DBBT
Digital Broadcasting &
Broadband Technologies

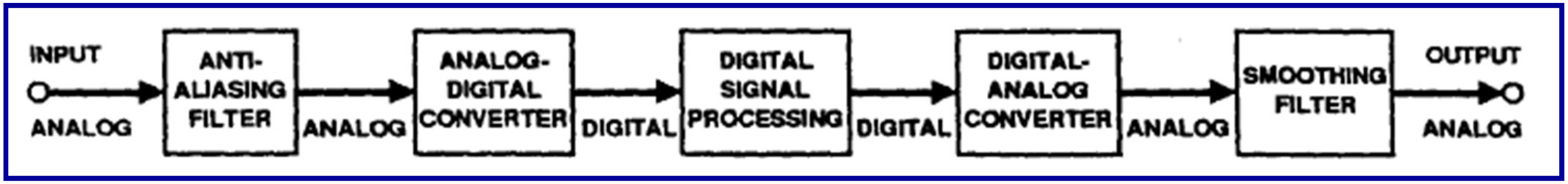
Co-funded by the
Erasmus+ Programme
of the European Union

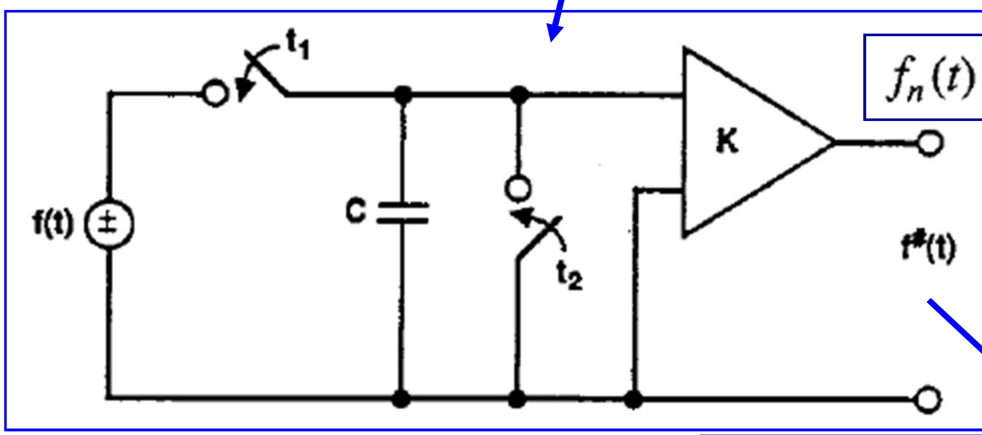
Procesiranje signala

Profesor dr Miroslav Lutovac

"This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein"

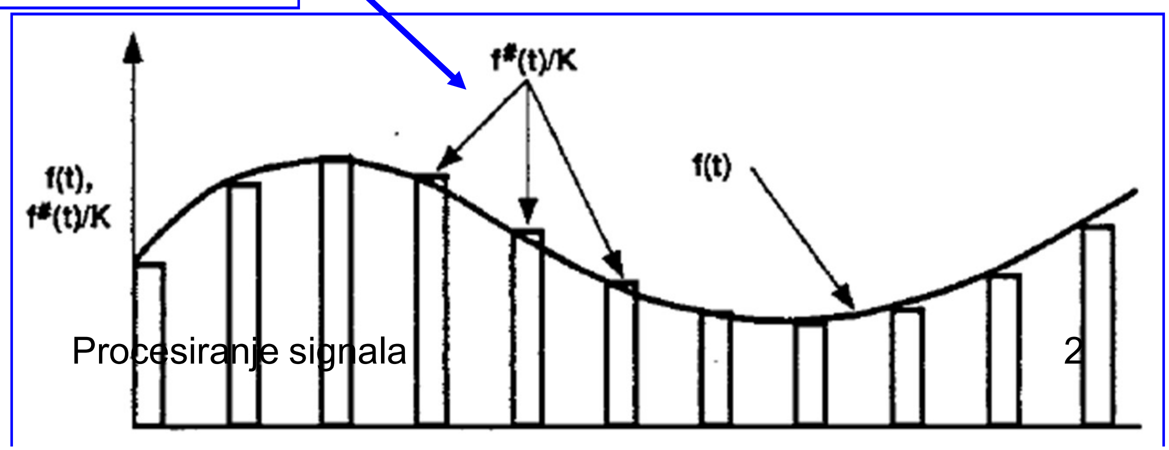
DSP sistem za obradu analognog signala



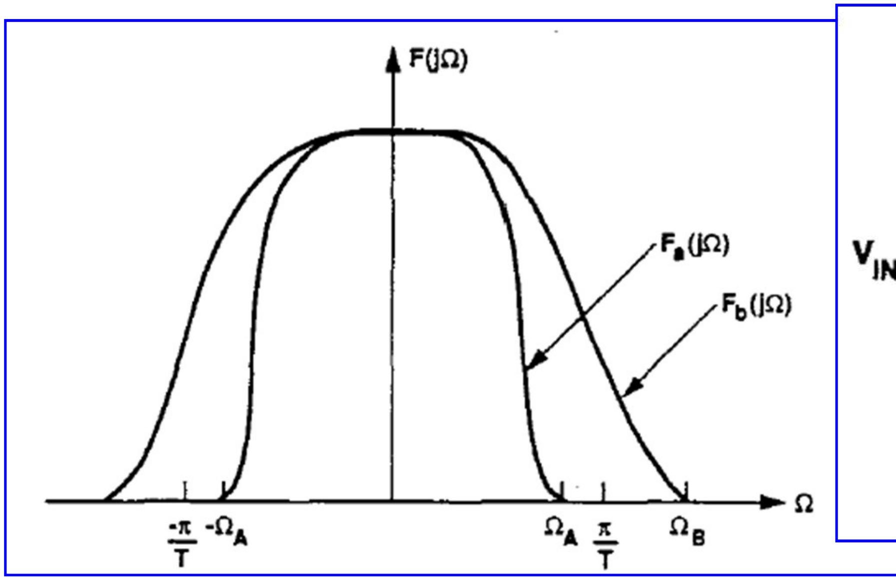


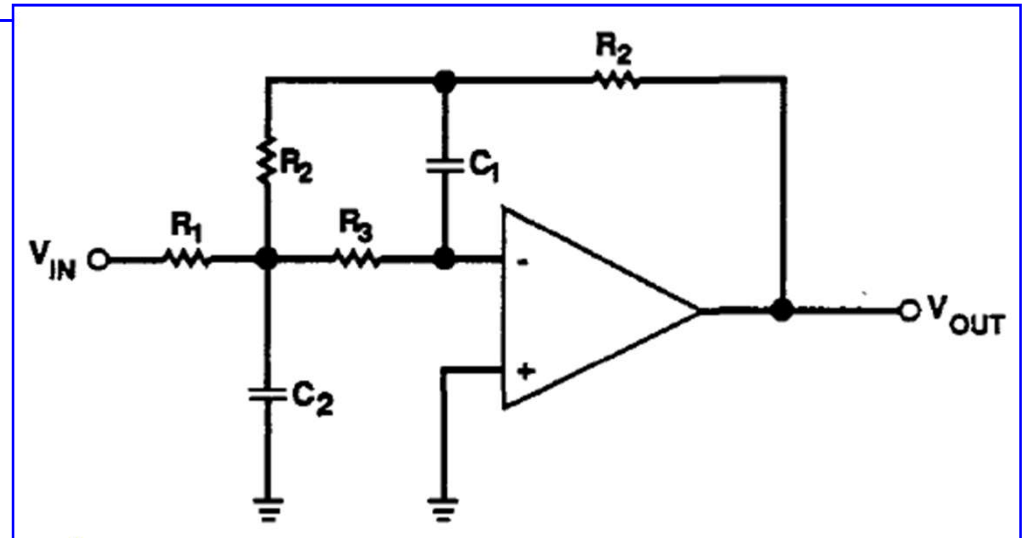
$$f_n(t) = kf(nT)[\mu(t - nT) - \mu(t - nT - \tau)]$$

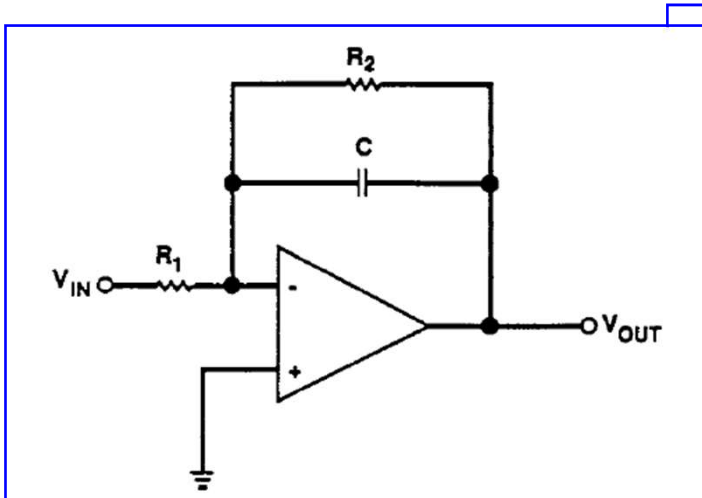
$$\mu(t) \equiv \begin{cases} 1, & t \geq 0, \\ 0, & t < 0. \end{cases}$$

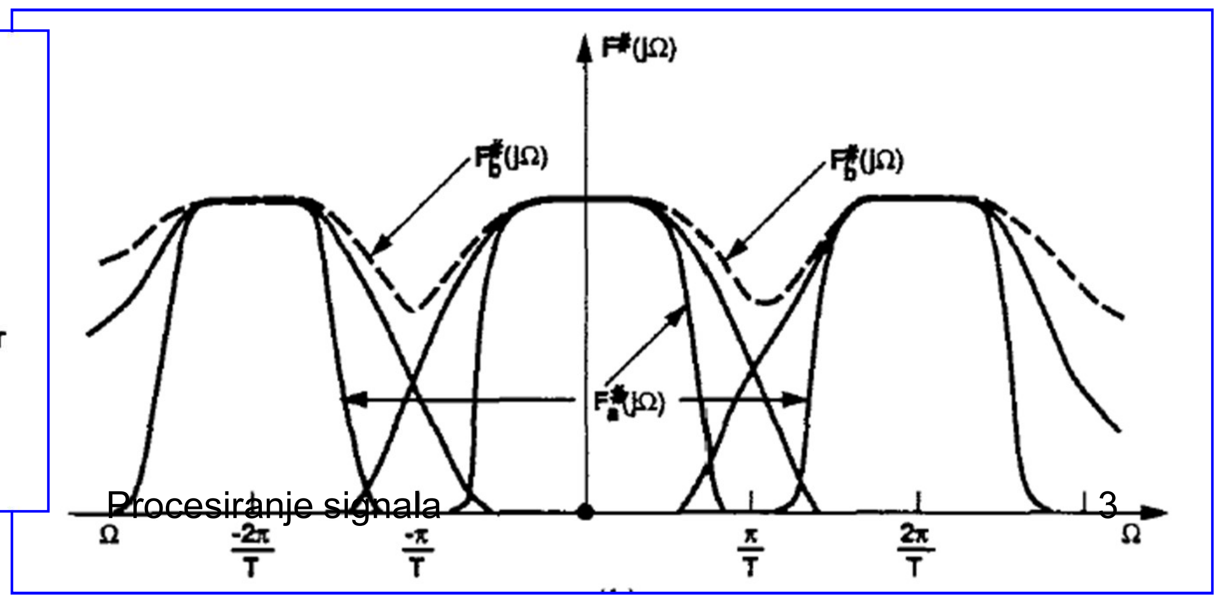


Analogni filtar









Odnos signal-šum (SNR)

$$\mathrm{SNR} = 6n + 1.8\,\mathrm{dB}$$

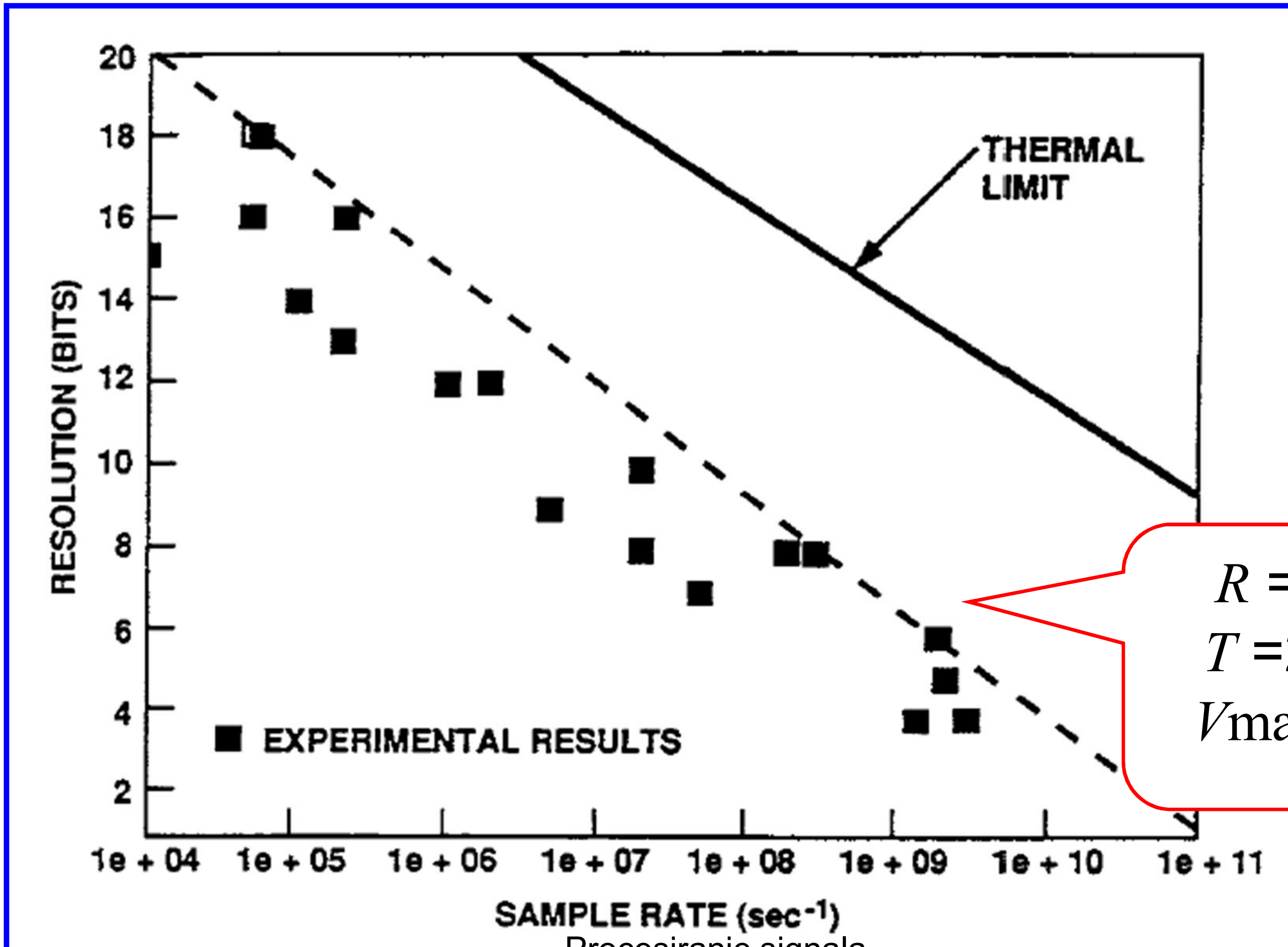
n je broj bita,
za ceo opseg učestanosti
od 0 do *Fs*/2

Odnos signal-šum (SNR)

$$N_{\max} = \log_2 \sqrt{\frac{V_{\max}^2}{8kTR\,\Delta f}}$$

R je imedansa na ulazu,
T je temperature,
Δf je opseg učestanosti,
k je Bolcmanova konstanta

Dinamički opseg – frekvencijski opseg



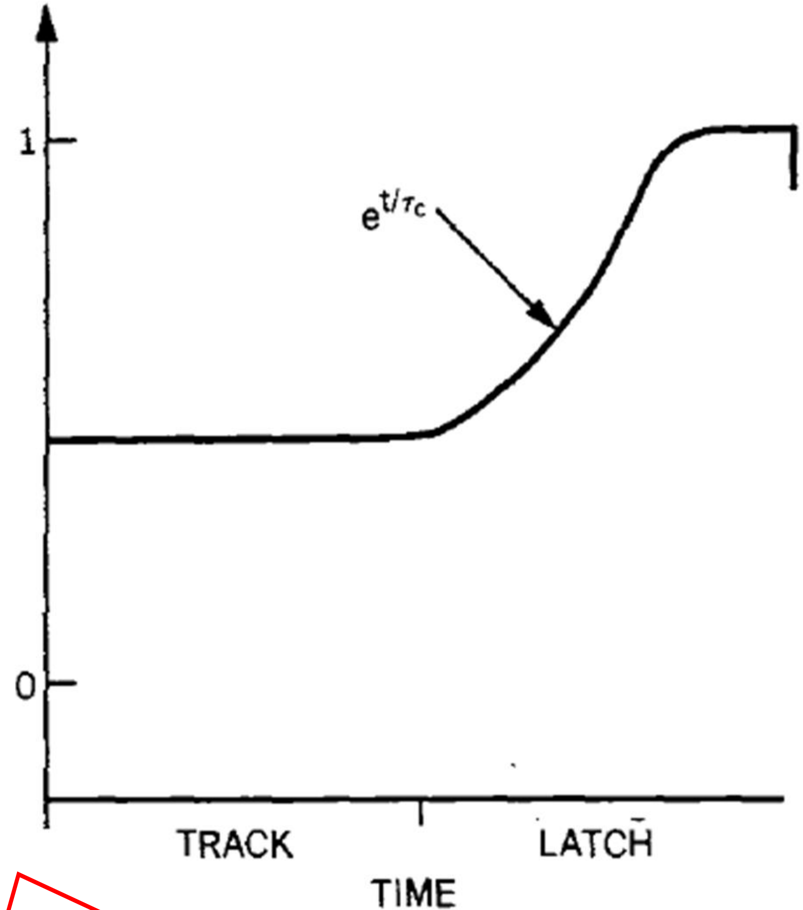
R =50 Ω,
T =270 K,
Vmax = 1V

Degradacija SNR zbog džitera

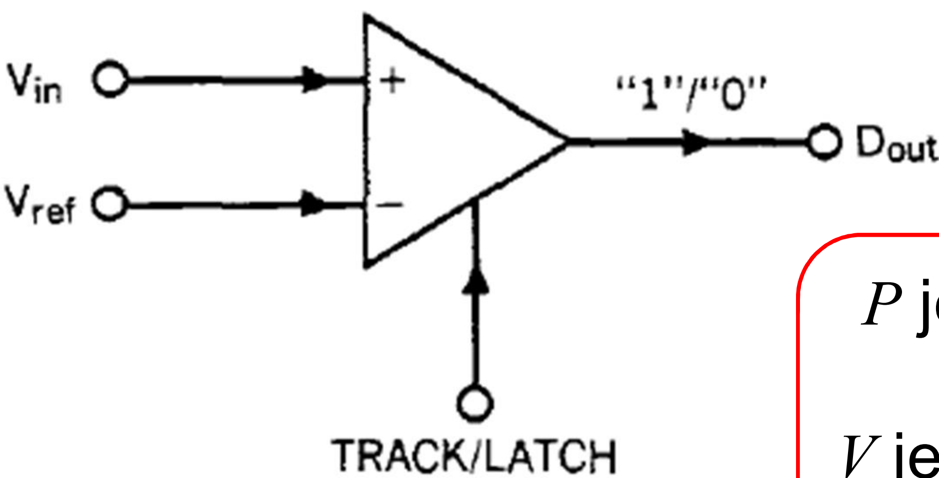
$$2^N f_{sig} \tau_a \le 1$$

τ_a je rms džitera,
f_{sig} je maksimalna učestanost

Degradacija SNR

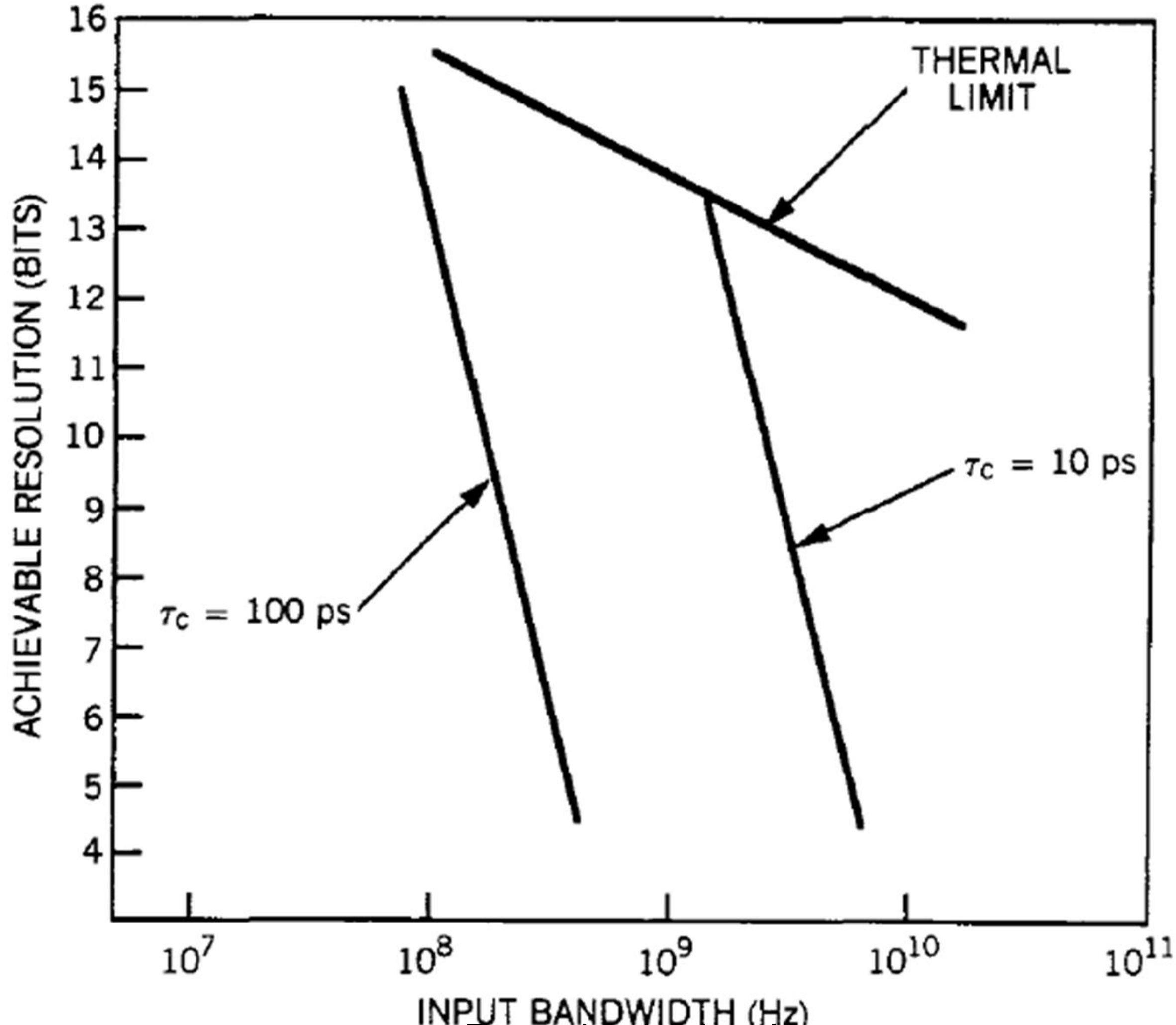


$$P_i = \frac{2V_L}{A_0 q} e^{-t/\tau_c}$$



P je verovatnoća degradacije,
A je pojačanje,
V je napon izlaza (logike),
τ je vreme regeneracije

