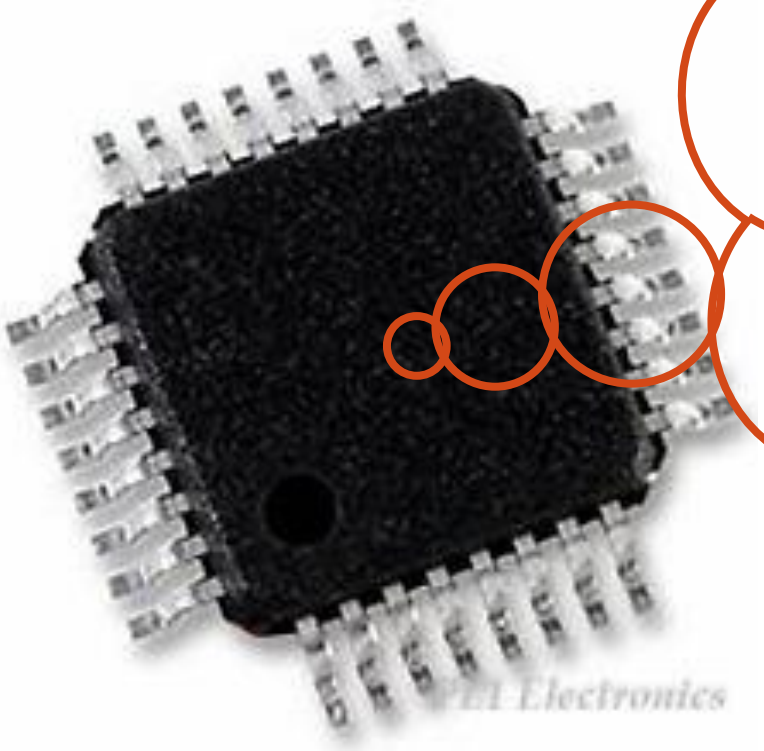
Osnove mikroprocesorske elektronike

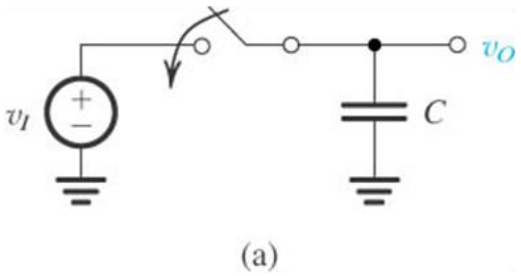
Marko Jankovec

A/D pretvorba

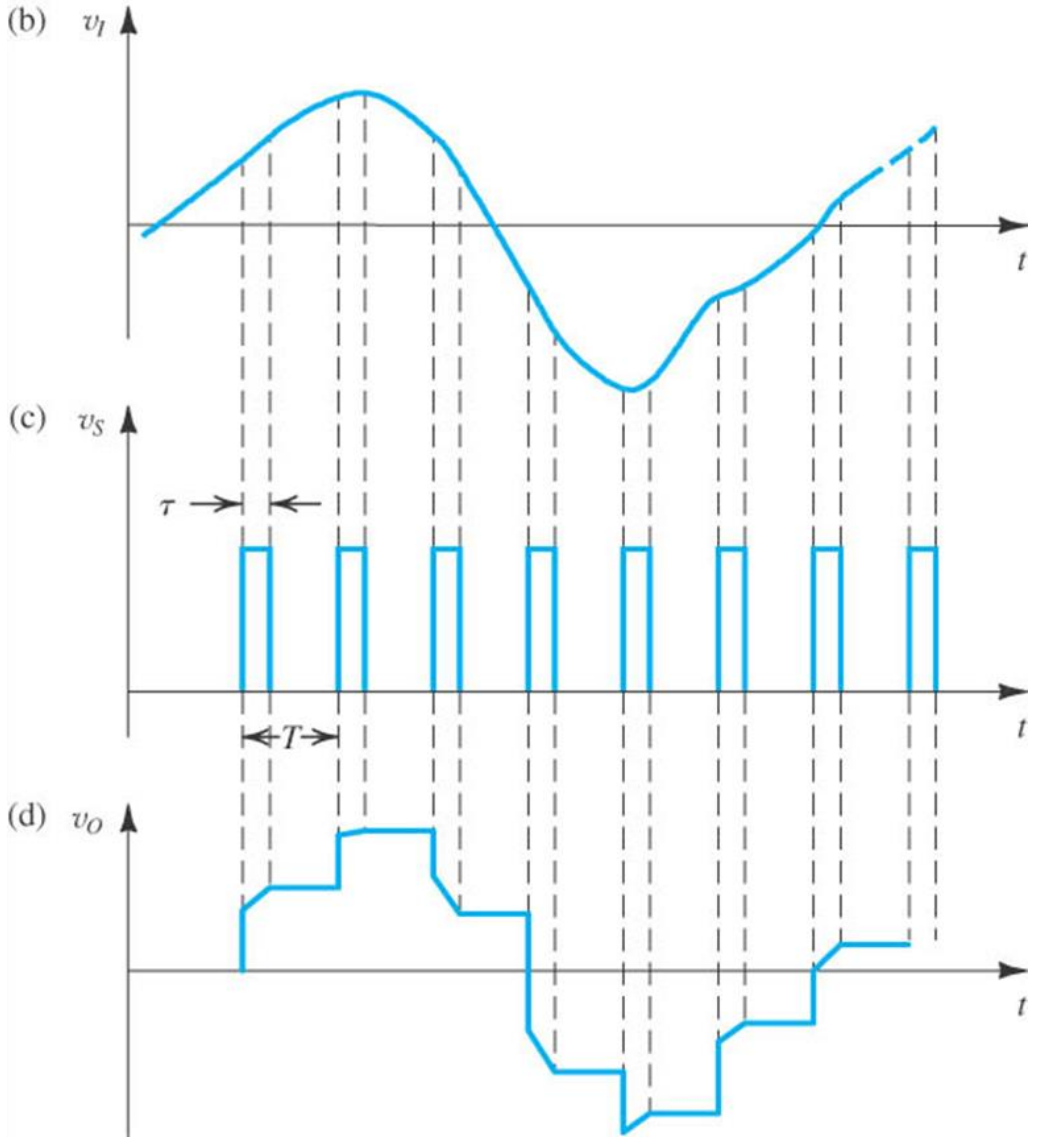
AD pretvorba



Vzorčenje in zadrževanje (Sample&Hold)



(a)



