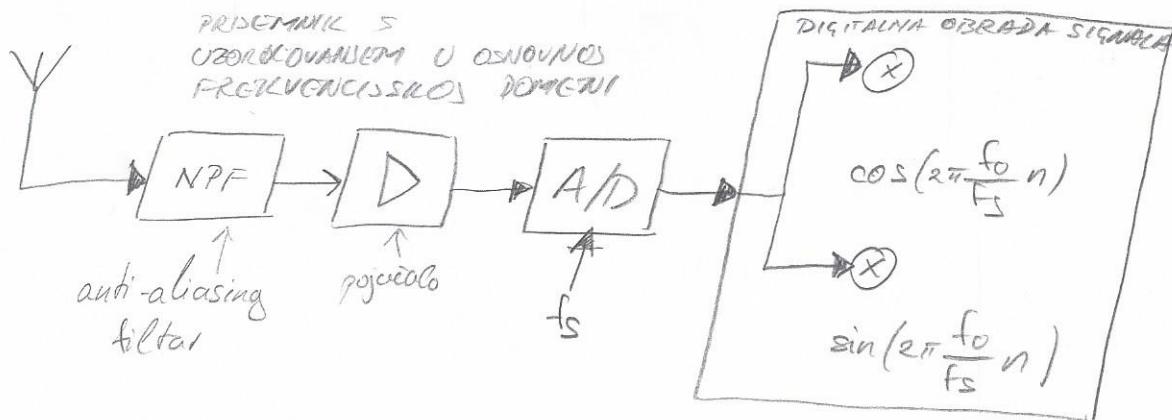


# 10. IZVEDBE PROGRAMSKI IZVEDENIH PRIMJERNIKA

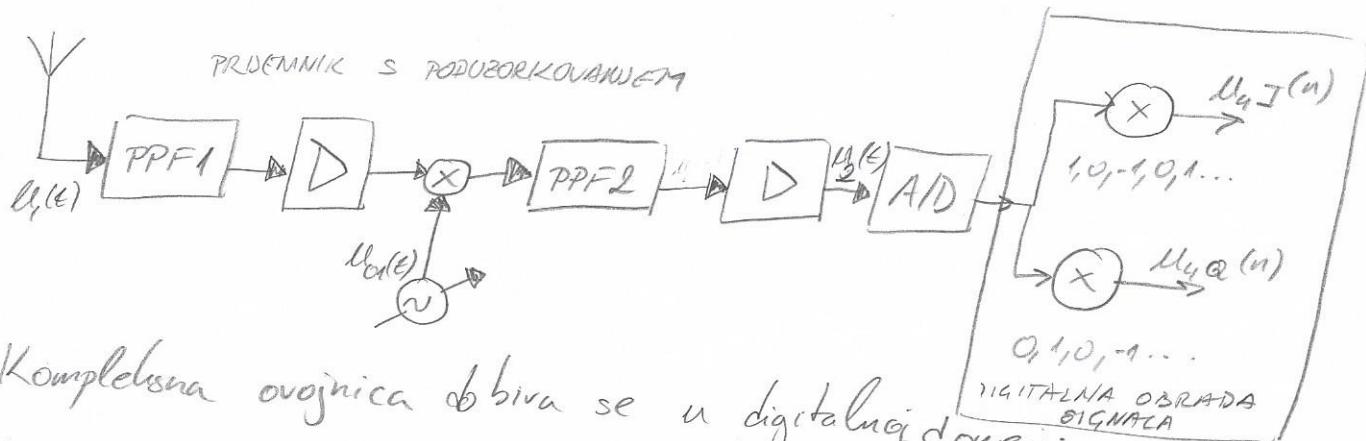
(56)



Kompleksna ovojnica dobiva se u digitalnoj domeni

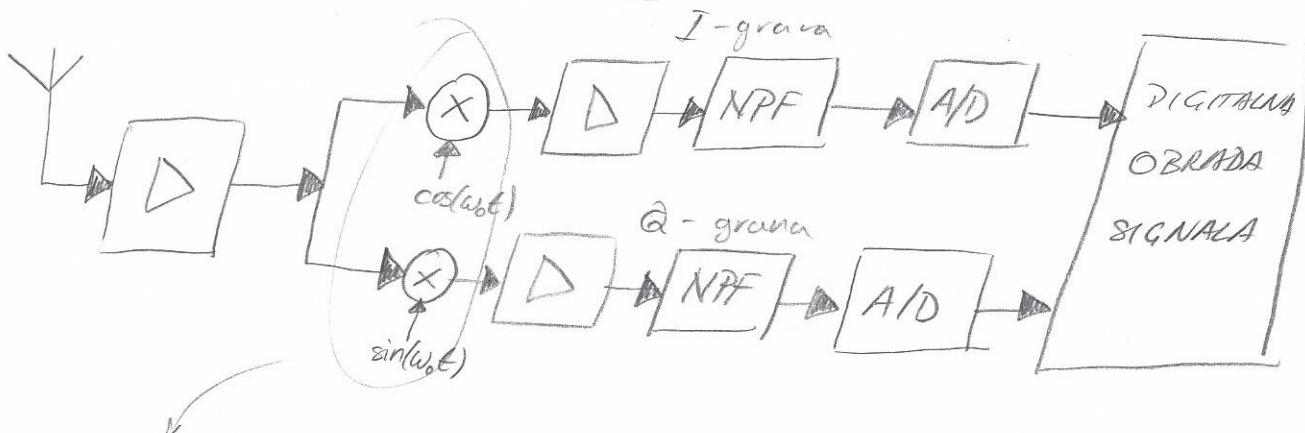
Kada je željeno frekvencijsko područje na području propusanja  
NPF filtra:  $f_s > f_i$

(57)



Kompleksna ovojnica dobiva se u digitalnoj domeni

OSCILATOR?  $\pi/2$ ? str. 234



Kompleksna ovojnica dobiva se u analognoj domeni.

Problemi koji proizlaze iz arhitekture:

- I i Q grana moraju se što manje razlikovati
- izvor sinusa i kosinusa moraju imati točne amplitude i fazni pomak

Problemi koji proizlaze iz nulte medufrekvencije

- signali iz oscilatora prelazeju se na drugi ulaz mjesala, zbog čega se na izlazu mjesala pojavljuje DC (istosmjerna) komponenta, koja može biti višestruko veća od željenog signala. Kompleksna ovojnica željenog kanala se transponira na frekvenciju  $\omega = 0$

Dok prijemnik s nultom medufrekvencijom može generirati neželjene komponente na izlazu ( $\cos(\omega_0 t) \cdot h \cos(\omega_0 t) = \frac{1}{2} h + \frac{1}{2} h \cos(2\omega_0 t)$ ), prijemnik s

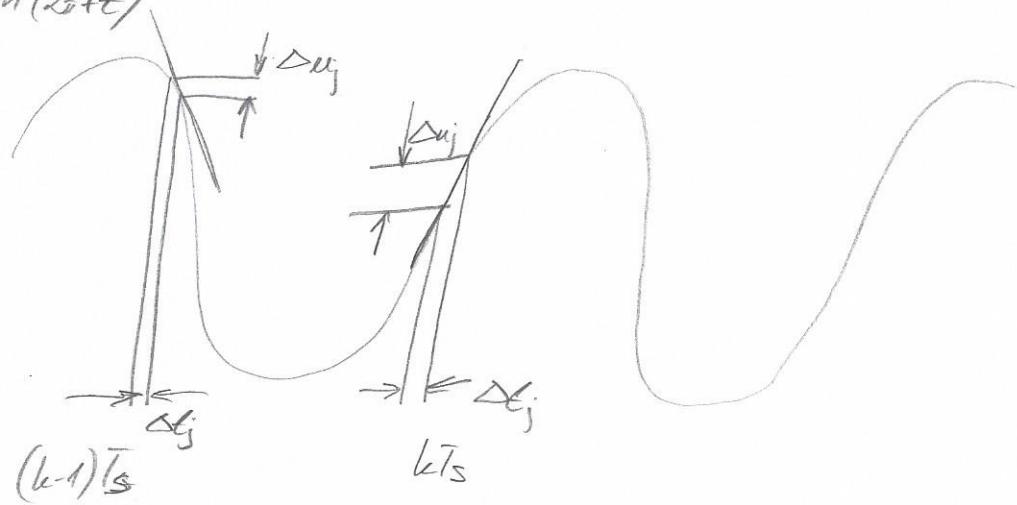
niskom medufrekvencijom će izbjegći takve probleme jer se neželjena komponenta neće pojaviti u željenom kanalu u nihajućoj transpoziciji

$$\omega_0 = \omega_{0ul} + hB, h \neq 0$$

(59)

Podrhtavanje brida talata uzorkovanja (jitter) utrošuje pogresku u amplitudi. pogreska je proporcionalna derivaciji signala.

