BLM4021 Gömülü Sistemler

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Yıldız Teknik Üniversitesi – Bilgisayar Mühendisliği

Sunum 8 – Analog Sensörlerden Veri Toplama ve Dönüştürücüler

- Analog-Dijital Dönüştürme
- Dijital-Analog Dönüştürme
- Önemli Parametreler
- Uygulama Örneği

~~Hafta~~	~~Teorik~~	~~Laboratuvar~~
~~1~~	~~Giriş ve Uygulamalar, Mikroişlemci, Mikrodenetleyici ve Gömülü sistem kavramlarının açıklanması~~	~~Grupların oluşturulması & Kitlerin Testi~~
~~2~~	~~Bir Tasarım Örneği, Mikroişlemci, Mikrodenetleyici, DSP, FPGA, ASIC kavramları~~	~~Kitlerin gruplara dağıtımı + Raspberry Pi Kurulumu~~
~~3~~	~~16, 32 ve 64 bitlik mikrodenetleyiciler, pipeline~~	~~Raspberry Pi ile Temel Konfigürasyon~~
~~4~~	~~PIC ve MSP430 özellikleri~~	~~Uygulama 1 – Raspberry Pi ile Buzzer Uygulaması~~
~~5~~	~~ARM ve RISC-V tabanlı mimariler ve özellikleri~~	~~Uygulama 2 – Raspberry Pi ile Ivme ve Gyro Uygulaması~~
~~6~~	~~ARM Komut setleri ve Assembly Kodları-1~~	~~Uygulama 3 – Raspberry Pi ile Motor Kontrol Uygulaması~~
~~7~~	~~ARM Komut setleri ve Assembly Kodları-2, Raspberry Pi vers. ve GPIO'ları~~	~~Uygulama 4 – Raspberry Pi ile Görüntü İşleme Uygulaması~~
~~8~~	~~Vize Sınavı~~	
~~9~~	~~Çoklu ortam algılayıcıları ve arayüzleri (SPIE, I2C…)~~	~~Uygulama 5 – Raspberry Pi ile Network Uygulaması~~
10	Sensörlerden Veri Toplama, Algılayıcı, ADC ve DAC	Proje Soru-Cevap Saati
11	Zamanlayıcı, PWM ve Motor Sürme	Proje kontrolü-1
12	Gerçek Zaman Sistemlerinde temel kavramlar	Proje Kontrolü-2
13	Gerçek zaman İşletim Sistemleri	Mazeret sebepli son proje kontrollerinin yapılması
14	Nesnelerin İnterneti	
15	Final Sınavı	

Ders Materyalleri

Gerekli Kaynaklar:

- Derek Molloy, Exploring Raspberry Pi: Interfacing to the Real World with Embedded Linux, Wiley, 2016.
- M. Wolf, Computers as Components: Principles of Embedded Computing System Design, Elsevier, 2008.

Yardımcı Kaynaklar:

- D. Zhu, T. Sifleet, T. Nunnally, Y. Huang, Analog to Digital Converters, Lecture Notes.
- Fast abd Effective Embedded System Design: Applying the ARM mbed.
- Farid Farahmand, Chapter- 3, Embedded Systems with ARM Cortex-M, 2018.
- Tolga Ayav, Embedded Control Systems, Data Acquistion and Digital Signal Processing.
- Simon Monk, Raspberry Pi Cookbook, O’Reilly.

Analog and Digital Signals

Data Converters: Basic Concepts

$1.2-8 bit

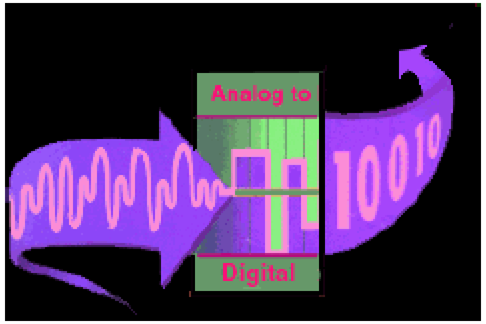
$48-18 bit

- Analog signals are continuous, with infinite values in a given range.
- Digital signals have discrete values such as on/off or 0/1.
- Limitations of analog signals
  - Analog signals pick up noise as they are being amplified.
  - Analog signals are difficult to store.
  - Analog systems are more expensive in relation to digital systems.

Analog and Digital Signals

- Advantages of digital systems (signals)
  - Noise can be reduced by converting analog signals in 0s and 1s.
  - Binary signals of 0s/1s can be easily stored in memory.
  - Technology for fabricating digital systems has become so advanced that they can be produced at low cost.
- The major limitation of a digital system is how accurately it represents the analog signals after conversion.

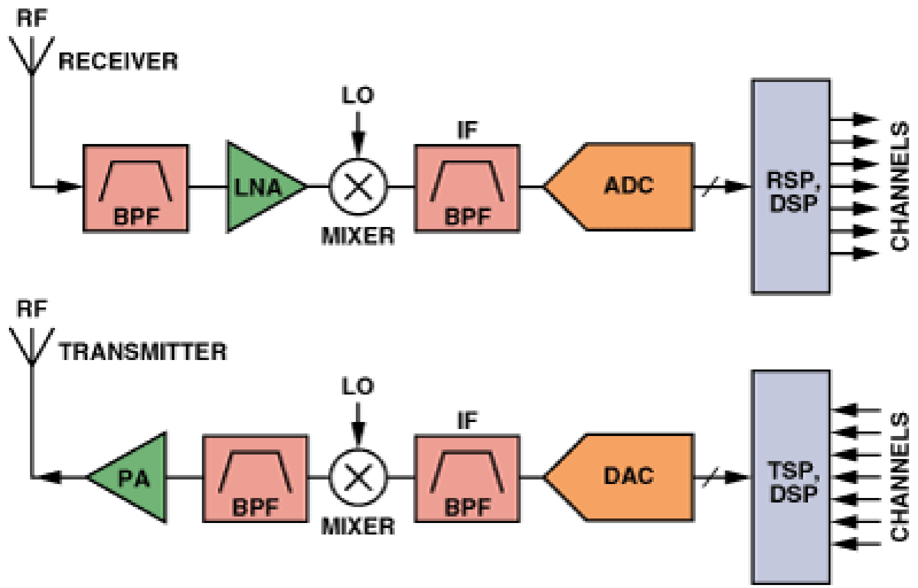
Accuracy is the key concept!



Application of ADC

- ADC are used virtually everywhere where an analog signal has to be processed, stored, or transported in digital form.
- Some examples of ADC usage are digital volt meters, cell phone, thermocouples, and digital oscilloscope.
- Microcontrollers commonly use 8, 10, 12, or 16 bit ADCs, our micro controller uses an 8 or 10 bit ADC.

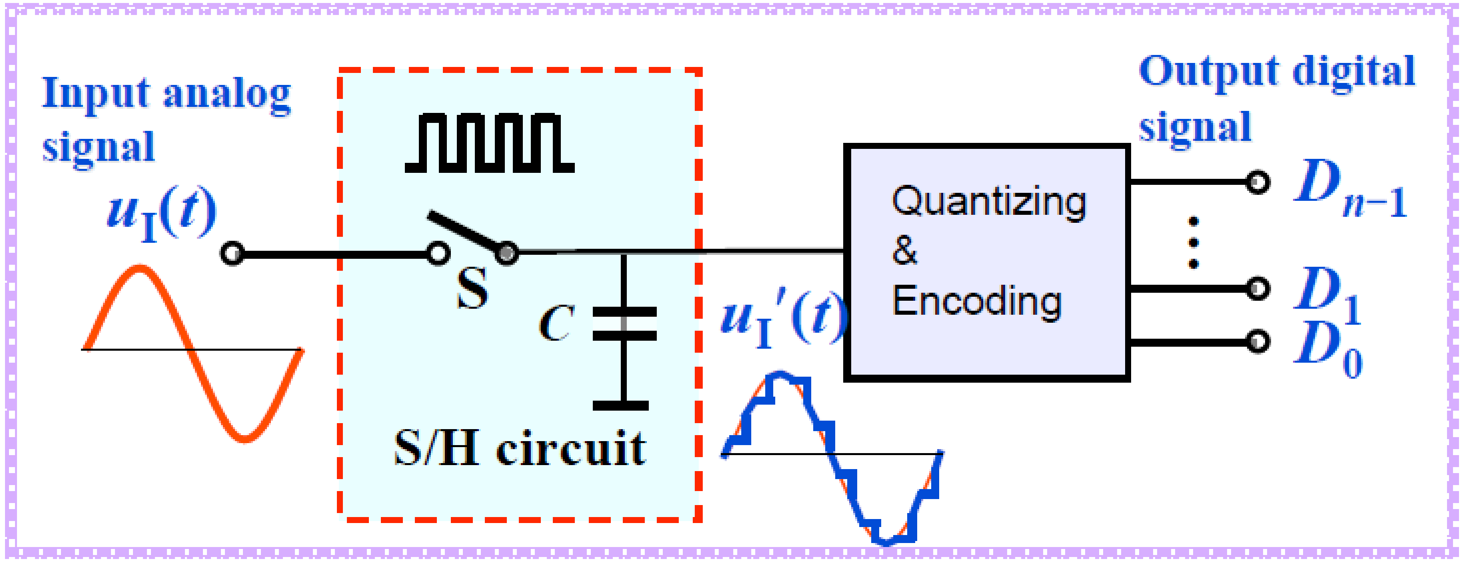
<u>Radio Receiver and Transmitter:</u>



- LNA: Low-noise amplifier
- LO: Local Oscillator

Credit by Dapeng Zhu

ADC Process



2 steps

- Sampling and Holding (S/H)
- Quantizing and Encoding (Q/E)