Ostvarljiva rezolucija



Degradacija SNR

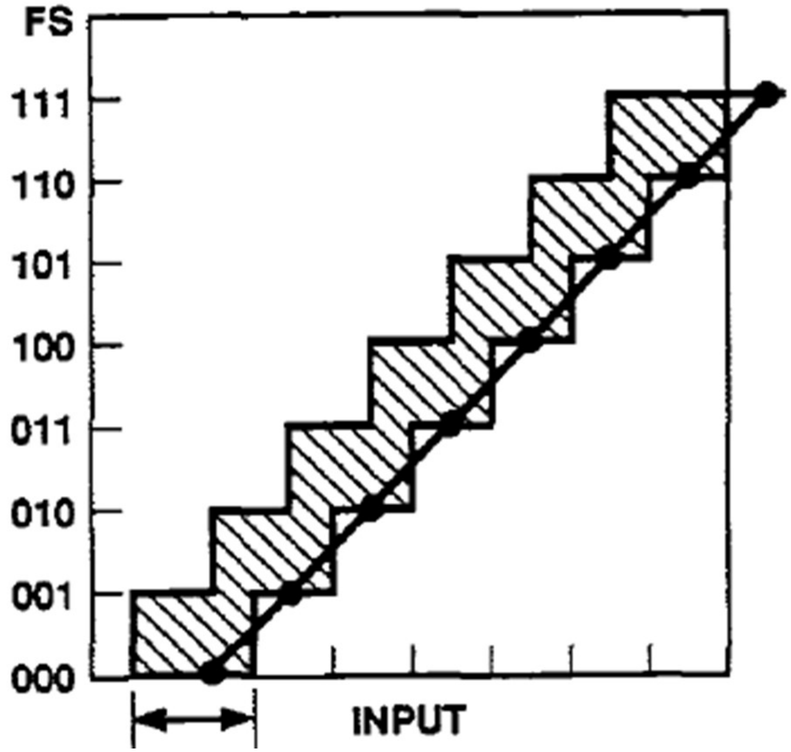
Vreme regeneracije komparatora,

Neidealni elementi (R, C, pojačanje)

Nelinearnost ulaz-izlaz

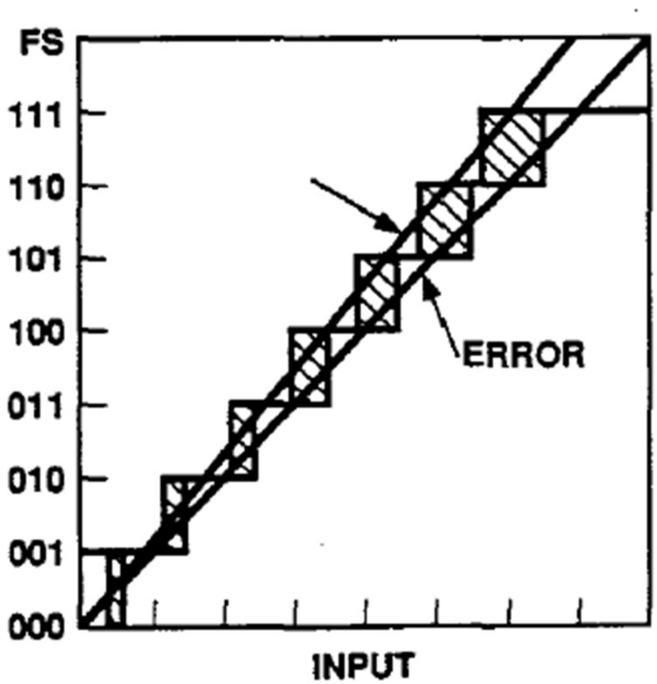
Differential nonlinearity (DNL)	The maximum difference between any actual step and the ideal step size (1 LSB)
Integral nonlinearity (INL)	The maximum difference between the conversion curve and a straight-line reference
Monotonicity	Larger input gives larger output
Absolute linearity	Maximum difference between ideal and actual characteristics, including offset and gain errors
Missing code in A/D converter	Some digital codes cannot be generated

Statičke greške



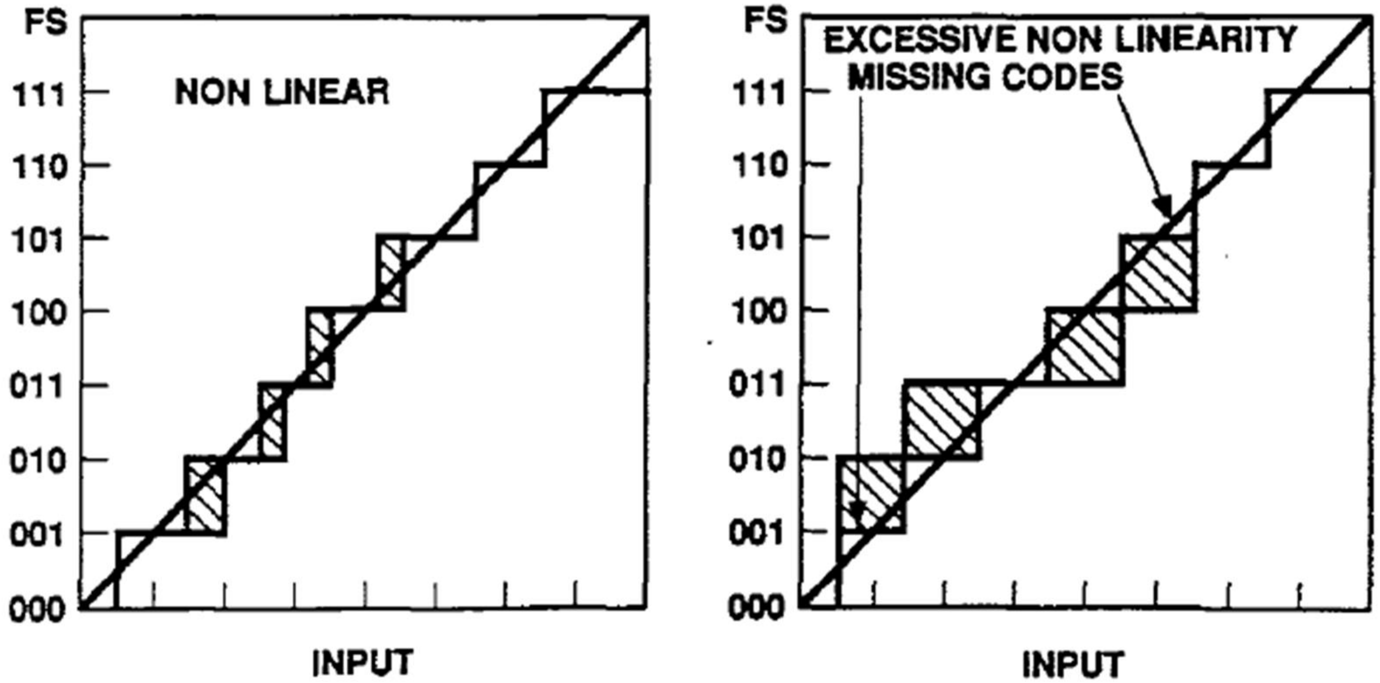
ofset

Statičke greške



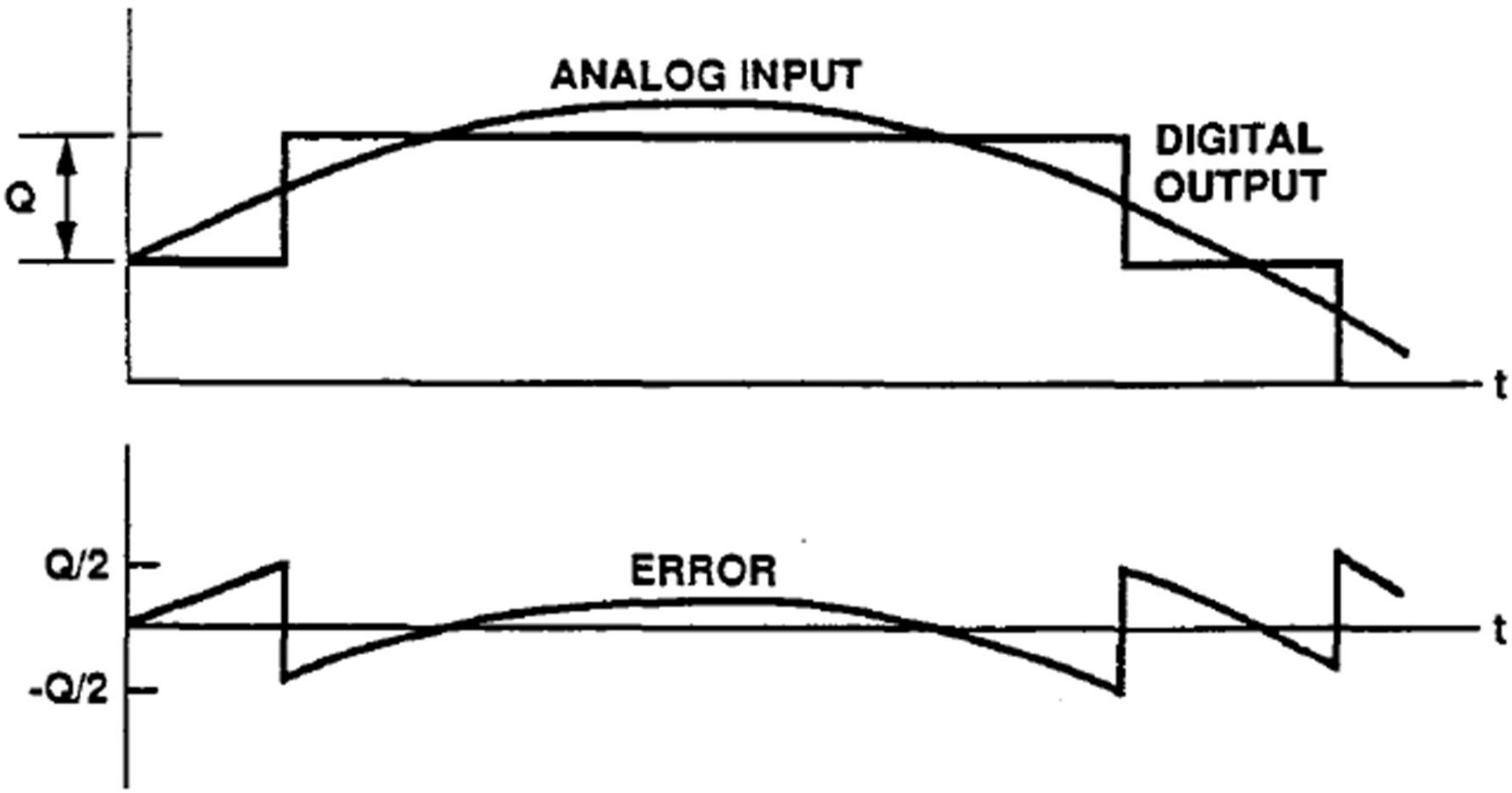
pojačanje

Statičke greške



nelinearnost

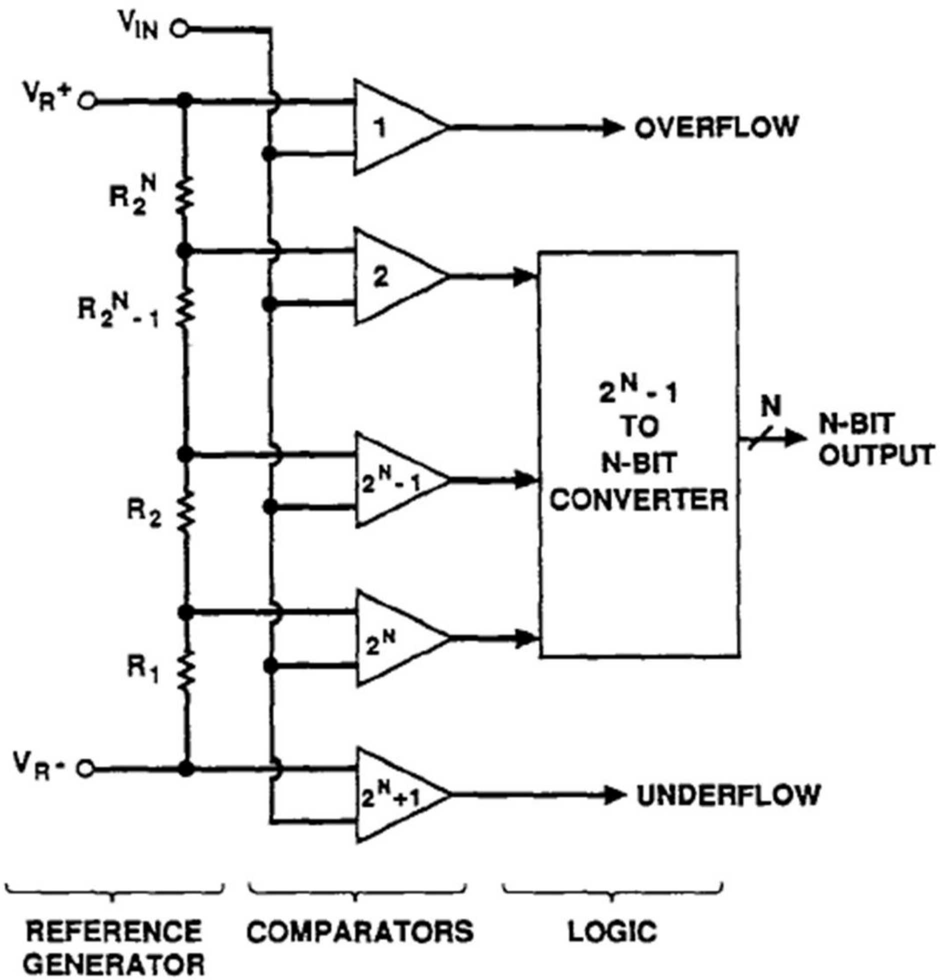
Greška kvantizacije



Vrste ADC

- Flash – paralelni
- Pipelining – protočni
- Uzastopna aproksimacija
- Sa nadodabiranjem (delta - sigma)
- Serijski
- Sa brojanjem

Flash



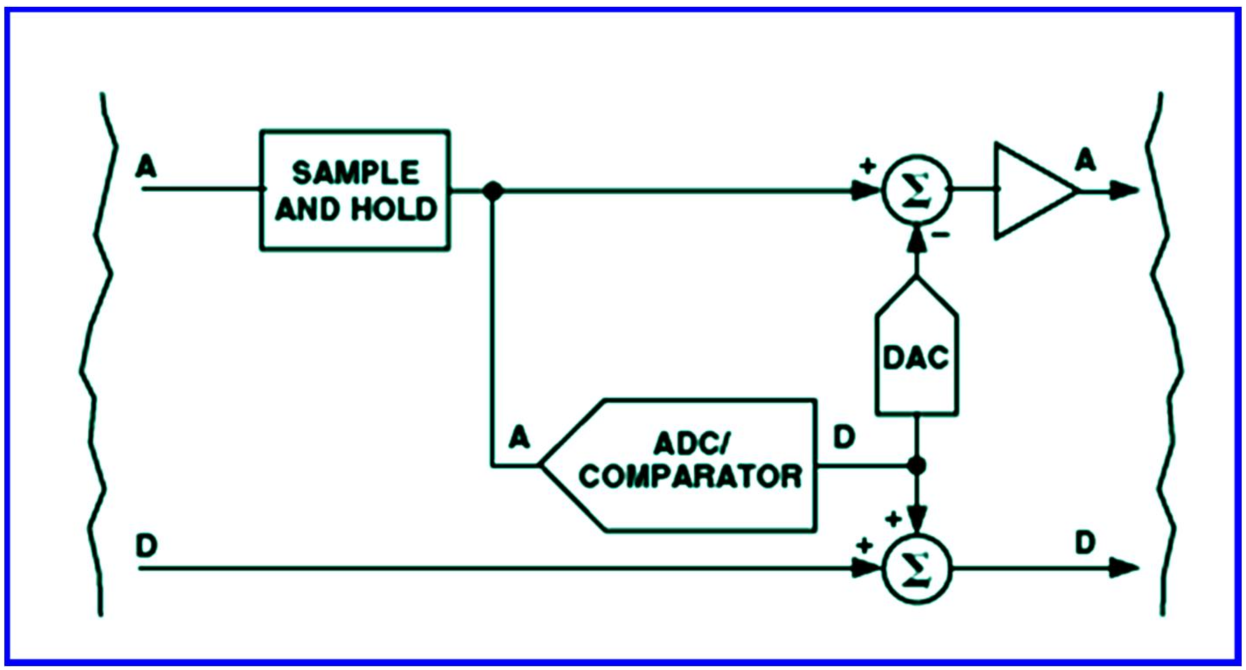
1. Referentni naponi
2. Komparatori
3. Logika za konverziju u binarni format

- u jednom ciklusu (trenutno)
- 2^N-1 komparatora
  4 b – 15 komparatora
  16 b – 65535 komparatora

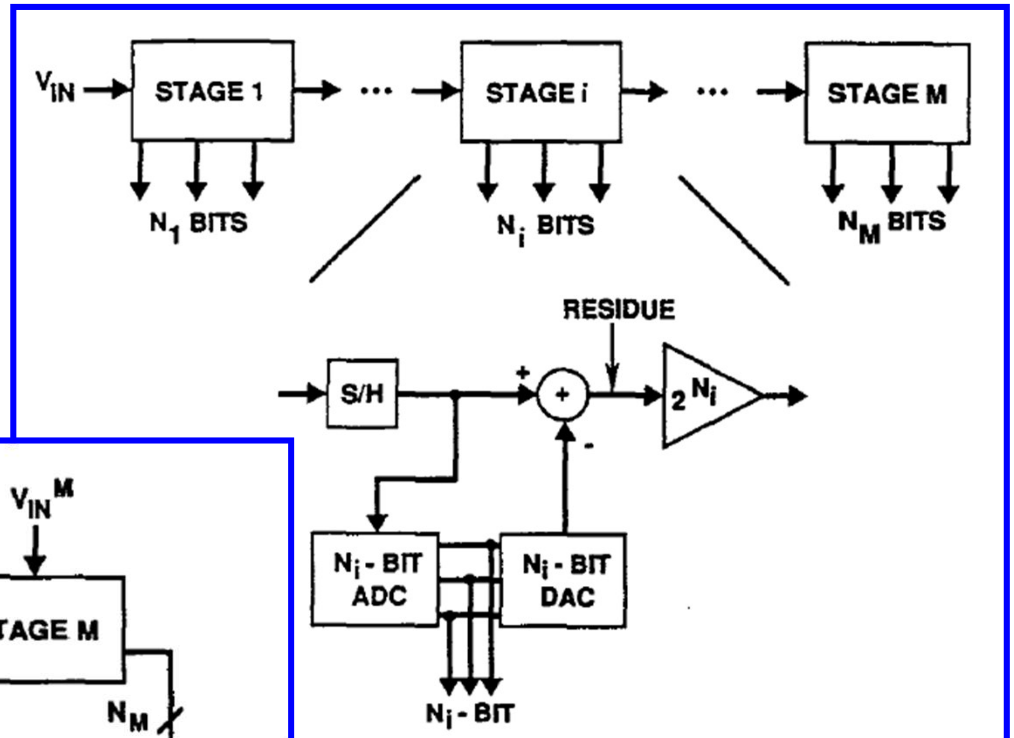
Protočni

- P*2^N-1 komparatora
  P=2, N=3 – 30 k.
  P=4, N=16 – 60 k.

