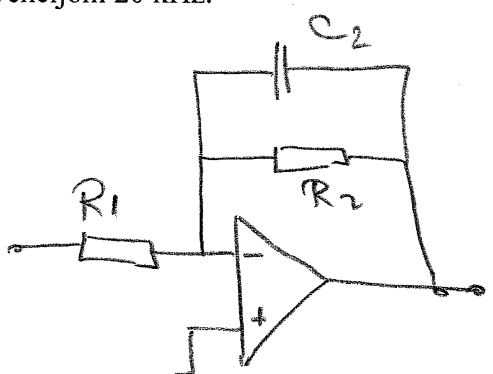
Z1. Odredite izlazni napon šuma invertirajućeg pojačala izvedenog operacijskim pojačalom. Pojačanje pojačala je –10, ulazni otpor 10 kΩ. Otpornici su odabrani tako da je minimiziran izlazni napon pomaka pojačala. Operacijsko pojačalo ima spektralnu gustoću ulaznog napona šuma $4 \cdot 10^{-16}$ V^2/Hz i spektralnu gustoću ulazne struje šuma $0{,}09 \cdot 10^{-24}$ A^2/Hz (bijeli šum). Pojačalo je sustav prvoga reda s gornjom graničnom frekvencijom 20 kHz.



$A = -10$

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

$R_2 = 10 R_1 = 100\ k\Omega$

$R_3 = R_1 \| R_2 \doteq 9{,}1\ k\Omega$

$Z_1 = R_1$

$Z_2 = R_2 \| \frac{1}{j\omega C_2} = \frac{R_2}{1 + j\omega R_2 C_2}$

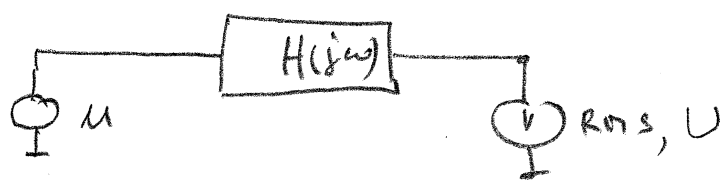
$Z_3 = R_3$

$f_g = 20\ kHz = \frac{1}{2\pi} \frac{1}{R_2 C_2} \Rightarrow$

$C_2 = 79{,}58\ pF$

$u_p^2 = 4 \cdot 10^{-16}\ V^2/Hz$

$i_p^2 = 0{,}09 \cdot 10^{-24}\ A^2/Hz$



$$U^2 = \int_0^\infty u^2 \cdot |H(j\omega)|^2 \, d\omega$$

PRIJENOSNE KARAKTERISTIKE ZA SVAKI OTPORNIK:

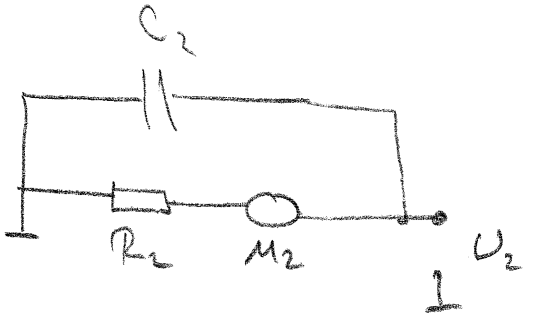
R_1 ,

$$A_1 = -\frac{R_2}{R_1} \cdot \frac{1}{1 + j\omega R_2 C_2} = -\frac{Z_2}{Z_1} = -\frac{R_2}{R_1} \cdot \frac{1}{1 + j f/f_g}$$

R_3

$$A_2 = 1 + \frac{Z_2}{Z_1} = 1 + \frac{R_2}{R_1} \cdot \frac{1}{1 + j\omega R_2 C_2} = 1 + \frac{R_2}{R_1} \cdot \frac{1}{1 + j f/f_g}$$

R_2



$$A_2 = \frac{\mu_{o2}}{\mu_2} = \frac{\frac{1}{j\omega C_2}}{R_2 + \frac{1}{j\omega C_2}} = \frac{1}{1 + j\omega R_2 C_2}$$

DOPRINOS OTPORNIKA ŠUMU:

$k = 1{,}38 \cdot 10^{-23}\ J/K$

$T = 300\ K$

$$\mu_1^2 = 4kTR_1 = 1{,}656 \cdot 10^{-16}\ V^2/Hz$$

$$U_1^2 = \int_0^\infty \mu_1^2 \cdot \frac{(R_2/R_1)^2}{|1 + jf/f_g|^2}\, df = \left(\frac{R_2}{R_1}\right)^2 \mu_1^2 \cdot \frac{\pi}{2} f_g =$$

$$= 100 \cdot 1{,}656 \cdot 10^{-16}\ V^2/Hz \cdot \frac{\pi}{2} \cdot 10\,kHz = 5{,}202 \cdot 10^{-10}\ V^2$$

$$\mu_2^2 = 4kTR_2 = 1{,}656 \cdot 10^{-17}\ V^2/Hz$$

$$U_2^2 = \mu_2^2 \cdot \frac{\pi}{2} f_g = 5{,}202 \cdot 10^{-11}\ V^2$$

$$\mu_3^2 = 4kTR_3 = 1{,}507 \cdot 10^{-16}\ V^2/Hz$$

$$U_3^2 = \int_0^\infty \mu_2^2 \cdot \left| 1 + \frac{R_2/R_1}{1 + j\,f/f_g} \right|^2 df \doteq \left(1 + \frac{R_2}{R_1}\right)^2 \cdot \mu_3^2 \frac{\pi}{2} f_g =$$

$$= 11^2 \cdot 1{,}507 \cdot 10^{-16}\ V^2/Hz \cdot \frac{\pi}{2} \cdot 20\,kHz =$$

$$= 5{,}729 \cdot 10^{-10}\ V^2$$

DOPRINOS POJAČALA

$$U_p^2 = \left(1+\frac{R_2}{R_1}\right)^2 \cdot \left[u_p^2 + 2\,(R_1 \| R_2)^2\, i_p^2\right] \cdot \frac{\pi}{2} f_g$$

$$= 121 \cdot \left(4\cdot 10^{-16}\, V^2/Hz + 2\cdot (9{,}1\,k\Omega)^2 \cdot 0{,}09\cdot 10^{-24}\, A^2/Hz\right) \cdot \frac{\pi}{2} \cdot 20\,kHz$$

$$= 121\left(4\cdot 10^{-16}\, V^2/Hz + 1{,}491\cdot 10^{-17}\, V^2/Hz\right) \frac{\pi}{2} \cdot 20\,kHz = 1{,}577\cdot 10^{-9}\, V^2$$

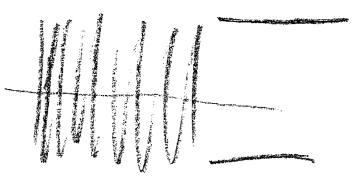
UKUPNI ŠUM NA IZLAZU

$$U_N^2 = U_1^2 + U_2^2 + U_3^2 + U_p^2 =$$

$$= 5{,}202\cdot 10^{-10}\, V^2 + 5{,}202\cdot 10^{-11}\, V^2 + 5{,}723\cdot 10^{-10}\, V^2 + 1{,}577\cdot 10^{-9}\, V^2 =$$

$$= 2{,}722\cdot 10^{-9}\, V^2$$

$$U_N = 5{,}217\cdot 10^{-5}\, V = 52{,}17\,\mu V$$



$$U_{N\,PP} = 6\cdot U_N = 313\,\mu V$$

16 bit ADC $\quad LSB = \frac{5\,V}{2^{16}} = 76{,}3\,\mu V$

$U = 5\,V$

Z2 ~~Z1~~. Analogno-digitalni pretvronik s 12-bitnom razlučivošću ima raspon ulaznog napona od 0 V do 5 V. Odredite kvantizacijski korak, maksimalnu kvantizacijski pogrešku (u milivoltima) te omjer signala i šuma pretvornika za sinusni napon pune skale.

