Analog-to-digital conversion (ADC) MEC100x-Lectures 7_1

Energy, Power and Intelligent Control

School of Electronics, Electrical Engineering and Computer Science

Ashby Building

Queen's University Belfast

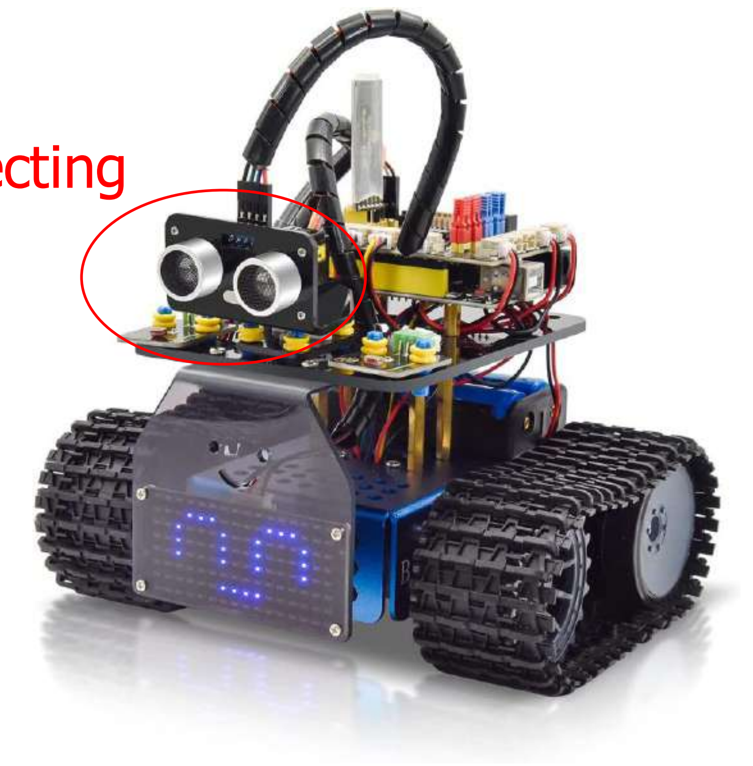
Aims of this lecture are:

1. Why ADC?
2. Sample/Hold
3. ADC Essentials
4. Converter errors, converter resolution, conversion time, Quantization Interval
5. Analog input signal ranges and resolution
6. Parallel or Flash ADC

Good understanding Analog Vs Digital

- Many of our electronic devices are digital circuits; robotic systems- industrial plants- Daily Life systems
- These kind of electronic devices use analog sensors **to interact with the real world/ industrial processes.**
- Analog signal provides a signal that can be between 0 volts and give a maximum voltage like 5 volts or 9 volts.