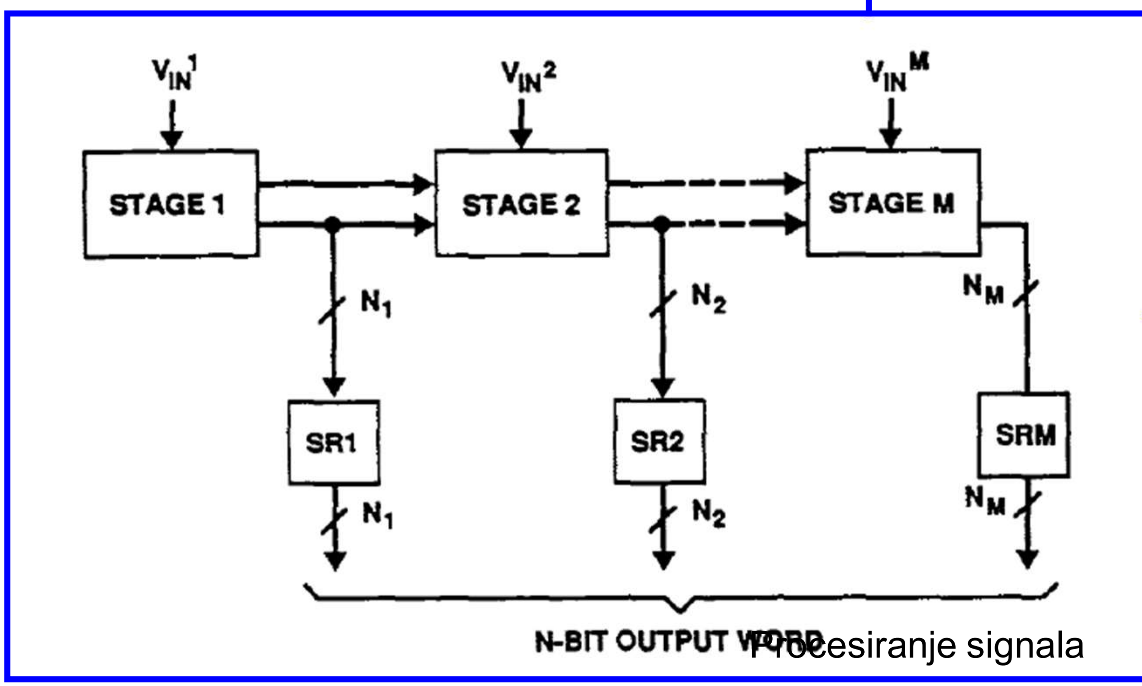
- Kašnjenje
- Vreme procesiranja



Protočni

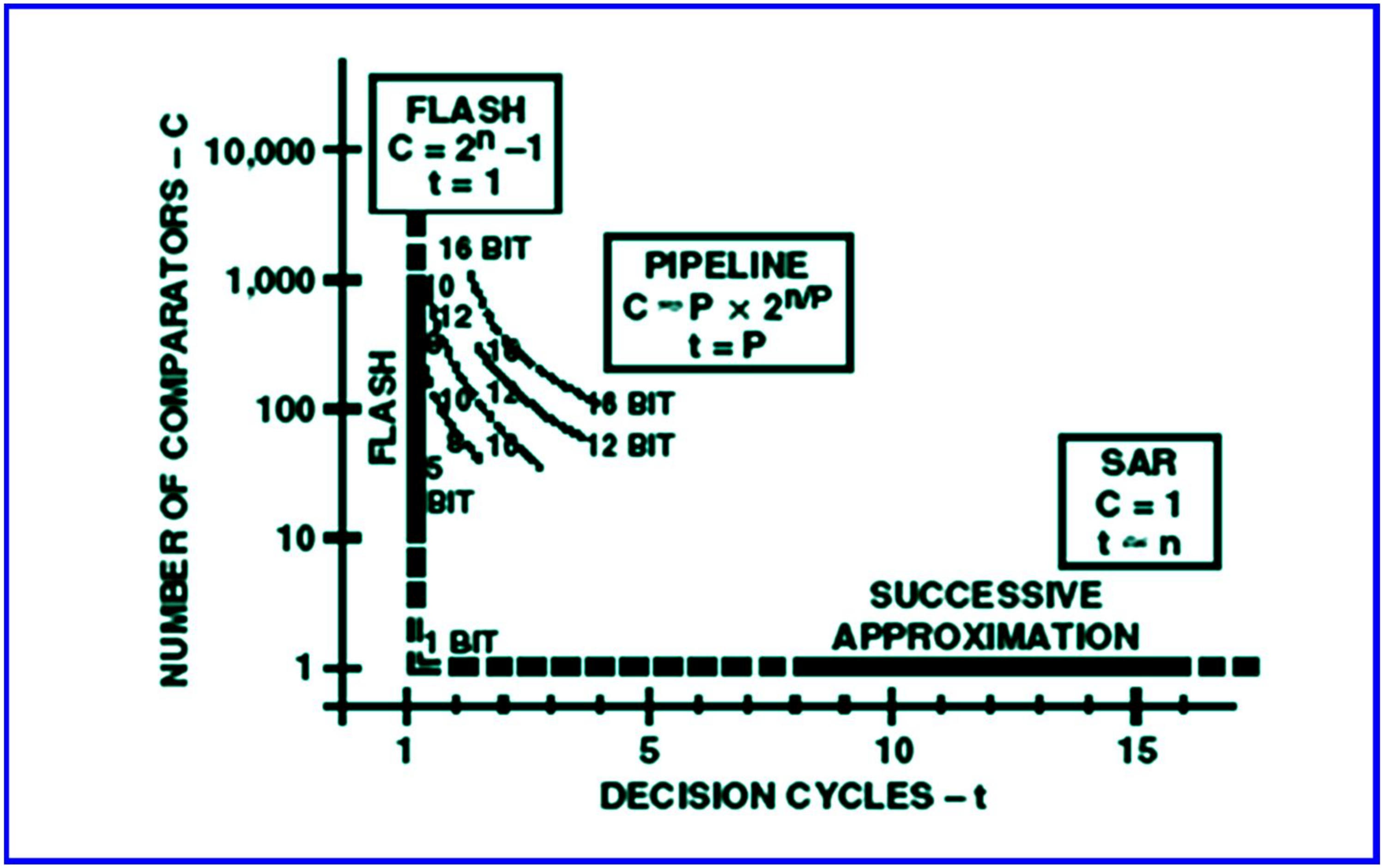


V_{IN}
STAGE 1
STAGE i
STAGE M
N_1 BITS
N_i BITS
N_M BITS
RESIDUE
S/H
+
-
2^{N_i}
N_i - BIT ADC
N_i - BIT DAC
N_i - BIT

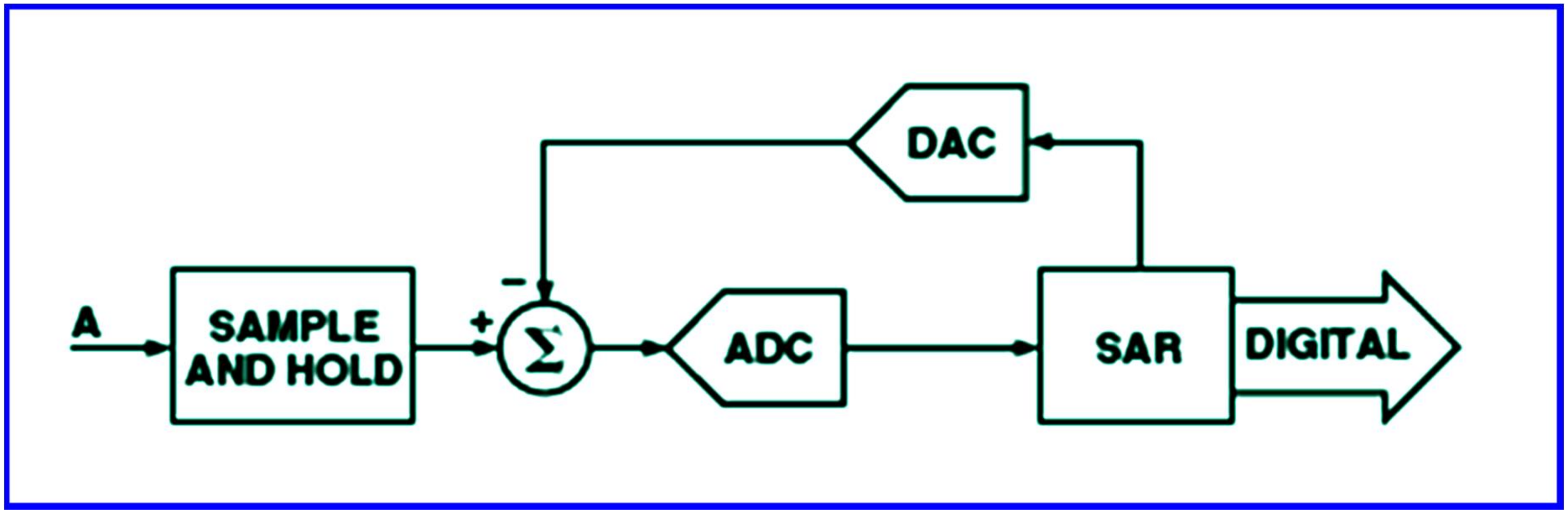


V_{IN}^1
V_{IN}^2
V_{IN}^M
STAGE 1
STAGE 2
STAGE M
N_1
N_2
N_M
SR1
SR2
SRM
N-BIT OUTPUT WORD

Broj komparatora – broj ciklusa



Uzastopna aproksimacija

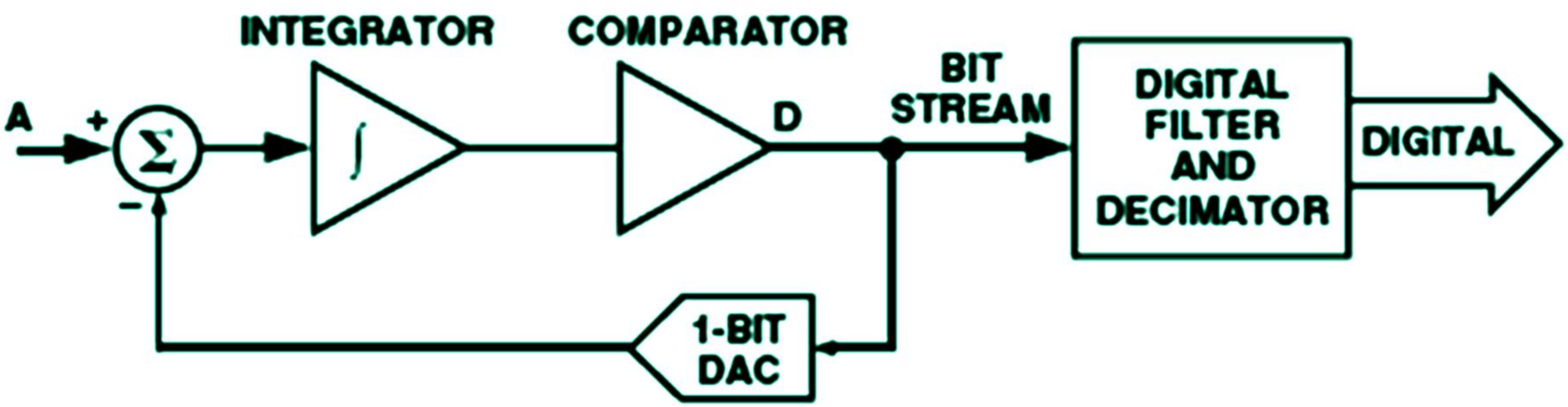


Serija koraka se ponavlja n puta tako da se koriste različiti težinski faktori

Poboljšana rezolucija za 1/2bita

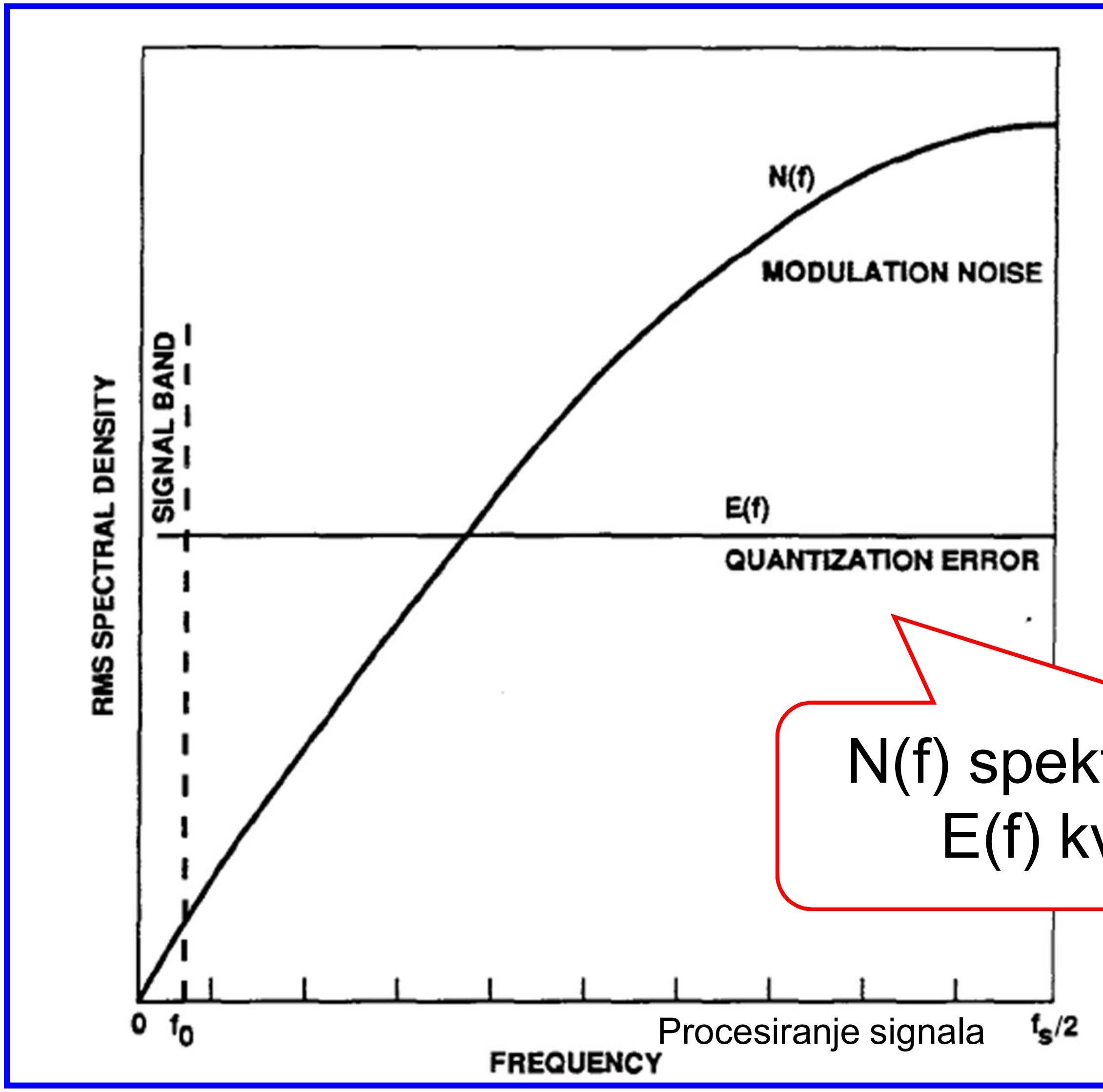
SAR successive approximations (shift) register

Sigma-delta



Analog-to-Digital Converter Architectures and Choices for System Design, Brian Black, Analog Dialogue, 1999.

Spektralna gustina šuma



N(f) spektralna gustina šuma
E(f) kvantizacioni šum

Primer 1

- 4 kanala, 16 bita,
  3 opsega od 0 do 15 kHz
  1 opseg od 0 do 45 kHz
- Učestanost odabiranja
  (2×15+2×15+2×15+2×45) kHz =180 kHz

Converter	Architecture	Total Throughput (16-Bit Resolution)	Effective Multiplexed Throughput	Converters Needed for Application
AD974	SAR	200 kSPS	200 kSPS	1
AD7722	Sigma-Delta	195 kSPS	2.3 kSPS	4
AD9260	Pipelined/ Sigma-Delta	2500 kSPS	75 kSPS	3

Primer 2

- 16 kanala, 14 bita, opseg od 0 do 100 kHz
- Učestanost odabiranja
  (2×100×16) kHz = 3.2 MHz

Converter	Architecture	Total Throughput (14-Bit Resolution)	Effective Multiplexed Throughput	Converters Needed for Application
AD7865	SAR	416 kSPS	416 kSPS	8
AD7722	Sigma-Delta	220 kSPS	2.3 kSPS	16
AD9240	Pipelined	10 MSPS	10 MSPS	1

Uporedne karakteristike

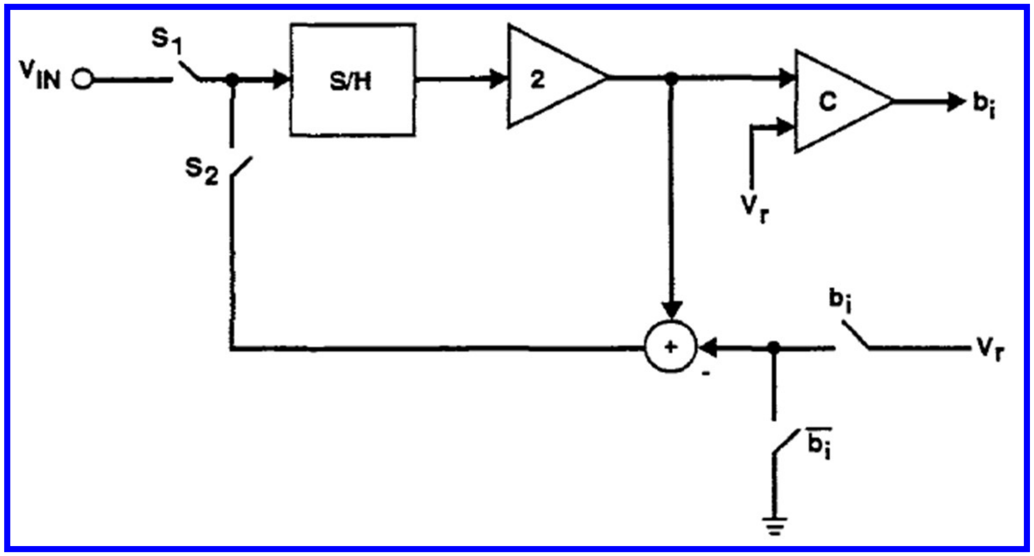
Characteristic	Flash	Pipelined	SAR	Sigma-Delta
Throughput	1	2	3	4
Resolution (ENOB)	4	3	2	1
Latency	1	3	2	4
Suitability for converting multiple signals per ADC	1	2	1	3
Capability to convert non-periodic multiplexed signals	1	2	1	3
Simplified anti-aliasing				*
Can undersample	*	*	*	
Can increase resolution through averaging (with dither noise)	*	*	*	

Uporedne karakteristike

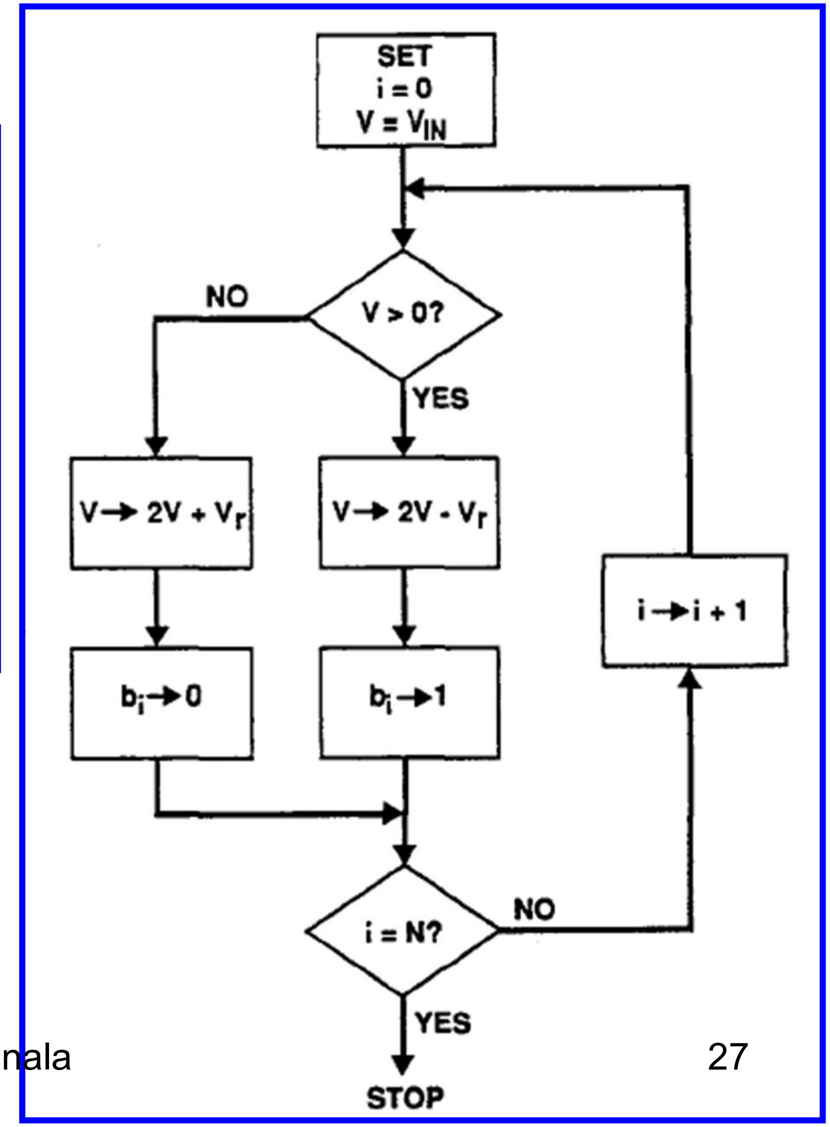
TABLE 10-2 Properties of Basic ADC Architectures

Converter Type	Minimum Number of Nyquist Periods per Sample	Typical Accuracy (bits)	Minimum Number of Analog Stages	Complexity of Digital Circuitry
Flash (half-flash)	1 (2)	8 (10)	2^N ($2^{N/2}$)	Medium
Pipeline/multiplexing	1, also N periods of delay (latency)	9	N	Medium
Serial	N	14	1	High
Oversampling	OSR ~ 128	16	1	Very high
Counting	2^N	18	1	Medium