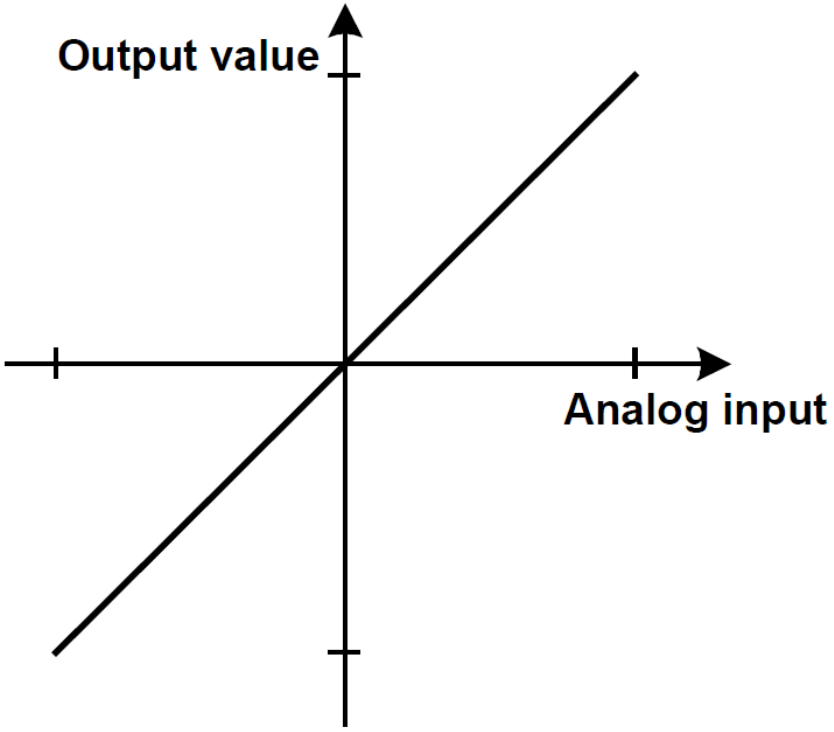
Idealni in realni ADC

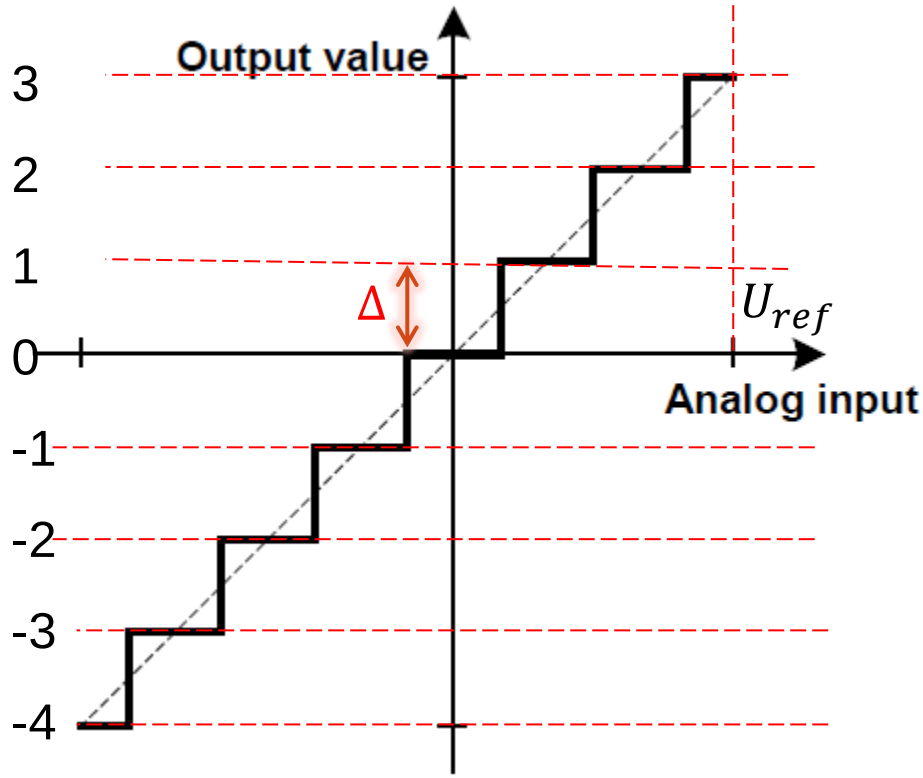
$U_{ref} = 1V$ *(ref. napetost)*

$Q = 3\ bit$ *(št. bitov)*

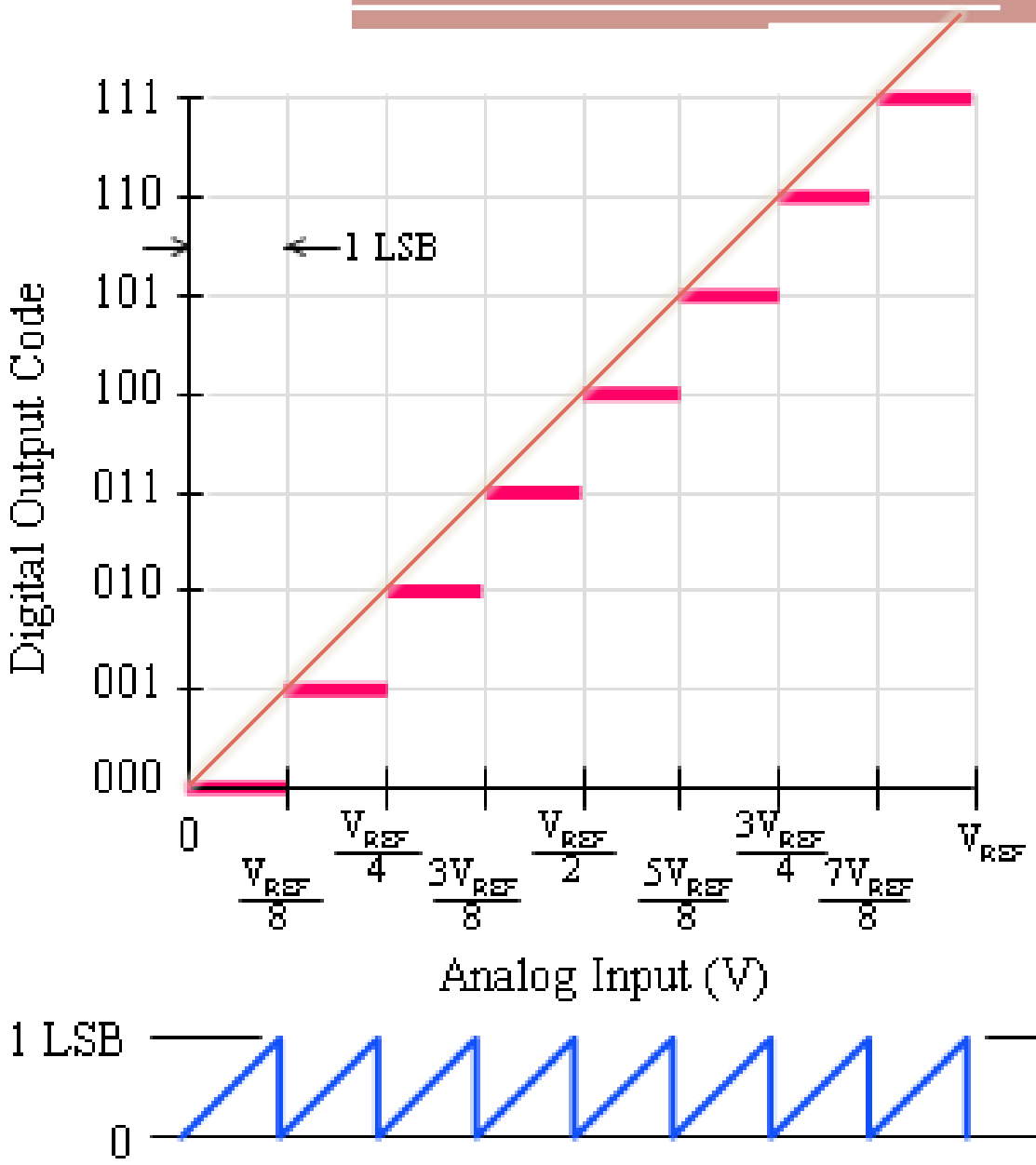
$N = 2^3 = 8$ *(ločljivost)*

$\Delta = \frac{U_{ref}}{N} = 125\ \text{mV}$ *(LSB)*



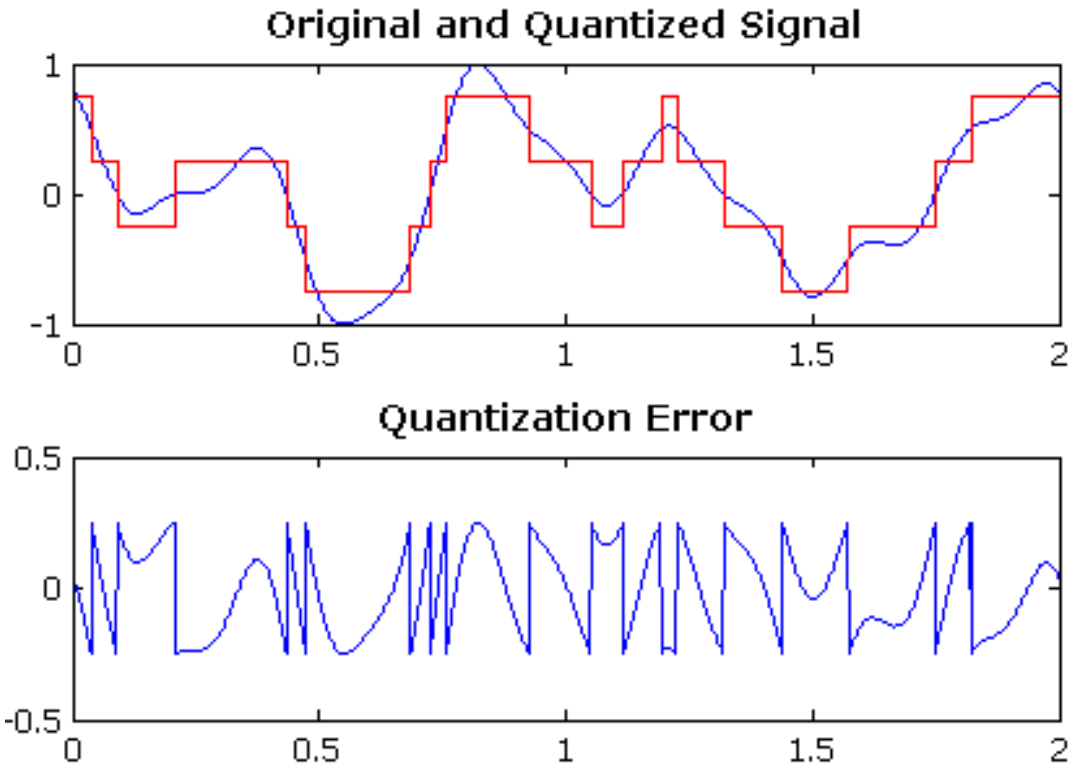


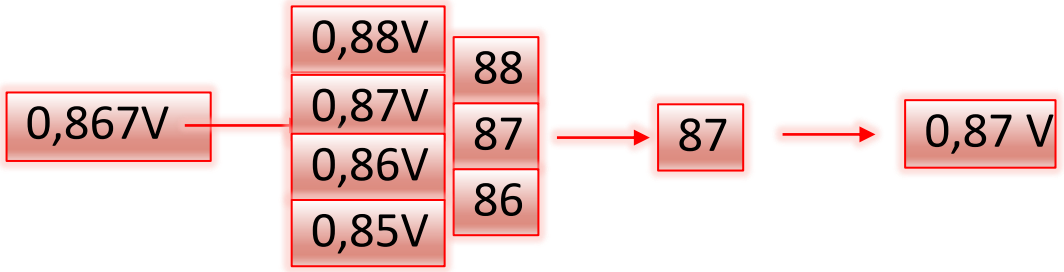
Kvantizacija



$$Napaka_{maks} = 1\ LSB$$

Kvantizacija





$$Napaka_{rms} = \frac{\Delta}{\sqrt{12}}$$

$$SNR = 20\log(2^Q)$$

$U_{ref} = 1{,}1\ V$ *(ref. napetost)*

$Q = 10\ bit$ *(št. bitov)*

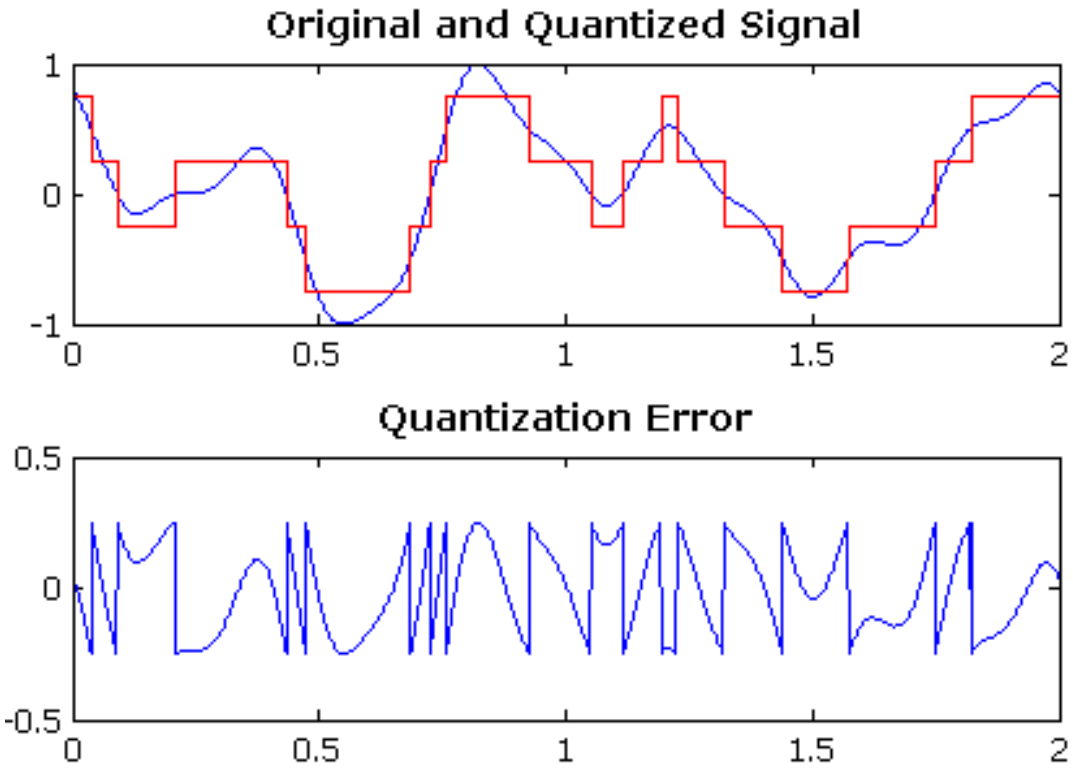
$N =$ $(ločljivost - št.stop.)$

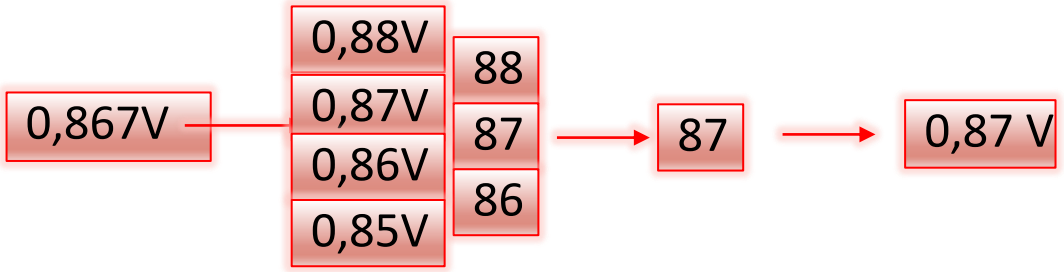
$\Delta =$ (LSB)

