1. MJERENA NESIGURNOST, multimetar

1.1. SUSTAVNA POGREŠKA

$R = 100\ \Omega$

$R_{MULTIMETAR} = 109{,}3\ \Omega$ $\Rightarrow$ $R_m = R_k + R \Rightarrow R = 99{,}3\ \Omega$

$R_{KABELA} = 10\ \Omega$

↳ sustavna pogreška, možemo ukloniti:

- PROMJENOM MJERNOG POSTAVA ili METODE
  - → kraći kabel, manji R_{kabela}, direktno spajanje otpora na multimeter, četveroelektrodno mjerenje
- KOREKCIJOM MJERENJA

1.2. PRECIZNOST i ISKAZIVANJE MJERNOG REZULTATA

$R = 100\ \Omega$

* razlučivost $= 0{,}01\ \Omega$ $\quad \langle 109{,}27\ ,\ 109{,}33 \rangle$

$n = 1000$

normalna razdioba, preciznost uređaja ?

$$p(R) = \frac{1}{\sqrt{2\pi}\cdot\sigma_R}\exp\left[-\frac{1}{2}\left(\frac{R-\bar{R}}{\sigma_R}\right)^2\right]$$

$$\bar{R} = \frac{\sum_{i=1}^{M} N_i \cdot R_i}{\sum_{i=1}^{M} N_i} = 99{,}30\ \Omega \qquad \sigma_R = \sqrt{\frac{1}{N-1}\sum_{i=1}^{M}(R_i-\bar{R})^2} = 0{,}01\ \Omega$$

POUZDANOST	REZULTAT
68,27 %	$\bar{R} \pm \sigma_R$
95,45 %	$\bar{R} \pm 2\sigma_R$
99,73 %	$\bar{R} \pm 3\sigma_R$

1.3. TOČNOST ; RELATIVNA POGREŠKA

$R_m = 99{,}3\ \Omega$; tablica (uniformna gustoća razdiobe)

OPSEG : 200 Ω → razlučivost: 0,1 Ω → TOČNOST: ± (0,8% + 3 digita)

VJEROJATNOST SE 100% nalazi u intervalu $\bar{R} \pm a$

$\pm(x\% + y\ \text{digita}) \Longrightarrow a = \frac{x}{100}\cdot R + y\cdot r$

$a = \frac{0{,}8}{100}\cdot 99{,}3 + 3\cdot 0{,}1 = 1{,}1\ \Omega \Rightarrow \boxed{(99{,}3 \pm 1{,}1)\ \Omega}$

RELATIVNA POGREŠKA $\quad p = \frac{\text{IZMJERENO} - \text{REF}}{\text{REF}}\cdot 100\% = \frac{99{,}3 - 100}{100}\cdot 100\% = -0{,}7\ \%$

1.4. SLOŽENA MJERNA NESIGURNOST i KORELACIJA

* 2 multimetra
  - I. NAČIN → koristimo samo 1 ; $r = 1$!
  - II. NAČIN → koristimo oba ; $r = \emptyset$!

} VAŽNO ! * u stvarnosti nikad nije 0 ; nikad nije 1

jednakih značajki, koje mjerenje ima manju nesigurnost ?

$U = 100,0\ V$ $\quad \sigma_1 = u(U) = 0,2\ V$

$I = 2,00\ A$ $\quad \sigma_2 = u(I) = 0,01\ A$

} $P = U \cdot I$

$$\sigma_y = \sqrt{\sum_{i=1}^{m} \left(\frac{\partial f}{\partial x_i}\right)^2 \sigma_i^2 + 2 \cdot \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} r(x_i, x_j)\, \sigma_i \sigma_j}$$

$$r(\sigma_i, \sigma_j) = \frac{cov(x_i, x_j)}{\sigma_i \cdot \sigma_j}$$

I. način

$$\sigma_{P1} = \sqrt{I^2 \cdot \sigma_U^2 + U^2 \cdot \sigma_I^2 + 2 \cdot I \cdot U \cdot \sigma_I \cdot \sigma_U} = 1,4\ W$$

II. način $\Rightarrow$ $\sigma_{P2} = \sqrt{I^2 \cdot \sigma_U^2 + U^2 \cdot \sigma_I^2} \approx 1,1\ W$ $\longrightarrow$ BOLJE ! $\quad (200,00 \pm 1,1)\ W$

1.5. ZADACI

1. P → nekoreliranim mjerenjima U i R → $r = 0$

$\sigma_U = 0{,}05\ V$ $\quad U = 1900\ V$

$\sigma_R = 0{,}07\ \Omega$ $\quad R = 20{,}00\ \Omega$

$$\sigma_P = \sqrt{\left(2\frac{U}{R}\right)^2 \cdot \sigma_U^2 + \left(-\frac{U^2}{R^2}\right)^2 \cdot \sigma_R^2 + 2\sum_{i=1}^{n-1}\sum_{j=1}^{n} r(x_i, x_j)\,\sigma_i \sigma_j}$$

$$= 0{,}053\ W$$

$$P = \frac{U^2}{R} = 5\ W$$

$$P = (5{,}000 \pm 0{,}053)\ W$$

2. $R_1 = 1200\ \Omega$ $\quad \sigma_{R_1} = 5\ \Omega$ (jednim multimetrom)

$R_2 = 2500\ \Omega$ $\quad \sigma_{R_2} = 7\ \Omega$ (drugim multimetrom)

$r(R_1, R_2) = 0{,}371$

$$R = R_1 + R_2 = 3700\ \Omega$$

$$R = (3700 \pm 10)\ \Omega$$

$$\sigma_R = \sqrt{\sigma_{R_1}^2 + \sigma_{R_2}^2 + 2 \cdot 0{,}371 \cdot 5 \cdot 7} = 10\ \Omega$$

3. $P = U \cdot I$ (jedan multimetar $\Rightarrow r = 1$)

$I = 2{,}5\ A$, $U = 160\ V$ } tablica

za I $\Rightarrow$ M.O. $= 4\ A \rightarrow r = 0{,}001\ A \rightarrow \pm(2{,}5\% + 5)$

$$\sigma_I = a_1 = \frac{2{,}5}{100} \cdot 2{,}5 + 5 \cdot 0{,}001\ A = 0{,}0675\ A$$

za U

$\Rightarrow$ M.O. $= 500\ V \rightarrow r = 100\ mV \rightarrow \pm(1\% + 5)$

$$\sigma_U = a_2 = \frac{1}{100} \cdot 160 + 0{,}1 \cdot 5 = 2{,}1\ V$$

$a = \frac{x}{100} \cdot$ izmjereno $+ y \cdot r$

$$\sigma_P = \sqrt{I^2 \sigma_U^2 + U^2 \cdot \sigma_I^2 + 2 \cdot U \cdot I \cdot 1 \cdot \sigma_I \cdot \sigma_U} = 16\ W$$

$$P = (400 \pm 16)\ W$$

4. $U_{DC} = 4\ V$

$U_{AC,ef} = 3\ V$ / sinus

a) za DC

$U = 4\ V$

$\sigma_{DC} = \frac{0{,}8}{100} \cdot 4 + 0{,}001 = 0{,}033\ V$

$U_{DC} = (4{,}000 \pm 0{,}033)\ V$

b) za AC

$U = 3\ V$

$\sigma_{AC} = \frac{1}{100} \cdot 3 + 5 \cdot 0{,}001 = 0{,}035\ V$

$U_{AC} = (3{,}000 \pm 0{,}035)\ V$

$$U_{ef} = \sqrt{U_{DC}^2 + U_{AC,ef}^2} = 5\ V$$

5. dva multimetra ⇒ mjerimo R

prvi mult: $U_{e1} = 9{,}40\ V$, $\sigma_1 = 0{,}04\ V$

drugi mult: $I_{e1} = 5{,}00\ mA$, $\sigma_2 = 0{,}01\ mA$

$r = -0{,}15$

$$R = \frac{U}{I}$$

$$\sigma_R = \sqrt{\left(\frac{1}{I}\right)^2 \cdot \sigma_U^2 + \left(-\frac{U}{I^2}\right)^2 \cdot \sigma_I^2 + 2 \cdot \frac{1}{I} \cdot \frac{-U}{I^2} \cdot (-0{,}15) \cdot \sigma_U \cdot \sigma_I}$$

2 mult

$= 8{,}6\ \Omega$

$R_{jednim\ mult} = 1{,}076\ k\Omega$

$$\sigma_R = \frac{1}{100} \cdot 1076 + 2 \cdot 1 = 12{,}76\ \Omega = 13\ \Omega$$

1 mult

$R_{STVARNO} = 1079{,}000\ \Omega$

dva mult: $R = (1080{,}0 \pm 8{,}6)\ \Omega$ → točnije

jedan mult: $R = (1076 \pm 13)\ \Omega$

6. $U_{DC_1} = 250{,}3$ M.P. = 400 mV → $\sigma_1 = a_1 = \frac{0{,}8}{100} \cdot 250{,}3 + 3 \cdot 0{,}1 = 2{,}3024\ mV = \boxed{2{,}3\ mV}$

$U_{DC_2} = 0{,}250$ M.P. = 4V ⇒ $\sigma_2 = a_2 = \frac{0{,}8}{100} \cdot 0{,}250 + 1 \cdot 0{,}001 = 0{,}003\ V$

preciznije

7. $u_{ul} = 3 \sin(2\pi f t) + 3\ [V]$

$G_{AC} = \pm (1\% + 5 \text{ znamenki})$

$G_{DC} = \pm (0{,}8\% + 1 \text{ znamenka})$

} $r = 1\ mV$

$U_{DC} = \underline{3\ V}$

$U_{AC} = U_{ef} = \frac{U_m}{\sqrt{2}} = \underline{2{,}121\ V}$

$$U_{ef} = \sqrt{U_{DC}^2 + U_{AC}^2}$$

$G_{DC} = \sigma_{DC} = \frac{0{,}8}{100} \cdot 3 + 1 \cdot 0{,}001 = 0{,}025\ V$

$G_{AC} = \sigma_{AC} = \frac{1}{100} \cdot 3 + 5 \cdot 0{,}001 = 0{,}035\ V$

zaokružimo

$U_{ef\ min} = 3{,}639\ V$ $U_{ef\ max} = 3{,}710\ V$

8.

