[redacted]

2. DZ 2015

(1)

$f_1 = 810 MHz$

$f_2 = 820 MHz$

$f_{s,max} = 75 MHz$

$f_g = 1 GHz$

$f_s = ?$

$f_c = \frac{f_1 + f_2}{2} = 815 MHz$

pozicija alias-banda

$k = \frac{f_c}{f_s} - \frac{1}{4} \Rightarrow f_s = \frac{4 f_c}{4k+1} = 72,44\ MHz$

$k_{min} = \left\lceil \frac{f_c}{f_{s,max}} - \frac{1}{4} \right\rceil = \lceil 10,61 \rceil = 11$

širina područja propuštanja

$B_{pass} = f_2 - f_1 = 10 MHz$

širina prijelaznog područja

$B_{tran} = f_1 - k f_s = 13,6 MHz$

(2)

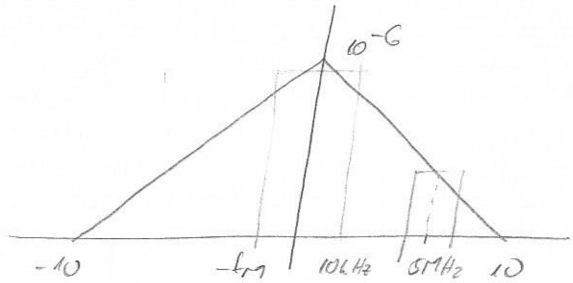
$f_M = 10 kHz$

$f_0 = 5 MHz$

$m = 1,25$

$M = ?$

$\frac{\Delta f}{f_M} = m$




$M_{FM} = \frac{3}{2} (m_{FM})^2 \Rightarrow$ za AWGN kanal

$M = \frac{SNR_O}{SNR_C} = M_{AWGN} \cdot \frac{S_N(5kHz)}{S_N(5MHz)} = 4,685$

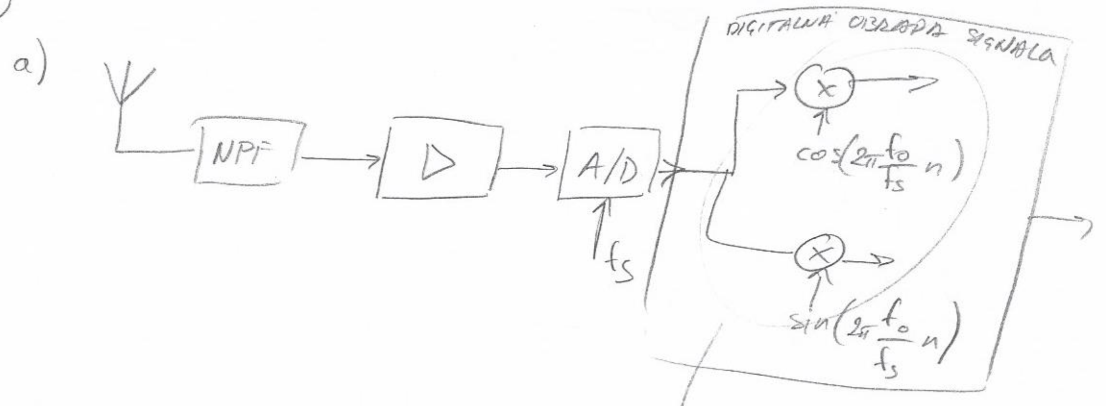
$\to f_m/2$

$\hookrightarrow f_0$

$\boxed{S_N = -\frac{10^{-6}}{10 \cdot 10^6} f + 10^{-6}}$

(3.)

a)




⇒ dobivamo kompleksne ovojnice

b) $f_s = 20MHz$ $\quad A_a = 100dB$

$f_{s,izl} = 20kHz$

$R = 10^3 = 1000$

$\Delta f = 6kHz$

$$20\log_{10}|H(e^{j\omega})|_{\omega=\omega_a} \leq -A_a$$

$$20\log_{10}\left|\frac{1}{R}\frac{\sin\left(\frac{\omega_a R}{2}\right)}{\sin\left(\frac{\omega_a}{2}\right)}\right|^N \leq -A_a$$

$$\omega_a = \frac{2\pi}{R} - \frac{\cancel{2}\pi f_c}{\cancel{2}f_s} = 5{,}34\cdot 10^{-3}\ rad/s$$

$$N \geq -\frac{A_a}{20\log_{10}\left|\frac{1}{R}\frac{\sin\left(\frac{\omega_a R}{2}\right)}{\sin\left(\frac{\omega_a}{2}\right)}\right|}$$

$$N \geq \frac{-100}{20\log_{10}\left|\frac{1}{1000}\cdot\frac{\sin\left(\frac{5{,}34\cdot10^{-3}\cdot 1000}{2}\right)}{\sin\left(\frac{5{,}34\cdot 10^{-3}}{2}\right)}\right|} = 6{,}5 \quad \Rightarrow N = 7$$

c) $$\omega_g = \frac{\frac{B}{\cancel{2}}}{f_{s_2}}\cdot\cancel{2}\pi = \frac{B\pi}{f_{s_2}} = 0{,}94$$

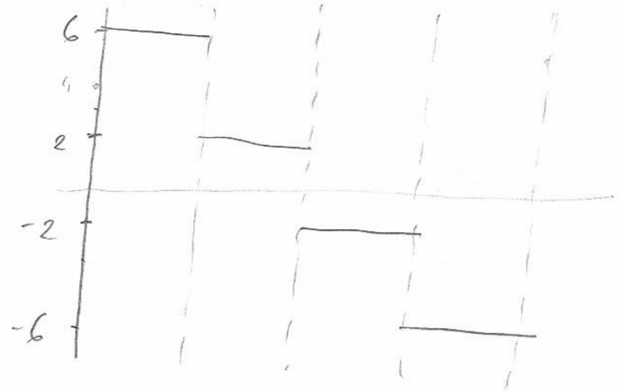
d) $$PG_{CIC} = 10\log_{10}(R) = 30dB$$

$$PG_F = 10\log_{10}\left(\frac{f_{s_2}}{B}\right) = 10\log_{10}\left(\frac{\pi}{\omega_g}\right) = 5{,}23dB$$

$$PG_{UK} = PG_{CIC} + PG_F = 35{,}23dB$$

(4.)

$M=4 \qquad \frac{N_0}{2}=7\cdot10^{-4} \qquad \sigma^2=\frac{N_0}{2}\cdot\frac{1}{T_s}=0{,}07\,V^2$



| | |
|---|---|
| 0 0 | 6 |
| 0 1 | 2 |
| 1 1 | -2 |
| 1 0 | -6 |

$$P_{e1}=P_{e4}=\int_{-4}^{\infty} f_y(y|s_1)\,dy=\frac{1}{\sqrt{2\pi}\,\sigma}\int_{-4}^{\infty}\exp\left(-\frac{(y+6)^2}{2\sigma^2}\right)dy$$

$y+6=u$
$dy=du$
$y=-4 \Rightarrow u=2$
$y=\infty \Rightarrow u=\infty$

$$\frac{1}{\sqrt{2\pi}\,\sigma}\int_{2}^{\infty}\exp\left(-\frac{u^2}{2\sigma^2}\right)du$$

$\frac{u}{\sqrt{2}\,\sigma}=z$

$u=2 \Rightarrow z=\frac{2}{\sqrt{2}\,\sigma}$

$dz=\frac{1}{\sqrt{2}\,\sigma}du$

$$\frac{\cancel{\sqrt{2}\,\sigma}}{\cancel{\sqrt{2\pi}\,\sigma}}\int_{\frac{2}{\sqrt{2}\,\sigma}}^{\infty}\exp(-z^2)\,dz=\frac{1}{2}\operatorname{erfc}\Big(\underbrace{\frac{\sqrt{2}}{\sigma}}_{\approx 5{,}34}\Big)=\frac{1}{2}\cdot10^{-12}$$