$Napaka_{rms} =$ mV

$SNR =$ dB

Kvantizacija





$$Napaka_{rms} = \frac{\Delta}{\sqrt{12}}$$

$$SNR = 20\log(2^Q)$$

$U_{ref} = 1{,}1\ V$ *(ref. napetost)*

$Q = 10\ bit$ *(št. bitov)*

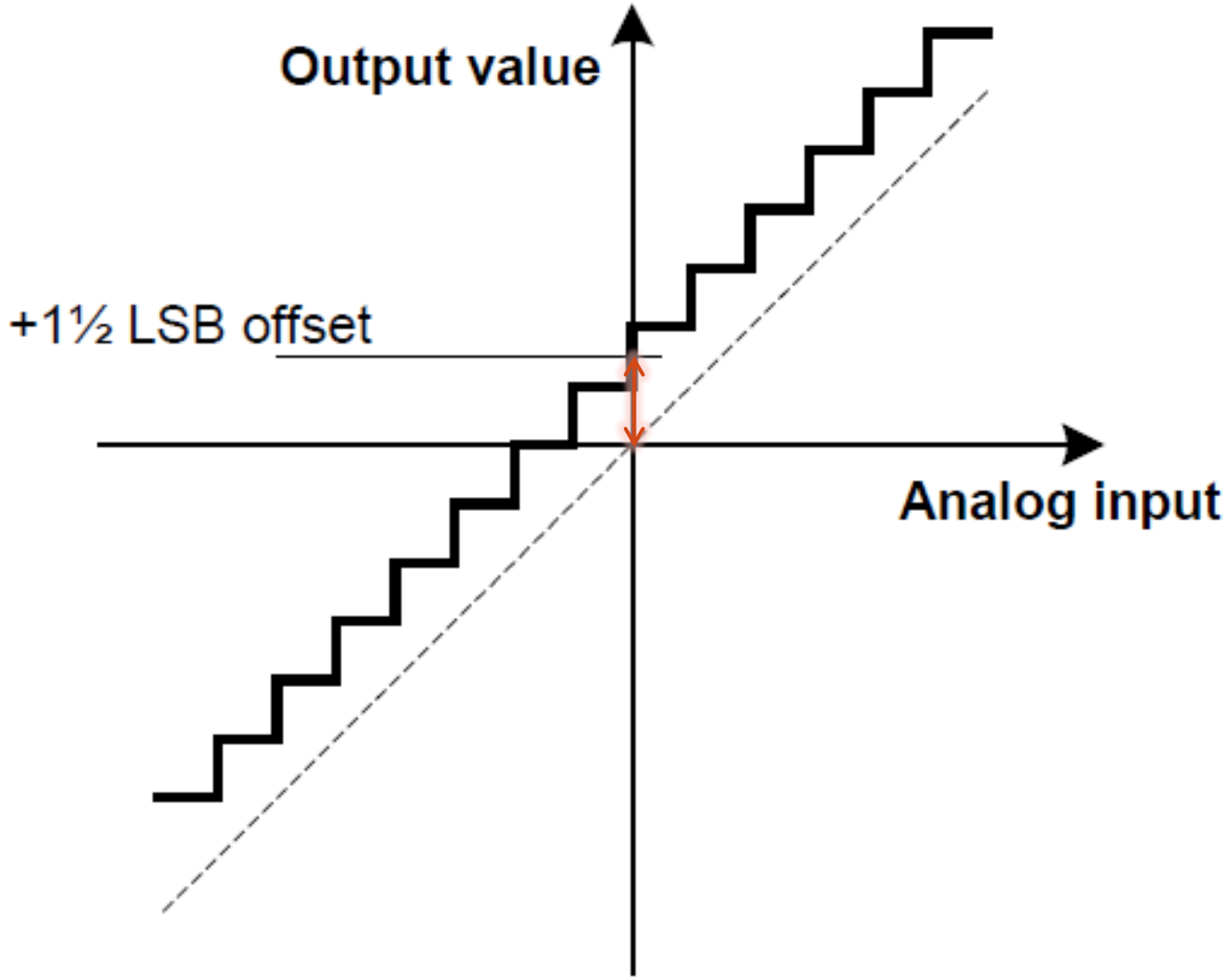
$N = 1024 (ločljivost - št. stp.)$

$\Delta = 1{,}07\ mV \quad (LSB)$

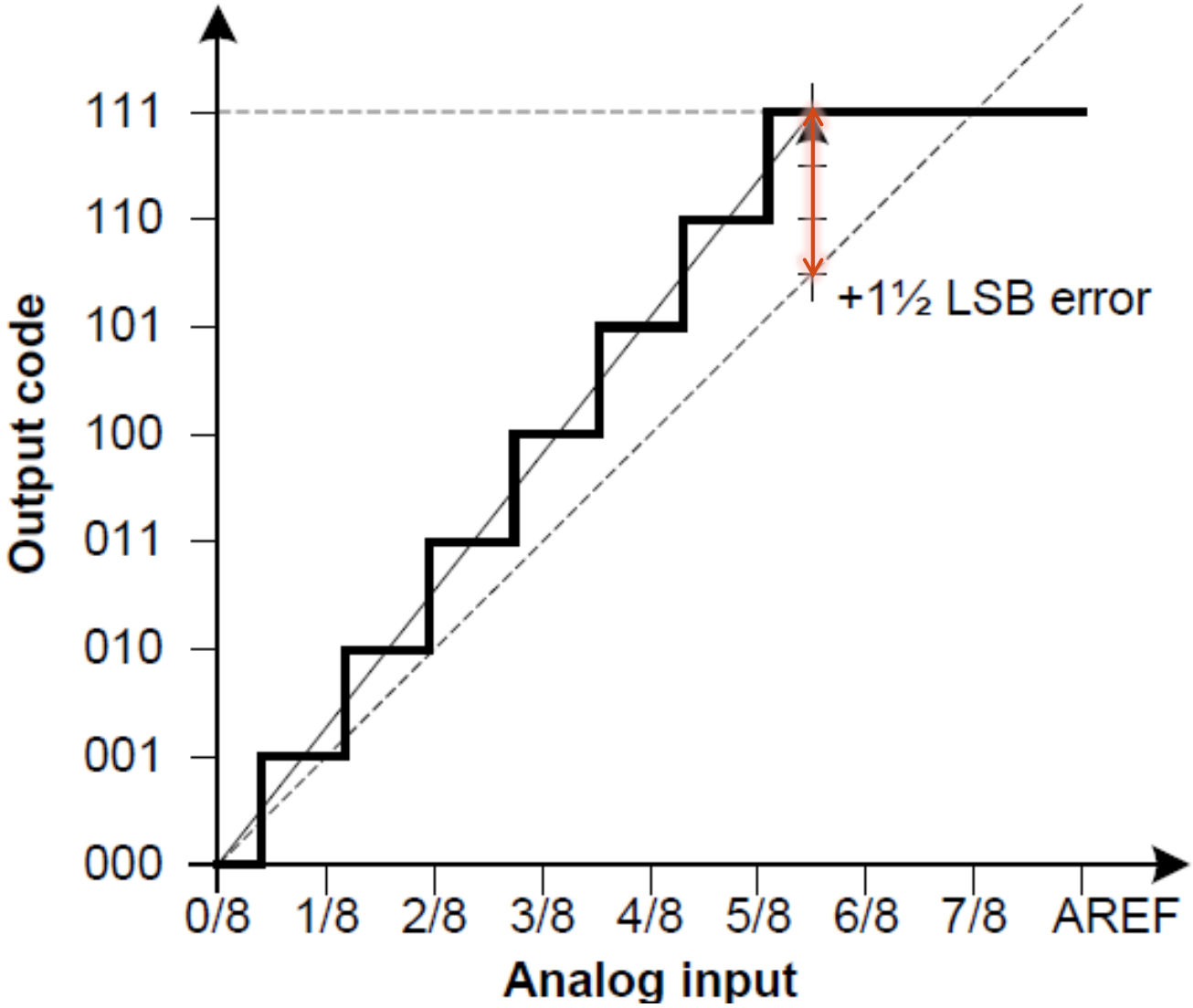
$Napaka_{rms} = 0{,}31 \quad mV$

