6.6 $N = 28$ bit

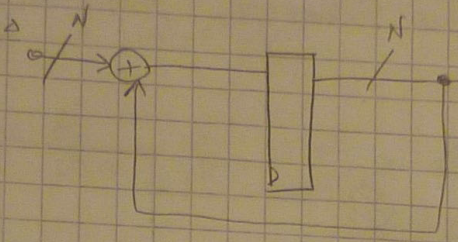
$f_s = 50$ MHz

$f_{max} = ?$

$f_{min} = ?$

$R = ?$

$\Delta f = ?$ → 9.7 MHz



$$\Phi[n] = \frac{\phi[n]}{\frac{2\pi}{2^N}} = \phi[n] \cdot \frac{2^N}{2\pi}$$

korak → $\Delta = \Omega_0 \cdot \frac{2^N}{2\pi}$

$$\Omega_0 = 2\pi \frac{f_0}{f_s} = 2\pi \frac{\omega_0}{\omega_s}$$

$$f_{0max} = \frac{f_s}{2} = 25\,\text{MHz}$$

$$f_{0min} = \frac{f_s}{2^N} = 1.862 \cdot 10^{-1} = 0.1862\,\text{Hz}$$

$$\Delta = \frac{f_0}{f_s} 2^N = \frac{\omega_0}{\omega_s} 2^N$$

$$\Delta = \left\lfloor \frac{f_0}{f_s} \cdot 2^N + 0.5 \right\rfloor = \left\lfloor \frac{\omega_0}{\omega_s} \cdot 2^N + 0.5 \right\rfloor$$

Δf_{0min} = najmanji korak = $\frac{f_s}{2^N} = 0.1862\,\text{Hz}$

$$\Delta = 2^N \cdot \frac{\omega_0}{\omega_s} = \frac{2^{28}}{50\,\text{MHz}} \cdot 9.7\,\text{MHz} = 52.036772 \cdot 10^6$$ rad

6.7 $f_{s_1} = 24\,\text{kHz}$

$f_{g_1} = 0.3\pi$

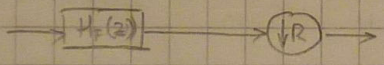
$f_{s_2} = 14.4\,\text{kHz}$

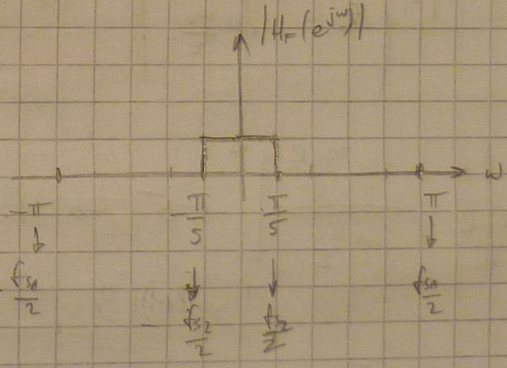
$f_{g_2} = ?$

$$R = \frac{f_{s_1}}{f_{s_2}} = \frac{24\,\text{kHz}}{14.4\,\text{kHz}} = \frac{5}{3}$$ R

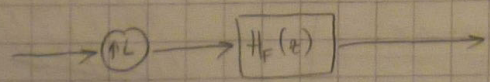
→ nije cijeli broj, pa pro umetamo uzorke pa ih izbacujemo

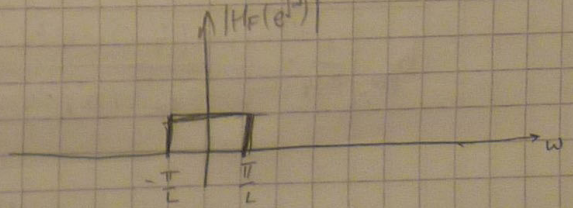
kad decimacija



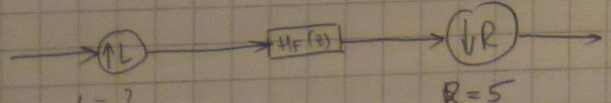


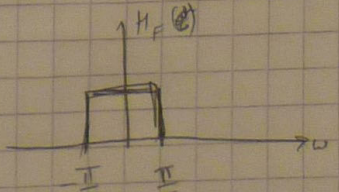
kad interpolacija





→ kaskadu filtra možemo skupiti u jedan filtar, sa $\omega_g = \min\left(\frac{\pi}{R}, \frac{\pi}{L}\right)$





68 – digitalni prijemnik s direktnom pretvorbom frekvencije i kompleksnom obradom signala