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



POGRESKA

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

najgori slučaj  $\cos=1$   $\Delta u_{j,\max}(t) = U_m 2\pi f \Delta t_j$

$t_{j,\text{rms}}$  - poznata srednja vrijednost podrhtavanja brida talata

$$U_{j,\text{rms,max}} = U_m \cdot 2\pi f \cdot t_{j,\text{rms}}$$

$$\text{SNR} = 20 \log_{10} \frac{\frac{U_m}{\sqrt{2}}}{U_m \cdot 2\pi f \cdot t_{j,\text{rms}}} = -20 \log_{10} (2\sqrt{2} \pi f t_{j,\text{rms}}), \text{ pri čemu je } f \text{ frekvencija}$$

Kada postoji više ulogova koji unose podrhtavanje, ondani se zbrojavaju

(60)

Uzorkovanjem se sum svih oblasti preložiti u željeno frekvencijsko područje

Često je ~~šire~~?

(61)

$\Delta U_{DL} = U_{LSB} + \underbrace{u_{DNL}}$  - diferencijalna nečinjenost  
 $\rightarrow$  razlika između stvarne i idealne naponašte razine LSB-a

$$\varepsilon = \frac{U_{DNL}}{U_{LSB}} \quad [LSB]$$

$$\sigma_a^2 = \frac{(U_{LSB} + U_{DNL})^2}{12} = \frac{U_{LSB}^2 (1+\varepsilon)^2}{12}$$

$$U_{LSB} = \frac{U_m}{2^{N-1}}$$

$$SNR = 10 \log_{10} \frac{\frac{U_m^2}{2}}{\sigma_a^2} = 10 \log_{10} \frac{\frac{U_m^2}{2}}{\frac{U_{LSB}^2 (1+\varepsilon)^2}{12}} = 10 \log_{10} \frac{\frac{U_m^2}{2}}{\frac{(U_m)^2 (1+\varepsilon)^2}{(2^{N-1})^2}} = \frac{10 \log_{10} \frac{6}{(1+\varepsilon)^2}}{2^{N-2}}$$

$$\frac{3 \cdot 2}{(1+\varepsilon)^2} = \frac{3 \cdot 2}{2^{2N-2}}$$

$$SNR = 10 \log_{10} \left( \frac{3}{2} \cdot 2^N \cdot \frac{1}{(1+\varepsilon)^2} \right)$$

$$SNR = 1,76 + 6,02N - 20 \log_{10} (1+\varepsilon) \quad [dB]$$

(62)

6

- 1) Sum uljedč gittera  $U_{j\text{rms}, \text{max}}(\epsilon) = U_m \cdot \text{dift} \cdot t_{\text{rms}}$
  - 2) Sum neuniformne kvantizacije  $t_Q = \frac{U_{LSB} (1+\epsilon)}{\sqrt{3}} = \frac{U_m}{2^{N-1}} \cdot \frac{(1+\epsilon)}{\sqrt{3}} = \frac{U_m}{2^N \sqrt{3}} (1+\epsilon)$
  - 3) Sum ulaznog broja  $U_{nIN}$
- $v(t) = U_m \sin(2\pi f t)$ ,  $U_{\text{rms}, \sin} = \frac{U_m}{\sqrt{2}}$

Vrhuna efektivna vrijednost signala suma

$$U_{nAD} = \sqrt{(U_{\text{dift}, \text{jens}})^2 + \left(\frac{U_m}{2^N \sqrt{3}} (1+\epsilon)\right)^2 + U_{nIN}^2}$$

$$\begin{aligned} \text{SNR}_{\sin} &= -20 \log_{10} \frac{U_{nAD}}{U_{\text{rms}, \sin}} = -20 \log_{10} \frac{\sqrt{(U_{\text{dift}, \text{jens}})^2 + \left(\frac{U_m}{2^N \sqrt{3}} (1+\epsilon)\right)^2 + U_{nIN}^2}}{\frac{U_m}{\sqrt{2}}} \\ &= -20 \log_{10} \sqrt{\left(2\sqrt{2} \cdot \text{dift}_{\text{jens}}\right)^2 \left(\frac{\sqrt{2}(1+\epsilon)}{2^N \sqrt{3}}\right)^2 + \left(\frac{\sqrt{2} U_{nIN}}{U_m}\right)^2} \end{aligned}$$

ako je  $U_{nIN}$  normiran  $U_{nIN, LSB} = \frac{U_{nIN}}{U_m} 2^N \Rightarrow U_{nIN} = \frac{U_{nIN, LSB} \cdot U_m}{2^N}$

$$\text{SNR}_{\sin} = -20 \log_{10} \sqrt{\left(2\sqrt{2} \cdot \text{dift}_{\text{jens}}\right)^2 \left(\frac{\sqrt{2}(1+\epsilon)}{2^N \sqrt{3}}\right)^2 + \left(\frac{\sqrt{2} U_{nIN, LSB}}{2^N}\right)^2}$$

(63)

(6)

| BINARNI S<br>POMAKOM<br>(SOB) |   | DVOJNI<br>KOMPLEMENT (TC) |
|-------------------------------|---|---------------------------|
| 0 0 0                         | 0 | 0                         |
| 0 0 1                         | 1 | 1                         |
| 0 1 0                         | 2 | 2                         |
| 0 1 1                         | 3 | 3                         |
| 1 0 0                         | 4 | -4                        |
| 1 0 1                         | 5 | -3                        |
| 1 1 0                         | 6 | -2                        |
| 1 1 1                         | 7 | -1                        |

PRETVORBA SOB  $\rightarrow$  TC

$$TC = \overline{SOB} + 1$$

npr

|     |                  |     |
|-----|------------------|-----|
| SOB | $\overline{SOB}$ | TC  |
| 010 | 101              | 110 |

## CJELOBRODNA INTERPRETACIJA

- decimalna točka podrazumijeva se iza zadaje znakom

## FRAKCIJALNA INTERPRETACIJA

format: broj-cjelobrojnih-bitova.broj-bitova-frakcije

najčešće se koristi format kod kojega je točka odmah iza predznaka

$$0,111 = 7/2^3 = 0,875$$

$$0,110 = 3/2^2 = 0,75$$

$$0,001 = -7/2^3 = -0,875$$

$$0,000 = -8/2^0 = -8$$

Za N bitova dvojni komplement prikazuje se u zapisu  $[1.(N-1)]$ , a brojevi su u intervalu  $[-1, 1-2^{N-1}]$

Množenje duže riječi dvizine  $N$  daje riječ dvizine  $LN$  SX. xxx...xxx

Bitovi lijevo od decimalne točke su proširenje predznaka

$S=X \Rightarrow$  možemo zanemariti MSB na izlazu i množila

$b_{MSB}$

Nakon množenja SNR je losiji za 3dB, odsijecanje na sirinu ulazne riječi smanjuje SNR za barem još 3dB. Zbog toga

st. 261

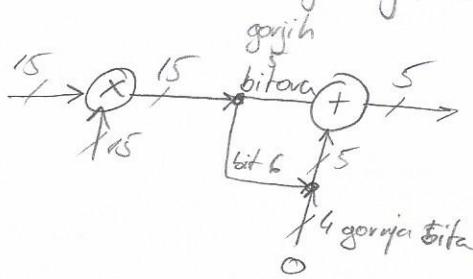
se u praksi na izlazu množila uzima riječ koja je dva do tri bita sira od već od duju ulaznih riječi

