1. Nacrtajte shemu fazno osjetljivog pojačala (*lock-in*) s jednim operacijskim pojačalom i FET sklopkom. Izračunajte napon na izlazu niskopropusnog filtra ako ulazni sinusni signal amplitude 3 V kasni u fazi u odnosu na referentni signal za 60°.

2. Na ulaz analognog fazno osjetljivog pojačala (*lock-in* pojačalo) doveden je signal:

$$u(t) = 4\ \text{V} \cdot \sin(2\pi \cdot 500\ \text{Hz} \cdot t + 30°) +$$
$$+ 1\ \text{V} \cdot \sin(2\pi \cdot 1230\ \text{Hz} \cdot t + 50°) + 0{,}5\ \text{V} \cdot \sin(2\pi \cdot 2730\ \text{Hz} \cdot t + 70°).$$

Odredite napon horizontalne i vertikalne projekcije (*in-phase* i *quadrature* komponente) na izlazu iz pojačala ako je frekvencija referentnog signala 2730 Hz.

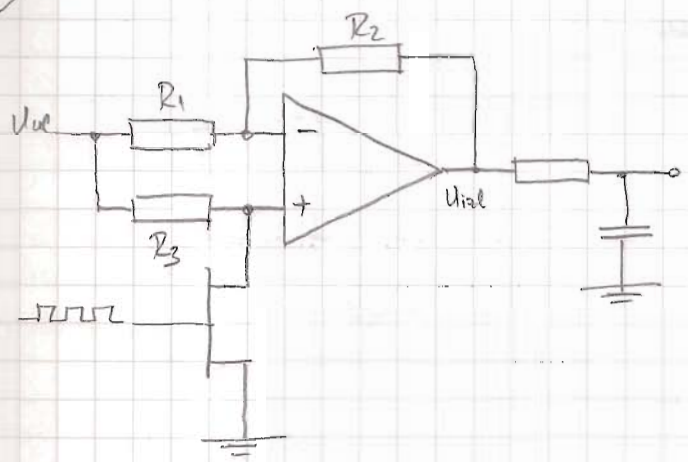
3. Na ulaz sklopa s fazno vezanom petljom (PLL) doveden je signal vremenski promjenjive frekvencije oblika $f(t) = 10\ \text{kHz} + 200\ \text{Hz} \cdot \sin(2\pi \cdot 5000\ \text{Hz} \cdot t)$. Odredite amplitudu promjene frekvencije signala na izlazu iz naponski kontroliranog oscilatora PLL-a ako je niskopropusni filtar u PLL-u prvog reda, istosmjernog jediničnog pojačanja i gornje granične frekvencije 100 Hz. Konstanta PLL-a je $K_V = 10^4 \text{s}^{-1}$, a frekvencija oscilatora u slobodnom režimu je 10 kHz.

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

5. Na instrumentacijsko pojačalo AD8429 pojačanja 1000 spojen je otpornički most s jednakim otpornicima otpora 50 kΩ. Izračunajte vrijednost od vrha do vrha šuma na izlazu pojačala ako je frekvencijski pojas ograničen od 1 kHz do 11 kHz.

4. AUDITORNE

1



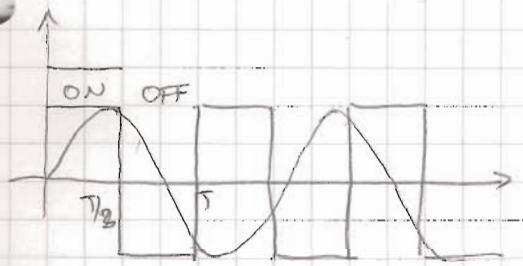
$R_2 = R_1$

$U_{izl} = U_{ul}\left(-\frac{R_2}{R_1}\right) = -U_{ul}$ "ON"

$U_{izl} = U_{ul}\left(-\frac{R_2}{R_1}\right) + U_{ul}\left(1+\frac{R_2}{R_1}\right) = U_{ul}$ "OFF"

Pojačanje 1 ili −1

$U_{ul} = U_0 \sin(\omega t + 60°)$



$$U_{izl} = \frac{1}{T}\int_0^T U_{ul}(t)\cdot A(t)\,dt =$$

$$= \frac{1}{T}\left[-\int_0^{T/2} U_0 \sin(\omega t - \varphi)\,dt + \int_{T/2}^{T} U_0 \sin(\omega t - \varphi)\,dt\right] =$$

$$= \frac{2U_0}{\pi}\cdot\cos\varphi = \frac{2\cdot 3V}{\pi}\cdot\cos(60°) = 0{,}955\,V$$