– prima DSB-TC-AM uz $\Delta f = 6\,kHz$

$N_{ADC} = 12\,bit$

$f_s = 25\,MHz$

$f_{out} = 24.4\,kHz$

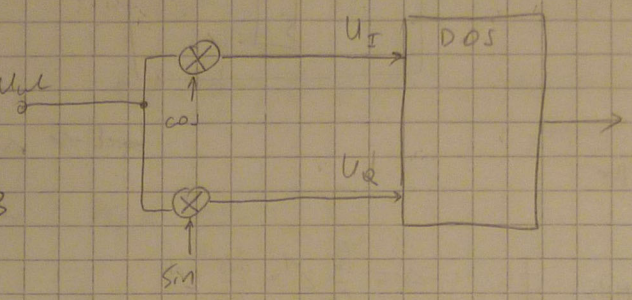
a) $|H_{cic}(\omega_d)| < -100\,dB$

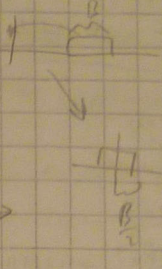
b) $PG_{cic} = ?$

$PG = 10 \log \frac{f_s}{2B}$

c) $f_g = ?$ → za filter kanala

d) $PG_{FK} = ?$





$H_{cic} = \left(\frac{1}{R} \cdot \frac{1 - z^{-R}}{1 - z^{-1}}\right)^N$ $\quad R = \frac{25\,MHz}{24.4\,kHz} \approx 1024$

$|H_{cic}(e^{j\omega})| = \left|\frac{1}{R} \cdot \frac{\sin \frac{\omega \cdot R}{2}}{\sin \frac{\omega}{2}}\right|^N$

a) gušenje alisa je najmanje na $\omega_c = \frac{2\pi}{R} - \omega_c$ $\quad \omega_c = \frac{\pi \cdot f_c}{f_s}$ → širina kanala u digitalnoj domeni

$\omega_c = \frac{\pi \cdot 6\,kHz}{25\,MHz} = 7.5358 \cdot 10^{-3}$

$\omega_c = \frac{2\pi}{R} - 7.5358 \cdot 10^{-3} = \frac{2\pi}{1024} - 7.5358 \cdot 10^{-3} = 5.3782 \cdot 10^{-3}$

$|H_{cic}(\omega_d)| = \left|\frac{1}{R} \cdot \frac{\sin \frac{\omega_c \cdot R}{2}}{\sin \frac{\omega_c}{2}}\right|^N \Rightarrow 20 \log \left|\frac{1}{R} \cdot \frac{\sin \frac{\omega_c \cdot R}{2}}{\sin \frac{\omega_c}{2}}\right|^N = -100\,dB$

$\log_{10} \left|\frac{1}{R} \cdot \frac{\sin \frac{\omega_c \cdot R}{2}}{\sin \frac{\omega_c}{2}}\right|^N = 5 \rightarrow N \cdot \log_{10} \left|\frac{1}{R} \cdot \frac{\sin \frac{\omega_c \cdot R}{2}}{\sin \frac{\omega_c}{2}}\right| = 5$

$N = \frac{-5}{\log_{10} \left|\frac{1}{1024} \cdot \frac{\sin(4.627 \cdot 10^{-3} \cdot 1024 \cdot 0.5)}{\sin(0.5 \cdot 4.627 \cdot 10^{-3})}\right|} =$

$N = 5.79 \geq 6$

b) $P_{G_{dB}} = 10 \log \frac{f_s}{2B} = 10 \log \frac{6\,GHz}{6\,kHz}$

$PG = \frac{\text{Rauschleistung (Ausgang)}}{\text{Rauschleistung (Eingang)}}$

idealer Filter: $\frac{N}{2} \rightarrow P_{rAD} = \frac{N}{2} \cdot 2 \cdot \frac{f_s}{2} = N \cdot \frac{f_s}{2}$

realer Filter: $\frac{N}{2} \rightarrow P_{rRE} = \frac{N}{2} \cdot 2 \cdot \frac{f_s}{2} = N \cdot \frac{f_s}{2}$

$PG = \frac{P_{rE}}{P_{rAD}} = \frac{N \cdot \frac{f_s}{2}}{N \cdot \frac{f_s}{2}} = \frac{f_s}{6\,GHz}$ → $PG_{dB} = 10 \log \frac{f_s}{6\,GHz}$

$PG = \frac{\frac{N f_s}{2}}{\frac{N f_s}{2^n}} = \frac{f_s}{f_s} \rightarrow$ noch...

$= 30{,}1\,dB$

c) π Filter kaskade → $\omega_g = ?$

6.9 digitalni prijemnik s direkt. pretvorbom f i kompl. obradom signala

$\Delta f = 100kHz$

$N = 14 bit$

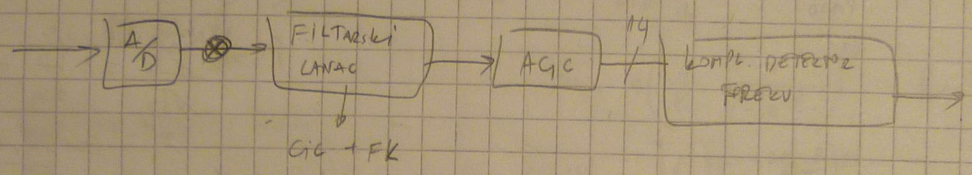
$f_{s_1} = 51.2 MHz$

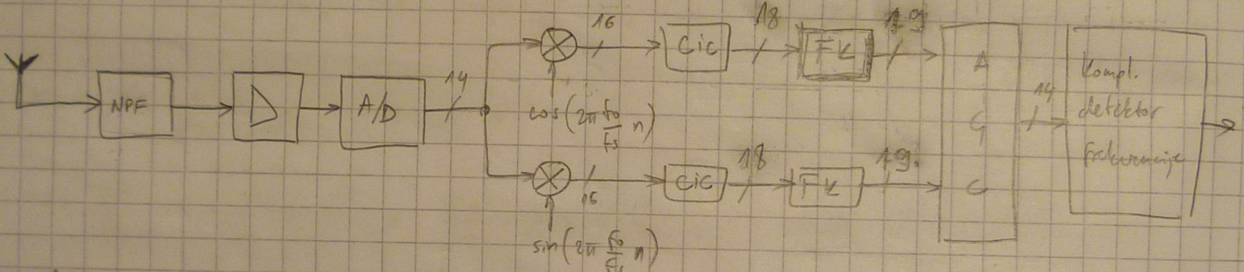
na ulazu mijenjate u izlaznu 2 bita više signal od onog iz pretvarača