(65)

Odsijecanje dvojnog komplementa prekidača zadržavanje prema dolje  
Srednja vrijednost pogreške koja time nosiće imosi pola LSB-a i  
pojavljuje se DC komponenta (DC offset). Zahvaljujući i dalje imu DC  
vrijednost jer 0.5 unjeh zadržava prema gore, ali je ona mala i u  
prekusi u glavnom zanemariva

S. ABCDEFG      ako je  $EFG < 0.5$  prema dolje } smjer ovisi samo o  
ako je  $EFG \geq 0.5$  prema gore } bitu E

SKLOPOVSKI - nakon odsijecanja S.ABCD pribrojiti 0.000E



(66)

LOKALNI OSCILATOR

$$x_o(t) = \cos(2\pi f_o t) \quad t = nT_s = n \frac{1}{f_s}$$

$$x_o[n] = \cos\left(2\pi \frac{f_o}{f_s} n\right) = \cos(\omega_o n)$$

ULAZNI SIGNAL

$$x_{ul}[n] = \cos(\omega_{ul} n)$$

IZLAZ IZ MJEŠALA

$$y[n] = \cos(\omega_o n) \cdot \cos(\omega_{ul} n) = \frac{1}{2} \left\{ \cos[(\omega_o - \omega_{ul})n] + \cos[(\omega_o + \omega_{ul})n] \right\}$$

- filtriramo komponente (npr gornju)

$$y[n] = \left( \frac{1}{2} \right) \cos[(\omega_o - \omega_{ul})n]$$

↳ pojačanje amplitud mješala

(67)

Obrada prije teže se provodi decimacija signala, kako bi se smanjila frekvencija  
čitanja (time i kompleksnost pojedinih filtera) naziva se VISETAKTNA OBRADA SIGNALA

Problemi u dizajnu decimatora:

gusenje filtra u području gusenja mora biti  
jako veliko

za veliki R područje propuštanja  
filtra je jako usko

Zahtijeva visoki red filtra

↳ mnogo množenja po uzorku

CIC-decimator rješenje

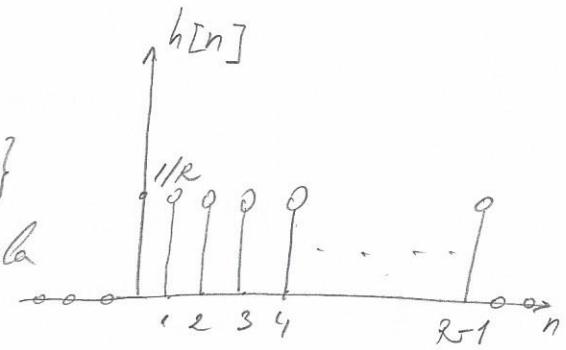
zgodan za veliki R

ne sadrži množila

(68)

$$h[n] = \frac{1}{R} \{ \delta[n] + \delta[n-1] + \delta[n-2] + \dots + \delta[n-R+1] \}$$

→ linijski filter osredjjava R varijablu ulaznog signala



$$y[n] = x[n] * h[n] = \sum_{k=-\infty}^{+\infty} x[k] h[n-k] = \frac{1}{R} \{ x[n] + x[n-1] + \dots + x[n-R+1] \}$$

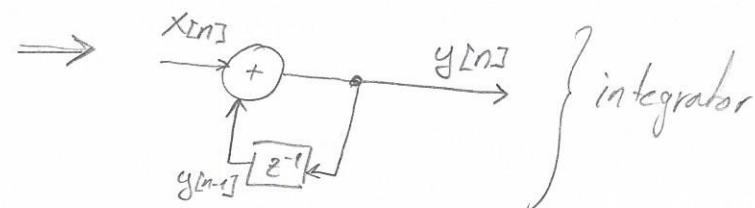
$$H(z) = Z\{h[n]\} = \frac{1}{R} \left[ 1 + z^{-1} + z^{-2} + \dots + z^{-R+1} \right] = \frac{1}{R} \sum_{k=0}^{R-1} z^{-k} \rightarrow \text{geometrijski niz } \sum_{n=0}^{N-1} q^n = \frac{1-q^N}{1-q}$$

$$H(z) = \frac{1}{R} \frac{1-z^{-R}}{1-z^{-1}} = \frac{1}{R} \frac{1}{1-z^{-1}} (1-z^{-R}) \Rightarrow$$

REKURZIVNI DIO

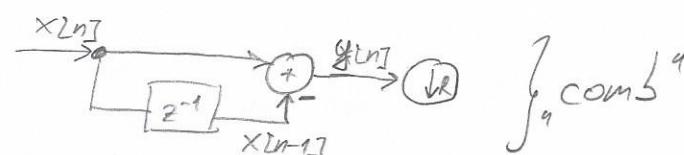
$Y(z) = \frac{1}{1-z^{-1}} X(z) \Rightarrow Y(z) - z^{-1} Y(z) = X(z)$  → poznata verzija

$$Y(z) = X(z) + z^{-1} Y(z)$$

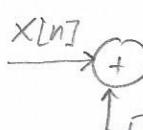


$$Y(z) = (1-z^{-R}) X(z) = X(z) - z^{-R} X(z)$$

$$y[n] = x[n] - x[n-R]$$



CIC DECIMATOR PRVOG REDA



$$\text{N-TOG REDA} \quad H(z) = \left( \frac{1}{R} \frac{1-z^{-R}}{1-z^{-1}} \right)^N$$

$N$  integratori sekoj

$N$ , comb sekoj

(69.)

$$H(z) = \left( \frac{1}{MR} \sum_{k=0}^{MR-1} z^{-k} \right)^N, \text{ ulazna riječ sirine } B_{in} \text{ bitova}$$

faktor  $M$  se može staviti za dodatnu ušćecaj shaličnjaka

najveći broj na izlazu filtra (ne računajući  $1/RM$ )  $\lceil -2^{B_{in}-1} \cdot (RM)^N \rceil$   
po modulu

Za takav broj potreban je registar sirine  $B_{out,max} = \lceil \log_2 (2^{B_{in}-1} (RM)^N) + 1 \rceil$

najveći broj (pravzapravo)

$$B_{out,max} = \lceil \log_2 (2^{B_{in}-1}) + \log_2 (RM)^N + 1 \rceil = \lceil N \log_2 RM + B_{in} \rceil$$

(70.)

Konvolucija impulsa i provolnihniha daje kontinuirani kvadratizirani signal

$$u_{DA}(t) = u_s(t) * g(t) = \underbrace{\sum_{k=-\infty}^{\infty} u_c(kT_s) \delta(t-kT_s)}_{\text{discreet}} \underbrace{\int_{-\infty}^{\infty} u_s(\tau) g(t-\tau) d\tau}_{\text{rect}} = u_s(t) = \sum_{k=-\infty}^{\infty} u_c(kT_s) \delta(t-kT_s)$$