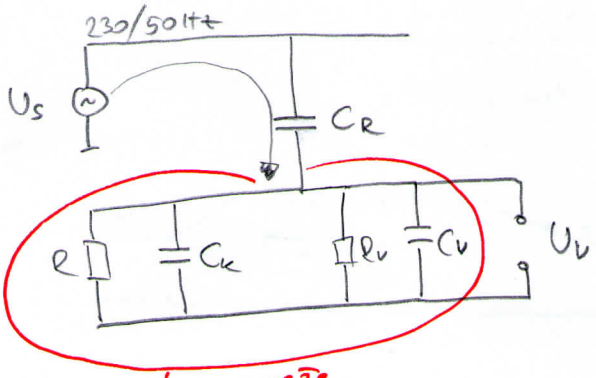
3. ELEKTROMAGNETSKE SMETNJE

3.1. ASIMETRIČNI SPOJ

$l_{kabel} = 5\,m$

$R = 1\,k\Omega$

Iznos smetnji uslijed kapacitivnog vezanja kabela s vodom gradske mreže?



$C_K = \overbrace{100\,pF/m}^{\text{zadano}} \cdot 5\,m = 500\,pF$

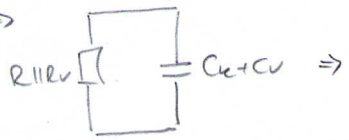
$C_R = 10\,pF$

$R_V = 1\,M\Omega$

$C_V = 25\,pF$

$$U_V = U_S \cdot \frac{\text{otpor mreže}}{\frac{1}{j\omega C_R} + \text{otpor mreže}}$$

otpor mreže $\Rightarrow$



$\Rightarrow \quad \dfrac{(R_V \| R)\cdot\left(\frac{1}{j\omega(C_K+C_V)}\right)}{(R_V \| R) + \frac{1}{j\omega(C_K+C_V)}} = \dfrac{999}{j\omega\, 5{,}24475\cdot 10^{-7} + 1}$

$999\,\Omega$

$C_K + C_V = 5{,}25\,pF$

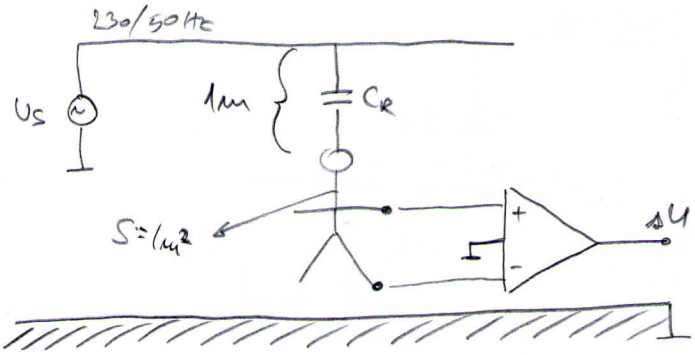
$$\frac{\text{otpor mreže}}{\frac{1}{j\omega C_R} + \text{otpor mreže}} = \frac{\frac{999}{1 + j\omega\, 5{,}24475\cdot 10^{-7}}}{1 + \frac{j\omega 10\cdot 10^{-12} - \omega^2 \cdot 5{,}24475\cdot 10^{-18}}{j\omega\, 10\cdot 10^{-12}}}$$

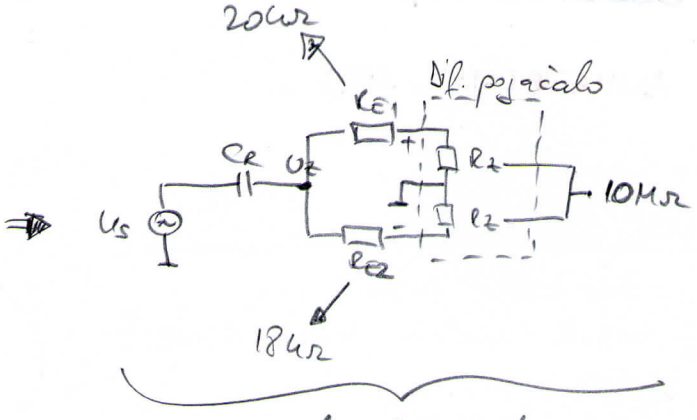
$$\frac{R_V \| R}{1 + j\omega(C_K+C_V)(R_V \| R)} \Rightarrow \frac{\frac{R_V \| R}{1 + j\omega(C_K+C_V)(R_V \| R)}}{\frac{1}{j\omega C_R} + \frac{R_V \| R}{1 + j\omega(C_K+C_V)(R_V \| R)}} = \frac{R_V \| R}{\left(1 + j\omega(C_K+C_V)(R_V \| R)\right) + R_V \| R \cdot j\omega C_R}$$

$$= \boxed{\frac{j\omega C_R (R_V \| R)}{1 + j\omega(C_K + C_V + C_R)(R_V \| R)}} = X$$

$$U_V = U_S \cdot X = 7{,}21844\cdot 10^{-4}\,V = 0{,}722\,mV$$

3.2. DIFERENCIJALNI SPOJ



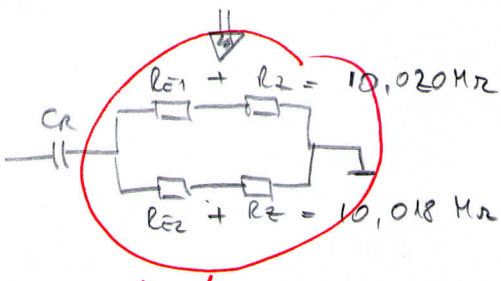


nadomjesna shema

$$C_R = \varepsilon_0 \cdot \frac{S}{d} = 8{,}854 \cdot 10^{-12} \frac{F}{m} \cdot \frac{1\,m^2}{1\,m} = 8{,}854\,pF$$

$$U_Z = U_S \cdot \left| \frac{R_{most}}{\frac{1}{j\omega C_R} + R_{most}} \right|$$

$$= U_S \cdot \left| \frac{j\omega C_R R_{most}}{1 + j\omega C_R R_{most}} \right| = U_S \cdot \frac{\omega C_R R_m}{\sqrt{1^2 + \omega^2 C_R^2 \cdot R_m^2}} =$$



$R_{most} = R \| R = 5.0095\,M\Omega$

$\boxed{= 3{,}2\,V}$ naponu smetnje

↳ R_{E1} i R_{E2} nisu isti pa će se ta smetnja pojaviti na izlazu

$$\Delta U = U_Z \cdot \left(\frac{R_Z}{R_{E1} + R_Z} - \frac{R_Z}{R_{E2} + R_Z} \right) = 0{,}637\,mV$$

* ako je $R_{E1}, R_{E2} \ll R_Z \Rightarrow \Delta U \approx U_Z \frac{R_{E1} - R_{E2}}{R_Z} = 640\,\mu V$

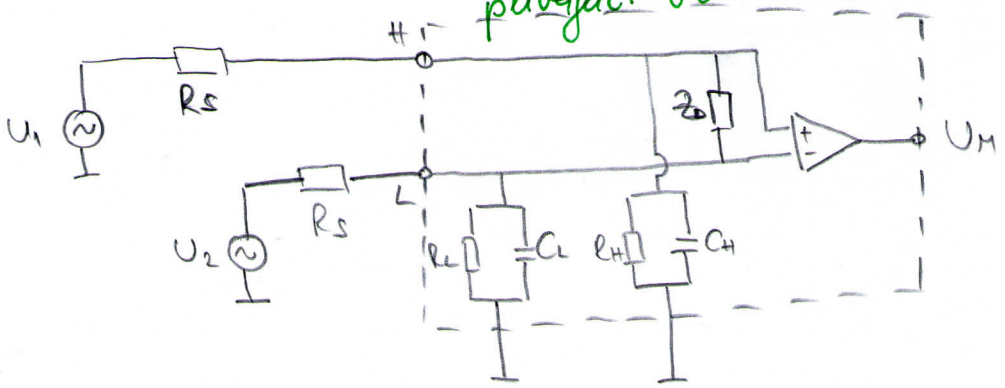
→ ima par rješenja za ovaj problem, ali najbolje je

PLIVAJUĆE POJAČALO

→ povećavamo impedanciju R_Z

3.3. PLIVAJUĆI SPOJ

plivajući voltmetar



$Z_H = 2\,G\Omega \,||\, 2pF$

$Z_L = 1\,G\Omega \,||\, 10pF$

U_z (smetnja) $< 100\,\mu V$ — 50 Hz, 1000 Hz, 10 kHz, 100 kHz

$R_S = 100\,\Omega$, $Z_D = \infty$

$$U_M = U_H - U_L = U_1 \cdot \frac{Z_H}{R_S + Z_H} + U_2 \cdot \frac{Z_L}{R_S + Z_L} \Rightarrow \frac{1}{2}\left[\frac{Z_H}{Z_H + R_S} + \frac{Z_L}{Z_L + R_S}\right](U_1 - U_2) + \left[\frac{Z_H}{Z_H + R_S} - \frac{Z_L}{Z_L + R_S}\right]\frac{U_1 + U_2}{2}$$

KORISTAN — diferencijalni napon

SMETNJA — zajednički napon

$Z_H, Z_L \gg R_S$ → dif. pojačanje teži → 1

→ zajednički pojačanje teži → ∅

} princip rada plivajućeg pojačala

UVJET: $\left(\frac{Z_H}{Z_H + R_S} - \frac{Z_L}{Z_L + R_S}\right) \cdot U_z \leq 100\,\mu V$

$$Z_H = \frac{R_H \cdot \frac{1}{j\omega C_H}}{R_H + \frac{1}{j\omega C_H}} = \frac{R_H}{1 + j\omega C_H R_H}$$

