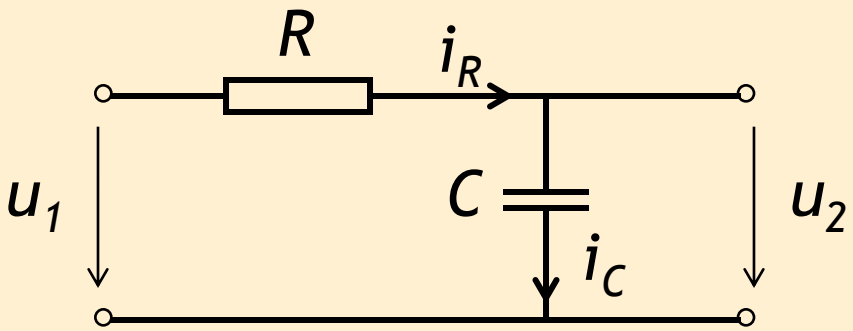
VAJA 2

Besedilo naloge

Ugotovite odzivni čas T_a in mejno frekvenco f_m merilnega člena in poiščite njun medsebojni odnos. Uporabite digitalni spominski osciloskop.

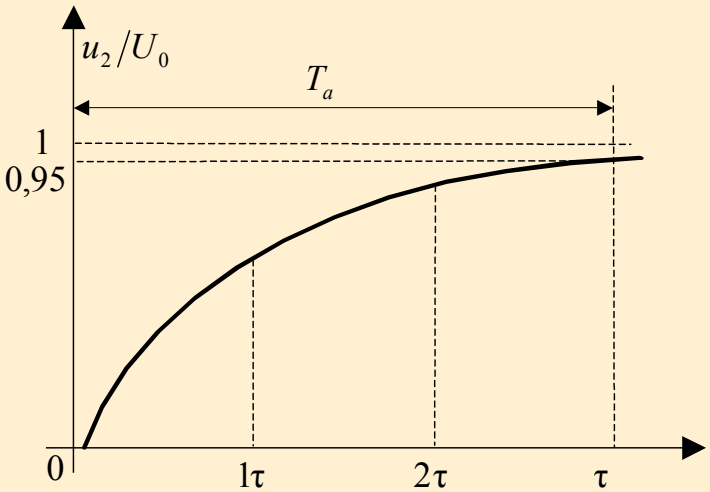


Matematični model merilnega člena



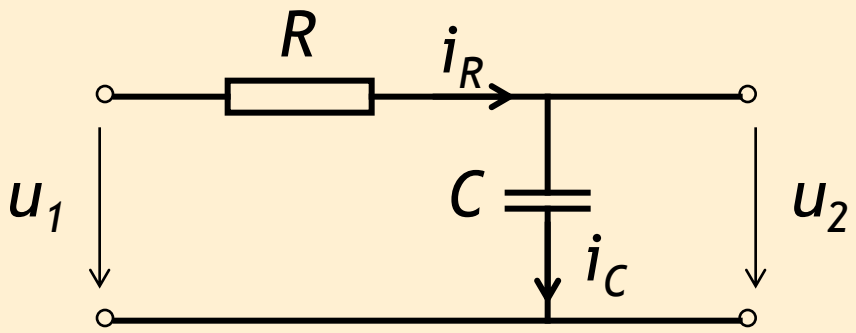
Odziv merilnega člena na stopnico

$$u_2 = U_0\left(1 - e^{-t/\tau}\right)$$



$$\frac{u_2}{U_0} = 0{,}95 = \left(1 - e^{-T_a/\tau}\right) \Rightarrow \underline{T_a \approx 3\tau}$$

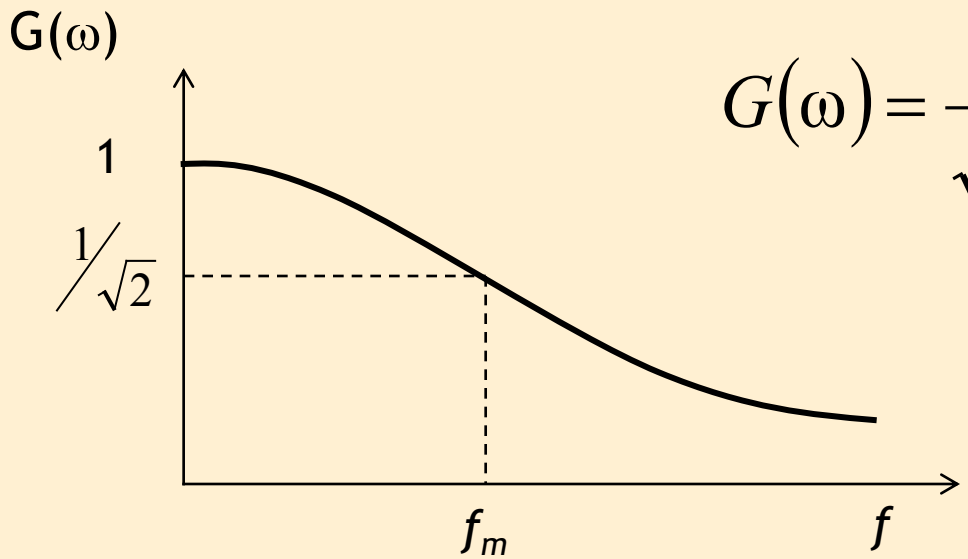
Odziv merilnega člena na sinusno obliko vhodnega signala



$$U_2(\mathrm{j}\omega) = U_1(\mathrm{j}\omega)\frac{R}{R+\mathrm{j}\omega C} = U_1(\mathrm{j}\omega)\frac{1}{1+\mathrm{j}\omega\tau} \quad , \qquad \tau = RC$$

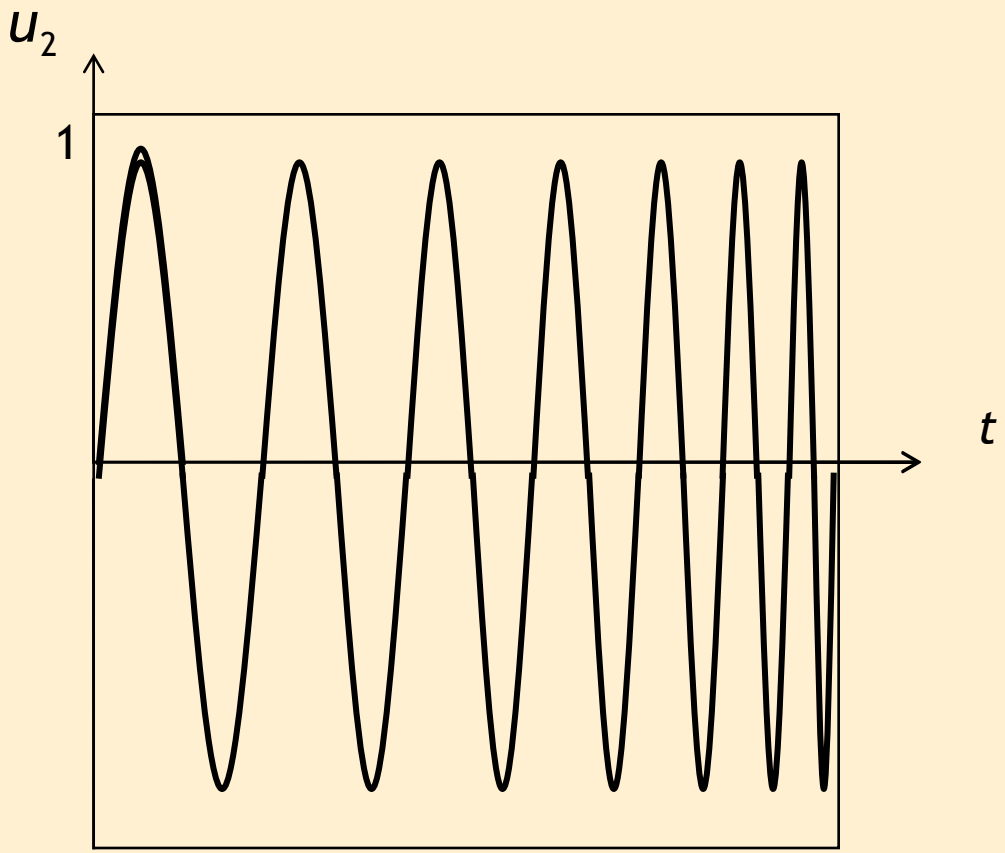
$$|G(\mathrm{j}\omega)| = \left|\frac{U_2(j\omega)}{U_1(j\omega)}\right| = G(\omega) = \frac{1}{\sqrt{1+\omega^2\tau^2}} = \frac{\hat{u}_2(\omega)}{\hat{u}_1(\omega)}$$