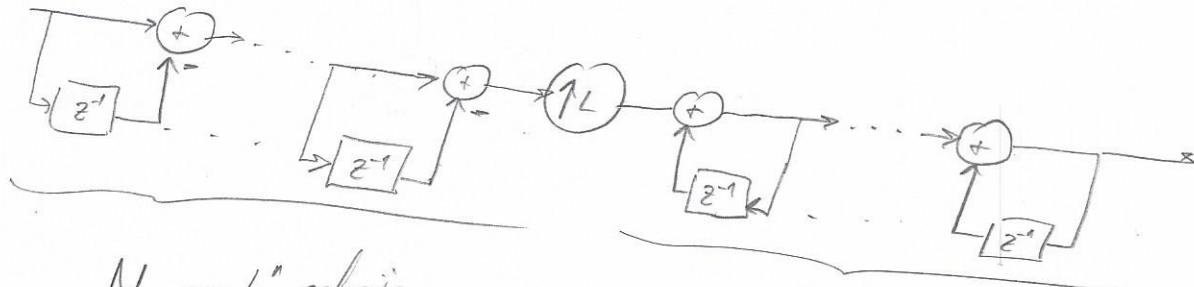
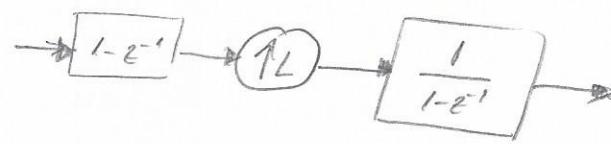
$$u_{DA} = \sum_{k=-\infty}^{\infty} u_c(kT_s) \underbrace{\int_{-\infty}^{\infty} \delta(t-kT_s) g(t-\tau) d\tau}_{g(t-kT_s)} = \sum_{k=-\infty}^{\infty} u_c(kT_s) g(t-kT_s)$$

$$\mathcal{F}\{u_{DA}(t)\} = \mathcal{F}\{u_s(t)\} \mathcal{F}\{g(t)\} \Rightarrow |G(f)| = \left| T_s \operatorname{sinc}\left(\frac{f}{f_s}\right) \right|$$

(60)

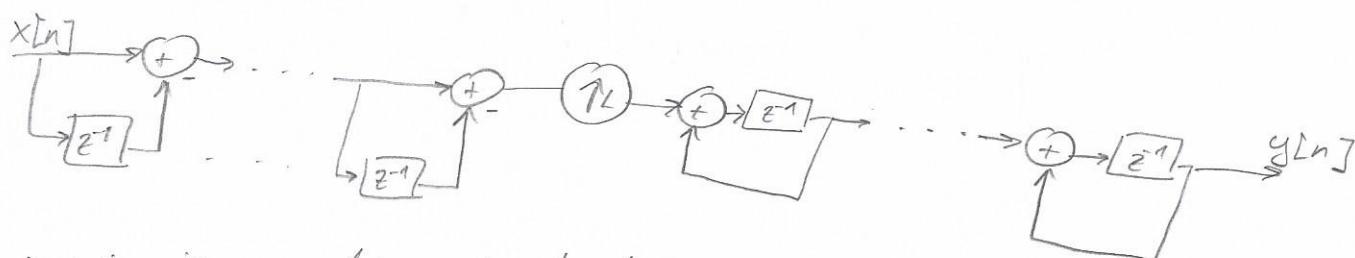
(7)

$$H_F(z) = \left( \frac{1}{L} \sum_{k=0}^{L-1} z^{-k} \right)^N = \left( \frac{1}{L} \cdot \frac{1-z^{-L}}{1-z^{-1}} \right)^N$$

*N „comb“ schem**N integratorskih sekvija*

- korišćenja se implementiraju pomoći registara
- u integratorskoj sekviji signal propagira s  $N$  zbrojnika  
⇒ s poređanjem  $N$  pada uobičajena frekvencija takta na kojem  
cic integrator može raditi

Uobičajena frekvencija takta postiže se ako se signal iz svakog  
stupnja vodi sa izlaza registra



→ ovim je u svakoj integratorskoj sekviji dodano korišćenje sa 1 uзорak,  
a prijenosna funkcija imat će bar slaganje oblik

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

(72)

Processing signal je onjor snage sume na ulazu i na izlazu filtra

snaga sume na ulazu

$$P_{nAD} = \frac{N}{2} \cdot 2 \cdot \underbrace{\frac{f_s}{2}}_{\text{spektralna gustina snage na ulazu}} = N \frac{f_s}{2}$$

$$\left[ -\frac{f_s}{2}, \frac{f_s}{2} \right]$$

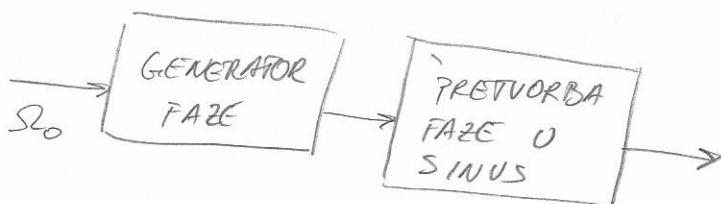
snaga sume na izlazu (u području frekvencije B)

$$P_{nF} = \frac{N}{2} \cdot 2 \cdot B = NB$$

onjor PG

$$PG = \frac{P_{nAD}}{P_{nF}} = \frac{N \frac{f_s}{2}}{NB} = \frac{f_s}{2B} \Rightarrow PG = 10 \log_{10} \left( \frac{f_s}{2B} \right) [\text{dB}]$$

(73)



KORAK Δ

$$\Delta = S_o \frac{2^N}{2\pi} \quad ; \quad S_o = 2\pi \frac{f_o}{f_s} = 2\pi \frac{\omega_o}{\omega_c}$$

$$\Delta = \frac{\omega_o}{\omega_c} 2^N$$

IZLAZNA FREKVENCija

$$\rightarrow u \text{ praktički} \rightarrow \Delta = \left\lfloor \frac{f_o}{f_s} 2^N + 0,5 \right\rfloor$$

RAZLUČIVOST FREKVENCije

$$f_o = f_o(\Delta) = f_s \frac{\Delta}{2^N}$$

$$\Delta f_{\min} = f_o(\Delta+1) - f_o(\Delta)$$

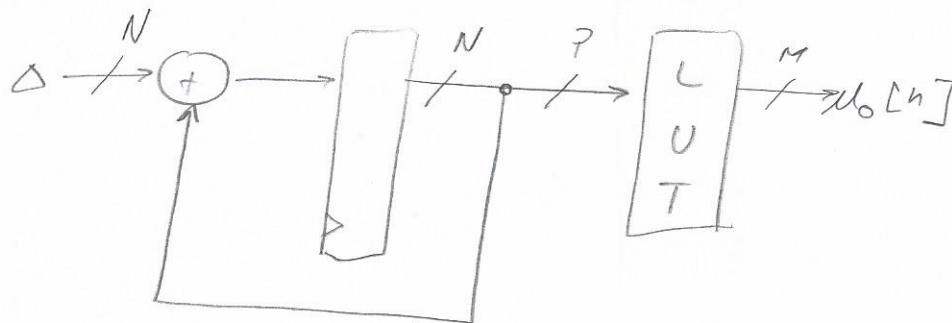
$$\Delta f_{\min} = f_s \frac{\Delta+1}{2^N} - f_s \frac{\Delta}{2^N}$$

$$\boxed{\Delta f_{\min} = \frac{f_s}{2^N}}$$

(74)

(74)

(13)



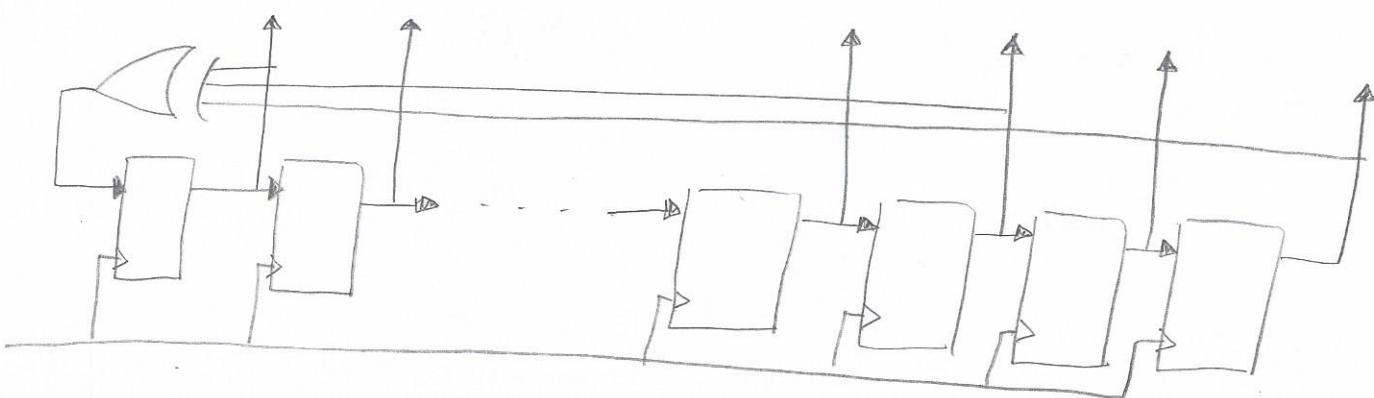
S obzirom da LUT-ova je adresa ova od 18 bitova nije praktičan, a rezolucija bilo od 191 Hz je rijetko potreban, za adresiranje LUT-a uvek smo samo gornji dio faze.

