Z-1 nacrtati i proračunati zaštitu

VDR

$U = 500 \cdot I^{0,032}$ [V]

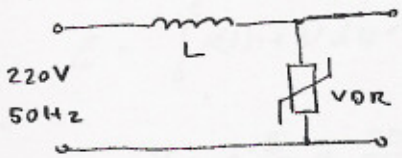
$U = 1800 \cdot \sin(\pi \cdot 10^6 t) \cdot \exp(-10^5 t)$ [V]

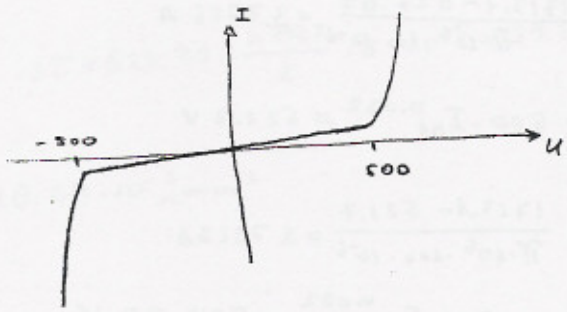
a) prenapon na uređaju = ?

b) Volumen VDR = ?

$L = 100\ \mu H$

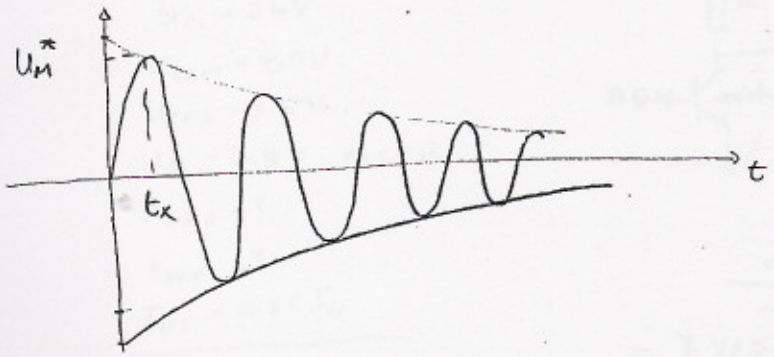
$A = 1000\ W/s/cm^3$





$X_L = \omega L$

↳ predstavlja veliku impedanciju za visoke frekvencije i zbog toga ograničava ulazne struje kod prenapona



a) najprije tražimo U_m^* (najveći ulazni prenapon)

$\frac{dU}{dt} \equiv 0 \qquad u = U_m \sin\omega t \cdot e^{-t/\tau}$

$\omega = 2\pi f = \pi \cdot 10^6 \Rightarrow f = 500\ kHz$

$\tau = 10^{-5}$

$\frac{dU}{dt} = U_m \omega \cos\omega t\, e^{-t/\tau} - \frac{1}{\tau} U_m \sin\omega t\, e^{-t/\tau} \equiv \phi$

$U_m e^{-t/\tau} \left[\omega \cos\omega t - \frac{1}{\tau} \sin\omega t\right] = 0$

$\omega \cos\omega t = \frac{1}{\tau} \sin\omega t$

$\operatorname{tg}\omega t_x = \omega\tau = \pi \cdot 10^6 \cdot 10^{-5} \Rightarrow t_x = \frac{\operatorname{arctg}(10\pi)}{\pi \cdot 10^6} = 489.87\ ns$

Samo je jedan Mali Ivica!

$U_M^* = 1800 \cdot \sin(\pi \cdot 10^6 \cdot 489{,}87 \cdot 10^{-9}) \cdot \exp(-10^5 \cdot 489{,}87 \cdot 10^{-9})$

$U_M^* = 1713.1\ V$

→ možemo za t_x uzeti $\approx \frac{T}{4}$ → $U_M^* = 1712.2V$

Računamo napon na VDR-u za najgori slučaj U_M^* (iterativnim postupkom)

1) $I_{n0} = \frac{U_R^* - 0}{\omega L} = \frac{1713.1}{\pi \cdot 10^6 \cdot 100 \cdot 10^{-6}} = 5.453\ A$

$U_{p0} = 500 - I_{n0}^{0.032} = 527.89\ V$

2) $I_{n1} = \frac{1713.1 - 527.89}{\pi \cdot 10^6 \cdot 100 \cdot 10^{-6}} = 3{,}7726\ A$

$U_{p1} = 500 - I_{n1}^{0.032} = 521.7\ V$

3) $I_{n2} = \frac{1713.1 - 521.7}{\pi \cdot 10^6 \cdot 100 \cdot 10^{-6}} = 3.7923 A$