Odziv merilnega člena na sinusno obliko vhodnega signala

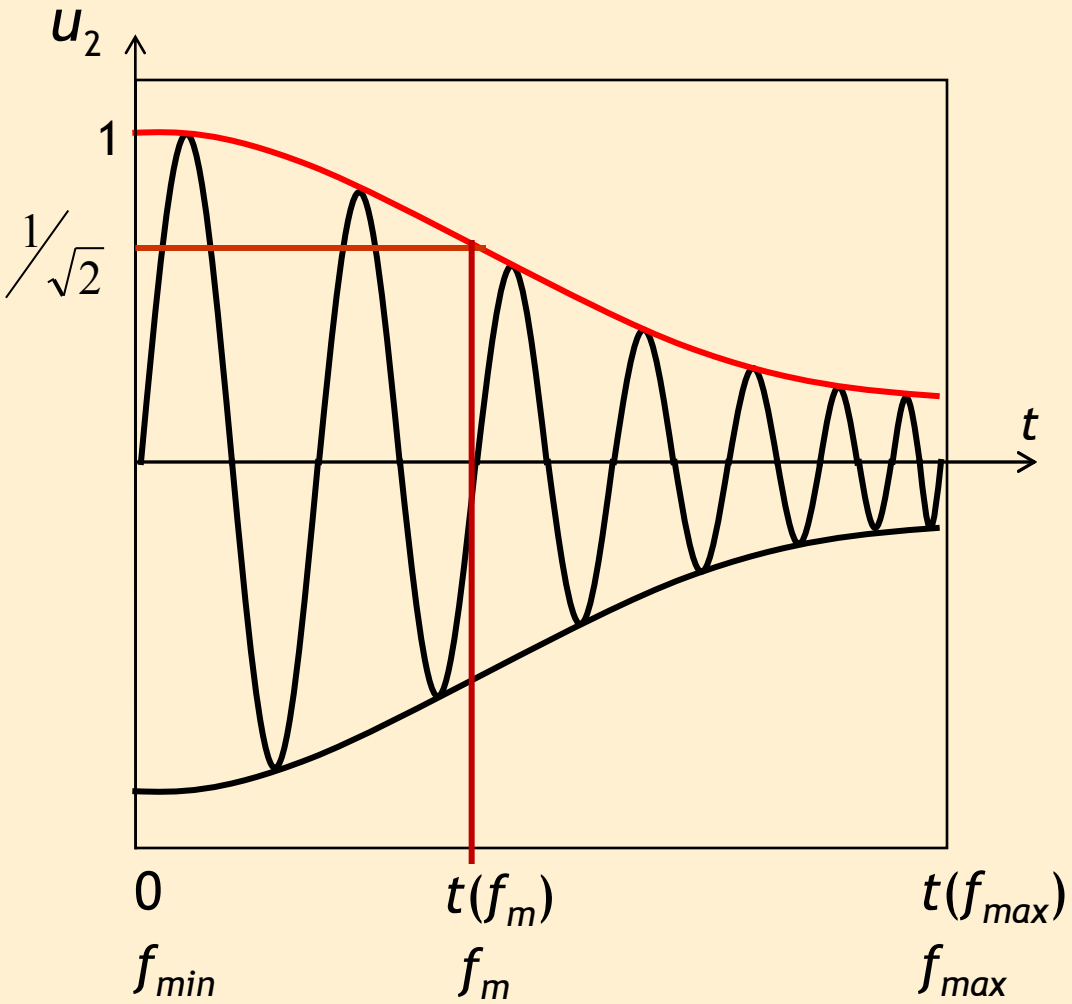


$$G(\omega) = \frac{1}{\sqrt{1+\omega^2\tau^2}}$$

Eksperimentalno ugotavljanje amplitudne karakteristike



Eksperimentalno ugotavljanje amplitudne karakteristike



Eksperimentalno ugotavljanje amplitudne karakteristike

$$\frac{t(f_m)}{t(f_{\max})} = \frac{f_m - f_{\min}}{f_{\max} - f_{\min}}$$

$$\Rightarrow f_m = \frac{t(f_m)}{t(f_{\max})}\left(f_{\max} - f_{\min}\right) + f_{\min}$$

Povezava med T_a in f_m

$$G(\omega) = \frac{1}{\sqrt{1+\omega^2\tau^2}} = \frac{1}{\sqrt{2}}$$

$$\Downarrow$$

$$\omega\tau = 1 \qquad \text{oz.} \qquad 2\pi\, f_m \frac{T_a}{3} = 1$$

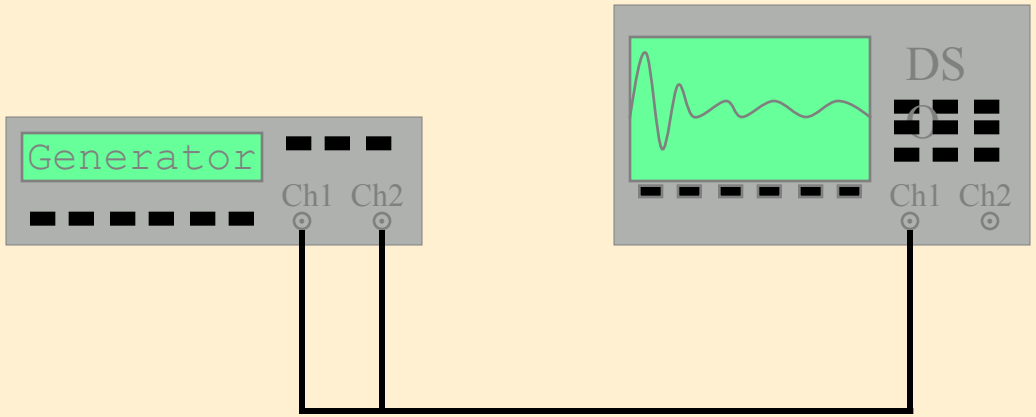
$$\Downarrow$$

$$f_m = \frac{3}{2\pi\, T_a} \approx \frac{1}{2T_a}$$

VAJA 3

Besedilo naloge

Opazujte napetostne signale v odvisnosti od časa in frekvence z digitalnim spominskim osciloskopom (DSO).



- transformacija

- prostor

Opazovanje signala v frekvenčnem prostoru

Periodični signal $u(t)$ s periodo T zapišemo v obliki Fourierove trigonometrijske vrste

$$u(t) = U_0 + \sum_{k=1}^{n} a_k \cos k\omega_1 t + \sum_{k=1}^{n} b_k \sin k\omega_1 t$$

$$a_k = \frac{2}{T}\int_0^T u(t)\cos k\omega_1 t \, \mathrm{d}t \qquad b_k = \frac{2}{T}\int_0^T u(t)\sin k\omega_1 t \, \mathrm{d}t$$

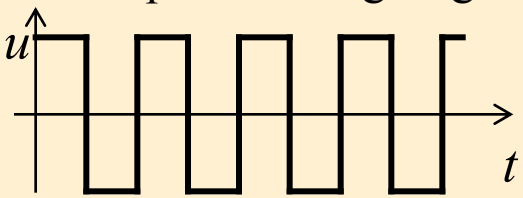
ali

$$U_k = \sqrt{a_k^2 + b_k^2}$$

$$u(t) = U_0 + \sum_{k=1}^{n} U_k \cos\left(k\omega_1 t + \varphi_k\right)$$

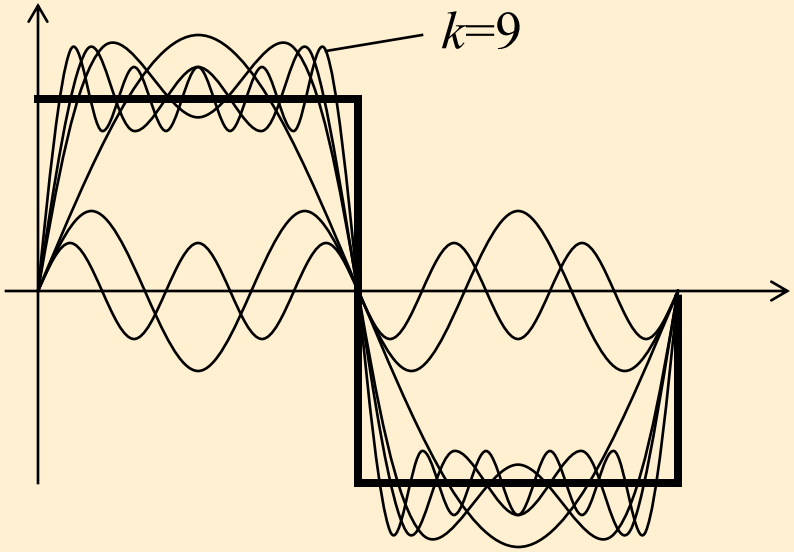
$$\varphi_k = -\mathrm{arctg}\,\frac{b_k}{a_k}$$