Zbog odjecanja faze presjek bili linearna, dolazi do kavne modulacije, a s obzirom da je pogreska periodična u spektru se očišćuju diskretni neželjene komponente.

$$SFDR = 6,02P - 3,92 \text{ dB}$$

(75)

Diskretni komponenti u spektru signala nisu postojati, ali fazna pogreška nemaju diskretnih komponenti (ali nisu periodične). Zbog toga u faznu pogrešku ubacujemo sum (DITHERING) te očlanjujući diskretne komponente prečaramo SFDR.



(76.)

(14)

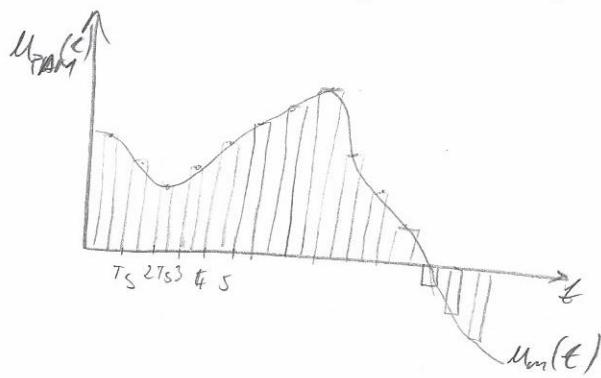
LUT ima karakteristiku srednje vrijednosti frekvencije do pogrešaka uveličaj  
LEVANTZEVSE AMPITUDU:

- $\rightarrow$  karakteristika je om:  $SNR = (6,02m + 1,76) \text{ dB}$
- $\rightarrow$  pogreška karakteristike nije jednolika
- $\rightarrow$  karakteristika je om: nije bijela
- $\rightarrow$  pogrešku je distribuirana komponenta u spektru

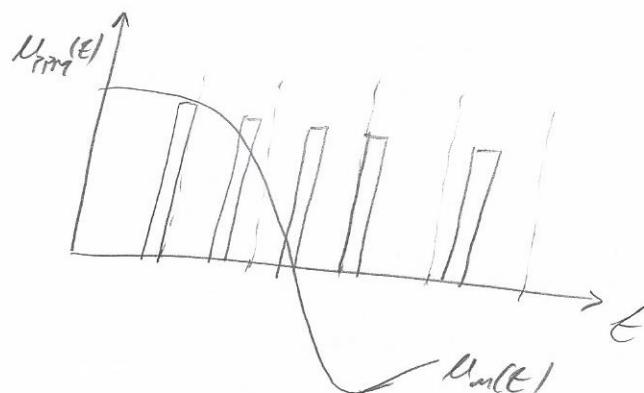
broj bilova na izlazu LUT-a

(77.)

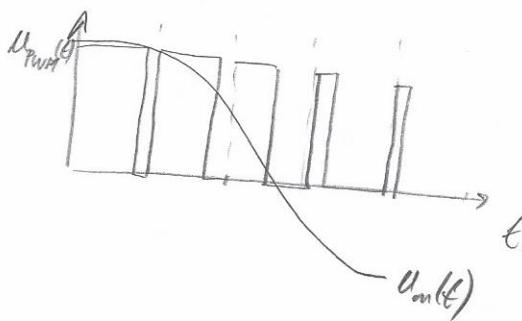
PAM - pulsna amplitudna modulacija



PPM



PWM - pulsna srasinska modulacija



78.

5

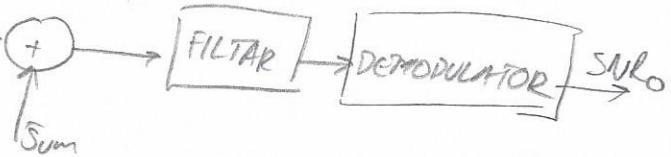
$$M = \frac{\text{SNR}_0 \text{ izlaz}}{\text{SNR}_C} = \frac{\text{SNR na izlazu}}{\text{SNR u kanalu porde}}$$

(channel)

MODEZ:

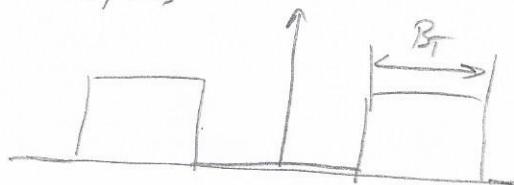
DOSNICK

Signal

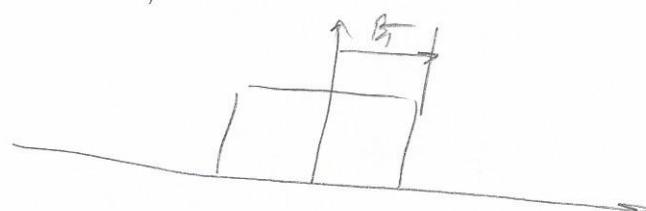


Amp. karakteristika

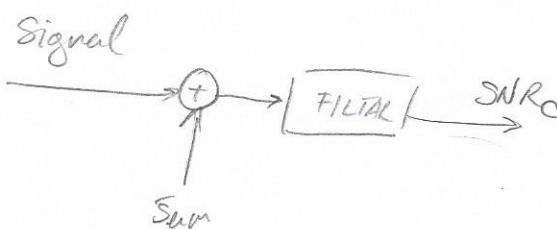
Band pass



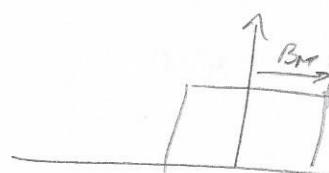
Lowpass



NAZIVNIK:



Amp. karakteristika



$$M = \frac{\text{SNR}_0}{\text{SNR}_C} = \frac{\text{srednja snaga signala na izlazu je prijedolica}}{\text{srednja snaga sumer na izlazu je prijedolica}} \cdot \frac{\text{srednja snaga signala porde}}{\text{srednja snaga sumer je kanale porde}}$$

PREPOSTAVKA srednja snaga moduliranog signala = srednja snaga signala porde

$\exists$  je M veci, sastoji se bolje

$M=1$   $\Rightarrow$  sastoji se isti SNR kao i onaj koji koristi "baseband"

(29)

(16)

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

signal na izlazu je pričuvanica  $P_{SO}$

$$\left. \begin{aligned} U_{S,PP} &= KT_S \\ U_{S,rms} &= \frac{KT_S}{2\sqrt{2}} \end{aligned} \right\} P_{SO} = \frac{KT_S^2}{8}$$