Serijski

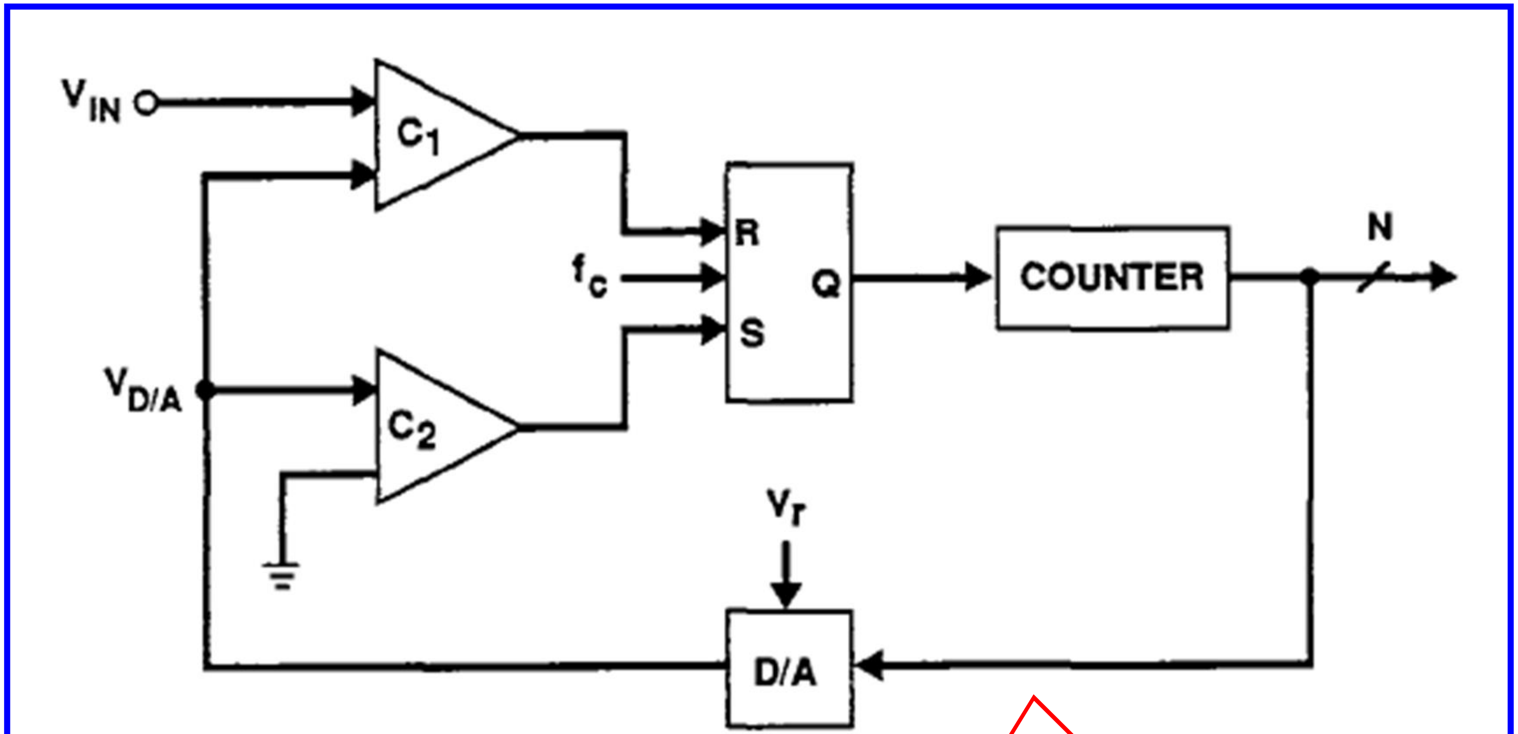


V_{IN}
S_1
S_2
S/H
2
C
b_i
V_r
b_i
V_r
+
-
$\overline{b_i}$



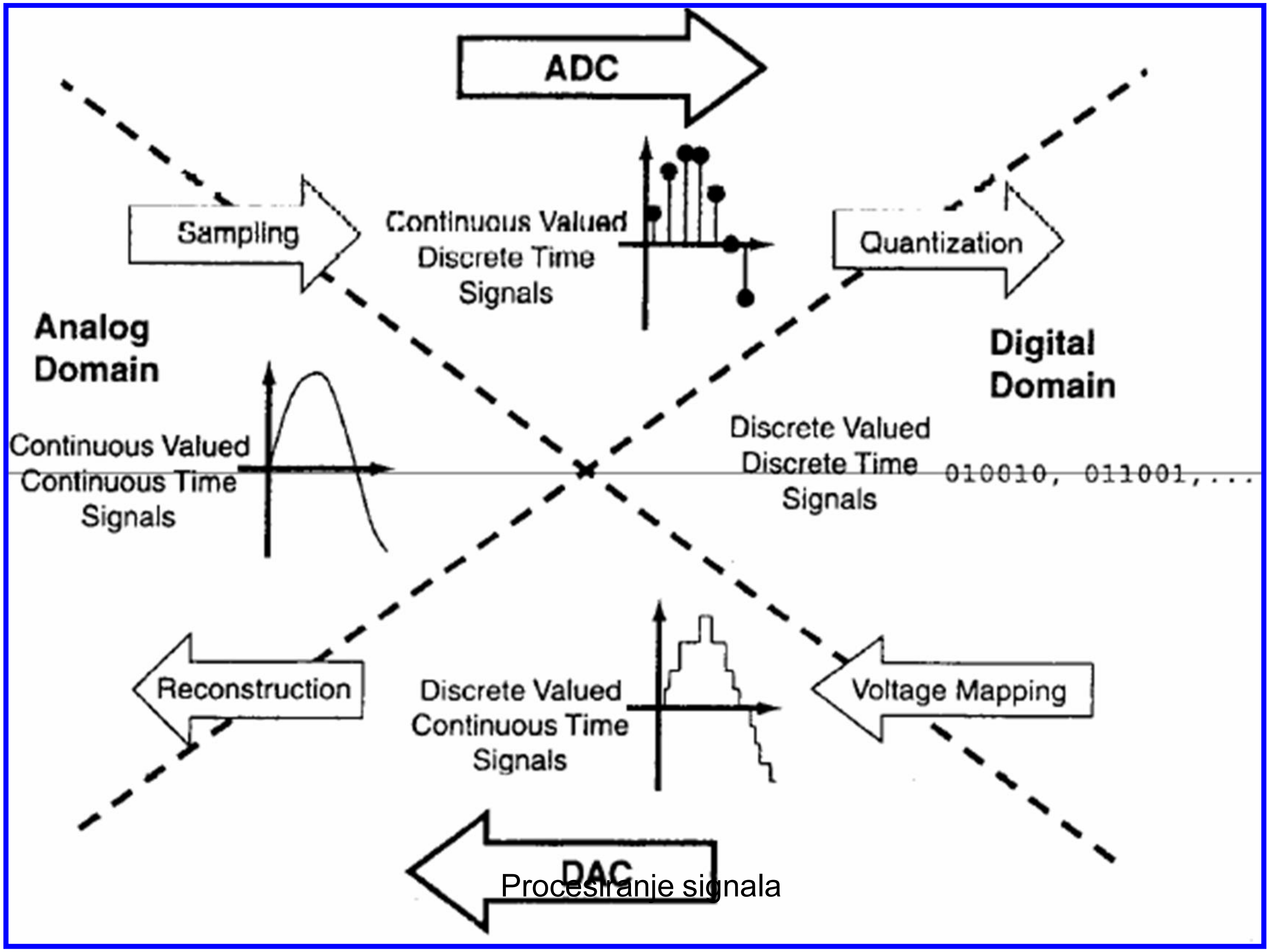
SET
i = 0
V = V_{IN}
V > 0?
NO
YES
V→ 2V + V_r
V→ 2V - V_r
b_i→0
b_i→1
i→i + 1
i = N?
NO
YES
STOP

Sa brojanjem

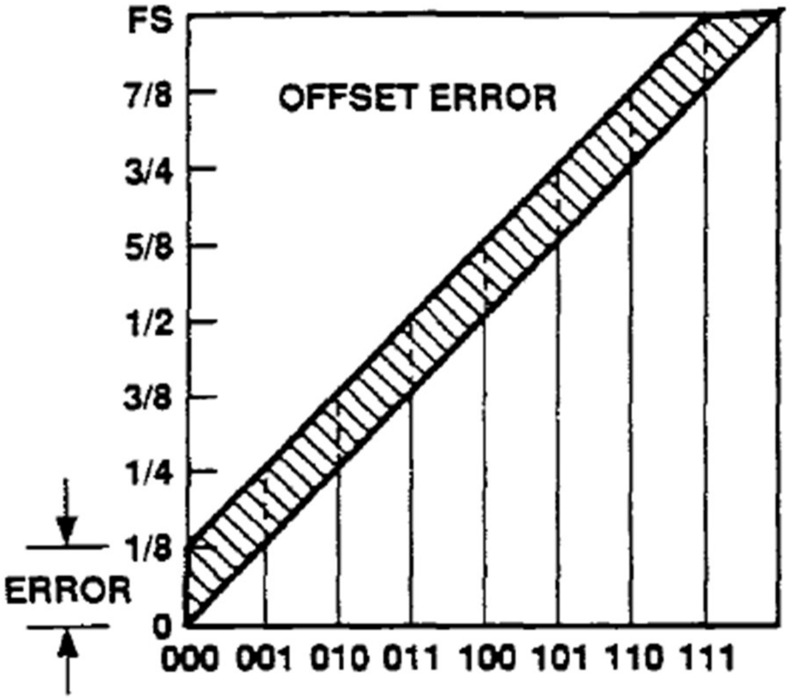


Najtačniji i najsporiji

D/A pretvarači

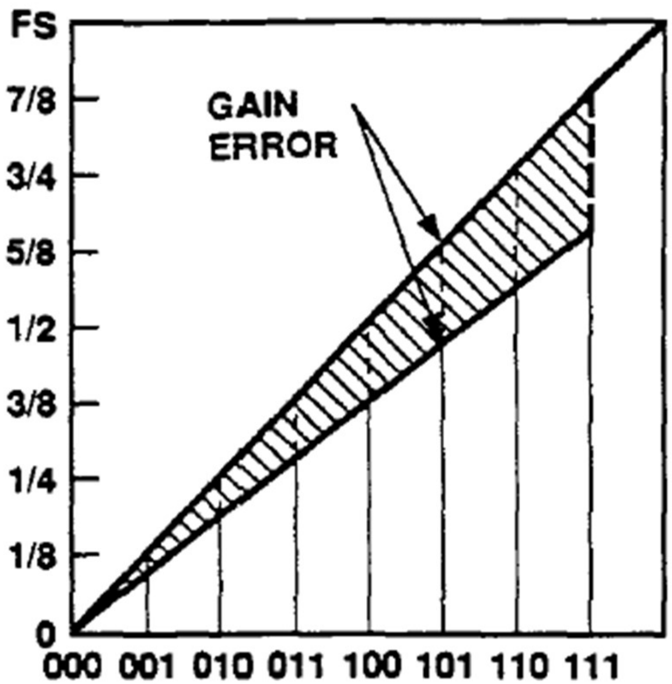


Statičke greške



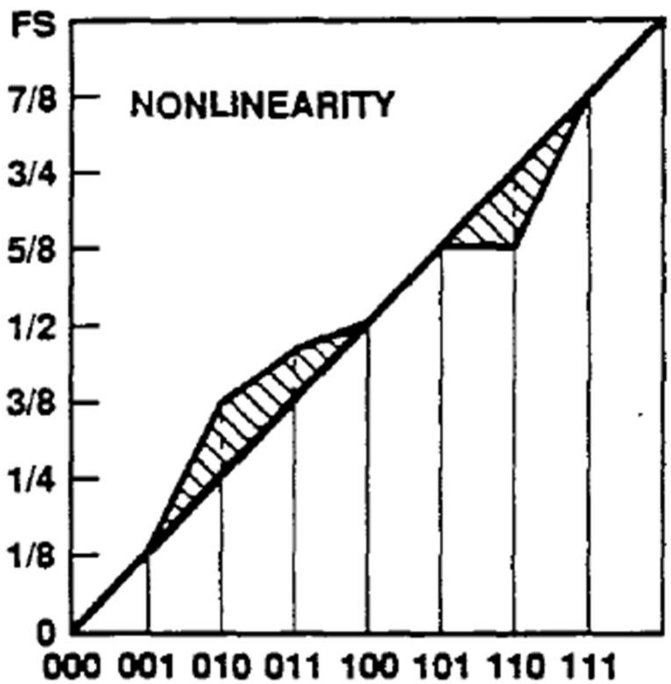
ofset

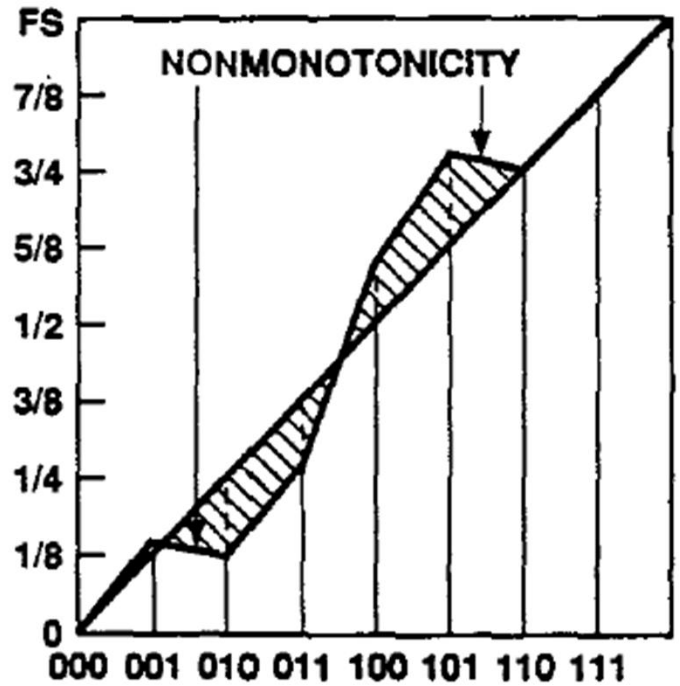
Statičke greške



pojačanje

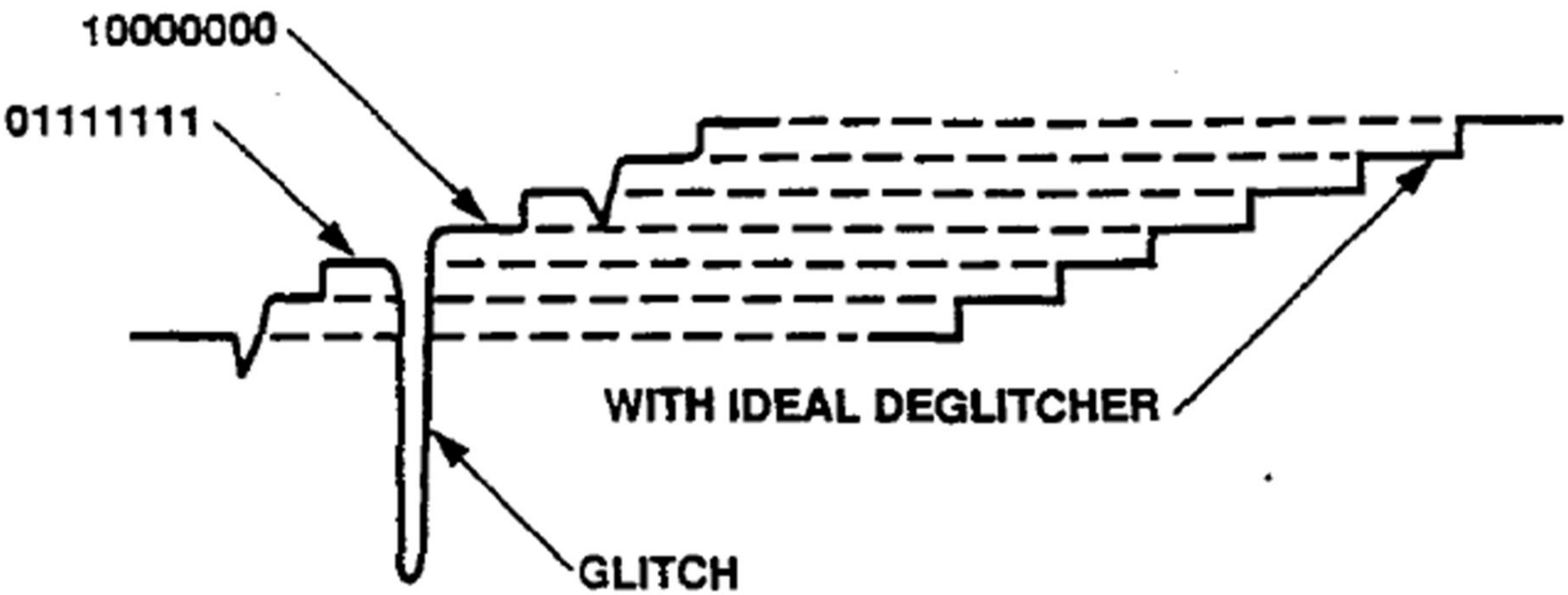
Statičke greške





nelinearnost

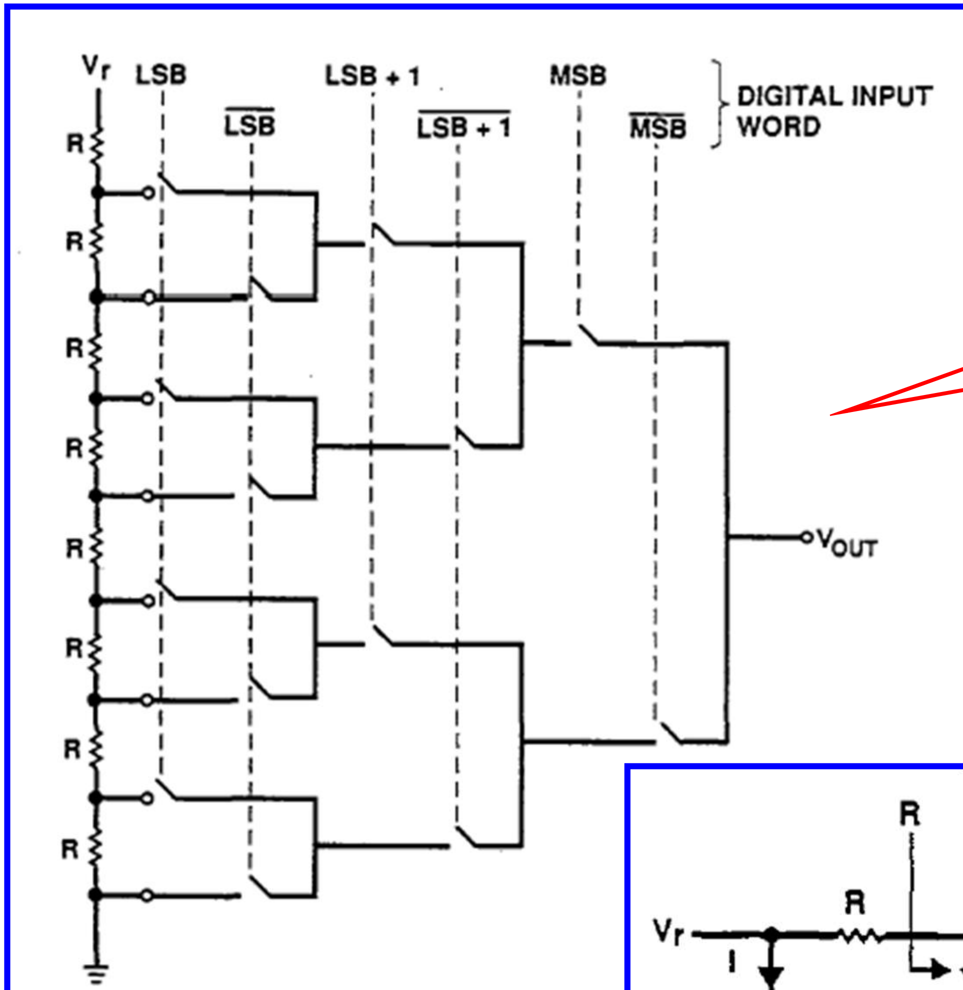
Gličevi



Arhitekture DAC

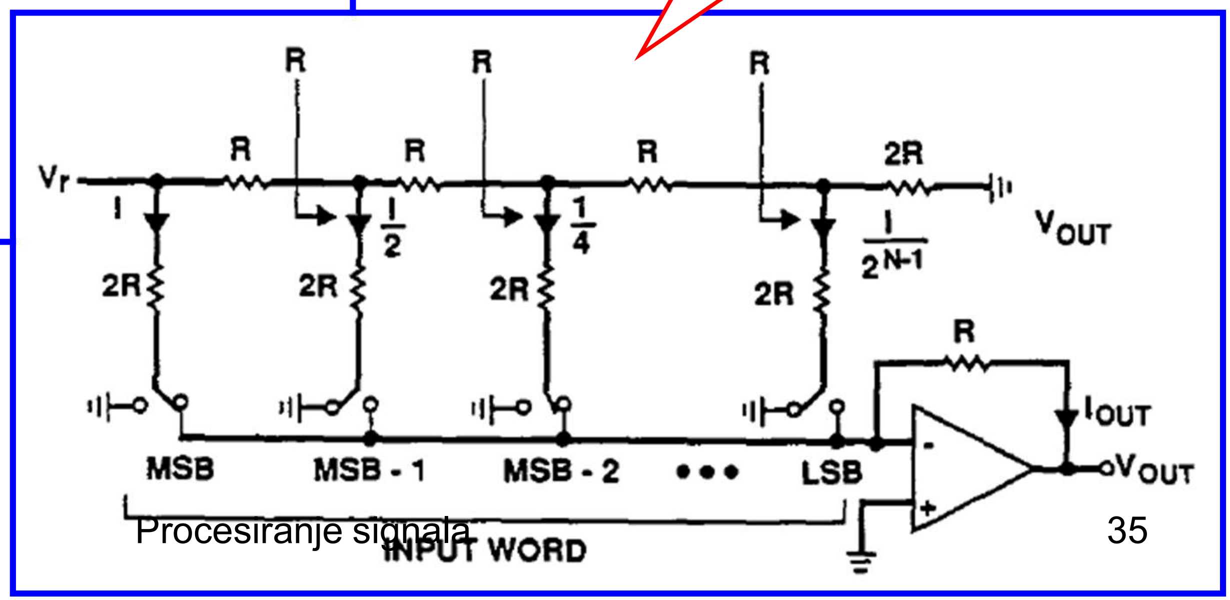
- Paralelni
- Protočni
- Serijski
- Nadodabiranje
- Sa brojanjem