İdeal Örnekleme

Örnek: x(t)= cos $(2\pi 100t)$

Genel form: x(t)= cos $(2\pi f t)$ -> Frekans: $f = \frac{1}{T}$

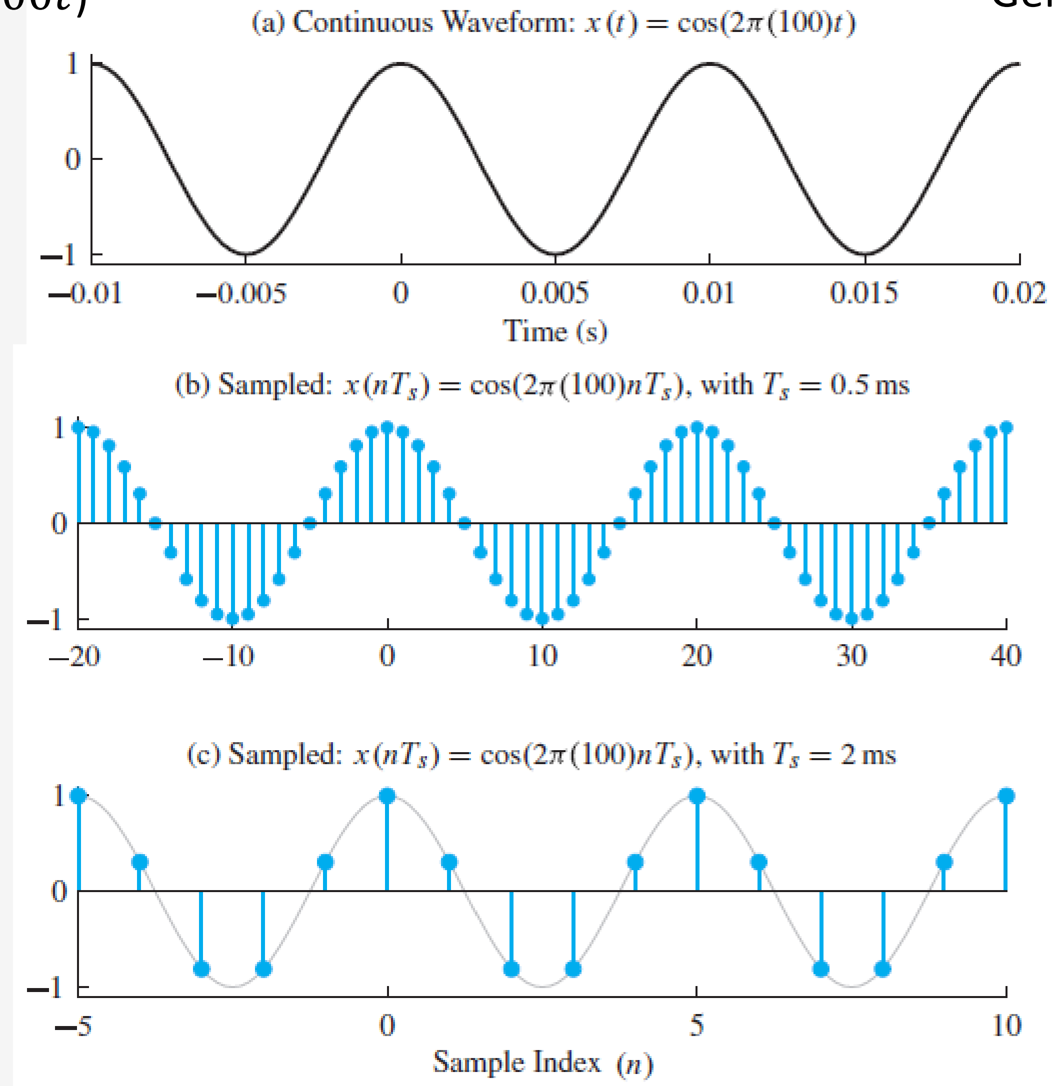
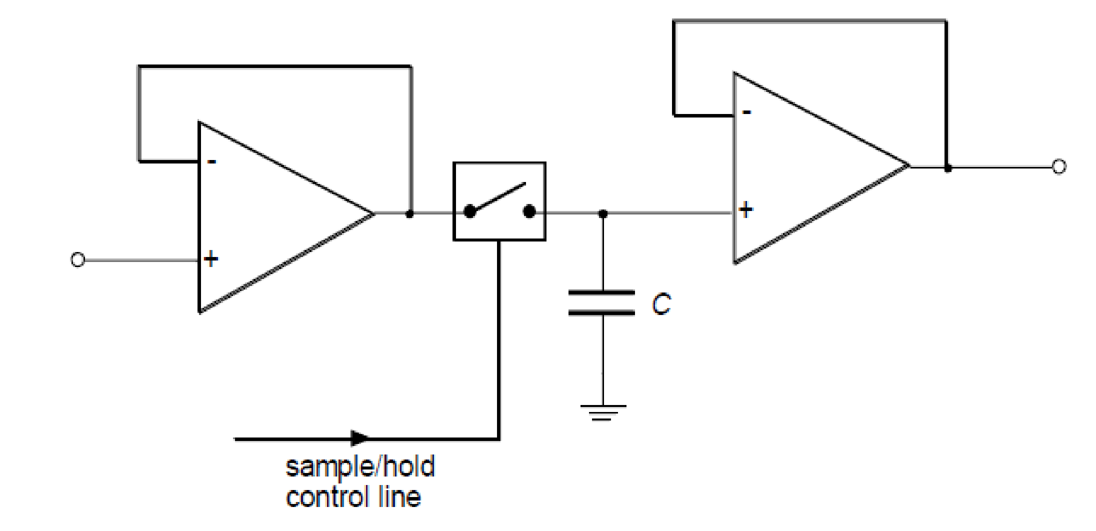
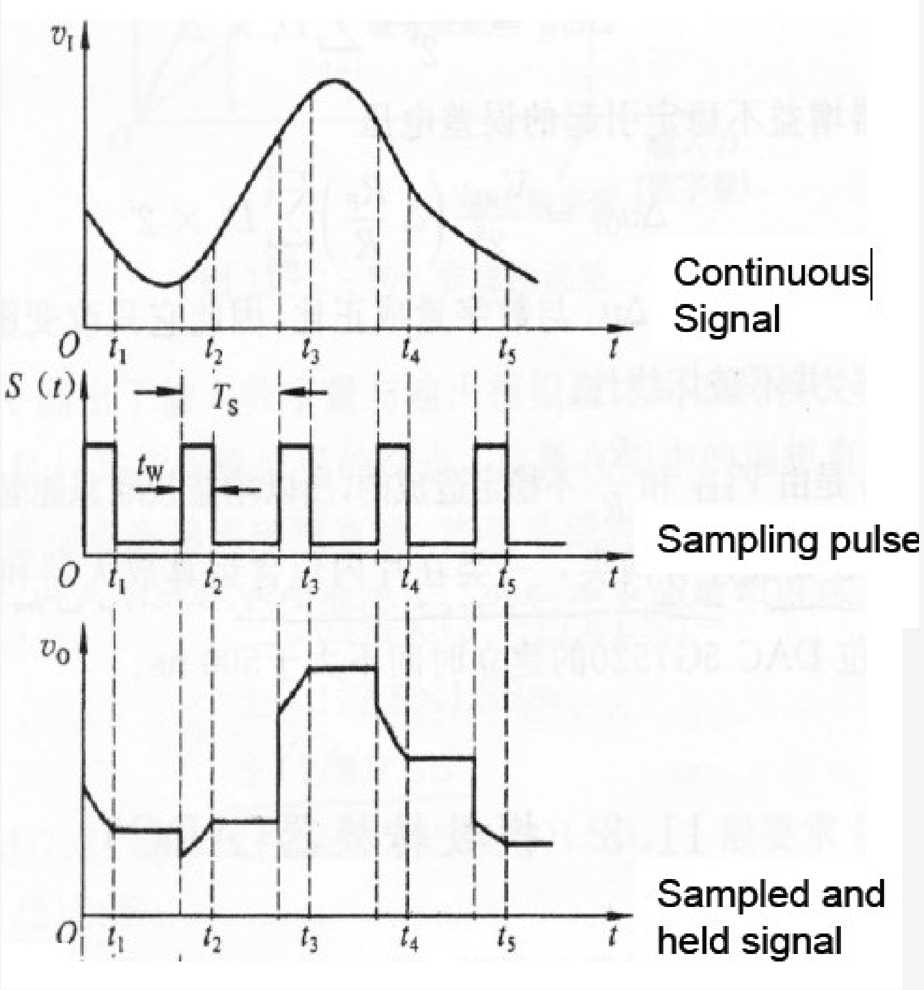


Figure 4-3 A continuous-time 100 Hz sinusoid (a) and two discrete-time sinusoids formed by sampling at $f_s = 2000$ samples/s (b) and at $f_s = 500$ samples/s (c).