$P_{e2}=P_{e3}=2P_{e1}=10^{-12} \qquad p_1=p_2=p_3=p_4=\frac{1}{4}$

$$P=p_1P_{e1}+p_2P_{e2}+p_3P_{e3}+p_4P_{e4}=\frac{1}{4}\cdot3\cdot10^{-12}=\frac{3}{4}10^{-12}$$

5. Podrhtavanje takta uzorkovanja uzrokuje pogrešku pri očitavanju amplitude. Pogreška je proporcionalna derivaciji signala

$$u(t) = U_m \sin(2\pi f t)$$


POGREŠKA

$$\Delta u_j = \frac{du(t)}{dt}\Delta t_j = \frac{d(U_m \sin(2\pi f t))\cdot \Delta t_j}{dt} = U_m \cdot 2\pi f \cdot \cos(2\pi f t)\cdot \Delta t_j$$

najgori slučaj $\Delta u_{j_{max}} = U_m 2\pi f \Delta t_j$

$t_{jRMS}$ - poznata efektivna vrijednost jittera

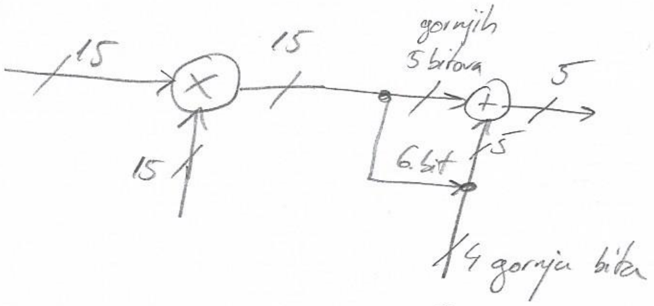
$$U_{jRMSmax} = U_m 2\pi f t_{jRMS}$$

$$SNR = 20\log_{10}\frac{\frac{U_m}{\sqrt{2}}}{U_m 2\pi f t_{jRMS}} = -20\log_{10}(2\sqrt{2}\pi f t_{jRMS})$$

VIŠE sklopova - SNR se zbrajaju

6. Odsijecanje dvojnog komplementa predstavlja zaokruživanje prema dolje. Srednja vrijednost pogreške koja time nastaje iznosi 0,5 LSB-a te se pojavljuje neželjena DC komponenta (DC offset).
Zaokruživanje također unosi DC komponentu jer 0,5 uvijek zaokružuje prema gore, ali je ona mala i u praksi uglavnom zanemariva

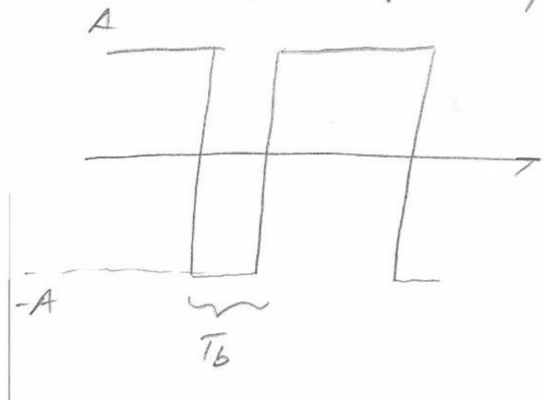
SKLOP




DSP procesori imaju ugrađeno sklopovlje za zaokruživanje
- množila se mogu konfigurirati da odsijecaju ili zaokružuju rezultat
- kod zaokruživanja se dodatno umanjuje DC komponenta tako što se nasumično zaokružuje gore/dolje, upravljano generatorom slučajnih brojeva

7.

NRZ signal




$$x(t) = \begin{cases} A + w(t) \Rightarrow \text{„1"} \\ -A + w(t) \Rightarrow \text{„0"} \end{cases}$$

poslana je 0

$x(t) = -A + w(t)$, izlaz prilagođenog filtra $y(T_b) = K\int_0^{T_b} x(t)\,dt = -KAT_b + K\int_0^{T_b} w(t)\,dt$

$$K = \frac{1}{T_b} \Rightarrow y(T_b) = -A + \frac{1}{T_b}\int_0 w(t)\,dt$$

$$\sigma^2 = E\left[(Y-A)^2\right], \quad \sigma_y^2 = E\left[\frac{1}{T_b}\int_0^{T_b} w(t)\,dt \cdot \frac{1}{T_b}\int_0^{T_b} w(u)\,du\right] = \frac{1}{T_b^2}\int_0^{T_b}\int_0^{T_b} E[w(t)w(u)]\,dt\,du$$

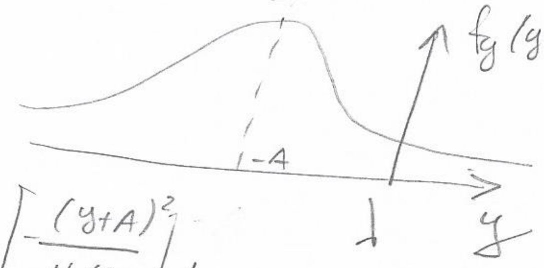
$$E[w(t)w(u)] = R_W(t,u) = \frac{N_0}{2}\delta(t-u) \quad \text{-autokorelacija}$$

$$\sigma_y^2 = \frac{1}{T_b^2}\int_0^{T_b}\int_0^{T_b}\frac{N_0}{2}\delta(t-u)\,dt\,du = \frac{N_0}{2T_b}$$

FUNKCIJA GUSTOĆE UZ UVJET DA SE ŠALJE STALNO „0"

$$f_y(y|0) = \frac{1}{\sqrt{2\pi}\,\sigma_y}\exp\left[-\frac{(y+A)^2}{2\sigma_y^2}\right] = \frac{1}{\sqrt{2\pi}\sqrt{N_0/2T_b}}\exp\left[-\frac{(y+A)^2}{2\frac{N_0}{2T_b}}\right]$$

$$f_y(y|0) = \sqrt{\frac{T_b}{\pi N_0}}\exp\left[-\frac{(y+A)^2}{N_0/T_b}\right]$$




$$P_{e0} = \int_\lambda^\infty f_y(y|0)\,dy = \frac{1}{\sqrt{\frac{\pi N_0}{T_b}}}\int_\lambda^\infty \exp\left[-\frac{(y+A)^2}{N_0/T_b}\right]dy \quad / \ \lambda = 0$$

$y=0 \Rightarrow z = \frac{A}{\sqrt{N_0/T_b}} = \sqrt{\frac{A^2T_b}{N_0}} = \sqrt{\frac{E_b}{N_0}}$ - energija koja odgovara 1 bitu

$\frac{y+A}{\sqrt{N_0/T_b}} = z$

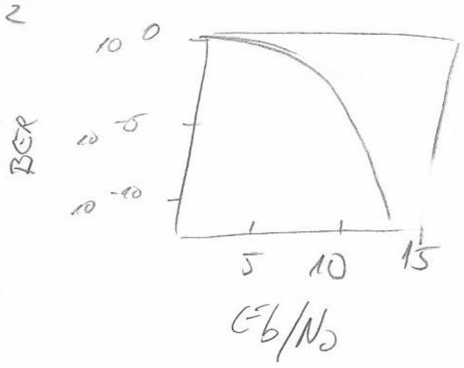
$dy = \sqrt{\frac{N_0}{T_b}}\,dz$

$y=\infty \Rightarrow z=\infty$

$$P_{e0} = \frac{1}{\sqrt{\pi \cancel{N_0/T_b}}}\int_{\sqrt{E_b/N_0}}^\infty \exp(-z^2)\cancel{\sqrt{N_0/T_b}}\,dz \Rightarrow P_{e0} = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)$$

$P_{e1} = P_{e0}$ $\qquad P_e = p_1P_{e1} + p_0P_{e0} = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)$

$p_1 = p_2 = \frac{1}{2}$



(8.) Zaštitni interval razmak od $N_g$ uzoraka koji se ostavlja između uzoraka

Za ispravnu demodulaciju potrebno je prepoznati početak simbola. Početak je lakše prepoznati ako mu svaki puta prethode nule