Sum na izlazu je pričuvanica  $P_{NO}$

$$U_{N,PP} = K \tilde{C} \text{ zrak u vremenu, } \tilde{C} = \frac{2U_h}{A_\pi B_T}$$

$$U_{N,PP} = \frac{2KU_h}{A_\pi B_T}$$

$$U_{N,rms}^2 = \frac{4K^2}{A_\pi^2 B_T^2} E[U_n^2] \Rightarrow \frac{N_0}{2} \cdot 2B_T = N_0 B_T$$

$$U_{N,rms}^2 = \frac{4K^2 N_0}{A_\pi^2 B_T^2} \Rightarrow P_{NO} = \frac{U_{N,rms}^2}{12} = \frac{4K^2 N_0}{A_\pi^2 B_T^2}$$

srednja snaga moduliranog signala  $P_S$

$$P_S = \frac{1}{T_s} \int_{-T}^T g^2(t) dt = \frac{3A^2}{4T_s B_T}$$

$$g(t) = \frac{A}{2} [1 + \cos(\omega t)], -T \leq t \leq T$$

srednja snaga sume u kanalu  $P_{NC}$

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

$$\frac{KT_S^2}{8}$$

$$\frac{4K^2 N_0}{A_\pi^2 B_T}$$

$$\frac{3A^2}{4T_s B_T}$$

$$\frac{N_0 B_M}{N_0 B_M}$$

$$M = \frac{\frac{KT_S^2}{8}}{\frac{4K^2 N_0}{A_\pi^2 B_T} \frac{3A^2}{4T_s B_T}} = \frac{\pi^2}{24} B_T^2 T_s^3 B_M, f_s = 2B_M \Rightarrow T_s = \frac{1}{f} = \frac{1}{2B_M}$$

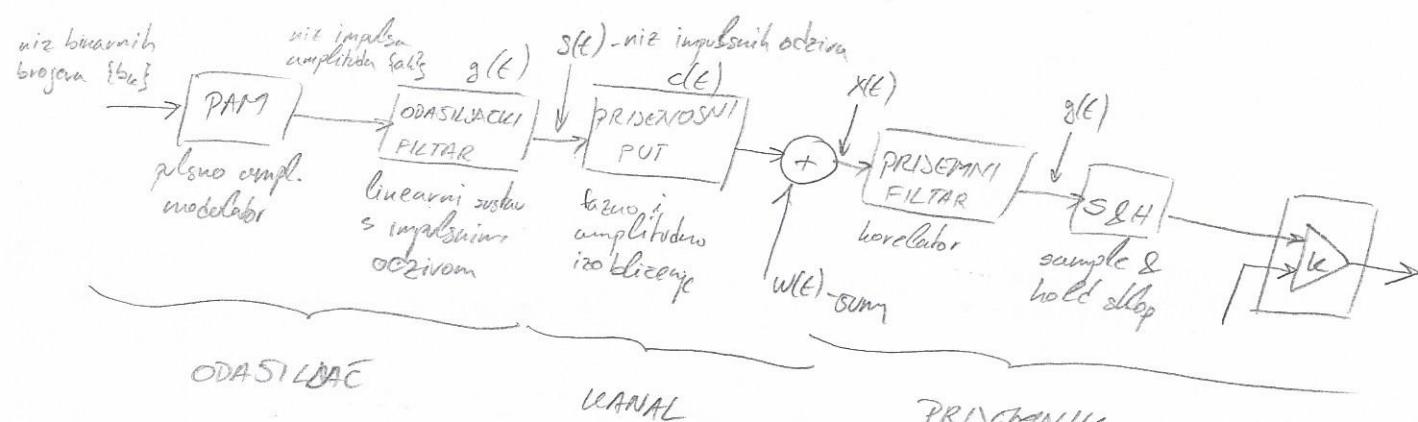
$$M = \frac{\pi^2}{192} \left( \frac{B_T}{B_M} \right)^2$$

(80)

(80)

## 14. PRIMENOS IMPULSA O PCM SUSTAVIMA

(81)



Prilagođeni filter umaksimizira omjer vršne snage signala i srednje snage sume

$$\max \left\{ \frac{|g_0(T_b)|^2}{E[w^2(t)]} \right\}$$

$$h_{opt}(t) = K \cdot g(T_b - t)$$

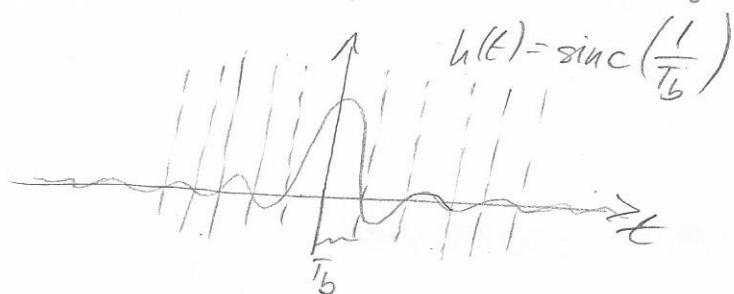
/      \

proizvoljna konstanta      signal enakovan u vremenu

$$H(\omega) = F[h_{opt}(t)]$$

(82.)

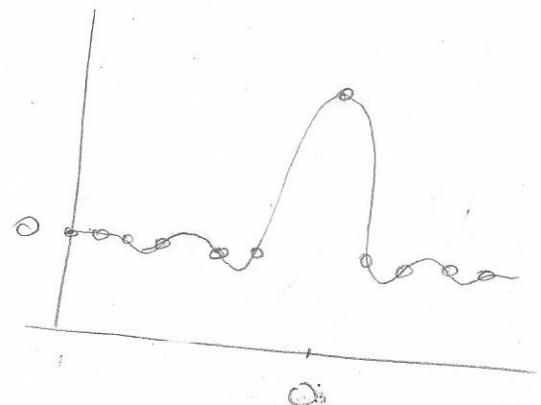
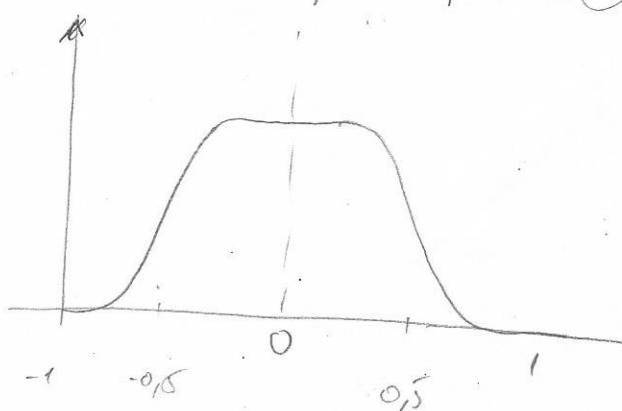
Inter Symbol Interference je preljevanje spektra nekog susjednog simbola učinjeno izdvajanjem frekvencijskog odziva te mu je vrijednost razlicita od nule a trenutno ocitavajuca amplitudu odziva slijedeceg (prethodnog) simbola



(83.)

Raised Cosine Filter je filter koji prijelazno područje ima konacnu duljinu

$\beta$ -faktor prematnja  $\beta = 2T_b(\Delta f)$   $\rightarrow$  koliko rep kosiusa prolazi Nyquistove frekvencije



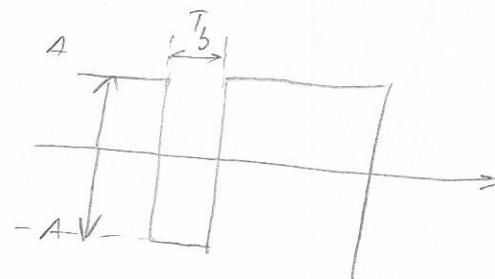
Za  $\Delta f = 0$  postoji se kao "brick wall" filter

Postoje Raised Cosine Filter - postoji ukupno karakteristiku kao RC filter  
- napraviti jednake odstojanja i prijamni filter

(84)

(85)

NRE signal



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

poslana je 0       $x(t) = -A + w(t)$

izlaz priлагodenog filtra u trenutku učinkovanja

$$y(T_b) = K \int_0^{T_b} x(t) dt = -KA T_b + K \int_0^{T_b} w(t) dt$$

$$K = \frac{1}{T_b}$$

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

$$\sigma_y^2 = E[(y-A)^2]$$

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

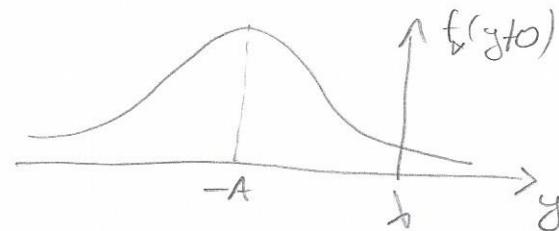
$$E[w(t) w(u)] = R_w(t, u) = \frac{N_0}{2} \delta(t-u) \Rightarrow \text{AUTOKOREZALIZA}$$