$f_{s_2} = 200 kHz$

$B_{out} = \lceil N \log_2 RM + B_{in} \rceil$

$R = \frac{f_{s_1}}{f_{s_2}} = \frac{51.2 M}{200 k} = 256$





~~na izlazu CIC-a: $B_{out} = \lceil \log_2 256 + 16 \rceil = 24$~~

- broj bitova (dodanih) se određuje pomoću PG-a

c) ~~SNR (na izlazu filt. lanca) = ? → recimo da je spekt. šuma snage $\frac{N}{2}$~~

PG (FK) = ?

~~$PG = \frac{SNR(izlaz)}{SNR(ulaz)}$~~

~~na ulazu FK: $P_n = \frac{N}{2} \cdot 2 \cdot \frac{f_s}{2} = \frac{N \cdot f_s}{2}$~~

~~na izlazu FK: $P_n = \frac{N}{2} \cdot 2 \cdot \frac{\Delta f}{2} = \frac{N \cdot \Delta f}{2}$~~

~~$PG = 10\log_{10} \frac{\frac{N \cdot f_s}{2}}{\frac{N \cdot \Delta f}{2}} = 10\log_{10} \frac{f_s}{\Delta f} = 10\log_{10} \frac{51.2M}{100k} = 27.09 dB → N_{out} = \frac{27.09 dB}{6 dB}$~~

~~$N_{dod} = 4.51 = 5$~~

→ USTVARI VALJA, ALI FK RADI NA f_{s_2}

$PG_{FK} = 10\log \frac{f_{s_2}}{\Delta f} = 10\log \frac{200k}{100k} = 3.01 dB$

→ 19 bit

c) SNR na izlazu filtarskog lanca? → $SNR = 20\log \frac{P_{signal}}{P_{šum}}$

$SNR = SNR_{A/D} + PG_{mix} + PG_{cic} + PG_{FK}$

$SNR_{AD} = \frac{P_s}{P_N}$ → imamo samo kvant. šum, $\sigma_Q^2 = \frac{U_{LSB}^2}{12} =$

$SNR_{AD} = 6.02N + 1.76\,dB = 14 \cdot 6.02 + 1.76$

$SNR_{AD} = 86.04\,dB$

b) Sinte signala na izlazu CIC decimatora i filtra kanala → šumovi signala se u CIC decimatoru i FK mijenjaju zbog PG. $PG = 10\log \frac{P_{šum,ulaz}}{P_{šum,izlaz}}$

→ digitalna domena i sve je od $-\pi$ do π

→ pretpostavimo da je spektr. gust. svega šuma $\frac{N}{2}$

$PG_{cic} = 10\log_{10} \frac{\frac{N}{2} \cdot 2\pi}{\frac{N}{2} \cdot \frac{2\pi}{R}} = 10\log_{10} R = 24.082\,dB$

$N_{bit\,cic} = B_{in} + \frac{PG_{cic}}{6dB} = 4\,bita$

→ na izlazu CIC-a imamo 18 bitova (jer fiksiramo broj bitova s obzirom na izlaz ADP-a) STEČNO!

→ na izlazu FK-a imamo 19 bitova

c) SNR → na izlazu filt. lanca?

→ 1 dB, jer smo morali uzeti dodatna 2 bita da SNR ostane isti

$SNR = SNR_{AD} + SNR_{mix} + PG_{cic} + PG_{FK}$

$SNR_{AD} = 6.02N + 1.76\,dB = 86.04\,dB$ $PG_{cic} = 24.08\,dB$ $PG_{FK} = 27.09\,dB$

$\sigma_Q^2 = \frac{U_{LSB}^2}{12} = \frac{\left(\frac{2U_m}{2^N}\right)^2}{12} = \frac{\frac{4U_m^2}{2^{2N}}}{\frac{12}{1}} = \frac{4U_m^2}{3 \cdot 2^{2N}}$ $P_s = \left(\frac{U_m}{\sqrt{2}}\right)^2 = \frac{U_m^2}{2}$

$SNR_{AD} = \frac{\frac{U_m^2}{2}}{\frac{U_m^2}{3 \cdot 2^{2N}}} = \frac{3}{2} 2^{2N}$ → $10\log_{10} \frac{3}{2} 2^{2N} = SNR_{AD} = 86.04\,dB$

$SNR = 86.04\,dB - 3.1\,dB + 24.082 + 3\,dB = 110.02\,dB$

d) - imali bismo 1 bit manje na izlazu FK = -6dB

Pa bi ukupni SNR bio 6 dB manji, što je ekvivalent 1 bita

⇒ 13 bitova bismo imali

6.10 prijemnik s podvzorkovanjem signala, direktno pretvorbo frekvence i kompleksno obdelavo signala