Paralelni DAC

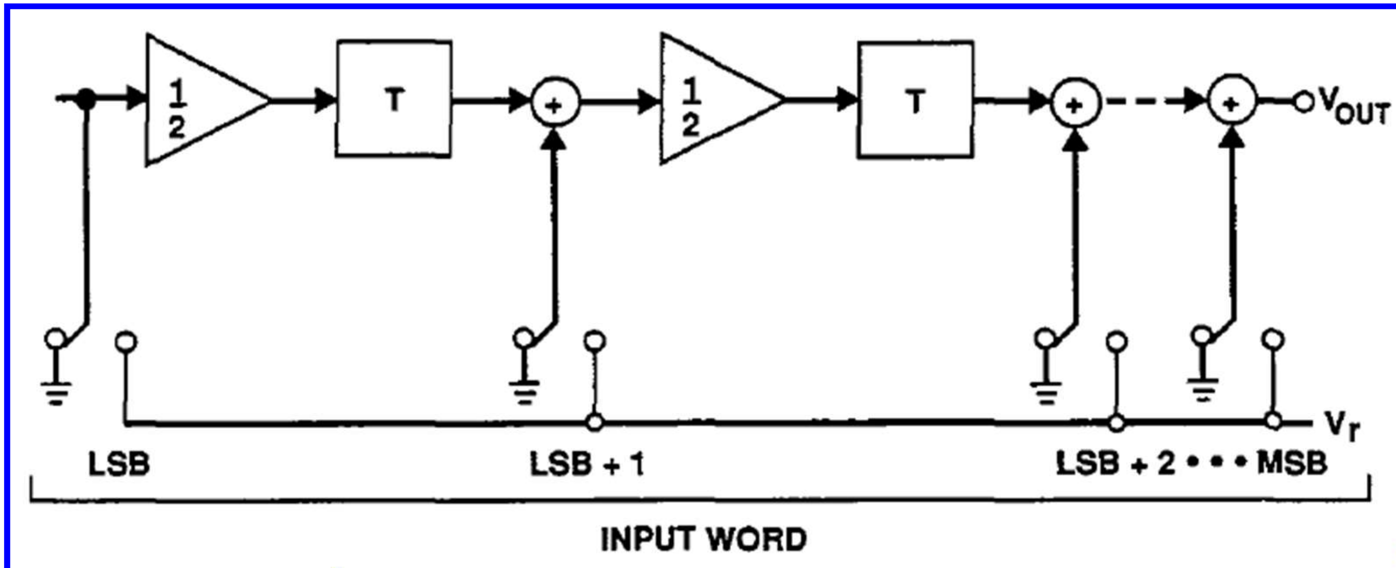


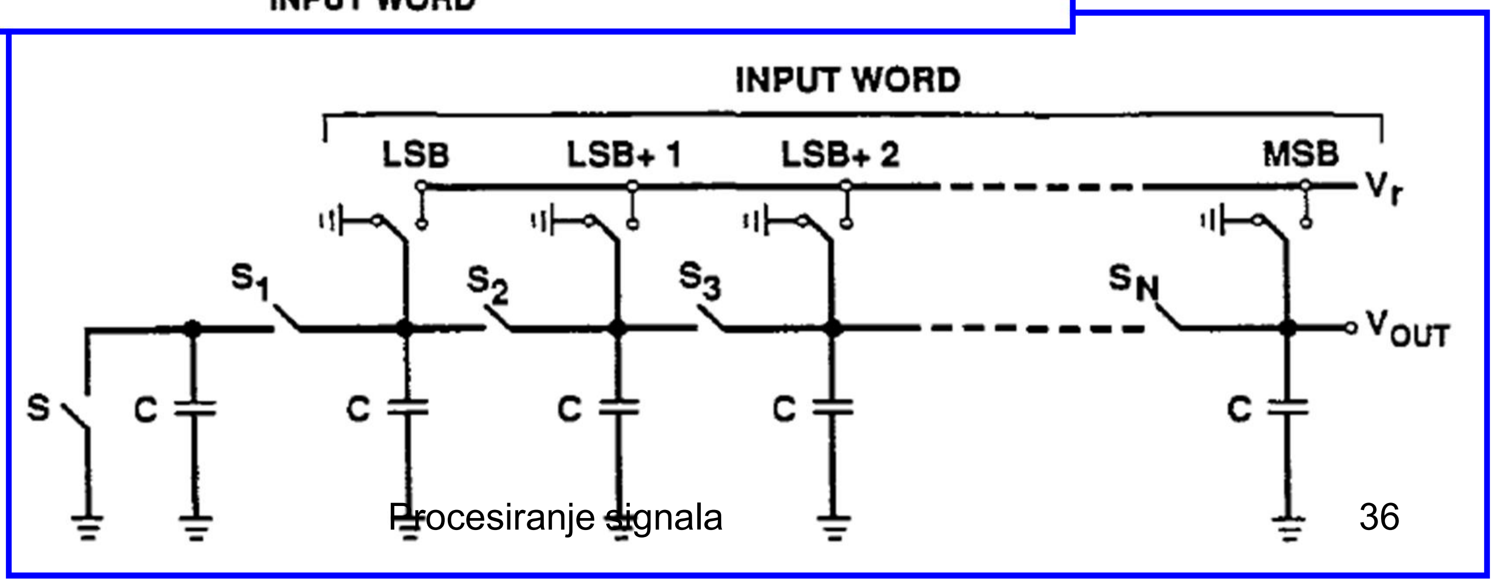
naponski

strujni

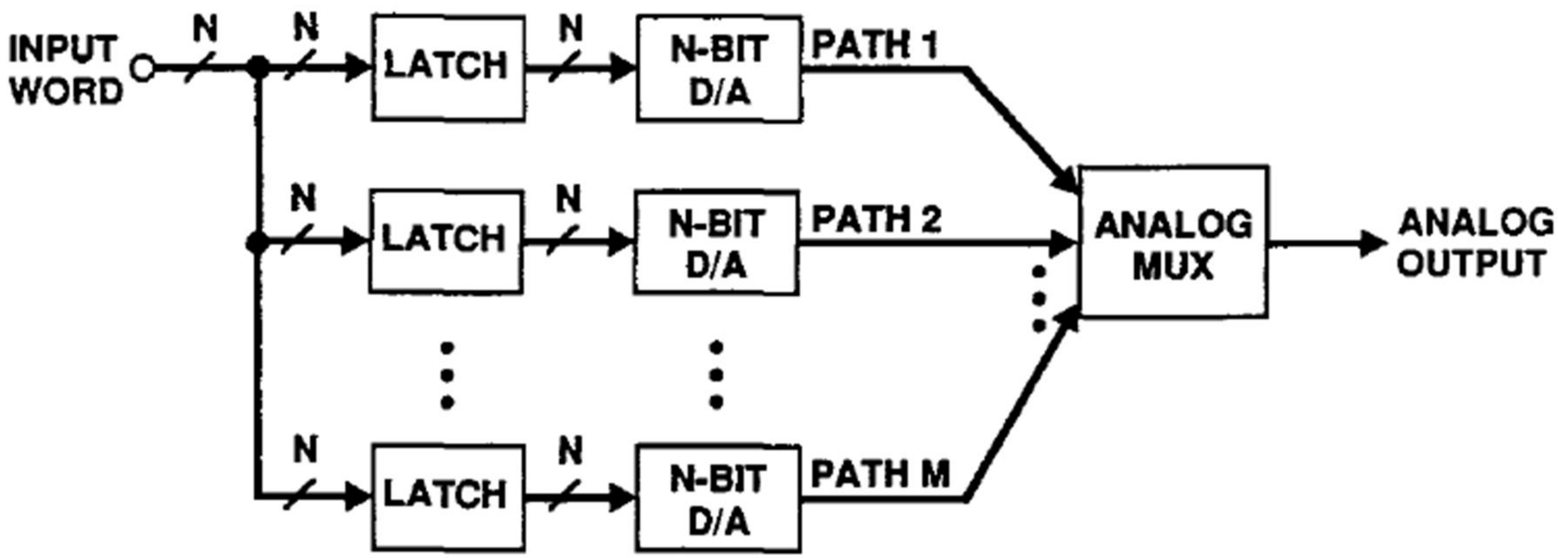


Protočni DAC

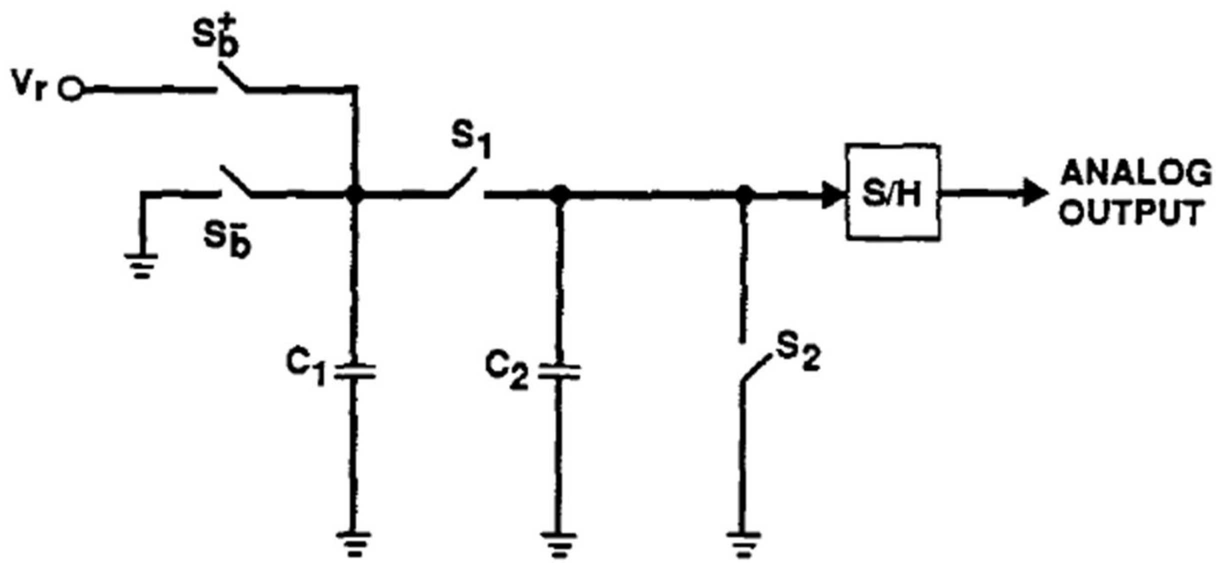




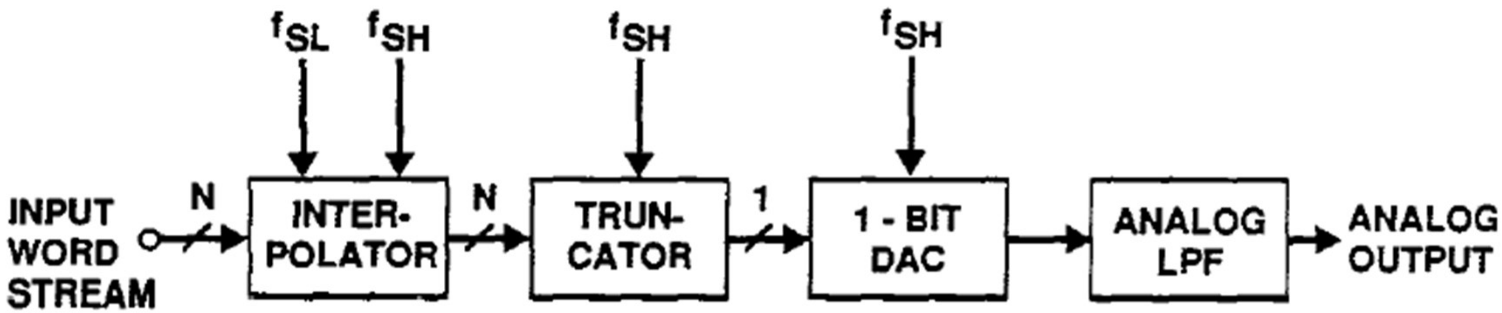
DAC sa multipleksiranjem



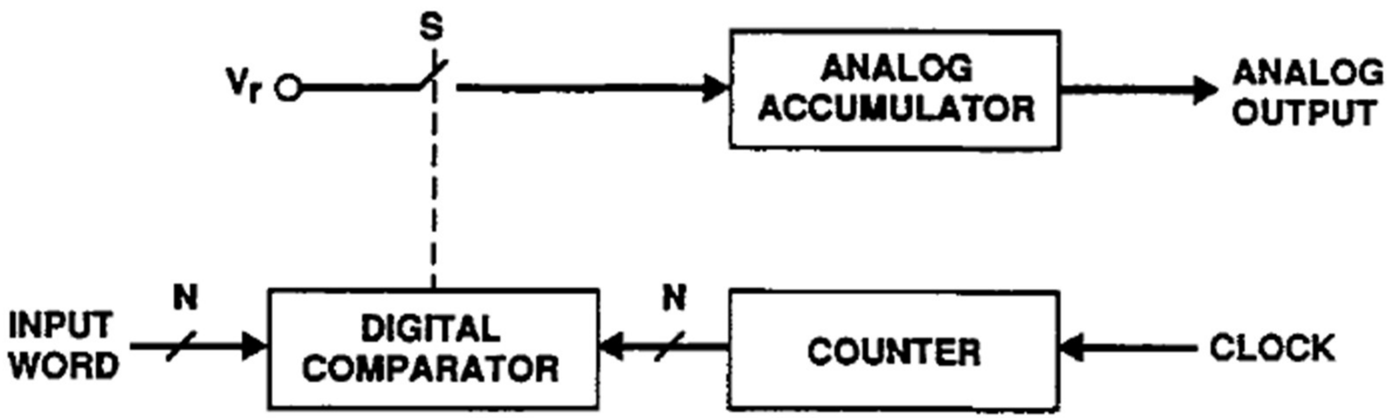
Serijski DAC



Sa nadodabiranjem



DAC sa brojanjem



Uporedne karakteristike

TABLE 10-3 Properties of Basic DAC Architectures

Converter Type	Minimum Number of Nyquist Periods per Sample	Typical Accuracy (bits)	Minimum Number of Analog Stages	Complexity of Digital Circuitry
Parallel	1	9	2^N	Medium
Pipeline/multiplexing	1, also an N periods of delay (latency)	8	N	Medium
Serial D/A converters	N	10	1	High
Oversampling D/A converters	OSR ~ 128	16	1	Very high
Counting D/A converters	2^N	18	1	Medium

FAQ

- ADC osciluje
- ADC daje netačne rezultate
- Podešavanje ofseta i pojačanja

ADC osciluje

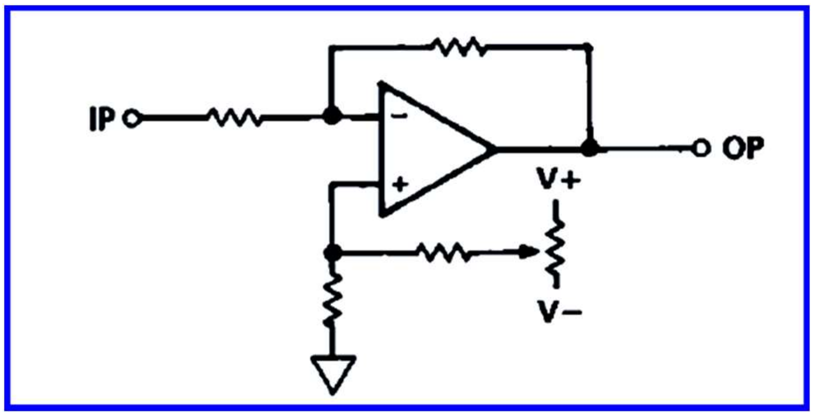
- ADC sa više kanala – ulaza osciluje
- ADC sa multipleksiranim ulazima mora da ima sve ulaze, koji se ne koriste, na masu

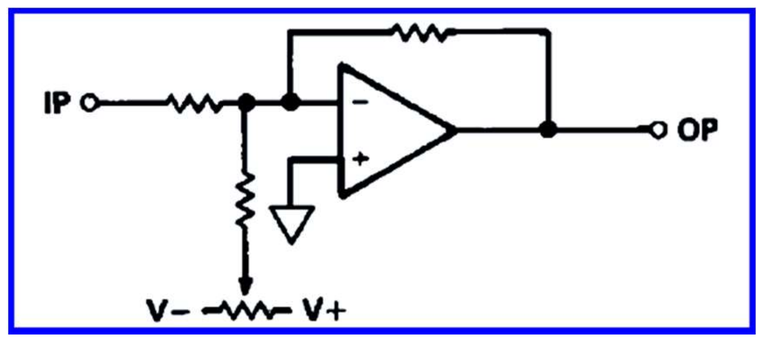
ADC ne radi tačno

- U power safe vrsti rada – ne radi tačno kada se uključi
- Posle vraćanja u normalan rad, dva merenje da budu da bi se stabilizovao, pa tek od trećeg da se koriste rezultati

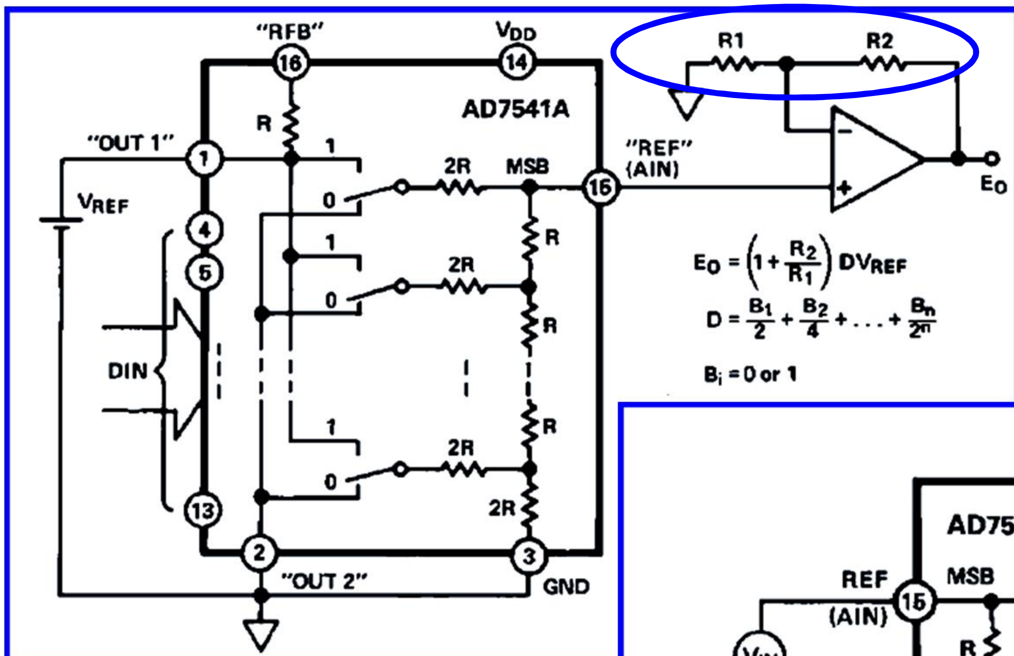
Podešavanje ofseta i pojačanja

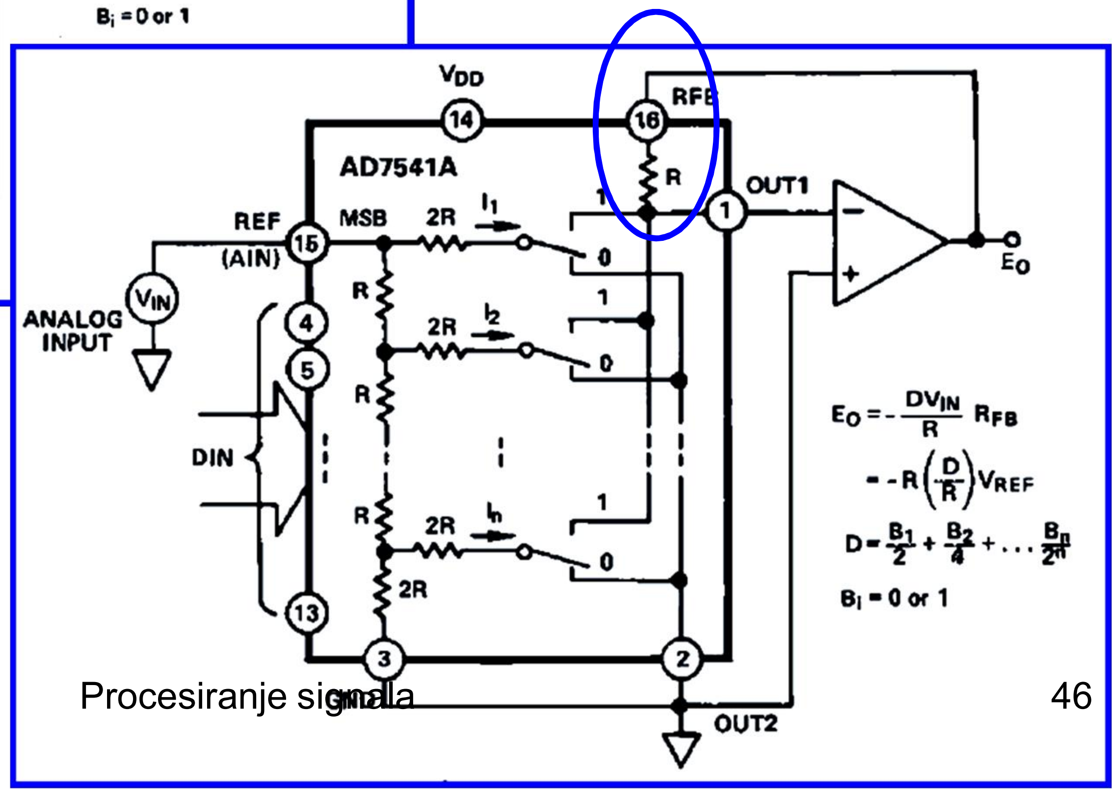
- Ne preporučuje se ručno podešavanje ofseta i pojačanja, već korišćenje automatizovanog sklopa



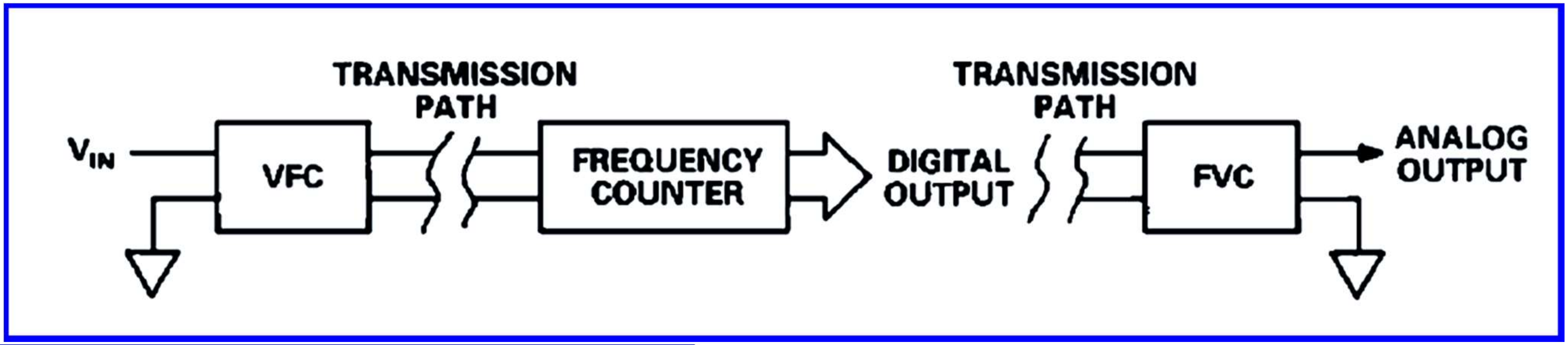


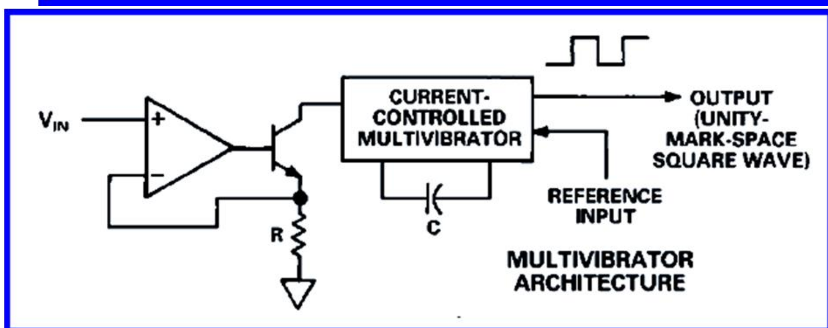
Podešavanje za DAC

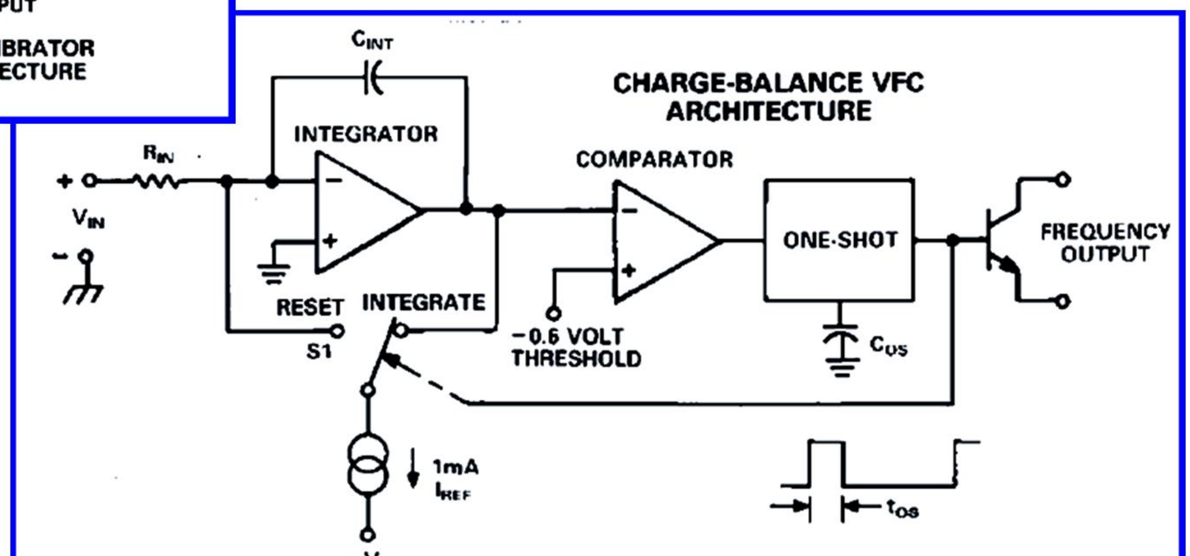




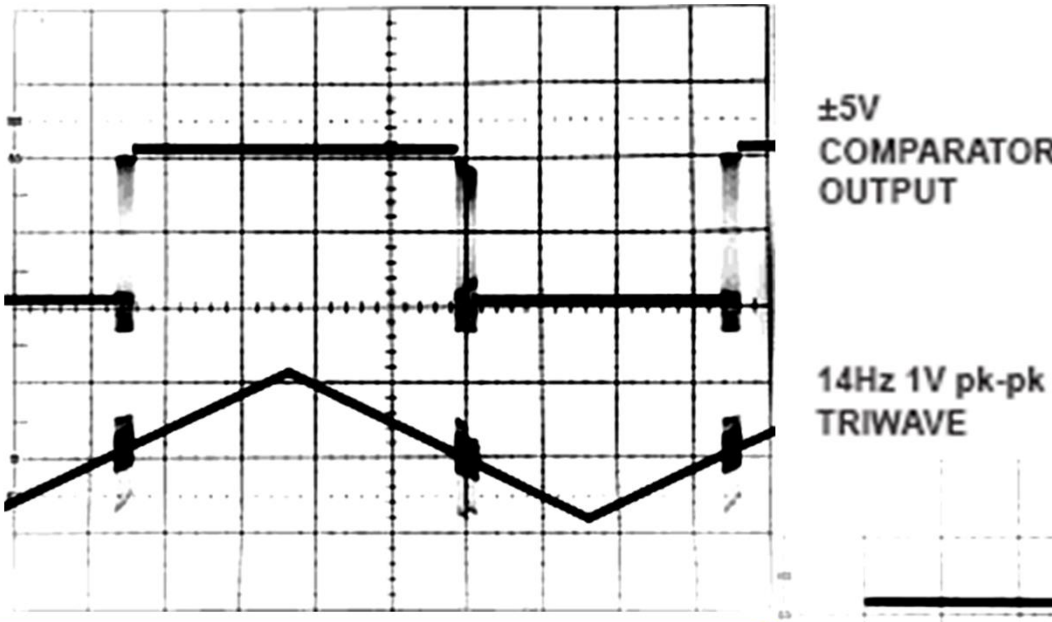
Kako se šalje analogni signal na veće daljine?