↑ fazni pomak

2.

$$U(t) = 4V\cdot\sin(2\pi\cdot 500t + 30°) + 1V\sin(2\pi\cdot 1230Hz\,t + 50°) + 0{,}5V\sin(2\pi\cdot 2730Hz\,t + 70°)$$

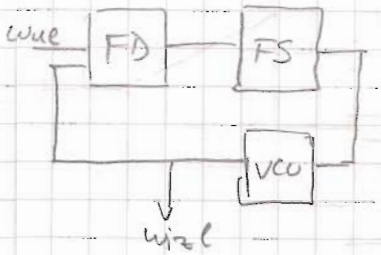
$U_{IN} = \frac{1}{2}U_0\sin\varphi = \frac{0{,}5}{2}\sin(70°) = 0{,}235\,V$

$U_Q = \frac{1}{2}U_0\cos\varphi = \frac{0{,}5}{2}\cos(70°) = 0{,}086\,V$

(3.) $u_{ul} = \sin\left[2\pi f(t) \cdot t\right]$

$f(t) = 10\,kHz + 200\,Hz \cdot \sin(2\pi \cdot 5000\,Hz \cdot t)$

↑ KONSTANTA ↑ PROMJENA U VREMENU



$H(s) = \frac{u_{izl}}{u_{ul}} = \frac{kF(s)}{s + kF(s)}$

$F(s) = \frac{1}{1 + \frac{s}{\omega_g}}$ ← sustav I. reda

$H(s) = \frac{K}{s\left(1 + \frac{s}{\omega_g}\right) + K}$

$|H(j\omega)| = \frac{K}{\left(K - \frac{\omega^2}{\omega_g}\right)^2 + \omega^2}$

$\omega_g = 2\pi \cdot 100\,Hz$

a) $\omega = 0$ $\quad |H(0)| = 1$

b) $\omega = 2\pi \cdot 5000$ $\quad |H(5000 \cdot 2\pi)| = 6{,}406 \cdot 10^{-3}$

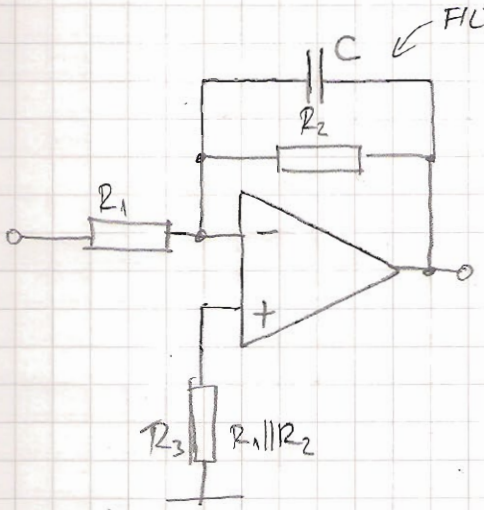
$f_{iz}(t) = 10\,kHz \cdot 1 + 200\,Hz \cdot 6{,}406 \cdot 10^{-3} \cdot \sin\left(2\pi\, 5000\, t + \arg\left(H(2\pi\, 5000)\right)\right)$

↑ $|H(0)|$ ↑ $|H(5000 \cdot 2\pi)|$

$f_{iz}(t) = 10\,kHz + 1{,}281\,Hz \cdot \sin(\ldots)$

4. AUDITORNE - NASTAVAK

4.



$R_1 = 10k\Omega$
$R_2 = 100k\Omega$
$R_3 = R_1 \| R_2 = 9{,}091\,k\Omega$

$f_g = \frac{1}{2\pi R_2 C} \Rightarrow C = \frac{1}{2\pi f_g R_2} = 7,\ pF$

$U_R^2 = 4kTR$

nakon integriranja A_{IHV} po f od $0 \to \infty$

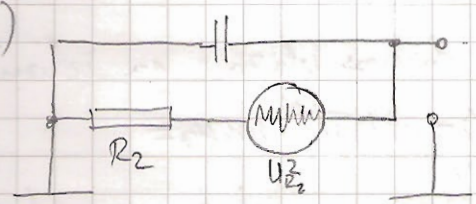
R_1)

$A_{IHV.} = -\frac{R_2}{R_1} \cdot \frac{1}{1+j\omega R_2 C} \Rightarrow U_{R_1}^2 = u_{R_1}^2 \cdot \left(\frac{R_2}{R_1}\right)^2 \cdot \frac{\pi}{2} \cdot f_g$