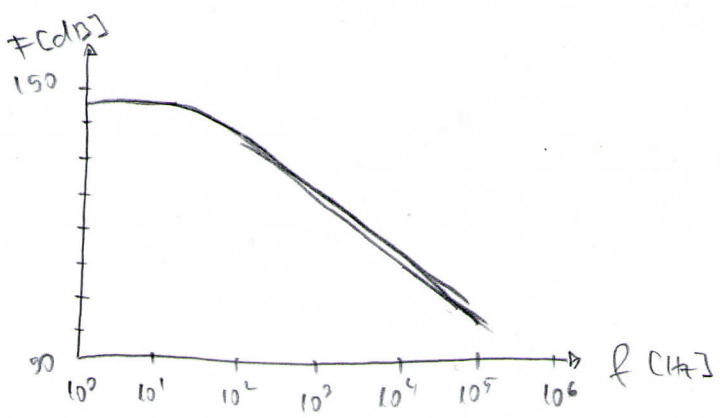
$$Z_L = \frac{R_L}{1 + j\omega C_L R_L}$$

f	$U_{z,max}$ [V]
50 Hz	1245
1 kHz	80
10 kHz	8
100 kHz	0,8

FAKTOR POTISKIVANJA:

omjer pojačanja dif. signala i pojačanja zajedničkog signala

$$F = \frac{\frac{1}{2}\left(\frac{Z_H}{Z_H + R_S} + \frac{Z_L}{Z_L + R_S}\right)}{\left(\frac{Z_H}{Z_H + R_S} - \frac{Z_L}{Z_L + R_S}\right)}$$

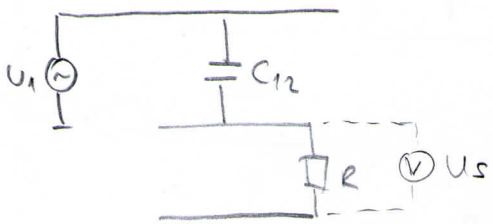


3.4. ZADACI

① $f = 10\ kHz$

$U_1 = 230\ V$

$U_s < 2{,}2\ mV$



oba vodiča $d = 1\ mm$

$C_{12} = \pi \cdot \varepsilon_0 / \ln(2D/d)$

$D = ?$

$$U_s = U_1 \cdot \frac{R}{R + C_{12}} = \frac{j\omega C_{12} \cdot R}{1 + j\omega C_{12} \cdot R} = \frac{\omega C_{12} \cdot R}{\sqrt{1^2 + \omega^2 \cdot C_{12}^2 \cdot R^2}}$$

$$U_s < 2{,}2\ mV \Rightarrow \quad U_s = U_1 \cdot \frac{2\pi f \cdot 10000 \cdot \frac{\pi \varepsilon_0}{\ln(2D/d)}}{\sqrt{1^2 + \underbrace{\omega^2 \cdot C_{12}^2 \cdot 10000^2}_{\gg 1}}} \Rightarrow C_{12} = \frac{U_s}{U_1} \cdot \frac{1}{\omega \cdot R} = 3{,}0447 \cdot 10^{-12}\ F$$

$$C_{12} = \frac{\pi \cdot \varepsilon_0}{\ln(2D/d)} \Rightarrow \ln(2D/d) = \frac{\pi \cdot \varepsilon_0}{C_{12}} \quad / e$$

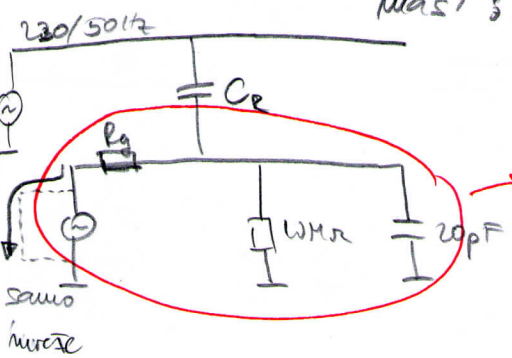
$$\frac{2D}{d} = e^{\frac{\pi \cdot \varepsilon_0}{C_{12}}} \Rightarrow D = \frac{d}{2} e^{\frac{\pi \cdot \varepsilon_0}{C_{12}}} = 4{,}64\ m$$

② $Z_{ul} = 10\ M\Omega \,||\, 20\ pF$ ASIMETRIČAN ULAZ → jedna priključnica na masi

$C_K = 5\ pF$

$R_g = ?$, $U_s < 50\ \mu V$ (visoka osjetljivost)

$230 \cdot \sqrt{2}$



$$Z = \frac{R_g \,||\, R_v \cdot \frac{1}{j\omega C_v}}{R_g \,||\, R_v + \frac{1}{j\omega C_v}} = \frac{R_g \,||\, R_v}{1 + j\omega C_v (R_g \,||\, R_v)} = \frac{R_g \cdot R_v}{R_g + R_v + j\omega C_v \cdot R_g \cdot R_v}$$

$$U_s = U \cdot \frac{Z}{Z + \frac{1}{j\omega C_K}} = \frac{j\omega C_K \cdot R_g \cdot R_v}{R_g + R_v + j\omega C_v \cdot R_g \cdot R_v + j\omega C_K \cdot R_g \cdot R_v}$$

$$Z + \frac{1}{j\omega C_K} = \frac{R_g + R_v + j\omega C_v \cdot R_g \cdot R_v + j\omega C_K \cdot R_g \cdot R_v}{j\omega C_K \cdot (R_g + R_v + j\omega C_v \cdot R_g \cdot R_v)}$$

$$\frac{U_s}{U \cdot \sqrt{2}} = \frac{\omega \cdot C_K \cdot R_g \cdot R_v}{\sqrt{(R_g + R_v)^2 + \underbrace{(\omega (R_g \cdot C_v \cdot R_v) + \omega C_K \cdot R_g \cdot R_v)^2}_{\text{zanemarivo}}}} = \frac{\omega C_K \cdot R_g \cdot R_v}{R_g + R_v} \Rightarrow R_g = \frac{-R_v}{\left(1 - \frac{U\sqrt{2}}{U_s} \omega \cdot C_K \cdot R_v\right)} = 97{,}86\ \Omega$$

③ asimetrický ulit

$R_{ul} = 10\,M\Omega$

$C_1 = 5\,pF$

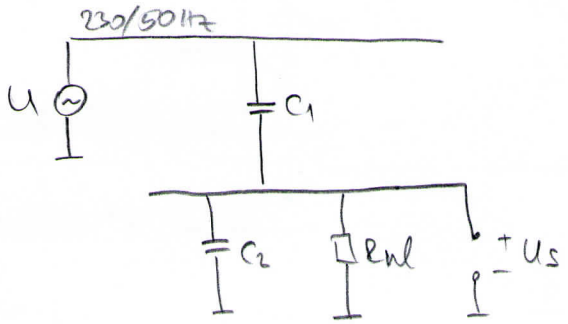
$C_2 = 5\,pF$

$C_3 \gg C_1 + C_2$

↓

zanedbatelné

C_3



$$U_S = U \cdot \frac{\frac{R_{ul}}{j\omega C_2}}{\frac{1 + j\omega C_2 \cdot R_{ul}}{j\omega C_2} + \frac{1}{j\omega C_1}} = \frac{j\omega C_1 \cdot R_{ul}}{1 + j\omega C_2 \cdot R_{ul} + j\omega R_{ul} \cdot C_1} \cdot U$$

$$U_S = U \cdot \frac{\omega C_1 \cdot R_{ul}}{\sqrt{1^2 + (\omega(C_2 \cdot R_{ul} + C_1 \cdot R_{ul}))^2}} = 3{,}61\,V$$

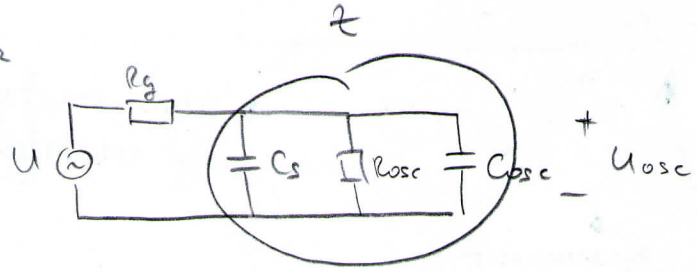
zanedbatelné

④ sonda $\times 1$ → $U = 1V$, $f = 1\,MHz$ $R_g = 1k\Omega$

$l_{sonde} = 1{,}5\,m$

$C_{sonde} = 60\,pF/m$ ⇒ $C_{sonde} = 90\,pF$

$Z_{ul} = 1M\Omega \| 30\,pF$



$$Z = \frac{R_{osc} \cdot \frac{1}{j\omega(C_s + C_{osc})}}{R_{osc} + \frac{1}{j\omega(C_s + C_{osc})}} = \frac{R_{osc}}{1 + j\omega(C_s + C_{osc}) \cdot R_{osc}}$$

$$U_{osc} = U \cdot \frac{Z}{Z + R_g} = \frac{R_{osc}}{R_{osc} + R_g + j\omega(C_s + C_{osc}) R_{osc} \cdot R_g} \cdot U$$

$$= \frac{R_{osc} \cdot U}{\sqrt{(R_{osc} + R_g)^2 + (\omega(C_s + C_{osc})\, R_{osc} \cdot R_g)^2}} = 0{,}7$$