$M = 12$ bit

$$q = \frac{U_{FS}}{2^M} = \frac{5\,V}{2^n} = 1{,}2207\ mV$$

max. pogreška $\quad \varepsilon = \pm \frac{1}{2} LSB = \pm \frac{1}{2} \cdot 1{,}2207\ mV =$

$$= 0{,}61035\ mV$$

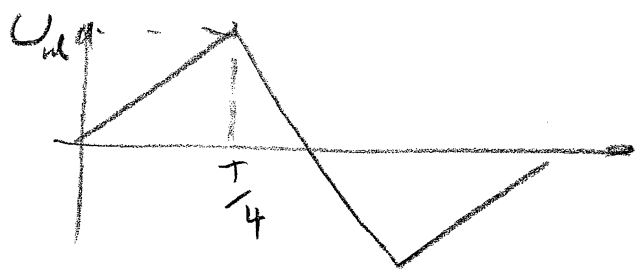
$$SNR = \frac{U_{RMS}}{\varepsilon_{RMS}} = 20 \log\left(2^{M-1} \cdot \sqrt{6}\right) \doteq$$

$$\doteq 6{,}02 \cdot 12 + 1{,}76\ dB = \underline{74\ dB}$$

$$\varepsilon_{RMS} = \frac{q}{\sqrt{12}}$$

$$U_{RMS} = \frac{U_{FS}}{2} \cdot \frac{1}{\sqrt{2}} = \frac{2^{M-1} \cdot q}{\sqrt{2}}$$

Z3 ~~12.~~ Trokutasti napon frekvencije 1 kHz, amplitude ±1 V digitalizira se 8-bitnim analogno-digitalnim pretvornikom sa S&H krugom. Kolika je najniža frekvencija uzorkovanja signala da se spriječi *aliasing* osnovnog harmonika ulaznog signala? Odredite brzinu porasta (*slew rate*) ulaznog signala. Koliko je najdulje vrijeme otvora S&H sklopa (aperturno vrijeme) uz koje neće doći do amplitude pogreške veće od ±0,5 LSB? Raspon ulaznog napona pretvornika iznosi ±1 V.



$M = 8$

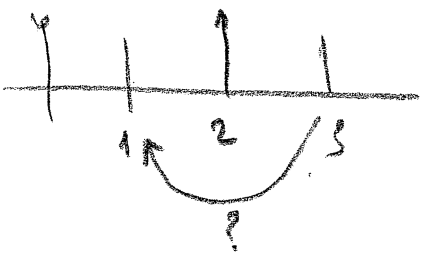
$U_{FS} = \pm 1\,V$

$Q = \frac{2\,V}{2^8} = 7{,}8125\,mV$

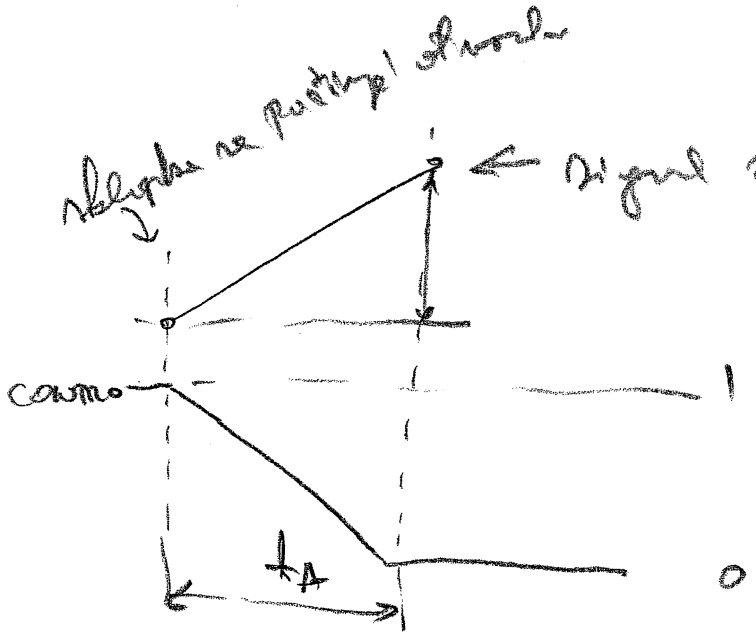
OSNOVNI HARMONIK $f = 1\,kHz$

$f_S > 2f_0 = 2\,kHz$

(FOLDING ??)