Primer pravokotnega signala



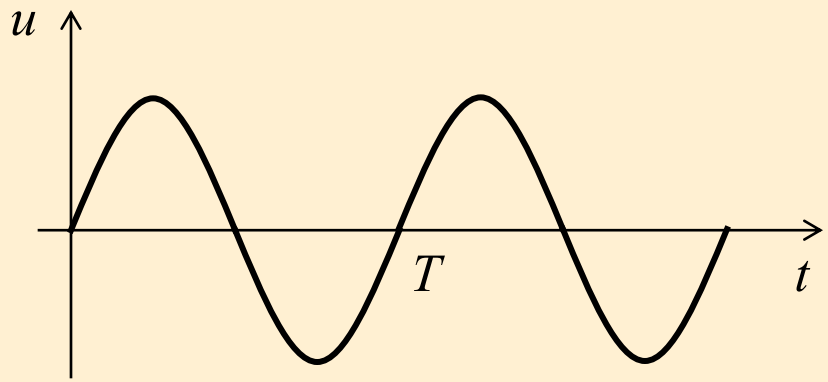
$$u(t) = \begin{cases} 1, & 0 \le t < \pi \\ -1, & \pi \le t < 2\pi \end{cases}$$

$$u(t) = \frac{4}{\pi}\left(\sin t + \frac{\sin 3t}{3} + \frac{\sin 5t}{5} + \ldots\right)$$



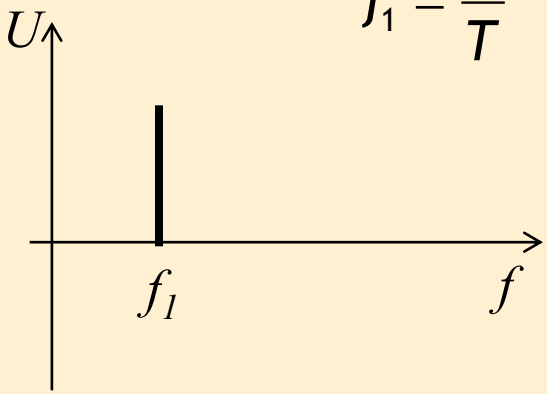
Primer sinusne omrežne napetosti

ČASOVNI PROSTOR



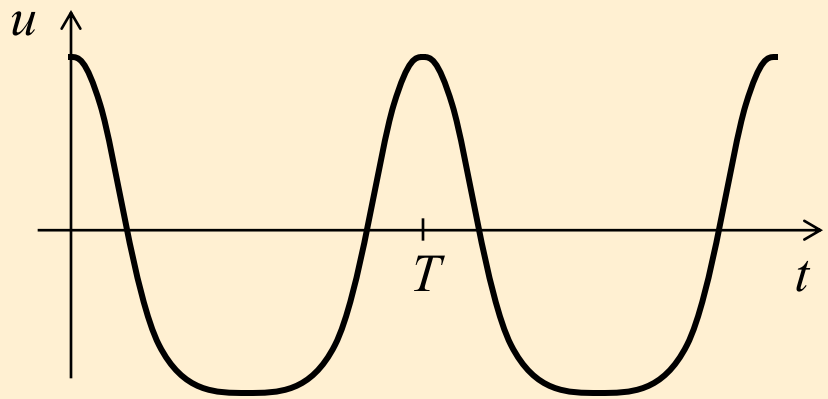
FREKVENČNI PROSTOR

$$f_1 = \frac{1}{T}$$



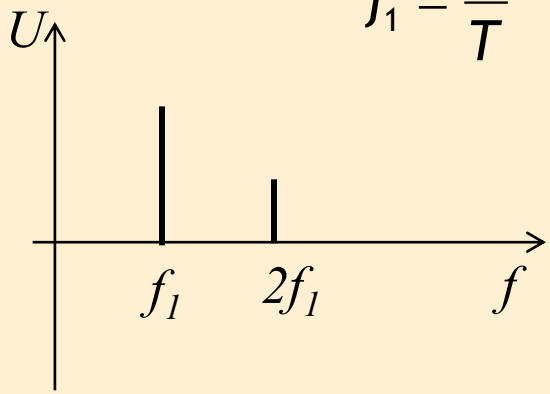
Pospešek bata motorja

ČASOVNI PROSTOR



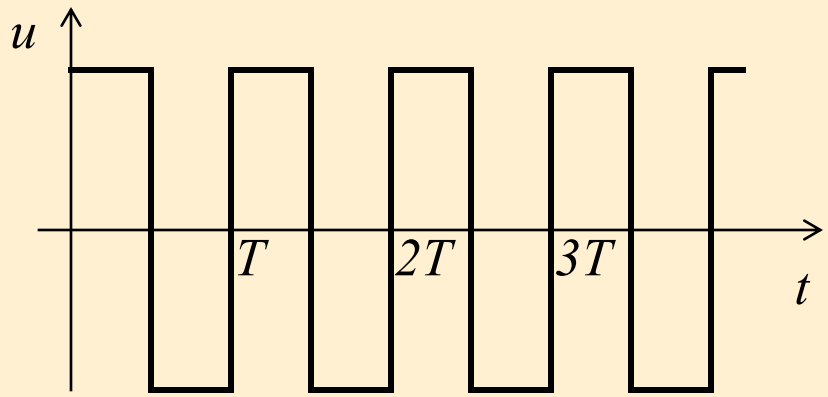
FREKVENČNI PROSTOR

$$f_1 = \frac{1}{T}$$



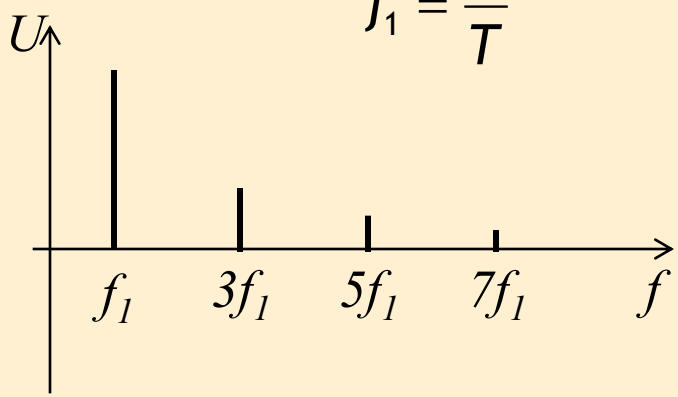
Pravokotna napetost

ČASOVNI PROSTOR



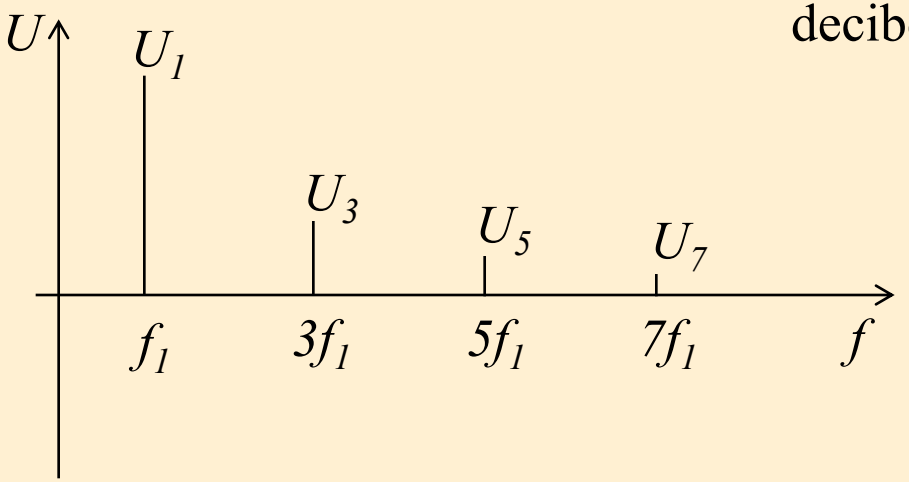
FREKVENČNI PROSTOR

$$f_1 = \frac{1}{T}$$



FREKVENČNI PROSTOR

Efektivne vrednosti U_k so izražene v decibelih (dBV) glede na določeno U_{ref}.