$f_1 = 88\,MHz$ $f_2 = 92\,MHz$

$\Delta f = 150\,kHz$

$N = 14\,bit$

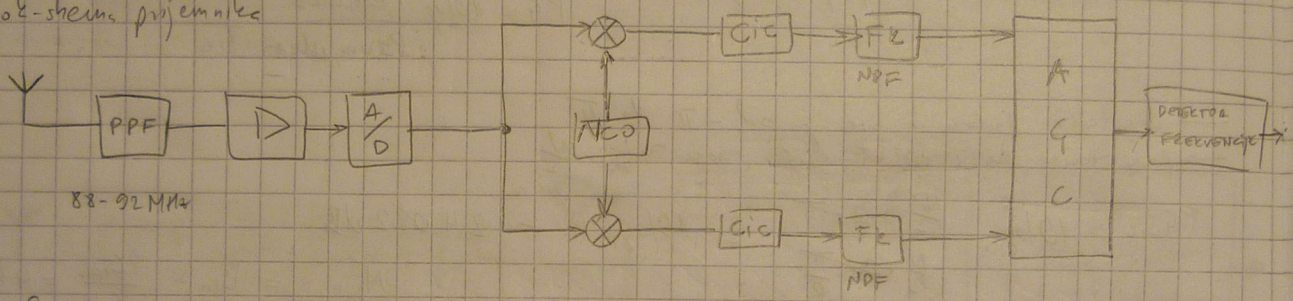
$SNR_{AD} = 74\,dB$

$f_s = 50\,MHz$

$f_{sL} = 400\,kHz$

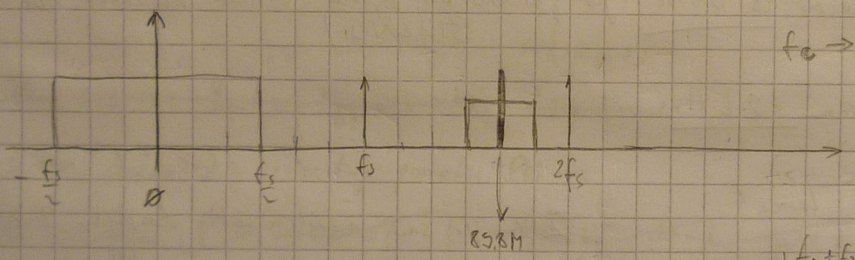
na izhodu AGC = 14 bits

a) blok-shema prijemnika



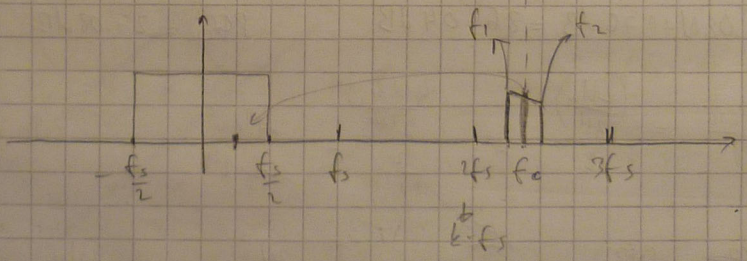
c)

b) $f_{NCO} = ?$ → da želimo prenesti kanal na $f_c = 89,8\,MHz$



$f_c \rightarrow \frac{f_s}{4} = \frac{50}{4} =$

podvzorkovanje:



d) r

f_c more biti na sredini 1. slike $\Rightarrow$ $f_c \rightarrow \frac{f_s}{4}$

$f_c - kf_s = \frac{f_s}{4} \rightarrow 4f_c = 4kf_s + f_s \rightarrow 4k+1 = \frac{4f_c}{f_s}$

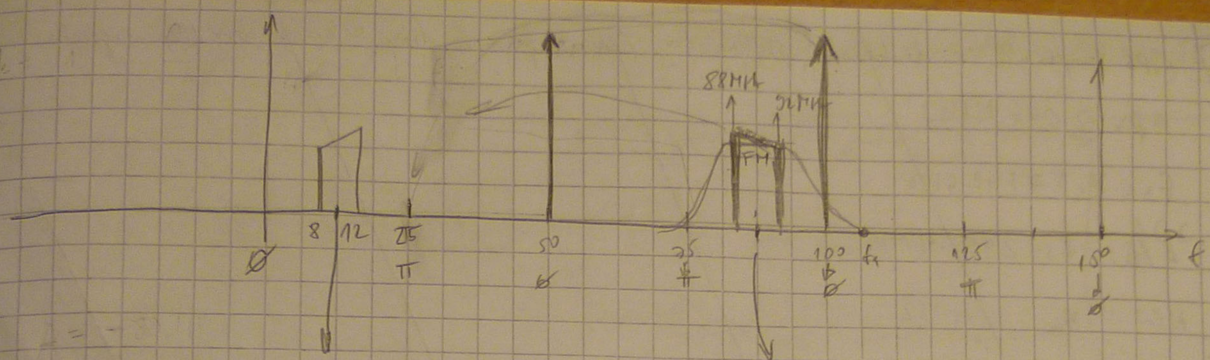
$4k = \frac{4f_c}{f_s} - 1$

$k = \left\lceil \frac{f_c}{f_s} - \frac{1}{4} \right\rceil$ → za $f_{s\,max}$ dobimo k_{min}

filtar: $B_{pass} = f_2 - f_1$ → širina prehodnega pasu:

centralna frekv. je f_c

prijetno področje $B_1 = f_1 - kf_s$



$f_0' = 100\,MHz - 89.8$
$= \underline{10.2\,MHz}$ → direktna pretvorba je, pa oscilator mora vratiti u 0 signal ⇒ $f_{osc} = 10.2\,MHz$