$S = \frac{U_{ul}}{T/4} = \frac{4 \cdot 1\,V}{1\,ms} = 4000\,V/s$



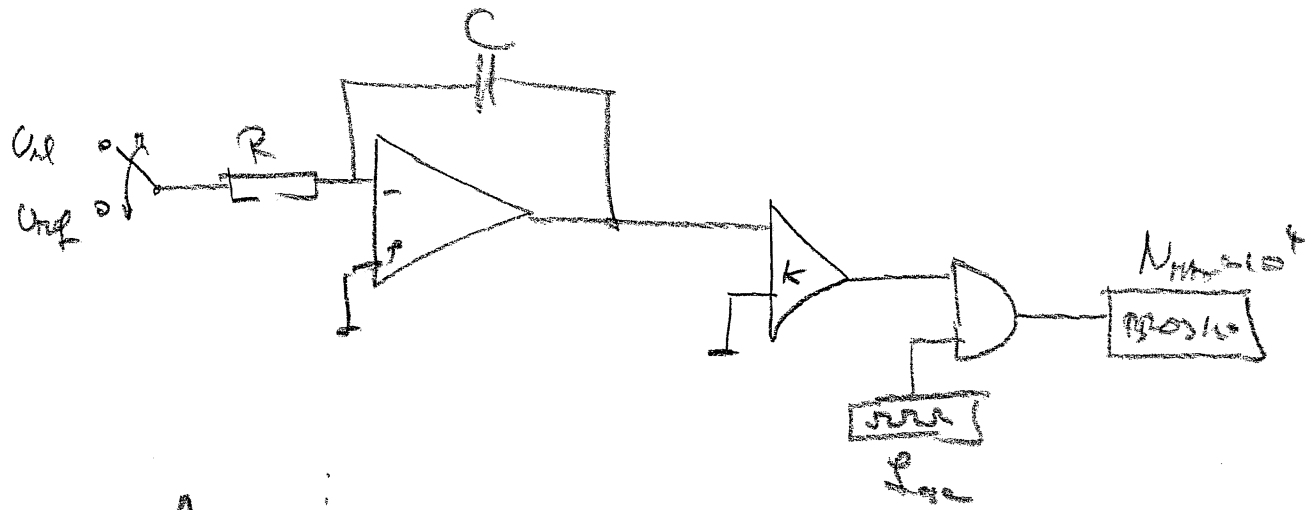
$\Delta U = S \cdot t_A$

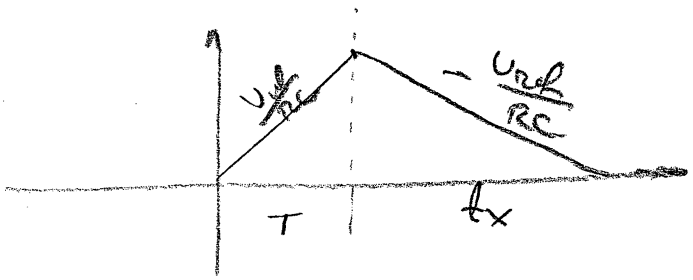
$\Delta U < \frac{1}{2}\,LSB$

$t_A < \frac{1}{2}\,\frac{LSB}{S} =$

$= \frac{1}{2} \cdot \frac{7{,}8125\,mV}{4000\,V/s} = 0{,}977\,\mu s$

Z4 ~~13.~~ U analogno-digitalnom pretvorniku s dvostrukim pilastim naponom frekvencija oscilatora je 400 kHz, referenti napon je 10 V, a brojilo broji do 10^4 impulsa. Nacrtajte blok shemu pretvornika. Koliko traje mjerni ciklus kad je na ulaz priključen najveći napon koji se može digitalizirati ovim pretvornikom? Koliki je iznos mjerenog napona, ako se uz superponiranu smetnju frekvencije 50 Hz i amplitude 500 mV na pokazniku spojenom na izlaz pretvornika očita 3,755 V.





$$\frac{U_{ul}}{RC}\cdot T = \frac{U_{ref}}{RC}\cdot t_x \Rightarrow U_{ul} = U_{ref}\cdot\frac{t_x}{T}$$

