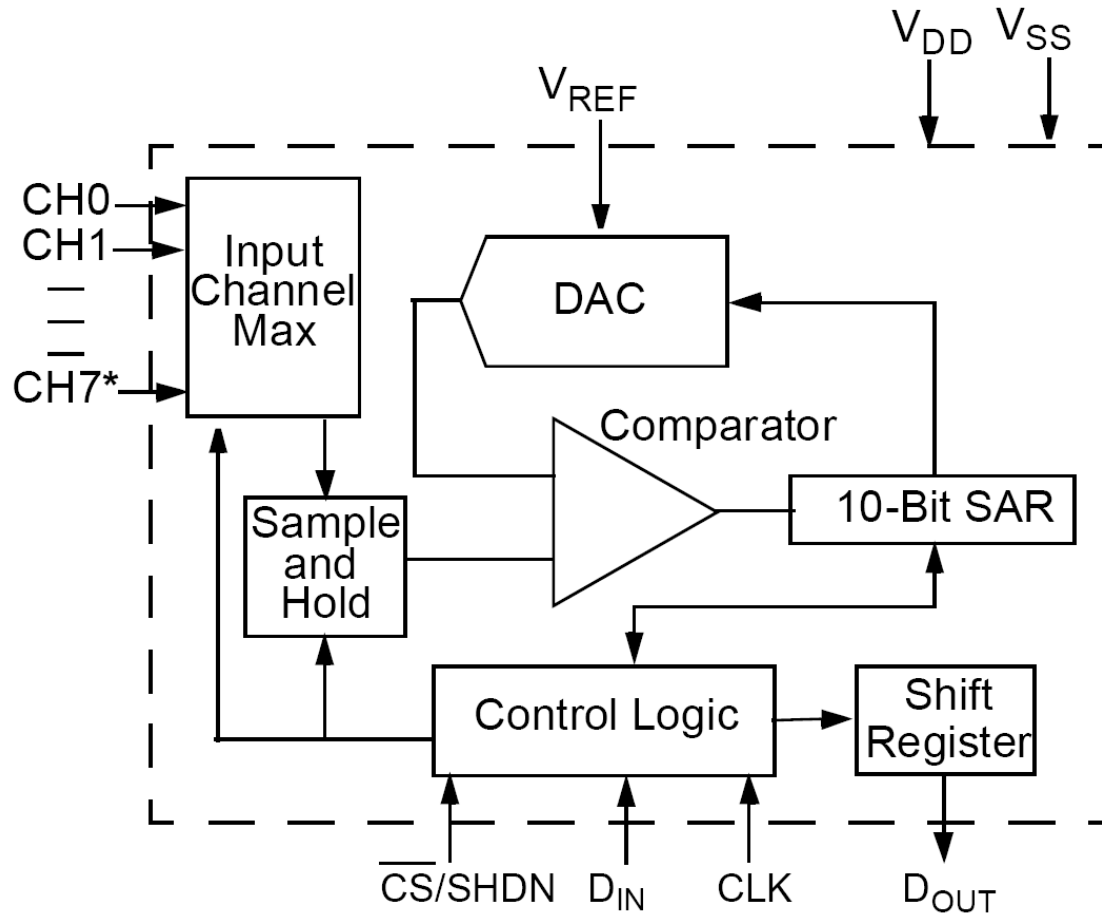


# ADC/DAC/Analog interface

# Analog I/O

- Analog inputs – convert to digital using an Analog to Digital converter (A/D or ADC)
- Analog output – convert digital output to analog using a Digital to Analog converter (D/A or DAC)
- A/D outputs and D/A inputs can be attached to digital I/O ports
- Design issues to consider – number of bits of accuracy, conversion time delay, and sample rate needed by application

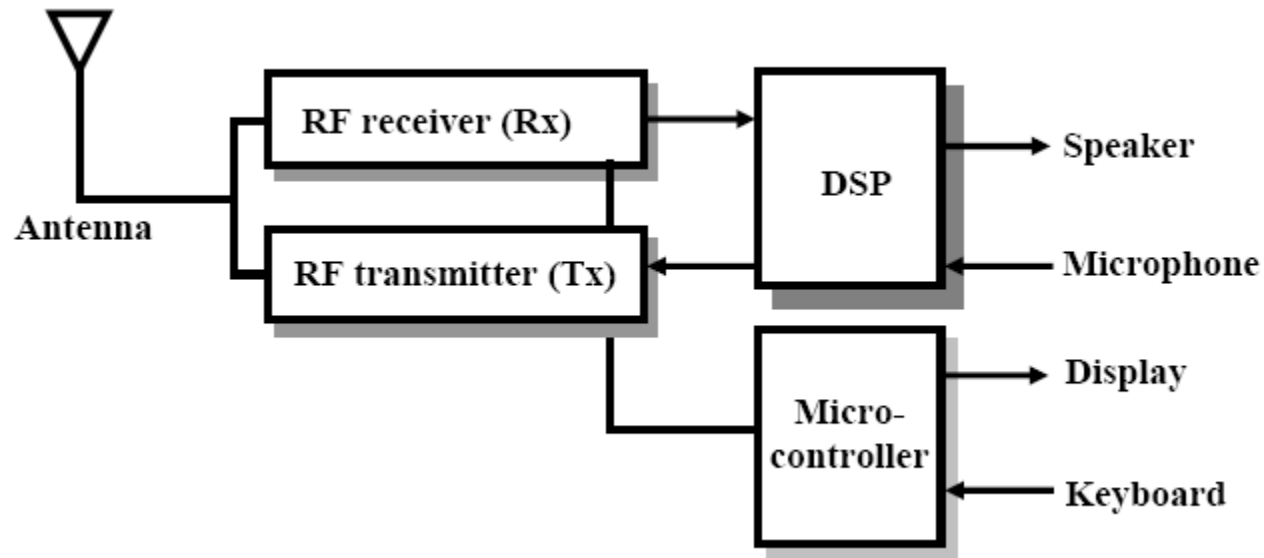


The MCP3008 10-bit 200Ksps A/D chip used in Phidget modules has an SPI interface.

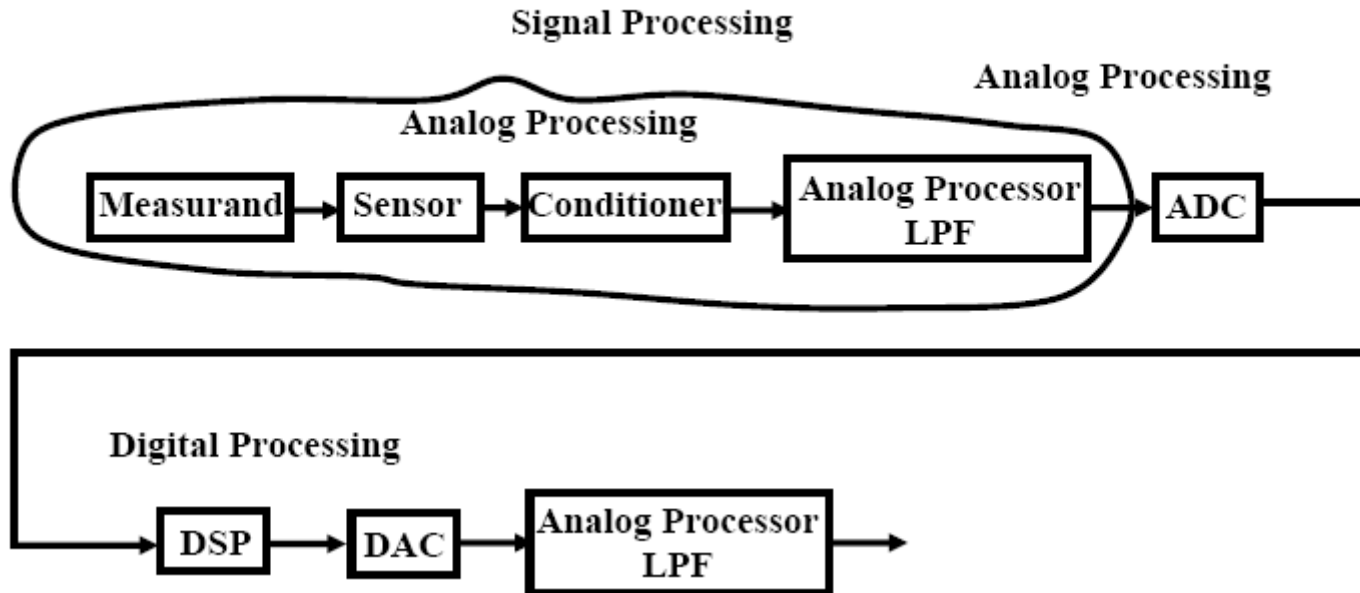
# Off-the-shelf ADC

- Resolution – smallest distinguishable change in input
- Precision – number of distinguishable inputs
- Accuracy – the absolute error of the entire system
- Monotonic – no missing codes
- Linear – constant resolution
- Speed – time to convert

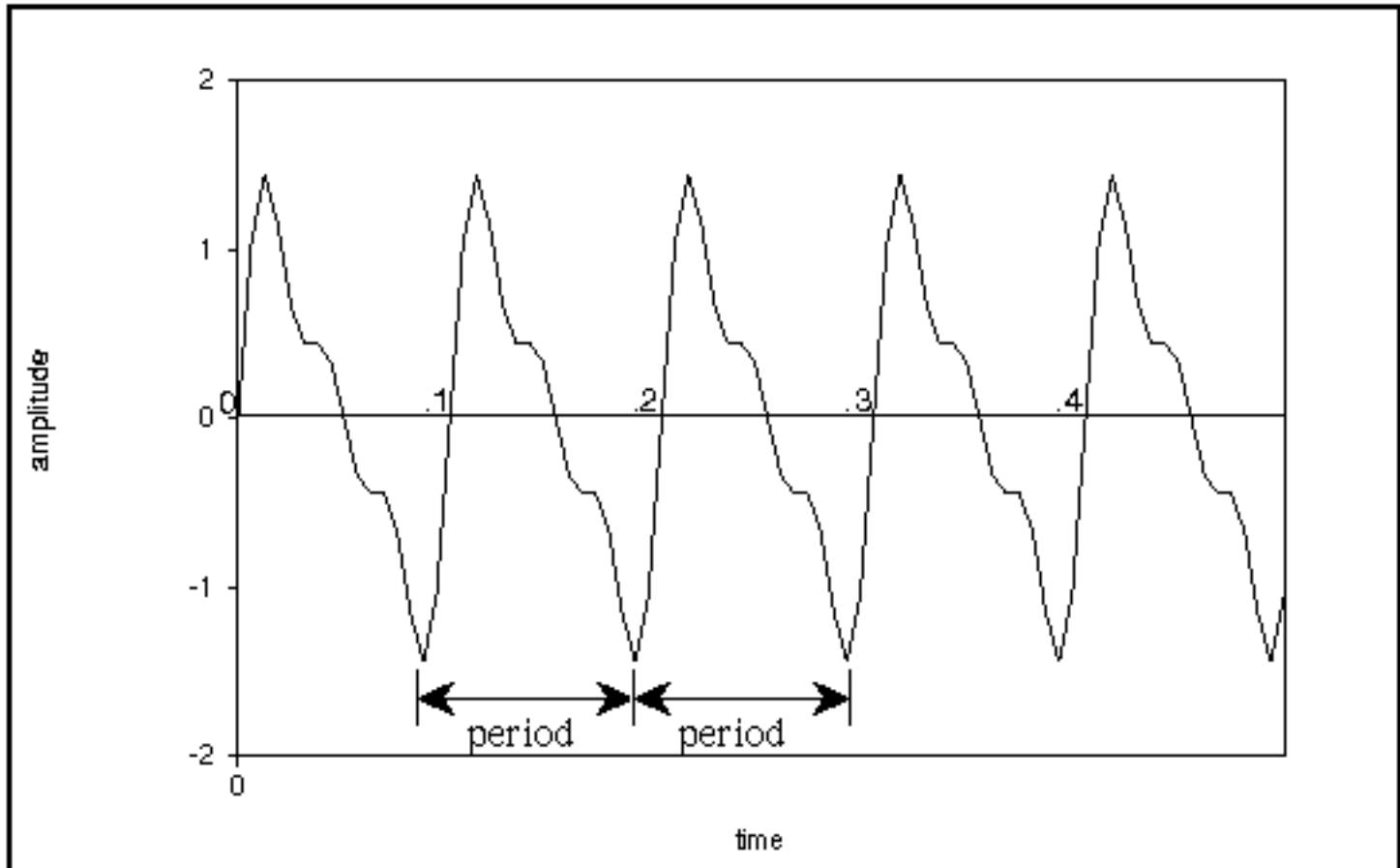
# Analog-digital interface



# Processing analog signal



# Analog input signal



# Analog input signal

- For periodic waveforms, the duration of the waveform before it repeats is called the period of the waveform
- The rate at which a regular vibration pattern repeats itself (frequency =  $1/\text{period}$ )

# Frequency of a Waveform

- The unit for frequency is cycles/second, also called Hertz (Hz).
- The frequency of a waveform is equal to the reciprocal of the period.

$$\text{frequency} = 1/\text{period}$$

# Frequency of a Waveform

- Examples:

frequency = 10 Hz

period = .1 (1/10) seconds

frequency = 100 Hz

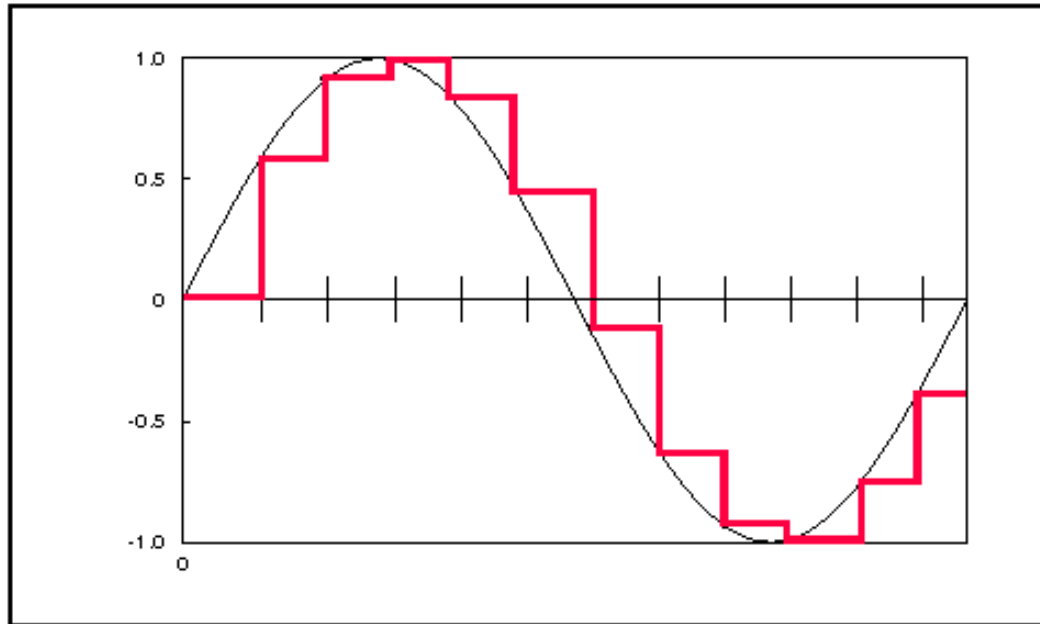
period = .01 (1/100) seconds

frequency = 261.6 Hz (middle C)

period = .0038226 (1/ 261.6) seconds

# Waveform Sampling (Quantization)

- To represent waveforms on digital computers, we need to digitize or sample the waveform.