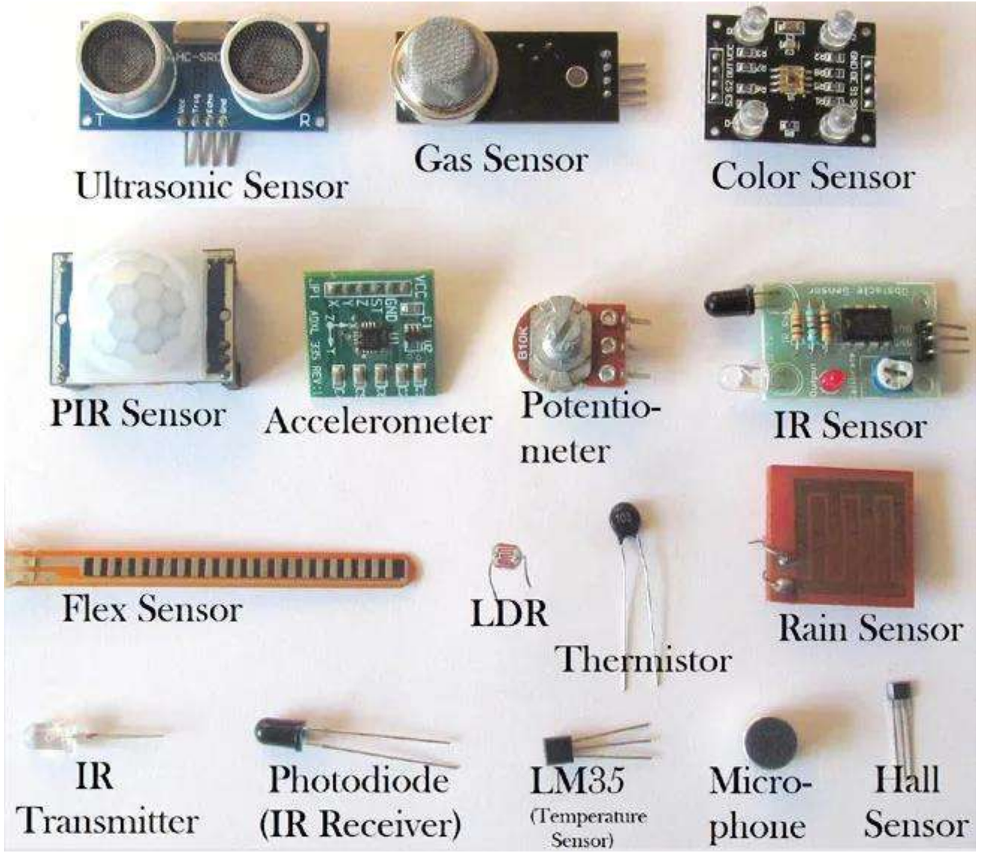
Detecting



LDR resistance- Light Sensor

Analog Sensors

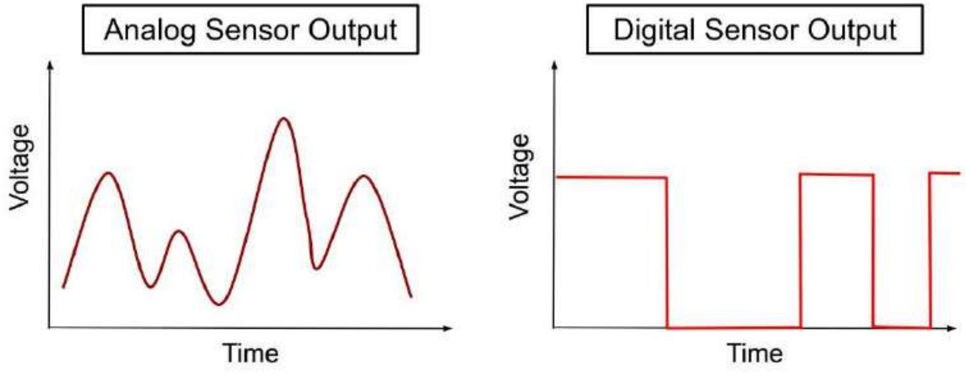
- Sensors produce continuous analog signal. Analog signals: There are continuity in the signal.
- Standard ranges of analog signal are: 5V DC, 10V DC, 0 to 20 mA, 4 to 20 mA,...
- There are various types of analog sensors such as **temperature, humidity, colour, pressure, light, sound sensor, ultrasonic sensor and gas sensor, etc.**



https://pijaeducation.com/arduino/sensor/

Zero is representing: 0V

1 is representing: 5/ 10 Volts



https://www.smlease.com/entries/automation/what-are-different-types-of-sensors-and-their-applications/

SMART EDU 4.0

QUEEN'S UNIVERSITY BELFAST

Binary

- Binary is a series of 1 and 0 **for example(4 bits: 1000, 0110, 0001, 1101,1111,…).**

We can compare:

- Digital **to a light switch turning the light either ON/OFF.**
- Analog would be like **a dimmer switch that is** able to set the light level to any brightness between **maximum and OFF.**

Watch this video clip:

video

https://www.youtube.com/watch?v=g4BvbAKNQ90

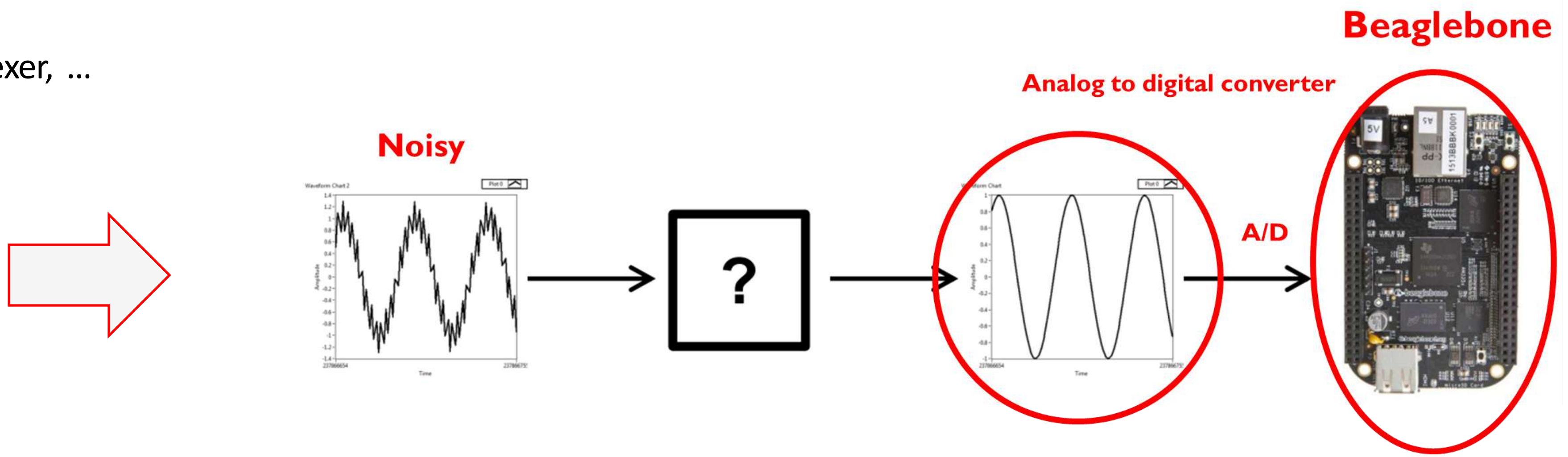
SMART EDU 4.0

QUEEN'S UNIVERSITY BELFAST

Why ADC?