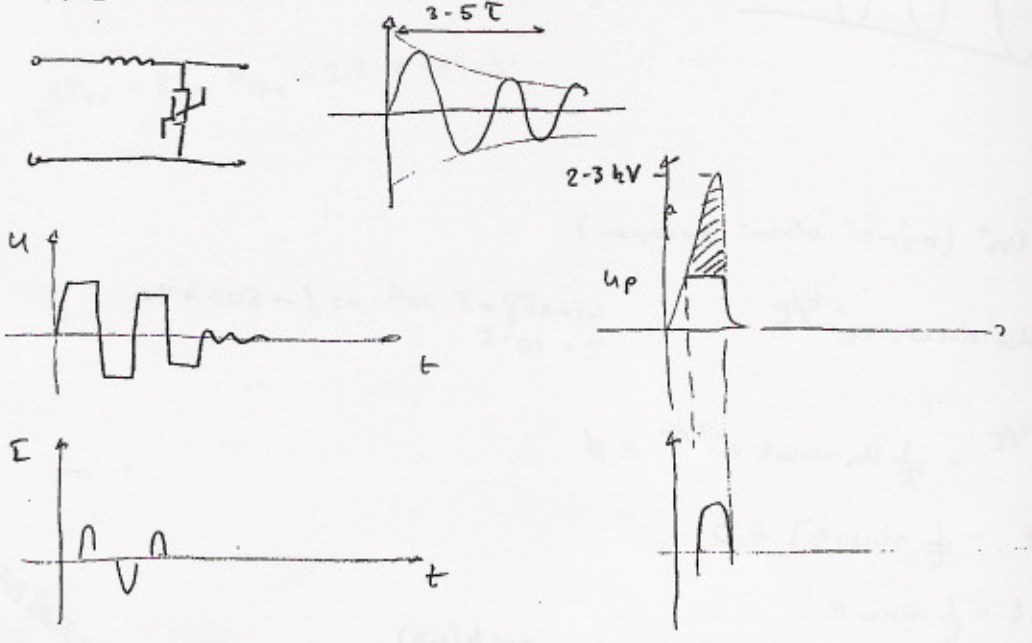
$U_{p2} = 500 \cdot I_{n2}^{0.032} = 521.79\ V$

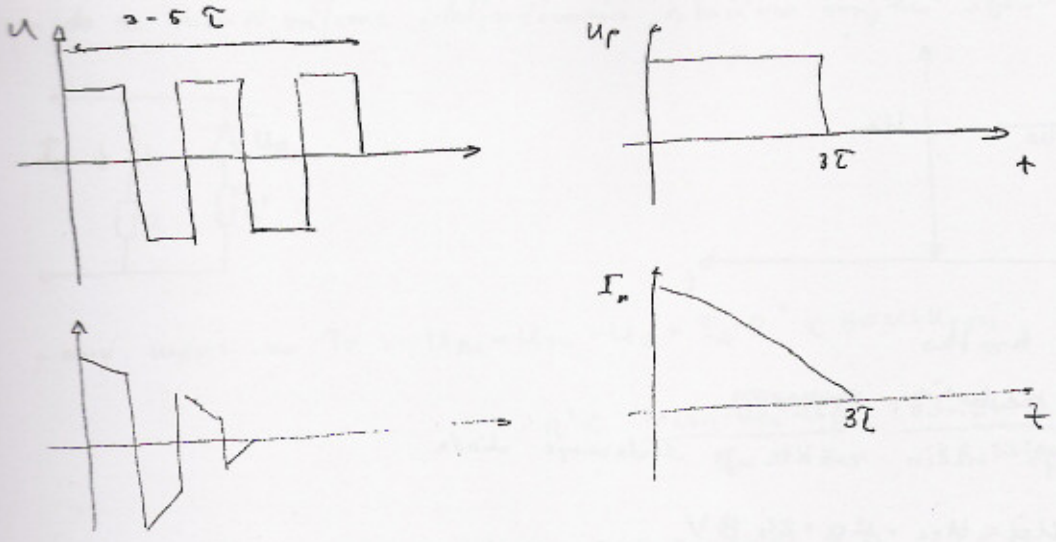
=> uzimamo $U_p = 521.79V$

b) $V_{min} = ?$

moramo znati energiju koju apsorbira VDR

$E_{max} = V_{min} \cdot A$





uzet ćemo 3τ

$$E = \int_0^t u(t)\cdot i(t)\,dt = U_p \cdot \frac{I_M}{2} \cdot 3\tau = 521.79 \cdot \frac{3.7923}{2} \cdot 3 \cdot 10^{-5} = 29.68\ mJ$$

$$V_{min} = \frac{E}{A} = \frac{29.68 \cdot 10^{-3}}{10^3} = 29.68 \cdot 10^{-3}\ mm^3$$