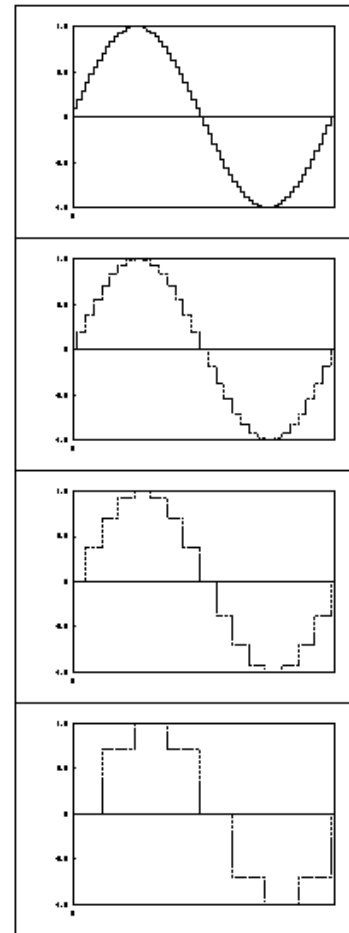
- side effects of digitization:
  - introduces some noise
  - limits the maximum upper frequency range

# Sampling rate

- The sampling rate (SR) is the rate at which amplitude values are digitized from the original waveform.
  - CD sampling rate (high-quality):  
SR = 44,100 samples/second
  - medium-quality sampling rate:  
SR = 22,050 samples/second
  - phone sampling rate (low-quality):  
SR = 8,192 samples/second

# Sampling rate

- Higher sampling rates allow the waveform to be more accurately represented



64 samples/cycle

32 samples/cycle

16 samples/cycle

8 samples/cycle

# Nyquist Theorem

- Nyquist Theorem:

We can digitally represent only frequencies up to half the sampling rate.

- Example:

- CD:  $SR=44,100$  Hz

- Nyquist Frequency =  $SR/2 = 22,050$  Hz

- Example:

- $SR=22,050$  Hz

- Nyquist Frequency =  $SR/2 = 11,025$  Hz

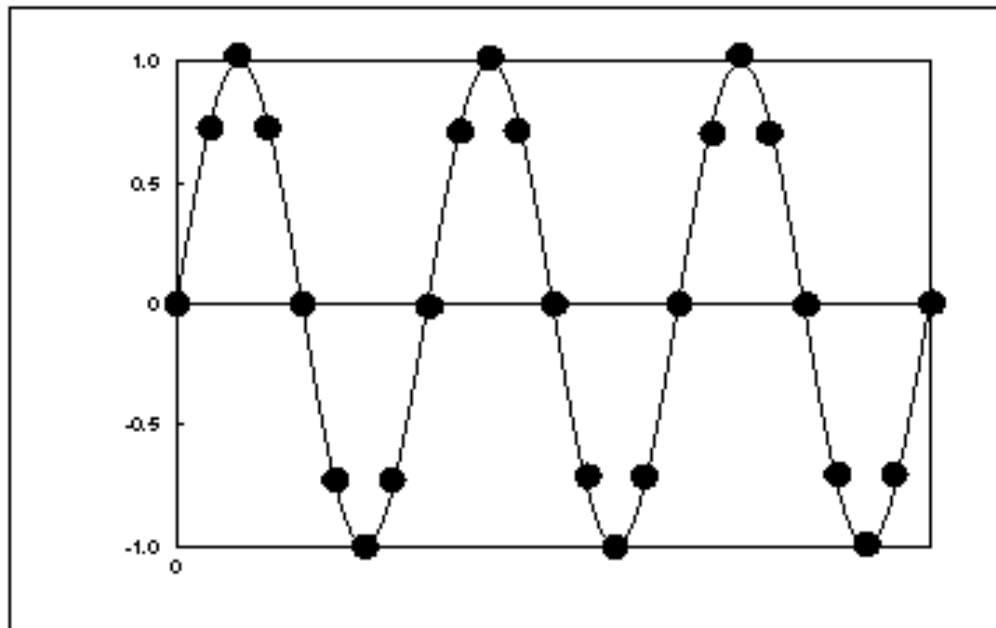
# Nyquist Theorem

Sampling rate (SR)  $> 2 f_{\max}$

$f_{\max}$  is the largest signal frequency of interest

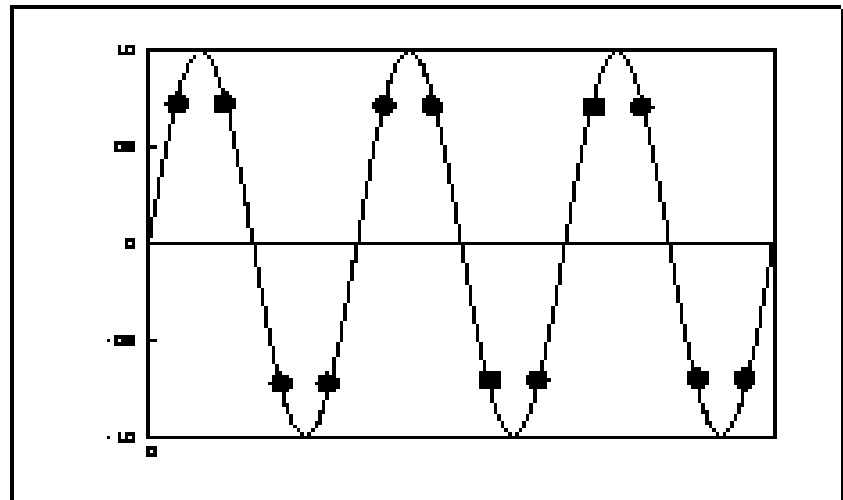
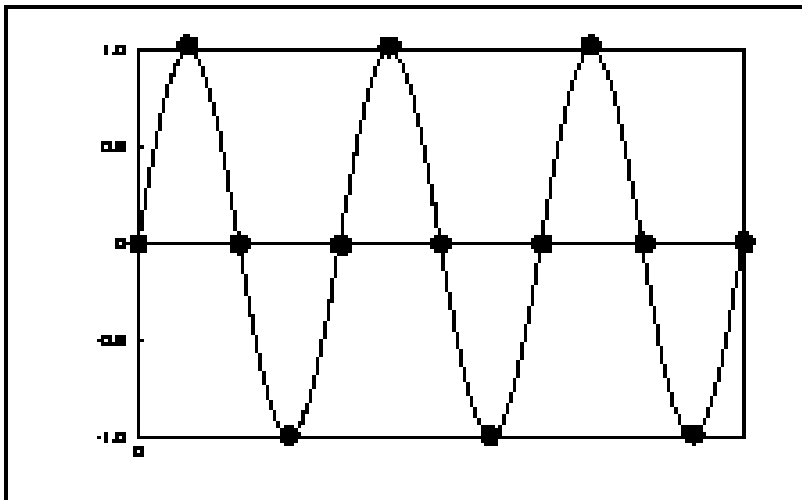
# Nyquist Theorem and Aliasing

- Graphical Example 1a:
  - $SR = 20,000$  Hz
  - Nyquist Frequency =  $10,000$  Hz
  - $f = 2,500$  Hz (no aliasing)



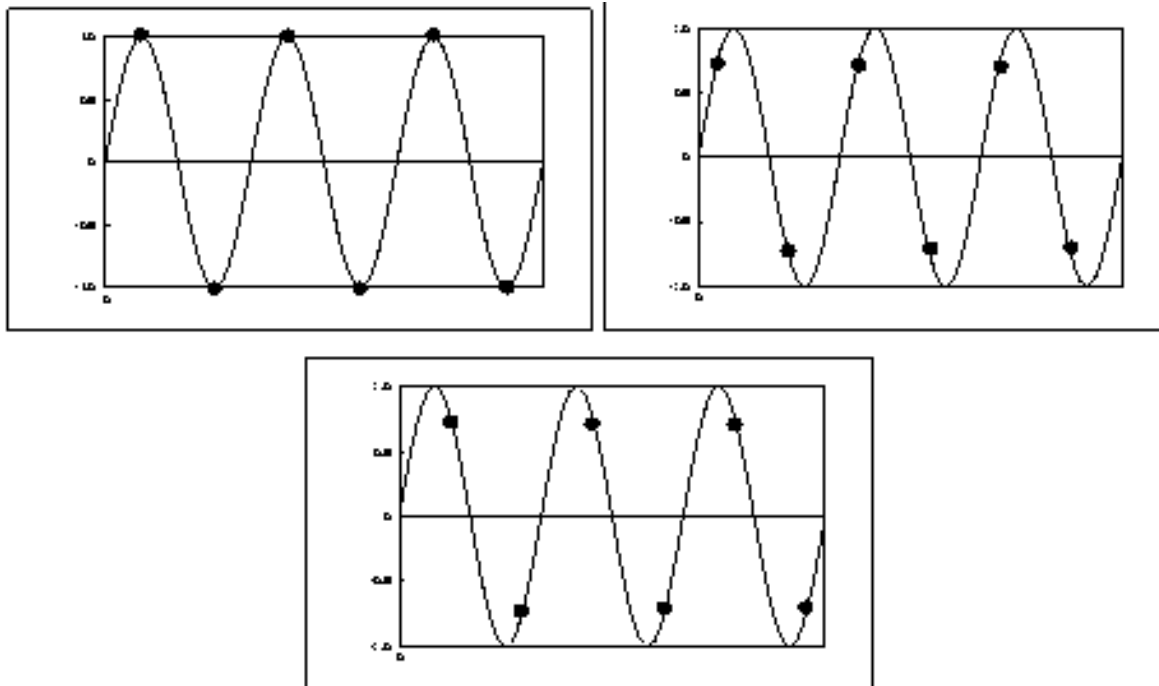
# Nyquist Theorem and Aliasing

- Graphical Example 1b:
  - $SR = 20,000$  Hz
  - Nyquist Frequency =  $10,000$  Hz
  - $f = 5,000$  Hz (no aliasing)



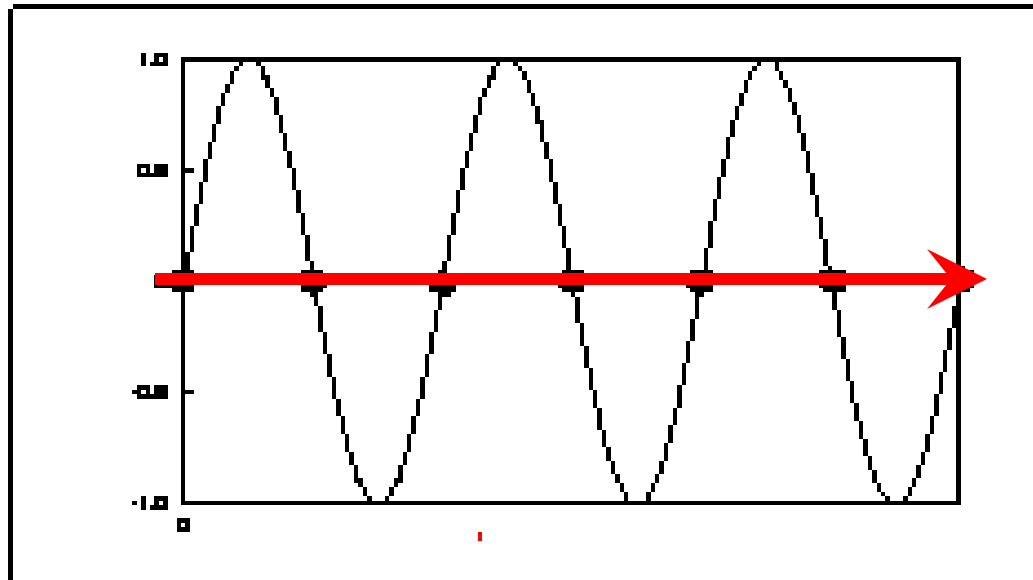
# Nyquist Theorem and Aliasing

- Graphical Example 2:
  - $SR = 20,000$  Hz
  - Nyquist Frequency =  $10,000$  Hz
  - $f = 10,000$  Hz (no aliasing)



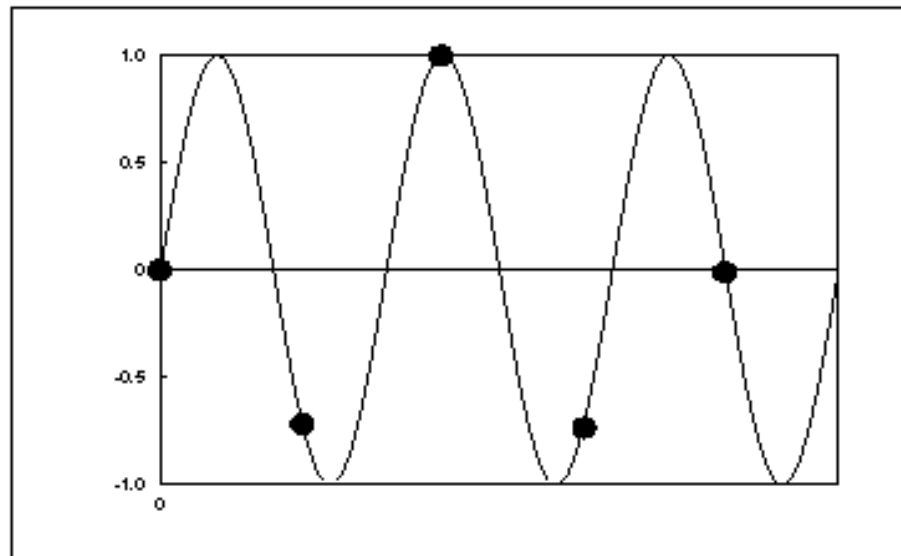
# Nyquist Theorem and Aliasing

- Graphical Example 2:
  - BUT, if sample points fall on zero-crossings the sound is completely cancelled out