- Digital Signal Processing is more popular
  - Low impact of noise on these signals
  - Computer and Microcontroller processing are binary and digital

- Data from real world are typically analog signal
  - Needs conversion system from raw measurements to digital data
- Digital Signal Processing Consists of
  - Amplifier, Filters
  - Sample and Hold Circuit, Multiplexer, …
  - ADC, DAC



ADC and DAC

Digital-to-Analog Conversion (DAC)

- D/A; Converts a binary value to a scaled ‘analog’ voltage
- D/A is used for controlling systems that require an analog actuators input such as :
  - DC servo motor
  - Resistive heater, etc.

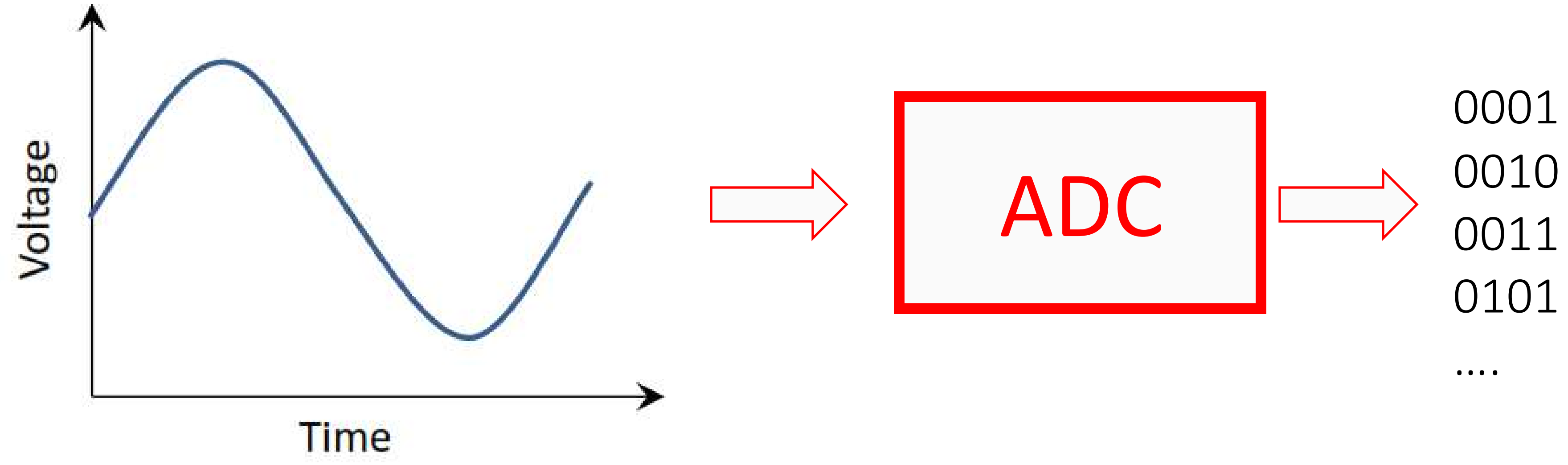
Analog-to-Digital Conversion (ADC)

- A/D; Converts a continuous analog voltage into discrete binary values
  - A/D is used to translate continuous physical phenomena into a language the computer understands **(Binary Code).**