Z-2

bipolarno sklopka

$R = 300\,\Omega$

$L = 10\,mH$

$U_{CC} = 24\,V$

$U_{CEM} = 80\,V$

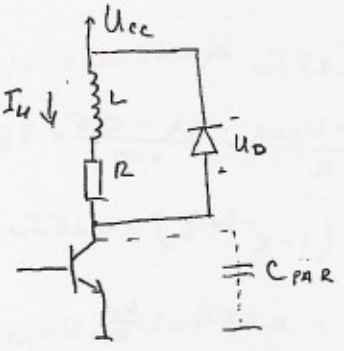
$U_{CES} = 0.5\,V$

$U_D = 0.8\,V$, $r_d \ll R$

$R_{MAX} = ?$

$t_{OFF} = ?$

$I_{OFF} = 0.25\,I_M$

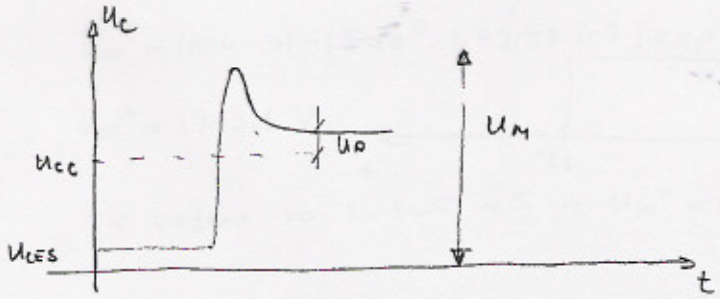


- isključujemo tranzistor
- struja se zatvara prema masi preko C_{PAR} → parazitni kondenzator

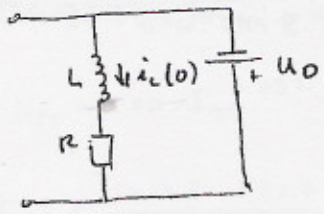
$$E_{ZAV} = \frac{L I_M^2}{2} = \frac{C U_M^2}{2} \Rightarrow U_M = \sqrt{\frac{L \cdot I_M^2}{C_{PAR}}}$$

- jako poraste napon na kondenzatoru (100 – 1000 V)

Samo je jedan Mali Ivica!



- ovo ove tvoje krivo
- kritičan je, međutim, prenapon
- najjednostavniji način zaštite je dodavanje diode
- sada je : $u_M = u_{cc} + u_D = 24.8\,V$



$$i_L(t) = i_L(0)\, e^{-t/\tau} - \frac{u_D}{R}\left(1 - e^{-t/\tau}\right)$$

$$\tau = \frac{L}{R} = \frac{10\,mH}{300} = 33.3\,\mu s$$

$$i_L(0) = I_M$$

$I_{OFF} = 0.25\, I_M$ → otpuštanje radnog kontakta

$t_x = ?$ za $i_L(t) = 0.25\, I_M$

$$I_M = \frac{u_{cc} - u_{CES}}{R} = \frac{24 - 0.5}{300} = 78.33\,mA$$

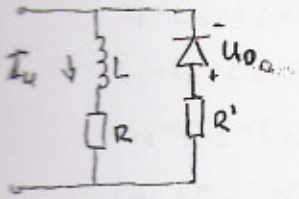
$$I_M\, e^{-t_x/\tau} - \frac{u_D}{R}\left(1 - e^{-t_x/\tau}\right) = 0.25\, I_M$$

$$\left(I_M + \frac{u_D}{R}\right) e^{-t_x/\tau} = 0.25\, I_M + \frac{u_D}{R}$$

$$e^{-t_x/\tau} = \frac{0.25 I_M + \frac{u_D}{R}}{I_M + \frac{u_D}{R}} = \frac{u_D + 0.25 \cdot I_M \cdot R}{u_D + I_M \cdot R} \quad / \ln$$

$$t_x = -\tau \ln \frac{u_D + I_M \cdot R \cdot 0.25}{u_D + I_M \cdot R} = -33.3 \cdot \ln \frac{0.8 + 78.33 \cdot 0.3 \cdot 0.25}{0.8 + 78.33 \cdot 0.3} = 43.03\,\mu s$$

- da se skratí vrijeme isključivanja, stavimo serijski otpor



- max. napon na Tr: $U_M = U_{CC} + U_D + I_A \cdot R' < BOV = U_{CEM}$

$$R' < \frac{U_{CEM} - U_{CC} - U_D}{I_N} = \frac{80 - 24 - 0.8}{78.33 \cdot 10^{-3}} = 704.7\ \Omega$$

- efektivno imamo $R'' = R + R' = 300 + 704.7 = 1004.7\ \Omega$, $\tau = \frac{L}{R''} = \frac{10nH}{1004.7} = 9.953\mu s$