$\omega_{osc} = \frac{f_{osc}}{f_s} \cdot 2\pi = \underline{0.408\pi}$

$f_{alias_1} = 100 + 8 = 108\,MHz$

$f_{alias_1} = 108\,MHz \Rightarrow \omega_a =$

$f_{alias_2} = 112\,MHz$

c) $|H_{NP}(\omega)|^N = 20\log_{10}\left(\frac{1}{\sqrt{1+\omega_{NORM}^{2N}}}\right) = \left| \begin{array}{l} NP \to PP \\ \omega_{NORM} = \frac{\omega^2-\omega_0^2}{B\omega} \end{array} \right| = -80$

$f_{c} = \sqrt{f_1 \cdot f_2} = \sqrt{88 \cdot 92}$
$= \underline{90\,MHz}$

$B = 4\,MHz$

$|H_{PP}(\omega)|^N = 20\log_{10}\left(\frac{1}{\sqrt{1+\left(\frac{\omega_c^2-\omega_0^2}{B\omega}\right)^{2N}}}\right) = -80 = -20\log_{10}\sqrt{1+\left(\frac{\omega_c^2-\omega_0^2}{B\omega}\right)^{2N}}$ (4)

$10^8 = 1 + \left(\frac{\omega_c^2-\omega_0^2}{B\omega}\right)^{2N} \approx \left(\frac{\omega_c^2-\omega_0^2}{B\omega}\right)^{2N} \Big/ \log$

$8 = 2N \cdot \log_{10}\frac{\omega_c^2-\omega_0^2}{B\omega} \to N = \frac{4}{\log_{10}\frac{356^4}{432}} = 4.36 \to \boxed{N=5}$

d) realizacija CIC-a t.d. guši aliase komponente bar 80 dB

$\omega_a = \frac{2\pi}{R} - \omega_c$ $\qquad \omega_c = 2\pi\frac{f_c}{f_s} \to \omega_c = 2\pi \cdot \frac{75\,kHz}{50\,MHz} = 3 \cdot 10^{-3}\pi$

$\omega_a = \frac{2\pi}{125} - 3 \cdot 10^{-3}\pi = \underline{0.013\pi}$ $\qquad R = \frac{f_{s_1}}{f_{s_2}} = \frac{50\,MHz}{400\,kHz} = \underline{125}$

$\to \boxed{N_{CIC} = 6}$

6.11 GPS prijemnik s direktnom pretvorbom frekvencije i kompleksnom obradom signala

$\Delta f = 2.046$ MHz

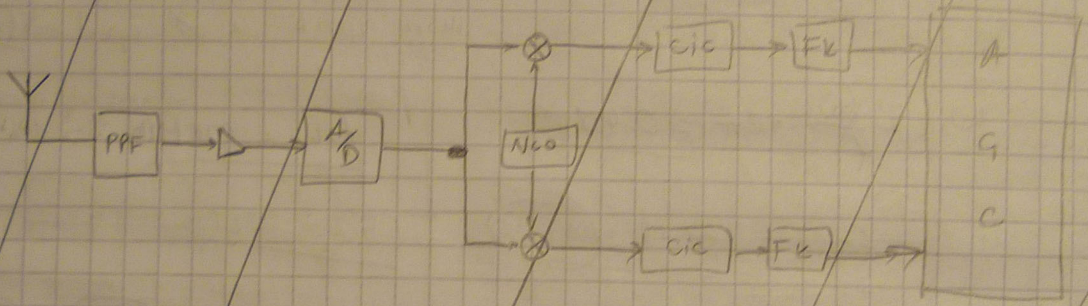
$f_c = 1.57542$ GHz

A/D: $f_s = 245.76$ MHz

NCO: $N_{faznih\ bita} = 32$

CIC: $R = 30$

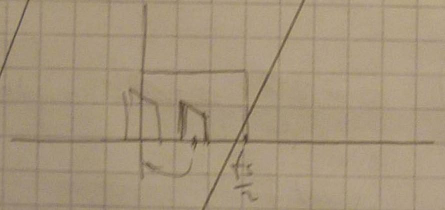
a) blokovska shema prijemnika



b) $f_{NCO} = ?$

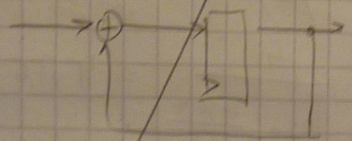
$\Delta = ?$

~~A/D ... f_c ... MHz~~



⇒ NCO mora prebaciti f_0 u nulu

~~f_{NCO} ... f_0~~



$$f_0 = f_s \cdot \frac{\Delta}{2^N}$$

$$\Rightarrow \Delta = \frac{f_0}{f_s} \cdot 2^N$$

$$\Delta = 1.073742 \text{ Grad}$$

c) Širina signala t.d. se osigura najveći SNR na izlazu

$$SNR_{izl} = SNR_{AD} + SNR_{mix} + PG_{CIC} + PG_{FK}$$

SNR_{AD} ↓ 74 dB

$$PG_{CIC} = 10\log_{10}\frac{f_{s1}}{f_{s2}} = \text{~~22.22~~ dB } 6 \cdot 3.45 \text{ dB} \rightarrow 4 \text{ bita}$$

$$PG_{FK} = 10\log_{10}\frac{f_{s2}}{B} = \text{~~28.83~~ dB} \rightarrow 5 \text{ bita}$$