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

FUNKCJA GUSTOĆE VEROJATNOSTI UZ UVJET DA SE STAVNO SAKJE "0"

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

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



vjerojatnost pogresne detekcije ako je poslana "0"

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

nove granice

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

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

$$P_{eo} = \frac{1}{\sqrt{\pi N_0/T_b}} \int_{\sqrt{E_b/N_0}}^{\infty} \exp(-z^2) \sqrt{N_0/T_b} dz \Rightarrow P_{eo} = \frac{1}{\sqrt{\pi}} \int_{\sqrt{E_b/N_0}}^{\infty} \exp(-z^2) dz$$

$$\frac{2}{\sqrt{\pi}} \int_u^{\infty} \exp(-z^2) dz = \operatorname{erfc}(u)$$

$$P_{eo} = \frac{1}{2} \operatorname{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right) - \text{vjerojatnost da posljemo } 0, \text{ a dobijemo } 1$$

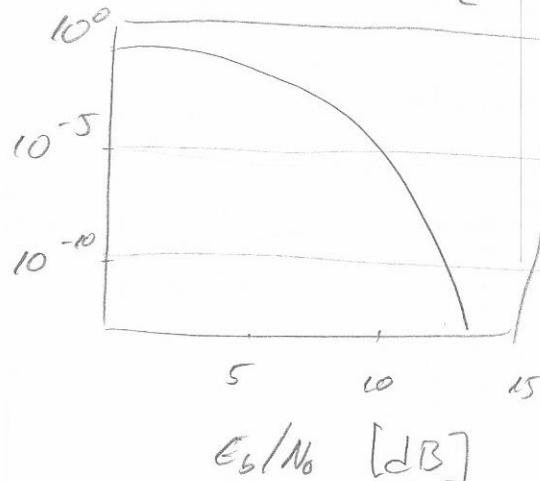
$$P_{e1} = P_{eo}$$

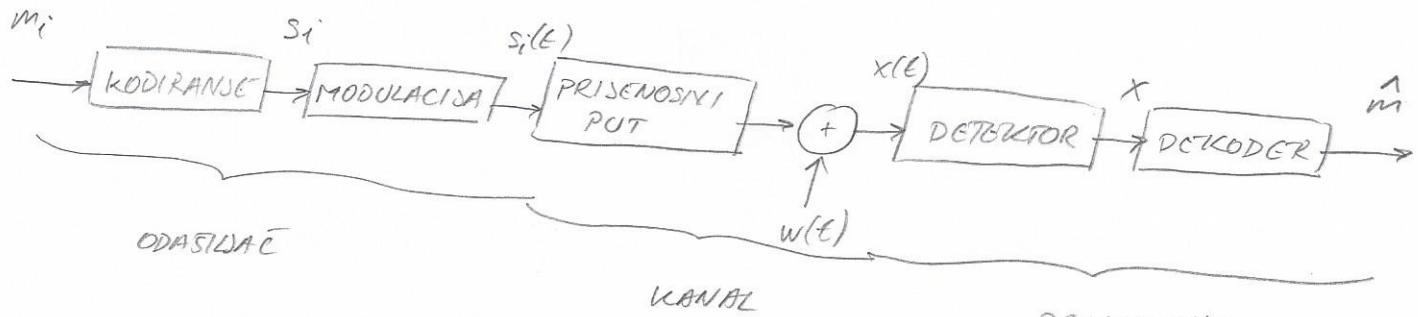
$$P_e = P_0 P_{eo} + p_1 P_{e1}$$

$$P_0 = p_0 = \frac{1}{2}$$

$$P_e = \frac{1}{2} \operatorname{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)$$

dB





signali  $s_i(t)$  mogu se prikazati kao linearne kombinacije funkcija  $\phi_j(t)$

$$s_i(t) = \sum_{j=1}^N s_{ij} \phi_j(t), \quad 0 \leq t \leq T_b, \quad \text{- modulator}$$

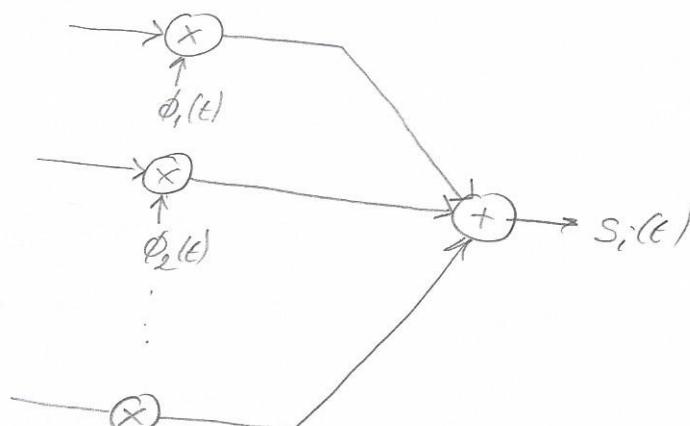
pri čemu

$$\int_0^{T_b} \phi_m \phi_j dt = \begin{cases} 1 & i=j \\ 0 & i \neq j \end{cases}$$

$$s_{ij} = \int_0^{T_b} s_i(t) \phi_j(t) dt \quad \text{demodulator}$$

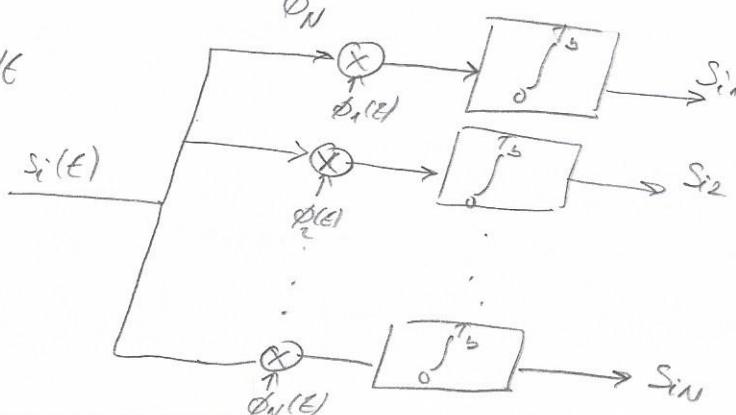
### MODULATOR

$$s_i(t) = \sum_{j=1}^N s_{ij} \phi_j(t)$$



### DEMODULATOR

$$s_{ij} = \int_0^{T_b} s_i(t) \phi_j(t) dt$$



$$\phi_i(t) = \frac{s_i(t)}{\sqrt{\int_0^{T_b} s_i^2(t) dt}} = \frac{s_i(t)}{\sqrt{E_i}}$$

energija signala  $s_i(t)$   
djeljeno s tim - normiranje baze

$$s_{ij} = \int_0^{T_b} s_i(t) \phi_j(t) dt \Rightarrow s_{21} = \int_0^{T_b} s_2(t) \phi_1(t) dt$$

$$g_e(t) = s_e(t) - s_{21} \phi_1(t)$$

$$\phi_2(t) = \frac{g_e(t)}{\sqrt{\int_0^{T_b} g_e^2(t) dt}}$$

$\therefore g_i(t) = s_i(t) - \sum_{j=1}^{i-1} s_{ij} \phi_j(t), s_{ij} = \int_0^{T_b} s_i(t) \phi_j(t) dt$

$$\phi_i(t) = \frac{g_i(t)}{\sqrt{\int_0^{T_b} g_i^2(t) dt}}$$

(86.)