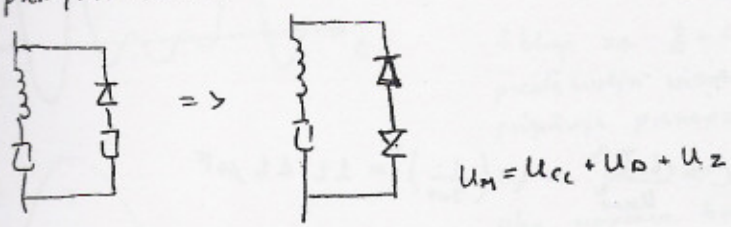
$$t_x' = -\tau \ln \frac{U_D + I_H \cdot R'' \cdot 0.25}{U_D + I_H \cdot R''} = -9.953 \ln \frac{0.8 + 78.33 \cdot 1.0047 \cdot 0.25}{0.8 + 78.33 \cdot 1.0047}$$

$$t_x' = 13.51\ \mu s$$

$$\Delta t_x = t_x - t_x' = 29.52\ \mu s$$

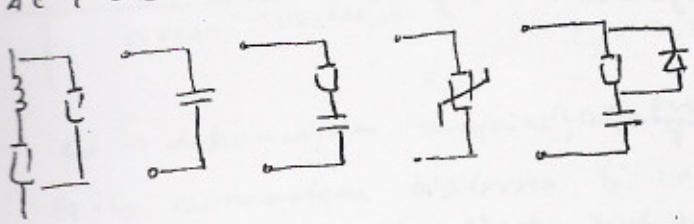
⇒ Ovo je relativno loš način smanjenja otpočinjanja

- bolji primjeri rješenja



$U_M = U_{CC} + U_D + U_Z$

AC i OC



Samo je jedan Mali Ivical

Z-3

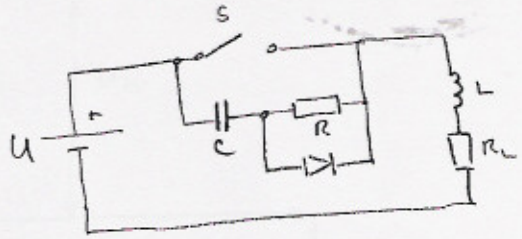
$R_L = 100\,\Omega$

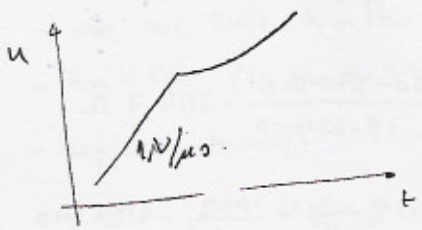
$L = 1\,H$

$U = 100\,V$

$I_{KM} = 5\,A$

RCD





treba upoštevati - lučni izboj
- tinjavi izboj

1) zaščita pred lučnim izbojem

$$\frac{dU}{dt} = \frac{I_0}{C} < 1\,V/\mu s$$

$$i = C\frac{dU}{dt}$$

$$I_0 = \frac{U}{R_L} = \frac{100}{100} = 1\,A$$

$$C > \frac{1\,A}{1\,V/\mu s} = 1\,\mu F$$

2) zaščita pred tinjavim izbojem

$U_{max} < 300\,V$

$$\frac{1}{2}LI_0^2 = \frac{1}{2}CU_{max}^2$$

$$C = \frac{LI_0^2}{U_{max}^2} \Rightarrow C > \frac{LI_0^2}{U_{max}^2} = 1\cdot\left(\frac{1}{300}\right)^2 = 11.11\,\mu F$$

3) upornik bi bilo bolje da omejimo tudi praznjenje kondenzatorja

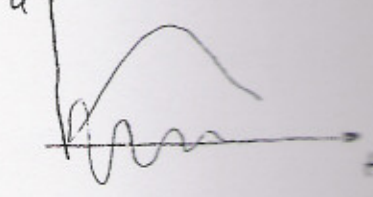
$I < I_{KM}$

$$I_{KM} = \frac{U}{R} \Rightarrow R_{min} = \frac{U}{I_{KM}} = \frac{100}{5} = 20\,\Omega$$

4) Niti toliko ne bo, ali bilo bi dobro da bomo

$$C > 4\frac{L}{R_L^2} = 4\cdot\frac{1}{100^2} = 400\,\mu F$$

za preprečevanje ionizacije



Z-4 LC zaštita (Desetnopol)