ADC

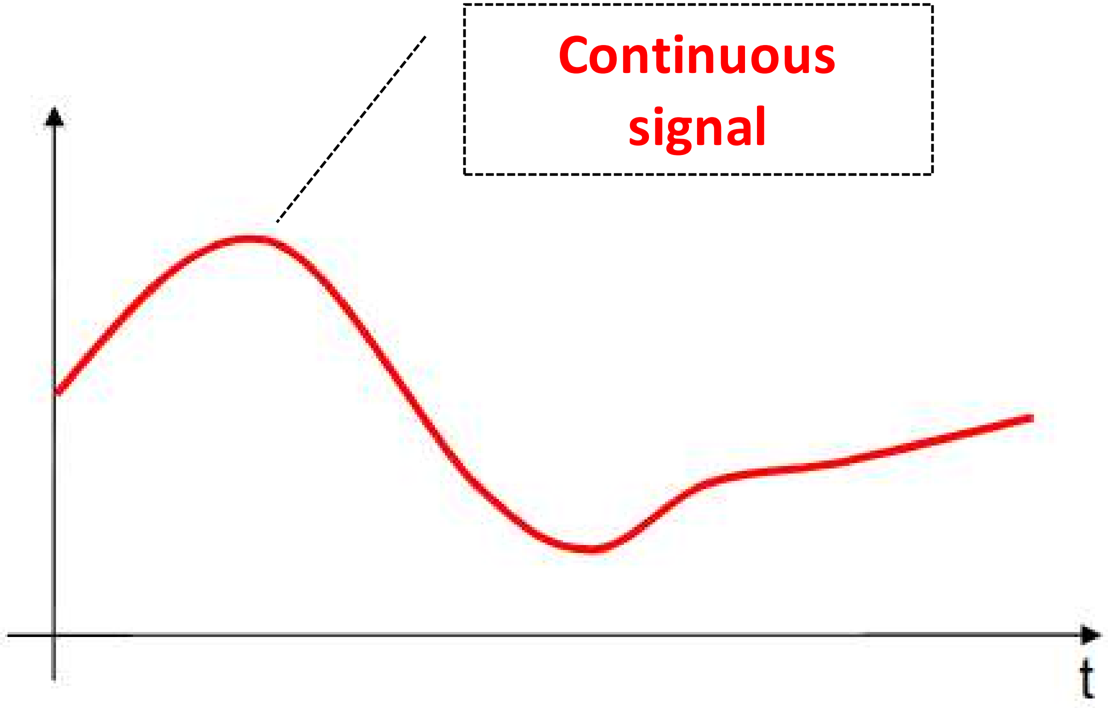
Analog signals

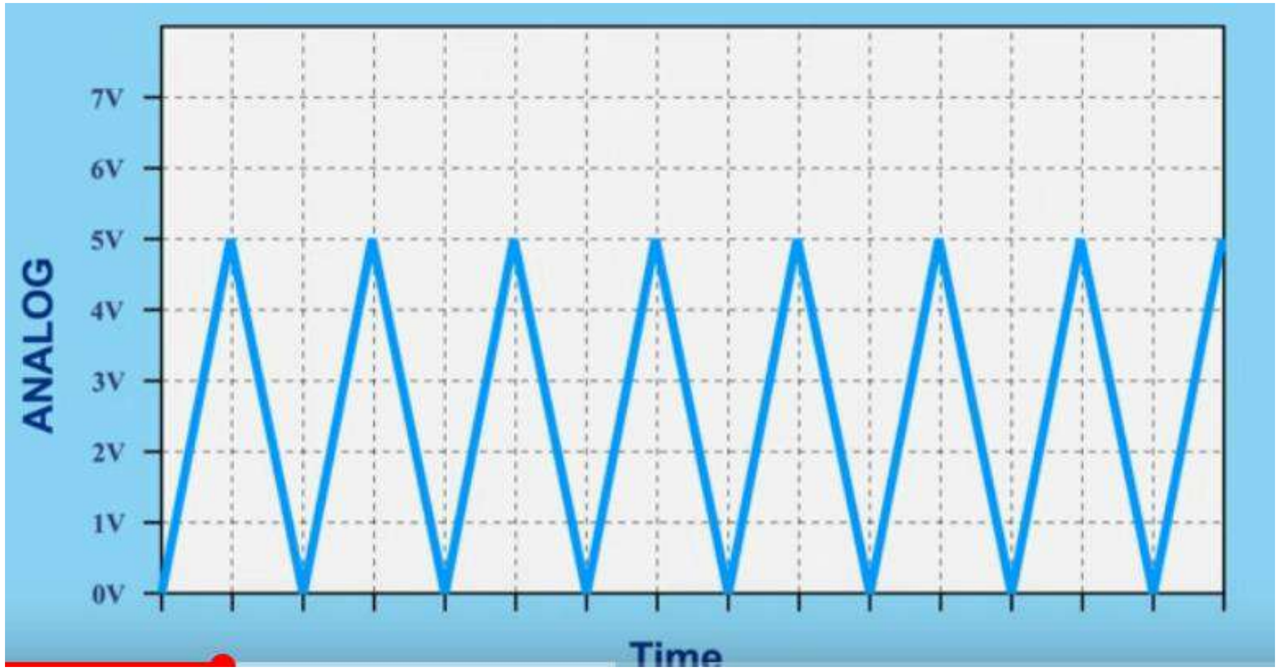
- Any **continuous signal- smooth continuous slope** that a time varying variable of the signal is a representation of some other **time varying quantity.**
- **Analog signal** is a form of electrical energy (voltage, current or electromagnetic power) that there is a linear relationship between electrical quantity and the value on each time.