Ciklički prefiks proširuje dijelom signala s njegovog kraja. Ukoliko dođe do pogreške u određivanju početka simbola, zbog cikličkog prefiksa dogodit će se pomak na periodičkom signalu. Amplitudna karakteristika ostat će nepromijenjena, a u fazi će se pojaviti pomak koji možemo iskoristiti za određivanje pravog položaja simbola

## 13.1

$f = 360\ kHz$

$P = 50\ W$

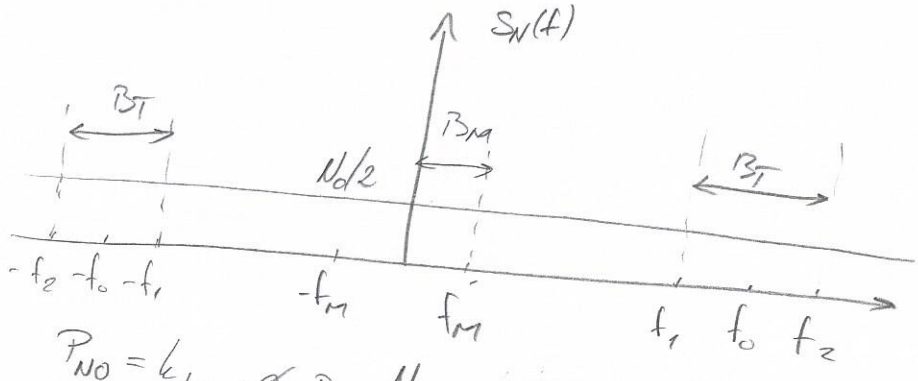
$B = 3\ kHz$

$SNR_o = ?$

$M_N = ?$

AWGN kanal

$P_{LSB} = P_{USB} = 5\ W$




$$M = \frac{SNR_o}{SNR_c} = \frac{\frac{P_{SO}}{P_{NO}}}{\frac{P_S}{P_{NC}}}$$

$$P_{NO} = k_{dem} \cdot \cancel{2} \cdot B_T \cdot \frac{N_0}{\cancel{2}} = k_{dem} B_T N_0$$

$$P_{NC} = 2 B_M \cdot \frac{N_0}{2}$$

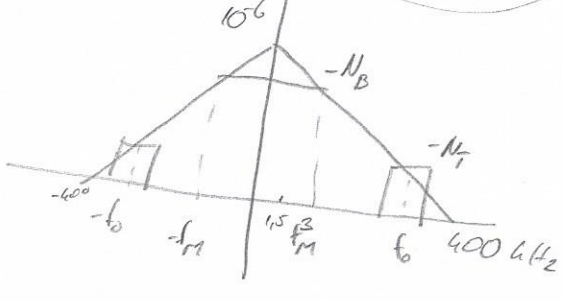
Opće:

$$\left.\begin{aligned} P_{NO} &= k_{dem} \cdot 2 \int_{f_1}^{f_2} S_N(f)\,df \\ P_{NC} &= 2 \int_0^{f_M} S_N(f)\,df \end{aligned}\right\} \quad M_N = \frac{\frac{P_{SO}}{k_{dem} \cancel{2} \int_{f_1}^{f_2} S_N(f)\,df}}{\frac{P_S}{\cancel{2} \int_0^{f_M} S_N(f)\,df}} \cdot \frac{\frac{1}{N_0 B_T B_M}}{\frac{1}{N_0 B_T B_M}}$$

$$M_N = \frac{\frac{P_{SO}}{k_{dem} N_0 B_T} \cdot \frac{1}{\int_{f_1}^{f_2} S_N(f)\,df} \cdot \frac{1}{B_M}}{\frac{P_S}{N_0 B_M} \cdot \frac{1}{\int_0^{f_M} S_N(f)\,df} \cdot \frac{1}{B_T}} = M_{AWGN} \cdot \frac{\overbrace{\frac{1}{B_M} \int_0^{f_M} S_N(f)\,df}^{N_M}}{\underbrace{\frac{1}{B_T} \int_{f_1}^{f_2} S_N(f)\,df}_{N_T}}$$

$M_{AWGN}$

$$M_N = M_{AWGN} \cdot \frac{N_M}{N_T}$$




$$S_N(f) = -\frac{10^{-6}}{400000}|f| + 10^{-6}$$

$$N_T = S_N(360\,kHz) = -\frac{10^{-6}}{400\cancel{000}} \cdot 360\cancel{000} + 10^{-6} = 10^{-7}\ W/Hz$$

$$N_M = S_N(1{,}5\,kHz) = -\frac{10^{-6}}{400\,000} \cdot 1500 + 10^{-6} = 9{,}9625 \cdot 10^{-7}\ W/Hz$$

$$P_0 = \frac{U_0^2}{2} = 50W \Rightarrow U_0^2 = 100W$$

$$P_{LSB} = P_{USB} = 5W \Rightarrow P_{DSB} = 10W$$

$$P_{DSB} = \frac{k_a^2 P_m}{2} \qquad k_a^2 P_m = 2P_{DSB} = 20W$$

$$M_{AWGN,DSB\_TC\_AM} = \frac{k_a^2 P_m}{U_0^2 + k_a^2 P_m} = \frac{20}{100+20} = \frac{1}{6}$$

$$M_N = M_{AWGN} \cdot \frac{N_M}{N_T} = \frac{1}{6} \cdot \frac{9{,}9625 \cdot \cancel{10^{-7}}}{\cancel{10^{-7}}} = 1{,}66$$

$$SNR_O = \frac{P_{DSB}}{f_M N_0} = \frac{k_a^2 P_m}{2 f_M N_0} \qquad \frac{N_0}{2} = N_T \Rightarrow N_0 = 2N_T$$

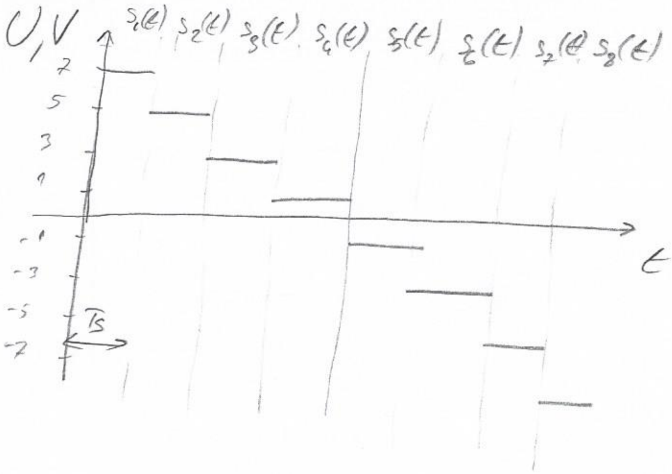
$$SNR_O = \frac{P_{DSB}}{2 f_M N_T} = \frac{20}{2 \cdot 3000 \cdot 10^{-7}} = 1{,}66 \cdot 10^4 \Rightarrow 42{,}22\,dB$$

(14.1)

$M=8$

$T_S = 10\ ms$

$\frac{N_0}{2} = 0{,}0007\ W^2/Hz$




$\phi_1(t) = \frac{s_1(t)}{\sqrt{E_1}}$

$E_1 = \int_0^{T_S} s_1^2(t)dt = \int_0^{T_S} 7^2 dt = 7^2 \cdot T_S = 0{,}49$

$\boxed{\phi_1(t) = \frac{7}{\sqrt{0{,}49}} = 10}$

$s_{21} = \int_0^{T_S} s_2(t)\phi_1(t) = \int_0^{T_S} 5 \cdot 10 dt = 50 \cdot 10 \cdot 10^{-3} = 0{,}5$

$\phi_2 = \frac{g_2}{\sqrt{\int_0^{T_S} g_2^2(t)dt}}$

$g_2(t) = s_2(t) - s_{21}\phi_1(t) = 5 - 0.5 \cdot 10 = 0$

$\Rightarrow$ postoji samo jedna funkcija baze!