$L_1 = L_2 = L_i = 27\,mH$

$L_3 = L_4 = L_d = 100\,\mu H$

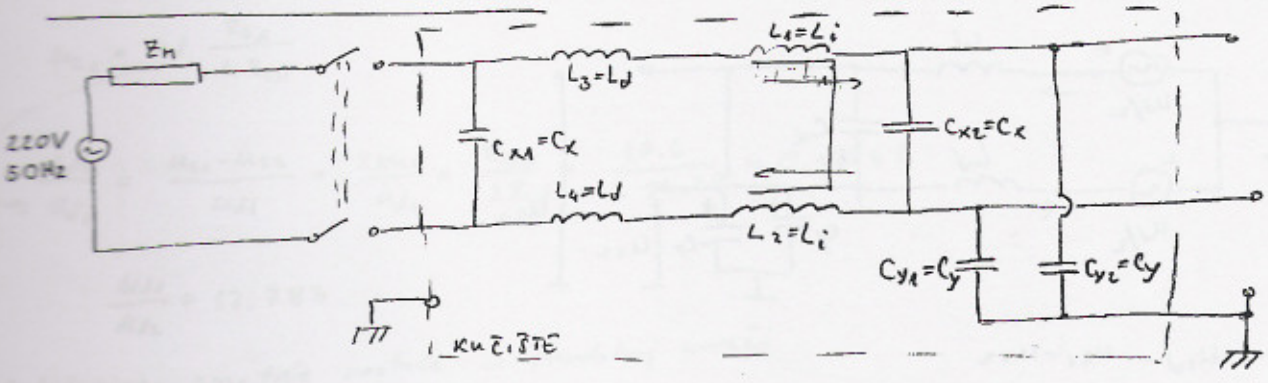
$C_{x1} = C_{x2} = C_x = 100\,nF$

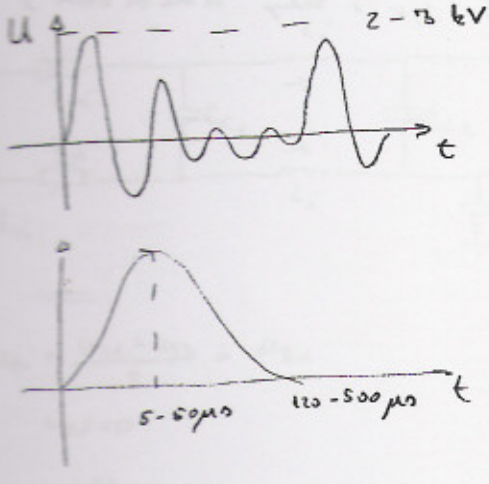
} za snage 10 – 100 tisuća W

$C_{y1} = C_{y2} = C_y = 2.2\,nF$

a) potiskivanje istofaznih i diferencijalnih smetnji nastalih izvan uređaja

b) potiskivanje istofaznih smetnji nastalih u uređaju





Sklop za $f = 150\,kHz \div 300\,MHz$ predstavlja visoku impedanciju pa priguši prenapone i smetnje na ulazu.

C_y mu potrebno biti mali za sigurnost jer ako neprave kratki spoj, onda oštećuju dovedu kućište na mrežni napon.

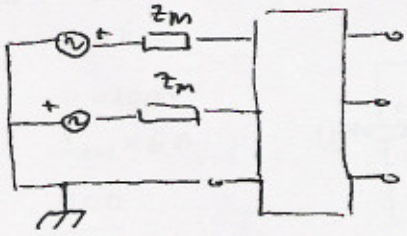
$C_y < 7.2\,nF$

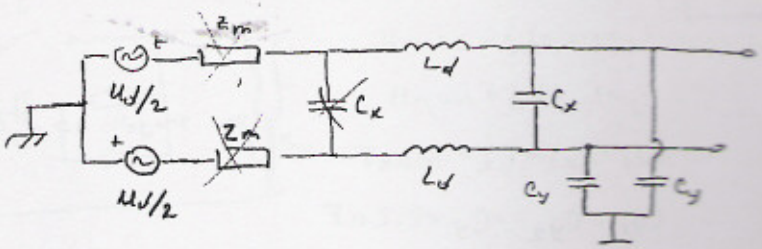
L_d -> diferencijalna zavojnica, djeluje na diferencijalne smetnje

L_1 i L_2 su namotane bifilarno tj. no istoj jezgri i zato se magnetska polja koja se javljaju uvelike poništavaju

Samo je jedan Mali Ivica!

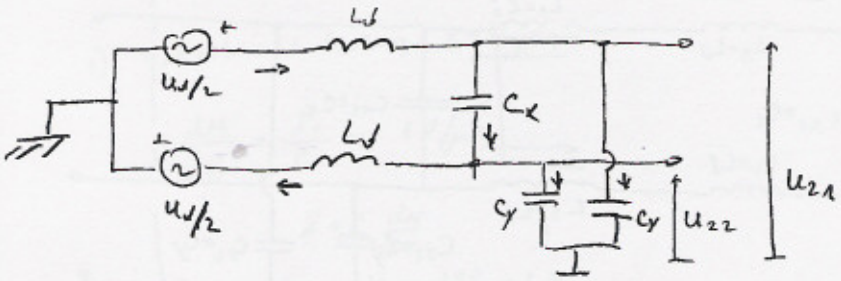
a) diferencijalne smetnje nastale izvan uređaja





Z_m - impedancija mreže → teško ju je modelirati pa nećemo puno pogriješih i ako je ne uzmemo u razmatranje

C_x na ulazu sam ne utječe na razmatranje (jer je napon direktno na njem)



$U_{2d} = U_{21} - U_{22}$

$U_{2i} = \frac{U_{21} + U_{22}}{2}$, $U_{21} = -U_{22} \rightarrow U_{2i} = 0$ (jer je sklop simetričan)

$\frac{U_d}{2} = U$

$$\frac{U - U_{21}}{Z_{Ld}} = \frac{U_{21} - U_{22}}{Z_{Cx}} + \frac{U_{21}}{Z_{Cy}}$$

$$\frac{U_{21} - U_{22}}{Z_{Cx}} = \frac{U_{22} + U}{Z_{Ld}} + \frac{U_{22}}{Z_{Cy}}$$