NAJDUGI MJERNI CIKLUS: $t_x = T$, $U_{ul} = U_{ref}$

$$T_c = T + t_x = 2T = 2\cdot\frac{N}{f_{ext}} = \frac{2\cdot 10000}{400\,kHz}$$

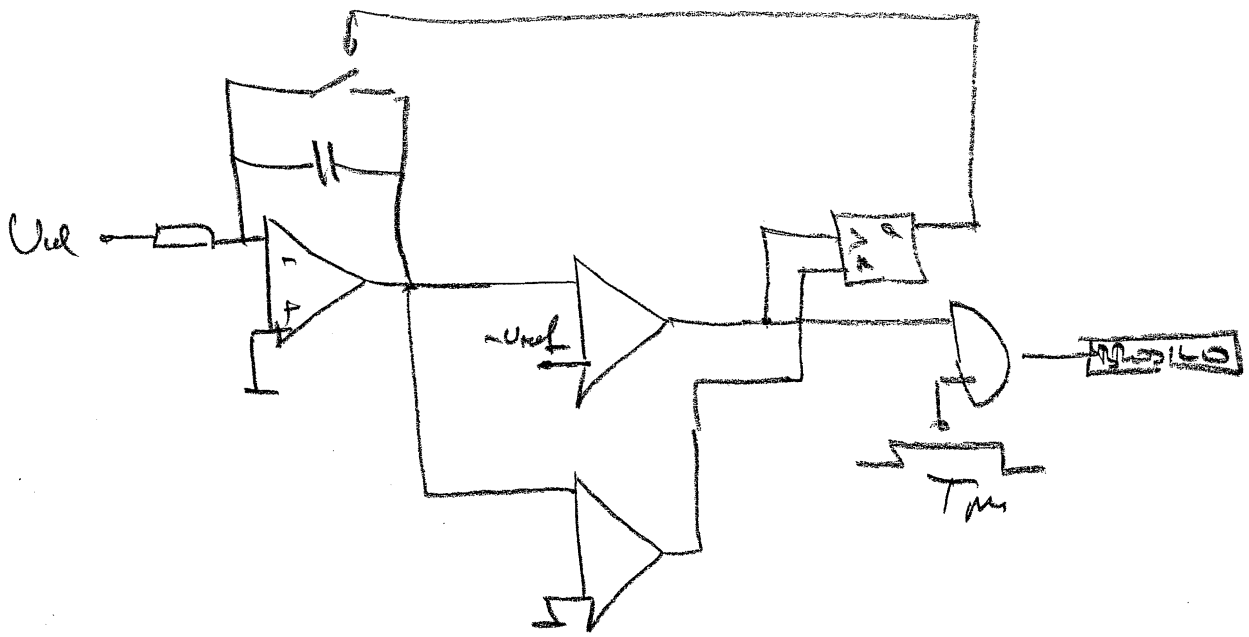
$$T_c = 50\,ms$$

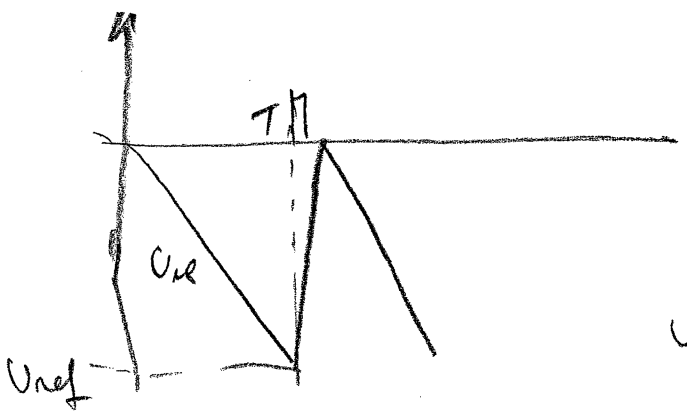
$$U_{izl} = U_{ul} + \frac{1}{T}\int_{-}^{T} U_{sm}\sin(2\pi f t)\,dt = U_{ul} \pm \frac{1}{T}U_{sm}\frac{1}{2\pi f}\left(1-\cos(2\pi f T)\right)$$

$$\boxed{U_{ul} = U_{izl} \pm U_{sm}\frac{1}{2\pi f T}\left(1-\cos(2\pi f T)\right) =}$$

$$\boxed{= 3{,}755\,V \pm 63{,}66\,mV}$$

25 14. Analogno-digitalnim pretvornikom napona u frekvenciju mjeri se napon 2,5 V. Pretvornik koristi Millerov integrator s vremenskom konstantom 220 μs i ulaznim otporom od 10 kΩ. Napon komparacije je –3 V. Kondenzator u integratoru se izbija tranzistorskom sklopkom zanemarivog otpora u vođenju. Nacrtajte blok shemu pretvornika i vremenski dijagram jednog ciklusa pretvorbe. Izračunajte trajanje nabijanja kondenzatora u integratoru. Koliko impulsa izbroji brojilo tijekom jednog mjernog ciklusa koji traje 250 ms?