vektori signala (imaju samo jednu koordinatu)

$s_1 = s_{11} = \int_0^{T_S} s_1(t)\phi_1(t)dt = 7 \cdot 10 \cdot 10^{-2} = 0{,}7 = \sqrt{E_{S1}}$

$s_2 = s_{21} = \int_0^{T_S} s_2(t)\phi_1(t)dt = 5 \cdot 10 \cdot 10^{-2} = 0{,}5 = \sqrt{E_{S2}}$

$s_3 = s_{31} = 3 \cdot 10^{-1} = 0{,}3$

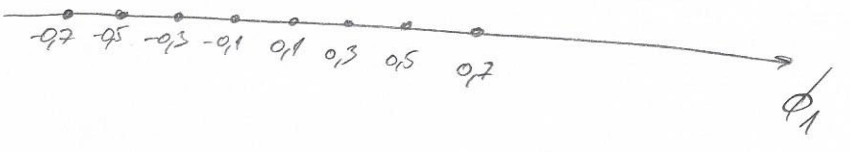
$s_4 = 0{,}1$

$s_5 = -0{,}1 = -\sqrt{E_{S5}}$

$s_6 = -0{,}3$

$s_7 = -0{,}5$

$s_8 = -0{,}7$



$$\sigma^2 = \frac{N_0}{2T_s} = \frac{0{,}0007}{0{,}01} = 0{,}07\,V^2$$

$$f_y(y/s_i) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left[-\frac{(y-A)^2}{2\sigma^2}\right]$$

na $-7$

$$P_{e1} = \int_{-6}^{\infty} f_y(y/s_1)\,dy = \frac{1}{\sqrt{2\pi}\,\sigma} \int_{-6}^{\infty} \exp\left[-\frac{(y+7)^2}{2\sigma^2}\right] dy = \left| \begin{array}{l} y+7 = z \quad dy = dz \\ y=-6 \Rightarrow z = 1 \\ y = \infty \Rightarrow z = \infty \end{array} \right|$$

prag komparacije

$$P_{e1} = \frac{1}{\sqrt{2\pi}\,\sigma} \int_{1}^{\infty} \exp\left[\frac{-z^2}{2\sigma^2}\right] dz = \left| \begin{array}{l} \frac{z}{\sqrt{2}\,\sigma} = u \\ du = \frac{1}{\sqrt{2}\,\sigma} dz \\ dz = \sqrt{2}\,\sigma\, du \\ z = 1 \Rightarrow u = \frac{1}{\sqrt{2}\,\sigma} \\ z = \infty \Rightarrow u = \infty \end{array} \right| = \frac{\cancel{\sqrt{2}\sigma}}{\cancel{\sqrt{2\pi}\,\sigma}} \int_{\frac{1}{\sqrt{2}\sigma}}^{\infty} \exp(-u^2)\,du$$

$$\frac{2}{\sqrt{\pi}} \int_{u}^{\infty} \exp(-z^2)\,dz = \mathrm{erfc}(u)$$

$$P_{e1} = \frac{1}{2}\,\mathrm{erfc}\left(\frac{1}{\sqrt{2}\,\sigma}\right)$$

$$p_1 = p_2 = \ldots = p_8 = \frac{1}{8}$$

$$P_{e2} = 2P_{e1} = P_{e3} = \ldots = P_{e7} = \mathrm{erfc}\left(\frac{1}{\sqrt{2}\,\sigma}\right)$$

$$P_{e8} = P_{e1}$$

$$P_e = p_1 P_{e1} + p_2 P_{e2} + \ldots + p_8 P_{e8}$$

$$\sigma = \sqrt{0{,}07}\ \mathrm{m}$$

$$P_e = \frac{7}{8}\,\mathrm{erfc}(2{,}67) = 1{,}374 \cdot 10^{-4}$$

| | |
|---|---|
| 000 | -7 |
| 001 | -5 |
| 011 | -3 |
| 010 | -1 |
| 110 | 1 |
| 111 | 3 |
| 101 | 5 |
| 100 | 7 |

(2.) $f_1 = 60\,MHz$ prijemnik s jednostrukom transpozicijom → poduzorkovanje!

$f_2 = 62{,}8\,MHz$

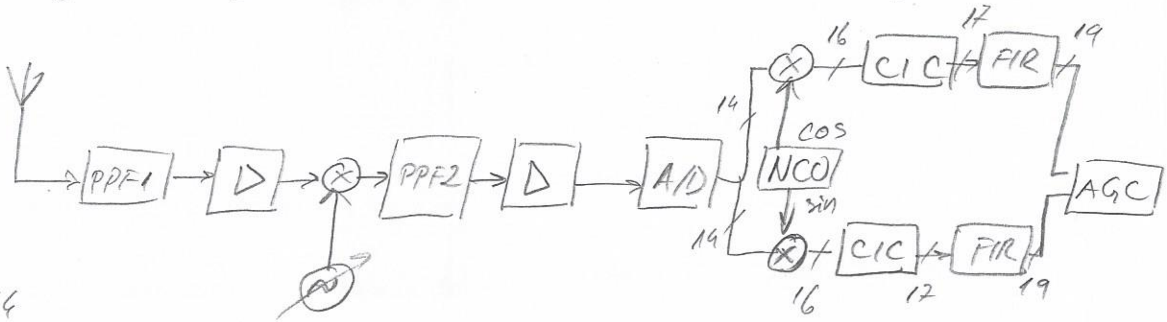
$\Delta f = 140\,kHz$

$N = 14$

$f_S = 44{,}8\,MHz$

$f_{S_2} = 200\,kHz$ $\Big\}\; R = 64$

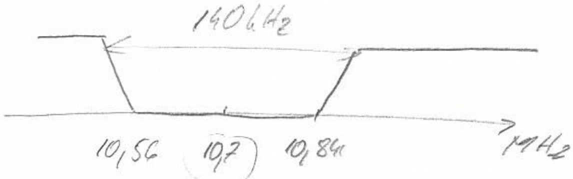
$SNR_{AD} = 75\,dB$




a)

PPF1


PPF2




→ među frekvencija

b)

$A = 60\,dB$

$f_{1k}' = f_{1k} - 2f_{PPF2}$

$\omega_Z = 62{,}8 - \frac{140}{2}\cdot 10^{-3} - 2\cdot 10{,}7 = 41{,}33\,MHz$ $\qquad \omega_{norm} = \frac{\omega^2 - \omega_c^2}{B\omega}$

$$|H(e^{j\omega})| = 20\log_{10}\left|\frac{1}{\sqrt{1+\left(\frac{\omega_Z^2-\omega_{PPF1}^2}{B_{PPF1}\cdot\omega_Z}\right)^{2N}}}\right| \le -60\,dB$$

$$\frac{\cancel{20}\;1}{\frac{1}{2}\log\left(1+\left(\frac{\omega_Z^2-\omega_{PPF1}^2}{B_{PPF1}\cdot\omega_Z}\right)^{2N}\right)} \le \overset{-3}{\cancel{-60}}\,dB \Rightarrow \frac{1}{N\log_{10}\left(\frac{\omega_Z^2-\omega_{PPF1}^2}{B_{PPF1}\cdot\omega_Z}\right)} = -3$$

$$-N\log_{10}\left(\frac{\omega_Z^2-\omega_{PPF1}^2}{B_{PPF1}\cdot\omega_Z}\right) = -3 \Rightarrow N = \frac{3}{\log\left|\left(\frac{\omega_Z^2-\omega_{PPF1}^2}{B_{PPF1}\cdot\omega_Z}\right)\right|} = 2{,}398 \quad N=3$$

$61{,}4^2$

$62{,}8-60$

c) $PG_{CIC} = 10\log_{10}\left(\frac{f_{s1}}{f_{s2}}\right) = 10\log_{10}(R) = 18{,}06$