$U_{21} = -U_{22} \rightarrow U_{2d} = 2U_{21}$

$$\frac{U - U_{21}}{Z_{Ld}} = \frac{2U_{21}}{Z_{Cx}} + \frac{U_{21}}{Z_{Cy}}$$

$$\frac{U - U_{21}}{Z_{Ld}} = \frac{U_{21}(2Z_{Cy} + Z_{Cx})}{Z_{Cx} Z_{Cy}} \quad / \cdot Z_{Cx} Z_{Cy} \cdot Z_{Ld}$$

$$Z_{Cx} Z_{Cy} \cdot U - Z_{Cx} \cdot Z_{Cy} \cdot U_{21} = Z_{Ld}(2Z_{Cy} + Z_{Cx}) \cdot U_{21}$$

$$Z_{Cx} Z_{Cy} U = U_{21}\left[Z_{Ld}(2Z_{Cy} + Z_{Cx}) + Z_{Cx} Z_{Cy}\right]$$

$$\frac{U}{Z_{Ld}} = U_{21}\left[\underbrace{\left(\frac{1}{Z_{Cx}} + \frac{1}{Z_{Cy}} + \frac{1}{Z_{Ld}}\right)}_{\frac{1}{Z_p}} \cdot \frac{1}{Z_{Cx}}\right]$$

$\frac{1}{Z_p} \doteq \frac{1}{Z_{Cx}}$

$Z_p \doteq Z_{Cx}$

$f = 150$ kHz

$|Z_{Cx}| = \frac{1}{2\pi f C_x} = 10.6\ \Omega$ $\quad |Z_{Cy}| = \frac{1}{2\pi f C_y} = 482.3\ \Omega$

$|Z_{Ld}| = 2\pi f L_d = 94.25\ \Omega$

$$u_{21} = u \frac{-Z_{Cx} Z_{Cy}}{2 Z_{Cy} Z_{Ld} + Z_{Ld} Z_{Cx} + Z_{Cx} Z_{Cy}}$$

$$u_{21} = u \frac{Z_{Cx}}{2 Z_{Ld} + \frac{Z_{Ld} Z_{Cx}}{Z_{Cy}} + Z_{Cx}} \times u \frac{Z_{Cx}}{2 Z_{Ld}}$$

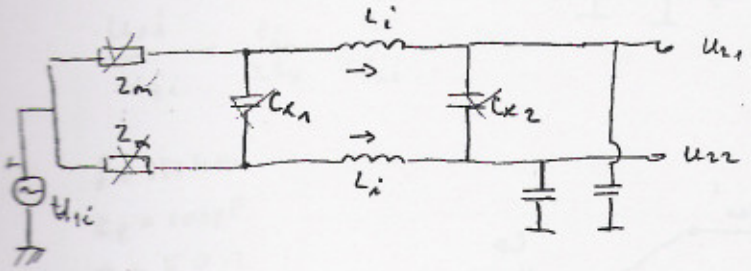
$u = \frac{u_d}{2}$

$u_{21} = u_d \frac{Z_{Cx}}{4 Z_{Ld}}$

$$\frac{u_{d2}}{u_{d1}} = \frac{u_{21} - u_{22}}{u_{d1}} = \frac{2u_{21}}{u_{d1}} = \frac{Z_{Cx}}{2Z_{Ld}} = \frac{10.6}{2 \cdot 94.25} = 0.0562$$

$\frac{u_{d1}}{u_{d2}} = 17.783$

b) izotofazne ometnje nastale u gradskoj mreži



potpuna simetrija → zanemarujemo C_{x2}

$u_{21} = u_{22}$

$Z_{Li} = 2\pi f L_{di} = 25446.9\ \Omega$

$u_{2i} = \frac{u_{21} + u_{22}}{2} = u_{21}$

$u_{2d} = 0$

$\frac{u_{1i} - u_{21}}{Z_{Ldi}} = \frac{u_{21}}{Z_{Cy}}$

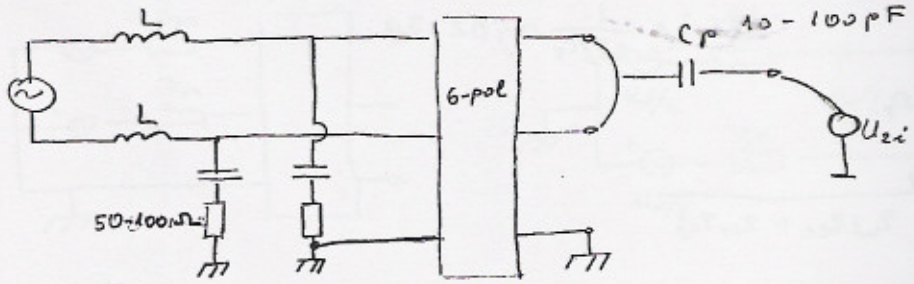
$u_{1i} \cdot Z_{Cy} - u_{21} Z_{Cy} = u_{21} \cdot Z_{Ldi}$