zanedbatelné

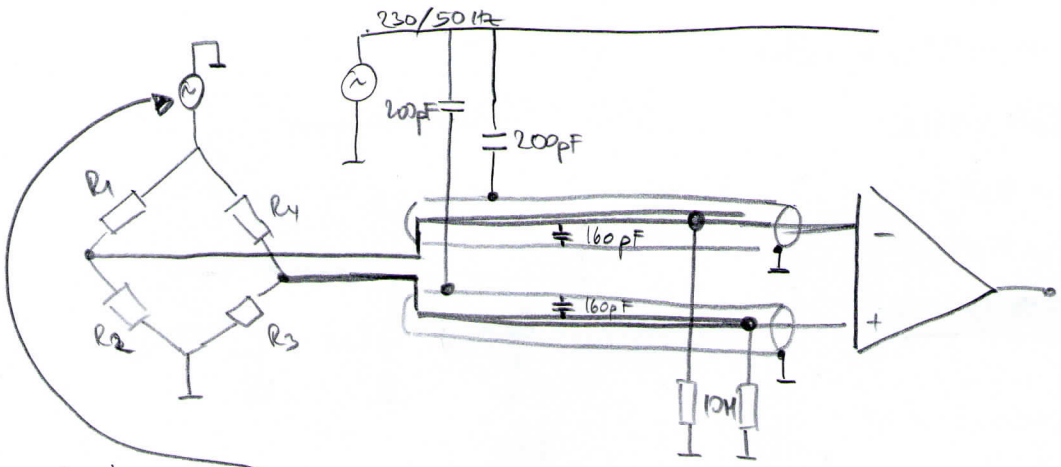
⑤ $A_D = 100$

$R_{ul} = 1\,M\Omega$

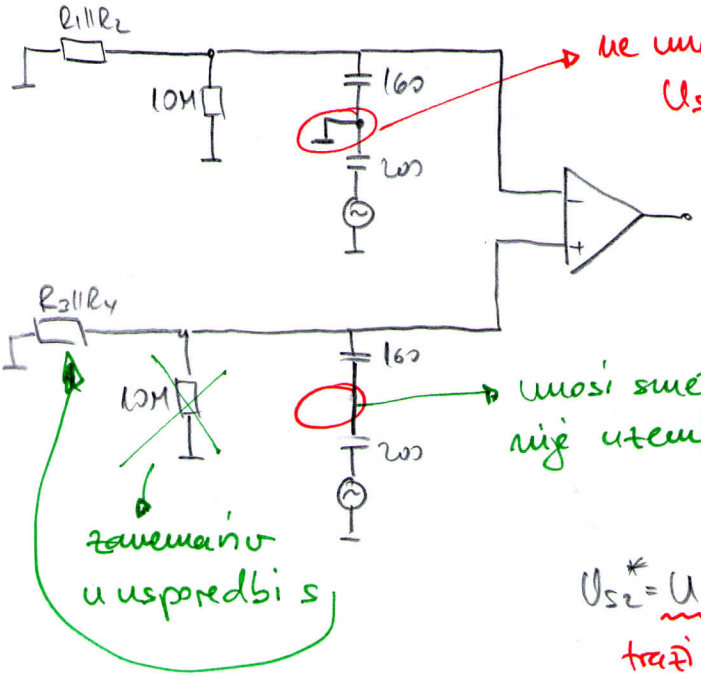
$R_1 = R_2 = R_3 = R_4 = 10\,k\Omega$

$C_{oklop/uvod} = 160\,pF$

$C_{oklop/mreža} = 200\,pF$



* zanima nas samo smetnja pa izvor kratko spojimo



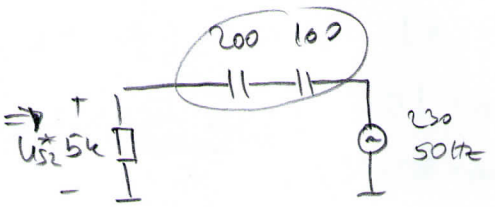
ne unosi smetnju $U_{s1} = 0$

zbog toga u zadatku

unosi smetnju jer nije uzemljen

zanemarujemo u usporedbi s

$C_{ekv} = \frac{C_1 \cdot C_2}{C_1 + C_2} = 88{,}88\,pF$



$U_{s2}^* = U \cdot \sqrt{2} \cdot \frac{5k}{5k + \frac{1}{j\omega C_{ekv}}} = U \cdot \sqrt{2} \frac{j\omega C_{ekv} \cdot 5k}{1 + j\omega C_{ekv} \cdot 5k} = 0{,}045\,V$

U_{s2}^* = $U \cdot \sqrt{2}$ traži se amplituda

$U_{s2} = A_D \cdot U_{s2}^* = 4{,}5\,V$

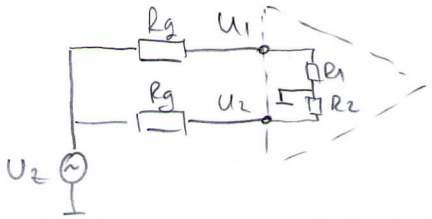
⑥ plivajući uređaj ⇒ voltmetar

$F = ?$, $U_z = 50\,V$

$R_g = 1\,k\Omega$

$R_1 = 2\,G\Omega$

$R_2 = 1{,}5\,\Omega$



pojačanje $\times 1$

$U_{iz} = A(U_1 - U_2)$

$$U_1 = U_z \cdot \frac{R_1}{R_g + R_1} = 49{,}999975\,V$$

$$U_2 = U_z \cdot \frac{R_2}{R_g + R_2} = 49{,}99996667\,V$$

$$\Delta U = U_1 - U_2 = 8{,}33 \cdot 10^{-6}\,V$$

$$F = \frac{A_D}{A_z} = \frac{\frac{U_{izD}}{U_{ulD}}}{\frac{U_{izz}}{U_{ulz}}} = \frac{1}{\frac{(U_1 - U_2)\cdot A}{U_z}} = \frac{U_z}{\Delta U} = 6000015{,}936 \Rightarrow 135\,dB$$

($A \gg 1$)

4. SENZORI

4.1. PIEZOELEKTRIČKI SENZOR SILE

$\varepsilon_r = 5$, $S = 1{,}5\ cm^2$, $d = 1{,}5\ mm$, $\alpha = 0{,}1\ mC/N$

$l_k = 5\ m$, $C_k^* = 80\ pF/m$

$Z_v = 10\ M\Omega \,||\, 12\ pF$

Nacrtaj shemu, $f_g = ?$

$F = ?$ ako $t = 2{,}5\ ms \rightarrow U_v = 375\ mV$

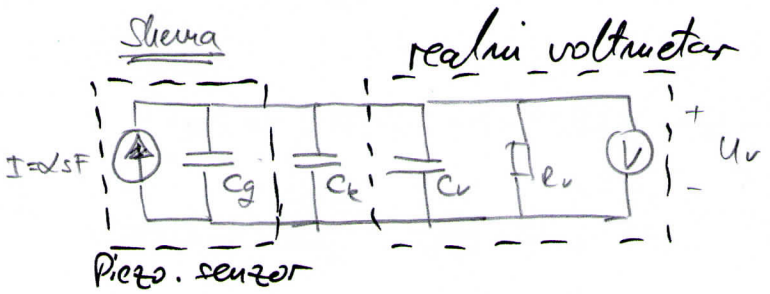
$$g(t) = \alpha \cdot F(t) \quad / \quad \mathcal{L}$$

$$i(t) = \frac{dg(t)}{dt} = \alpha \cdot \frac{dF(t)}{dt} \quad \circ\!\!-\!\!\bullet \quad I(s) = \alpha \cdot s F(s)$$

$$C_g = \varepsilon_0 \cdot \varepsilon_r \cdot \frac{S}{d} = 4{,}427\ pF$$

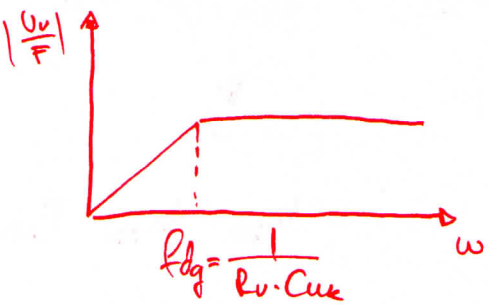
$$C_k = l \cdot C_k^* = 400\ pF$$

→ najveći pa najviše utječena f_{dg}



$$U_v = I \cdot Z_{ukupno} = \alpha s F(s) \cdot \frac{R_v \cdot \frac{1}{s(C_g + C_k + C_v)}}{R_v + \frac{1}{s(C_g + C_k + C_v)}} = \alpha \cdot s \cdot F(s) \cdot \frac{R_v}{1 + s(C_g + C_k + C_v) \cdot R_v}$$

$$f_d = \frac{\omega}{2\pi} = \frac{1}{2\pi \cdot \tau} = \frac{1}{2\pi} \cdot \frac{1}{(C_k + C_g + C_v) \cdot R_v} = 32{,}35\ Hz$$



$F(s) = \frac{F_0}{s}$ → konstantna sila u $t = 0^+$

$$U_v(s) = \frac{\alpha \cdot F_0}{(C_g + C_k + C_v)} \cdot \frac{1}{s + \frac{1}{\tau}} \quad \circ\!\!-\!\!\bullet \quad U_v(t) = \frac{\alpha F_0}{(C_g + C_v + C_k)} \cdot \exp\left(-\frac{t}{\tau}\right)$$

$U_v(t = 2{,}5\ ms) = 375\ mV \rightarrow F_0 = 2{,}846\ N$

4.2. TEMP. SENZOR U MOSNOM SPOJU → najvj u ispitu

↳ zašto most a ne obični R ?
↳ VEĆA OSJETLJIVOST

$\alpha_R = 3{,}96 \cdot 10^{-3}$ 1/°C

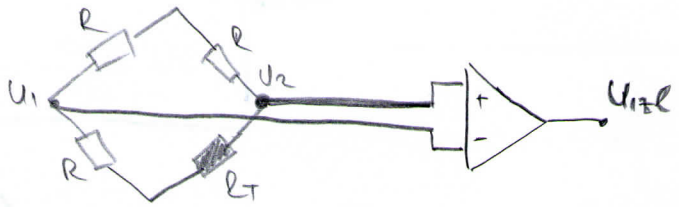
$R_0 = 100\,\Omega$ ($T = 0°C$)

$R_1 = R_2 = R_4 = R = 100\,\Omega$

$U = 5$ V

$A_D = 20$ dB $= 10$

$F = 100$ dB $= 100\,000$



U_{iz} ($T = 50°C$) = ?