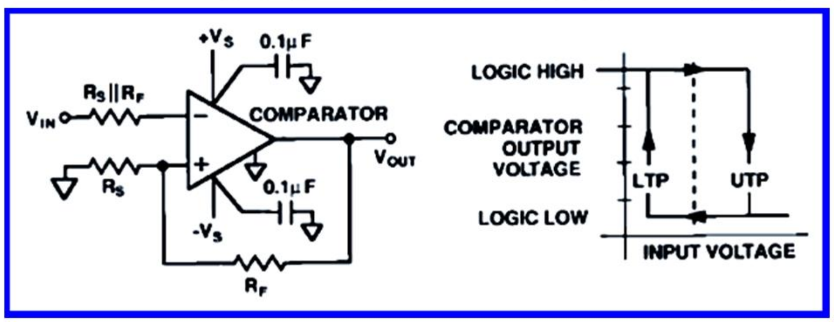


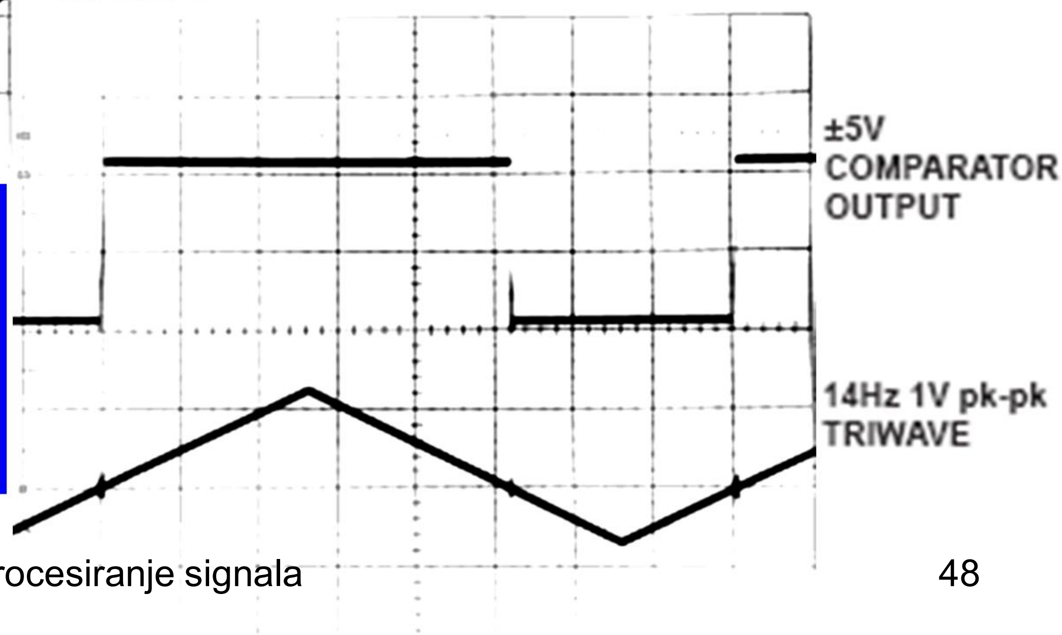




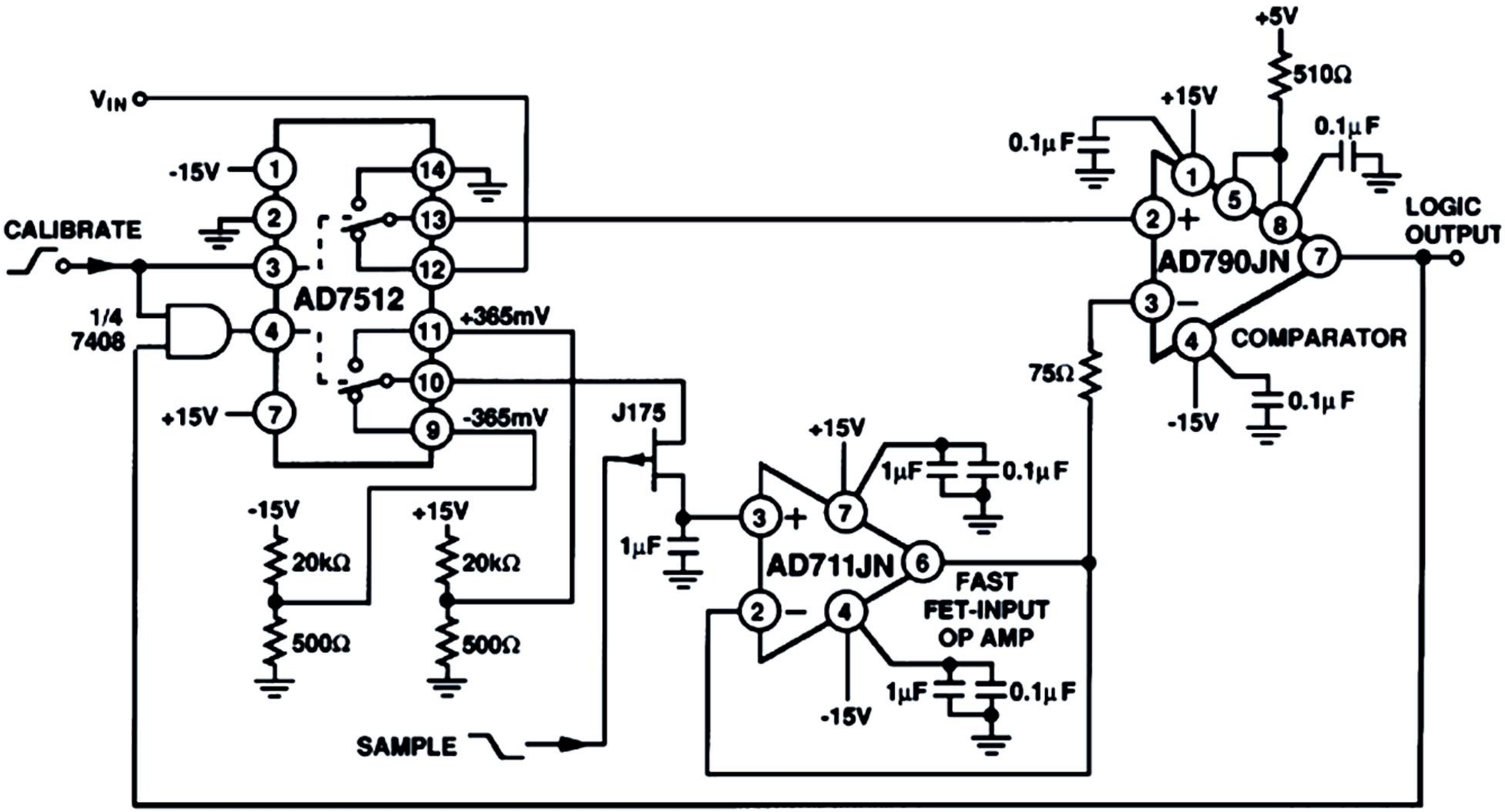
Potreban histerezis





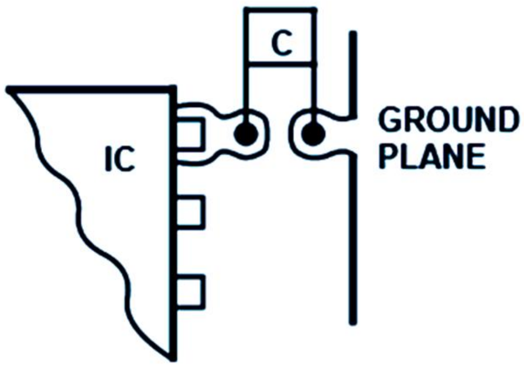


Auto-zero



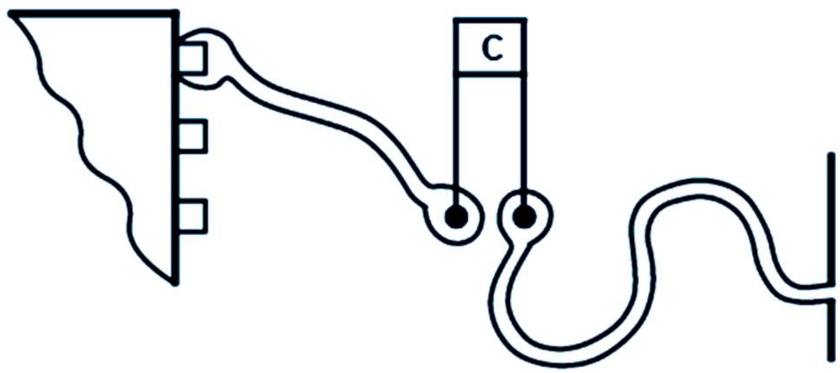
V_IN
-15V
CALIBRATE
1/4
7408
+15V
AD7512
+365mV
-365mV
-15V
20kΩ
500Ω
+15V
20kΩ
500Ω
SAMPLE
J175
1μF
+15V
1μF
0.1μ F
AD711JN
FAST
FET-INPUT
OP AMP
-15V
1μF
0.1μ F
+5V
510Ω
+15V
0.1μ F
0.1μ F
AD790JN
LOGIC
OUTPUT
COMPARATOR
75Ω
-15V
0.1μ F

Kondenzator



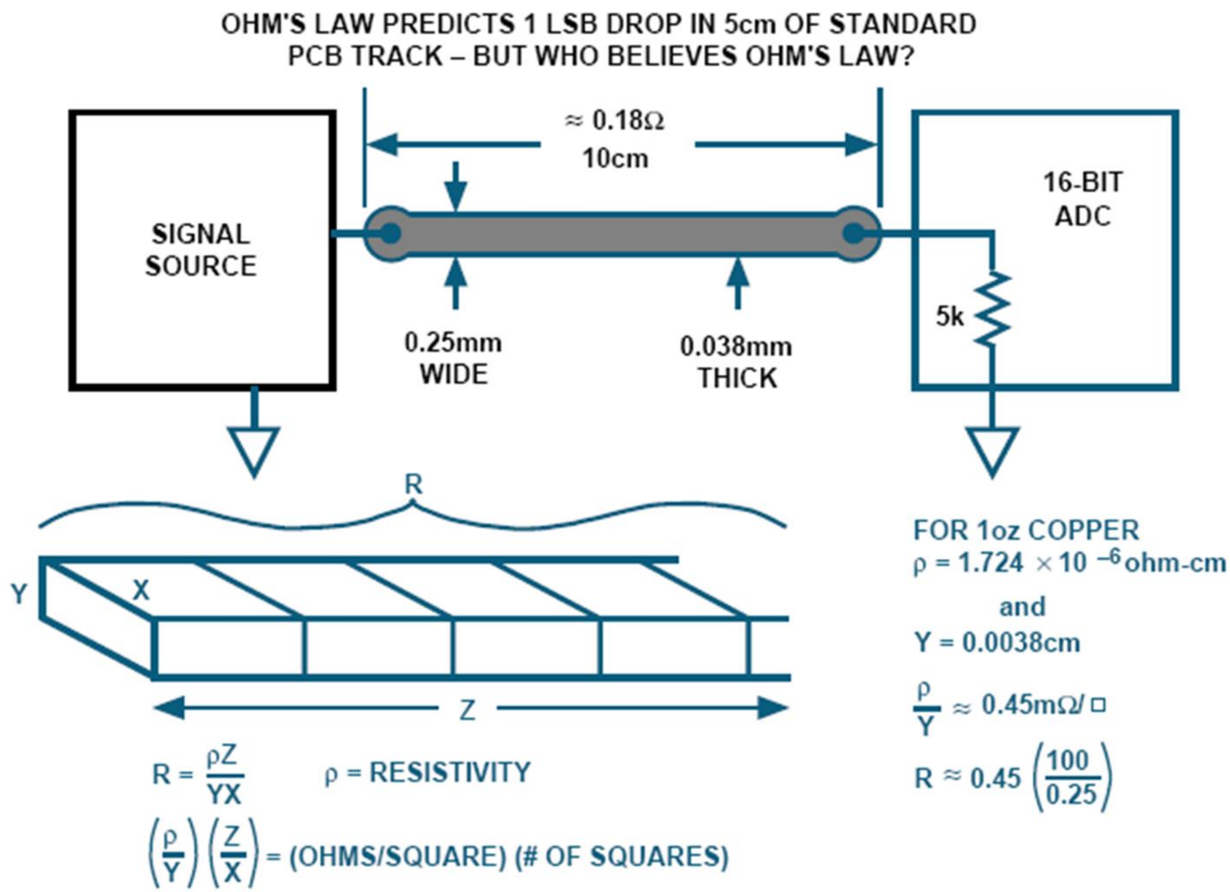
IDEAL HF DECOUPLING HAS
1. LOW INDUCTANCE CAPACITOR (MONOLITHIC CERAMIC)
2. MOUNTED VERY CLOSE TO THE IC
3. WITH SHORT LEADS
4. AND SHORT, WIDE PC TRACKS

IT MAY BE SHUNTED WITH A TANTALUM BEAD ELECTROLYTIC TO PROVIDE GOOD LF DECOUPLING AS WELL.

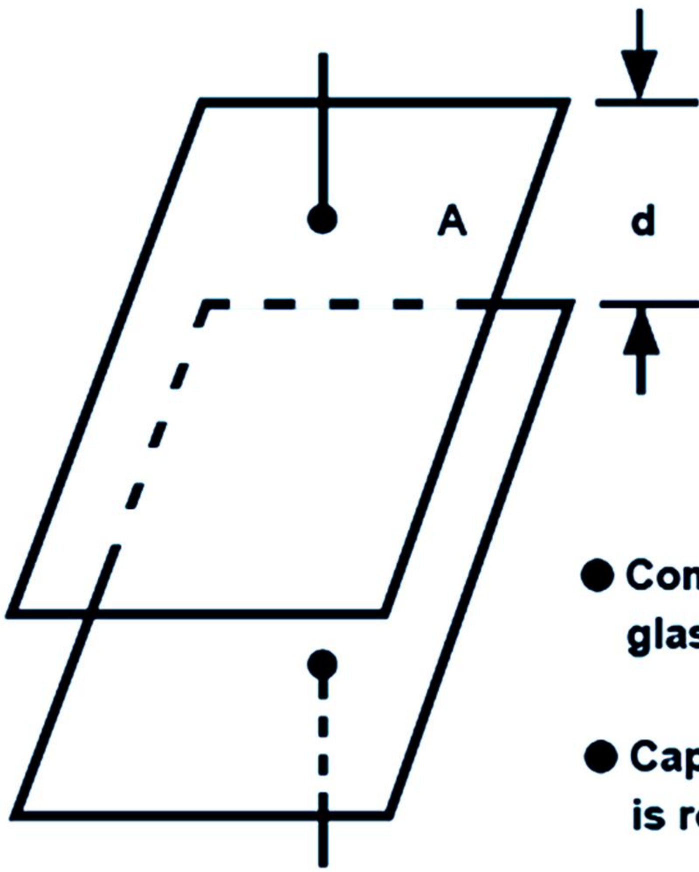


THIS SORT OF THING IS USELESS!

Parazitni uticaji



Parazitni uticaji



$$C = \frac{0.00885\, E_r\, A}{d}\ \text{pF}$$

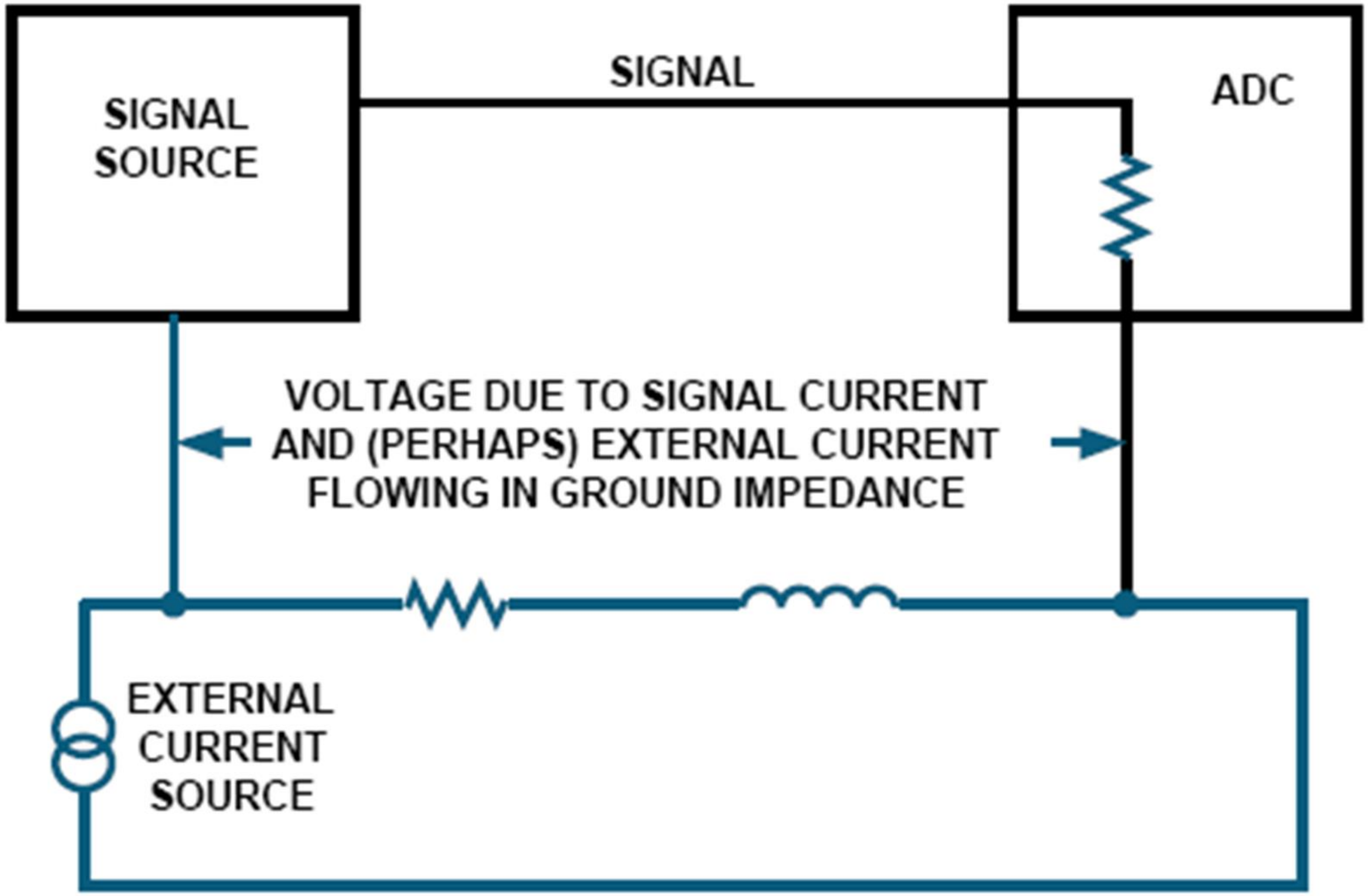
A = plate area in mm^2

d = plate separation in mm

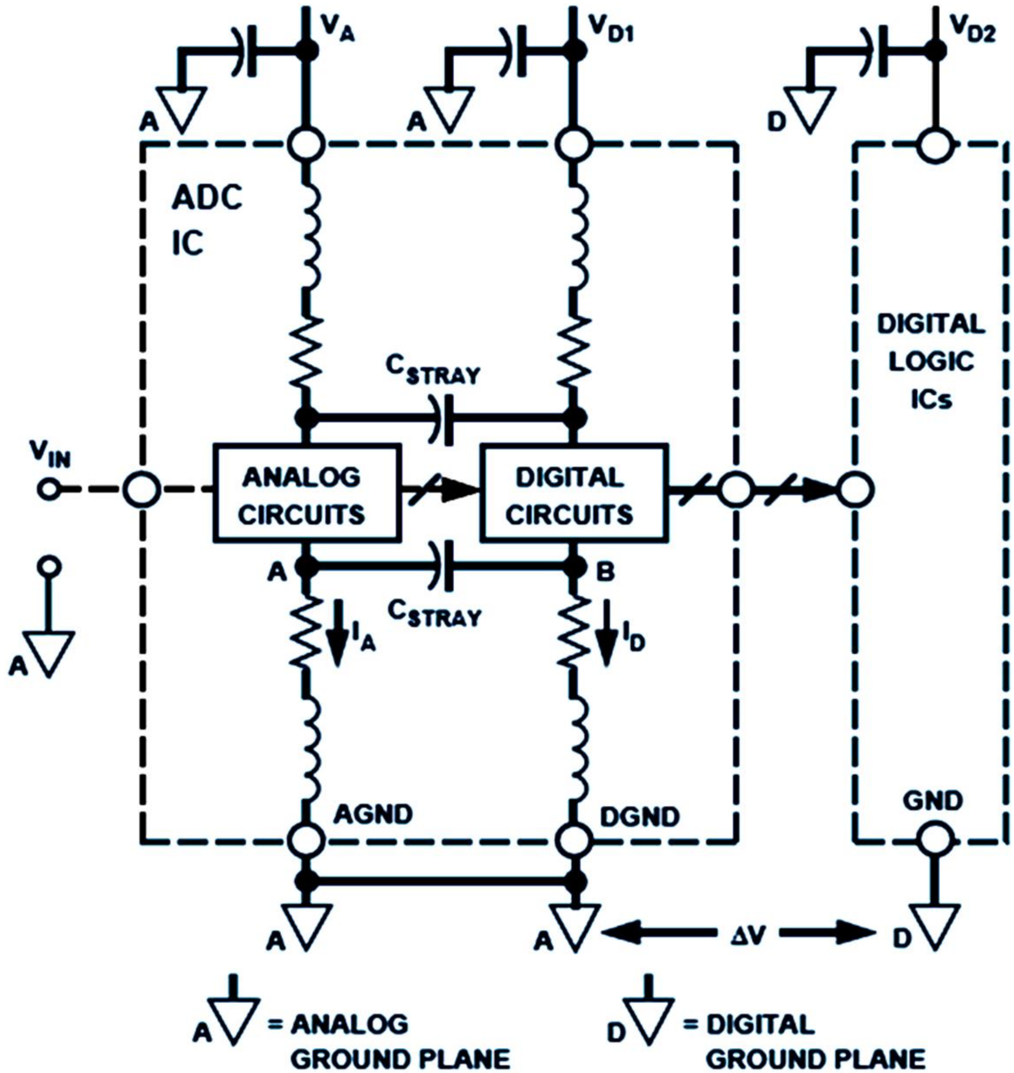
E_r = dielectric constant relative to air