$u_{1i} = u_{2i} \frac{Z_{Ld} + Z_{Cy}}{Z_{Cy}}$

$\frac{u_{2i}}{u_{1i}} = \frac{Z_{Cy}}{Z_{Ld} + Z_{Cy}} = \frac{482.3}{25446.9 + 482.3} = 0.0186 \Rightarrow \frac{u_{1i}}{u_{2i}} = 53.76 \Rightarrow 34.6\ dB$

Samo je jedan Mali Ivical

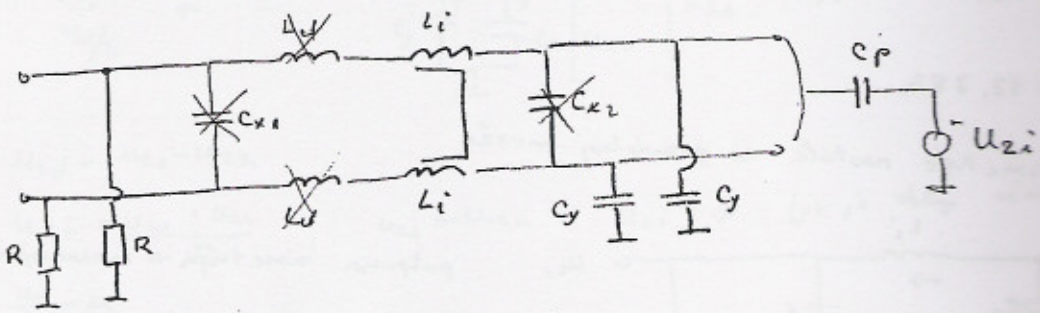
c) izotopazne smetnje naskale unutar uređaja



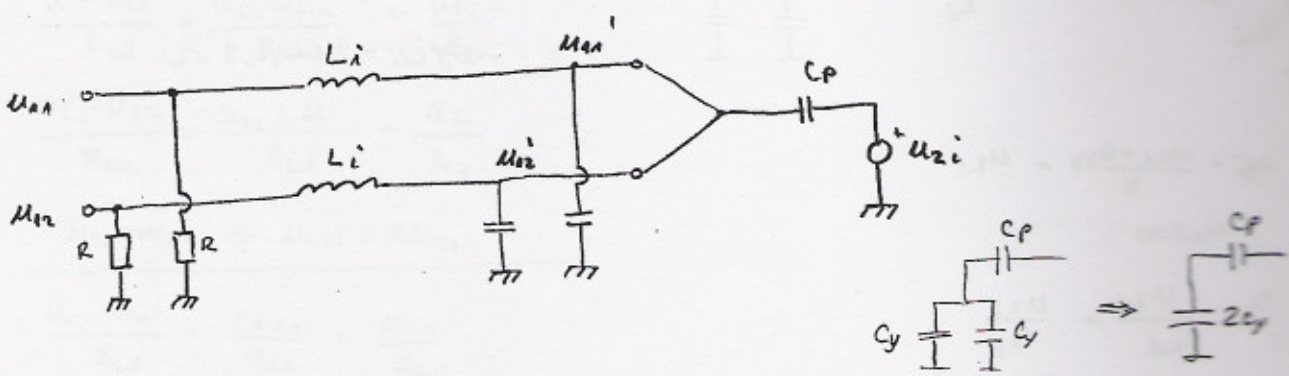
- dodaju se C-ovi koji imaju impedancije takvu da u radnom području ne utječe, a L-ovi predstavljaju visoku impedanciju da smetnje ne bi išle u mjerni

$$C \gg \frac{1}{2\pi f_1 R} \quad , f_1 \gg 150\ kHz$$

$$2\pi f_1 L \gg R_1 \quad , f_1 \gg 150\ kHz$$



$L_d \ll L_i$



$f = 150\ kHz$

$|Z_{Cy}| = 482.3\ \Omega$

$|Z_{Li}| = 25.4\ k\Omega$

Samo je jedan Mali Ivica!

$|Z_{Li}| >> |Z_{Cy}|$ → promatrajmo kapacitivno dijelilo odvojeno

$$u_{A1}' = u_{2i} \frac{Z_{Cy}}{Z_{Cp} + Z_{Cy}} = u_{2i} \frac{\frac{1}{\omega C_y}}{\frac{1}{\omega C_p} + \frac{1}{\omega C_y}} = u_{2i} \frac{\frac{1}{Z C_y}}{\frac{C_y 2C_y + C_p}{Z C_p C_y}} = u_{2i} \frac{C_p}{2C_y}$$