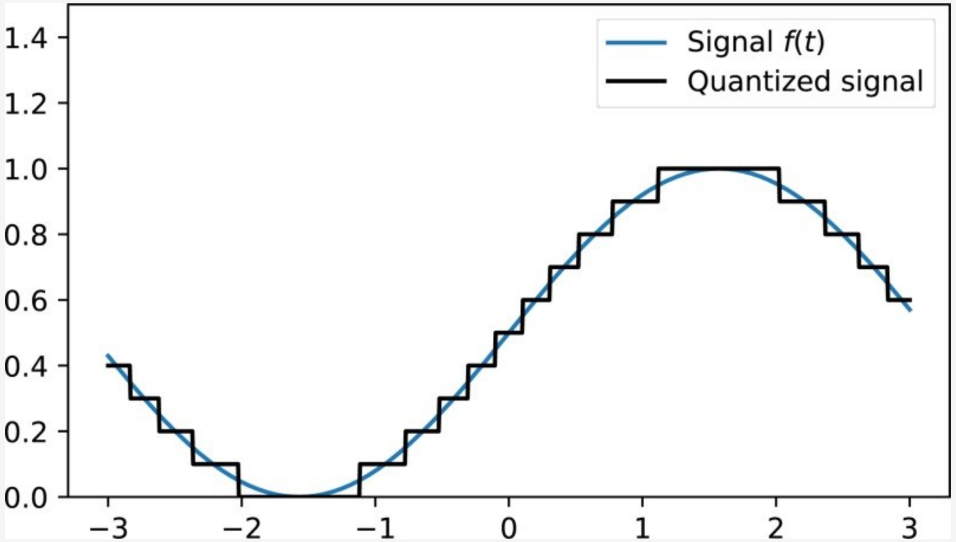
Pratikte Örnekleme

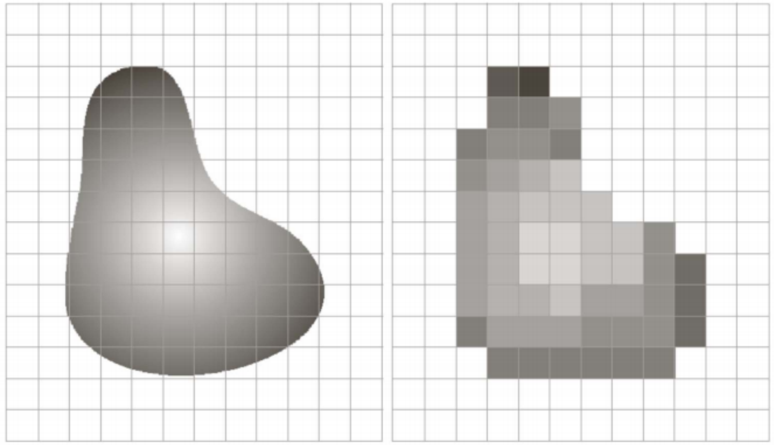
- Load placed on the input of the circuit by charging the capacitor during the sample phase.
- Current flowing from the capacitor used in the conversion will reduce the voltage stored on the capacitor





Nicemleme (Quantization)





a b

FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

<u>Çözünürlük</u>:

Sayısal sinyale dönüştürürken sonuca etki eden en küçük analog sinyalin değişimi

$$\Delta V = \frac{V_r}{2^N}$$

V = Reference voltage range

N = Number of bits in digital output.

2^N = Number of states.

ΔV = Resolution

Çözünürlük terimi nicemleme hatasıyla doğrudan ilişkilidir.

Problems about Resolution

Example 1: Temperature range of 0 K to 300 K to be linearly converted to a voltage signal of 0 to 2.5 V, then digitized with an 8-bit A/D converter.

$2.5 / 2^8 = 0.0098$ V, or about 10 mV per step

300 K $/ 2^8 = 1.2$ K per step

Example-2:

- Assumes the input analog voltage is changing between 0-5 V.
- Using a 3-bit A/D converter draw the output as the input signal ramps from 0 to 5V.
- Calculate the resolution in volts. 5/ 2^3V
- What is the maximum possible voltage out? (this is called the full-scale output) (5 – Resolution)
- If the output is 011, what is the input? 3x5/8Volt

Nicemlemenin Sese Etkisi

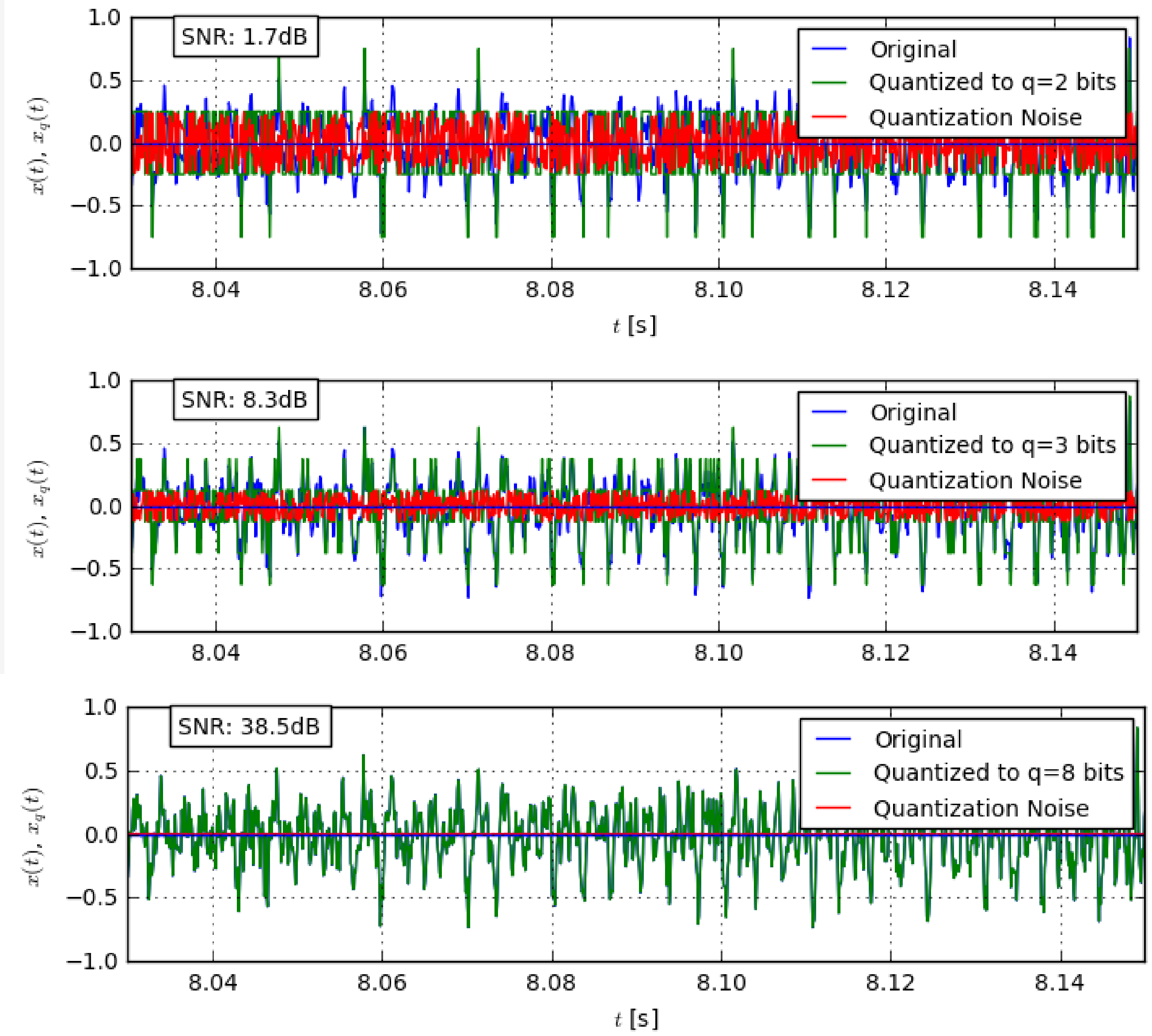
8 bit seviyesi:

3 bit seviyesi:

2 bit seviyesi:

Alternatif çözüm:

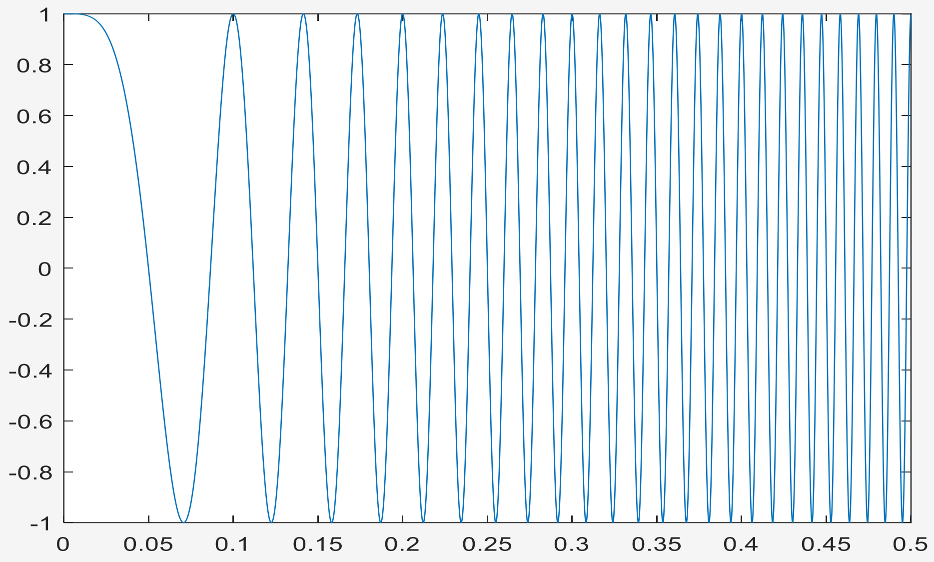
Non-uniform quantizier



Let take a look at quantized version of Chirp Signal

A chirp is a signal in which the frequency increases (up-chirp) or decreases (down-chirp) with time

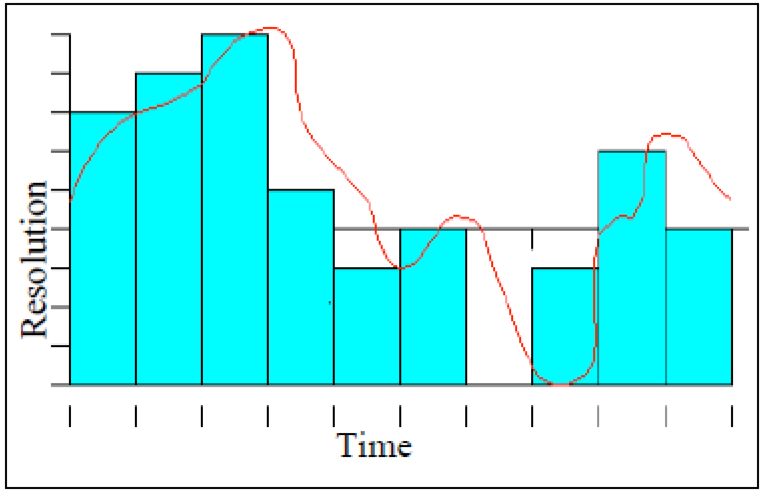
```
t = 0:1/8000:5;
y = cos(2*pi*100*(t.*t+1));

Qlevel = 2;
Qstep = (1.01 - (-1))/Qlevel;

Q = floor(y/Qstep)*Qstep + Qstep/2;

figure(1), plot(t(1:4000),y(1:4000));
figure(2), plot(t(1:4000),Q(1:4000));

sound(y);
sound(Q);
```