VEKTOR SIGNALA

- svaki signal može se opisati vektorom  $s_i = \begin{bmatrix} s_{i1} \\ s_{i2} \\ \vdots \\ s_{iN} \end{bmatrix}$  koji se zove vektor signala

PROSTOR SIGNALA -  $N$ -dimenzionalni prostor u kojem se nalaze vektori signalaTOČKA PORUKE - točka u prostoru koju određuje vektor  $s_i$ 

KONSTRUKCIJA - skup svih točaka u prostoru

$x(t) = s_i(t) + w(t) \Rightarrow x = s_i + w$  - vektor  $s_i$  se ponosi za vektor sume zbroja uticaja svim kanalima se maximum likelihood deoder, kod AWGN ujimanja vektor  $x$  se pripisuje onoj točki poruke koja je udaljenost

$$d_M = \|x - s_{rd}\| = \sqrt{\sum_{j=1}^N (x_j - s_{rj})^2}$$

GRANICA ODLUKE - sredina između dve točke poruke

(87.)

PSK - phase shifting keying,  $M=2$ 

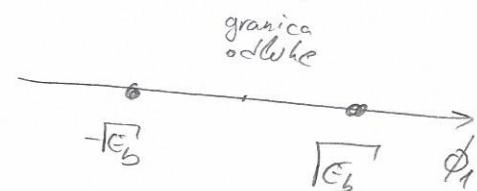
$$s_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_0 t)$$

$$s_2(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_0 t + \pi) = -\sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_0 t)$$

 $N=1$  - jedna funkcija baze

$$\phi_1(t) = \sqrt{\frac{2}{T_b}} \cos(2\pi f_0 t)$$

PROSTOR SIGNALA (1D)



(88.)

FSK - frequency shift keying,  $M=2$ 

$$s_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_1 t)$$

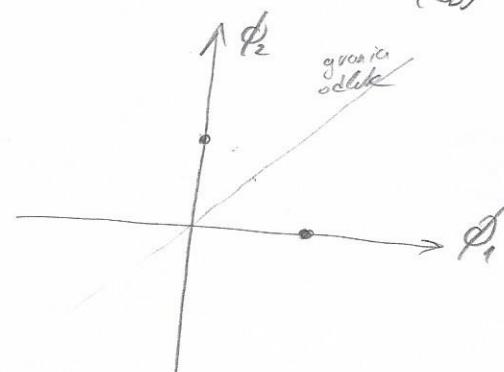
$$s_2(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_2 t)$$

 $N=2$ 

$$\phi_1(t) = \sqrt{\frac{2}{T_b}} \cos(2\pi f_1 t)$$

$$\phi_2(t) = \sqrt{\frac{2}{T_b}} \cos(2\pi f_2 t)$$

PROSTOR SIGNALA (2D)



(89.)

QPSK - quadri phase shift keying,  $M=4$ 

$$s_1(t) = \sqrt{\frac{2E_s}{T_s}} \cos(2\pi f_0 t + \frac{\pi}{4})$$

energija simbola

$$T_s = 2T_b, E_s = 2E_b$$

prvočasni simbol dva bita

$$s_2(t) = \sqrt{\frac{2E_s}{T_s}} \cos(2\pi f_0 t + \frac{3\pi}{4})$$

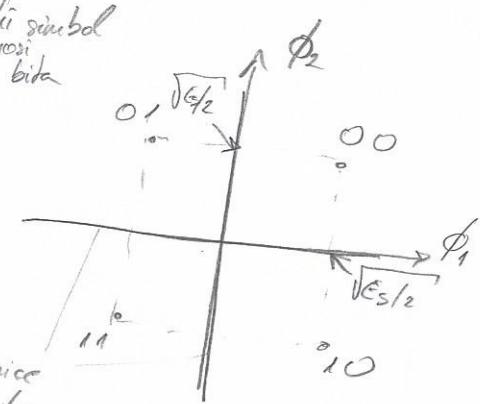
trajanje simbola

$$\phi_1(t) = \sqrt{\frac{2}{T_s}} \cos(2\pi f_0 t)$$

$$s_3(t) = \sqrt{\frac{2E_s}{T_s}} \cos(2\pi f_0 t + \frac{5\pi}{4})$$

$$\phi_2(t) = \sqrt{\frac{2}{T_s}} \sin(2\pi f_0 t)$$

$$s_4(t) = \sqrt{\frac{2E_s}{T_s}} \cos(2\pi f_0 t + \frac{7\pi}{4})$$



simboli su takođe dodijeljeni po  
Grayevom kode - susjedni bitovi imaju Hammingovu  
dodjelu

(90)

$$s_i(t) = \sum_{j=1}^N s_{ij} \phi_j(t) \quad i=1,2$$

$$s_i(t) = s_{i1} \phi_1(t) + s_{i2} \phi_2(t)$$

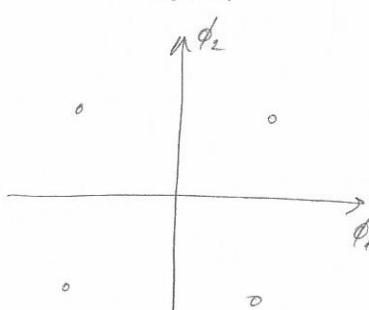
$$s_i(t) = s_{i1} \sqrt{\frac{2}{T_b}} \cos(2\pi f_c t) + s_{i2} \sqrt{\frac{2}{T_b}} \sin(2\pi f_c t)$$

$$s_i(t) = A_{mI} \cos(2\pi f_c t) + A_{mQ} \sin(2\pi f_c t)$$

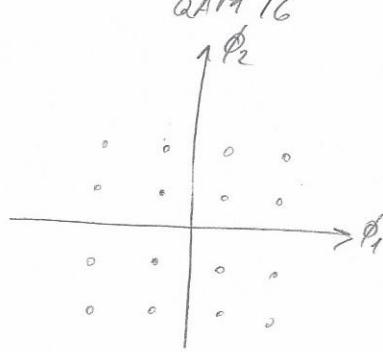
$$s_i(t) = \operatorname{Re} \left[ (A_{mI} + A_{mQ}) e^{-j2\pi f_c t} \right]$$

$$s_i(t) = \operatorname{Re} \left[ A_c e^{-j2\pi f_c t} \right]$$

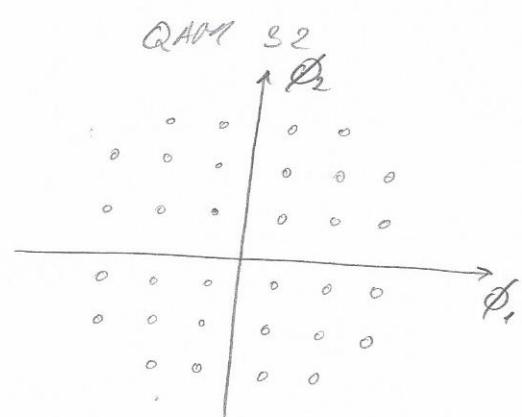
QAM4



QAM16

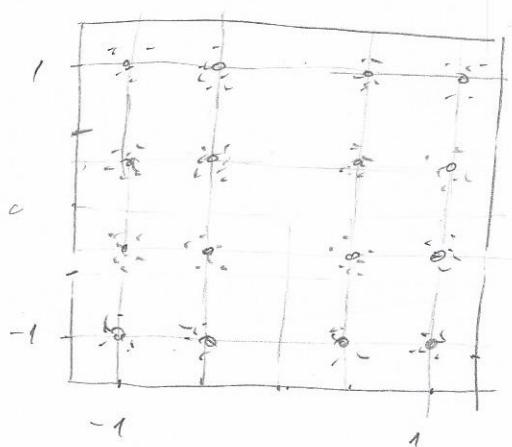


QAM32



(91.)

Sum - ozrajuje rasporede točaka prostora u konstelaciji



Zgrosba u sinkronizaciji - ozrajuje zadržanje ravnine konstelacije