$R_T = R_0 (1 + \alpha \cdot \Delta T) = 100 \cdot (1 + \alpha \cdot (50°C - 0°C)) = 119{,}8\,\Omega$

$U_1 = U \cdot \frac{R}{R+R} = 2{,}5$ V

$U_2 = U \cdot \frac{R_T}{R+R_T} = 2{,}7292$ V

$\Rightarrow U_z = \frac{U_1 + U_2}{2} = 2.6126$ V

$\Delta U = U_2 - U_1 = 0{,}2292$ V

$F = \frac{A_D}{A_z} \Rightarrow A_z = \frac{A_D}{F} = 1 \cdot 10^{-4}$

↓ u dB

$A_{z\,dB} = A_{D\,dB} - F_{dB} = -80$ dB

$U_{izl} = \Delta U \cdot A_D \pm U_z \cdot A_z$

$= 2{,}25200 \pm 0{,}00026$ V

4.3. INDUKTIVNI SENZOR POMAKA S PROMJENOM RELUKTANCIJE

* ispitni

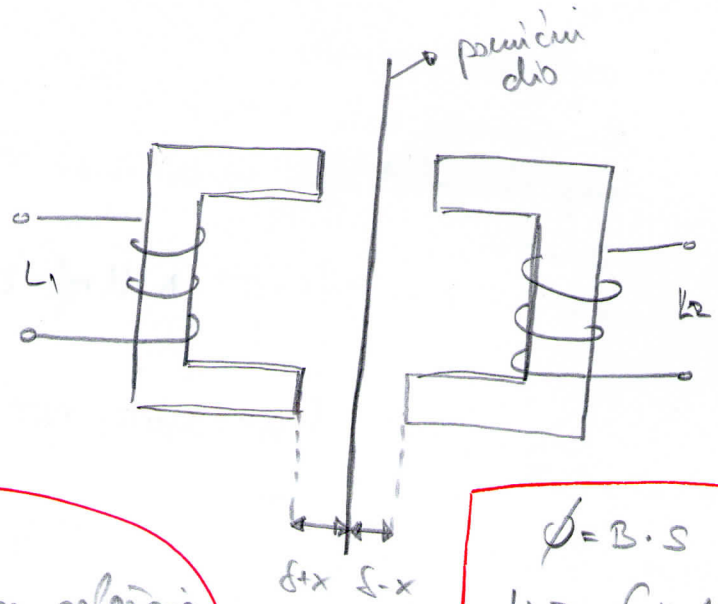
jako precizan senzor pomaka

$R = 4{,}7\ k\Omega$

$U_{sin} = 5\ V$, $f = 20\ kHz$

$\delta = 2\ mm$

$x = 0 \Rightarrow \boxed{I_L = 3 \cdot I_R}$ uvjet



broj namotaja ?

presjek jezgre $2\ cm^2$ i $\boxed{\mu_r \gg 1}$

$\Delta U = 70\ mV$, $x = ?$ → pomak od ravnotežnog položaja

Amperov zakon

$$L = \frac{N^2}{\frac{l_m}{\mu_0 \mu_r S} + \frac{2\delta}{\mu_0 \cdot S}}$$

- zanemarujemo jer ulupin put kroz zrak koji mag. tok prođe dok se ne zatvori kroz zavoj zavojnice
- površina presjeka jezgre
- reluktancija

$$\Phi = B \cdot S$$

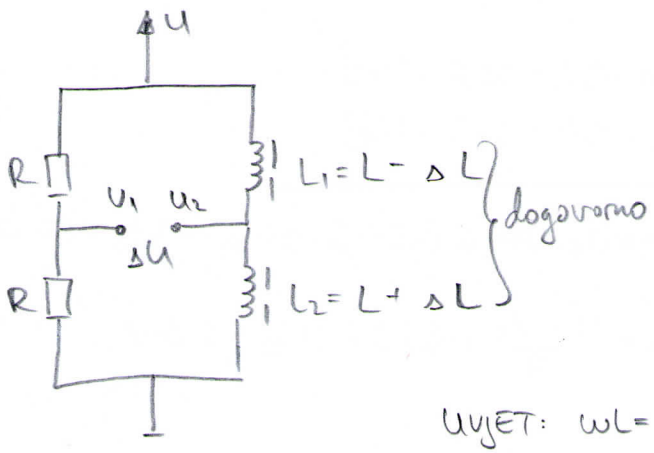
$$N \cdot I = \oint H \, dl$$

$$N \cdot I = B \left(\frac{l_m}{\mu_0 \cdot \mu_r} + \frac{2\delta}{\mu_0} \right)$$

$$B = \frac{\Phi}{S} \Rightarrow L = \frac{N \cdot \Phi}{I}$$

aproksimacija $L = \mu_0 \cdot N^2 \cdot S \frac{1}{2\delta}$

$$\frac{\Delta L}{x} \approx \frac{dL}{d\delta} = -\mu_0 N^2 S \frac{1}{2\delta^2} = -\frac{L}{\delta} \Rightarrow \boxed{\frac{\Delta L}{L} = -\frac{x}{\delta}} \Rightarrow \frac{\Delta L_1}{L_1} = -\frac{\Delta L_2}{L_2}$$



$$\frac{\Delta U}{U} = \frac{j\omega L_2}{j\omega (L_1 + L_2)} - \frac{1}{2} = \frac{L + \Delta L}{2L} - \frac{1}{2} = \boxed{\frac{\Delta L}{2L}}$$

$$\frac{\Delta L}{2L} = \frac{x}{2\delta}$$

UVJET: $\omega L = \frac{R}{3}$ (3 puta veća struja ⇒ 3× manji otpor)

$$L = \frac{R}{3 \cdot \omega} = 12.467\ mH \Rightarrow N = \sqrt{\frac{L \cdot 2\delta}{\mu_0 \cdot S}} = 445$$

$\Delta U = 70\ mV \Rightarrow \frac{\Delta U}{U} = \frac{x}{2\delta} \Rightarrow x = 56\ \mu m$

4.4. HALLOV SENZOR

↳ ne proizvodi vl. mag. polje

treba mjeriti ±10 A

Hallovi senzori: osjetljivost 300 V/T

lin. područje rada ± 5 mT

mag. ekvivalent max. izlaznog šuma 75 μT = B_{min}

$U = +5\,V$

$U_{IZ} = 2{,}5\,V \rightarrow$ polje = 0 T $\Rightarrow$ $U_{ref} = 2{,}5\,V$

$A_D = 20\,dB$

$\mp = 100\,dB$

mag. smetnje do 1 mT

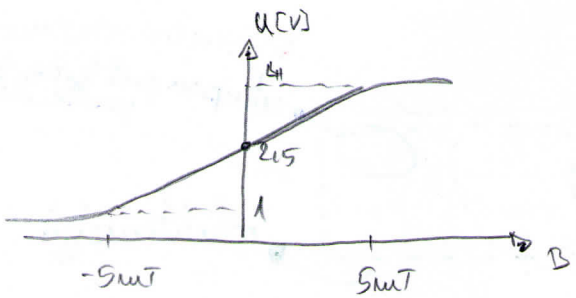
U_{IZ} = OSJETLJIVOST · POLJE + U_{ref}

služi da bi mogli mjeriti i negativne vrijednosti

$U_{IZ} = U_H = S \cdot B + U_{ref}$

ΔU = hod izlaznog napona = $S \cdot \Delta B = 300\,V/T \cdot (\pm 5\,mT) = \pm 1{,}5\,V$

$U_{IZ} = U_{ref} + \Delta U = 2{,}5 \pm 1{,}5\,V$

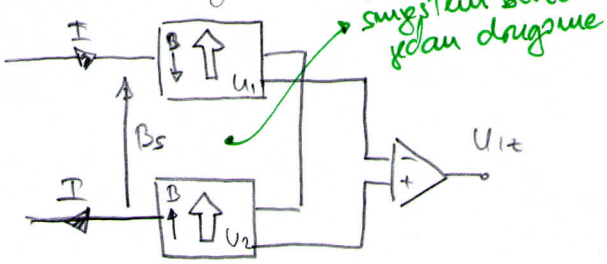


* za mjerenje jakosti struje Hallovim senzorom, vod mora biti na točno određenoj udaljenosti kako bi se postigla veza između struje i mag. polja koje senzor mjeri

$$B = \mu_0 \cdot \frac{I}{2\pi r} \Rightarrow r = \mu_0 \cdot \frac{S \cdot \Delta I}{2\pi \cdot \Delta U} = 1\,mm$$

zbog šuma $\Rightarrow$ $I_{min} \geq \frac{2\pi r B_{min}}{\mu_0} = 0{,}375\,A$

potiskivanje mag. smetnje:



$U_1 = -BS + B_S S + U_{ref}$

$U_2 = BS + B_S S + U_{ref}$

$U_D = U_2 - U_1 = 2BS = 2 \cdot 0{,}4\,mT \cdot 300\,V/T = 0{,}24\,V$

$U_Z = \frac{U_1 + U_2}{2} = B_S S + U_{ref} = 2{,}8\,V$

$U_{IZ} = A_D \cdot U_D \pm A_Z \cdot U_Z = 2{,}4\,V \pm 280\,\mu V$

4.5. OPTIČKI SENZOR (fotodioda)

→ za mjerenje udaljenosti r koristimo diodu i fotodiodu

upadno zračenje $E_e = 1\,mW\,cm^{-2}$

$U = 0\,V \rightarrow I = 40\,\mu A$

[ODAŠILJAČ] [PRIJEMNIK]

$I_E = 40\,mW\,sr^{-1}$ pri istosmjernoj struji $I_F = 250\,mA$; $U_F = 1{,}2\,V$

NA RASPOLAGANJU:

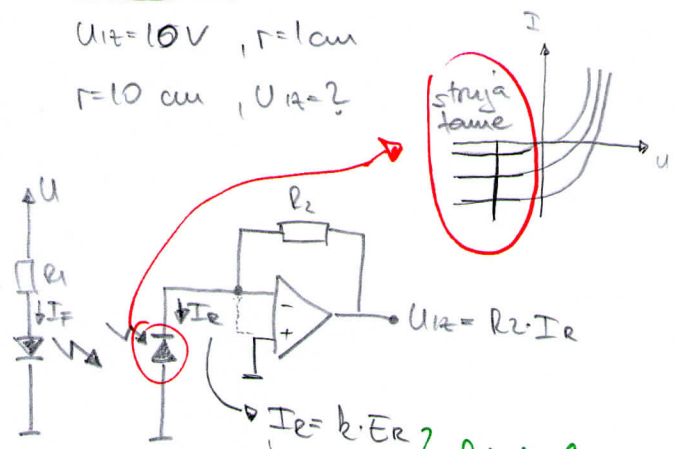
2 × R

O.P

U = 15 V

$U_{IZ} = 10\,V$, $r = 1\,cm$

$r = 10\,cm$, $U_{IZ} = ?$



$I_E = k \cdot E_R$ → fotodioda je u kratkom spoju pa je LINEARNO ovisna o upadnom zračenju