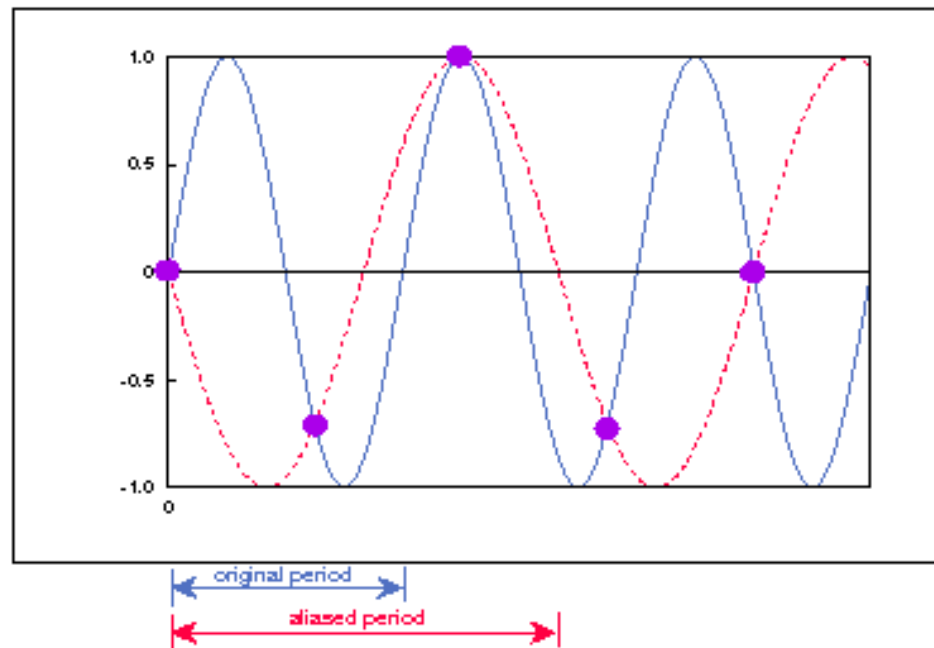
# Nyquist Theorem and Aliasing

- Graphical Example 3:
  - $SR = 20,000$  Hz
  - Nyquist Frequency =  $10,000$  Hz
  - $f = 12,500$  Hz,  $f' = 7,500$

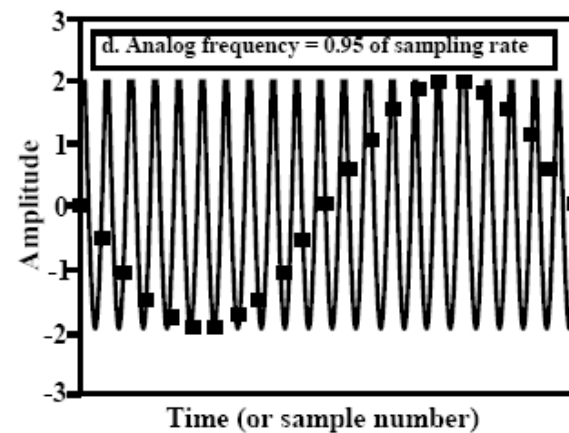
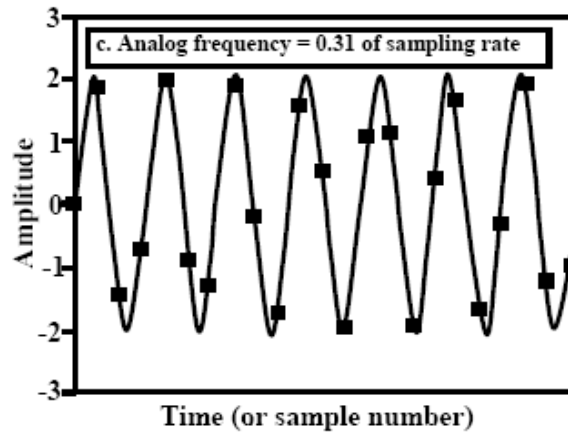
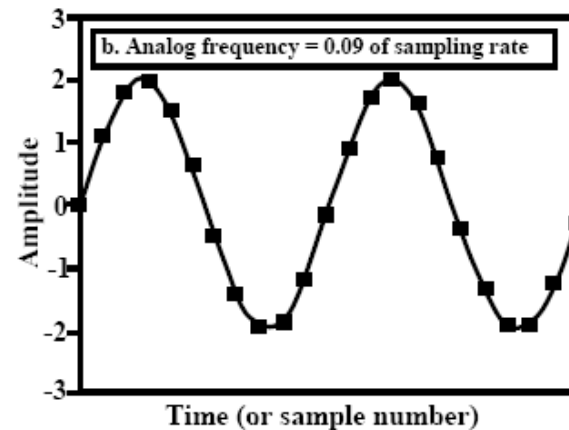
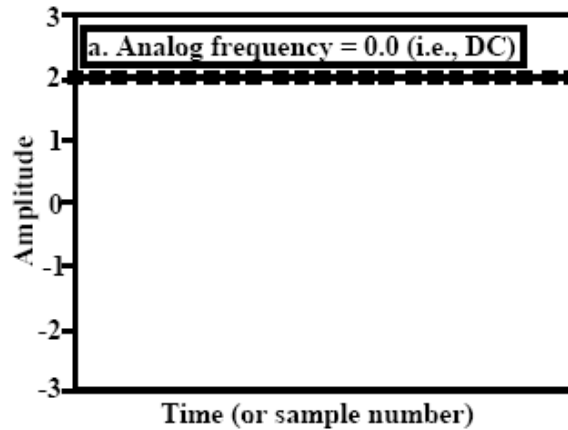


# Nyquist Theorem and Aliasing

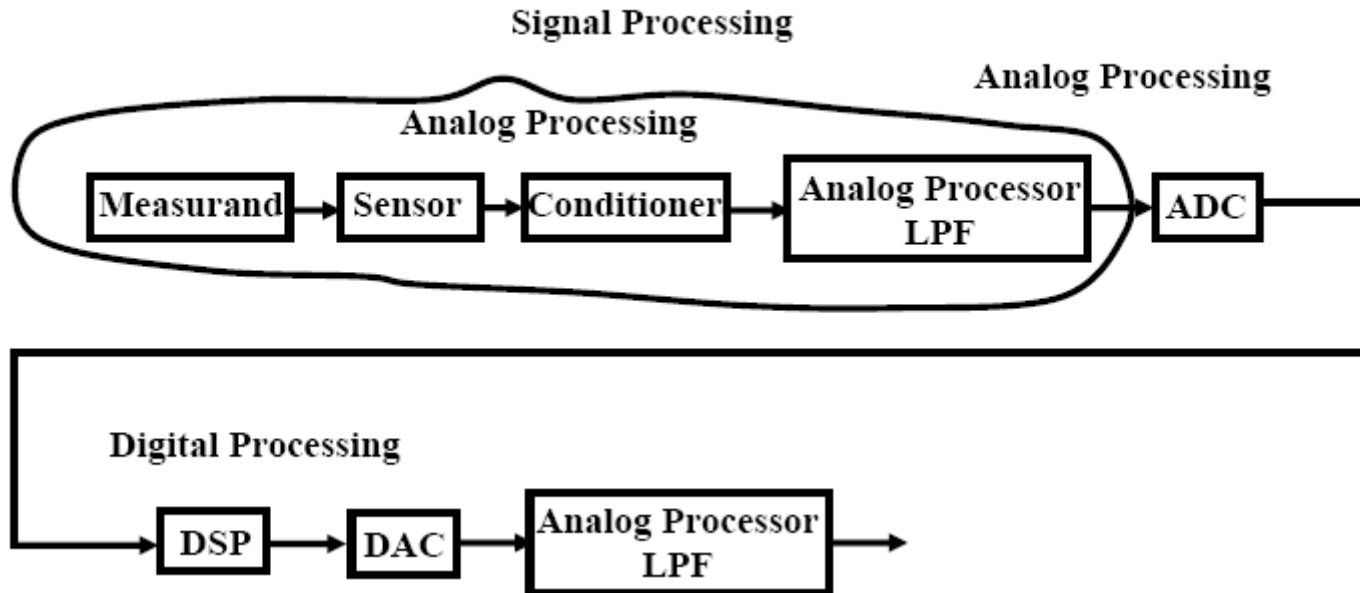
- Graphical Example 3:
  - Fitting the simplest sine wave to the sampled points gives an aliased waveform (dotted line below):



# Sample of sine wave at different freq.

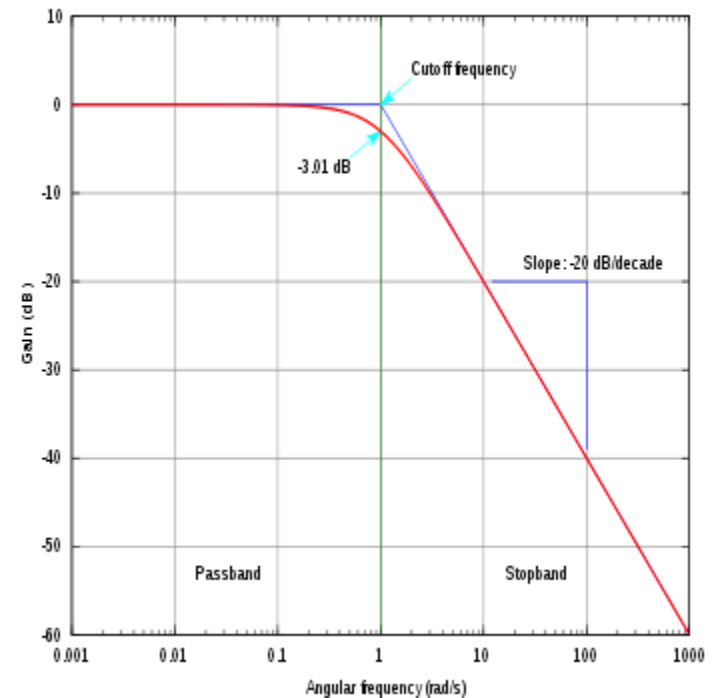


# Processing analog signal

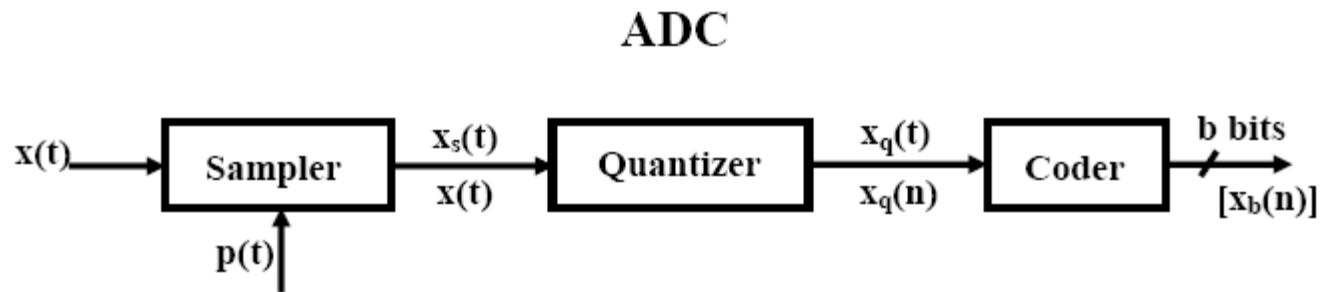


# Low pass filter

- Allow only low frequency value to pass
- Prevent aliasing



# Layout of ADC



# ADC precision

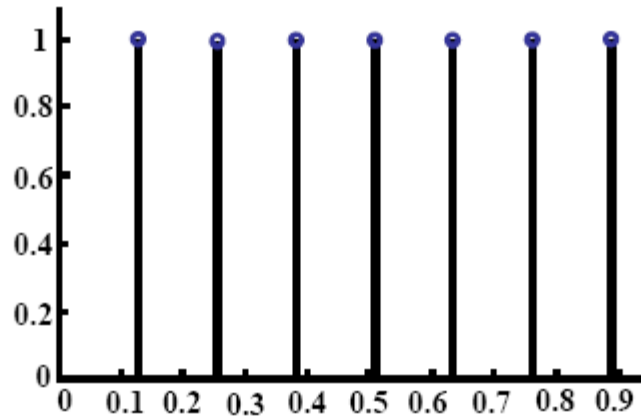
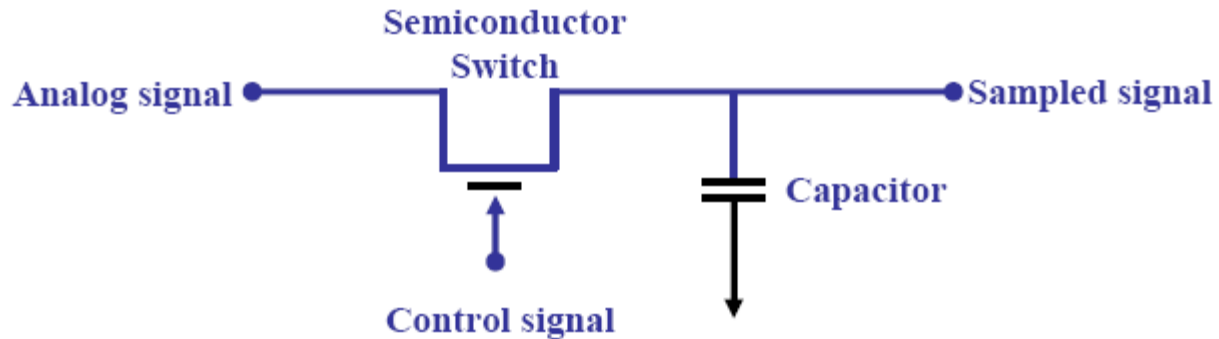
- Number of ADC bit output (n):  
 $n = \text{input range } (r) / \text{input resolution } \Delta y$