- **Commonest type of PCB uses 1.5mm glass-fiber epoxy material with $E_r = 4.7$**
- **Capacity of PC track over ground plane is roughly $2.8 pF/cm^2$**

Parazitni uticaji

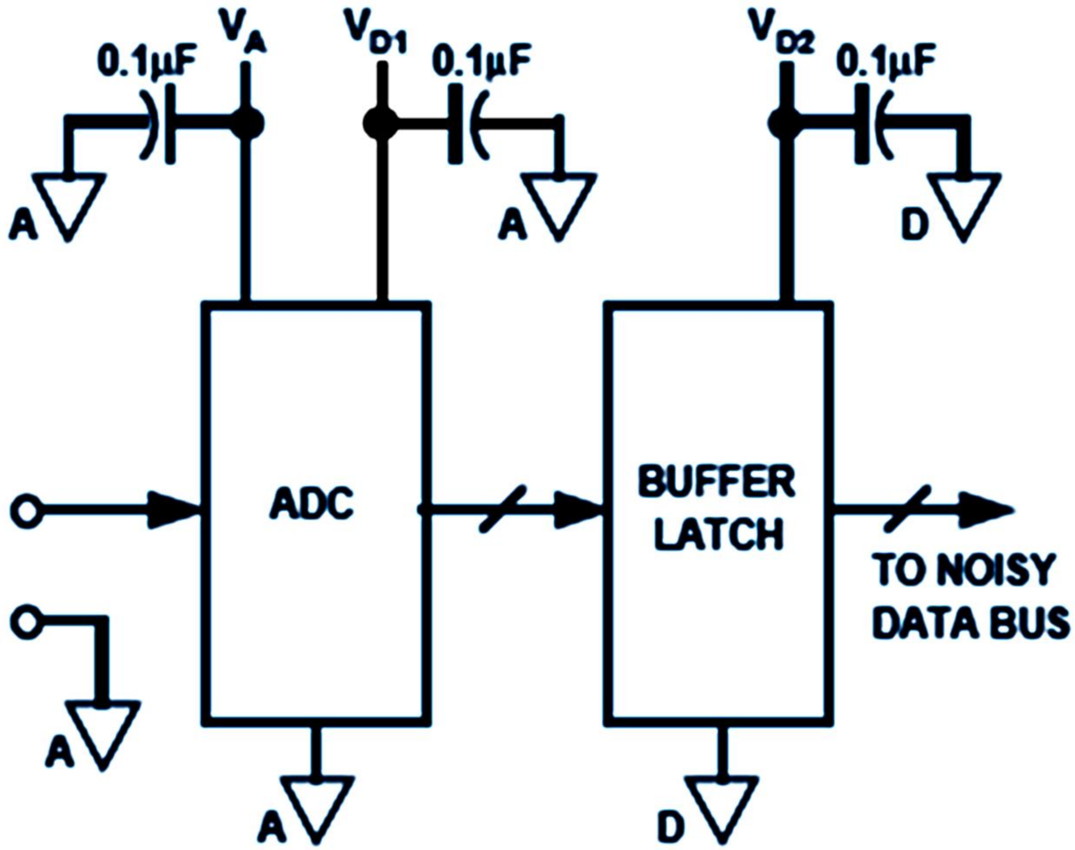


Ground



V_A
V_{D1}
V_{D2}
A
A
D
ADC
IC
DIGITAL
LOGIC
ICs
C_{STRAY}
V_{IN}
ANALOG
CIRCUITS
DIGITAL
CIRCUITS
A
B
C_{STRAY}
I_A
I_D
A
AGND
DGND
GND
A
A
ΔV
D
A = ANALOG
GROUND PLANE
D = DIGITAL
GROUND PLANE

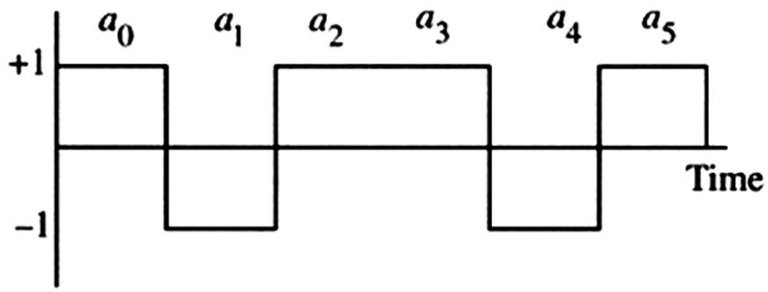
Bafer



0.1µF
V_A
V_D1
0.1µF
V_D2
0.1µF
A
A
D
ADC
BUFFER
LATCH
TO NOISY
DATA BUS
A
A
D

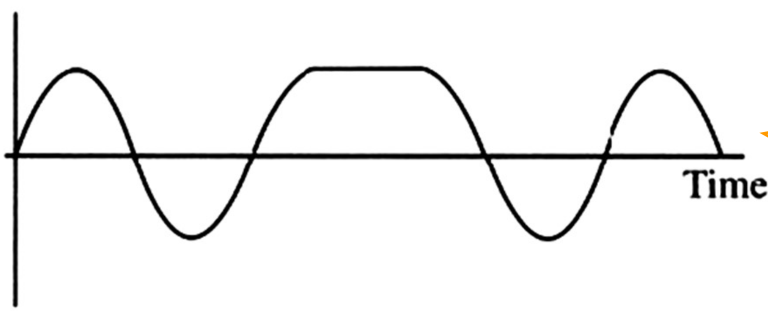
Prenos binarnih digitalnih podataka

- Binarni podaci mogu da se prenose serijski signalima koji imaju vrednosti +1 i -1



(a)

Poslat signal

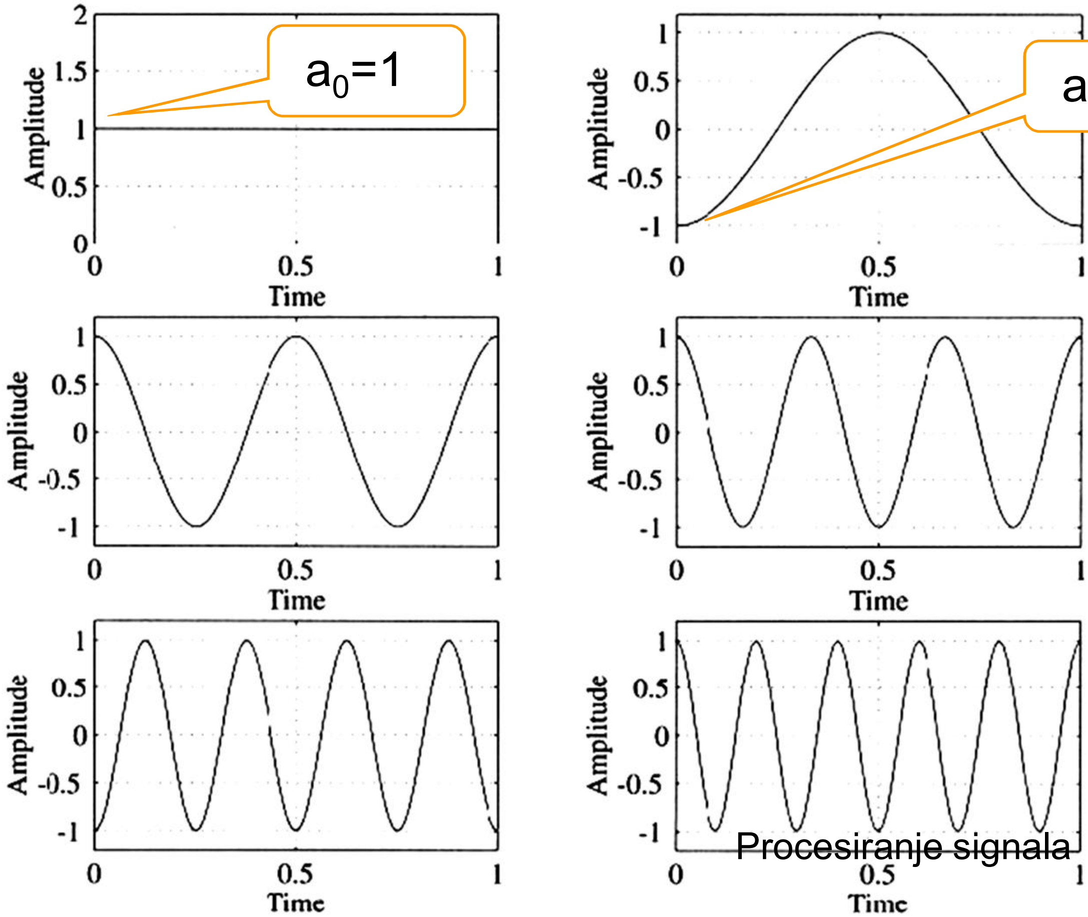


(b)

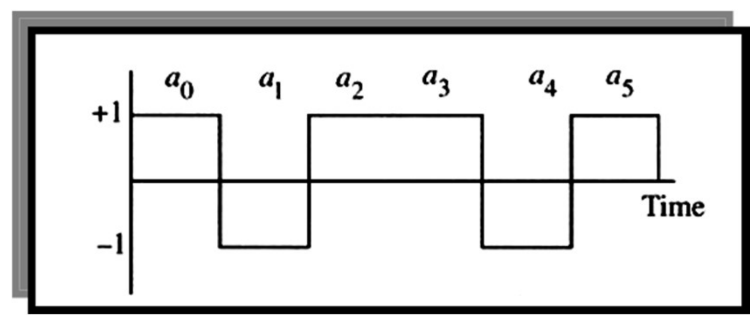
Primljen signal je drugačiji zbog nesavršenosti kanala i ograničenog frekvencijskog opsega.
Potrebna složena procedura ekvilizacije funkcije prenosa kanala.

Višetonski prenos digitalnih podataka

- N binarnih cifara se moduliše svojim nosiocem i sabira
- Prijemnik – koherentni demodulatori



DMT
Discrete
Multitone
Transmition



DMT - discrete multitone transmition

$$\{a_k[n]\}, \{b_k[n]\}, \quad 0 \le k \le M-1$$

Realni signali (sekvence)
učestanost odabiranja F_T

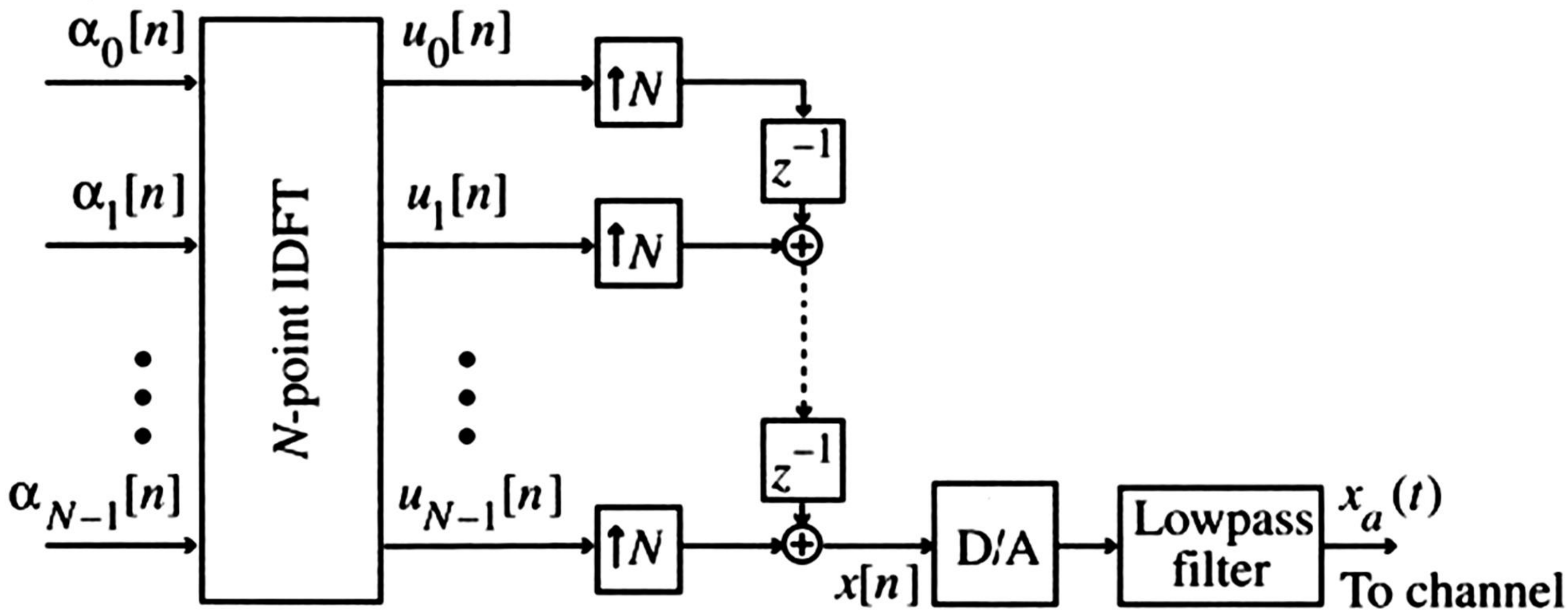
$$\alpha_k[n] = \begin{cases} a_0[n] & k = 0 \\ a_k[n] + jb_k[n] & 1 \le k \le N/2-1 \\ b_0[n] & k = N/2 \\ a_k[n] - jb_k[n] & N/2+1 \le k \le N-1 \end{cases} \qquad N = 2M$$

IDFT

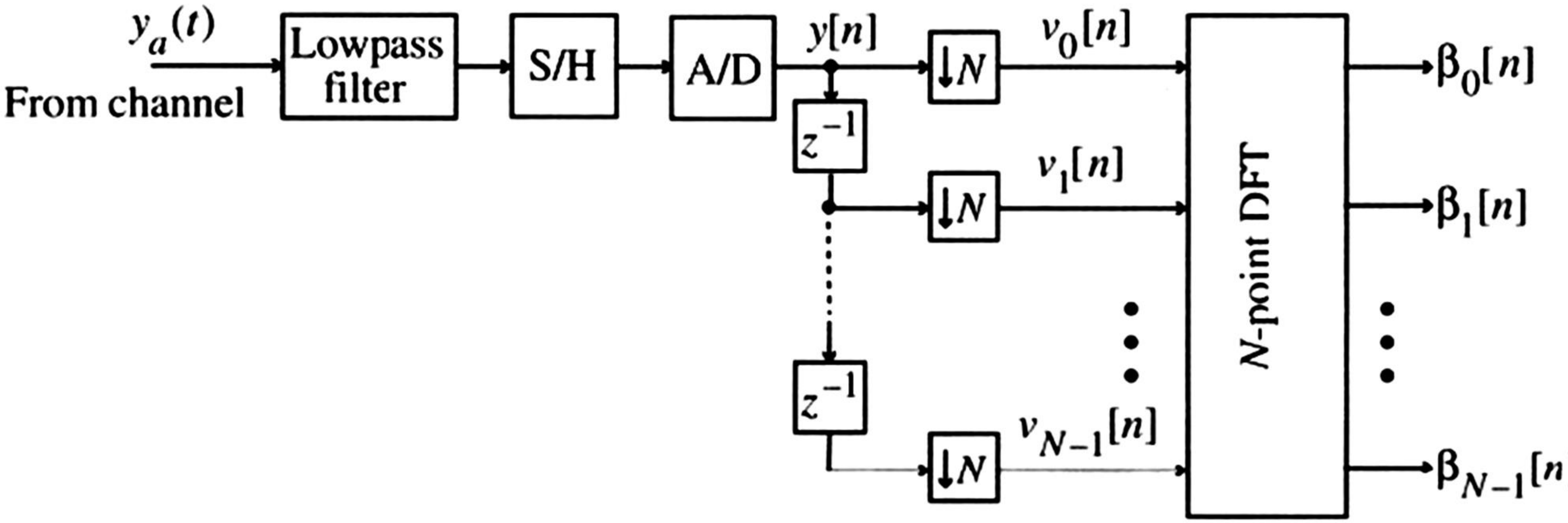
$$u_l[n] = \frac{1}{N} \sum_{k=0}^{N-1} \alpha_k[n] W_N^{-lk}, \quad 0 \le l \le N-1$$

$$W_N = e^{-j2\pi/N}$$

DMT - predajnik



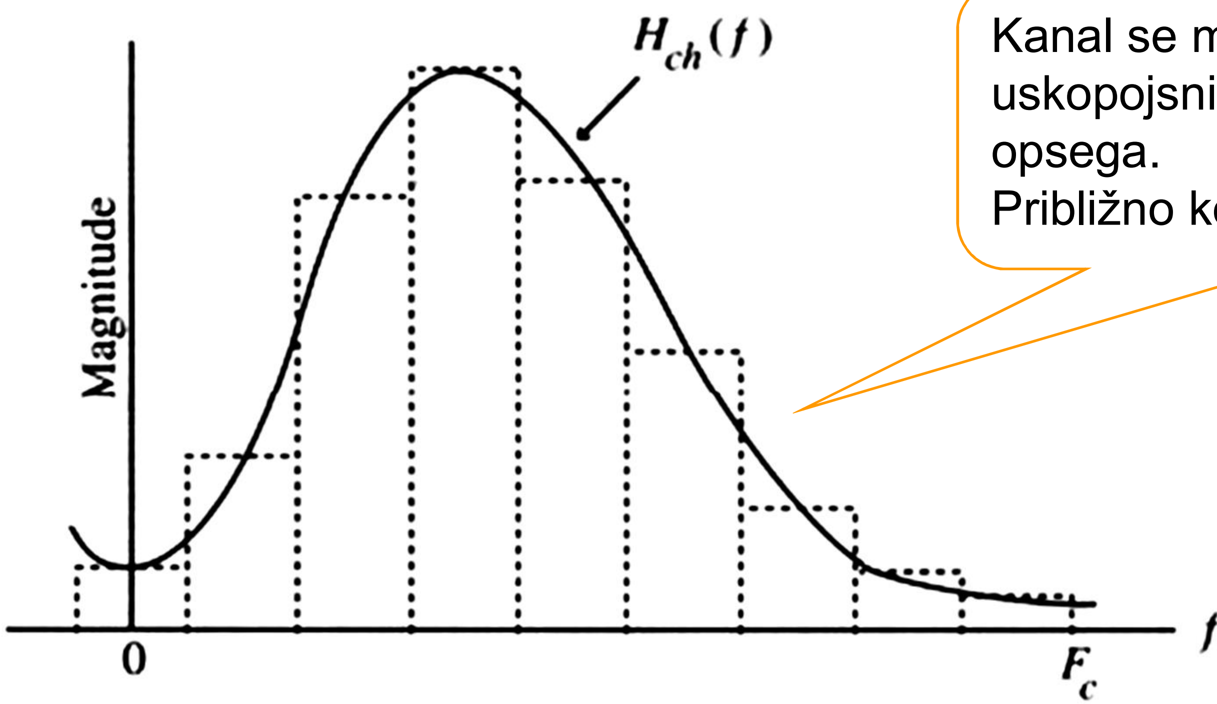
DMT - prijemnik



$$\beta_k[n] = \alpha_{k-1}[n], \quad 1 \le k \le N-1$$

$$\beta_0[n] = \alpha_{N-1}[n]$$

Karakteristika prenosnog kanala



Kanal se modeluje kao više uskopojsnih kanala propusnika opsega.
Približno konstantan u opsegu.