$SNR = 60 \quad dB$

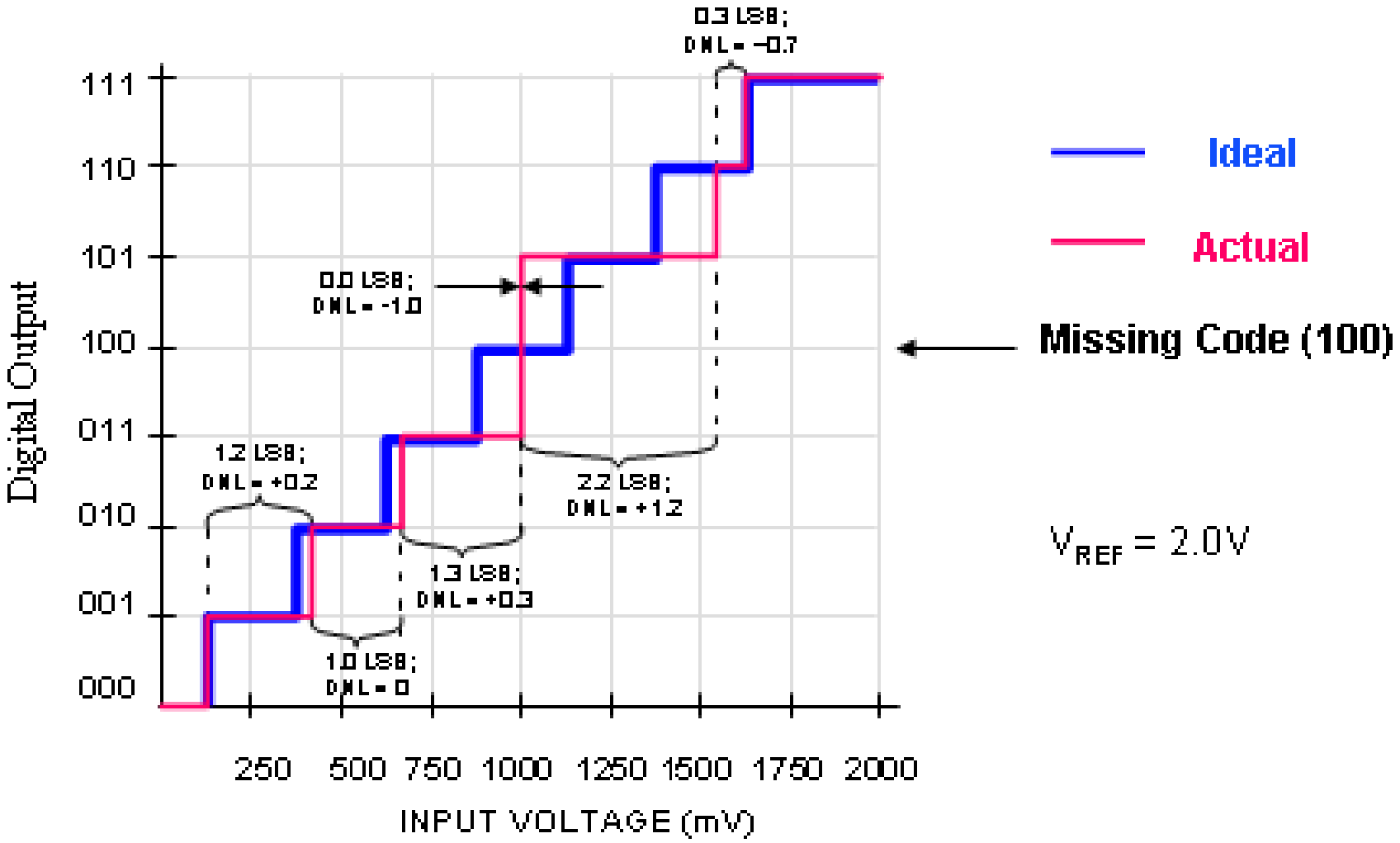
Napaka ničelne vrednosti



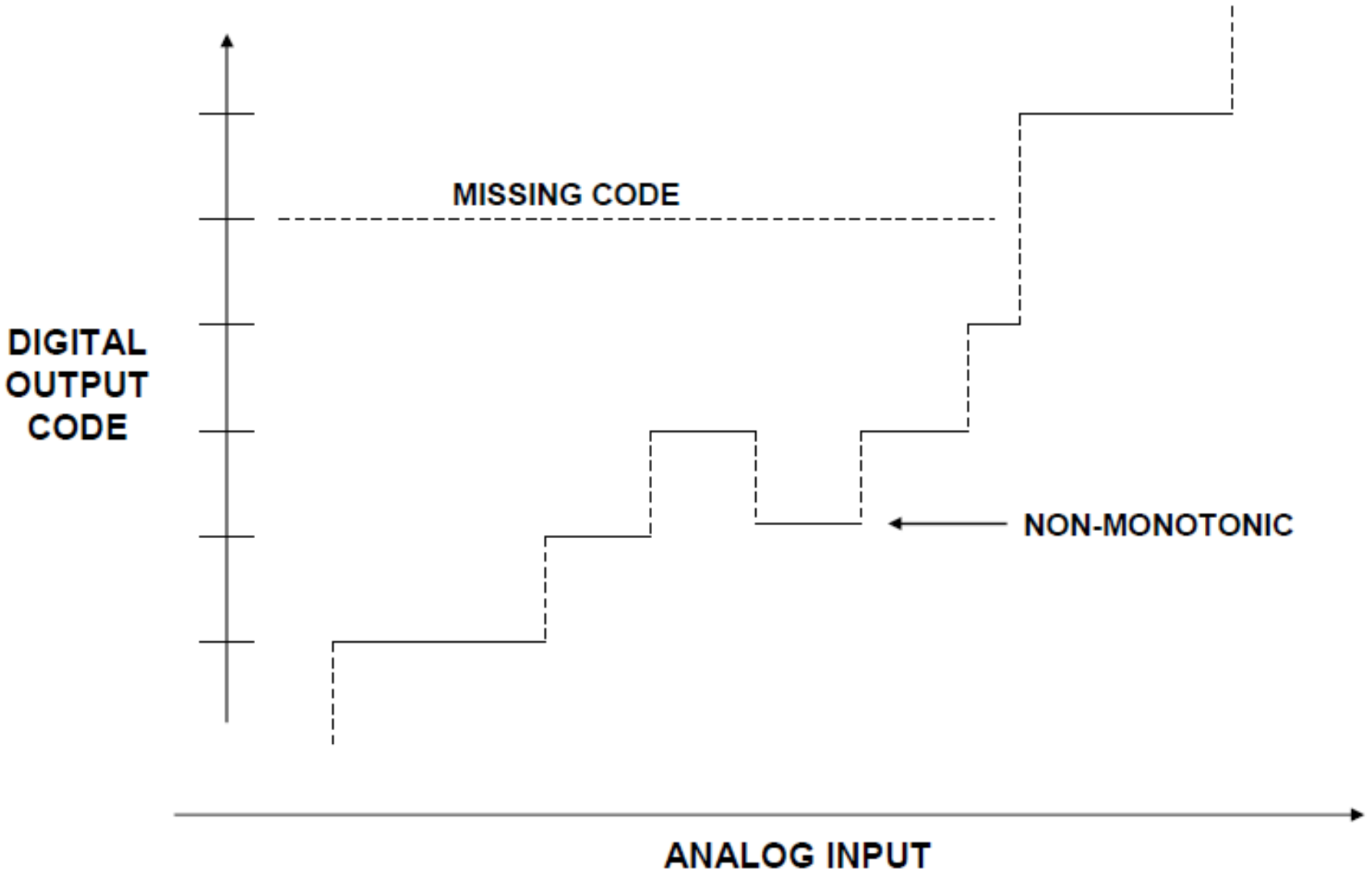
Napaka ojačenja



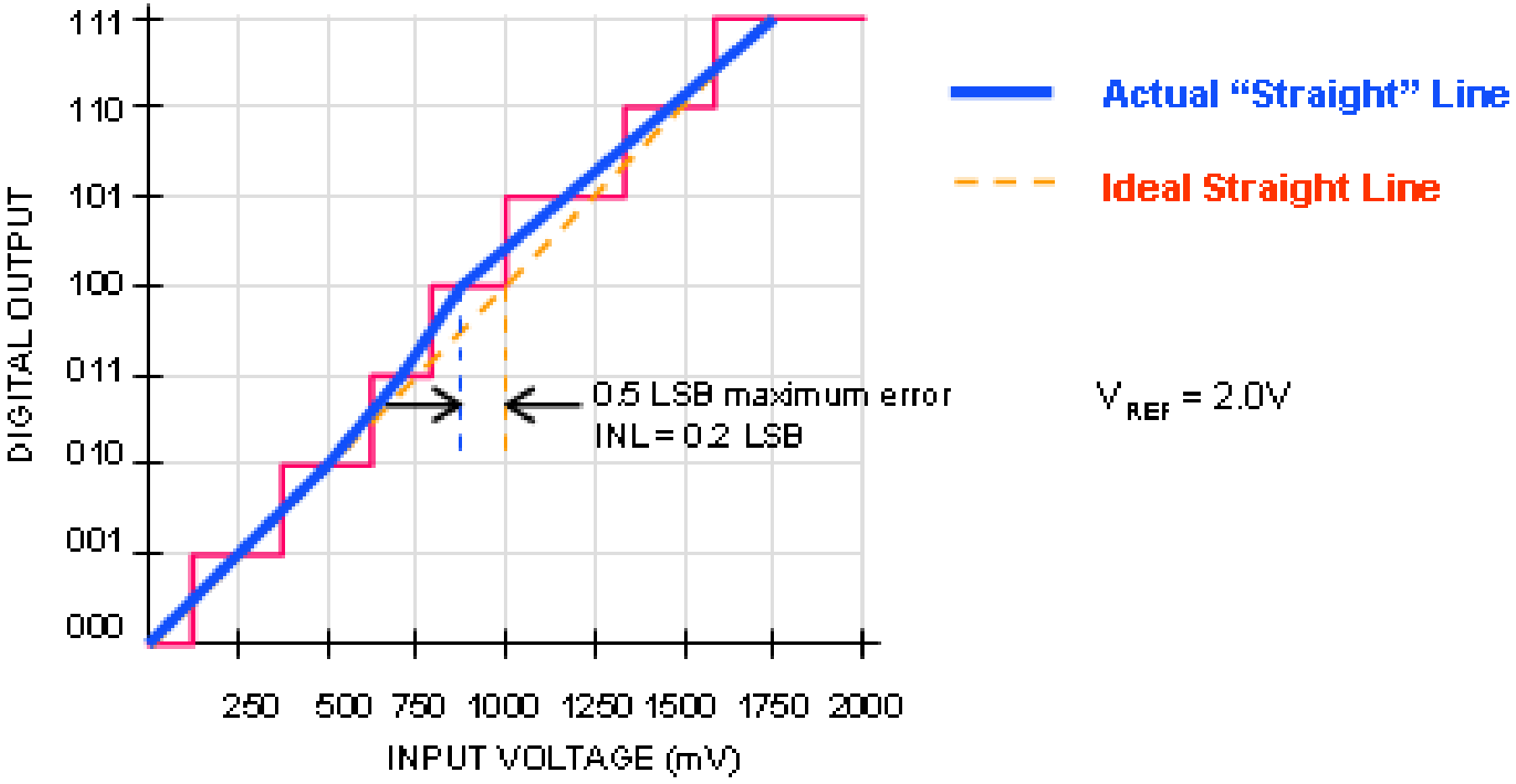
Diferencialna nelinearnost



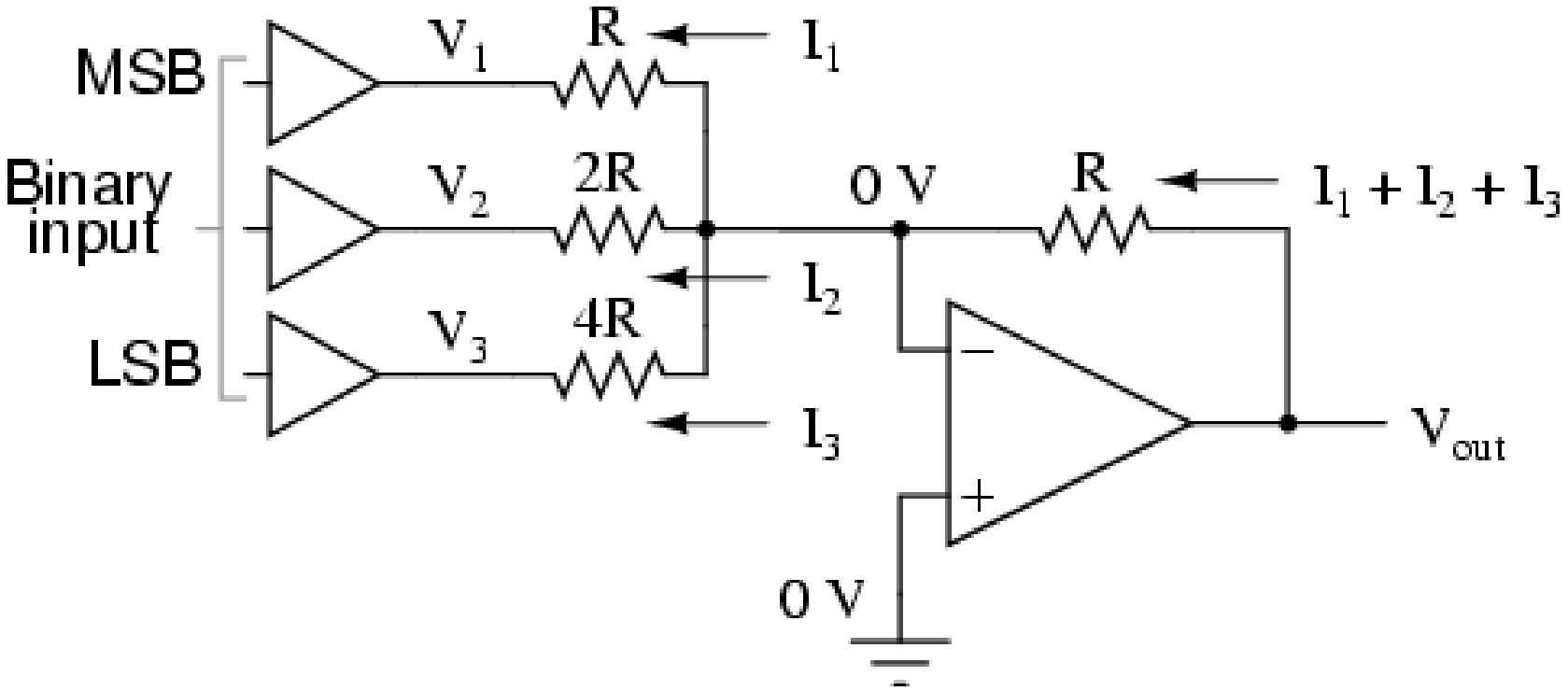
Monotonost


MISSING CODE
DIGITAL OUTPUT CODE
NON-MONOTONIC
ANALOG INPUT

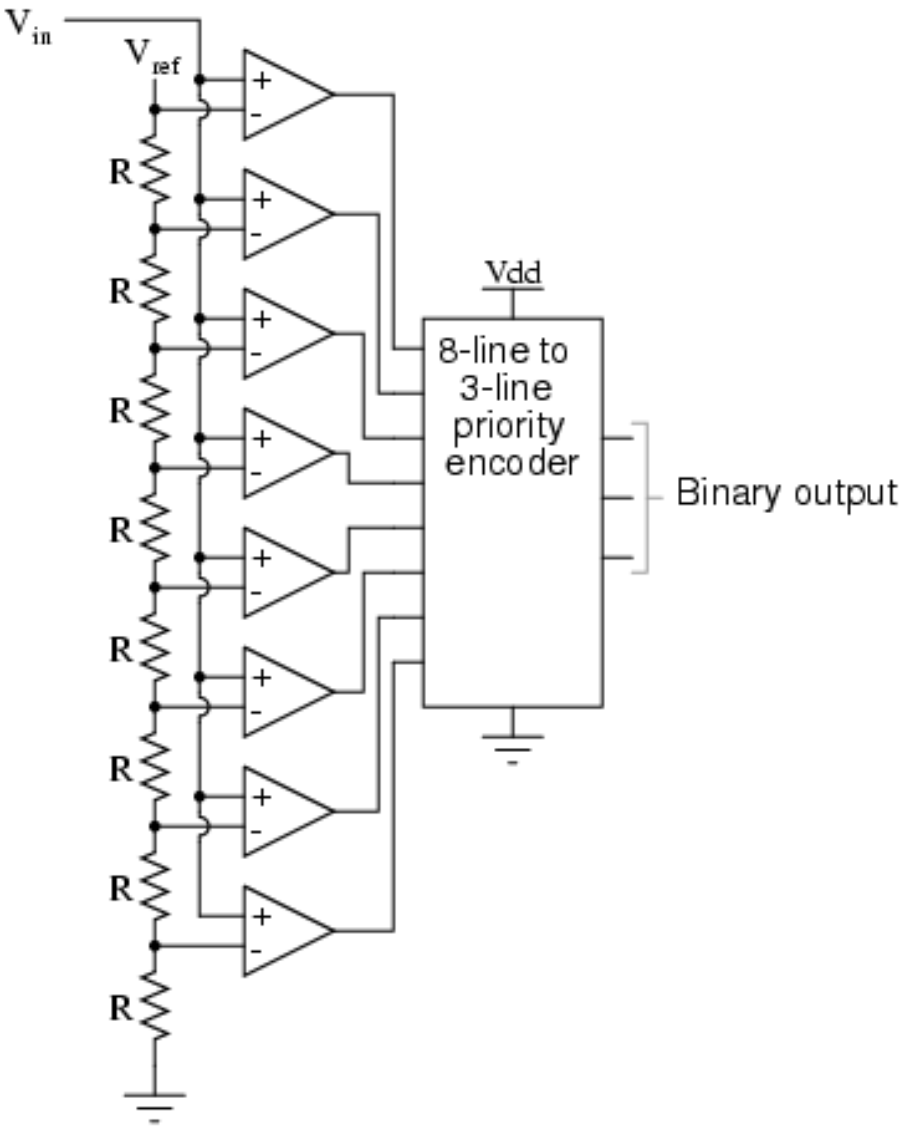
Integralna nelinearnost