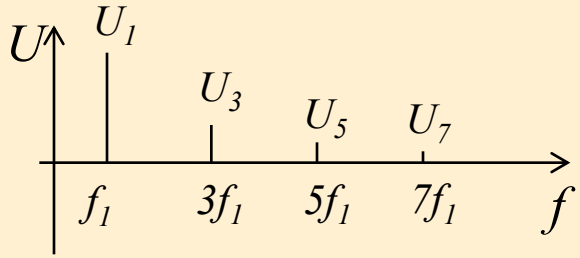


$$U_k/\mathrm{dBV} = 20\log\frac{U_k}{U_{ref}}$$

Primer: Odčitamo U_3 = -5 dBV

to pomeni $$U_3 = U_{ref}\cdot 10^{\frac{U_3/\mathrm{dBV}}{20}} = 1\,\mathrm{V}\cdot 10^{\frac{-5\mathrm{dBV}/\mathrm{dBV}}{20}} = 0{,}562\ \mathrm{V}$$

Skupna efektivna napetost



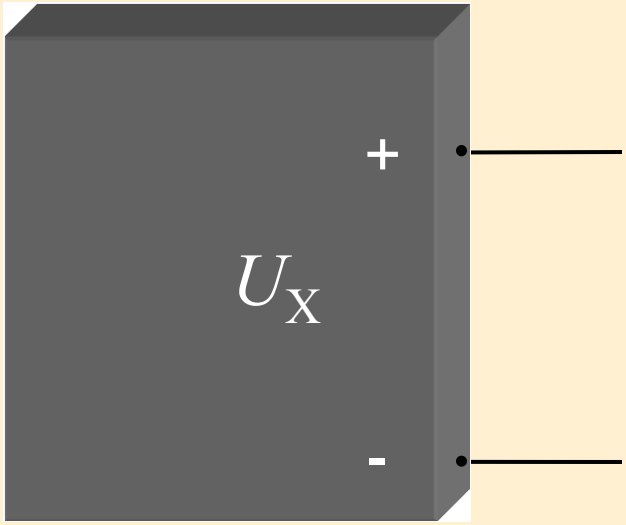
Ko odčitamo vse U_k, izračunamo U in jo primerjamo z odčitano vrednostjo v časovnem prostoru.

$$U = \sqrt{U_0^2 + U_1^2 + \ldots + U_n^2}$$

VAJA 4

Besedilo naloge

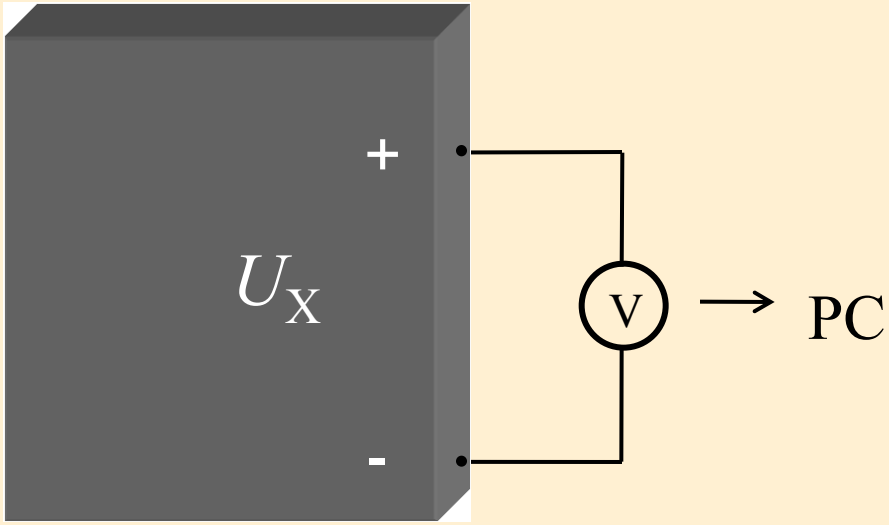
Izmerite neznano napetost U_x po odklonski in kompenzacijski metodi. Ugotovite vpliv ločljivosti na merilni rezultat.



VAJA 4

Besedilo naloge

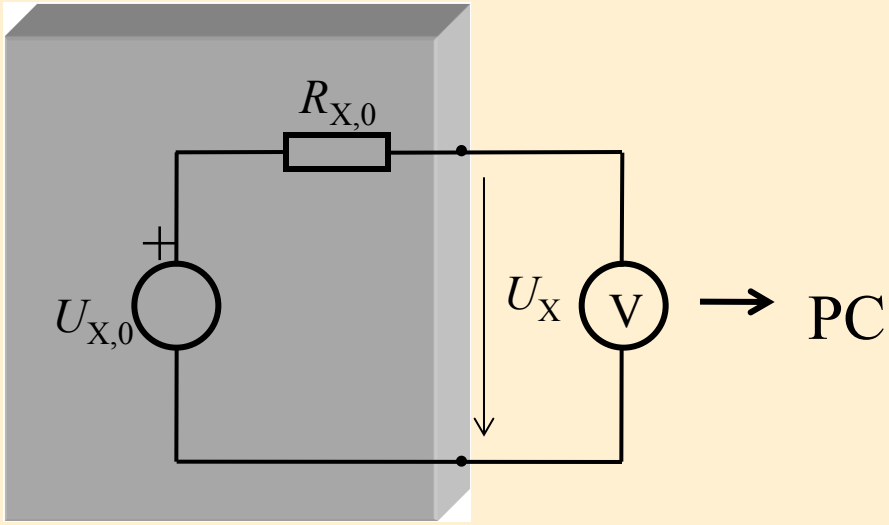
Izmerite neznano napetost U_x po odklonski in kompenzacijski metodi. Ugotovite vpliv ločljivosti na merilni rezultat.



VAJA 4

Besedilo naloge

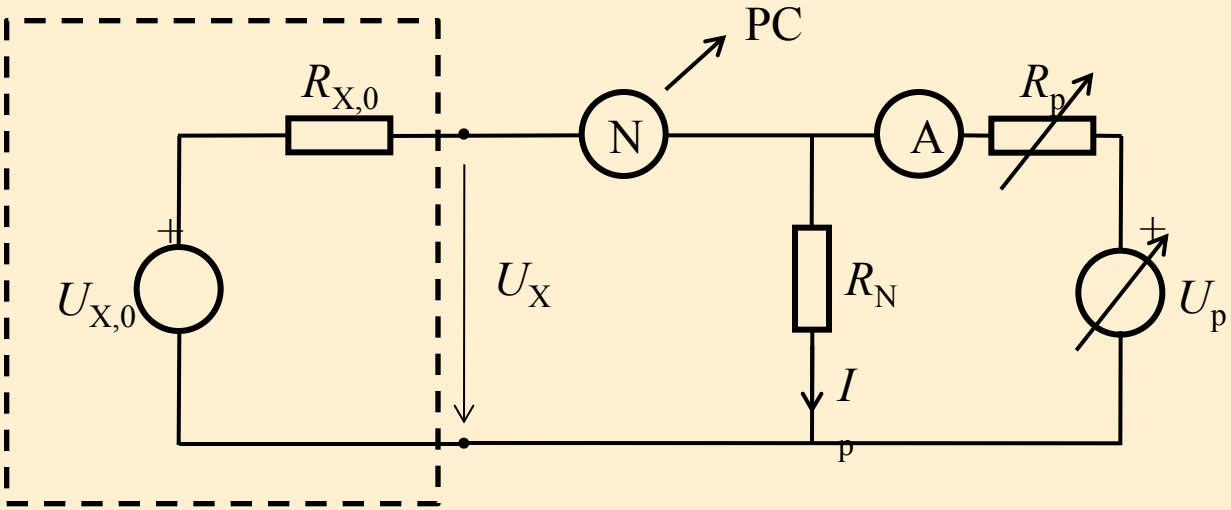
Izmerite neznano napetost U_x po odklonski in kompenzacijski metodi. Ugotovite vpliv ločljivosti na merilni rezultat.



VAJA 4

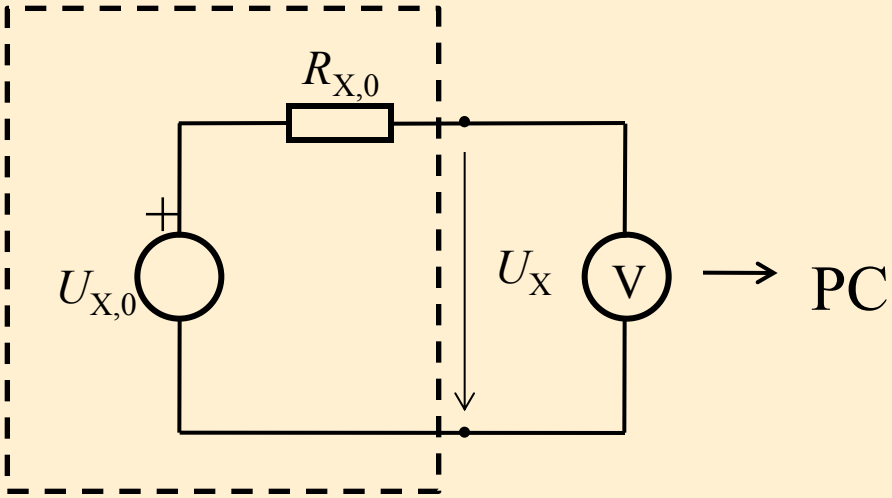
Besedilo naloge

Izmerite neznano napetost U_x po odklonski in kompenzacijski metodi. Ugotovite vpliv ločljivosti na merilni rezultat.