E.g., input range of 1, and resolution of 0.0001

$n = 10000$  alternatives or 15 bits value

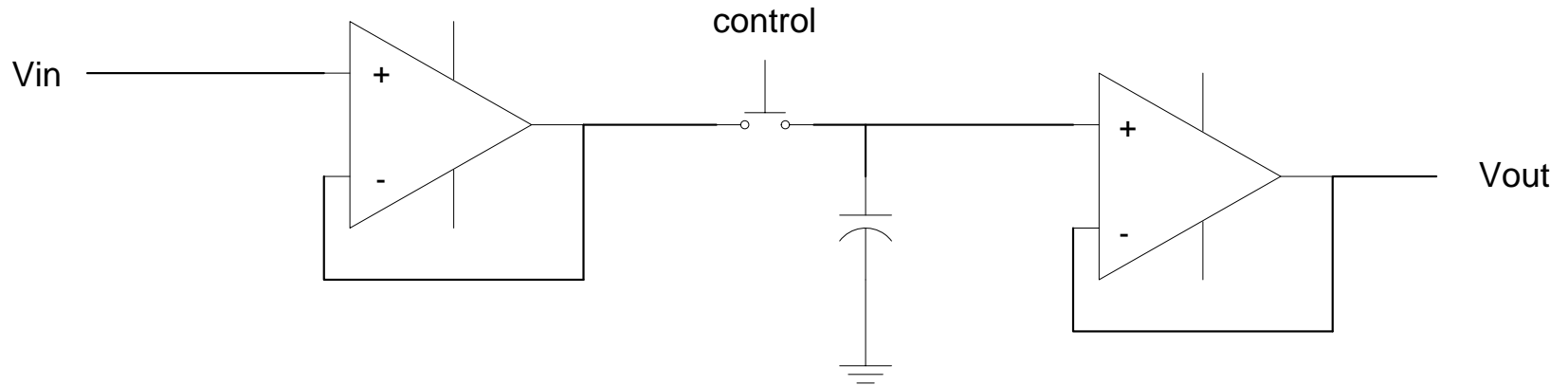
Assume linear ADC

# Sample and hold circuit

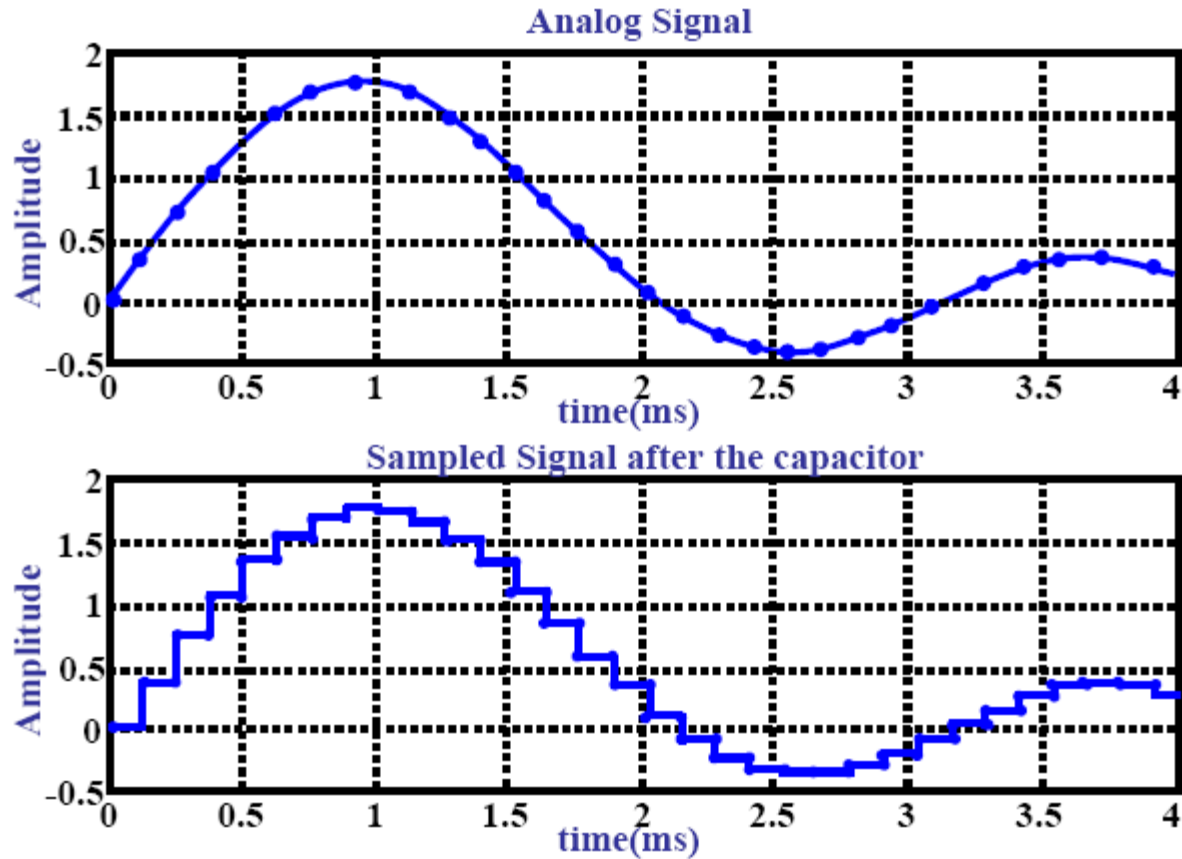


# Sample and hold circuit

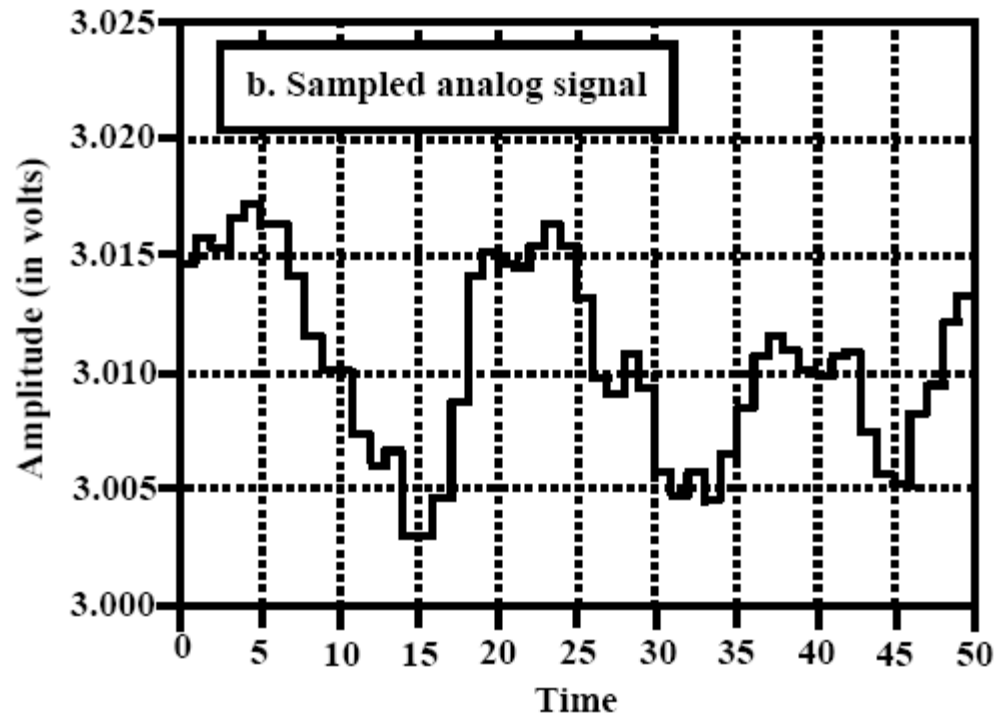
- Using op-amp to hold signal strength  
unity gain buffer



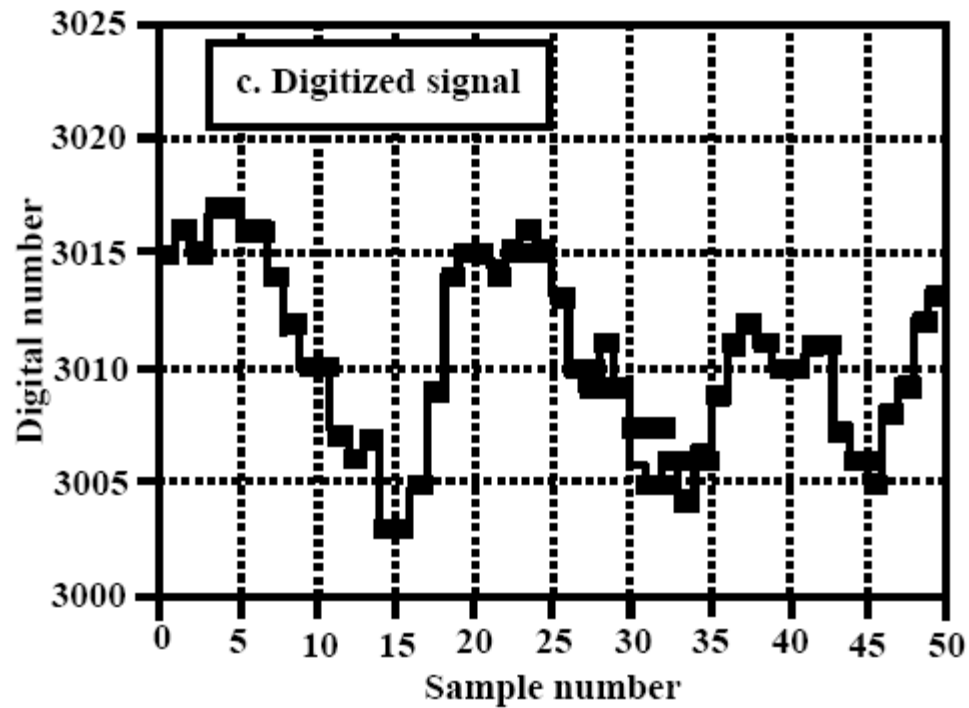
# Sample and hold signal



# Hold circuit output



# Quantized output



# Convert analog value to digital value

Bipolar codes	Offset binary	2s binary
+5.00	1111	0111
+2.50	1100	0100
+0.04	1000	0000
+0.00	1000	0000
-2.50	0100	1100
-5.00	0000	1000

# ADC types

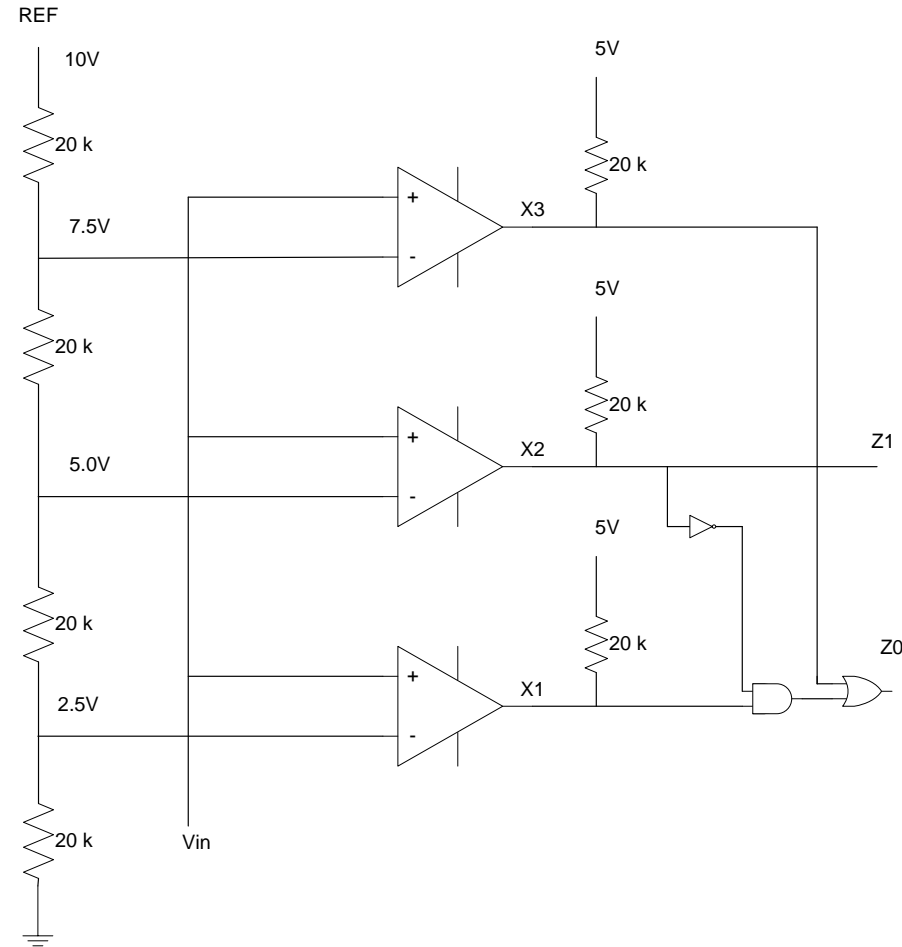
- Flash ADC
  - fast
- Successive Approximation ADC
  - most popular
- Sigma Delta ADC
  - highest output precision

# Flash ADC

- Use reference voltage and differential op-amp to generate digital output
- Fast conversion
- To increase the number of bits, it requires larger hardware support

# Two-bit flash ADC

$V_{in}$	X3	X2	X1	Z1	Z0
$V < 2.5$	0	0	0	0	0
$2.5 \leq V < 5.0$	0	0	1	0	1
$5.0 \leq V < 7.5$	0	1	1	1	0
$V \geq 7.5$	1	1	1	1	1



# Flash converter

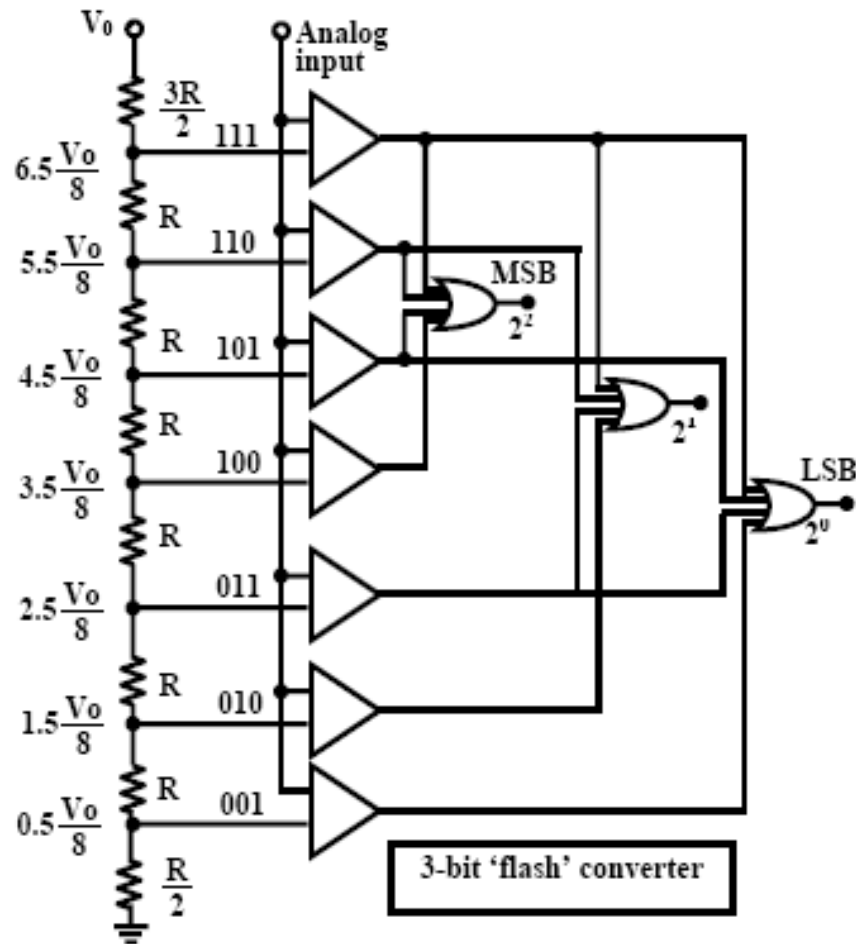
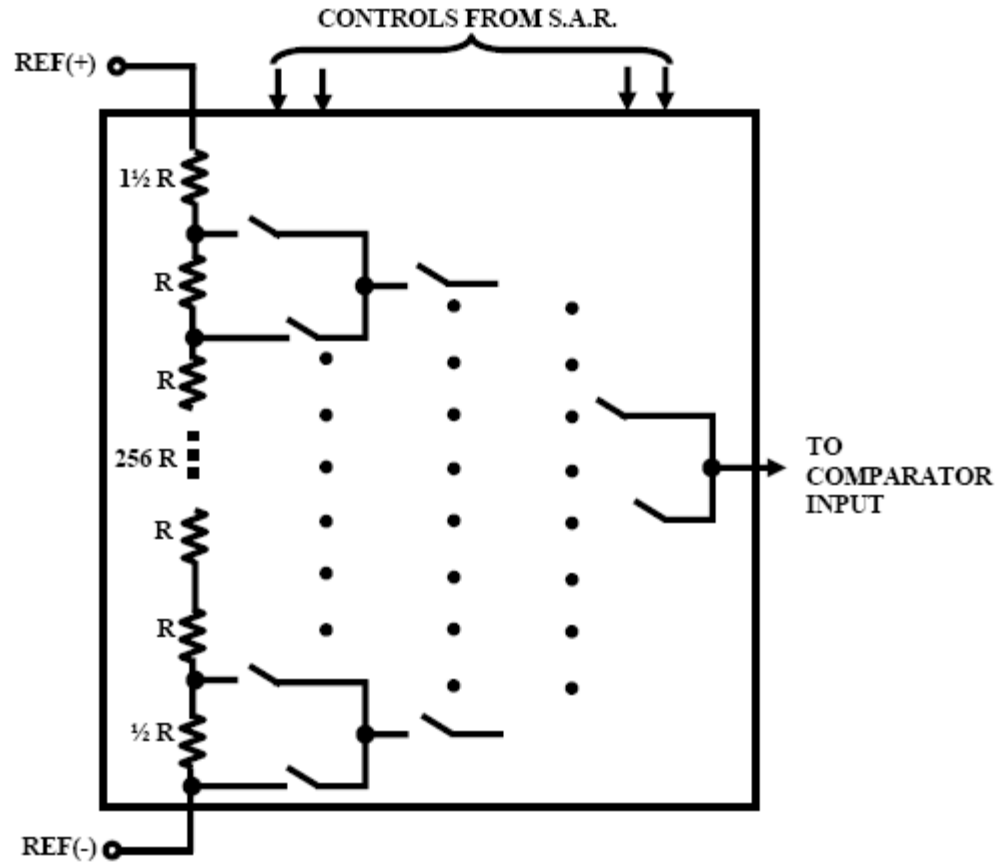