Signals:

continuous signal- smooth continuous slope





https://www.youtube.com/watch?v=g4BvbAKNQ90

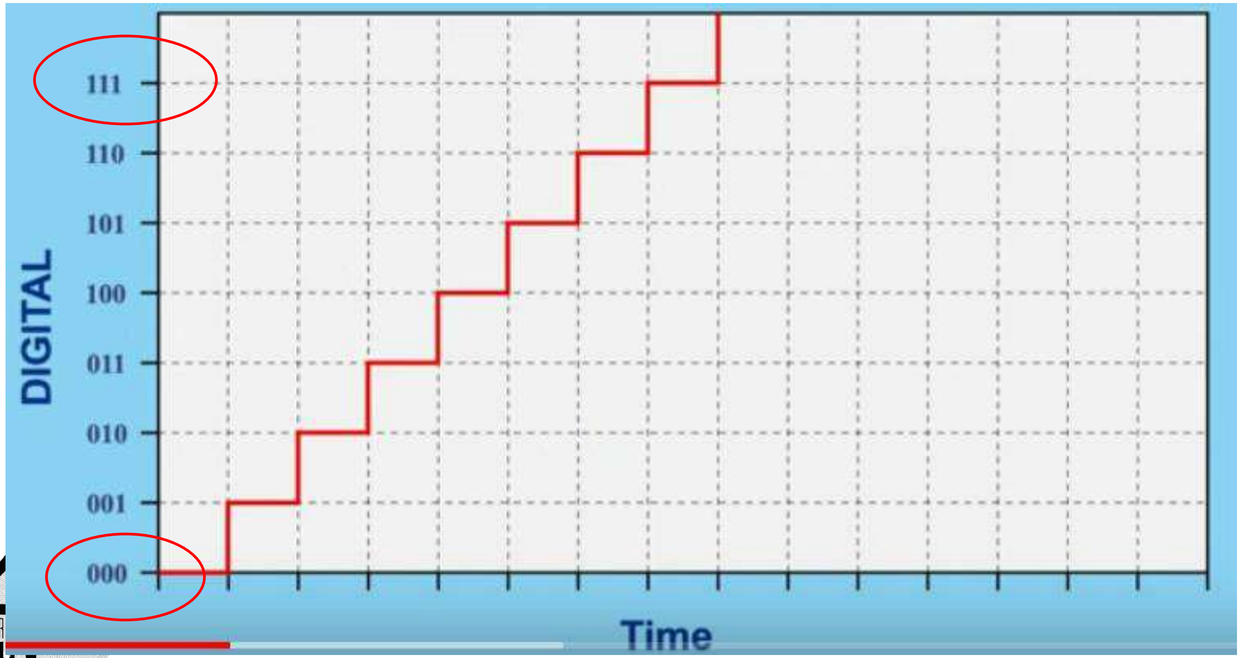
https://slideplayer.com/slide/4584344/

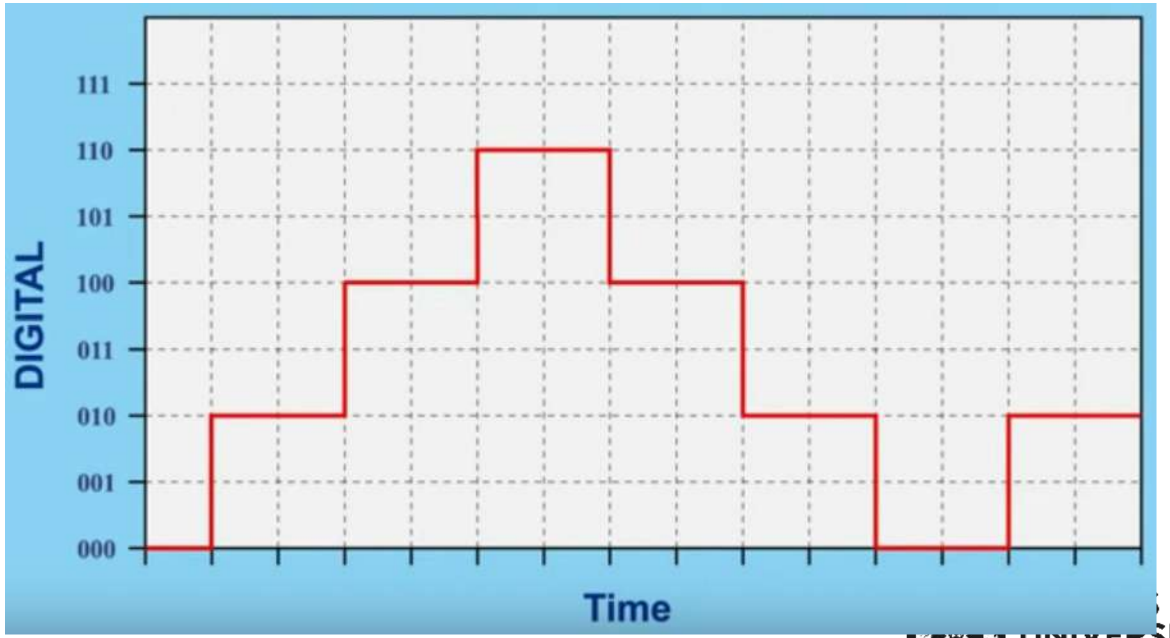
The Waveform of a digital signal changes in steps with **a finite number of steps** equal to the ADCs resolution divided between 0 Volts and the maximum voltage.