Odklonska metoda

merjenja napetosti

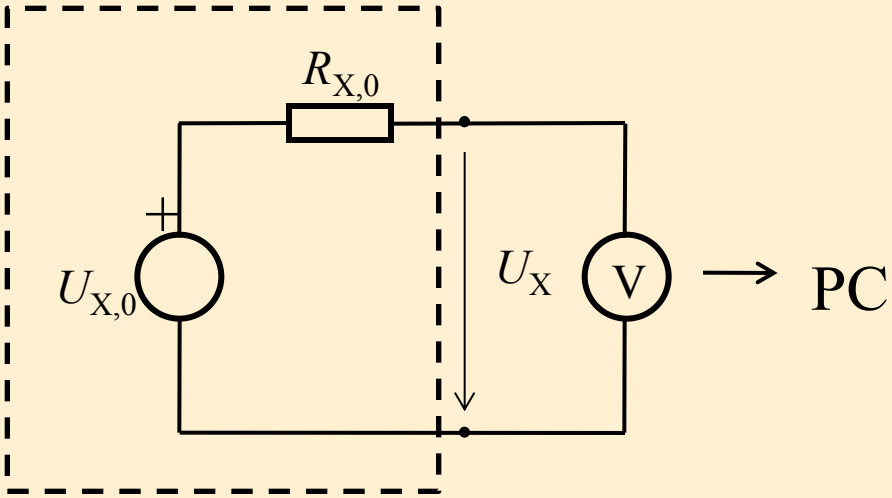


Sistematični pogrešek zaradi notranje upornosti vira:

$$E_1 = U_V - U_{x,0} \frac{R_{x,0}}{R_V + R_{x,0}}$$

Odklonska metoda

merjenja napetosti

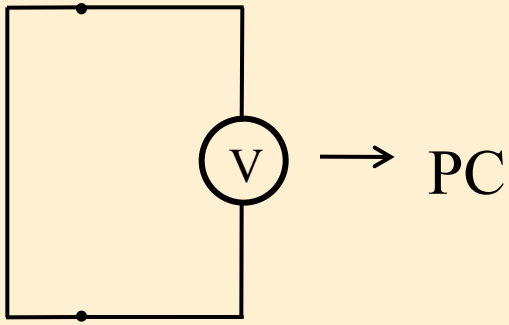


Sistematični pogrešek zaradi ničelnega odklona V-metra (offset):

$$U_x = U_V - \boxed{U_{V,0}} = E_2$$

Odklonska metoda

merjenja napetosti

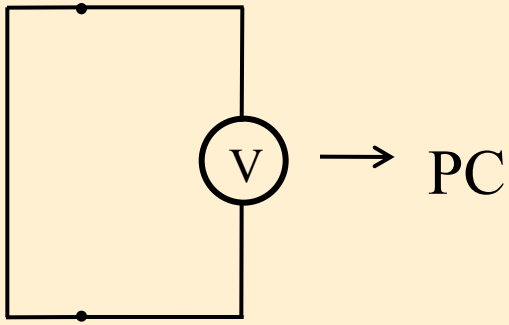


Sistematični pogrešek zaradi ničelnega odklona V-metra (offset):

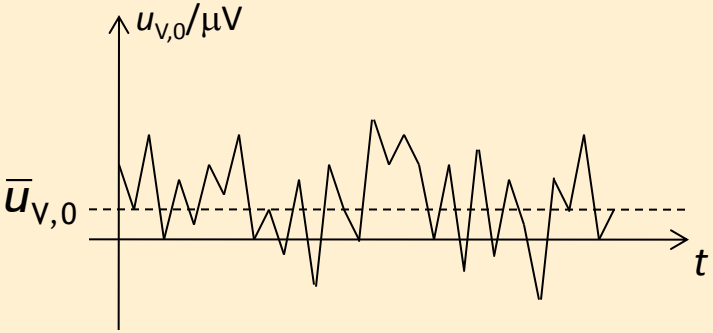
$$U_x = U_V - \boxed{U_{V,0}} = E_2$$

Odklonska metoda

merjenja napetosti



Če merimo z veliko ločljivostjo, opazimo, da napetost niha – negotovost merjenja

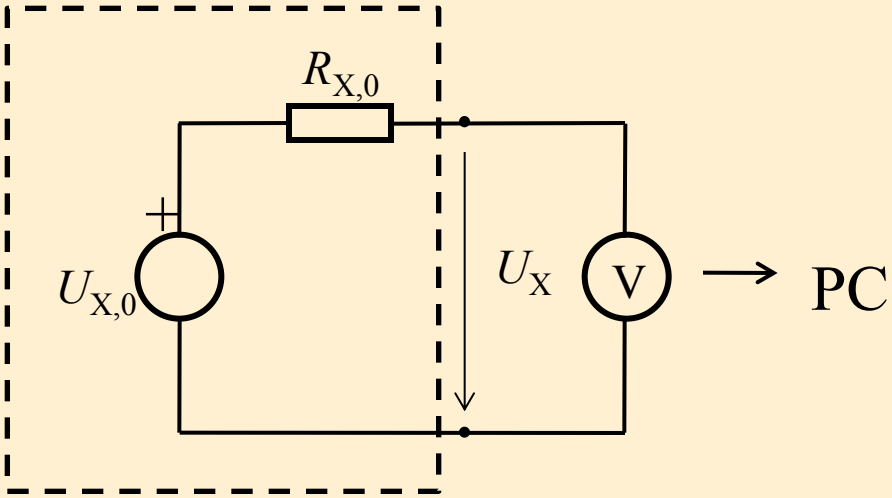


npr.:

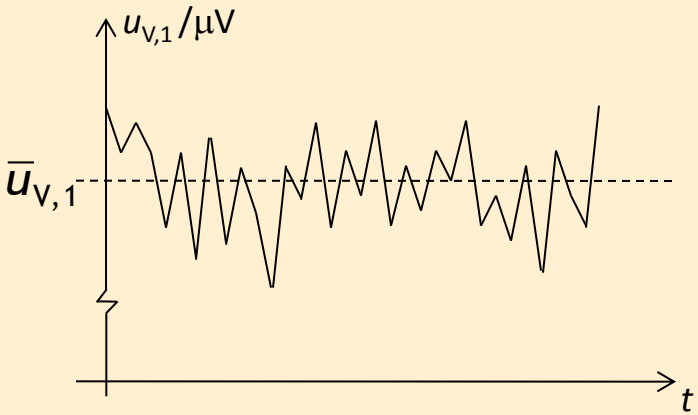
0,000 001 X V

Odklonska metoda

merjenja napetosti



Če merimo z veliko ločljivostjo, opazimo, da napetost niha – negotovost merjenja

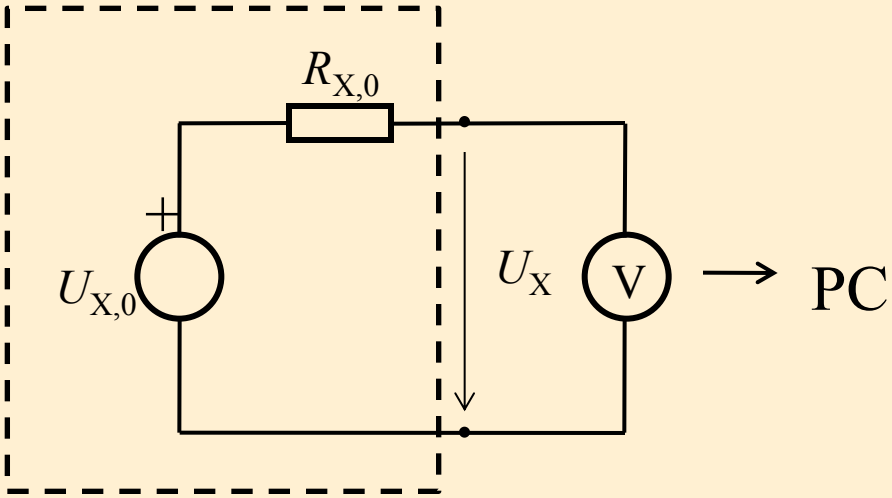


npr.:

0,960 4X X X V

Odklonska metoda

merjenja napetosti



Koliko različnih nivojev bi ločili s takim voltmetrom, če je npr. U_D=1 V?