Fig. 18.12 Flash Converter

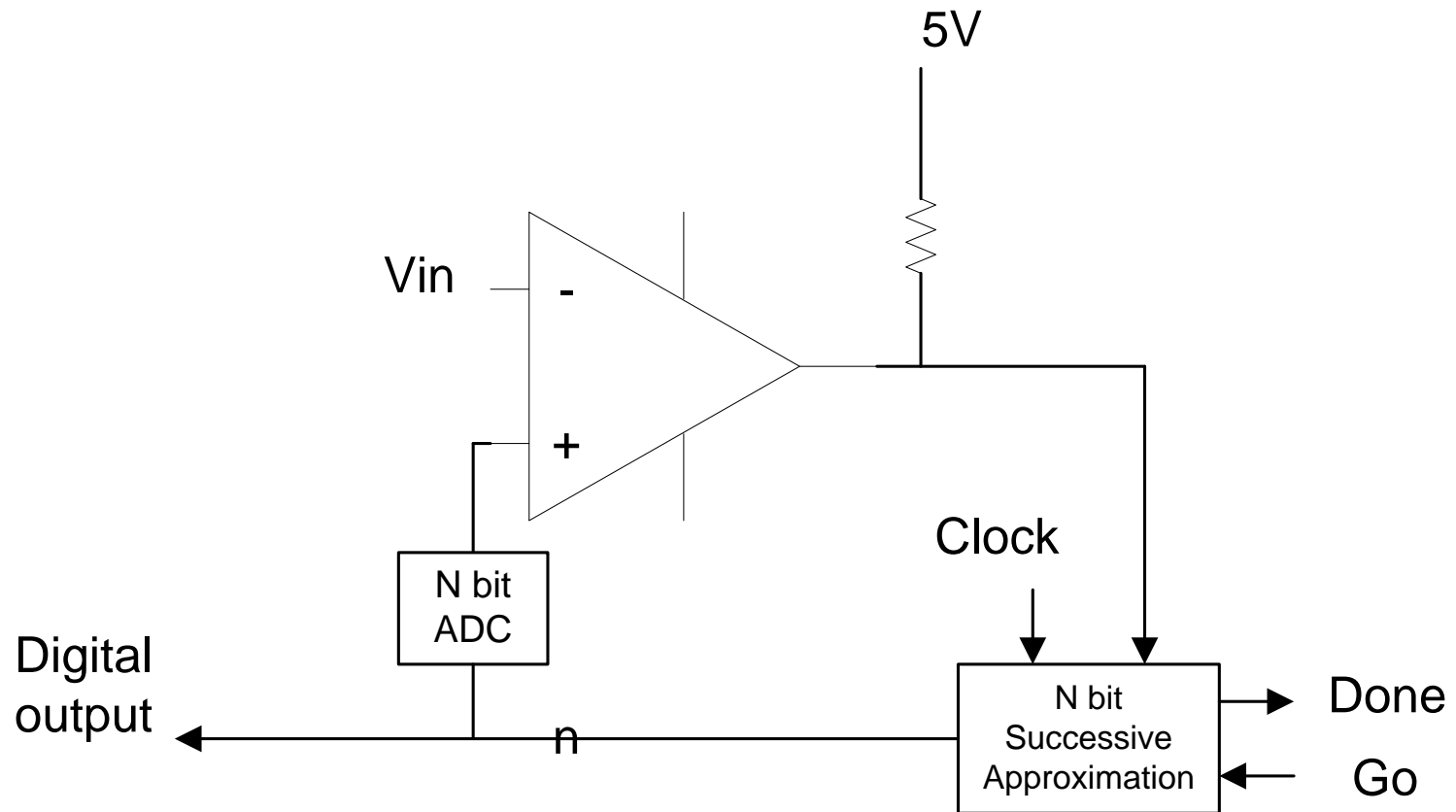
# 256R ladder network

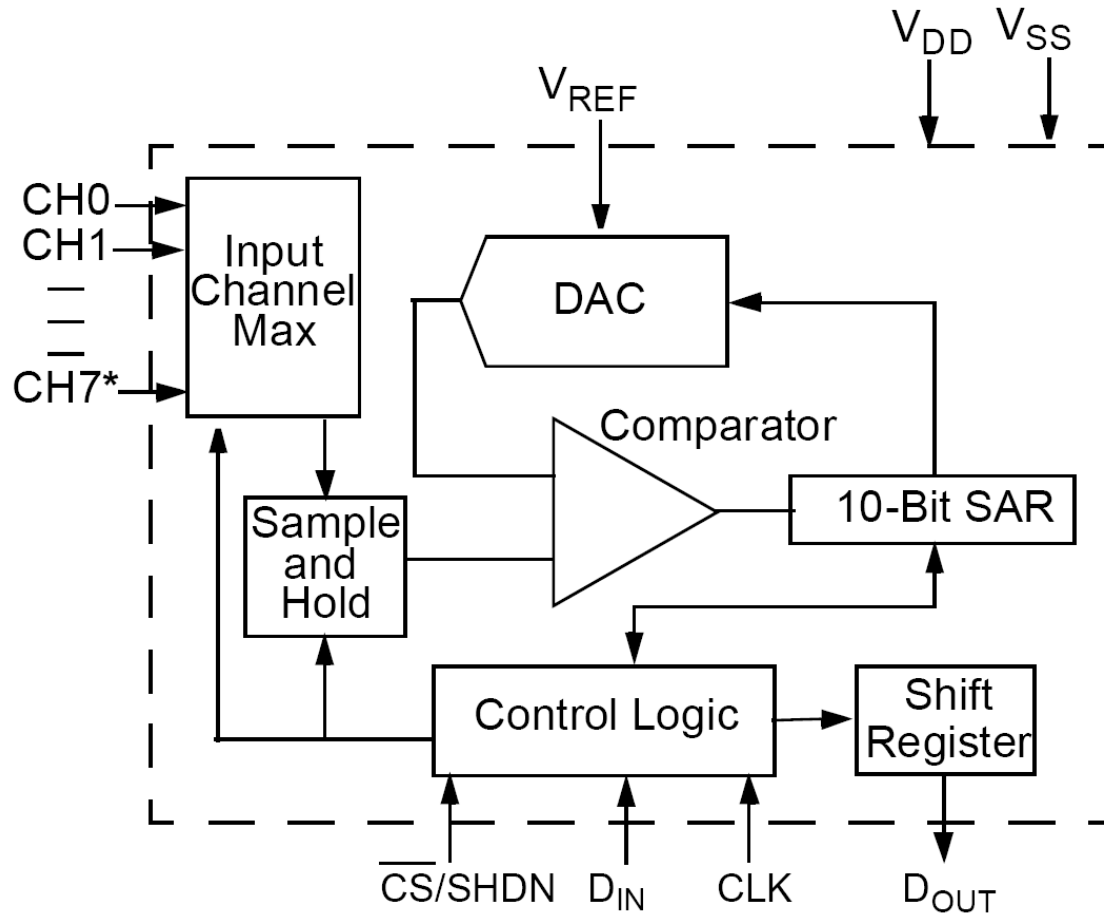


# Successive Approximation ADC

- Similar to Flash ADC, but use only one set of hardware
- Require longer time
- Fixed size of hardware
- Widely used

# Successive Approximation ADC

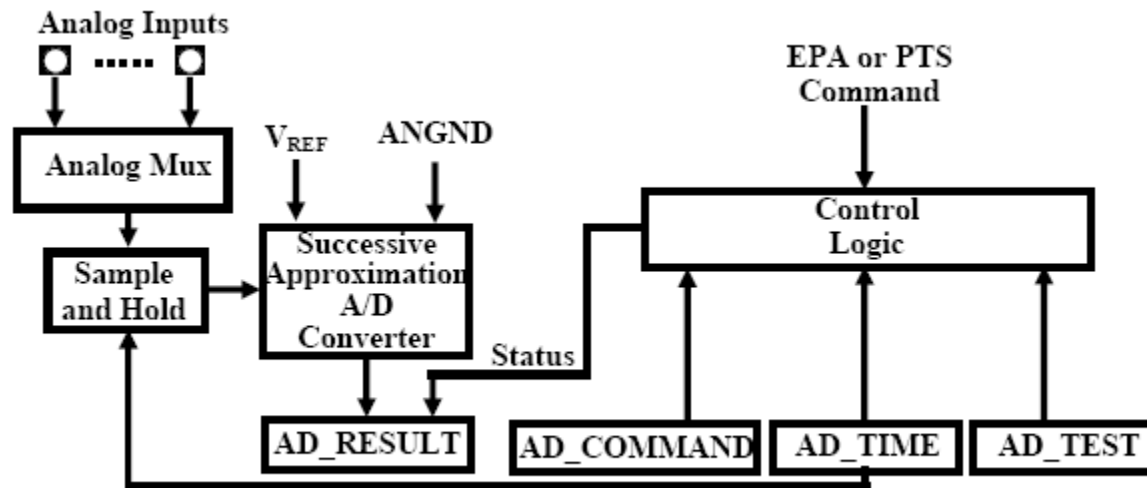




The MCP3008 10-bit 200Ksps A/D chip used in Phidget modules has an SPI interface.

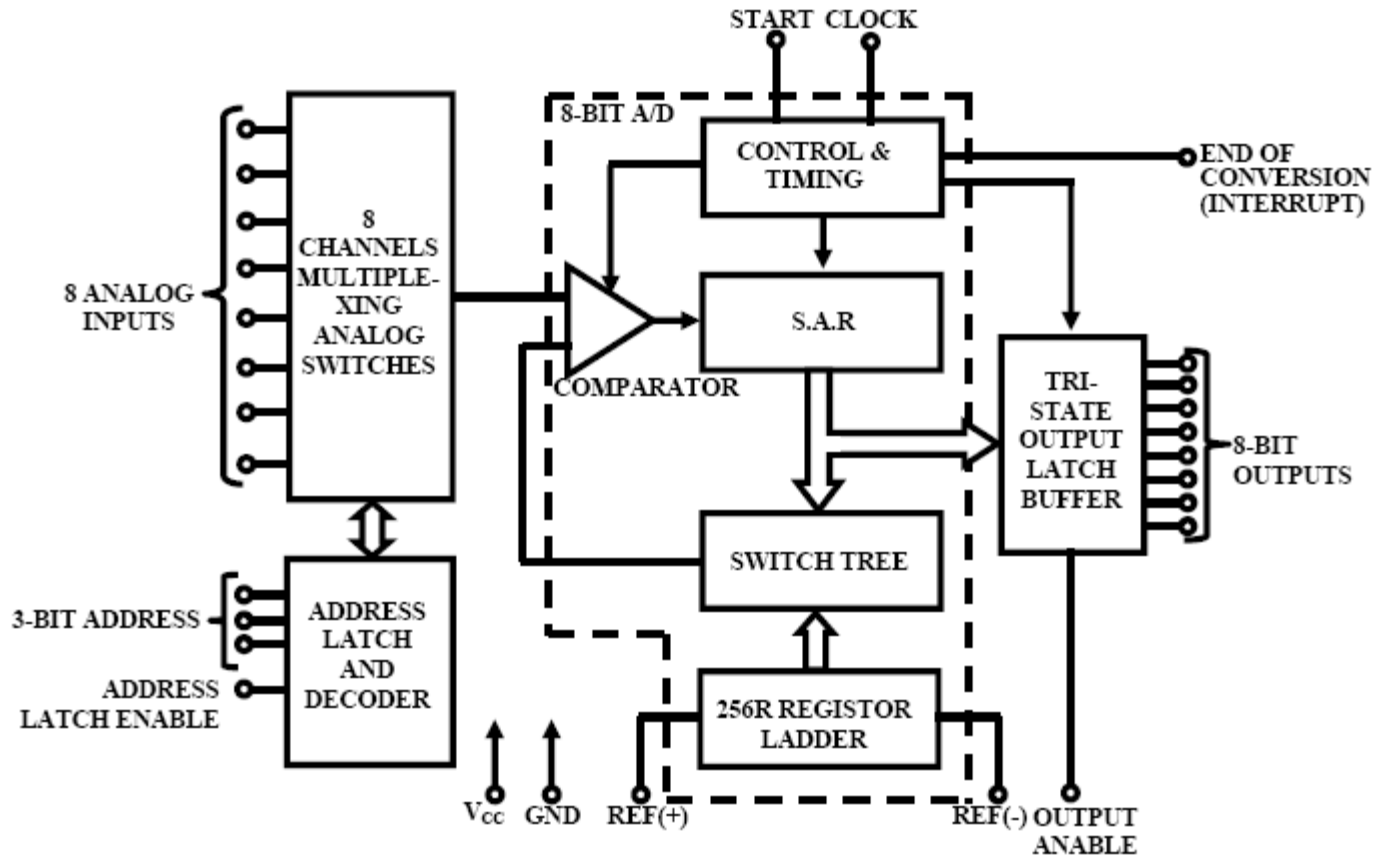


# Block diagram of internal AD converter

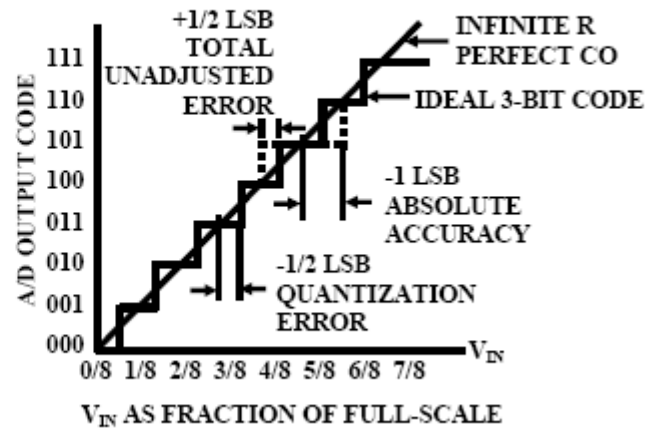
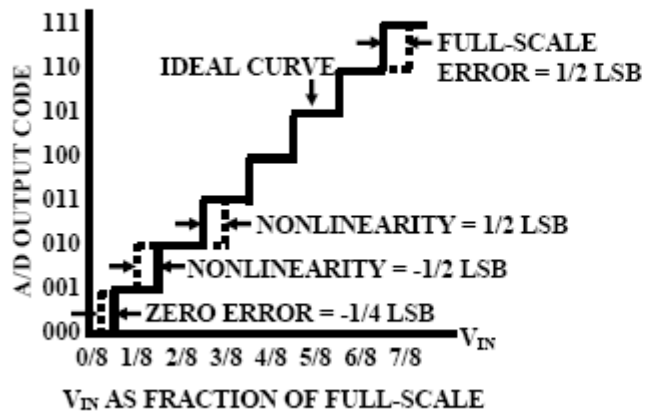