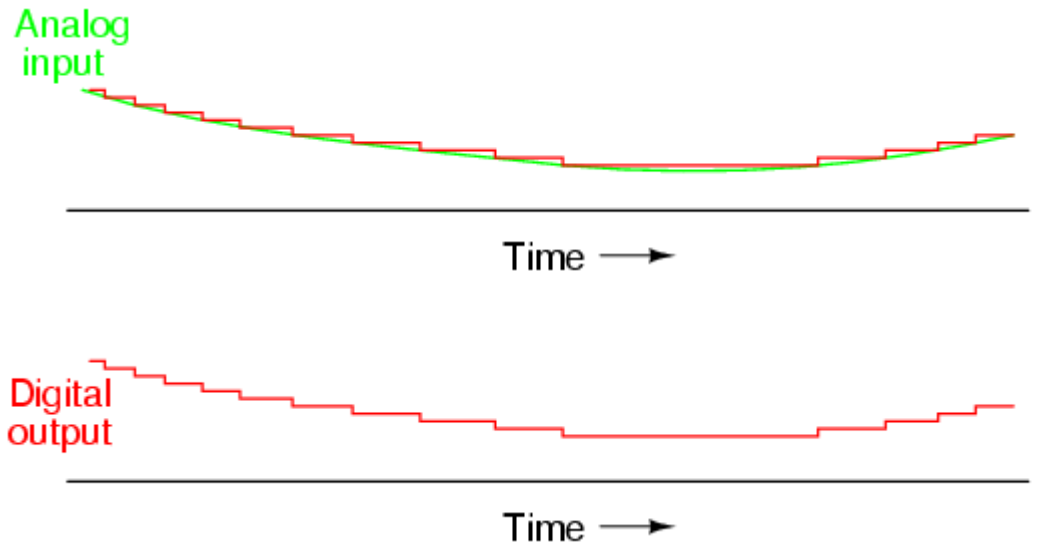


DA pretvornik

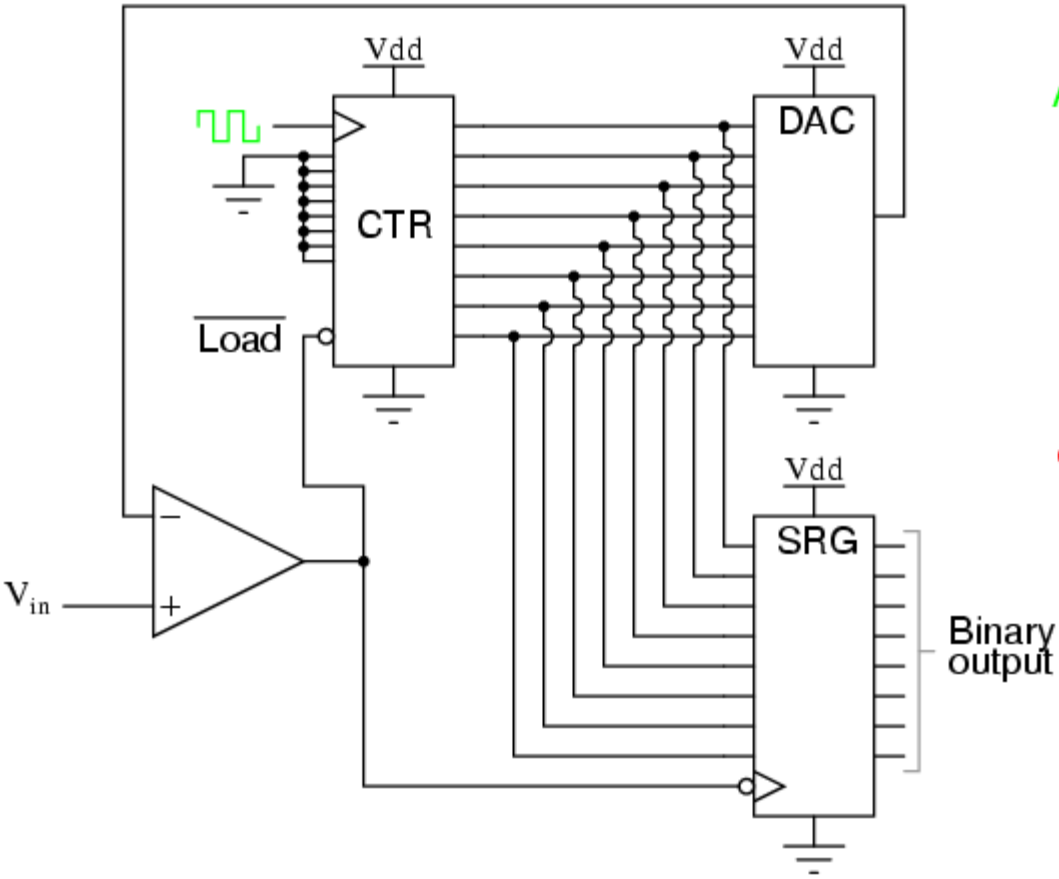


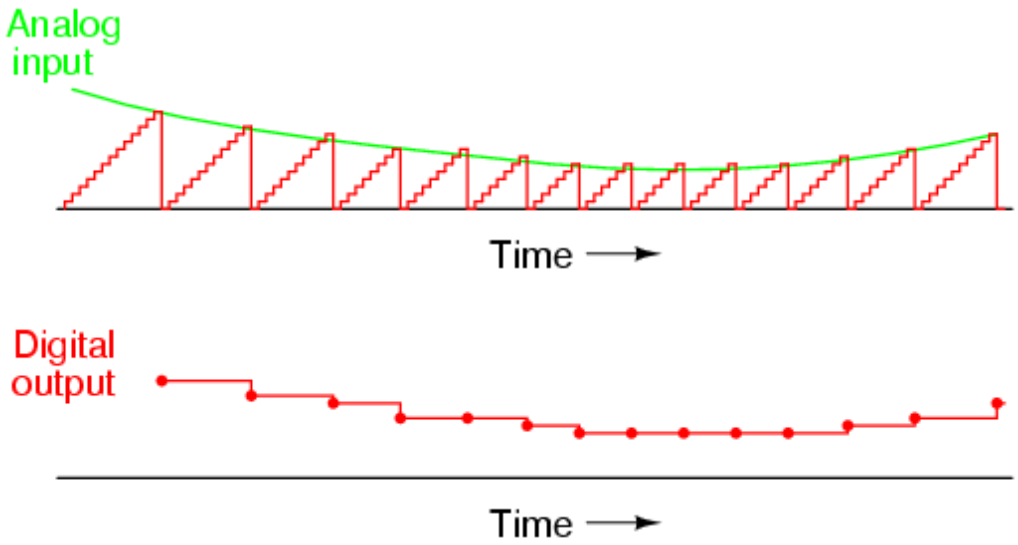
A/D pretvornik – FLASH



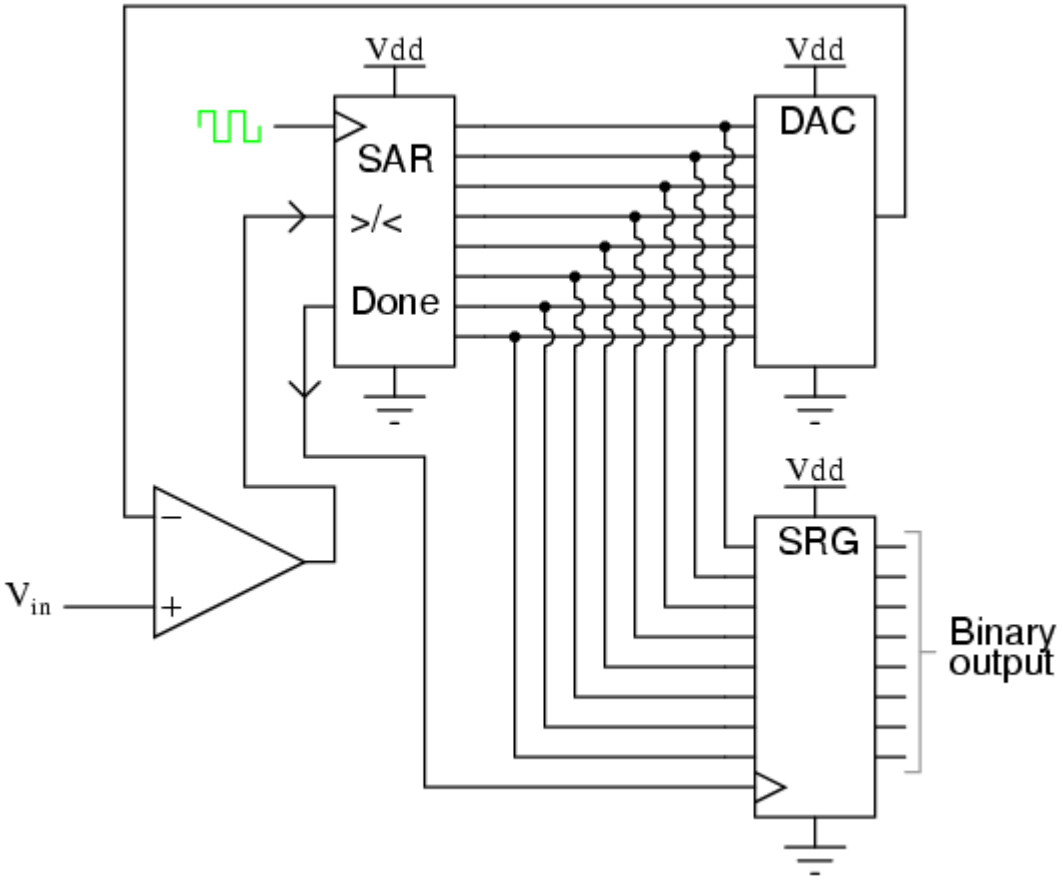


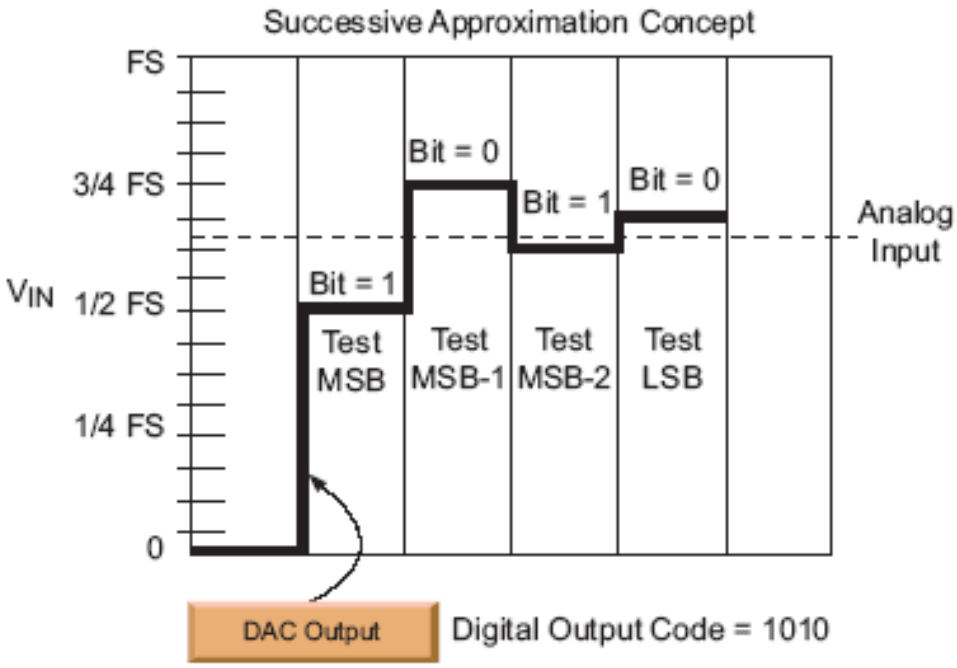
A/D pretvornik z digitalno rampo





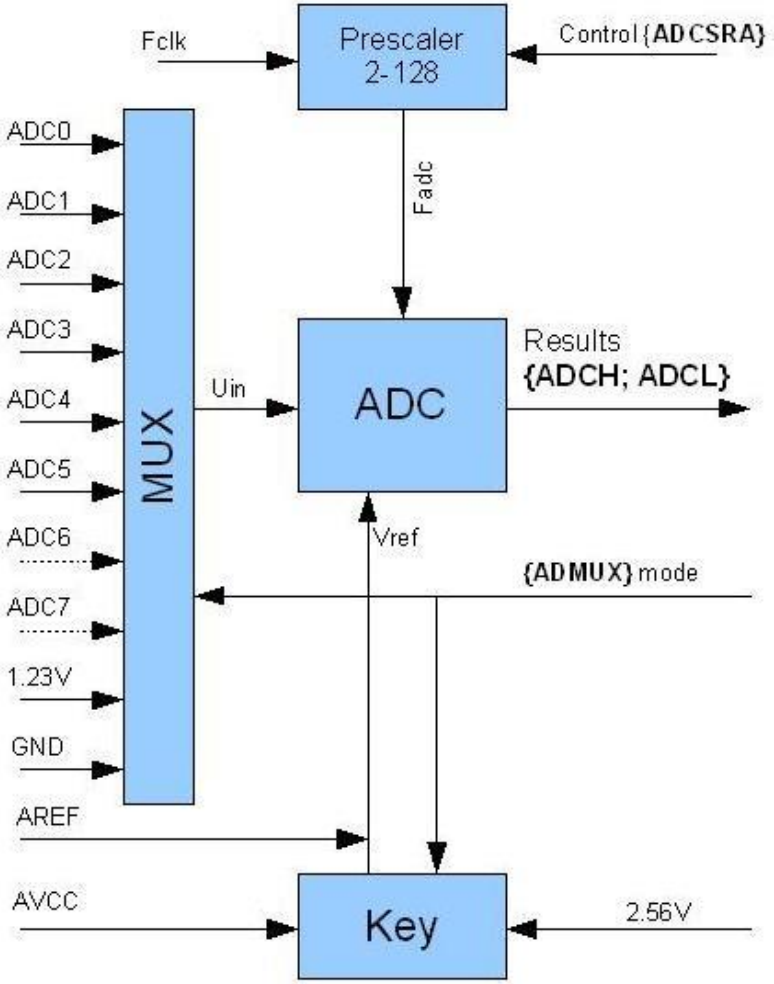
A/D pretvornik s postopnim približevanjem