R_3)

$A_{NIH} = \left(1 + \frac{Z_2}{R_1}\right) = 1 + \frac{R_2}{R_1} \cdot \frac{1}{j\omega R_2 C} \Rightarrow U_{R_3}^2 = u_{R_3}^2 \cdot \left(\frac{R_2}{R_1}\right)^2 \cdot \frac{\pi}{2} \cdot f_g$

R_2)



$A_{PV} = \frac{1}{1+j\omega R_2 C} \Rightarrow U_{R_2}^2 = u_{R_2}^2 \cdot \frac{\pi}{2} f_g$

za R_3

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

aproksimirano

integral divergira

$T = 300K$
$k = 1{,}38 \cdot 10^{-23}\ J/K$

$U_{R_1}^2 = 5{,}2 \cdot 10^{-10}\ V^2$
$U_{R_2}^2 = 5{,}2 \cdot 10^{-11}\ V^2 = kT/C$
$U_{R_3}^2 = 4{,}727 \cdot 10^{-10}\ V^2$

Doprinos pojačala

naponski izvor

$U_p^2 = \left(1 + \frac{R_2}{R_1}\right)^2 \cdot \left(u_p^2 + I_p^2 \cdot 2(R_1 \| R_2)^2 \right) \cdot \frac{\pi}{2} \cdot f_g = 1{,}576 \cdot 10^{-9}\ V^2$

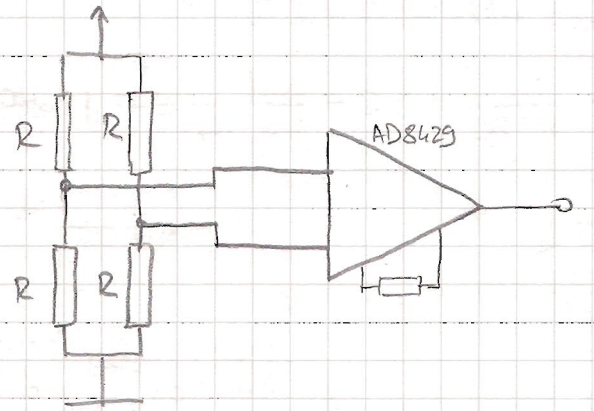
$U_N^2 = U_{R_1}^2 + U_{R_2}^2 + U_{R_3}^2 + U_p^2 = 2{,}621 \cdot 10^{-9}\ V^2$

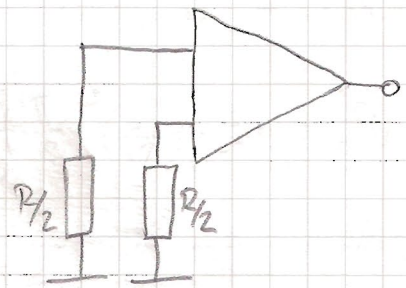
$U_N = 51{,}2\,\mu V$ ← srednja

$U_{N,pp} = 6\,U_{p,p} = 307{,}12\,\mu V$

5. AD8429

$A = 1000$
$R = 50k\Omega$





$u_R^2 = 4kT(R \| R) = 4{,}14 \cdot 10^{-6}\ V^2/Hz$

$u_{IN}^2 = u_{iN}^2 \cdot A^2 \cdot \Delta f = (1nV/\sqrt{Hz})^2 \cdot 1000^2 \cdot (11kHz - 1kHz)$

$= 10^{-8}\ V^2$ ← doprinos ulaza na izlazu

$u_{out}^2 = u_{out}^2 \cdot \Delta f = (45nV/\sqrt{Hz})^2 \cdot 10kHz =$

$= 2 \cdot 10^{-11}\ V^2$ ← doprinos izlaza na izlazu

$u_I^2 = 2(R \| R)^2 \cdot I_N^2 \cdot A^2 \cdot \Delta f = 2 \cdot (25k\Omega)^2 \cdot (1{,}5pA/\sqrt{Hz})^2 \cdot 1000^2 \cdot 10kHz = 2{,}812 \cdot 10^{-5}\ V^2$

↑ doprios šuma struje prema izlazu

$u_R^2 = 2 \cdot u_R^2 \cdot A^2 \cdot \Delta f = 8{,}8 \cdot 10^{-6}\ V^2$

$u_{N,izl}^2 = \sum (SVI4) = 3{,}7 \cdot 10^{-6}\ V^2$

$U_N = 6mV$

$U_{vpp} = 36mV = 6 \cdot U_N$