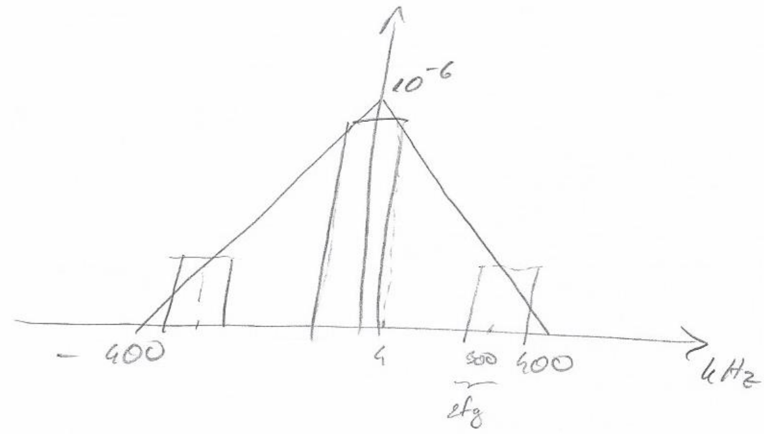
$PG_{FIR} = 10\log_{10}\left(\frac{\overset{700\,kHz}{f_{s2}}}{\underset{\hookrightarrow 140\,kHz}{f_{kanala}}}\right) = 6{,}99$

d) $SNR = SNR_{A/D} + PG_{CIC} + PG_{FIR} - \underset{\text{množilo}}{3_{dB}} = 97{,}05\,dB$

3. $f_g = 4\,kHz$

$f_c = 300\,kHz$

$M_{AWGN} = 1$



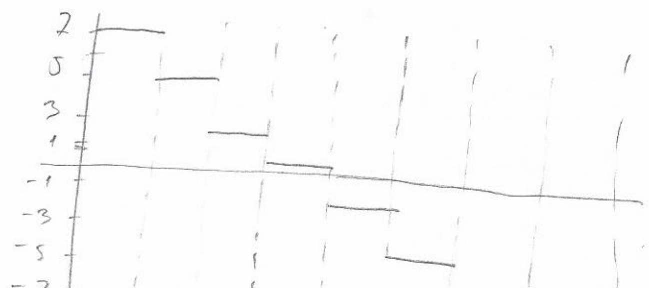

$S_N = -\frac{10^{-6}}{400\cdot 10^3}|f| + 10^{-6}$

$M = \frac{S_N\left(\frac{f_g}{2}\right)}{S_N(f_c)} = 3{,}98$

4. $[-7V, 7V]$

$M = 8$

$\sigma^2 = 0{,}07\,V^2$




a)

| | |
|---|---|
| 000 | 7 |
| 001 | 5 |
| 011 | 3 |
| 010 | 1 |
| 110 | -1 |
| 111 | -3 |
| 101 | -5 |
| 100 | -7 |

b) $p_0 = p_1 = \dots = p_8 = \frac{1}{8}$

$P_{e1} = P_{e8}$

$P_{e2} = P_{e3} = \dots = P_{e7} = 2P_{e1}$

$P_{e1} = \frac{1}{\sqrt{2\pi}\,\sigma}\int_{\infty}^{\infty} \exp\left[-\frac{(y+7)^2}{2\sigma^2}\right]dy = \left| \begin{array}{l} y+7 = u \quad du = dy \\ y=-6 \Rightarrow u=1 \\ y=\infty \Rightarrow u=\infty \end{array} \right|$

$= \frac{1}{\sqrt{2\pi}\,\sigma}\int_{1}^{\infty} \exp\left(-\frac{u^2}{2\sigma^2}\right)du = \left| \begin{array}{l} \frac{u}{\sqrt{2}\,\sigma} = z, \ du = \sqrt{2}\,\sigma\,dz \\ u=1 \Rightarrow z = \frac{1}{\sqrt{2}\,\sigma} \end{array} \right| =$

$= \frac{\cancel{\sqrt{2}\,\sigma}}{\cancel{\sqrt{2}}\sqrt{\pi}\,\cancel{\sigma}}\int_{1/\sqrt{2}\sigma}^{\infty} \exp(-z^2)\,dz = \frac{1}{2}\,\mathrm{erfc}\left(\underset{\hookrightarrow 2{,}67}{\frac{1}{\sqrt{2}\,\sigma}}\right)$

$P = p_1 P_{e1} + \dots + p_8 P_{e8}$

$$\boxed{P = \frac{7}{8}\,\mathrm{erfc}\left(\frac{1}{\sqrt{2}\cdot\sqrt{0{,}07}}\right)}$$

ZI 2011/2012

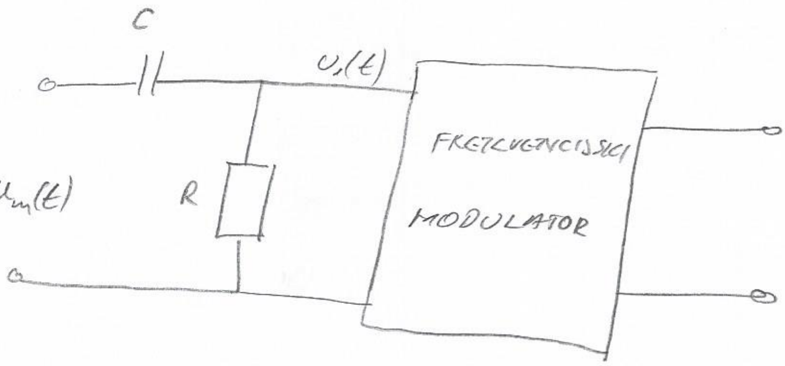
(1) $\tau = 22\mu s$

$K_f = 25 kHz/V$

$f_m \leq 9{,}1 kHz$

$U_m = 3V$

$K_{PM} = ?$ $B = ?$




$\tau = R \cdot C$

$$K_\omega = \frac{m \cdot \omega_m}{U_m} \Rightarrow K_f = \frac{m f_m}{U_m} \Rightarrow m = \frac{K_f U_m}{f_m} = 8{,}24$$

$$U_1(s) = U_m(s) \cdot \frac{R}{R + \frac{1}{sC}} = U_m(s) \cdot \frac{sRC}{1 + sRC} = U_m \frac{s\tau}{1+s\tau} = U_m(s) \cdot s\tau$$

$s\tau \ll 1$, zanemarujemo

$$u_1(t) = \tau \frac{du_m(t)}{dt}$$

$$u_{FM}(t) = U_0 \cdot \cos\left(\omega_0 t + K_\omega \cdot \int_0^t u_1(t) dt\right) =$$

$$= U_0 \cos\left(\omega_0 t + K_\omega \tau u_m(t)\right) =$$

$$= U_0 \cos\left(\omega_0 t + \underbrace{K_\omega \tau}_{K_{PM}} U_m \cos(\omega_m t)\right)$$

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

$$K_{PM} = K_\omega \tau = 2\pi K_f \tau = 3456 \text{ rad/V}$$

2.