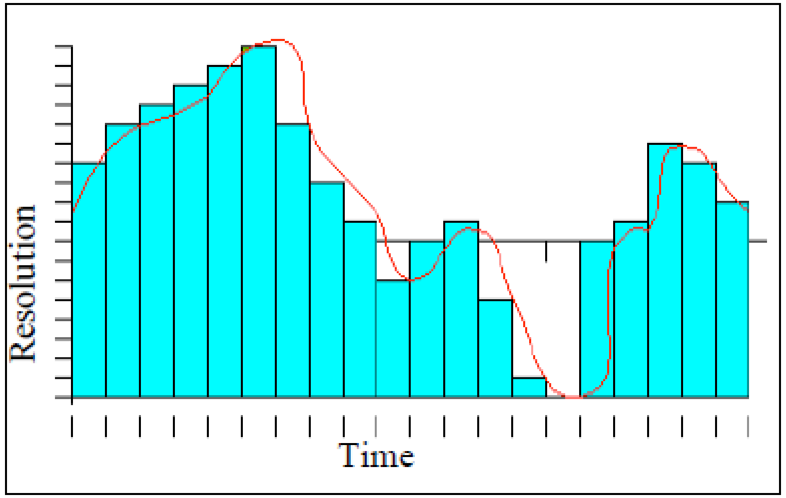


Accuracy of ADCs

There are two ways to best improve the accuracy of A/D conversion:

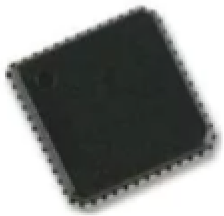
- increasing the resolution which improves the accuracy in measuring the amplitude of the analog signal.
- increasing the sampling rate which increases the maximum frequency that can be measured.





ADC Comparison

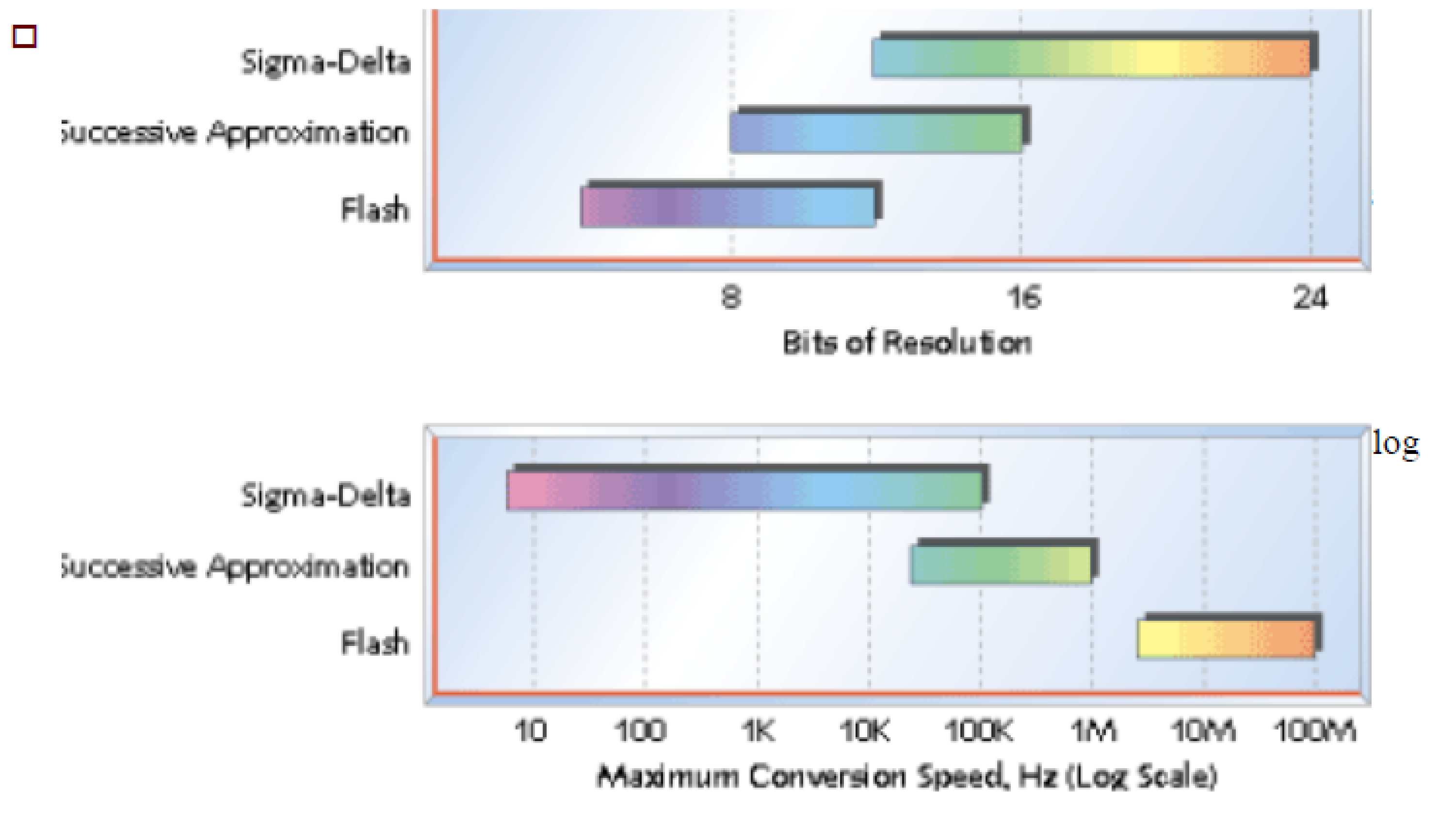
Product Attribute	Attribute Value
Manufacturer:	Analog Devices Inc.
Product Category:	Analog to Digital Converters - ADC
RoHS:	Details
Series:	AD7641
Mounting Style:	SMD/SMT
Package / Case:	LFCSP-48
Resolution:	18 bit
Number of Channels:	1 Channel
Sampling Rate:	2 MS/s
Input Type:	Differential
Interface Type:	Parallel, Serial, 2-Wire, DSP, SPI
Architecture:	SAR
Reference Type:	External, Internal
SNR - Signal to Noise Ratio:	93.5 dB
Minimum Operating Temperature:	- 40 C
Maximum Operating Temperature:	+ 85 C



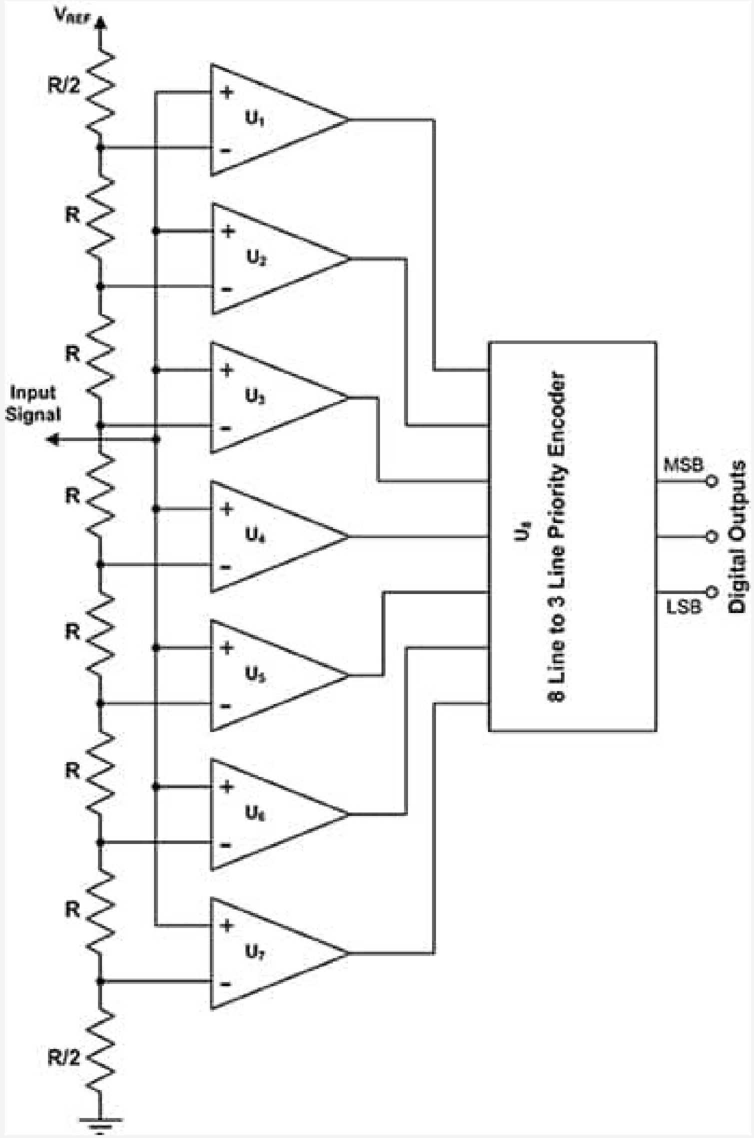
Product Attribute	Attribute Value
Manufacturer:	Texas Instruments
Product Category:	Analog to Digital Converters - ADC
RoHS:	Details
Series:	TLV0832
Mounting Style:	Through Hole
Package / Case:	PDIP-8
Resolution:	8 bit
Number of Channels:	2 Channel
Sampling Rate:	44.7 kS/s
Input Type:	Differential/Single-Ended
Interface Type:	Serial
Architecture:	SAR
Reference Type:	Supply
Analog Supply Voltage:	2.7 V to 3.6 V
Digital Supply Voltage:	2.7 V to 3.6 V
Minimum Operating Temperature:	- 40 C
Maximum Operating Temperature:	+ 85 C

Types of A/D Converters

- Delta-Sigma ADCs
- Flash ADCs
- Successive Approximation ADCs
- Dual Slope ADCs
- Others…

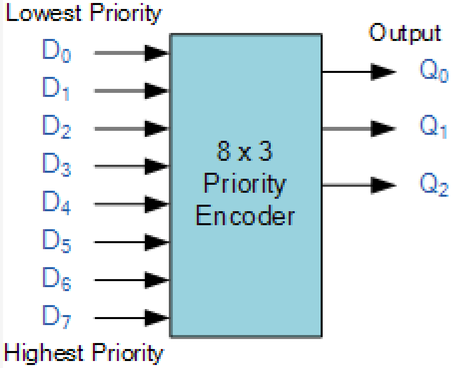


Flash ADC



If	Output
$V_{IN} > V_{REF}$	High
$V_{IN} < V_{REF}$	Low

- Requires 4095 parallel comparators for 12-bit.