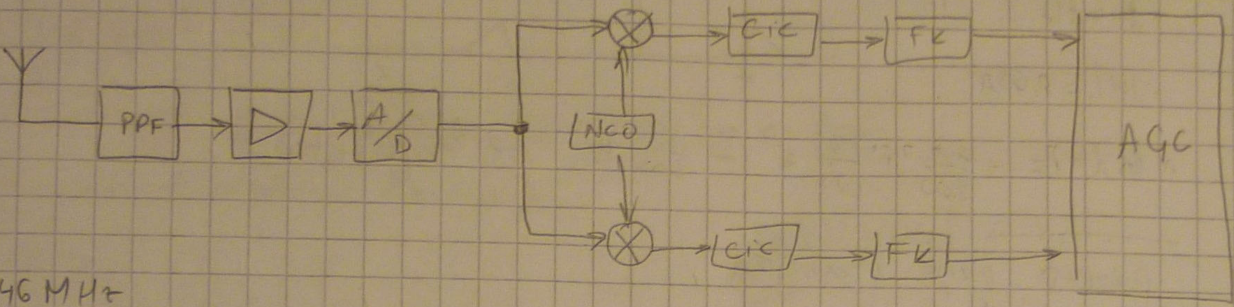
7.269 ... bita

→ izgubiti ... na mixeru ⇒ dodajem 2 bita na izl.

14 → 16 → ? → 15

f) SNR_{out} = ? $SNR_{out} = 74\,dB - 3.1\,dB + 7.269\,dB + 20.76\,dB = 99.029\,dB$?