Signal change at each step goes **low to high and high to low**

3-bit ADC

2^n step





ADC

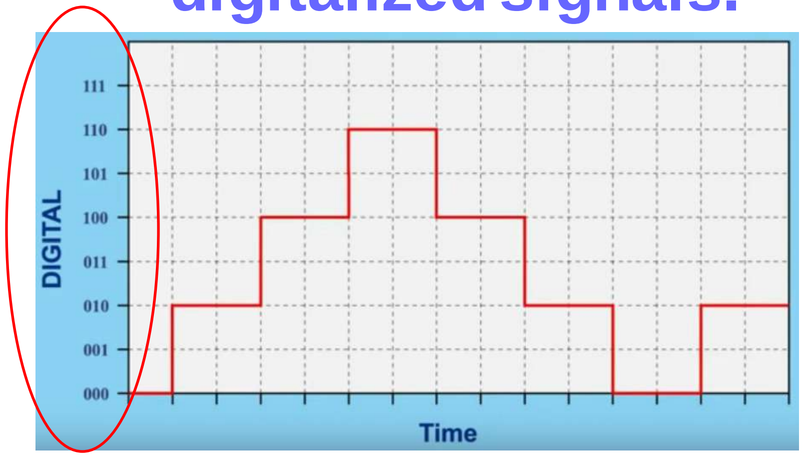
Digital signals

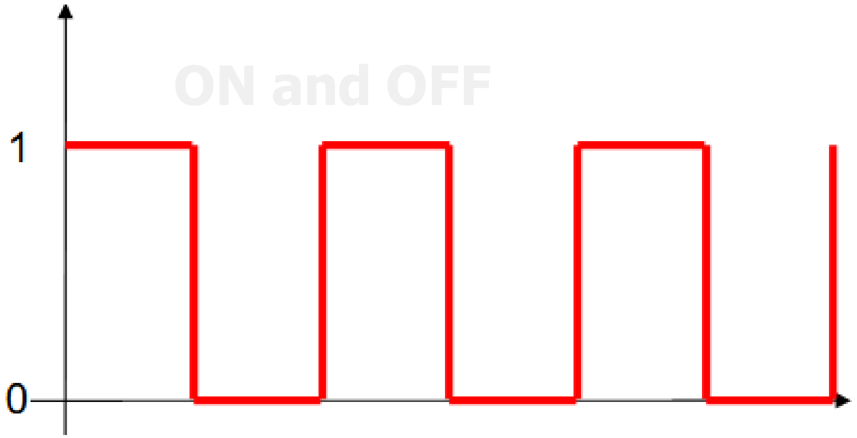
- Consist of only two states

- Binary states
- ON and OFF

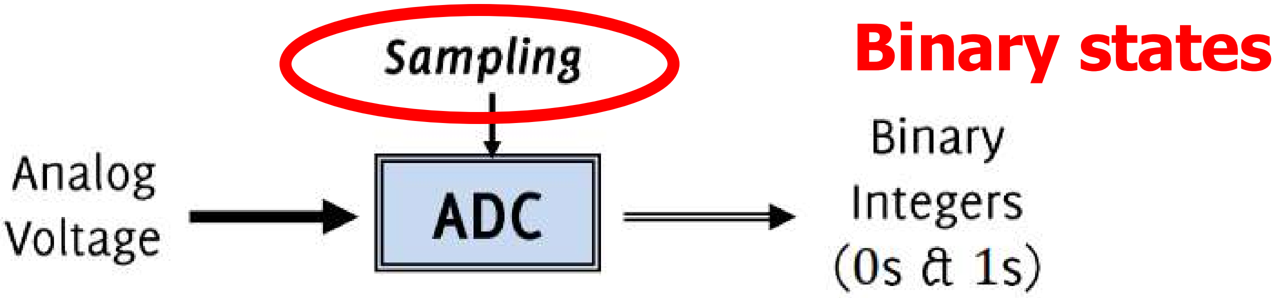
- Computers can only perform processing on digitalized signals.