$C_p << C_y$ 2.2nF

500 - 100pF

- sad izračunajmo ulaz

$$\frac{u_{A1}' - u_{A1}}{Z_{Li}} = \frac{u_{11}}{R}$$

$$u_{11}' R = u_{A1} (Z_{Li} + R)$$

$$u_{11} = u_{11}' \frac{R}{R + Z_{Li}}$$

$$u_{11} \doteq u_{A1}' \cdot \frac{R}{Z_{Li}}$$

$$u_{11} = u_{2i} \frac{C_p}{2C_y} \cdot \frac{R}{Z_{Li}}$$

$$u_{11} = u_{A1}$$

$$\frac{u_{A1}}{u_{2i}} = \frac{C_p}{2C_y} \cdot \frac{R}{Z_{Li}}$$

$f = 150\,kHz$

$C_p = 100pF$

$R = 50\,\Omega$

$$\left| \frac{u_{1i}}{u_{2i}} \right| = \frac{0.1}{2 \cdot 2.2} \cdot \frac{50}{2\pi \cdot 150 \cdot 10^3 \cdot 27 \cdot 10^{-3}} = 4.465 \cdot 10^{-5} \Rightarrow 87\,dB$$

Samo je jedan Mali Ivica!

S-1

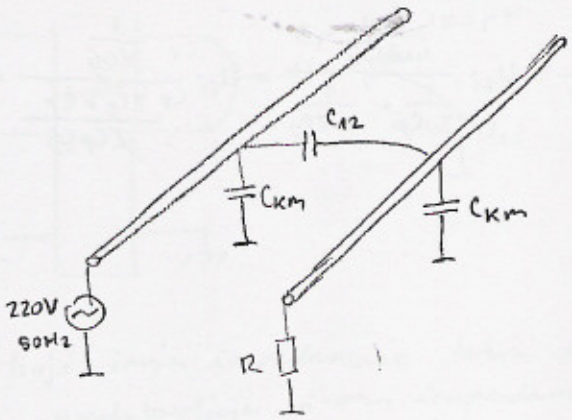
$l = 10\,m$

$U = 220\,V / 50\,Hz$

$D = 1\,cm$

$d = 2\,mm$

$U_{izm} = ?$



a) $R \to \infty$

:) $R = 50\,\Omega$

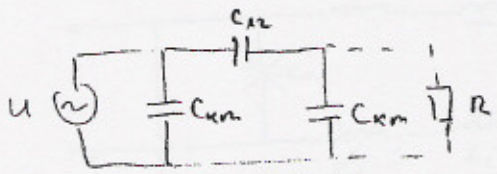
$C_{Km} = 2000\,pF$

b) oklopljen kabel

$\rightarrow 200\,pF/m$

$C_{12}' = 2\,pF$

$$C_{12} = \frac{\pi \varepsilon l}{\ln\left(2\frac{D}{d}\right)} = \frac{\pi \cdot 8.8542 \cdot 10^{-12} \cdot 10}{\ln\left(2\frac{10}{2}\right)} = 120.8\,pF$$



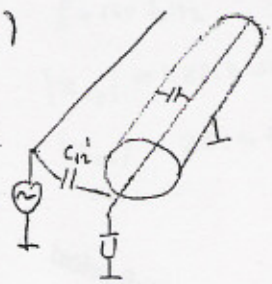
a) $R \to \infty \quad U_{izm} = U \dfrac{\frac{1}{\omega C_{Km}}}{\frac{1}{\omega C_{Km}} + \frac{1}{\omega C_{12}}} = U \dfrac{C_{12}}{C_{12} + C_{Km}} = 220 \dfrac{120.8}{120.8 + 2000} = 12.53\,V_{ef}$

$R = 50\,\Omega \quad U_{izm} = U \dfrac{R \| \frac{1}{j\omega C_{Km}}}{\frac{1}{j\omega C_{12}} + R \| \frac{1}{j\omega C_{Km}}} = U \dfrac{\frac{R}{1 + j\omega R C_{Km}}}{\frac{1}{j\omega C_{12}} + \frac{R}{1 + j\omega R C_{Km}}} = U \dfrac{j\omega R C_{12}}{1 + j\omega R (C_{12} + C_{Km})}$

Izr. nizke frekvencije (npr. 50 Hz) $R \ll \dfrac{1}{j\omega(C_{12} + C_{Km})}$

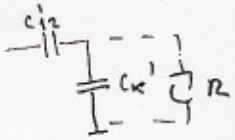
$U_{izm} = j\omega C_{12} R \cdot U \Rightarrow U_{izm} = 2\pi \cdot 50 \cdot 120.8 \cdot 10^{-12} \cdot 50 \cdot 220 = 0.417\,mV_{ef}$

b)



$C_K' = 200\,pF/m \cdot 10\,m = 2000\,pF$

$C_{12}' = 2\,pF$



$R \to \infty \quad U_{izm} = U \dfrac{C_{12}'}{C_{12}' + C_K'} = 220 \dfrac{2}{2 + 2000} = 219.78\,mV_{ef}$

$R = 50\,\Omega \quad U_{izm} = \omega C_{12}' R \cdot U = 2\pi \cdot 50 \cdot 2 \cdot 10^{-12} \cdot 50 \cdot 220$

$U_{izm} = 6.91\,\mu V_{ef}$

Samo je jedan Mali Fritzel