$R_1 = \frac{U - U_F}{I_F} = 55{,}2\,\Omega$

$E_R = \frac{I_E}{r^2}$, $\boxed{\beta = \phi}$

$k = \frac{I_R}{E_e} = \frac{40\,\mu A}{1\,mW/cm^2}$

$U_{IZ} = R_2 \cdot I_R \Rightarrow I_E = \frac{U_{IZ}}{R_2}$

$r^2 = \frac{I_E}{E_R} = \frac{R_2 \cdot k \cdot I_E}{U_{IZ}}$

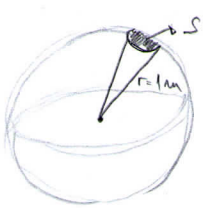
$E_R = \frac{I_R}{k}$

$R_2 = \frac{U_{IZ} \cdot r^2}{k \cdot I_E} = [U_{IZ} = 10,\ r = 1\,cm] = \frac{10\,V \cdot 1\,cm^2}{\frac{40\,\mu A}{1\,mW/cm^2} \cdot 40\,mW\,sr^{-1}} = 6250\,\Omega$

$R_2 = 6250\,\Omega$, $r = 10\,cm \Rightarrow U_{IZ} = \frac{R_2 \cdot k \cdot I_E}{r^2}$

$U_{IZ} = 0{,}1\,V$

* najvažnije fizikalne veličine u optoelektroničkim aplikacijama



def. steradijana

$\Omega_{max} = 4\pi\,sr$ (* jer je površina sfere $4\pi r^2$)

PROSTORNI KUT

$\Omega = \frac{S}{r^2}$ → površina isječka

dif. oblik → $d\Omega = \frac{1}{r^2} d\vec{S} \cdot \vec{r_0}$

INTENZITET ZRAČENJA

$I = \frac{d\Phi}{d\Omega}$ [W/sr] → snaga ili tok zračenja

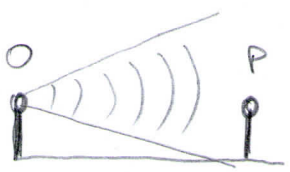
GUSTOĆA UPADNOG ZRAČENJA

$E = \frac{d\Phi}{dS}$ [W/m²]

* ZA TOČKASTI IZVOR

$d\Phi = \frac{I}{r^2} \cos(\beta)\, dS$

$E = \frac{I \cos(\beta)}{r^2}$



cos β → kut pod kojim je magnet prijemnik

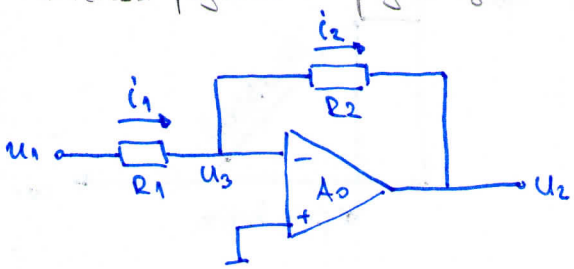
* ako su diode međusobno zakrenute za kut β, odnos između stvarne udaljenosti i udaljenosti dobivene na ovaj način je:

$r_{mjereno} = \frac{1}{\sqrt{\cos\beta}}\, r_{stvarno}$

5. POJAČALA

5.1. INVERTIRAJUĆE POJAČALO

→ Izvesti pojačalo s pojačanjem −10 i $R_{ul} = 10\,k\Omega$



* zanemarimo struje koje ulaze u O.P.

$$\frac{U_1 - U_3}{R_1} = \frac{U_3 - U_2}{R_2}$$

$$U_2 = A_0 \cdot (U_+ - U_-) = -A_0 \cdot U_3 \Rightarrow U_3 = -\frac{U_2}{A_0}$$

$$\frac{U_1 + \frac{U_2}{A_0}}{R_1} = \frac{-\frac{U_2}{A_0} - U_2}{R_2} \quad / \cdot R_1 R_2$$

$$R_2\left(\frac{U_1 A_0 + U_2}{A_0}\right) = R_1 \cdot \left(\frac{-U_2 - U_2(A_0)}{A_0}\right)$$

$$R_2 A_0 \cdot U_1 + R_2 U_2 + R_1 U_2 + R_1 A_0 U_2 = 0$$

$$U_1(R_2 A_0) = -U_2(R_2 + R_1 + R_1 A_0)$$

$$\frac{U_2}{U_1} = \frac{-R_2 A_0}{R_2 + R_1 + R_1 A_0} = -\frac{R_2}{R_1} \cdot \frac{A_0}{1 + \frac{1}{A_0}\cdot\left(1 + \frac{R_2}{R_1}\right)}$$

$A_{INV} = -\frac{R_2}{R_1} \cdot \frac{1}{1+\varepsilon}$ → ε odstupanje zbog konačnog pojačanja

$\varepsilon = \frac{1}{\beta A_0}$, $\beta = \frac{R_1}{R_1 + R_2}$

ovisi o frekvenciji → NF $A_0 \to \infty$

VF A_0 pada 20 dB/dek

* ULAZNI OTPOR NEINVERTIRAJUĆEG POJAČALA JE R_1 !

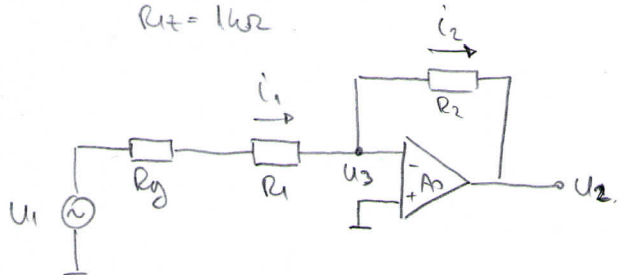
$$R_{ul} = \frac{U_1}{i_1} = R_1 = 10\,k\Omega \Rightarrow A_{INV} = -10 = -\frac{R_2}{R_1} \Rightarrow R_2 = 100\,k\Omega$$

5.2. utjecaj unutarnjeg otpora generatora na pojačanje

→ Izvesti pojačalo koje će invertirati napunski signal generatora?

$R_{ul} = 10\,k\Omega$

$R_{ut} = 1\,k\Omega$



$$A_{INV} = -\frac{R_2}{R_1 + R_g}$$

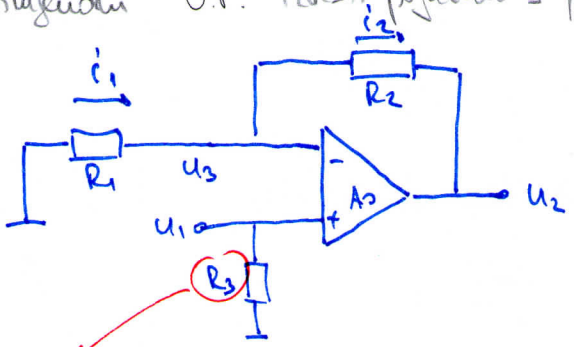
$R_{ul} = R_1 = 10\,k\Omega$

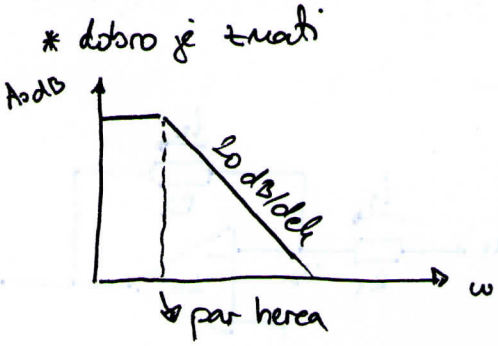
$R_1 + R_g = 11\,k\Omega$

velika razlika !

5.3. NEINVERTIRAJUĆE POJAČALO

→ primjenom O.P. izvesti pojačalo s pojačanjem +10 ; $R_{ul} = 10\,k\Omega$





R_3 je ulazni otpor neinvertirajućeg pojačala

↳ pravilo : $R_3 = R_1 \| R_2$ → tako smanjujemo naponsku pogrešku

$$\frac{0 - u_3}{R_1} = \frac{u_3 - u_2}{R_2}$$

$\boxed{u_2 = A_0 (u_1 - u_3)}$ → izrazi za konačno A_0

↳ $u_3 = \frac{-u_2}{A_0} + u_1$ ⟹ $A_{neinv} = \left(1 + \frac{R_2}{R_1}\right) \frac{1}{1 + \frac{1}{A_0}\left(1 + \frac{R_2}{R_1}\right)} = \boxed{\left(1 + \frac{R_2}{R_1}\right) \frac{1}{1+\varepsilon}}$

$A_{neinv} = 10 = 1 + \frac{R_2}{R_1} \Rightarrow \boxed{R_2 = 9R_1}$

$R_{ul} = R_3 = \frac{R_1 \cdot R_2}{R_1 + R_2} = 10\,k\Omega \rightarrow \frac{9R_1^2}{10R_1} = 10\,k\Omega \Rightarrow R_1 = \frac{10 \cdot 10}{9} = 11{,}1111\,k\Omega$