Inputs								Outputs		
D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Q_2	Q_1	Q_0
0	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	1	x	0	0	1
0	0	0	0	0	1	x	x	0	1	0
0	0	0	0	1	x	x	x	0	1	1
0	0	0	1	x	x	x	x	1	0	0
0	0	1	x	x	x	x	x	1	0	1
0	1	x	x	x	x	x	x	1	1	0
1	x	x	x	x	x	x	x	1	1	1

X = dont care

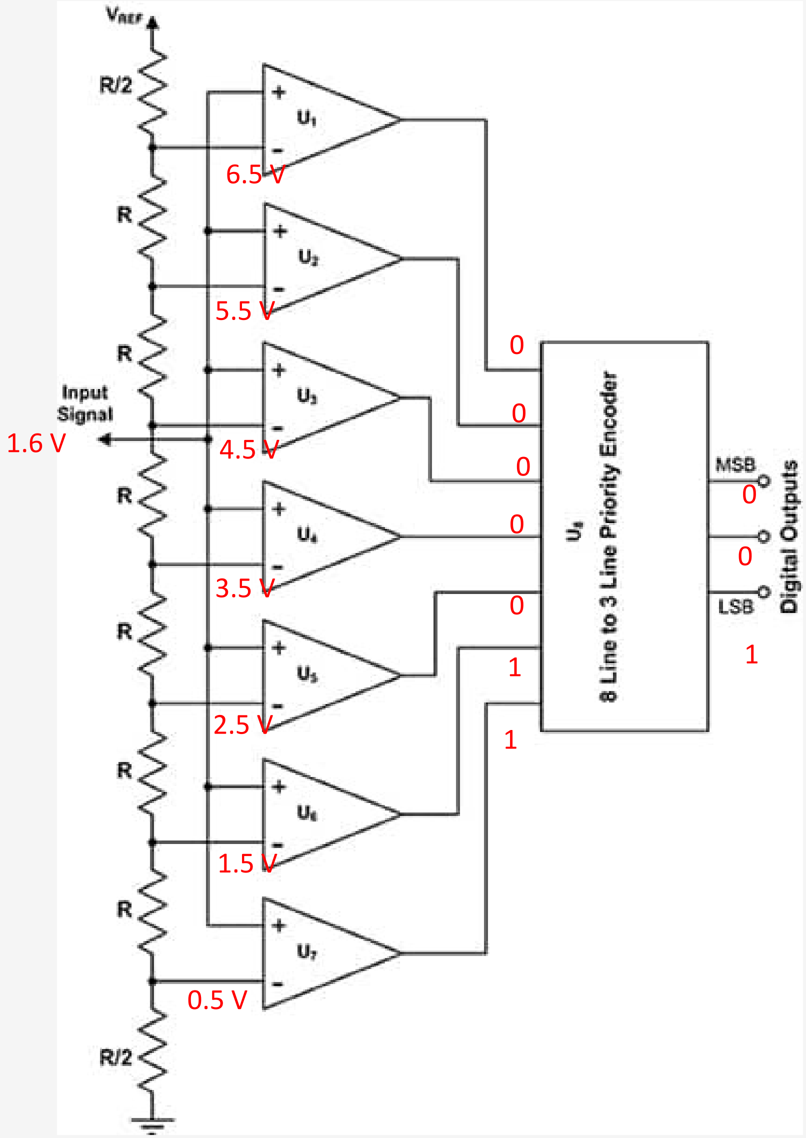
PROS

- Very Fast (Fastest)
- Very simple operational theory
- Speed is only limited by gate and comparator propagation delay

CONS

- Expensive
- Prone to produce glitches in the output
- Each additional bit of resolution requires twice the comparators.

Example: Flash ADC



Problem: If Vref = 8 Volt and Vin = 1.6 Volt then find digital outputs.

Encoder Input :   1 1 0 0 0 0 0

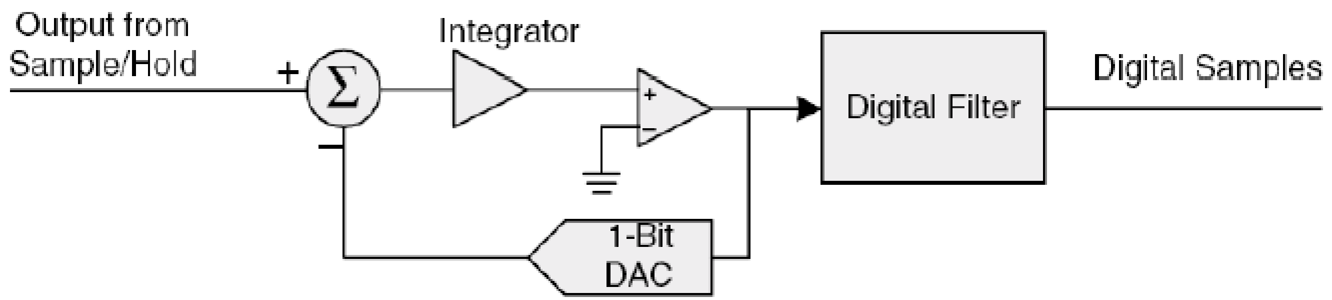
Digital Outputs, LSB to MSB :   0 0 1

Problem-2: If Vref = 8 Volt and Vin = 8 Volt then find digital outputs.

Encoder Input :   1 1 1 1 1 1 1

Digital Outputs, LSB to MSB :   1 1 1

Sigma-Delta ADC



Input is over sampled, and goes to integrator.

The integration is then compared to ground.

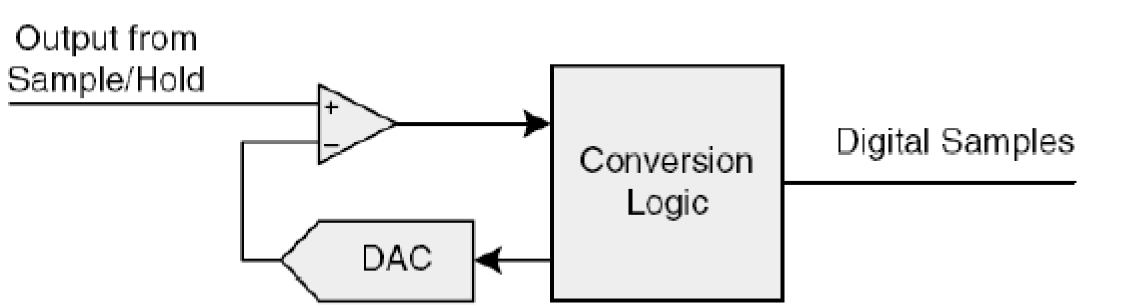
Iterates and produces a serial bit stream

Output is a serial bit stream with # of 1's

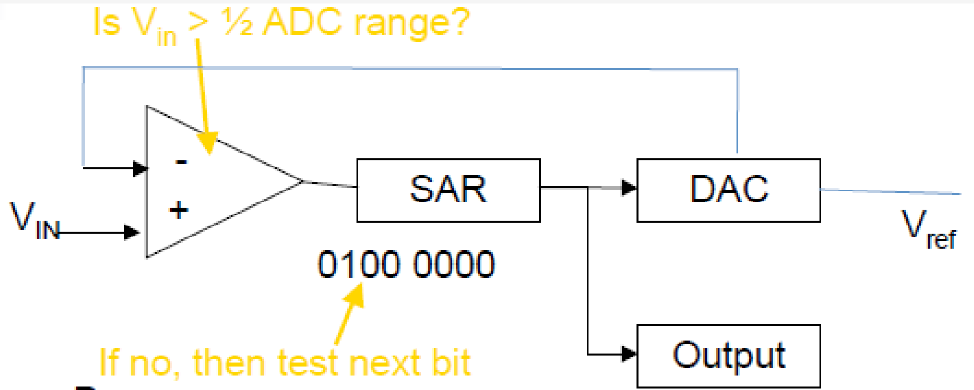
PROS	CONS
▪ High Resolution ▪ No need for precision components	▪ Slow due to over sampling ▪ Only good for low bandwidth

https://www.analog.com/en/design-center/interactive-design-tools/sigma-delta-adc-tutorial.html

Successive Approximation (SAR)



- Uses an internal n-bit DAC
- Conversion logic is a simple n-bit counter
- N-bit ADC requires 2^n cycles to perform a conversion in worst case.



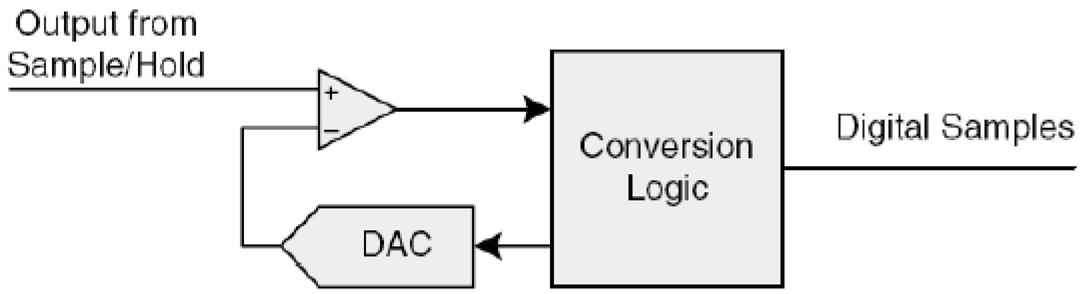
<u>Process</u>

1. MSB initialized as 1
2. Convert digital value to analog using DAC
3. Compares guess to analog input
4. Is $V_{in}>V_{DAC}$
   - Set bit 1
   - If no, bit is 0 and test next bit

Closed-Loop

Uses a closed-loop to obtain best approximation.