10 000 000 ?

npr.:

0,960 4X X X V

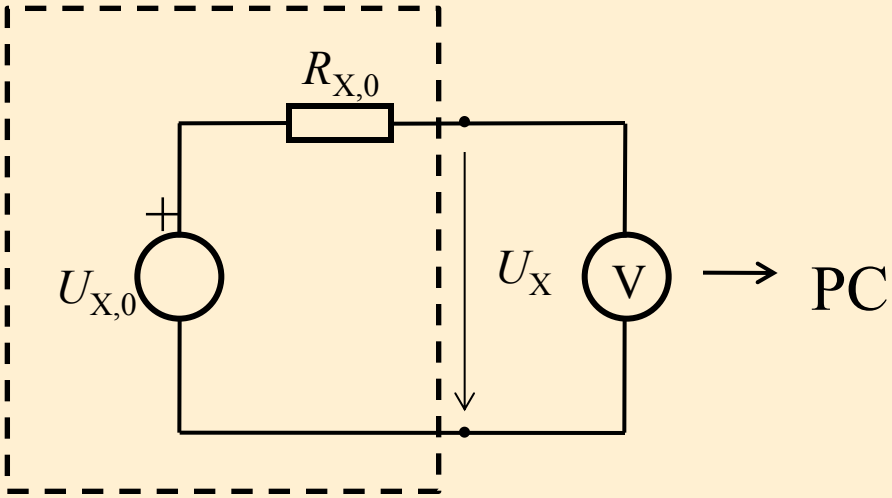
ločljivost

Se pravi

$$R = \frac{U_D}{Q} = \frac{1\,\mathrm{V}}{0{,}1\,\mu V}$$

Odklonska metoda

merjenja napetosti



Če prikaz ni stabilen, je *R* določen kot

$$R = \frac{U_D}{s(U_{V,1})}$$

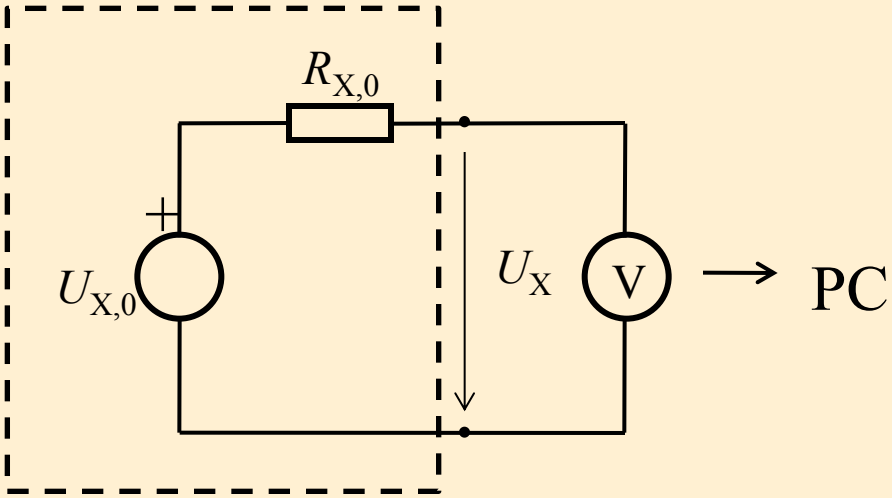
efektivna ločljivost

npr.:

0,960 4X X X V

Odklonska metoda

merjenja napetosti



Koliko bitov bi rabili za to?

$$ENOD = \log_{10} R$$

efektivno št. mest prikaza

npr.:

0,960 4X X X V

Odklonska metoda

merjenja napetosti

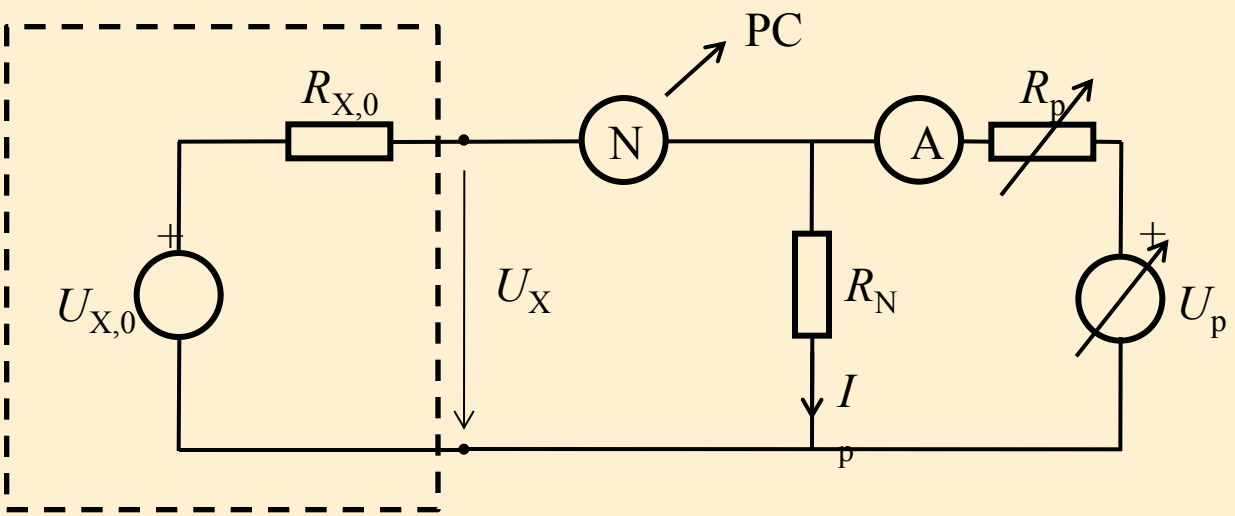
Kakšen bi bil merilni rezultat?

$$U_{x,0} = U_V - E_1 - E_2$$

$$u(U_{x,0}) = \sqrt{s^2(U_{V,0}) + s^2(U_{V,1})} \approx s(U_{V,1})$$

Kompenzacijska metoda

merjenja napetosti

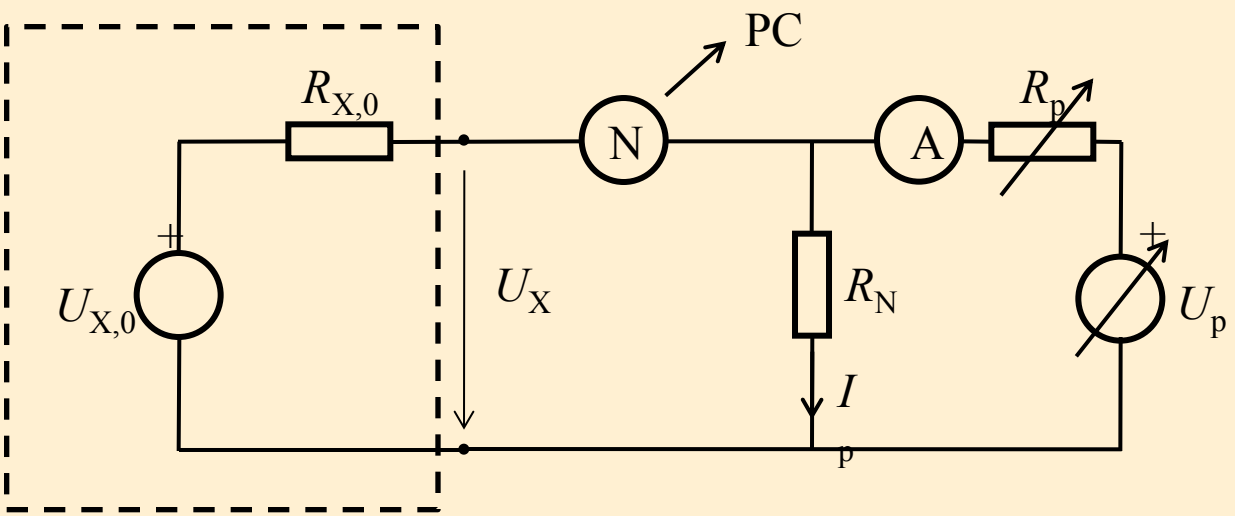


$$U_{x,0} - U_{R_N} = U_{V,2} \approx 0$$

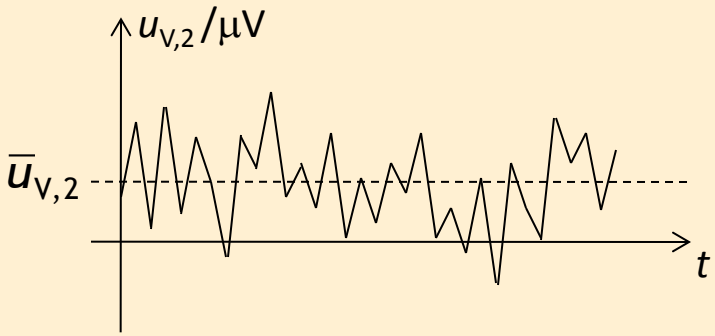
$$U_{R_N} = I_p \cdot R_N$$

Kompenzacijska metoda

merjenja napetosti

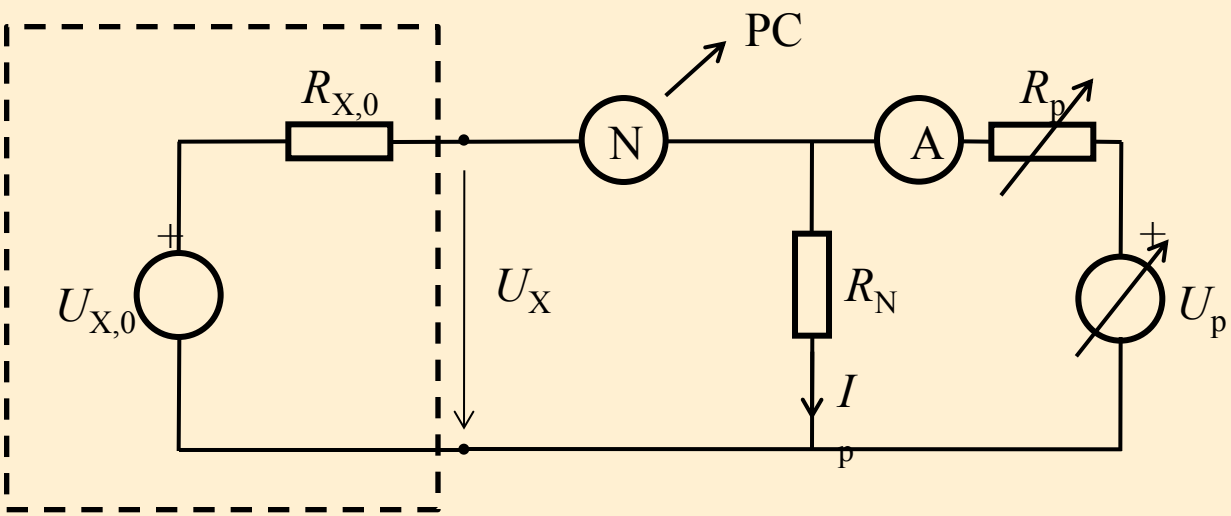


Odčitek voltmetra – stresanje nekoliko večje kot pri odklonskem principu:

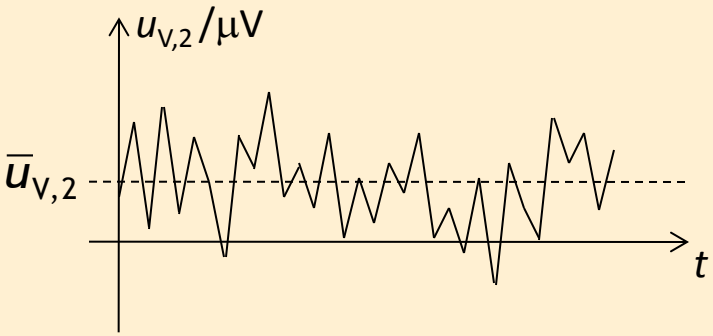


Kompenzacijska metoda

merjenja napetosti



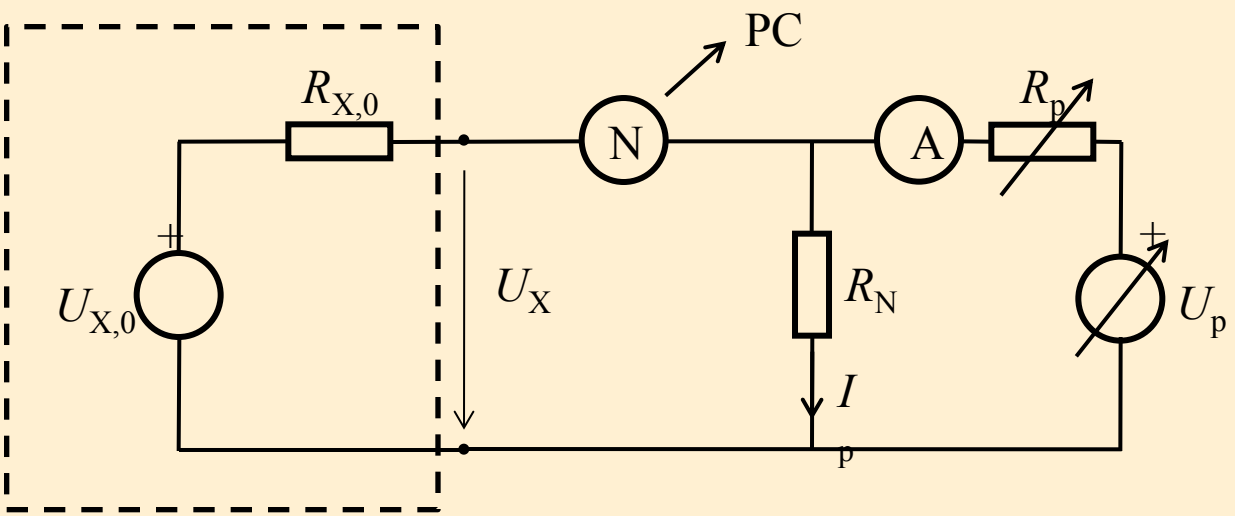
Odčitek voltmetra – stresanje nekoliko večje kot pri odklonskem principu:



npr. :

Kompenzacijska metoda

merjenja napetosti



Odčitek voltmetra – stresanje nekoliko večje kot pri odklonskem principu:

$$R = \frac{U_D}{s(U_{V,2})}$$

npr. :

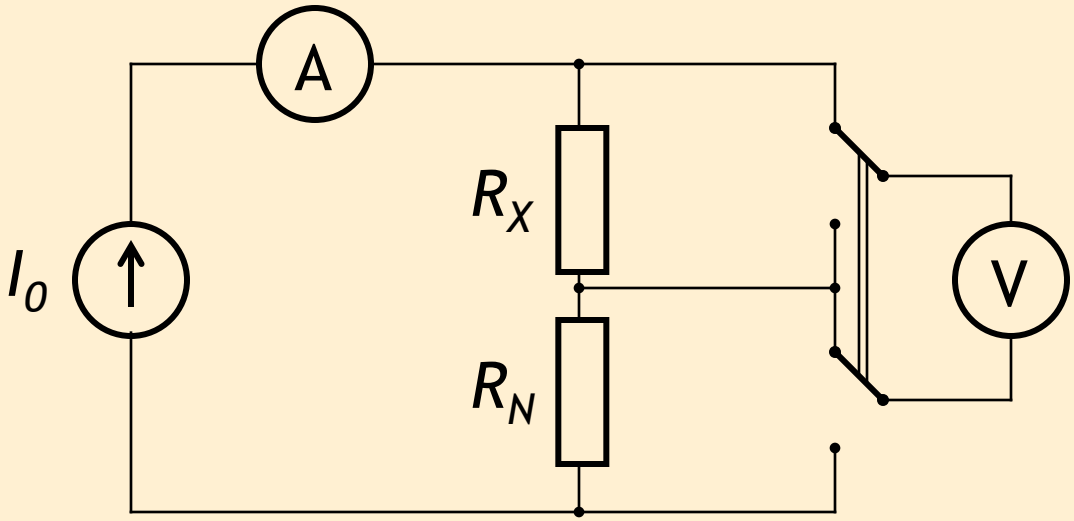
1,037 5XX X V

$$ENOD = \log_{10} R$$

VAJA 5

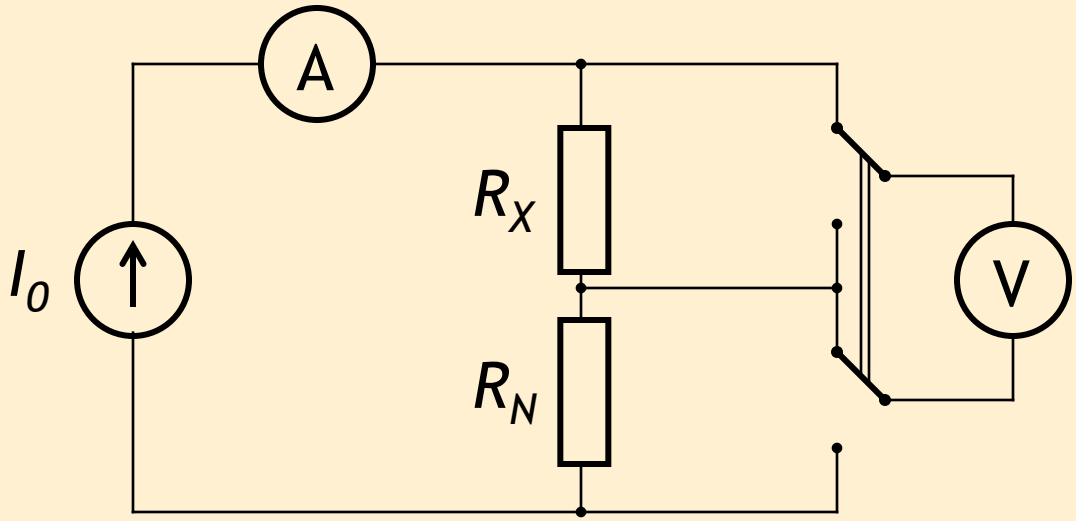
Besedilo naloge

Izmerite ohmsko upornost po UI in napetostni primerjalni metodi.