† Multiplexed with port inputs

# AD converter



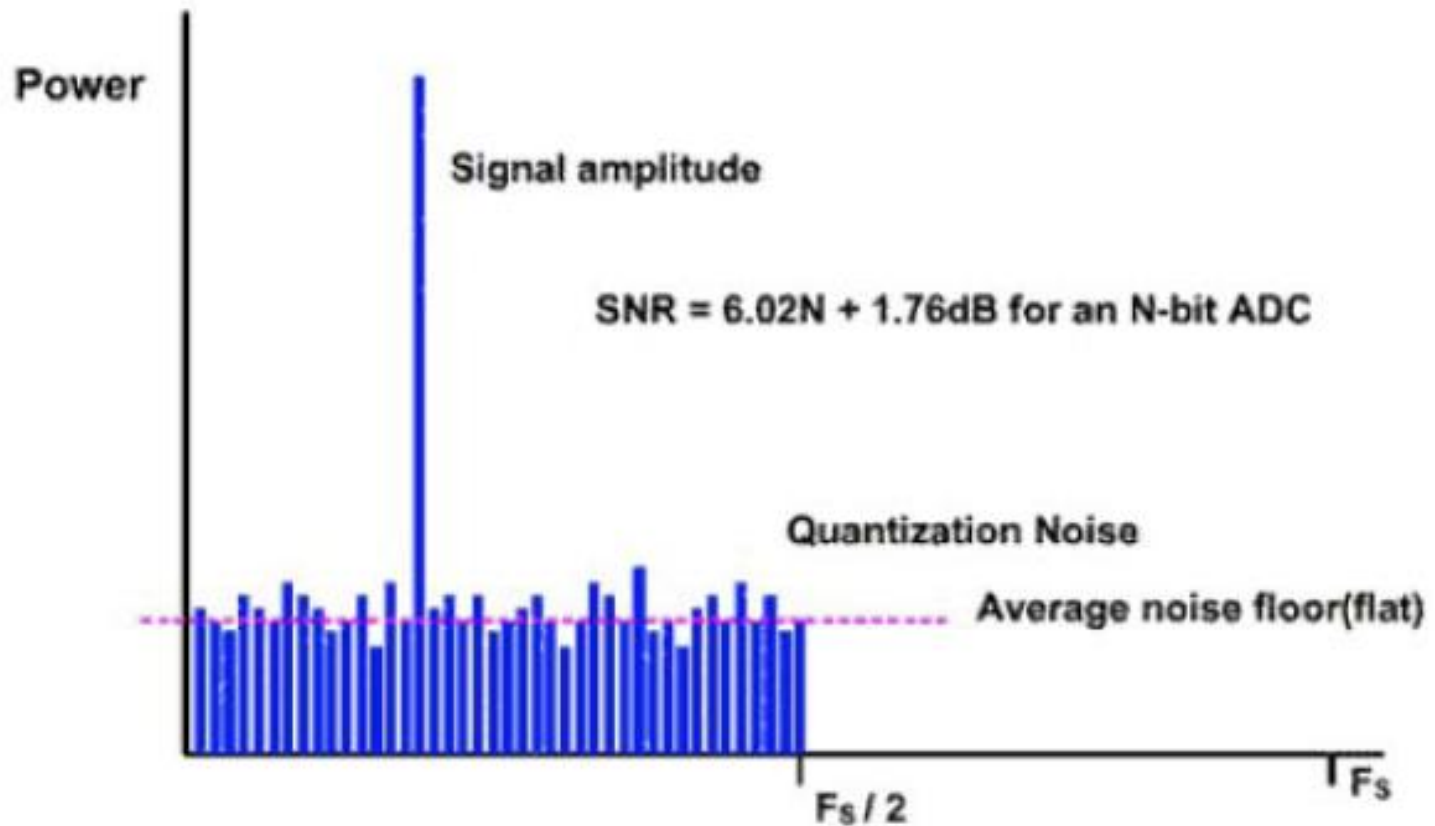
# 3-bit AD converter



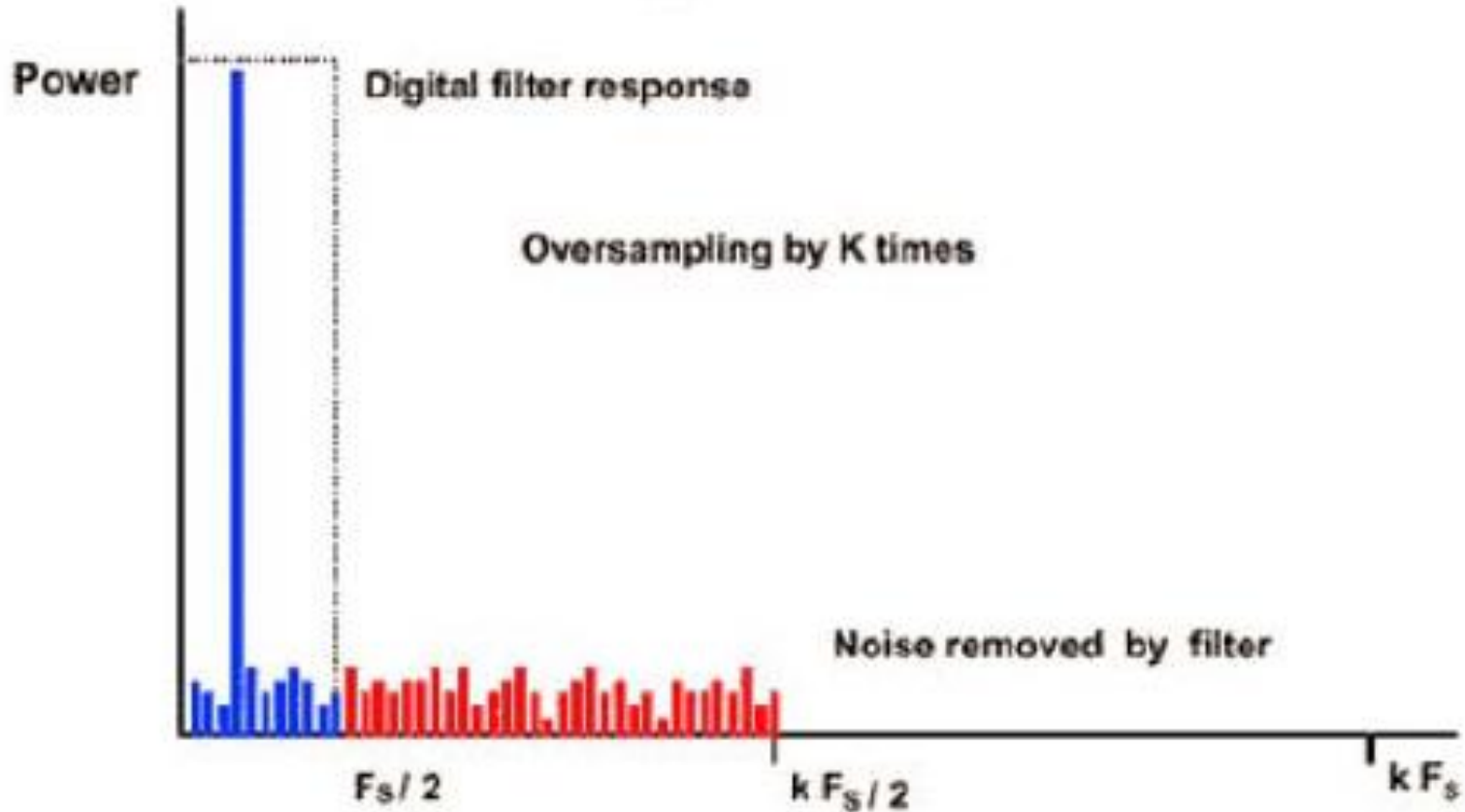
# Delta-Sigma ADC

- Quantization noise is uniformly distributed among frequency spectrum
- Using over-sampling technique to reduce the impact of quantization noise
- Results in higher bit-precision
- Slow

# Frequency domain



# Oversampling by K times



# Delta-Sigma circuit

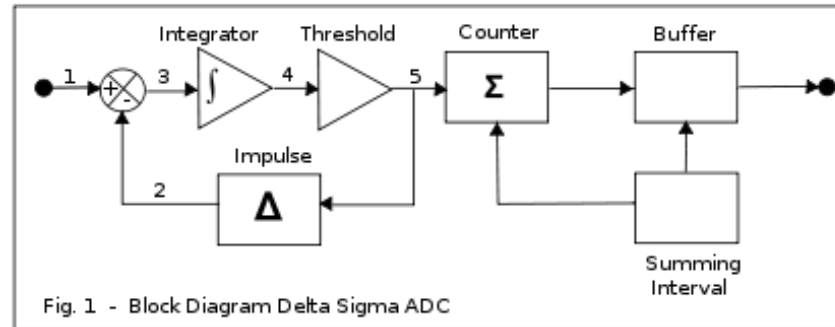
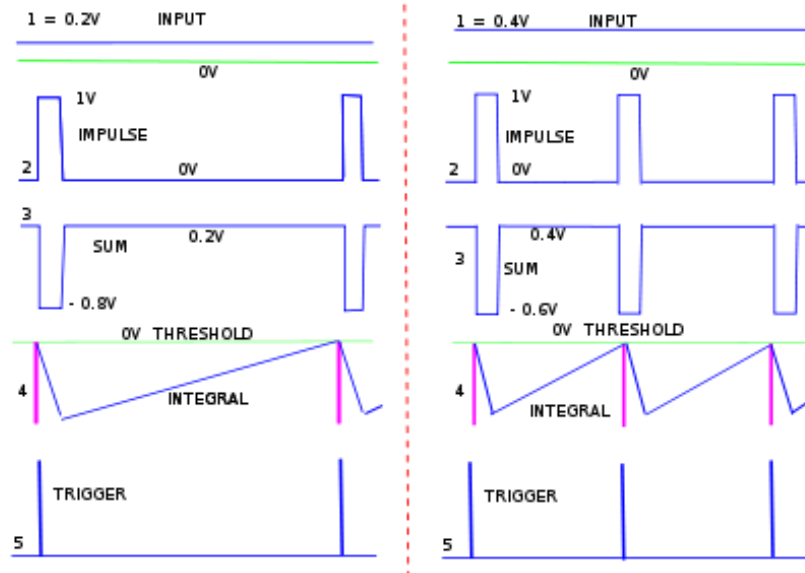
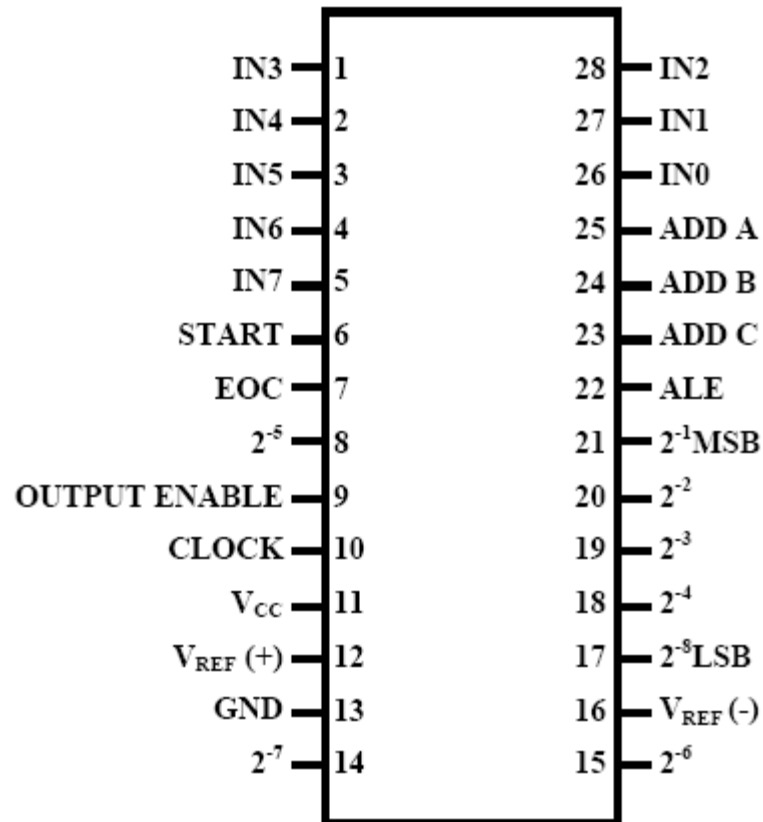