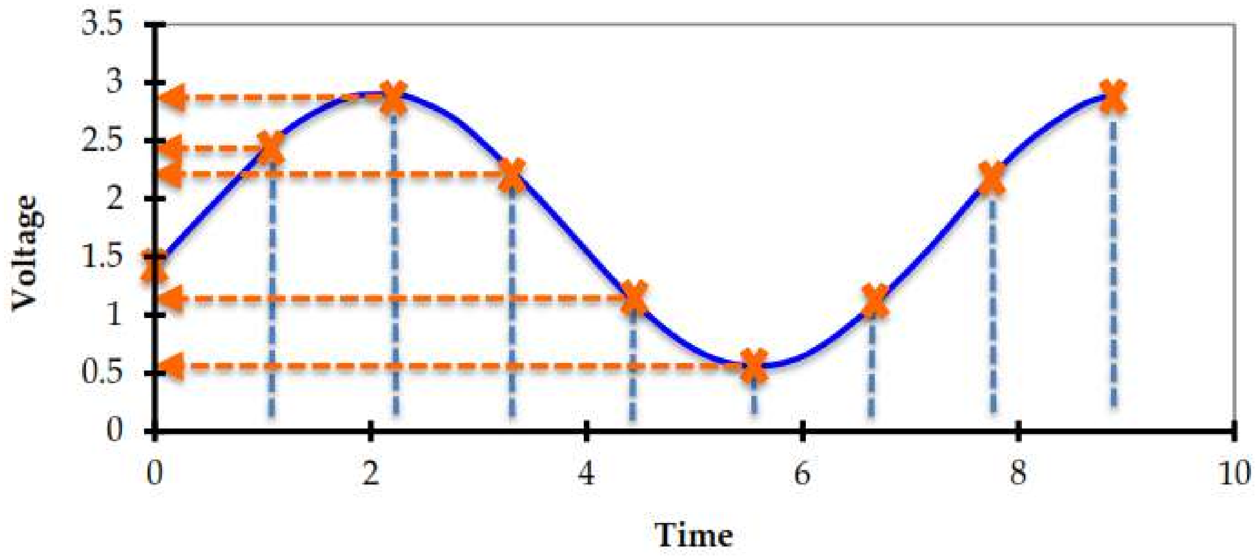
Binary states





A/D Conversion Converts analog input into digital values





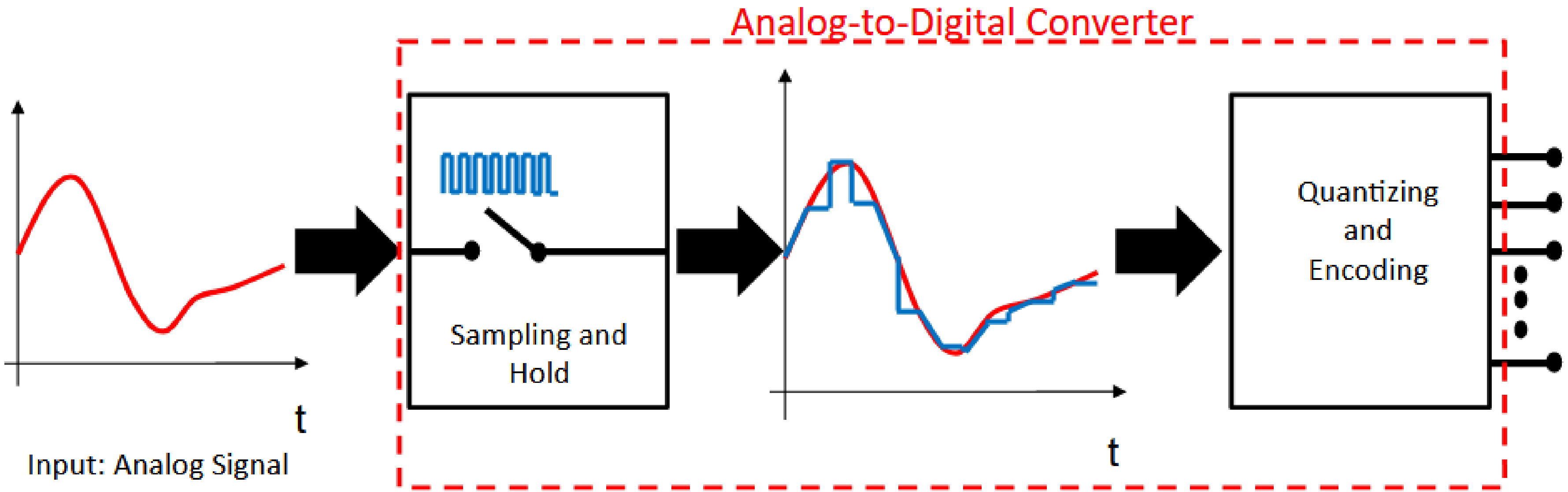
https://engineering.purdue.edu/ME588/LectureNotes/Unit5a--ADConversion.pdf