$$|H(\omega)| = 3|H_{CIC}(\omega)|^2 - 2|H_{CIC}(\omega)|^3 \quad / \cdot e^{j3f_{CIC}(\omega)} \quad , \; f_{CIC}(\omega) = -D\omega$$

delay

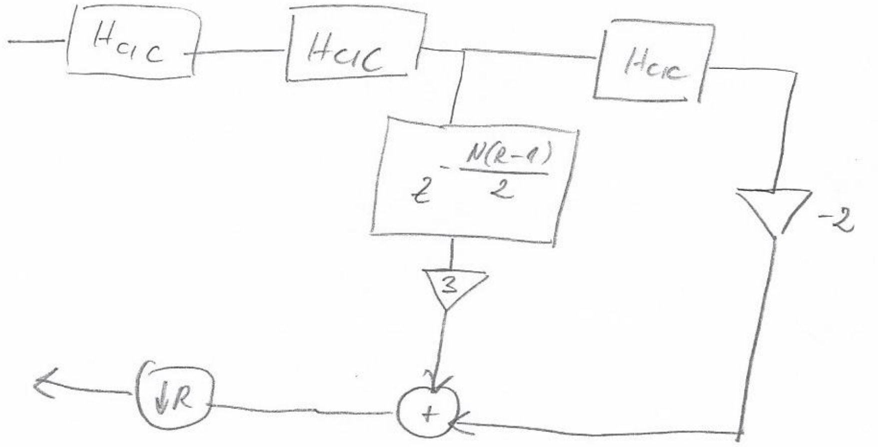
$$\underbrace{|H(\omega)| \cdot e^{j3f_{CIC}(\omega)}}_{H(z)} = 3|H_{CIC}(\omega)|^2 e^{j3f_{CIC}(\omega)} - 2|H_{CIC}(\omega)|^2 e^{j3f_{CIC}(\omega)}$$

$$H(z) = 3|H_{CIC}(\omega)|^2 e^{j2f_{CIC}(\omega)} \cdot \overbrace{e^{jf_{CIC}(\omega)}}^{e^{-jD\omega}} - 2|H_{CIC}(\omega)|^3 e^{j3f_{CIC}(\omega)}$$

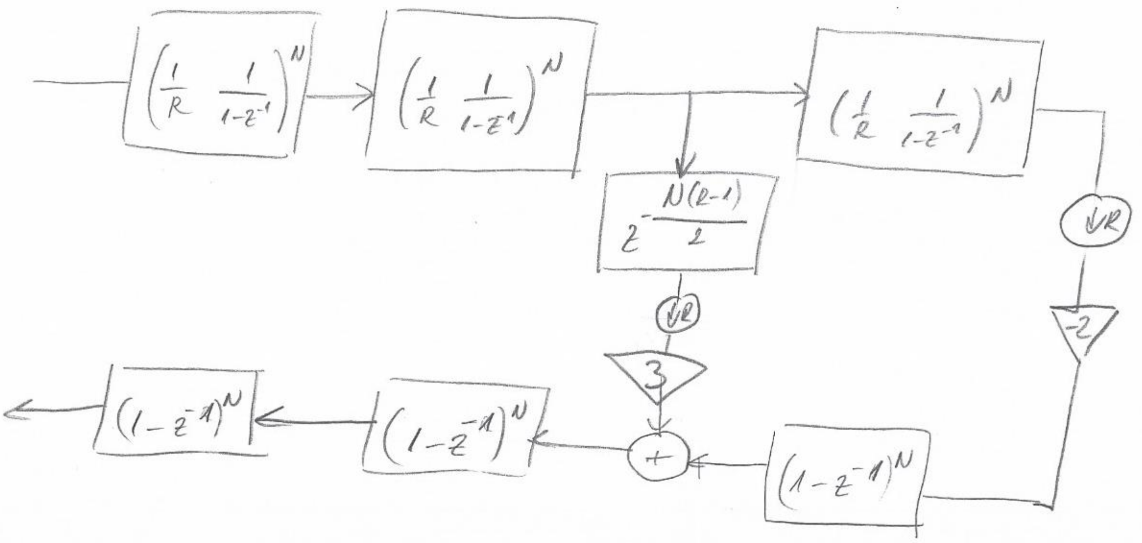
$$H(z) = 3H_{CIC}^2(z) \cdot z^{-D} - 2H_{CIC}^3(z)$$

$\boxed{L = N(R-1)+1}$ – DULJINA IMPULSNOG ODZIVA CIC FILTRA

$H_{CIC}(z)$ – FIR filtar s linearnom fazom $\quad \boxed{D = \frac{L-1}{2} = \frac{N(R-1)}{2}}$




$$H_{CIC} = \left(\frac{1}{R}\,\frac{1-z^{-R}}{1-z^{-1}}\right)^N$$



(3) $f_1 = 88\,MHz$

$f_2 = 108\,MHz$

$B = 150\,kHz$

$N = 14$

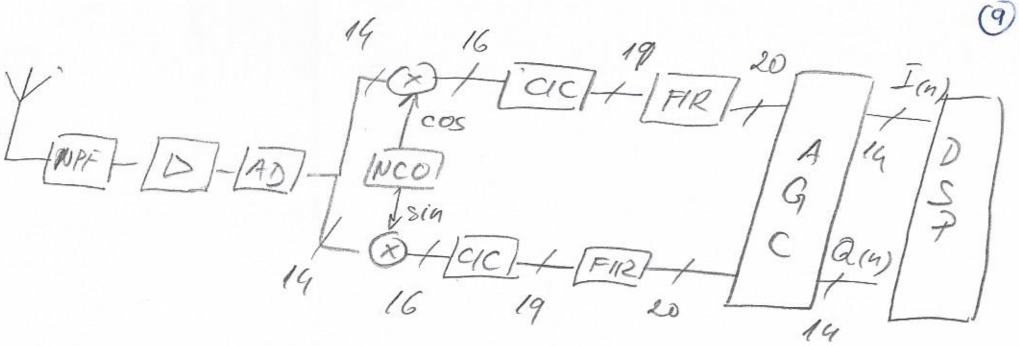
$f_{max} = 120\,MHz$

$SNR_{AD} = 70\,dB$

$f_S = 240\,MHz$

$f_{S2} = 300\,kHz$ $\Big\}\ R = \frac{f_{S1}}{f_{S2}} = 800$

a)




AGC - automatic gain counter

b) 1) MIJEŠALO $N \cdot N \to N+2 = -3dB$ (dodajemo dva bita da zadržimo na samo $-3dB$! inače $N \cdot N \to 2N = -3dB$, $N \cdot N \to N = -6dB$, $N \cdot N \to N+1 = -4dB$)

2) CIC FILTAR

$$PG_{CIC} = 10\log\left(\frac{f_{S1}}{f_{S2}}\right) = 10\log(R) = 29\,dB \Rightarrow 6dB = 1\,bit$$

$$\Rightarrow \frac{29}{6} = 4{,}8 \Rightarrow N = 5$$

(zaokružuje se uvijek prema gore)

$\Rightarrow$ IZLAZ IZ CIC $= 14 + 5 = 19$ bitova

Kao referentni broj se uzima broj bitova AD pretvarača!

3) FIR

$B = 150\,kHz$

$\frac{B}{2} = 75\,kHz$

$\frac{f_{S2}}{2} = 150\,kHz$

$PG_{FIR} = 10\log_{10}\left(\frac{f_{S2}}{B}\right) = 3dB \Rightarrow \boxed{3dB = 0{,}5\,bit}$ - zaokruživanje prema gore 1 bit

c) množenje

$SNR = SNR_{AD} + PG_{CIC} + PG_{FIR} - 3dB = 70 + 29 + 3 - 3 = 99\,dB$

(10)

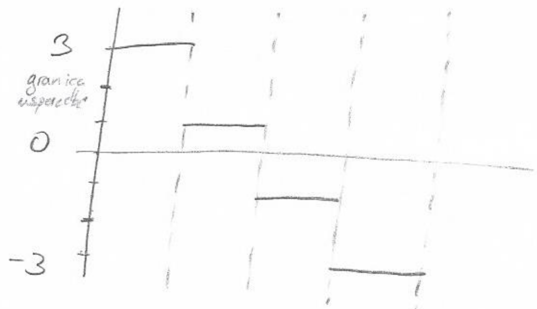
4

$M=4$

$[-3,3]$

$\sigma^2 = 0{,}07\,V^2$

$\sigma = \sqrt{0{,}07}$




a)

| | | |
|---|---|---|
| 0 | 0 | 3 |
| 0 | 1 | 1 |
| 1 | 1 | -1 |
| 1 | 0 | -3 |

b)