Fig. 1 - Block Diagram Delta Sigma ADC

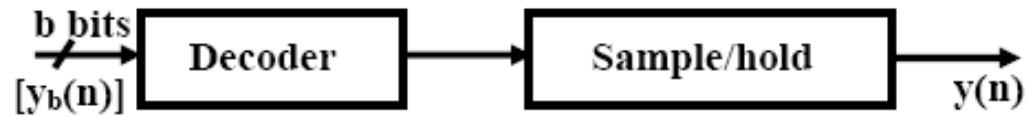


# Signal pin of AD converter

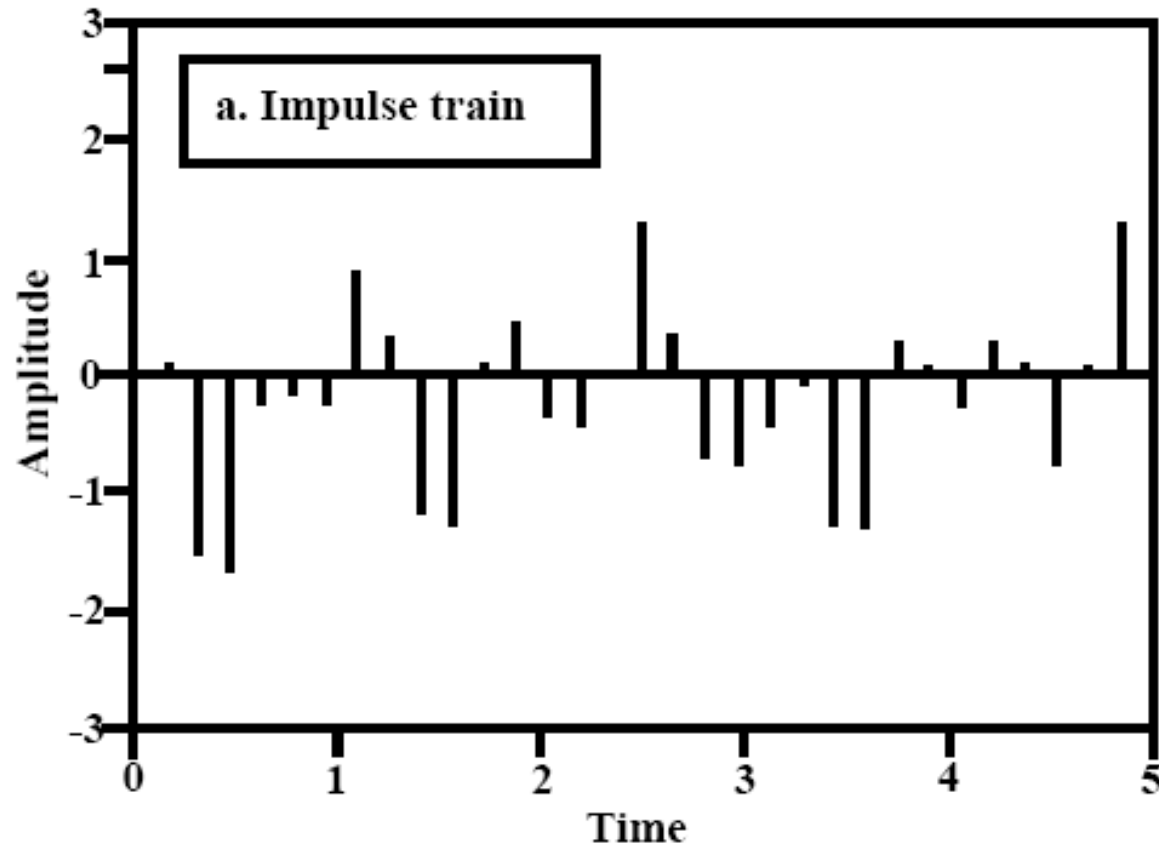


# Digital to Analog Converter (DAC)

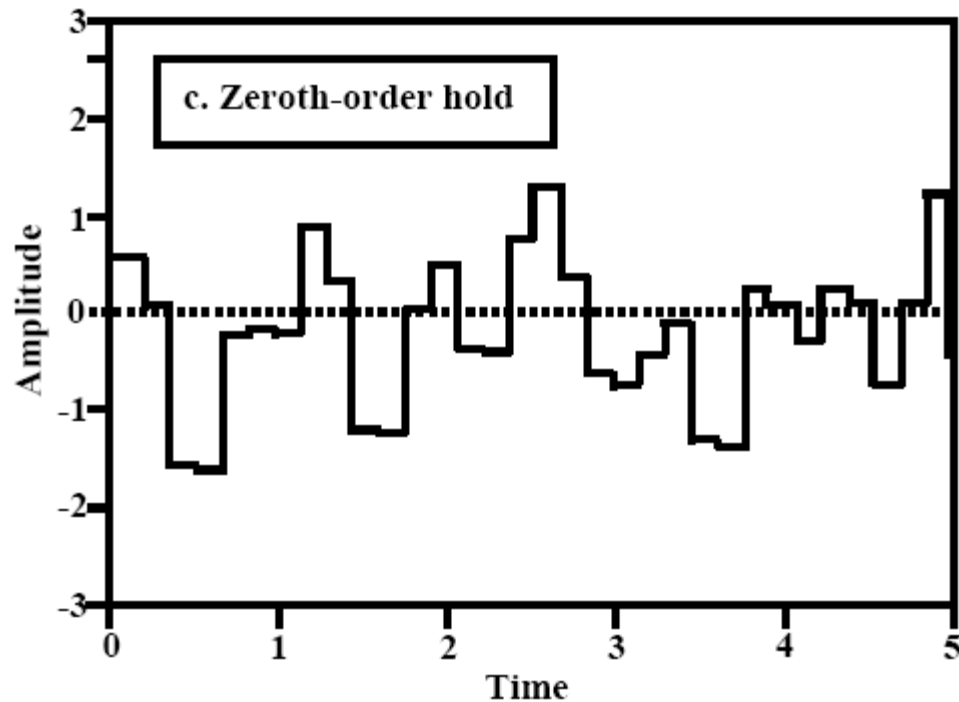
# Layout of DAC



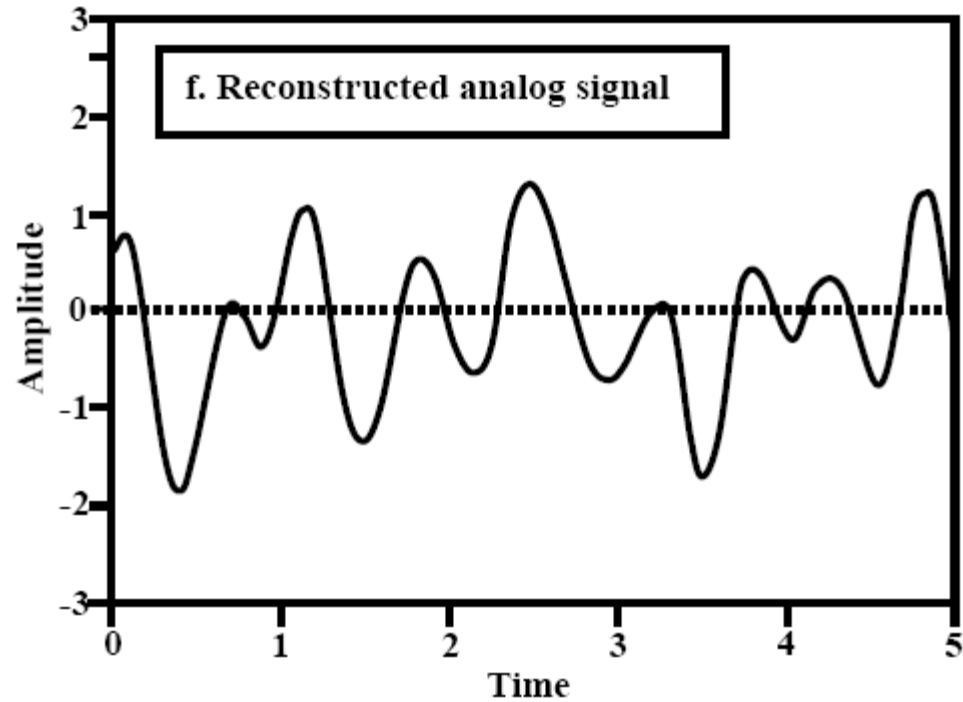
# Analog of digital conversion



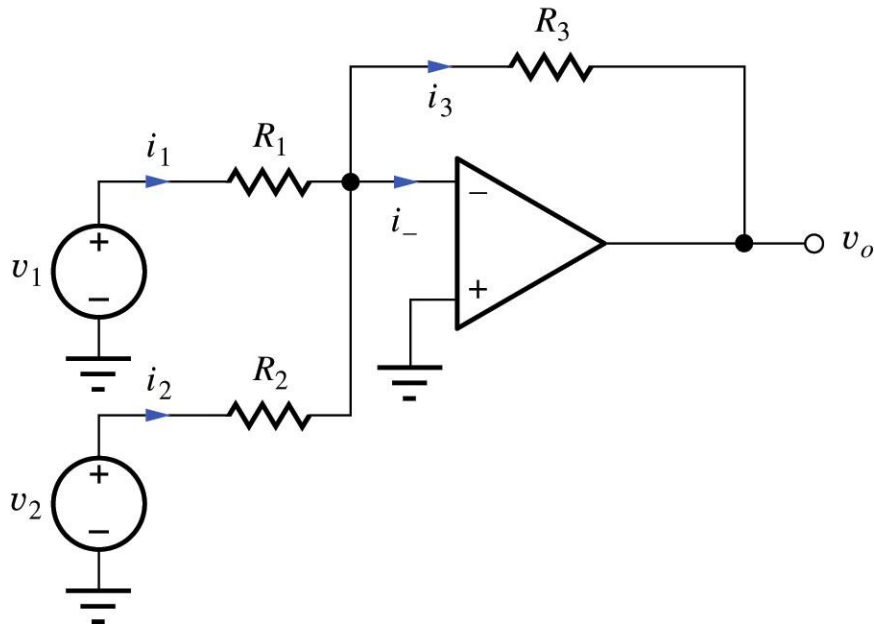
# Analog voltage of zero order



# Reconstruction



# Summing Amplifier



Since negative amplifier input is at virtual ground,

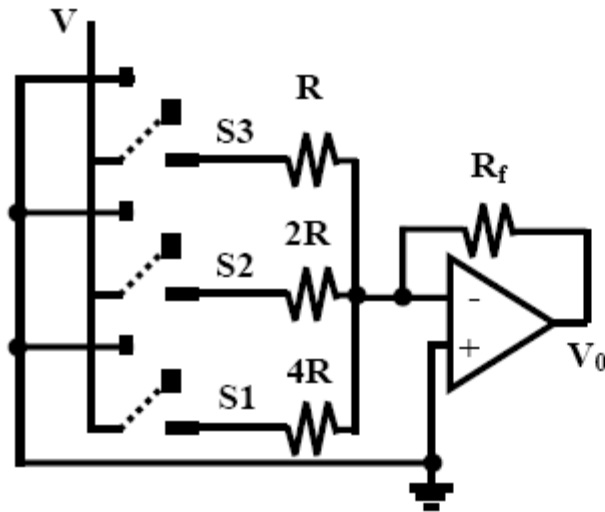
$$i_1 = \frac{v_1}{R_1} \quad i_2 = \frac{v_2}{R_2} \quad i_3 = -\frac{v_o}{R_3}$$

Since  $i_- = 0$ ,  $i_3 = i_1 + i_2$ ,

$$v_o = -\frac{R_3}{R_1} v_1 - \frac{R_3}{R_2} v_2$$

- Scale factors for the 2 inputs can be independently adjusted by proper choice of  $R_2$  and  $R_1$ .
- Any number of inputs can be connected to summing junction through extra resistors.
- This is an example of a simple digital-to-analog converter.

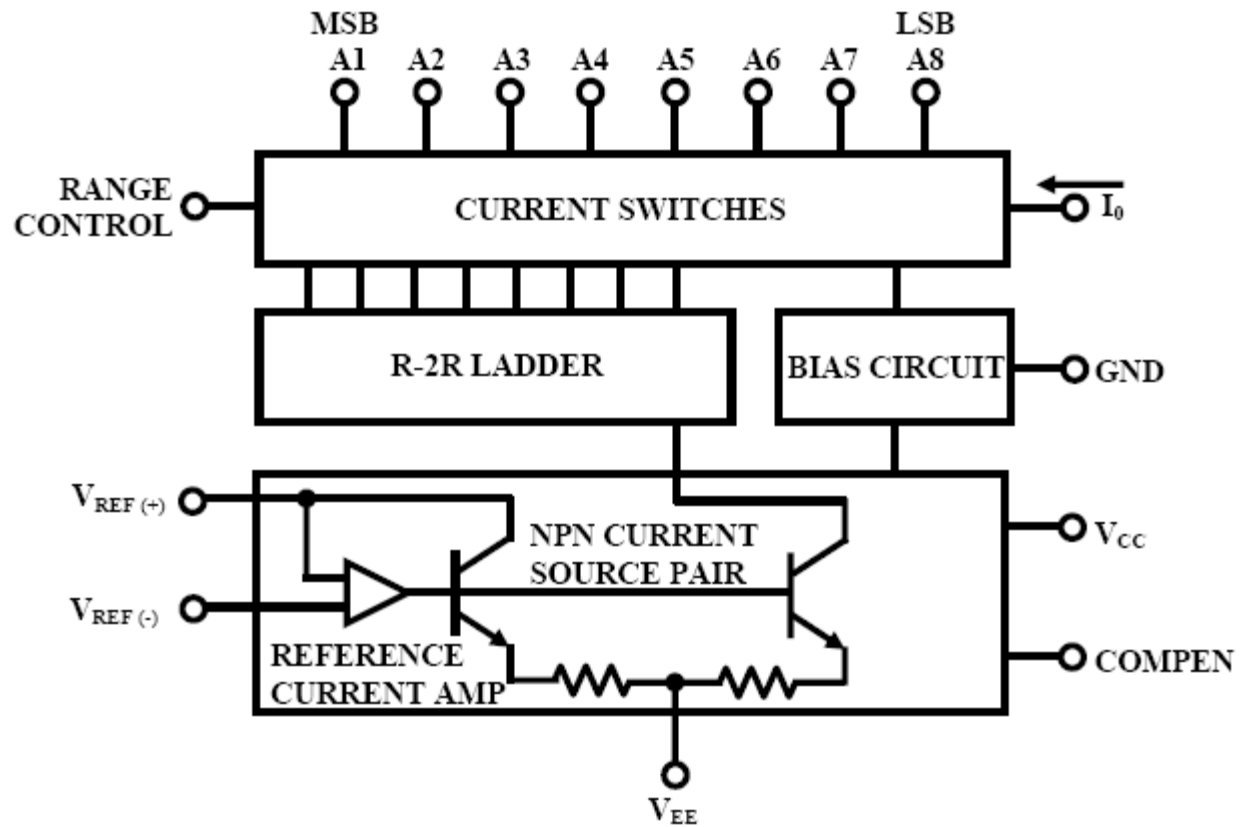
# Binary weight register method



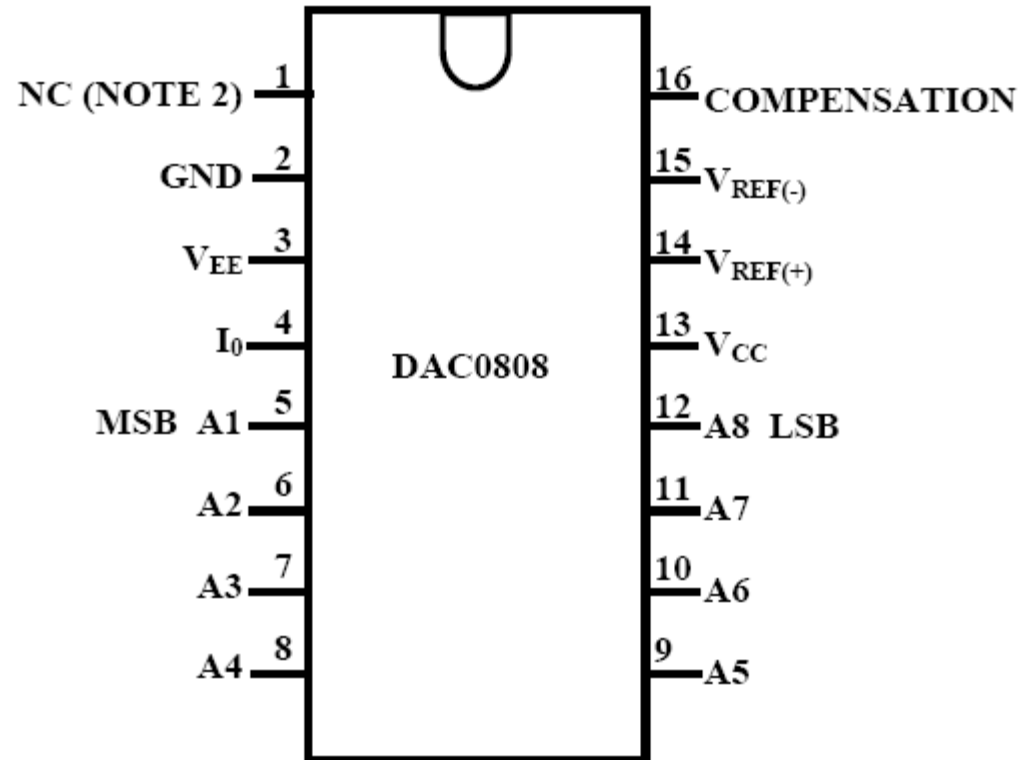
$$V_0 = -R_f \left( S_3 \frac{V}{R} + S_2 \frac{V}{2R} + S_1 \frac{V}{4R} \right)$$
$$= \frac{-R_f}{4R} V (4S_3 + 2S_2 + S_1)$$