Successive Approximation (SAR)



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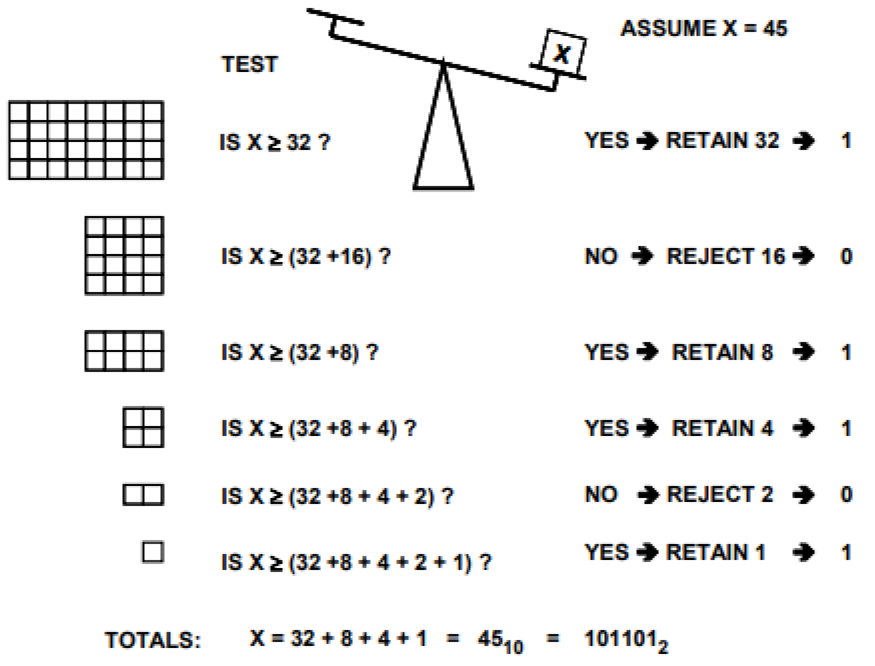
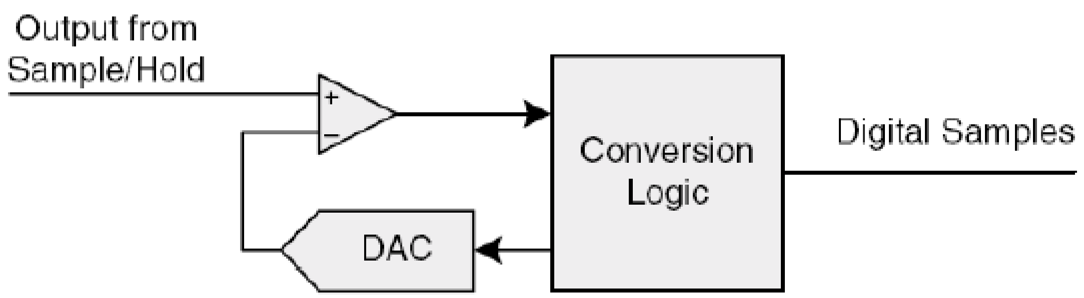


Figure 4: Successive Approximation ADC Algorithm

Uses a closed-loop to obtain best approximation.

Successive Approximation (SAR)



- Uses an internal n-bit DAC
- Conversion logic is a simple n-bit counter
- N-bit ADC requires 2^n cycles to perform a conversion in worst case.

Advantages

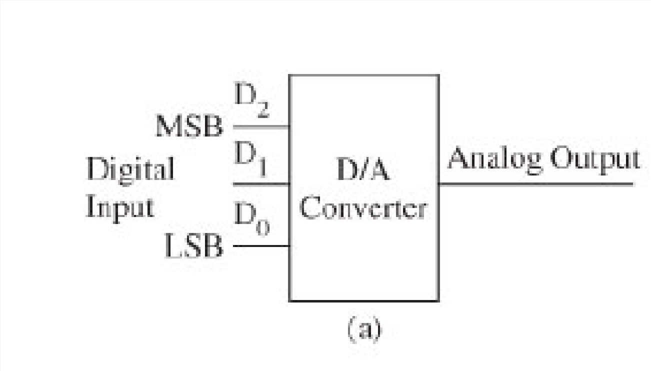
- Capable of high speed and reliable
- Medium accuracy compared to other ADC types
- Good tradeoff between speed and cost
- Capable of outputting the binary number in serial (one bit at a time) format.

Disadvantages

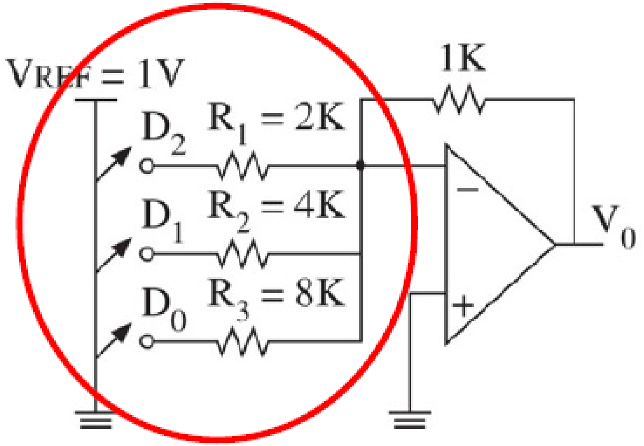
- Higher resolution successive approximation ADC's will be slower
- Speed limited to ~5Msps

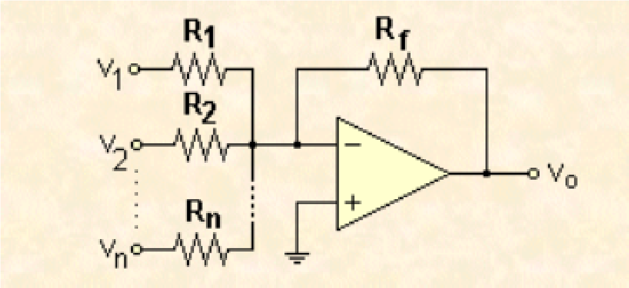
Uses a closed-loop to obtain best approximation.

Digital to Analog Conversion



- 3-bit D/A Converter Circuit





The transfer function of the summing amplifier :

$vo = -(v1/R1 + v2/R2 + \ldots + vn/Rn)Rf$

Thus if all input resistors are equal, the output is a scaled sum of all inputs.

If they are different, the output is a weighted linear sum of all inputs.

Summing amplifier

- R/2R Ladder Network for D/A Converter

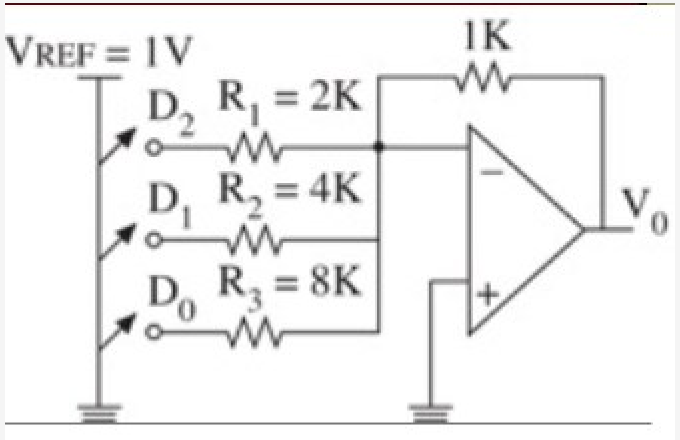
Example Case

- If the reference voltage is 1 V, and if all switches are connected, the output current can be calculated as follows:

$$I_o = I_T = I_1 + I_2 + I_3 = \frac{V_{REF}}{R_1} + \frac{V_{REF}}{R_2} + \frac{V_{REF}}{R_3} = \frac{V_{REF}}{1k}\left(\frac{1}{2} + \frac{1}{4} + \frac{1}{8}\right) = 0.875\,mA$$

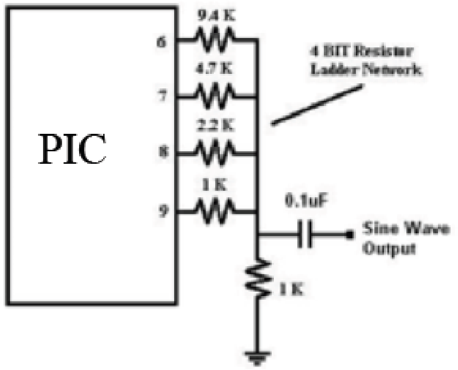
- Output voltage

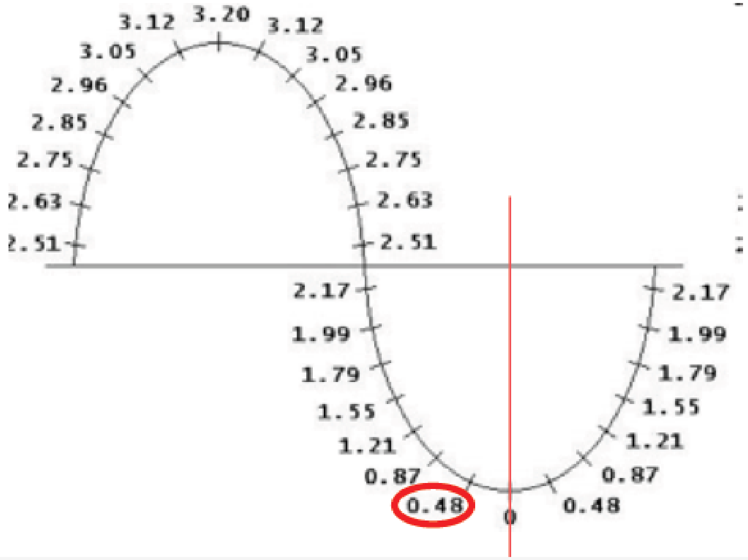
$$V_O = -R_f I_T = -(1k)\times(0.875\ mA) = -0.875\ V = \left|{}^{7}\!/_{8}\,V\right|$$



Can we generate a sinusoidal signal?