$R_2 = 99{,}9999\,k\Omega$

* u praksi nemoguće pronaći takve otpore pa se koriste potenciometri

5.6. DIFERENCIJALNO POJAČALO IZVEDENO JEDNIM O.P.

$A_D = 10$

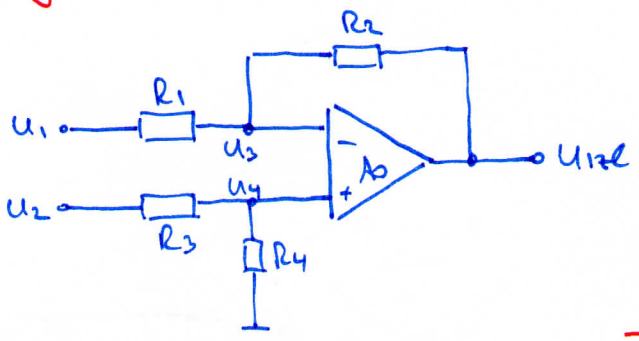
$R_{ul_D} = 20\,k\Omega$

$F_{OP.} = 60\,dB$

otpornici savršeno upareni osim jednog koji odstupa:

a) 0,1%

b) 1%



$$U_{izl} = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3+R_4}\right)\cdot U_2 - \frac{R_2}{R_1} U_1$$

neinvertirajuće · invertirajuće · potencijal U_4

IZVOD:

$$\left.\begin{aligned} U_D &= U_2 - U_1 \\ U_z &= \frac{U_2 + U_1}{2} \end{aligned}\right\} \Rightarrow \begin{aligned} U_1 &= U_z - \frac{U_D}{2} \\ U_2 &= U_z + \frac{U_D}{2} \end{aligned}$$

$$U_{izl} = \left(1+\frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3+R_4}\right)\left[U_z + \frac{U_D}{2}\right] - \frac{R_2}{R_1}\left[U_z - \frac{U_D}{2}\right]$$

$$= \frac{U_D}{2}\left[\frac{R_1+R_2}{R_1}\cdot\frac{R_4}{R_3+R_4} + \frac{R_2}{R_1}\right] \pm U_z\left[\frac{R_1+R_2}{R_1}\frac{R_4}{R_3+R_4} - \frac{R_2}{R_1}\right]$$

$$= \frac{U_D}{2}\left[\frac{R_1R_4 + R_2R_4 + R_2R_4 + R_2R_3}{R_1(R_3+R_4)}\right] \pm U_z\left[\frac{R_1R_4 + \cancel{R_2R_4} - R_2R_3 - \cancel{R_2R_4}}{R_1(R_3+R_4)}\right]$$

$$= \frac{1}{2}\cdot\left[\frac{R_1R_4 + R_2R_3 + 2\cdot R_2R_4}{R_1R_3 + R_1R_4}\right] U_D \pm \left[\frac{R_1R_4 - R_2R_3}{R_1R_3 + R_1R_4}\right] U_z$$

$$= A_D \cdot U_D \pm A_z \cdot U_z$$

VAŽNO!

→ IDEALNO DIF. POJAČALO: $A_D > 0$; $A_z = 0$ ⇒ da bi to vrijedilo mora biti:

$R_1 \cdot R_4 = R_2 \cdot R_3$, $\left.\begin{aligned} R_1 &= R_3 \\ R_2 &= R_4 \end{aligned}\right\}$ pravilo

ako to pravilo vrijedi

A_D idealno $= \frac{R_2}{R_1}$

A_z idealno $= \emptyset$

faktor potiskivanja (CMRR) ⇒ $F_R = \left|\frac{A_D}{A_z}\right| = \frac{R_1R_4 + R_2R_3 + 2R_2R_4}{2\,|(R_1R_4 - R_2R_3)|}$

≈ 100 dB

$$F = \frac{F_{OP}\,F_R}{F_{OP} + F_R}$$ (ovdje se uvrštavaju apsolutni brojevi!)

$R_{ul,D} = R_1 + R_3$, $R_1 = R_3 \Rightarrow R_{ul_D} = 2R_1$

$R_{ul,D} = 20\,k\Omega \Rightarrow R_1 = R_3 = 10\,k\Omega$

A_D idealno $= 10 = \frac{R_2}{R_1} \Rightarrow R_2 = R_4 = 100\,k\Omega$

* razlika ako se jedan otpornik promijeni je u skripti

5.7. SPOJ DIF. POJAČALA I OTPORNIČKOG MOSTA

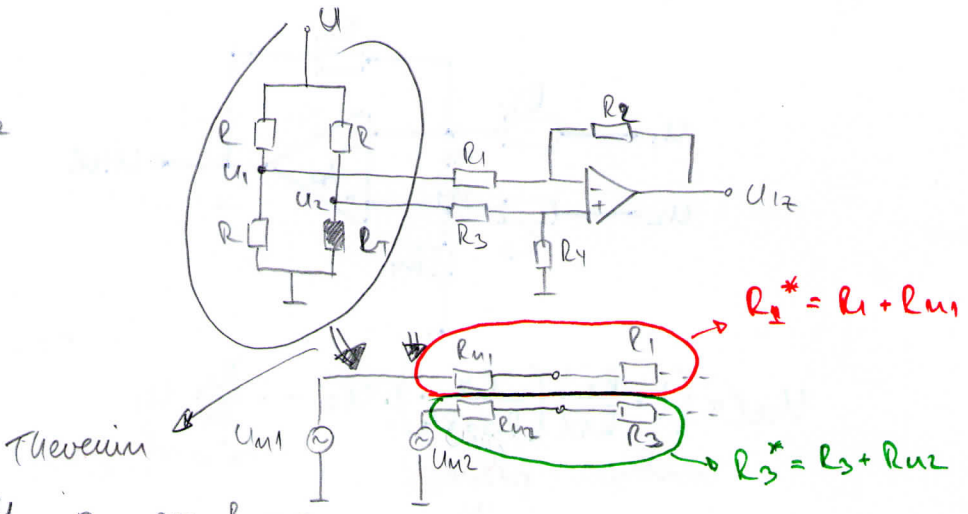
$R_1 = R_3 = 10\,k\Omega$

$R_2 = R_4 = 100\,k\Omega$

$F_{OP} = 60\,dB$

$R = 1k$

$R_T = 1{,}5k$



$U_{u1} = U \cdot \frac{R}{R+R} = \frac{U}{2}$ $\quad R_{u1} = R \| R = \frac{R}{2} = 500\,\Omega$

$U_{u2} = U \cdot \frac{R_T}{R_T+R} = \frac{3}{5}U$ $\quad R_{u2} = \frac{R_T \cdot R}{R_T+R} = 600\,\Omega$

bilo

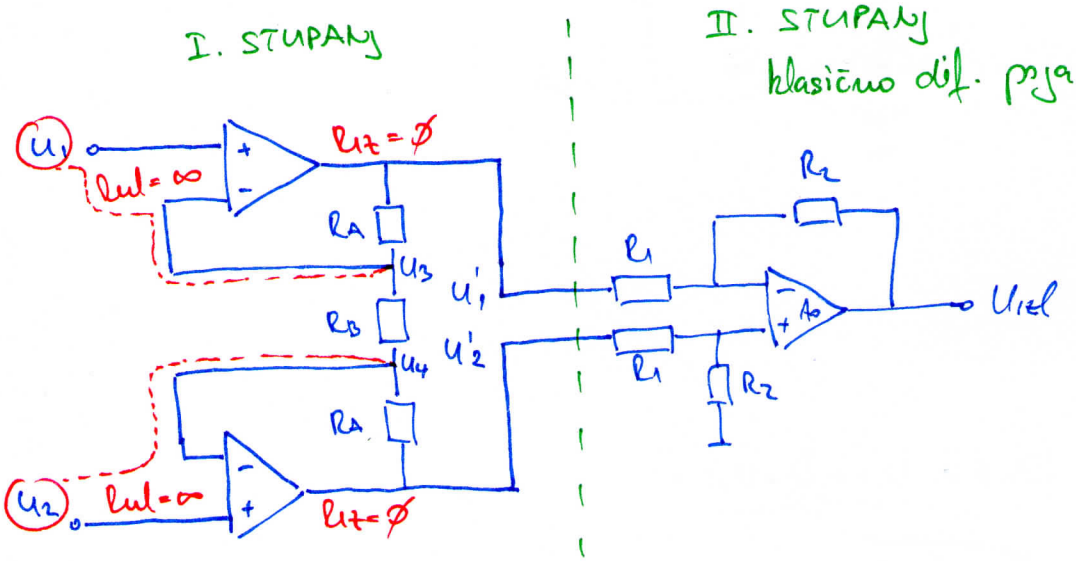
$\boxed{R_1^* \neq R_3^*}$ → nesavršenost otporničke mreže ⇒ $A_D = \frac{R_1R_4 + R_2R_3 + 2R_2R_4}{2(R_1R_3 - R_1R_4)} = 9{,}5195$ (10)

$|A_Z| = \left|\frac{R_1R_4 - R_2R_3}{R_1R_3 + R_1R_4}\right| = 8{,}611 \cdot 10^{-3}$ (ϕ)

$F_{most} = \frac{A_D}{|A_Z|} = 1105{,}5$ (∞)

$F_{ukupno} = \frac{F_{OP} \cdot F_{most}}{F_{OP} + F_{most}} \approx 525 \Rightarrow 54{,}4\,dB$

5.8. INSTRUMENTACIJSKO POJAČALO



IZVOD:

$$\frac{U_1'-U_3}{R_A}=\frac{U_3-U_4}{R_B}$$

$$\frac{U_3-U_4}{R_B}=\frac{U_4-U_2'}{R_A}$$

$U_1=U_3$, $U_2=U_4$ [zbog velikog pojačanja]

$$\frac{U_1'-U_1}{R_A}=\frac{U_1-U_2}{R_B} \Rightarrow U_1'=\frac{R_A}{R_B}(U_1-U_2)+U_1 \Rightarrow U_1'=-\frac{R_A}{R_B}(U_2-U_1)+U_1$$

$$\frac{U_1-U_2}{R_B}=\frac{U_2-U_2'}{R_A} \Rightarrow U_2'=-\frac{R_A}{R_B}(U_1-U_2)+U_2 \Rightarrow U_2'=\frac{R_A}{R_B}(U_2-U_1)+U_2$$

izvod za I. stupanj

→ II. stupanj
→ idealan pa pojačava samo dif. napon, $A_z=\emptyset$

$$U_2'-U_1'=2\frac{R_A}{B}(U_2-U_1)+U_2-U_1=\underbrace{\left(1+\frac{2R_A}{R_B}\right)\cdot(U_2-U_1)}$$ → dif. napon na ulazu u II. stupanj

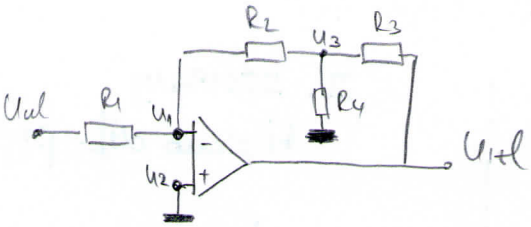
A II. STUPANJ JE ZAPRAVO DIF. POJAČALO PA:

$$U_{izl}=\left(1+\frac{2R_A}{R_B}\right)\frac{R_2}{R_1}(U_2-U_1)$$ → dif. napon na ulazu pojačala