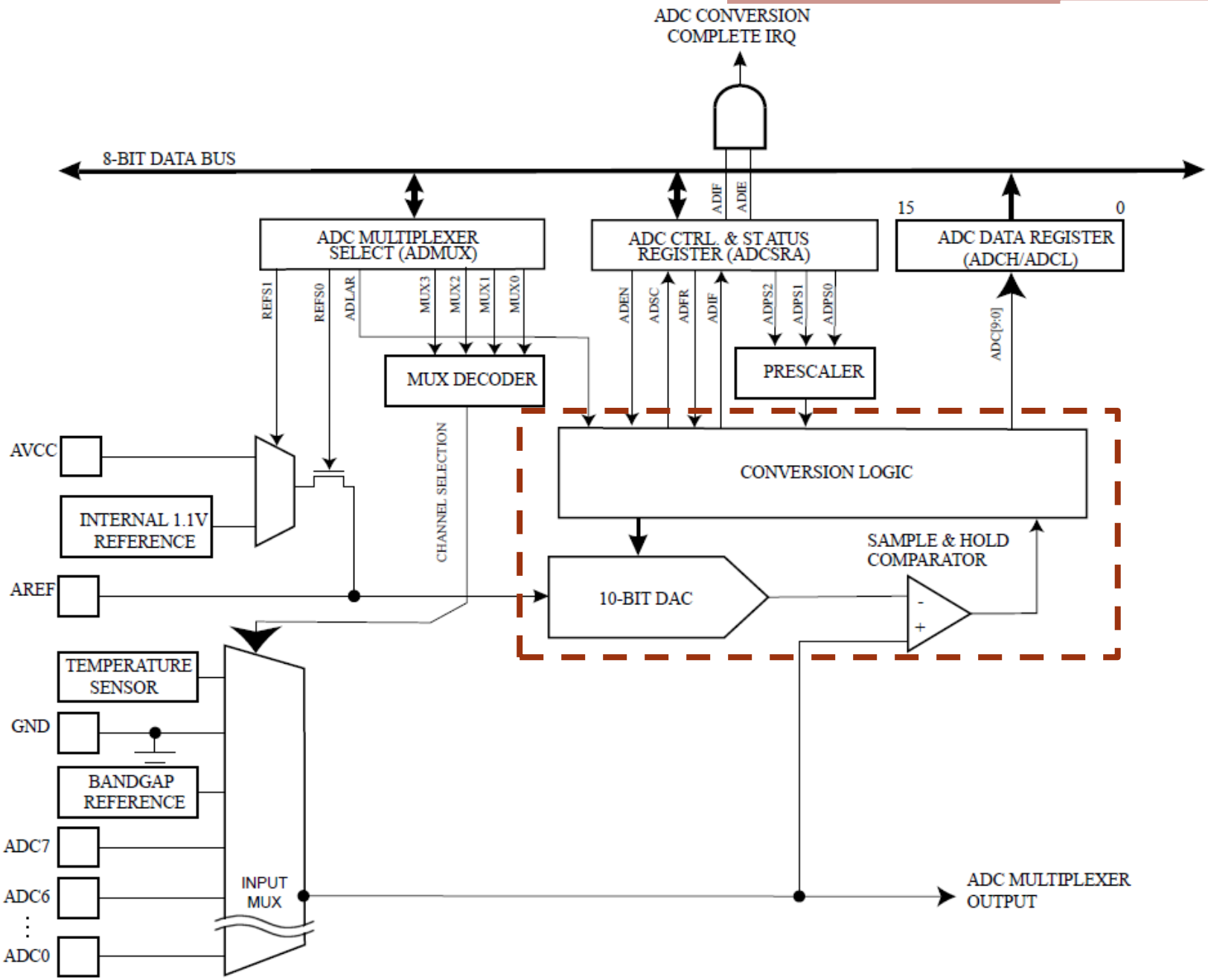




A/D pretvornik pri ATmega 328PB (ADC)

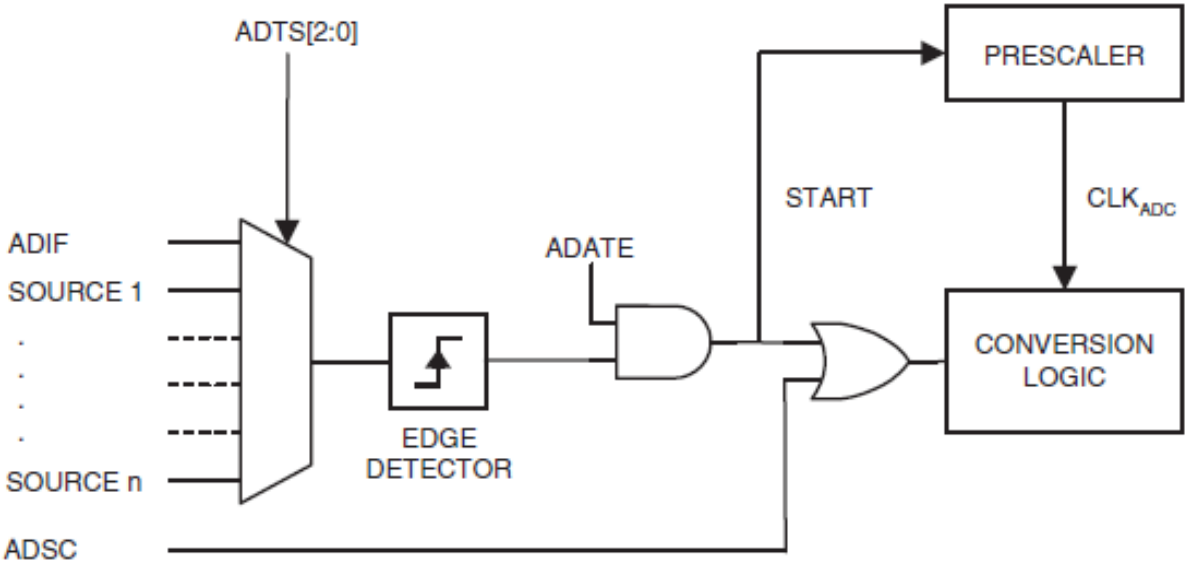
- Resolucija 10 bit
- Integralna nelinearnost 0,5 LSB
- Absolutna napaka ±2 LSB
- Čas pretvorbe 13 – 260 µs
- Hitrost pretvorbe do 15 000 vzorcev/s
- 6 multipleksiranih vhodov
- Senzor temperature
- Različni viri referenčne napetosti
  - Notranja referenca 1.1 V
  - Zunanji vir
  - Napajalna napetost AVcc
- Avtomatsko proženje iz različnih virov prekinitev




ADC CONVERSION COMPLETE IRQ
8-BIT DATA BUS
ADIF
ADIE
15
0
ADC MULTIPLEXER SELECT (ADMUX)
ADC CTRL. & STATUS REGISTER (ADCSRA)
ADC DATA REGISTER (ADCH/ADCL)
REFS1
REFS0
ADLAR
MUX3
MUX2
MUX1
MUX0
ADEN
ADSC
ADFR
ADIF
ADPS2
ADPS1
ADPS0
ADC[9:0]
MUX DECODER
PRESCALER
CHANNEL SELECTION
CONVERSION LOGIC
AVCC
INTERNAL 1.1V REFERENCE
AREF
SAMPLE & HOLD COMPARATOR
10-BIT DAC
TEMPERATURE SENSOR
GND
BANDGAP REFERENCE
ADC7
ADC6
ADC0
INPUT MUX
ADC MULTIPLEXER OUTPUT

Viri proženja pretvorbe

ADTS2	ADTS1	ADTS0	Trigger Source
0	0	0	Free Running mode
0	0	1	Analog Comparator
0	1	0	External Interrupt Request 0
0	1	1	Timer/Counter0 Compare Match A
1	0	0	Timer/Counter0 Overflow
1	0	1	Timer/Counter1 Compare Match B
1	1	0	Timer/Counter1 Overflow
1	1	1	Timer/Counter1 Capture Event

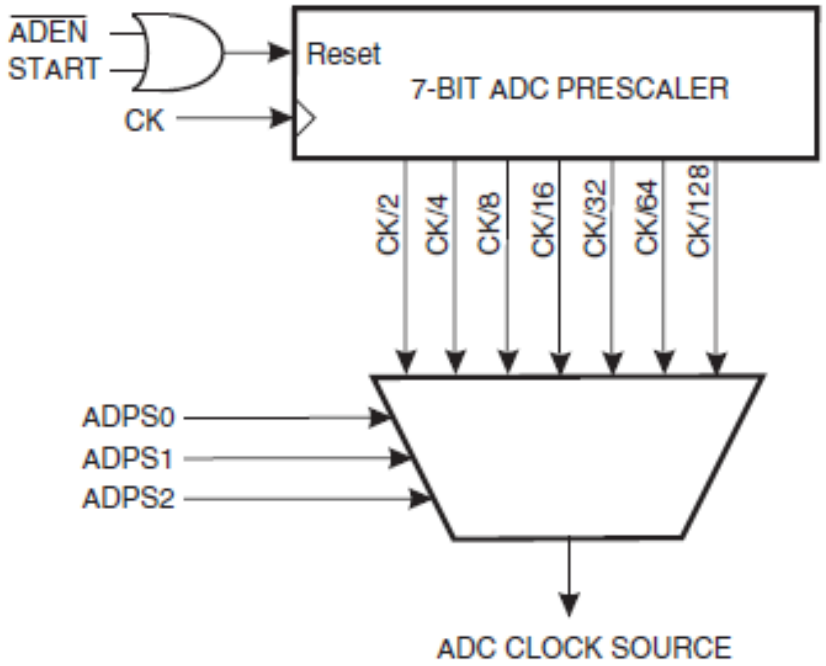


Bit	7	6	5	4	3	2	1	0	
(0x7A)	ADEN	ADSC	ADATE	ADIF	ADIE	ADPS2	ADPS1	ADPS0	ADCSRA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Bit	7	6	5	4	3	2	1	0	
(0x7B)	–	ACME	–	–	–	ADTS2	ADTS1	ADTS0	ADCSRB
Read/Write	R	R/W	R	R	R	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

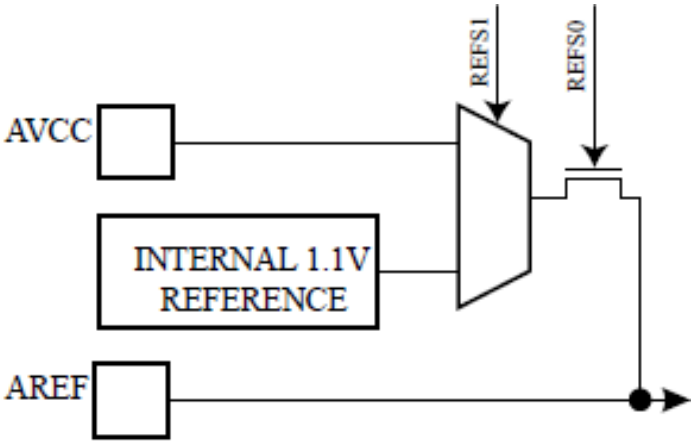
Čas pretvorbe

- Frekvenca med 50 in 200 kHz za maksimalno 10-bit resolucijo
- Čas pretvorbe
  - za prvo pretvorbo – 25 cikov
    - S/H 14,5 ciklov
  - za vse nadaljne pretvorbe: 13-14 ciklov
    - S/H 1,5-2,5 cikla