- Theoretically the voltages would range from 0 to 5
- How do you change the frequency?





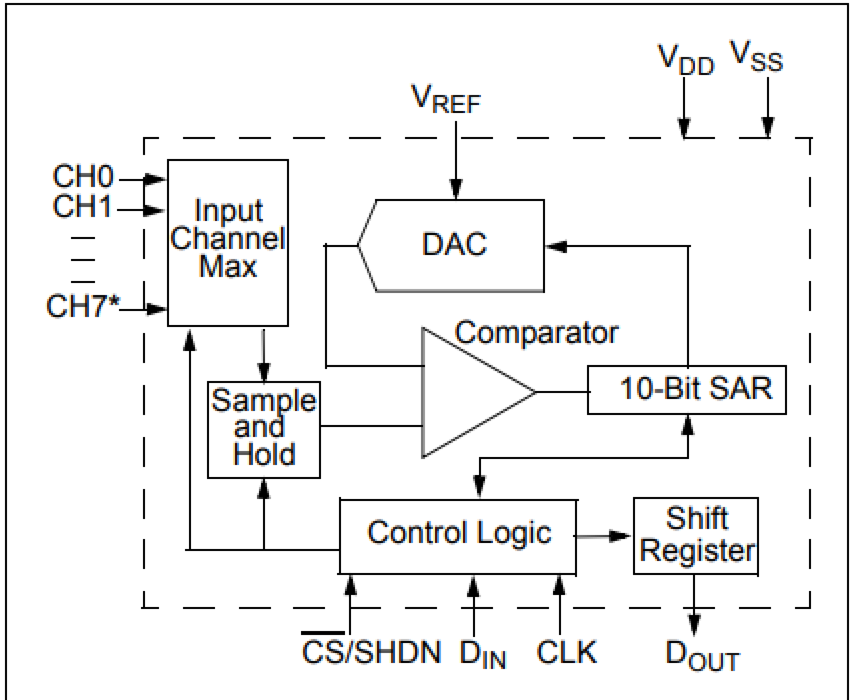
Voltage Out for BIT combinations		
Sine D Angle	Pins 9 8 7 6	Vout
270	0000	0
258.75, 281.25	1000	0.48
247.50, 292.50	0100	0.87
236.25, 303.75	1100	1.21
225.00, 315.00	0010	1.55
213.75, 326.25	1010	1.79
202.50, 337.50	0110	1.99
191.25, 348.75	1110	2.17
11.25, 168.75	0001	2.51
22.50, 157.50	1001	2.63
33.75, 146.25	0101	2.75
45.00, 135.00	1101	2.85
56.25, 123.75	0011	2.96
67.50, 112.50	1011	3.05
78.75, 101.25	0111	3.12
90	1111	3.20

Example: MCP3008 ADC - Adafruit

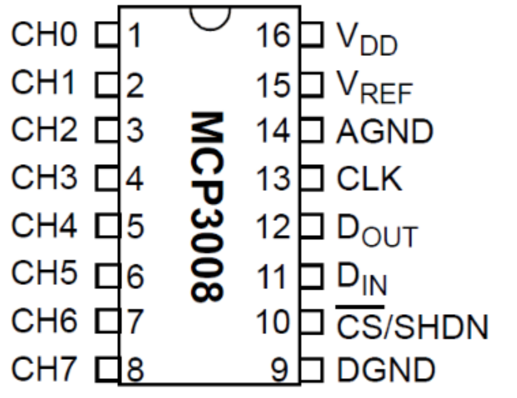
Features

- 10-bit resolution
- ± 1 LSB max DNL
- ± 1 LSB max INL
- 4 (MCP3004) or 8 (MCP3008) input channels
- Analog inputs programmable as single-ended or pseudo-differential pairs
- On-chip sample and hold
- SPI serial interface (modes 0,0 and 1,1)
- Single supply operation: 2.7V - 5.5V
- 200 ksps max. sampling rate at V_{DD} = 5V
- 75 ksps max. sampling rate at V_{DD} = 2.7V
- Low power CMOS technology
- 5 nA typical standby current, 2 µA max.
- 500 µA max. active current at 5V
- Industrial temp range: -40°C to +85°C
- Available in PDIP, SOIC and TSSOP packages

Functional Block Diagram



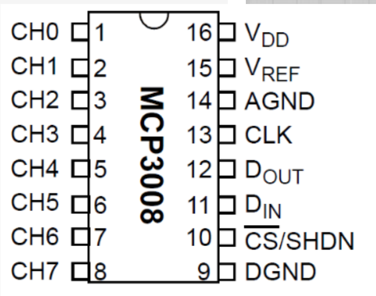
* **Note:** Channels 4-7 are available on MCP3008 Only



DIN: Serial Data In
DOUT: Serial Data Out
CLK: Serial Clock
CS: Chip Select

CHX: Analog Input for input X

Example – 1: Measuring a Voltage

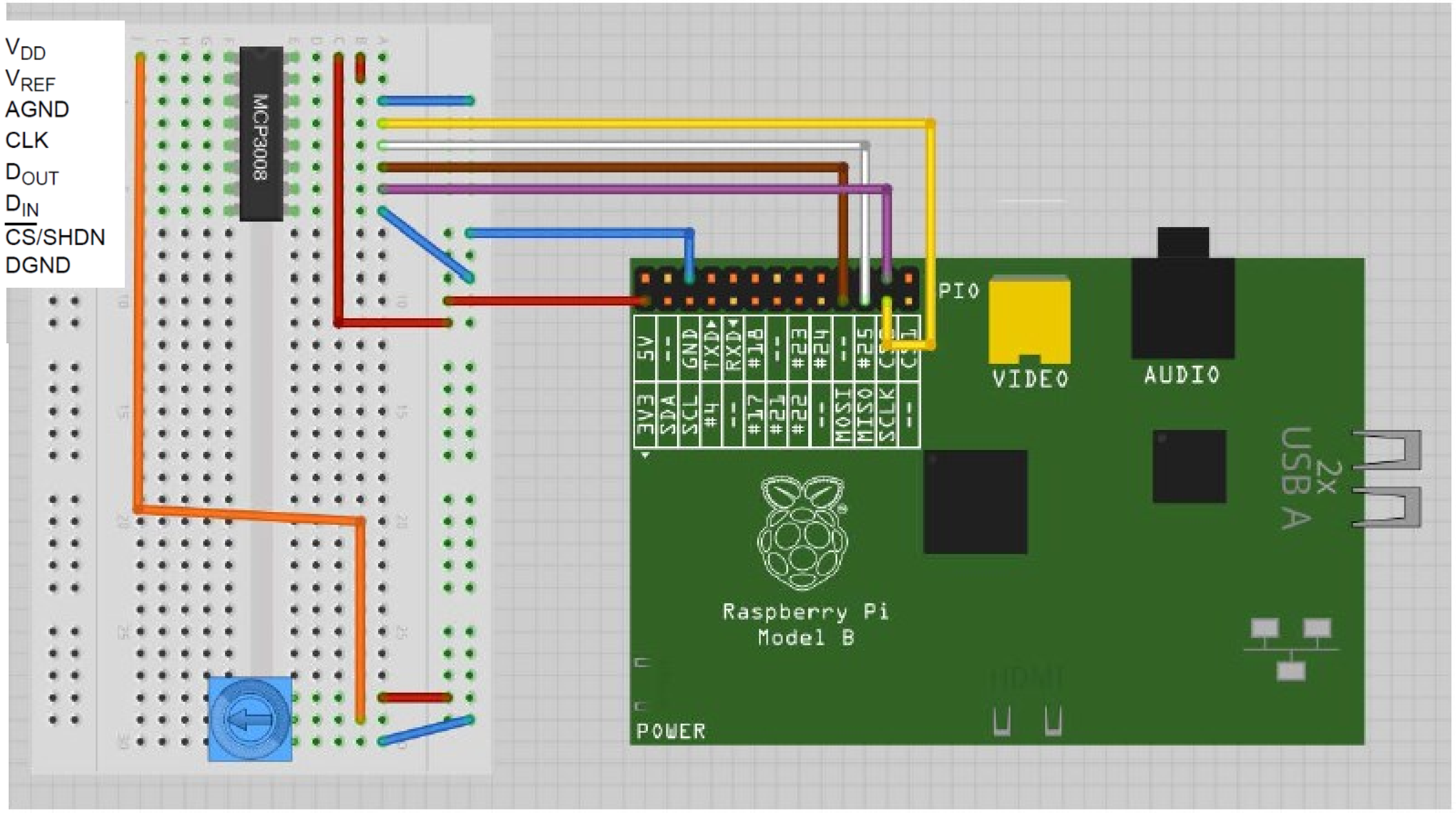



```python
import spidev, time

spi = spidev.SpiDev()
spi.open(0, 0)

def analog_read(channel):
    r = spi.xfer2([1, (8 + channel) << 4, 0])
    adc_out = ((r[1]&3) << 8) + r[2]
    return adc_out

while True:
    reading = analog_read(0)
    voltage = reading * 3.3 / 1024
    print("Reading=%d\tVoltage=%f" % (reading, voltage))
    time.sleep(1)
```



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spi.open(0, 0)