↳ ulazi se vanjskim čipa te njime namještamo pojačanje

$$\boxed{A_{D,ust}=\left(1+\frac{2R_A}{R_B}\right)\frac{R_2}{R_1}}$$

5.9. ZADACI



③ $R_1 = R_2 = R_3 = 2\ M\Omega$

$R_4 = 27{,}4\ M\Omega$

$A = ?$, $R_{ul} = ?$

$R_{ul} = R_1 = \underline{2\ M\Omega}$

$A = \frac{U_{izl}}{U_{ul}}$, $U_1 = U_2 = \emptyset$

1) $\frac{U_{ul} - U_1}{R_1} = \frac{U_1 - U_3}{R_2} \Rightarrow \frac{U_{ul}}{R_1} + \frac{U_3}{R_2} = \emptyset \Rightarrow \underline{U_3 = -\frac{R_2}{R_1} \cdot U_{ul}}$

2) $\frac{U_1 - U_3}{R_2} = \frac{U_3}{R_4} + \frac{U_3 - U_{izl}}{R_3} \Rightarrow \frac{U_3}{R_4} + \frac{U_3}{R_2} + \frac{U_3 - U_{iz}}{R_3} = 0 \Rightarrow -\frac{R_2}{R_1 R_4} U_{ul} - \frac{1}{R_1} U_{ul} - \frac{R_2}{R_1 R_3} U_{ul} - \frac{1}{R_3} U_{iz} = \emptyset$

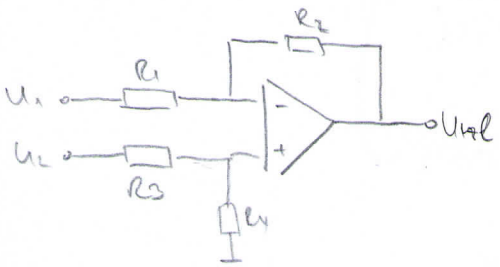
$U_{ul}\left(-\frac{R_2}{R_1 R_4} - \frac{1}{R_1} - \frac{R_2}{R_1 R_3}\right) = \frac{1}{R_3} U_{iz}$

$\frac{U_{izl}}{U_{ul}} = A = R_3 \cdot \left(-\frac{R_2}{R_1 R_4} - \frac{1}{R_1} - \frac{R_2}{R_1 R_3}\right) = \underline{-75}$

④ $A_D = 100$

$\boxed{R_2^* = 1.01 \cdot R_2} \Rightarrow A_D' = ?$ $F = ?$

* idealno $\Rightarrow$ $R_1 = R_3$, $R_2 = R_4$



$U_{iz} = \left(1 + \frac{R_2}{R_1}\right) \cdot \frac{R_4}{R_3 + R_4} \cdot U_2 + \frac{R_2}{R_1} U_1$

$U_d = U_2 - U_1$, $U_z = \frac{U_1 + U_2}{2}$ $\Rightarrow$ $U_1 = U_z - \frac{U_d}{2}$, $U_2 = U_z + \frac{U_d}{2}$

$U_{izl} = \underbrace{\left[\frac{R_1 R_4 + R_2 R_3 + 2 R_2 R_4}{2(R_1 R_3 + R_1 R_4)}\right]}_{A_d} U_d \pm \underbrace{\left[\frac{R_1 R_4 - R_2 R_3}{R_1 R_3 + R_1 R_4}\right]}_{A_z} U_z$

$A_{D,idealno} = \frac{R_2}{R_1} = 100$

$\boxed{A_D^* = 1.01 \cdot 100 = 101}$

$|A_z| = \left|\frac{100 R_1^2 - 101 R_1^2}{R_1^2 + 100 R_1^2}\right| = 0{,}0099$

$F = \frac{A_D^*}{A_z} = 10201 \Rightarrow \underline{80{,}17\ dB}$

⑥ tensometri

$R = 350\,\Omega$

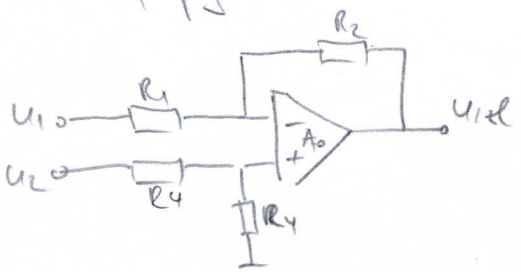
$k = 2$

$U = 10\,V$

$F_{op} = 100\,dB$

Dat nuova $\Rightarrow R_{id_D} = 7k\Omega$, $A_D = 10$

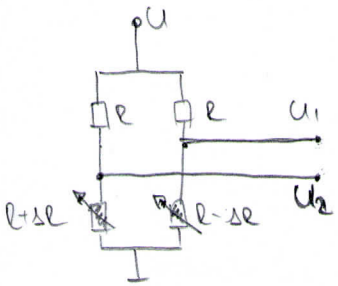
a) caratteristica dif. pilotato



$R_{id_D} = 7k\Omega = 2R_1 \Rightarrow R_1 = 3{,}5k\Omega = R_3$

$A_{D\,ideale} = 10 = \frac{R_2}{R_1} \Rightarrow R_2 = R_4 = 35k\Omega$

b) tensometri $\Delta l = 1\%$, $A_D, A_z, F = ?$



tensometri:

$$\frac{\frac{\Delta R}{R}}{\frac{\Delta l}{l}} = k \Rightarrow \frac{\frac{\Delta R}{350}}{\frac{0{,}01\,l}{l}} = 2 \Rightarrow \Delta R = 7\,\Omega \rightarrow R + \Delta R = 357\,\Omega$$

$R - \Delta R = 343\,\Omega$

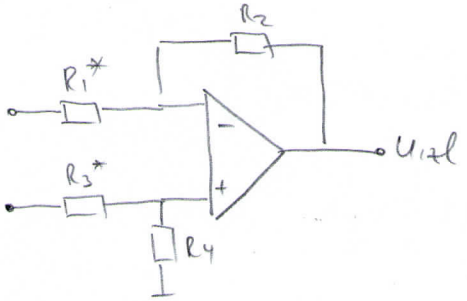
$R \| (R+\Delta R) = 176.73\,\Omega = R_x$

$R \| (R-\Delta R) = 173.23\,\Omega = R_y$

$U_1 = U \cdot \frac{R-\Delta R}{R+R-\Delta R} = 4{,}95\,V$

$U_2 = U \cdot \frac{R+\Delta R}{R+R+\Delta R} = 5{,}105\,V$

$\Rightarrow$



$R_1^* = R_1 + R_x = 3676{,}73\,\Omega$

$R_3^* = R_3 + R_y = 3673{,}23\,\Omega$

$U_c = \frac{U_1 + U_2}{2} = 5\,V$

$U_d = U_2 - U_1 = 0{,}1\,V$

$$U_{icl} = \left(1 + \frac{R_2}{R_1}\right)\frac{R_4}{R_3 + R_4} U_2 + \frac{R_2}{R_1} U_1$$

$$= \underbrace{\left(\frac{R_1R_4 + R_2R_3 + 2R_2R_4}{2 \cdot (R_1R_3 + R_1R_4)}\right)}_{A_d} U_d \pm \underbrace{\left(\frac{R_1R_4 - R_2R_3}{R_1R_3 + R_1R_4}\right)}_{A_z} U_z$$

$$A_d = \frac{R_1^* R_4 + R_2 R_3^* + 2R_2R_4}{2 \cdot (R_1^* R_3^* + R_1^* R_4)} = 9{,}52$$

$$A_z = \frac{R_1^* \cdot R_4 - R_2 R_3^*}{R_1^* R_3^* + R_1^* R_4} = 8{,}62 \cdot 10^{-4}$$

$$F_c = \left|\frac{A_d}{A_z}\right| = 11050{,}27$$

$$F = \frac{F_{op} \cdot F_c}{F_{op} + F_c} = 9950{,}69 \Rightarrow 80\,dB$$

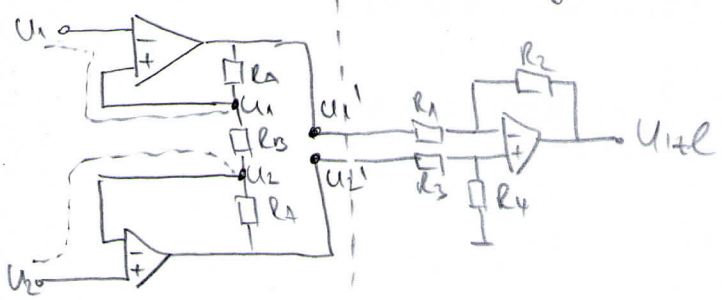
⑧ instrumentacijsko pojačalo

ukupno pojačanje $\langle 30 - 310 \rangle$ → $A = 30$, $R_B = 10\ k\Omega$

II. stupanj $R_{ul,D} = 100\ k\Omega$

$A_D = 10$

$F = \infty$



II. stupanj

$A_{D\,idealno} = \frac{R_2}{R_1} = 10 \Rightarrow R_2 = 10R_1 = 500\ k\Omega = R_4$

$R_{ul,D} = 2R_1 \Rightarrow R_1 = 50\ k\Omega = R_3$

I. stupanj

$$\frac{U_1' - U_1}{R_A} = \frac{U_1 - U_2}{R_B} \Rightarrow U_1' = -\frac{R_A}{R_B}(U_2 - U_1) + U_1$$

$$\frac{U_1 - U_2}{R_B} = \frac{U_2 - U_2'}{R_A} \Rightarrow U_2' = \frac{R_A}{R_B}(U_2 - U_1) + U_2$$

$$U_d = U_2' - U_1' = 2 \cdot \frac{R_A}{R_B}(U_2 - U_1) + U_1 + U_2$$

$$= \left(1 + 2\frac{R_A}{R_B}\right)(U_2 - U_1)$$

$$A_{D,\text{instrumentacijsko}} = \left(1 + 2\frac{R_A}{R_B}\right)\frac{R_2}{R_1}$$

$$30 = \left(1 + 2 \cdot \frac{R_A}{10}\right) \cdot 10 \Rightarrow R_A = 10\ k\Omega$$

$$310 = \left(1 + 2 \cdot \frac{10}{R_B}\right) \cdot 10 \Rightarrow R_B = 0{,}67\ k\Omega$$

$R_B \langle 0{,}67, 10 \rangle\ k\Omega$