6.11



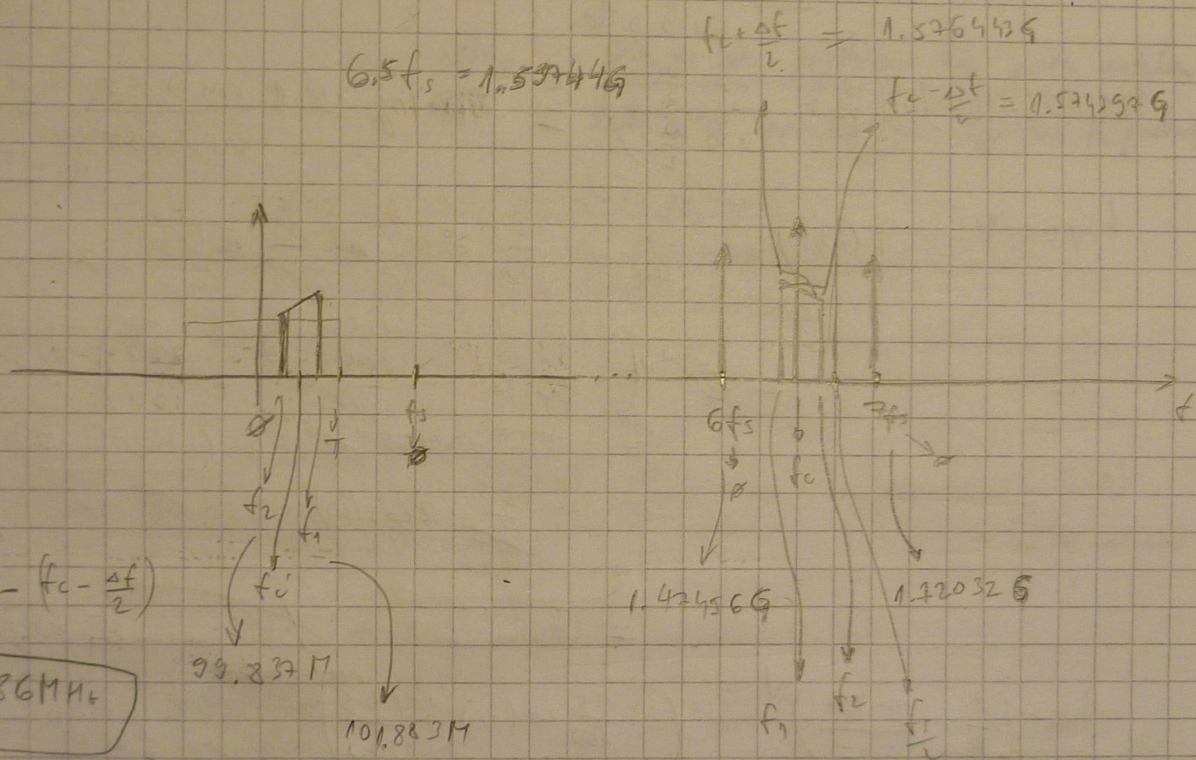
$\Delta f = 2.046\,MHz$

$f_c = 1.57542\,GHz$

$f_s = 245.76\,MHz$

$N_{osc} = 32\,bit$

$R = 30$



$f_1 = 6f_s - (f_c - \frac{\Delta f}{2})$

$f_{0} = 100.86\,MHz$

$= 0.8208\pi$

→ Δ ništa nije u $2\omega_0$

$\Delta = 2^N \cdot \frac{f_0}{f_s} = 2^{32} \cdot \frac{100.86}{245.76}$

$\Delta = 1762656256$

c) N_{cic} = ? t.d. $|H_{cic}(\omega_c)| \leq -60\,dB$

$$N = \frac{-60}{20\log\left(\frac{1}{30}\cdot\frac{\sin(15\cdot 0.1833)}{\sin(0.0916\,33)}\right)} = 3.5 \rightarrow N = 4$$

d) PROPAD → gledam na 1.023 MHz

$20\log|H_{cic}(1.023\,MHz)| = -0.83\,dB$

$f_{\text{najbliže}} = 201.72\,MHz \rightarrow -93\,dB$

6.12 CIC 4 REDA

$R = 10$

$|\omega| \leq 0{,}03\pi$

$H(z) = -\frac{33}{200} + \frac{133}{100} z^{-1} - \frac{33}{200} z^{-2}$ → kompenzator

PROPAD PRIJE I KAO NIJE

bez kompenzacije: $H_{cic} = \left(\frac{1}{R} \cdot \frac{\sin \frac{\omega R}{2}}{\sin \frac{\omega}{2}} \right)^N$

$\omega = 0.03\pi$

$PROPAD = N \cdot 20 \log \left(\frac{1}{R} \cdot \frac{\sin \frac{\omega R}{2}}{\sin \frac{\omega}{2}} \right) = 80 \cdot \log \frac{0.1 \sin 0.15\pi}{\sin 0.015\pi} = -1.28\,dB$

kompenzator: $H(e^{j\omega}) = -\frac{33}{200} + \frac{133}{100} e^{-j\omega} - \frac{33}{200} e^{-j2\omega} =$

$= e^{-j\omega} \left(-\frac{33}{200} e^{j\omega} - \frac{33}{200} e^{-j\omega} + \frac{133}{100} \right)$

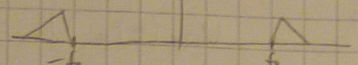
$-\frac{33}{200} \cdot 2\cos(\omega)$

$\frac{100}{100}$

$H_{uk} = \left(\frac{1}{R} \cdot \frac{\sin \frac{\omega R}{2}}{\sin \frac{\omega}{2}} \right)^N \cdot \underbrace{\left(-\frac{33}{100} \cos(\omega) + \frac{133}{100} \right)}_{\text{AMPLITUDA}}$

$PROPAD_2 = PROPAD_1 + 20 \log \left(-\frac{33}{100} \cos(\omega) + \frac{133}{100} \right) = -1.28\,dB +$

7. ŠUM U PRIJENOSNIM SUSTAVIMA

7.1 imamo USB-AM → 

prenosi se sustavom sa spekt. gustoćom snage šuma kao na slici

prijemnik → koristi koherentnu demodulaciju

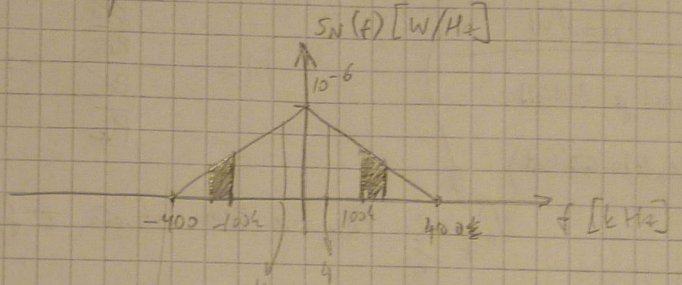
$f_M = 4\,kHz$

a) $f_0 = 100\,kHz$

b) $f_0 = 200\,kHz$

c) $f_0 = 396\,kHz$

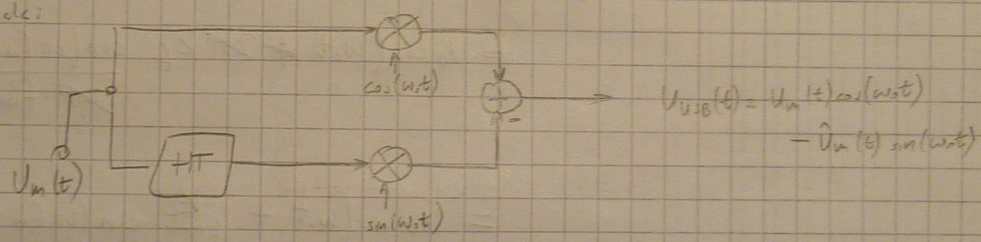
$M_1, M_2, M_3 = ?$



$$M = \frac{SNR_0}{SNR_C} = \frac{\text{SNR na izl. prijemnika koji prima modulirani s.}}{\text{SNR na izl. pr. koji prima sig. u osn. f. području}}$$