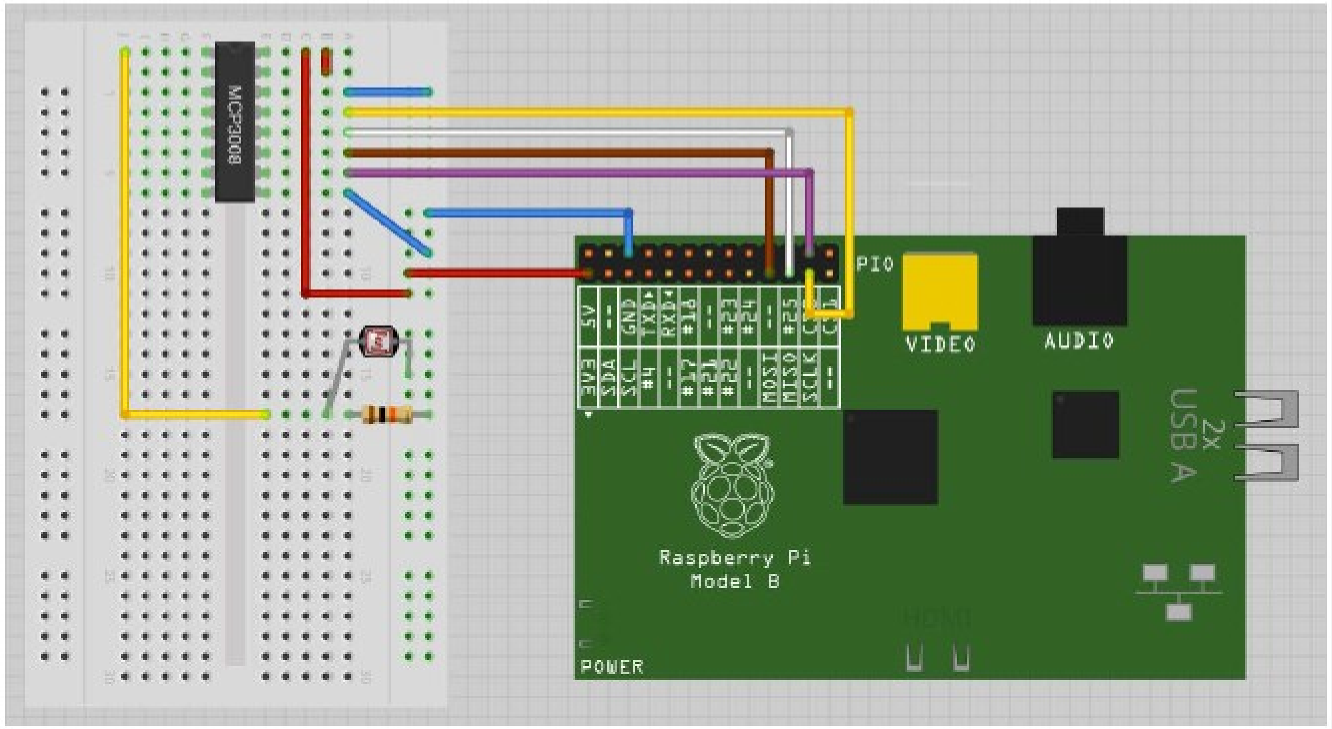
def analog_read(channel):
    r = spi.xfer2([1, (8 + channel) << 4, 0])
    adc_out = ((r[1]&3) << 8) + r[2]
    return adc_out

while True:
    reading = analog_read(0)
    voltage = reading * 3.3 / 1024
    print("Reading=%d\tVoltage=%f" % (reading, voltage))
    time.sleep(1)
```

```
$ sudo python adc_test.py
Reading=0       Voltage=0.000000
Reading=126             Voltage=0.406055
Reading=221     Voltage=0.712207
Reading=305     Voltage=0.982910
Reading=431     Voltage=1.388965
Reading=527             Voltage=1.698340
Reading=724     Voltage=2.333203
Reading=927     Voltage=2.987402
Reading=10      Voltage=3.296777
Reading=1020    Voltage=3.287109
Reading=1022    Voltage=3.293555
```

Example 2 – Measuring the Darkness

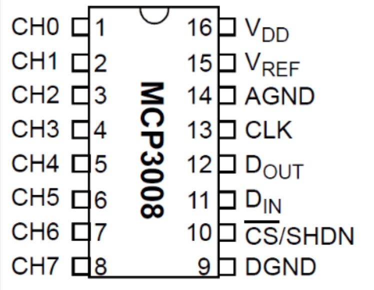
LDR: Photoresistor

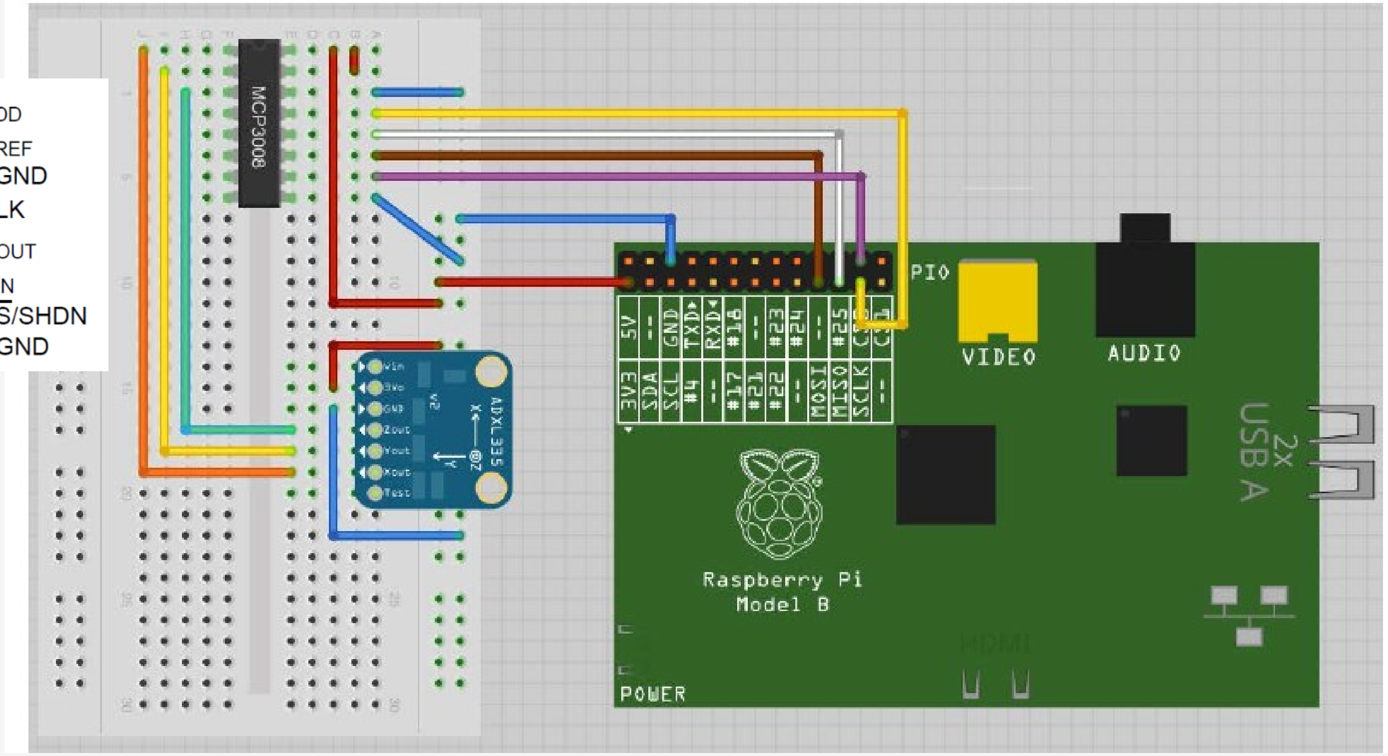


Example 3 – Using Triple-Axis Accelerometer

ADXL335 triple-axis accelerometer

It uses three channels of the ADC to measure the X, Y, and Z acceleration forces.



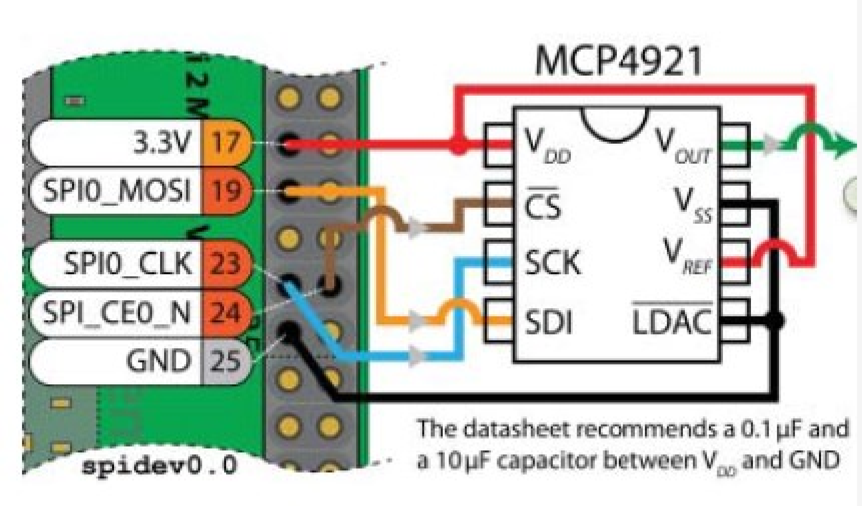



```python
import spidev, time

spi = spidev.SpiDev()
spi.open(0,0)

def analog_read(channel):
    r = spi.xfer2([1, (8 + channel) << 4, 0])
    adc_out = ((r[1]&3) << 8) + r[2]
    return adc_out

while True:
    x = analog_read(0)
    y = analog_read(1)
    z = analog_read(2)
    print("X=%d\tY=%d\tZ=%d" % (x, y, z))
    time.sleep(1)
```

Example – 4: SPI DAC with C pro

The MCP4921 is a low-cost ($2) single-channel 12-bit SPI DAC

The DAC does not send data back to the RPi, so there is no MISO connection required.




```
#include <iostream>
#include <math.h>
#include "bus/SPIDevice.h"
using namespace exploringRPi;

int main() {                    // mask = (MSB) 0 (BUF) 0 (GA) 1 (SHDN) 1

    busDevice->close();
    std::cout << "End of RPi SPI DAC Example" << std::endl;
    return 0;
}
```