$P_{e1} = P_{e4}$

$P_{e2} = P_{e3} = 2P_{e1}$

$p_1 = \dots = p_4 = \frac{1}{4}$

$$P_{e1} = \frac{1}{\sqrt{2\pi}\,\sigma}\int_{-2}^{\infty} \exp\left[-\frac{(y+3)^2}{2\sigma^2}\right]dy = \left|\begin{array}{l} y+3=u \\ dy=du \\ y=-2 \Rightarrow u=1 \\ y=\infty \Rightarrow u=\infty \end{array}\right|$$

$$P_{e1} = \frac{1}{\sqrt{2\pi}\,\sigma}\int_{1}^{\infty} \exp\left[-\frac{u^2}{2\sigma^2}\right]du = \left|\begin{array}{l} \frac{u}{\sqrt{2}\,\sigma} = z \\ du = \sqrt{2}\,\sigma\, dz \\ u=1 \Rightarrow z = \frac{1}{\sqrt{2}\,\sigma} \end{array}\right| =$$

$$= \frac{\cancel{\sqrt{2}\,\sigma}}{\sqrt{2\pi}\,\cancel{\sigma}}\int_{1/\sqrt{2}\sigma}^{\infty} \exp(-z^2)\,dz \Rightarrow \frac{1}{2}\operatorname{erfc}\left(\frac{1}{\sqrt{2}\,\sigma}\right)$$

$$P = \frac{3}{4}\underbrace{\operatorname{erfc}\left(\frac{1}{\sqrt{0{,}14}}\right)}_{\approx 1{,}6\cdot 10^{-4}} \approx 1{,}2\cdot 10^{-4}$$

(2) $f_M = 3kHz$

$P_m = 80mW$

$$M_{FM} = \frac{3K_f^2 P}{f_M^2}$$

$U_0 = 0{,}5V$

$K_a = 0{,}9$

$$M_{FM} > M_{DSB-TC-AM} = \frac{K_a^2 P_m}{U_0^2 + K_a^2 P_m} = 0{,}21$$

$$\frac{3K_f^2 P}{f_M^2} > 0{,}21 \Rightarrow K_f > 2806$$

$$m_{FM} = \frac{\Delta f}{f_M} > \frac{K_f \cdot U_0}{f_M} \qquad m_{FM} > 0{,}468$$

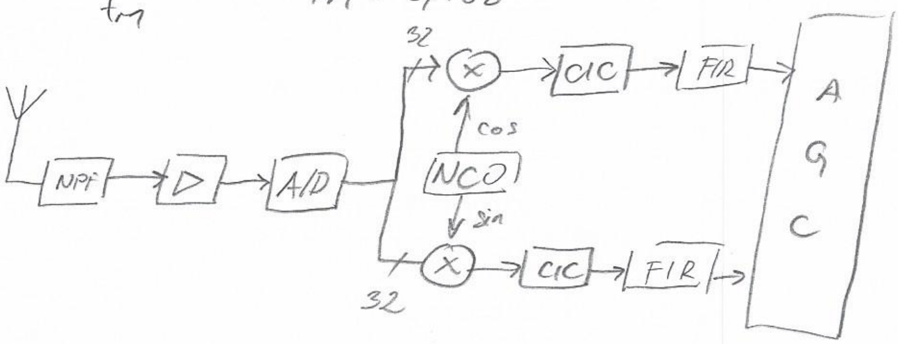
(3.) $\Delta f = 2046\ MHz$

$f_c = 1{,}57542\ GHz$

$f_s = 245{,}76\ MHz$

$N = 32$

$R = 30$




$6{,}41 f_s = f_c$

$$f_1 = 6f_s - \left(f_c - \frac{\Delta f}{2}\right) = 94{,}837\ MHz$$

$$f_2 = 6f_s - \left(f_c + \frac{\Delta f}{2}\right) = 101{,}88\ MHz$$

4.

12

$d = 4$ - udaljenost između točaka

$\frac{N_0}{2} = 0{,}3 \; W/Hz$

1.

$f_M = 5\,kHz$

$f_0 = 400\,kHz$

$A_p = 0{,}05\,dB \qquad R = 50\,\Omega$

$L, C = ?$

$A_s = ?$

a) $$H(\omega) = \frac{R}{R + j\left(\omega L - \frac{1}{\omega C}\right)} \qquad \omega_R = \frac{1}{\sqrt{LC}} = \omega_0$$

$$20\log\left|H(\underbrace{f_0 - f_M}_{})\right| \geq -A_p$$

$$f_1 = 400 - 5 = 395\,kHz$$

$$\frac{R}{\sqrt{R^2 + j\left(\omega_1 L - \frac{1}{\omega_1 C}\right)^2}} = 10^{-\frac{A_p}{20}} \Big/^2 \Rightarrow \left(\omega_1 L - \frac{1}{\omega_1 C}\right)^2 = R^2\left(10^{-\frac{A_p}{10}} - 1\right) \Big/ \sqrt{\ }$$

$$L \cdot \left|\omega_1 - \underbrace{\frac{1}{\omega_1 LC}}_{}\right| = R\sqrt{10^{-\frac{A_p}{10}} - 1} \qquad \Rightarrow L = \frac{R\sqrt{10^{-\frac{A_p}{10}} - 1}}{2\pi\left|f_1 - \frac{f_0^2}{f_1}\right|} = 85\,\mu H$$

$$\frac{\omega_0^2}{\omega_1} = 2\pi\frac{f_0^2}{f_1}$$

$$C = \frac{1}{4\pi^2 f_0^2 L} = 1{,}86\,nF$$

b) $$A_s = -20\log\left|\frac{1}{3}H(3f_0 - f_M)\right| = 30{,}7\,dB$$

(2.)

$f_1 = 88MHz$

$f_2 = 92MHz$

$\Delta f = 150kHz$

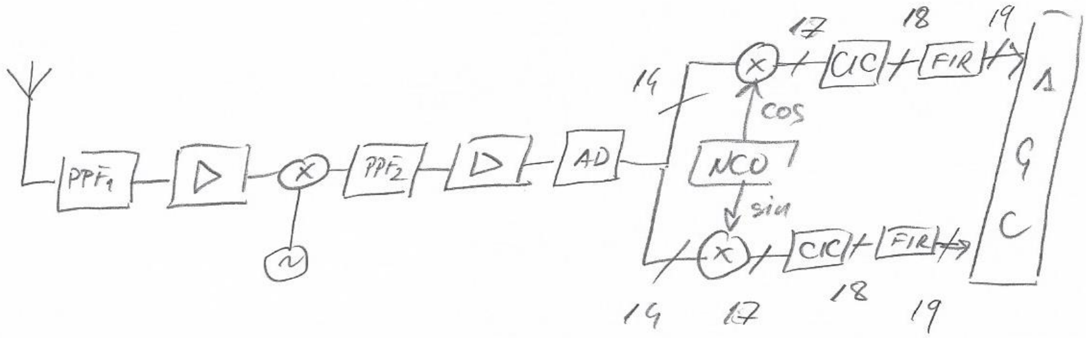
$N = 14$

$SNR_{AD} = 74dB$

$f_{s1} = 50MHz$ $\quad f_{smax} = 100MHz \quad R = 125$

$f_{s2} = 400kHz$

a)




$f_{NCO} = ?$

$f_c = \frac{f_1 + f_2}{2} = 90MHz$ ¡ALI! zadana je 89,8 MHz

$f_c - kf_s = \frac{f_s}{4} \Rightarrow k = \left\lceil \frac{f_c}{f_s} - \frac{1}{4} \right\rceil =$

najbliži $f_s$

$f_0' = 100MHz - 89{,}8MHz = 10{,}2\ MHz \qquad \omega_{osc} = \frac{f_{osc} \cdot 2\pi}{f_s} = 0{,}408\pi$

↳ $f_{osc}$ $\qquad \omega_a = \frac{2\pi}{R} - \frac{\pi f_c}{f_s}$

c)

d) $f_c = \frac{150}{2} = 75kHz$

$A_a = 80dB$

$20\log(|H(e^{j\omega})|) \geq -A_a \quad , H(e^{j\omega}) = \left( \frac{1}{R} \frac{\sin\left(\frac{\omega_a R}{2}\right)}{\sin\left(\frac{\omega_a}{2}\right)} \right)$

$\omega_a = \frac{2\pi}{R} - \frac{2\pi f_c}{f_s} = 0{,}0408 \quad N \geq \frac{-A_a}{20\log\left| \frac{1}{R} \frac{\sin\left(\frac{\omega_a R}{2}\right)}{\sin\left(\frac{\omega_a}{2}\right)} \right|} = 6{,}05 \Rightarrow \boxed{N = 7}$

e) $PG_{CIC} = 10\log_{10}(R) = 21\ dB \Rightarrow 6dB = 1\ bit \quad \frac{21}{6} = 3{,}5$

$\boxed{N=4}$ – u odnosu na broj bitova AD pretvarača!