$$= \frac{\text{Srednja snaga signala na izlazu prijemnika}}{\text{Srednja snaga šuma na izlazu prijemnika}} \Big/ \frac{\text{srednja snaga moduliranog signala}}{\text{snaga šuma u kanalu prema}}$$

definiramo USB-AM signale:



$$SNR_0 = \frac{P_{SC}}{P_{NC}} \qquad SNR_0 = \frac{P_{S0}}{P_{N0}} = \frac{P_S}{P_{N0}} \qquad P_{S0} = P_{SC}$$

$$S_N(f) = 10^{-6} - \frac{10^{-6}}{400k} \cdot f$$

$$P_{N0} = 2 \cdot \int_{100k}^{104k} S_N(f)\,df = 2 \cdot \int_{100k}^{104k} \left(-\frac{10^{-6}}{400k} f + 10^{-6} \right) df =$$

$$P_{NC} = 2 \cdot \int_0^{4k} S_N(f)\,df =$$

$$= 2 \left[-\frac{10^{-6}}{400k} \cdot \frac{f^2}{2} \Big|_{100k}^{104k} + 10^{-6} \cdot f \Big|_{104k}^{104k} \right] =$$

$$= 2 \cdot \left[-\frac{10^{-6}}{400k} \cdot \frac{f^2}{2} \Big|_0^{4k} + 10^{-6} \cdot f \Big|_0^{4k} \right]$$

$$= 2 \left[-\frac{51}{50000} + \frac{1}{250} \right] = \underline{5.96 \cdot 10^{-3}\,W} \rightarrow \text{za } f_0 = 100k$$

$$= 2 \left[-\frac{1}{50000} + 4 \cdot 10^{-3} \right] = 7.96 \cdot 10^{-3}\,W$$

$$M = \frac{\frac{P_{S0}}{P_{N0}}}{\frac{P_S}{P_{NC}}} = \frac{P_{NC}}{P_{N0}} = \frac{7.96}{5.96}$$

$$\boxed{M = 1.3355}$$

7.2 $k_f = ?$

t.d. $M_{FM} > M_{AM-USB}$

$f_M = 3\,kHz$

$u_m(t) = U_m \sin(\omega_m t)$

$P_M = 1\,W$

kanal je AWGN

$\Rightarrow u_n(t) = \cos(\omega_0 t)$

frekvencijski modulirani signal:

$$u_{FM}(t) = U_0 \cos\left(\omega_0 t + 2\pi k_f \int_0^t u_m(t)\,dt\right)$$

1) računamo omjer za USB-AM signal

$$M = \frac{\frac{P_{S0}}{P_{N0}}}{\frac{P_{SC}}{P_{NC}}} = \frac{P_{NC}}{P_{N0}} \qquad P_{S0} = P_{SC} = P_S$$

$U_{uk} = \frac{U_0}{\sqrt{2}}$ P_{NC} → šum obuhvaća $\pm f_M$ → $P_{NC} = \frac{N_0}{2} \cdot 2 \cdot f_M$

$= N_0 \cdot f_M$

P_{N0} → šum obuhvaća 2×USB → $P_{N0} = \frac{N_0}{2} \cdot 2 \cdot f_M$

$M_{USB} = 1$

2) mjerimo FM signal:

$$u_{FM}(t) = U_0 \cos\left(\omega_0 t + 2\pi \cdot k_f \int_0^t \cos(2\pi f_m t)\,dt\right) =$$

$$= U_0 \cos\left(\omega_0 t + 2\pi \cdot k_f \frac{\sin(2\pi f_m \cdot t)}{2\pi \cdot f_m}\Big|_0^t\right) =$$

$$= U_0 \cos\left(\omega_0 t + \frac{k_f}{f_m} \sin(2\pi f_m \cdot t)\right)$$

$B_{FM} = 2 f_M (m+1)$

$m = \frac{k_f}{f_M}$

$P_{NC} = N_0 \cdot f_M$

$P_{N0} = \frac{N_0}{2} 2 f_M (m+1) = \frac{N_0}{2} 2 f_M \left(\frac{k_f}{f_M} + 1\right) = (2k_f + 2f_M) \cdot \frac{N_0}{2}$

$$M_{FM} = \frac{P_{NC}}{P_{N0}} = \frac{N_0 \cdot f_M}{(2k_f + 2f_M)\frac{N_0}{2}} = \frac{f_M}{2k_f + 2f_M} > 1 \qquad M_{FM} = \frac{3}{2}(m_{FM})^2 > 1$$

$f_M > 2k_f + 2f_M \rightarrow -f_M$

$$\frac{k_f^2}{f_M^2} \cdot \frac{3}{2} > 1$$

$$k_f^2 > \frac{2}{3} \cdot f_M^2$$

$$k_f^2 > \frac{2}{3} \cdot 3 \cdot 10^6$$

$$k_f \geq 1.73\,kHz/V$$

7.3 dinamika $\pm 4V$

$N = 8$ bite

$$\sigma^2 = \frac{U_{LSB}^2}{12} = \frac{(8V/2^8)^2}{12} = 8.138 \cdot 10^{-5} W$$

$$SNR_D = 10 \log \frac{10W}{8.138 \cdot 10^{-5} W}$$

$$SNR = 50.89 dB$$