$$U_{ref} = U_{ul} \cdot \frac{1}{RC} \cdot T$$

$$N = \frac{T_m}{T}$$

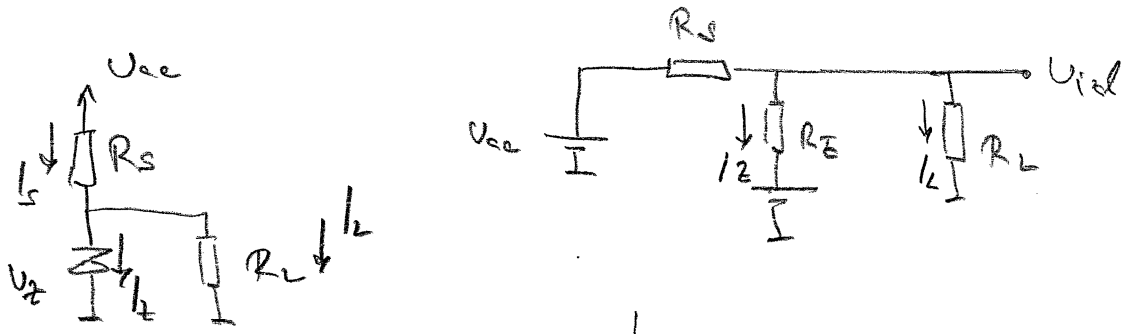
$$T = \frac{RC U_{ref}}{U_{ul}} = 264\,\mu s$$

$$U_{ref} = U_{ul} \cdot \frac{1}{RC} N T_m$$

$$U_{ul} = \frac{RC U_{ref}}{T_m} \cdot N$$

$$N = \frac{T_m}{T} = \frac{250\,ms}{264\,\mu s} \doteq 946$$

Z6. Zenerova dioda nazivnog napona U_{ZO}=6,8 V koristi se u izvoru referentnog napona. U području proboja strujno-naponska karakteristika diode može se opisati pravcem $U_Z=U_{ZO}+R_Z(I_Z-I_{ZO})$, $I_Z \geq I_{ZO}$=2 mA, R_Z=10 Ω. Napon napajanja je 15 V±20%. Izvor referentnog napona opterećen je strujom 2–4 mA. Odredite vrijednost serijskog otpora u izvoru referentnog napona te promjene referentnog napona s promjenama napona napajanja i izlazne struje.



$$\frac{U_{izl}-U_{cc}}{R_S}+\frac{U_{izl}-U_{zo}}{R_z}+I_{zo}+I_L=0$$

$$U_{izl}(R_S+R_z)-R_zU_{cc}-R_SU_{zo}+(I_{zo}+I_L)R_SR_z=0$$

$$U_{izl}=U_{cc}\frac{R_z}{R_S+R_z}+\frac{R_S}{R_S+R_z}U_{zo}-(I_{zo}+I_L)(R_S\|R_z)$$

↑ NAPONSKA REGULACIJA $\quad\simeq U_{zo}\quad$ ↑ STRUJNA REGULACIJA

– I_{zMAX} DISIPACIJA

– I_{zMIN}, U_{ccMIN}, I_{LMAX}

$$R_S=\frac{U_{ccMIN}-U_{zo}-R_zI_{zo}}{I_{zo}+I_{LMAX}}=$$

$$=\frac{15\cdot0{,}8-6{,}8-10\cdot2\cdot10^{-3}}{2\cdot10^{-3}+4\cdot10^{-3}}=860\,\Omega$$

$$\Delta U_{cc}\frac{R_z}{R_S+R_z}=\pm3\,V\cdot\frac{10}{860+10}=\pm34{,}5\,mV$$

$$\Delta U_L=\Delta I_L(R_S\|R_z)=2\,mA\cdot10\,\Omega=\pm20\,mV$$