Oversampling AD konverzija

- Učestanost odabiranja treba da bude 2 puta veća od najviše učestanosti korisnog signala
- Pre AD konverzije mora da se koristi filtar propusnik niskih učestanosti čija je učestanost granice propusnog opsega jednaka najvišoj učestanosti korisnog signala, učestanost granice nepropusnog opsega neznatno veća od granice propusnog opsega
- Analogni filtar mora da bude visokog reda sa kvalitetnim komponentama (visoka cena)
- Filtar sa oštrom karakteristikom unosi fazna izobličenja u propusnom opsegu
- Alternativa – učestanost odabiranja je znatno veća, filtar nema strmu karakteristiku, digitalnim filtrom se realizuje oštra karakteristika, smanji se učestanost odbiranja

Analiza šuma (1)

- AD konvertor sa b bita i učestanost odabiranja F_T
- Full-scale peack-to-peack ulazni signal (napon) je R_{FS}
- Najmanji opseg vrednosti koji se predstavlja binarno ΔV

$$\Delta V = \frac{R_{FS}}{2^b - 1} \approx \frac{R_{FS}}{2^b}$$

Analiza šuma (2)

- Snaga kvantizacionog šuma je σ_e^2
- Podrazumeva se uniformna distribucija greške u opsegu između $-\Delta V/2$ i $\Delta V/2$
- Gustina šuma je snaga šuma po jedinici frekvencijskog opsega (*noise density*)
- Snaga (ukupna) u korisnom opsegu (*in-band noise power*)

$$\sigma_e^2 = \frac{(\Delta V)^2}{12}$$

$$P_{e,n} = \frac{\sigma_e^2}{F_T/2} = \frac{(\Delta V)^2}{6F_T}$$

$$P_{\text{total}} = \frac{\sigma_e^2}{F_T/2} = \frac{\left(R_{FS}/2^b\right)^2/12}{12}\frac{F_m}{F_T/2}$$

Analiza šuma (3)

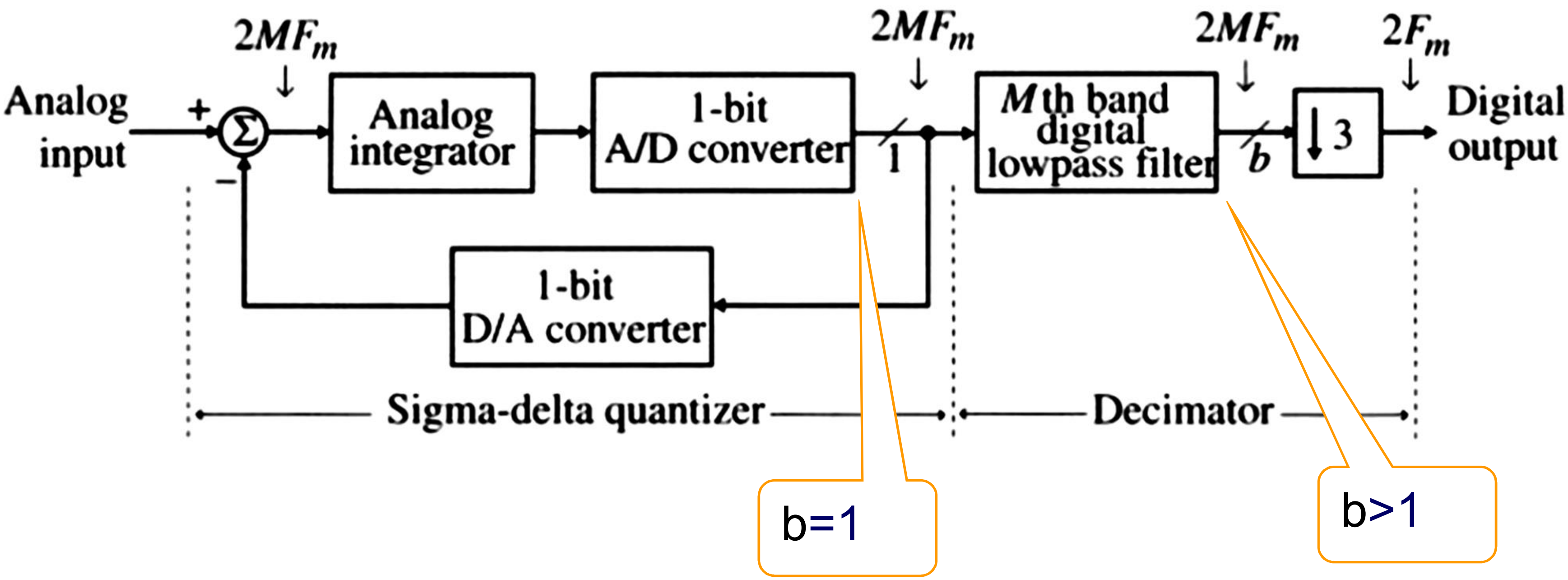
- Za učestanost odabiranja F_T=$2F_m$, broj bita β
- Za učestanost odabiranja F_T=$2MF_m$, broj bita je b
- Oversampling ratio (OSR) M=$F_T/2F_m$
- Koristi se idealni filtar propusnik niskih učestanosti
- Koliko bita treba manje za veće M?

$$\beta = b + \frac{1}{2}\log_2 M$$

Brži a manje tačan AD konvertor – ekonomičnije rešenje

M=1000, b=8
isto kao da se koristi
M=1, b=13

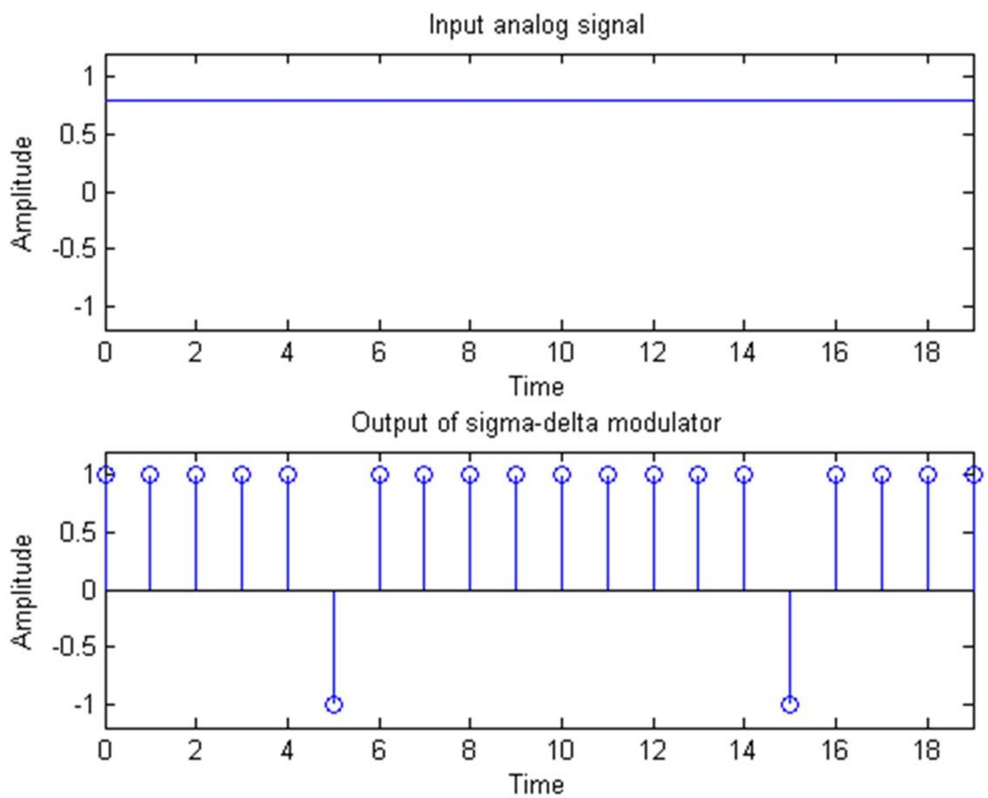
Sigma-delta (ΣΔ) AD konvertor



Sigma-delta konvertor (1)

```
N = 20;
n = 1:1:N;
m = n-1;
A = 0.8;
x = A*ones(1,N);
subplot(2,1,1),
plot(m,x);
subplot(2,1,2)
y = zeros(1,N+1);
v0 = 0;
   for k = 2:1:N+1;
        v1 = x(k-1) - y(k-1) + v0;
        y(k) = sign(v1);
        v0 = v1;
   end
yn = y(2:N+1);
stem(m, yn);
```

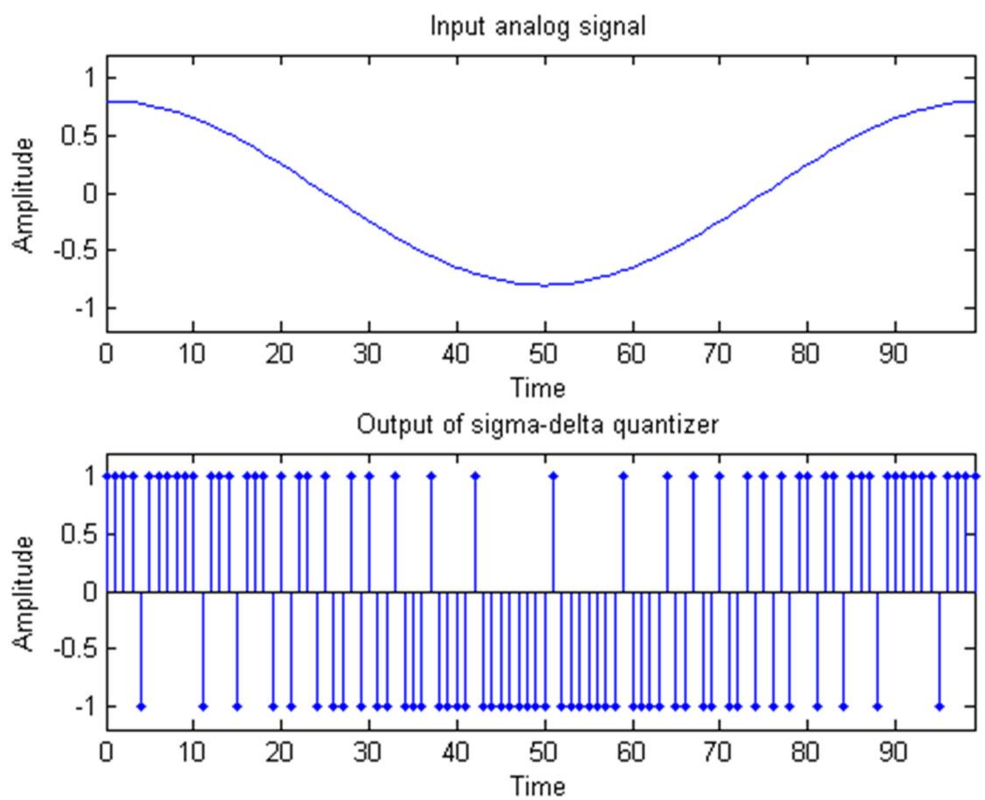
Sigma-delta konvertor (2)



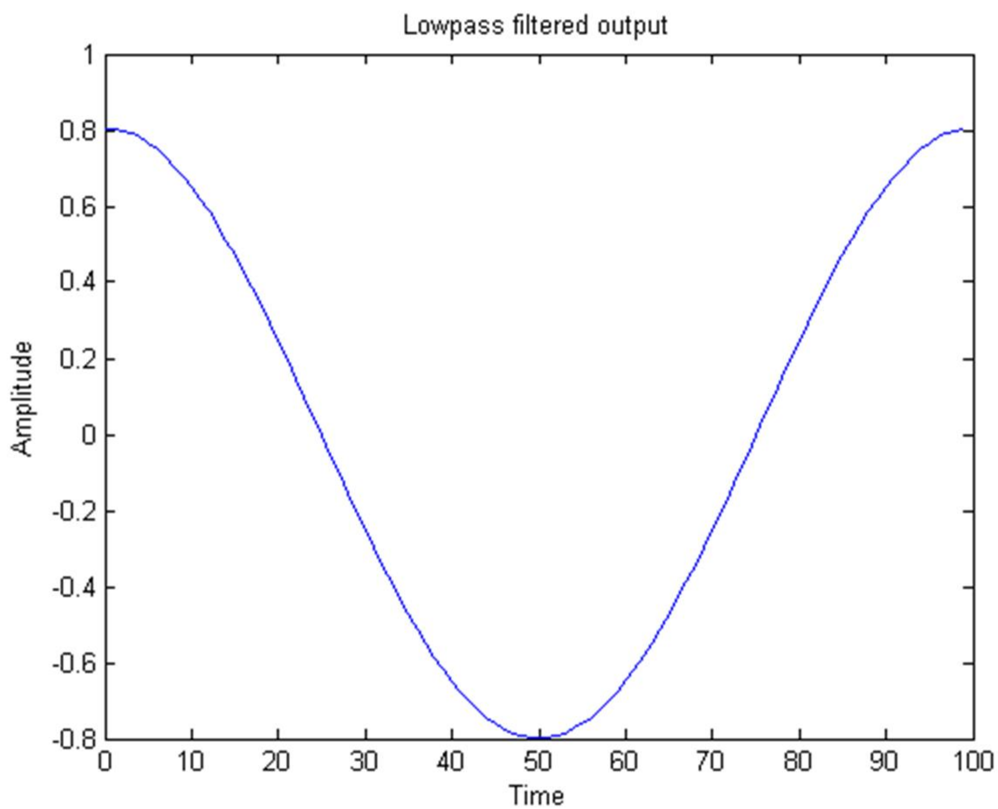
Sigma-delta konvertor (3)

```
wo = 2*pi*0.01;
sequence = ');
N = 100;
n = 1:1:N;
m = n-1;
A = 0.8;
x = A*cos(wo*m);

. . .

figure
H = [1 1 0.5 zeros(1,N-5) 0.5 1];
YF = Y.*H;
out = ifft(YF);
axis([0 N-1 -1.2 1.2]);
plot(m,out);
xlabel('Time'); ylabel('Amplitude');
title('Lowpass filtered output');
```

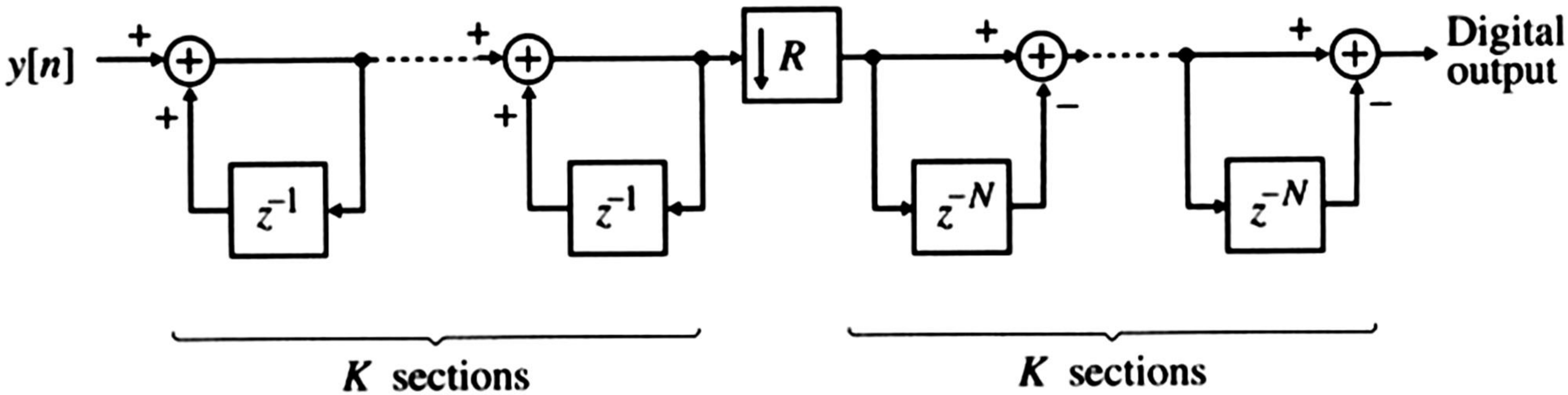
Sigma-delta konvertor (4)



Sigma-delta konvertor (5)



CIC decimator

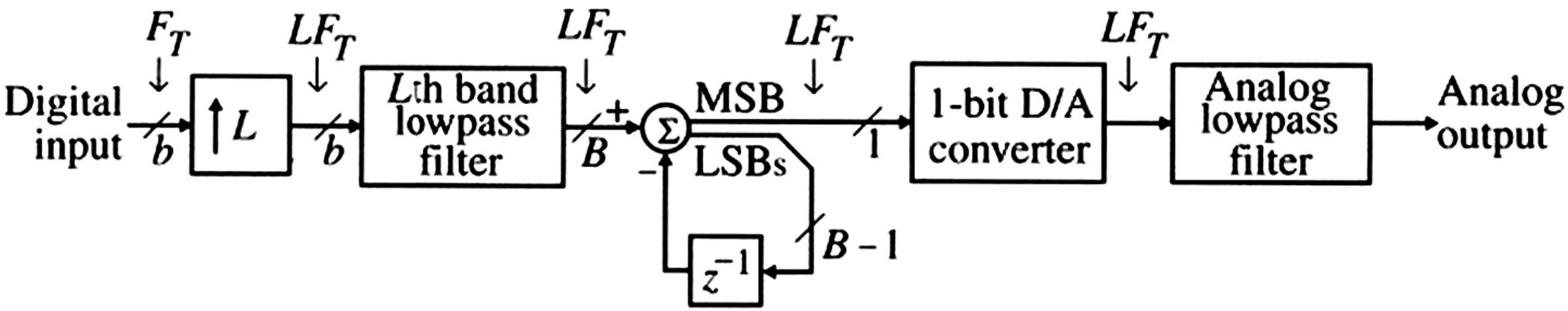


$$H(z) = \left(\frac{1 - z^{-RN}}{1 - z^{-1}} \right)^K$$

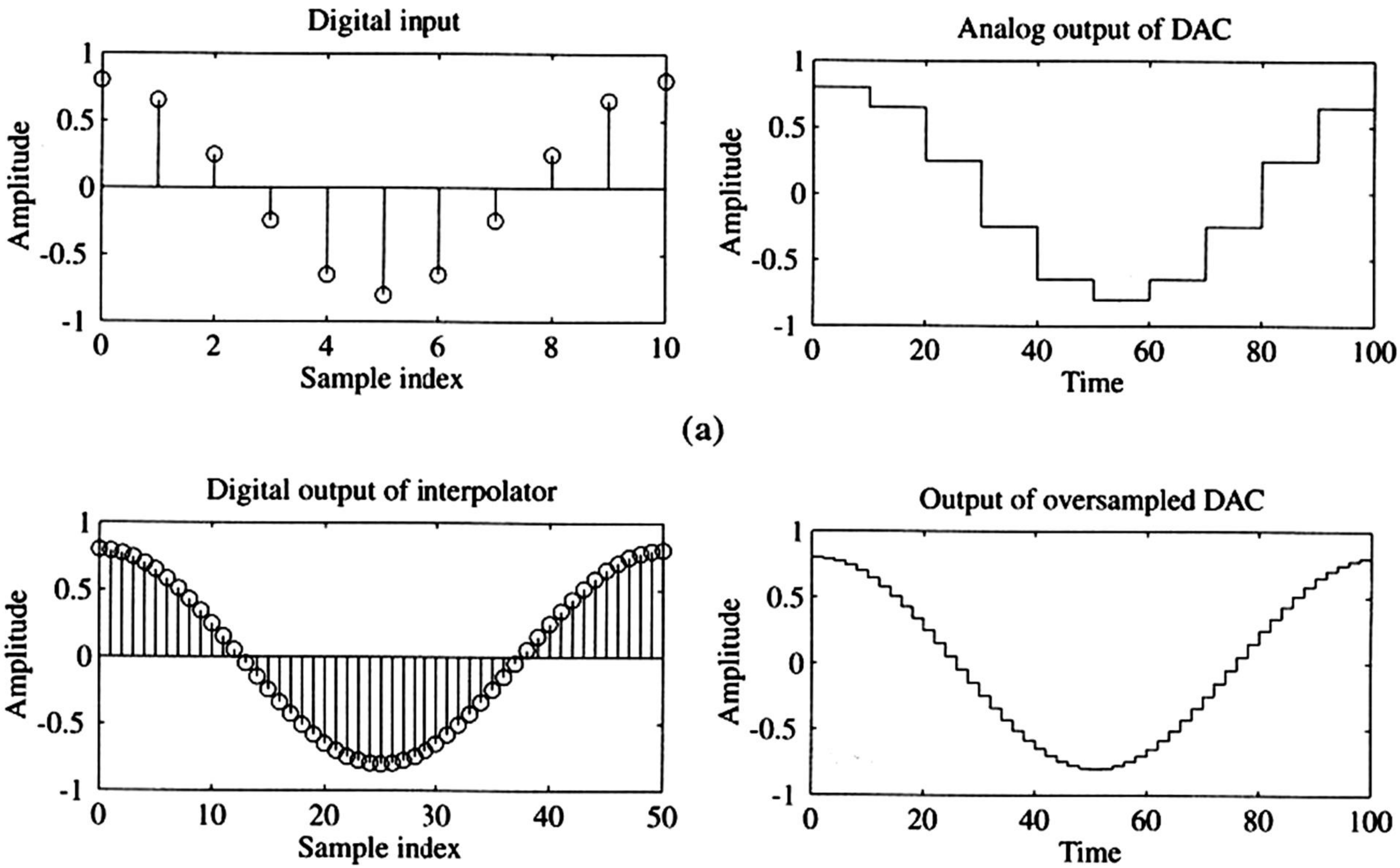
Oversampling DA konverzija

- DA konverzija se sastoji od konverzije u kontinualni signal i analognog filtra
- Ako je učestanost odabiranja blizu dvostrukoj najvećoj učestanosti korisnog sgnala, filtar mora da ima oštru karakteristiku, da bude visokog reda, od skupih komponenti
- Da se značajno poveća učestanost odabiranja, digitalnim filtrom potisnu neželjene komponente, upotrebi ekonomičan analogni filtar (niskog reda od komponenti koje nisu skupe) koji ima široku prelaznu zonu

Realizacija DA konverzije

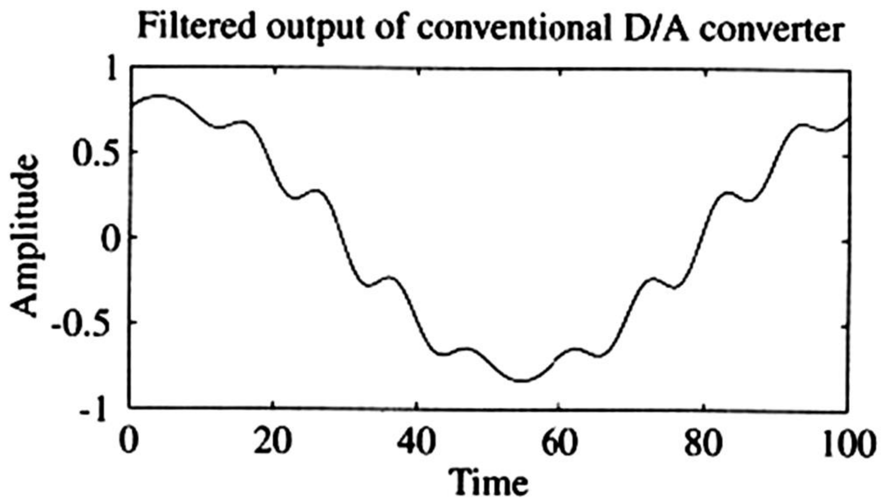


Ulazni i izlazni signal DA konvertora

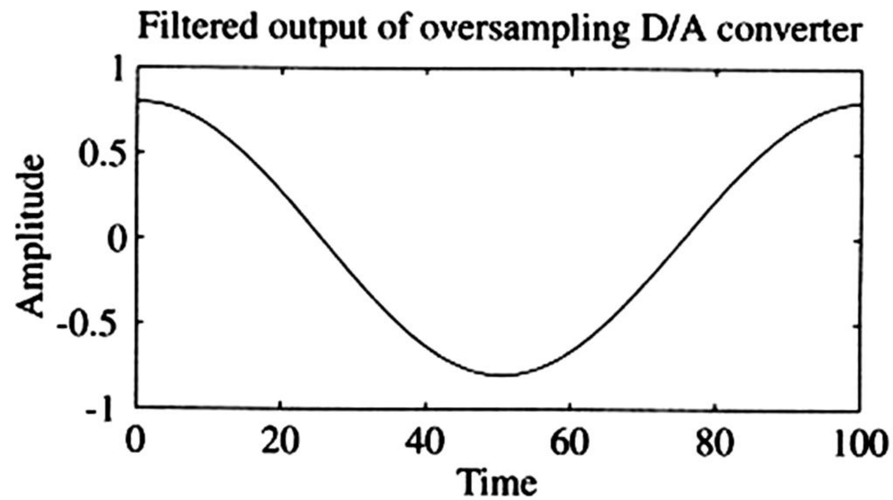


(b)

Filtrirani signal



(a)



(b)

Profesor dr Miroslav Lutovac
mlutovac@viser.edu.rs