UI metoda

$$I_A = I + I_V = \frac{U_V}{R_x} + \frac{U_V}{R_V} \quad \Rightarrow \quad \frac{I_A}{U_V} = \frac{1}{R_x} + \frac{1}{R_V}$$



UI metoda

$$I_A = I + I_V = \frac{U_V}{R_x} + \frac{U_V}{R_V} \quad \Rightarrow \quad \frac{I_A}{U_V} = \frac{1}{R_x} + \frac{1}{R_V}$$

$$R_x = \frac{U_V}{I_A} \frac{1}{1 - \frac{U_V}{R_V I_A}}$$

Sistematični pogrešek

$$e = \frac{\boxed{\frac{U_V}{I_A}} - \boxed{\frac{U_V}{I_A} \frac{1}{1 - U_V/(R_V I_A)}}}{\boxed{\frac{U_V}{I_A} \frac{1}{1 - U_V/(R_V I_A)}}} = \frac{\frac{R_x R_V}{R_x + R_V} - R_x}{R_x} = \boxed{-\frac{R_x}{R_x + R_V}}$$

UI metoda

Merilna negotovost

$$R_x = \frac{U_V}{I_A} \quad \Rightarrow \quad \frac{u_c(R_x)}{R_x} = \sqrt{\left(\frac{u(U_V)}{U_V}\right)^2 + \left(\frac{u(I_A)}{I_A}\right)^2}$$

R_x

$$e < \frac{1}{10}\frac{u_c(R_x)}{R_x} \quad \Rightarrow \quad R_x = \frac{U_V}{I_A}$$

UI metoda

Merilna negotovost

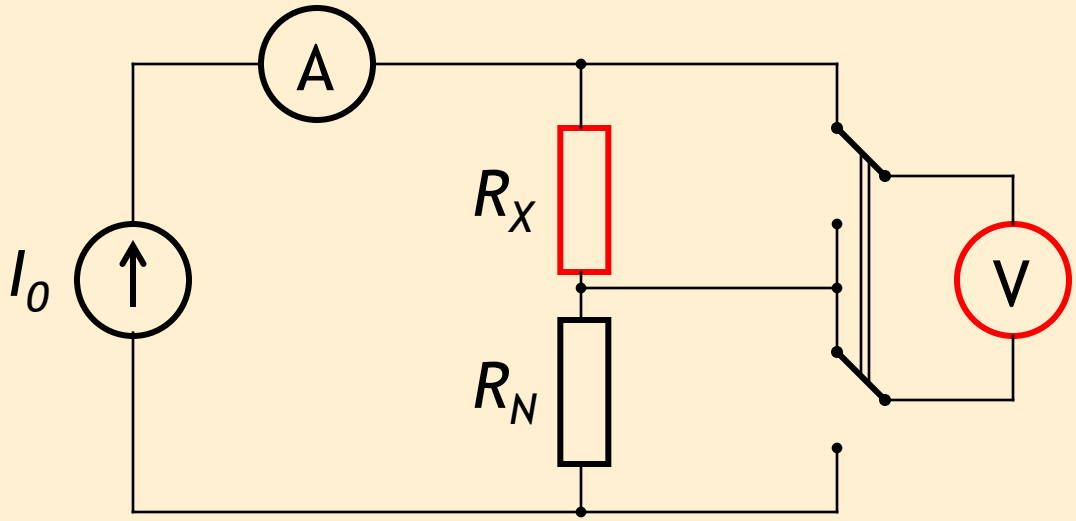
$$R_x = \frac{U_V}{I_A} \quad \Rightarrow \quad \frac{u_c(R_x)}{R_x} = \sqrt{\left(\frac{u(U_V)}{U_V}\right)^2 + \left(\frac{u(I_A)}{I_A}\right)^2}$$

R_x

$$e \geq \frac{1}{10}\frac{u_c(R_x)}{R_x} \quad \Rightarrow \quad R_x = \frac{U_V}{I_A}\frac{1}{1-\frac{U_V}{R_V I_A}}$$

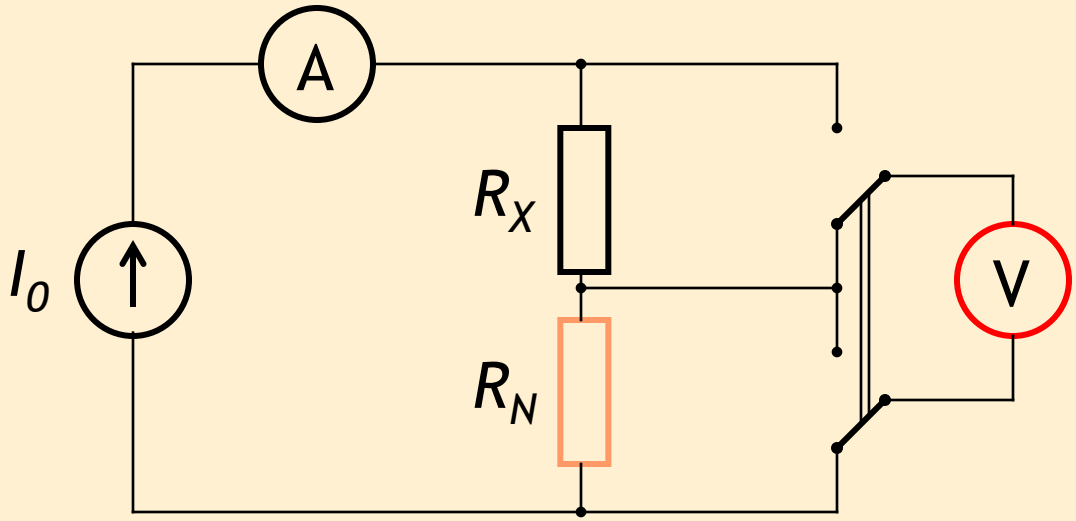
Napetostno primerjalna metoda

$$U_x = I_0 \frac{R_x R_V}{R_x + R_V}$$



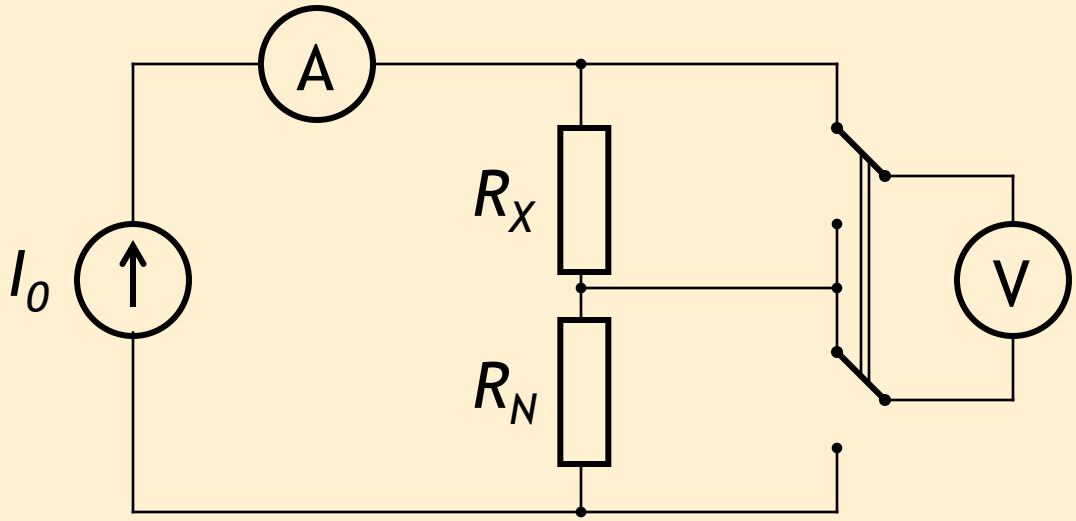
Napetostno primerjalna metoda

$$U_N = I_0 \frac{R_N R_V}{R_N + R_V}$$



Napetostno primerjalna metoda

$$R_X = R_N \frac{U_X}{U_N} \cdot \frac{R_X + R_V}{R_N + R_V}$$



Napetostno primerjalna metoda

Sistematični pogrešek

$$e = \frac{R_N \frac{U_x}{U_N} - R_N \frac{U_x}{U_N} \frac{R_x + R_V}{R_N + R_V}}{R_N \frac{U_x}{U_N} \frac{R_x + R_V}{R_N + R_V}} = \frac{R_N + R_V}{R_x + R_V} - 1 = \boxed{\frac{R_N - R_x}{R_x + R_V}}$$

Napetostno primerjalna metoda

Merilna negotovost

$$R_X = R_N \frac{U_X}{U_N}$$

$$\Rightarrow \quad \frac{u_c(R_x)}{R_x} = \sqrt{\left(\frac{u(R_N)}{R_N}\right)^2 + \cancel{\left(\frac{u(U_X)}{U_X}\right)^2} + \cancel{\left(\frac{u(U_N)}{U_N}\right)^2}}$$

$$R_X \approx R_N$$

Napetostno primerjalna metoda

Merilna negotovost

$$R_X = R_N \frac{U_X}{U_N}$$

$$\frac{u_c(R_x)}{R_x} = \sqrt{\left(\frac{u(R_N)}{R_N}\right)^2 + \quad ?}$$

$$R_X \approx R_N$$

Napetostno primerjalna metoda

Merilna negotovost

$$R_X = R_N \frac{U_X}{U_N}$$

$$\frac{u_c(R_x)}{R_x} = \sqrt{\left(\frac{u(R_N)}{R_N}\right)^2 + 2\left(\frac{u(U_X)_q}{U_X}\right)^2}$$

$$R_X \approx R_N$$

Rezultati meritev (vaje)

- 2 merilna rezultata za obe metodi

$$R_x = \_\_\_\_\_,\ u(R_x) = \_\_\_\_\_,\ n = \_\_\_\_\_$$

- primerjava