$PG_F = 10\log_{10}\left(\frac{f_{S_2}}{B}\right) = 4{,}26dB \Rightarrow 3dB = 0{,}5\ bit$

$f_{S_2} \to 400\ kHz$, $B \to 150\ kHz$

$\Rightarrow N = 1$

miješalo $\Rightarrow -3dB$ · dodajemo da zadržimo na samo 3dB

$N \cdot N \Rightarrow 2N = -3dB,\ N\cdot N \Rightarrow N = -6dB,\ N \cdot N \Rightarrow N+2 = -3dB$

f) $SNR_{uk} = 74dB + 21dB + 4{,}26dB - 3dB = 96{,}26dB$

3.

$$|H(\omega)| = 6|H(\omega)|^2 - 8|H(\omega)|^3 + 3|H(\omega)|^4 \quad / \cdot e^{j4f_{cic}(\omega)}$$

$$, \ f_{cic}(\omega) = -D\omega \quad \text{(D → delay)}$$

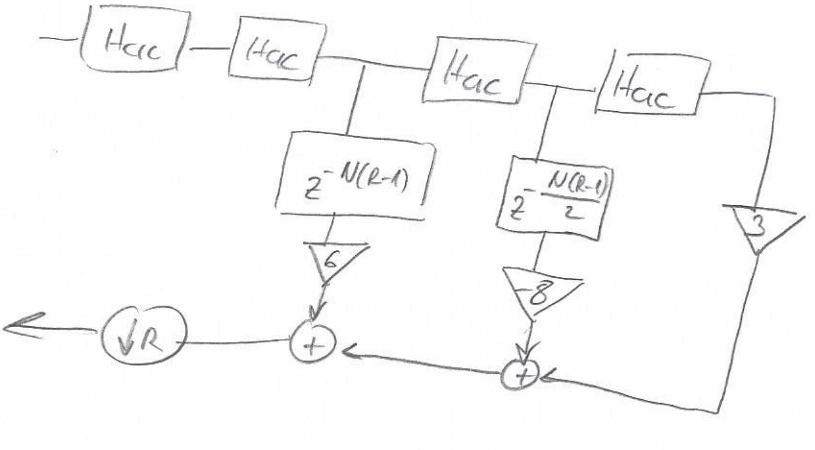
$$\underbrace{|H(\omega)|e^{j4f_{cic}(\omega)}}_{H(z)} = 6|H(\omega)|^2 \cdot e^{j2f_{cic}(\omega)} \cdot e^{j2f_{cic}(\omega)} - 8|H(\omega)|^3 e^{j3f_{cic}(\omega)} e^{jf_{cic}(\omega)} + 3|H(\omega)|^4 e^{j4f_{cic}(\omega)}$$

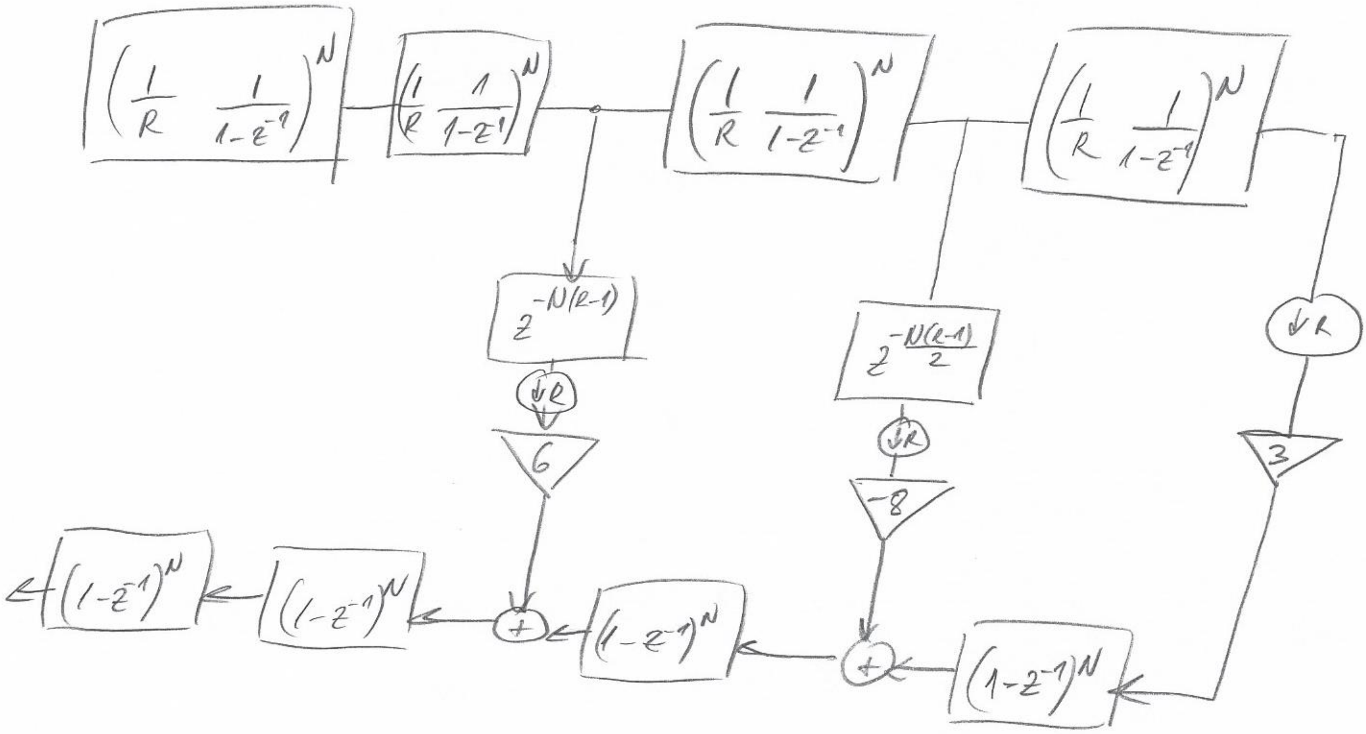
$$H(z) = 6H^2(z) \cdot z^{-2D} - 8H^3(z)\, z^{-D} + 3H^4(z)$$

$L = N(R-1)+1$

$D = \frac{L-1}{2} = \frac{N(R-1)}{2}$

$H_{CIC} = \left(\frac{1}{R}\ \frac{1-z^{-R}}{1-z^{-1}}\right)^N$




$\left(\frac{1}{R}\ \frac{1}{1-z^{-1}}\right)^N$
$\left(\frac{1}{R}\ \frac{1}{1-z^{-1}}\right)^N$
$\left(\frac{1}{R}\ \frac{1}{1-z^{-1}}\right)^N$
$\left(\frac{1}{R}\ \frac{1}{1-z^{-1}}\right)^N$
$z^{-N(R-1)}$
$z^{-\frac{N(R-1)}{2}}$
$\downarrow R$
$\downarrow R$
$\downarrow R$
6
-8
3
+
+
$(1-z^{-1})^N$
$(1-z^{-1})^N$
$(1-z^{-1})^N$
$(1-z^{-1})^N$

4. bla