Bit	7	6	5	4	3	2	1	0	
(0x7A)	ADEN	ADSC	ADATE	ADIF	ADIE	ADPS2	ADPS1	ADPS0	ADCSRA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

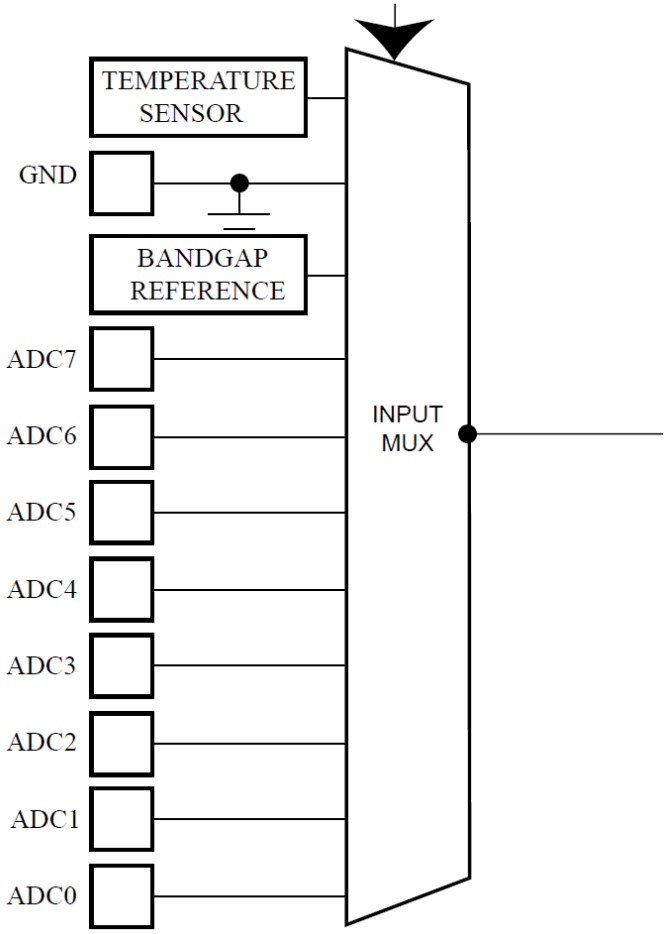
Izbira reference



REFS[1:0]	Voltage Reference Selection
00	AREF, Internal V_{ref} turned off
01	AV_{CC} with external capacitor at AREF pin
10	Reserved
11	Internal 1.1V Voltage Reference with external capacitor at AREF pin

Bit	7	6	5	4	3	2	1	0	
(0x7C)	REFS1	REFS0	ADLAR		MUX3	MUX2	MUX1	MUX0	ADMUX
Read/Write	R/W	R/W	R/W		R/W	R/W	R/W	R/W	
Initial Value	0	0	0		0	0	0	0	

Izbira vira vhodnega signala



MUX[3:0]	Single Ended Input
0000	ADC0
0001	ADC1
0010	ADC2
0011	ADC3
0100	ADC4
0101	ADC5
0110	ADC6
0111	ADC7
1000	Temperature sensor
1001	Reserved
1010	Reserved
1011	Reserved
1100	Reserved
1101	Reserved
1110	1.1V (V_{BG})
1111	0V (GND)

Bit	7	6	5	4	3	2	1	0	
(0x7C)	REFS1	REFS0	ADLAR		MUX3	MUX2	MUX1	MUX0	ADMUX
Read/Write	R/W	R/W	R/W		R/W	R/W	R/W	R/W	
Initial Value	0	0	0		0	0	0	0	

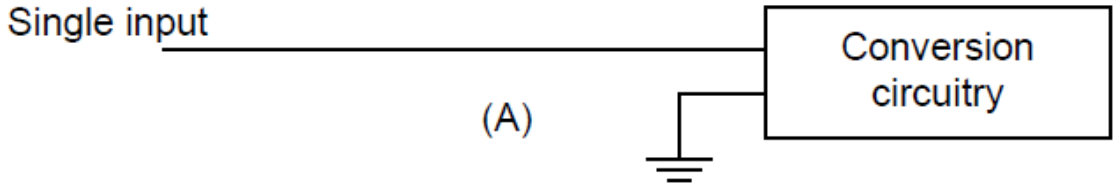
Kdaj lahko zamenjamo vir vhodnega signala oz. reference?

- Kadar je ADC onemogočen (ADEN = 0) ali
- Kadar je onemogočeno samoproženje (ADATE = 0)
- Če je vključeno samoproženje:
  - med pretvorbo, ampak šele 1 cikel po proženju
    - double buffering registra ADMUX omogoča, da se vsebina spremeni šele po končani pretvorbi
    - največkrat spreminjamo v prekinitveni rutini (ampak šele za naslednjo pretvorbo)
  - Po končani pretvorbi
    - ampak preden se zbriše zastavica, ki je pretvorbo sprožila

Rezultat pretvorbe

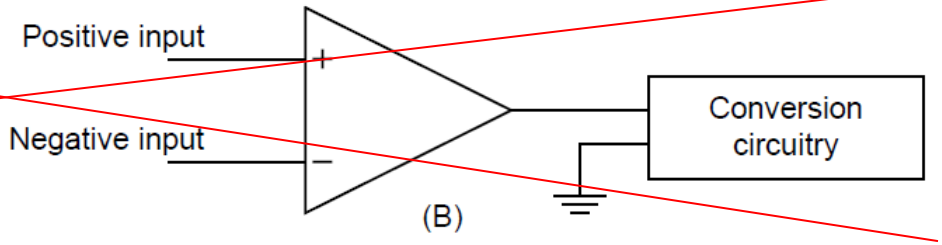
- Merjenje proti masi

$$ADC = \frac{U_{IN}}{U_{REF}} 1024$$



- Diferencialno merjenje

$$ADC = \frac{U_{INp} - U_{INn}}{U_{REF}} GAIN\ 512$$



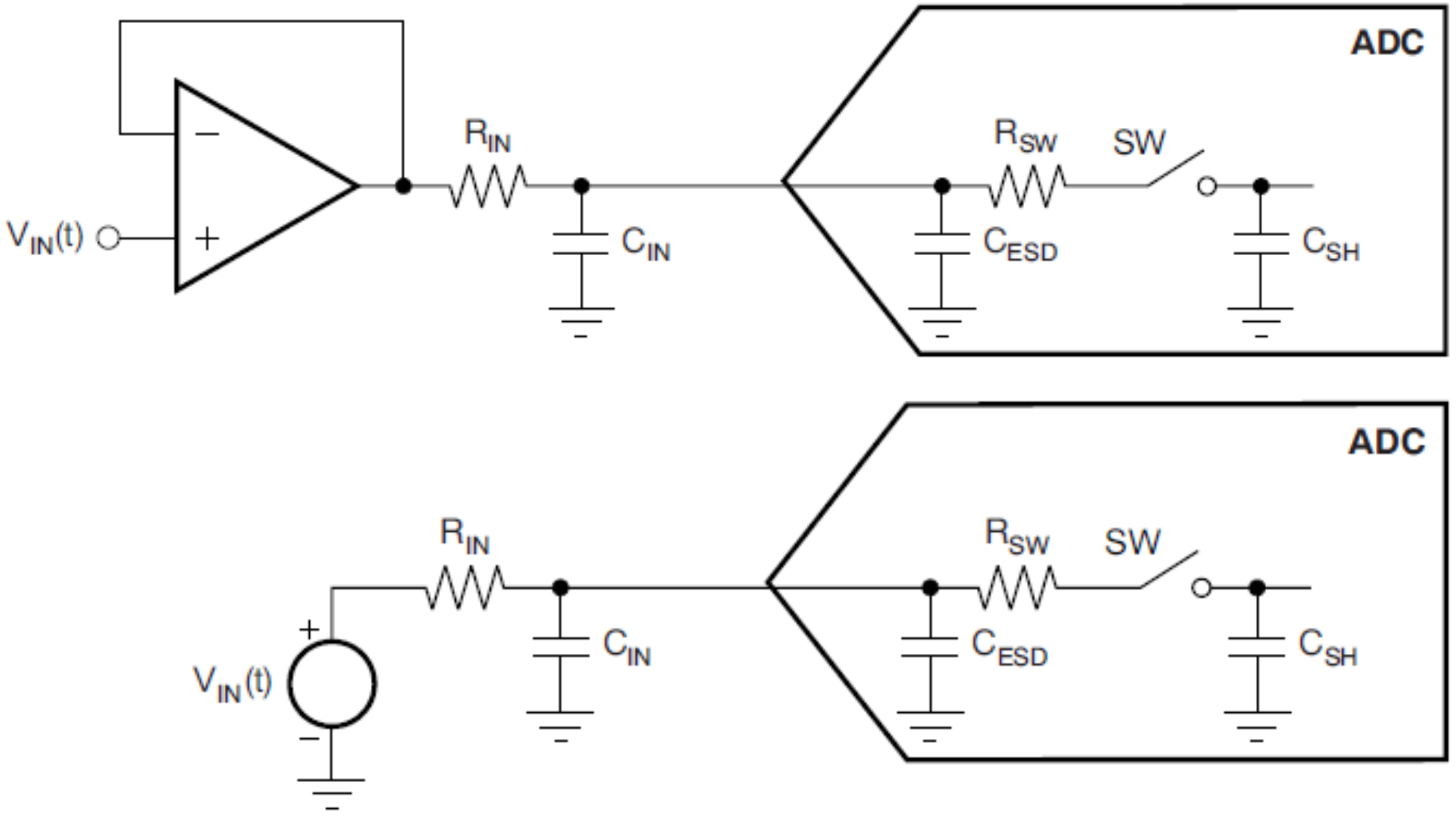
ADLAR = 1

Bit	15	14	13	12	11	10	9	8	
(0x79)	ADC9	ADC8	ADC7	ADC6	ADC5	ADC4	ADC3	ADC2	ADCH
(0x78)	ADC1	ADC0	–	–	–	–	–	–	ADCL

ADLAR = 0

Bit	15	14	13	12	11	10	9	8	
(0x79)	–	–	–	–	–	–	ADC9	ADC8	ADCH
(0x78)	ADC7	ADC6	ADC5	ADC4	ADC3	ADC2	ADC1	ADC0	ADCL
	7	6	5	4	3	2	1	0	

Ekvivalentno vezje vhoda AD pretvornika

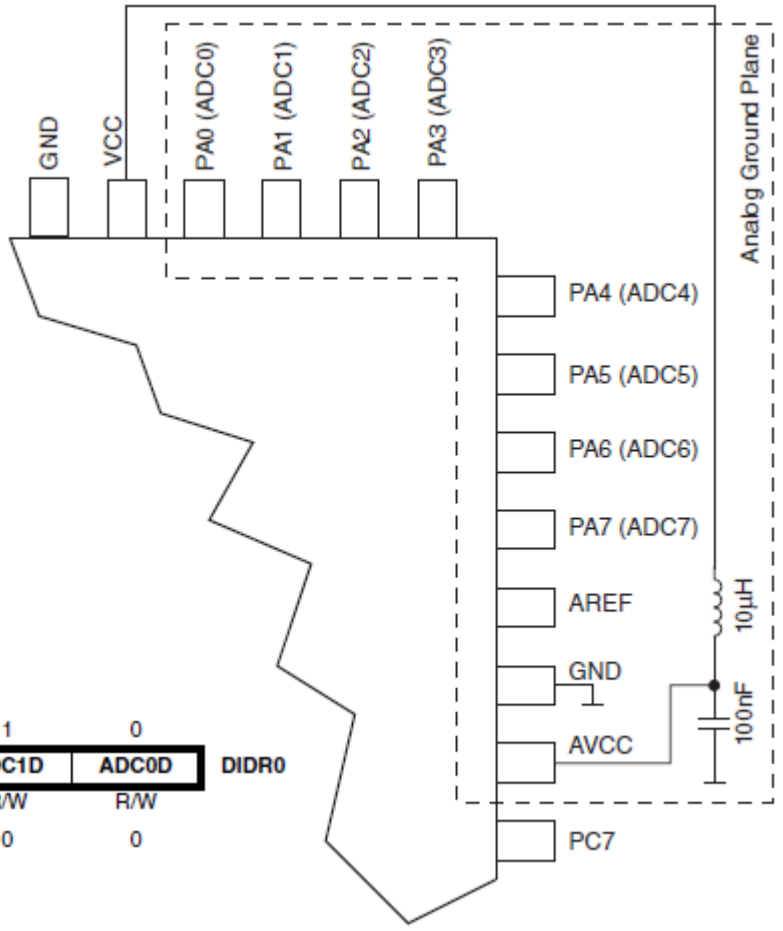


Zmanjšanje šuma ADC

- ADC noise reduction mode
- Pogoji
  - omogočen ADC noise reduction način (SM2..0 = 001)
  - ročno proženje pretvorbe (ADATE = 0)
  - omogočena prekinitev ob končani pretvorbi (ADIE = 1)
- Sprožitev AD pretvorbe
  - ADC mora biti omogočen (ADEN = 1)
  - pretvorbo sproži ASM ukaz „sleep“
  - procesor gre v stanje nizke porabe (koda se ne izvaja)
  - zbudi ga prekinitev ob končani pretvorbi