	S3	S2	S1
0	0	0	0
1	0	0	1
2	0	1	0
3	0	1	1
4	1	0	0
5	1	0	1
6	1	1	0
7	1	1	1

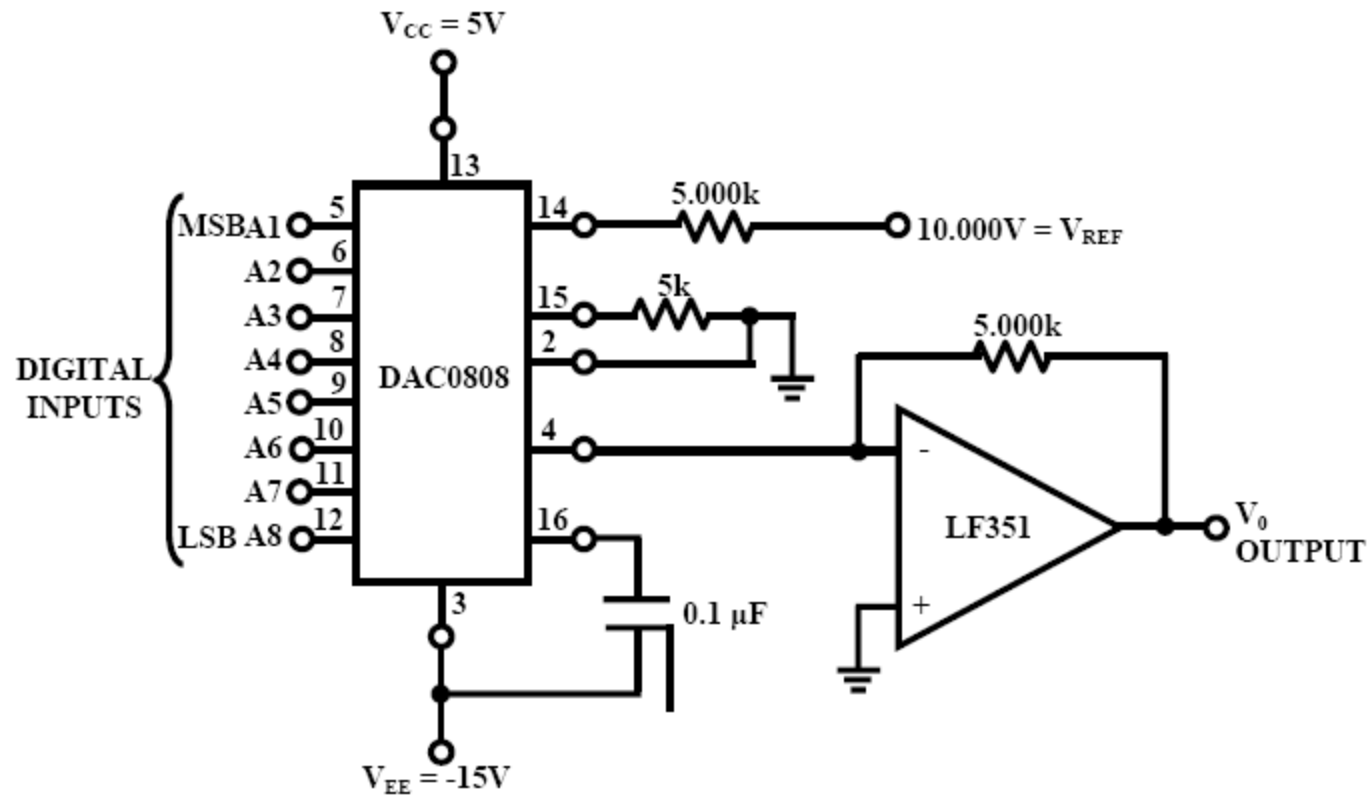
# DA converter



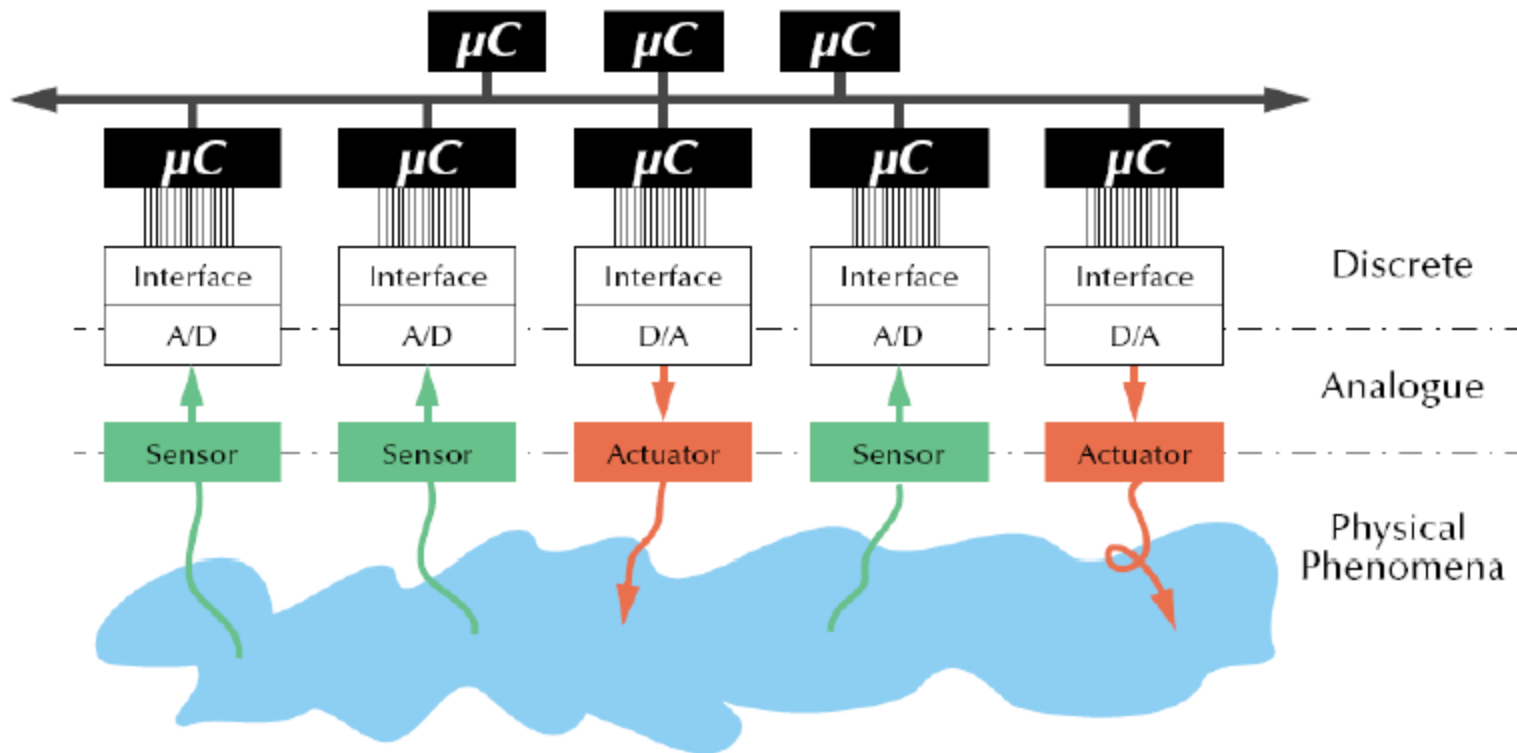
# DA pin signal



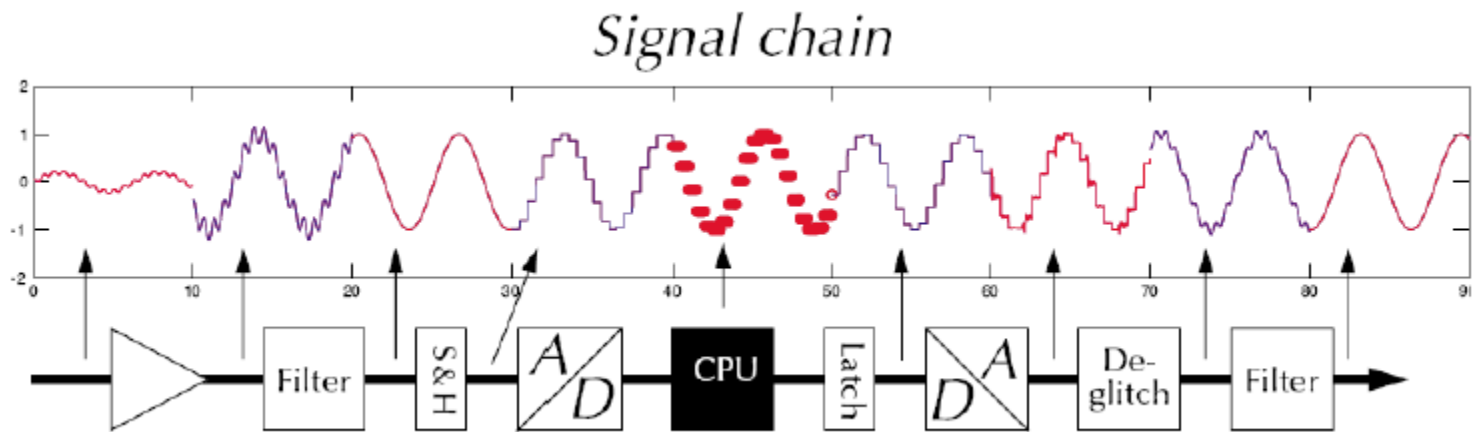
# Connection of DAC



# Analog interfacing network



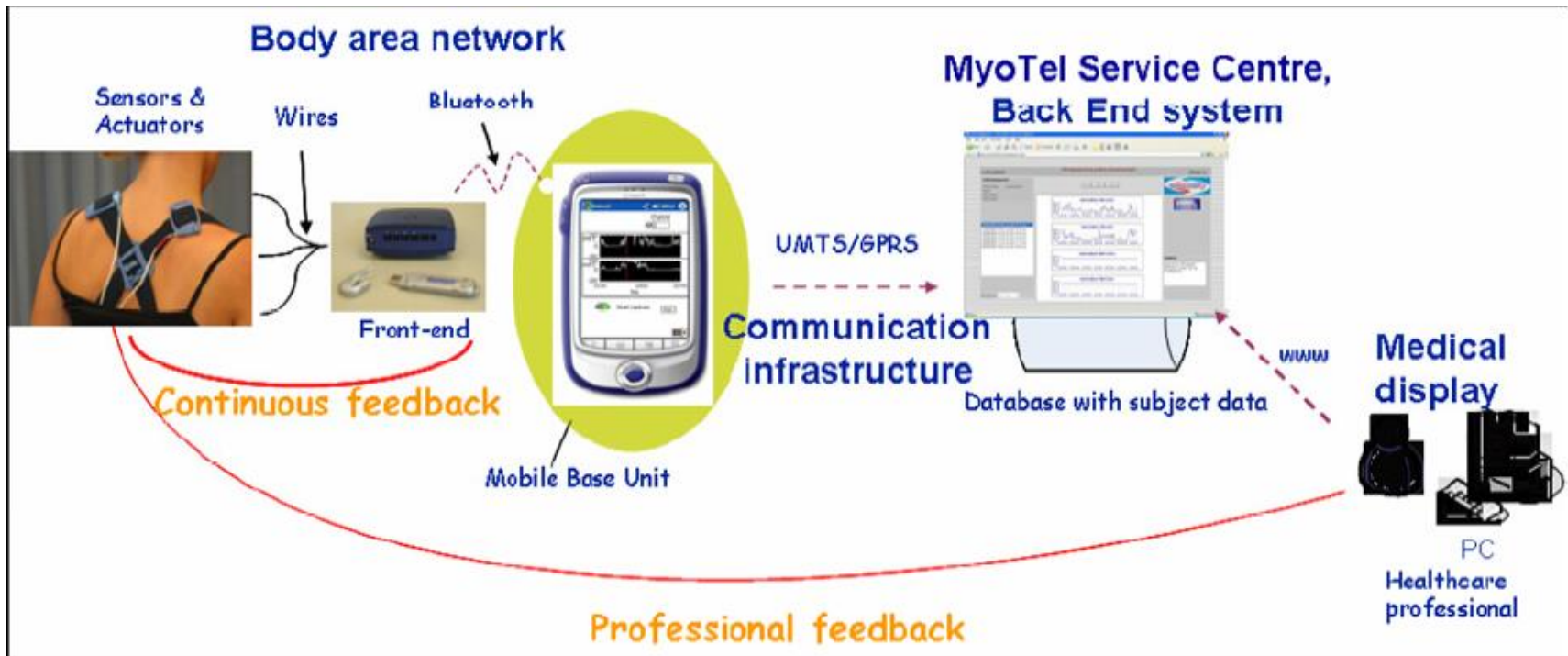
# Analog-digital-analog path



# Applications

- Body Sensor Network
- Personal Health Monitor

# Body Sensor Network



# Personal Health Monitor



# Questions?