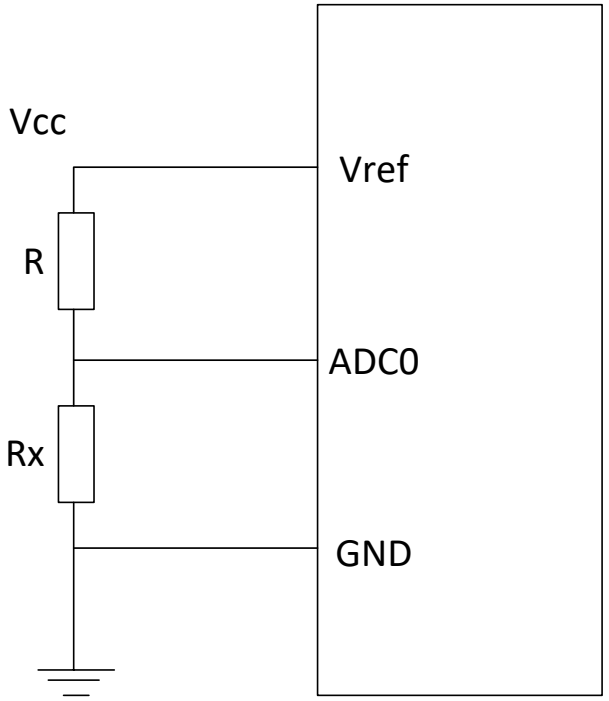
Zmanjšanje šuma ADC

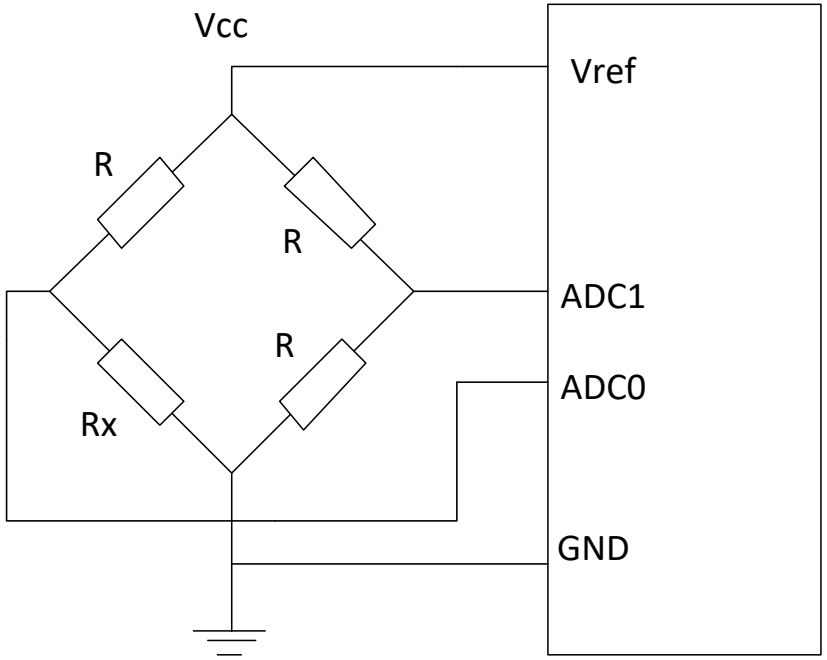
- Analogne povezave naj bodo čim krajše
- AVCC povezan na VCC preko LC filtra
- Uporaba ADC noise canceller načina
- Če so vhodi ADC uporabljeni hkrati kot I/O pini, jih ne preklapljati v času pretvorbe
- Onemogočitev vhodnih digitalnih ojačevalnikov I/O pinov



Bit	7	6	5	4	3	2	1	0	
(0x7E)	ADC7D	ADC6D	ADC5D	ADC4D	ADC3D	ADC2D	ADC1D	ADC0D	DIDR0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Raciometrična pretvorba



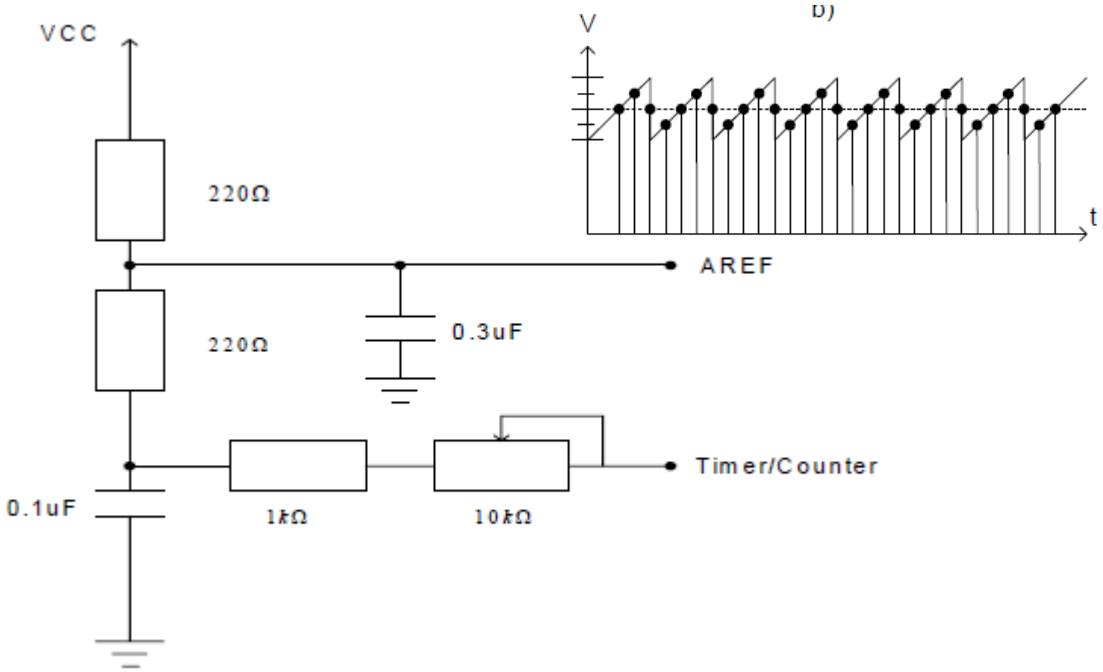


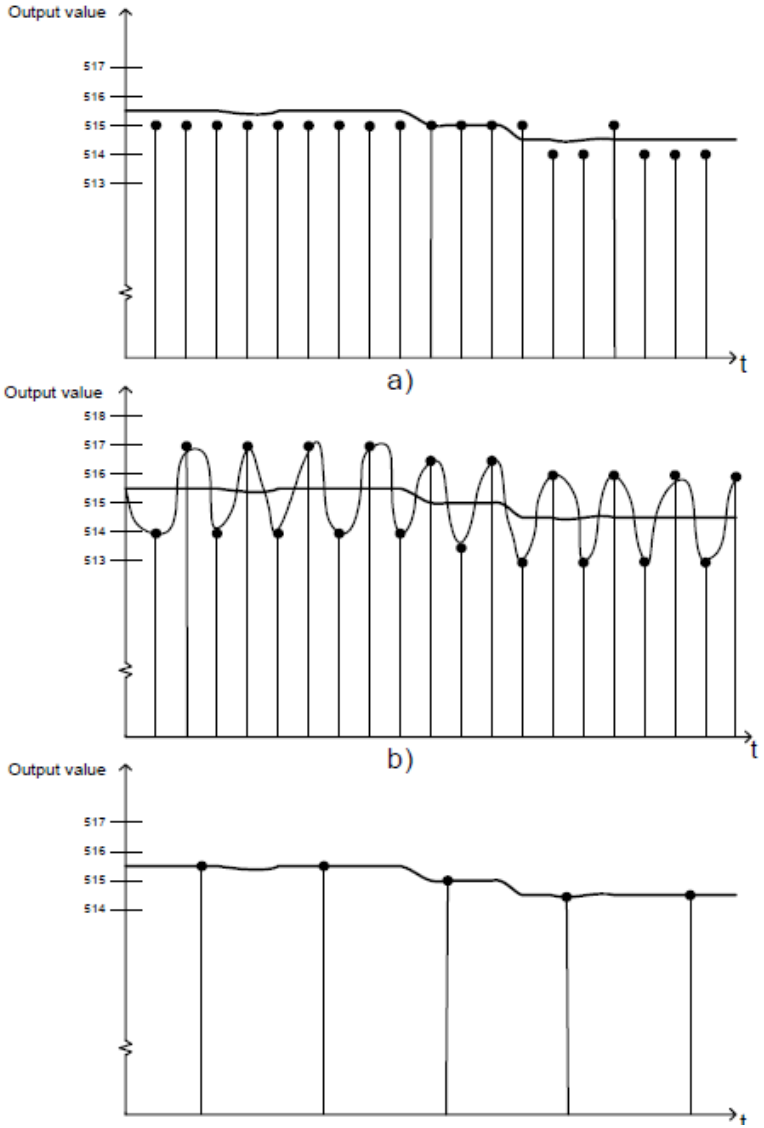
$$ADC = \frac{R_x}{(R + R_x)} 1024$$

$$ADC = \frac{R - R_x}{R + R_x} 1024 = k * \frac{F}{FS} 1024$$

Povečanje ločljivosti (oversampling & dithering)

- Podvojitev frekvence vzorčenja x4 (povprečenje 4 vzorcev) doda 1 bit ločljivosti
- Dodatek šuma vsaj 1 LSB





Na koncu se pričakuje, da znate

- predstaviti teorem vzorčenja, zadrževanja in kvantizacije
- prepoznati glavne vire napak pri AD-pretvorbi
- razložiti delovanje in primerjati lastnosti različnih principov AD-pretvorbe
- s pomočjo podatkovnega lista analizirati pomen registrov in nastaviti ustrezno delovanje AD-pretvornika v mikrokrmilnikih AVR
- izbrati najprimernejši vir referenčne napetosti glede na aplikacijo

At the end we expect you to be able to

- describe the sample & hold theory and quantization
- recognize the most important inaccuracy sources of AD-conversion
- explain different principles of AD conversion and compare their advantages and disadvantages
- analyze the meaning of ADC control registers using a datasheet and be able to set them to the correct values to achieve the desired mode of operation for AVR microcontrollers
- select the appropriate reference source for your application

Literatura/Literature

knjiga/ povezava book/ link	poglavje/ chapter
ATmega328PB datasheet	28
Programming and customising the AVR microcontroller	6.7
Introduction to Microcontrollers	2.4
Dithering - povečanje ločljivosti A/D pretvornika	pdf
Uporaba komparatorja za integracijski A/D pretvornik	pdf
Lastnosti in kalibracija AD pretvornika	pdf
O raciometrični pretvorbi	pdf

Priprava na laboratorijsko vajo

- Inicializacija AD:
  - PC0..PC3 –> HiZ vhodi
    - PORTC=?, DDRC=?
  - Izključiti digitalne vmesnike na PC0..PC3
    - DIDR0 =?
  - Referenca AVCC, desna poravnava, ročno proženje, hitrost konverzije znotraj specifikacij
    - ADCSRA=?, ADCSRB=?
- Delo z EEPROM-om:
  - Preuči funkcije v avr/eeprom.h
  - Pred glavno while(1) zanko
    - Branje EEPROMA z lokacije 0
    - Povečaj prebrano vrednost za 1
    - Pisanje na lokacijo 0 EEPROM-a