Two main steps of process

1- sampling and holding

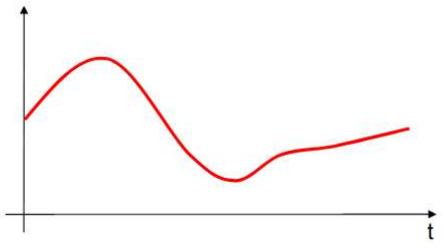
- **2- quantization and coding**

High frequency switch



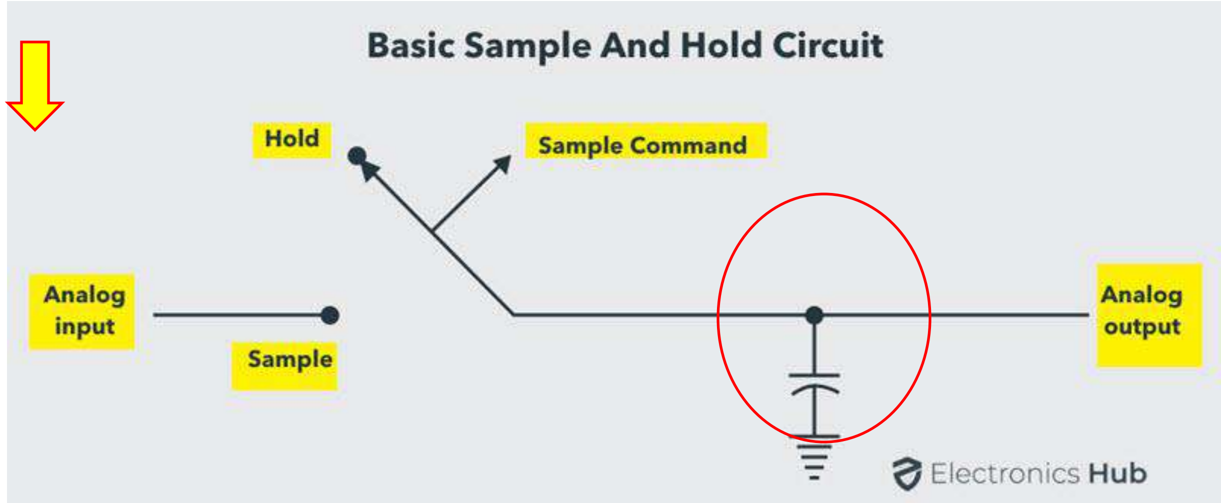
ADC Process

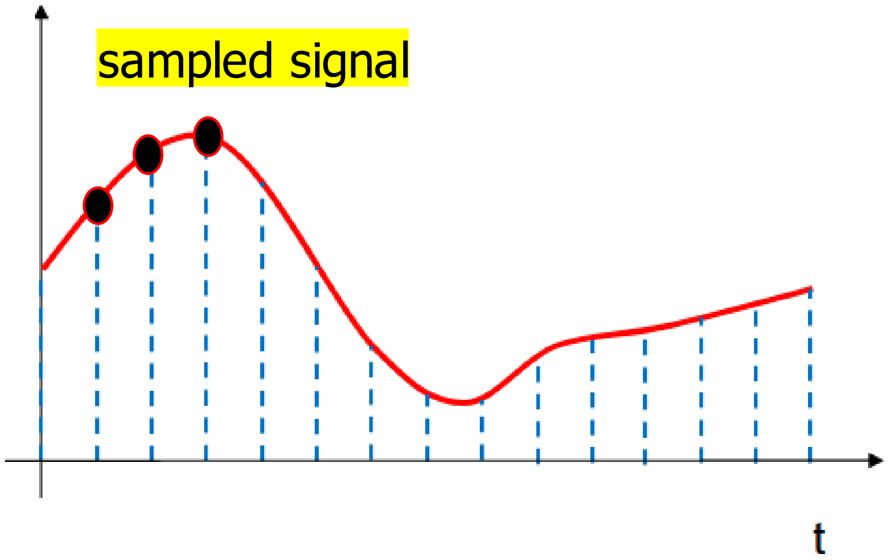
1- sampling



- ❑ Measuring analog signals at **uniform time intervals (Ts)**

(Ideally twice as fast as what we are sampling)





https://www.electronicshub.org/sample-and-hold-circuit/

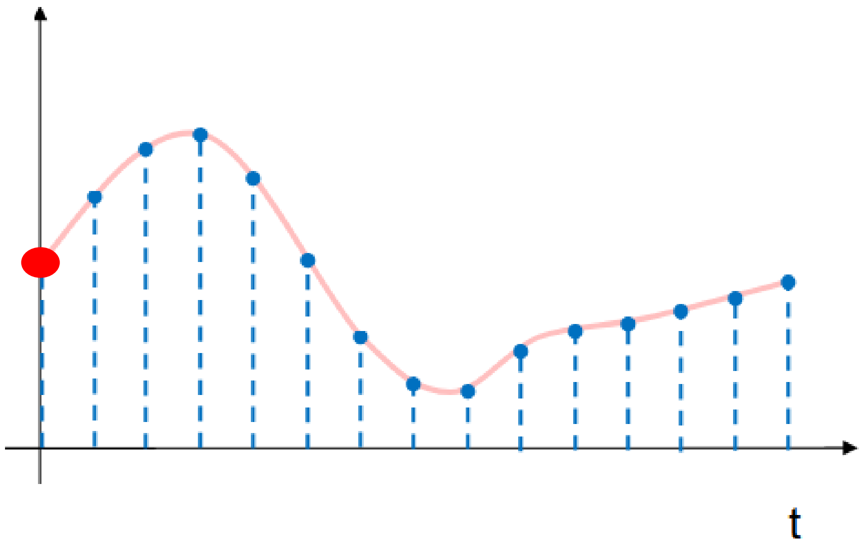
https://slideplayer.com/slide/4584344/

ADC Process

1- sampling

- ❑ Digital system works with discrete states
- ❑ Taking a sample from each location.

Ts=Uniform time step
Ts= Sampling time period

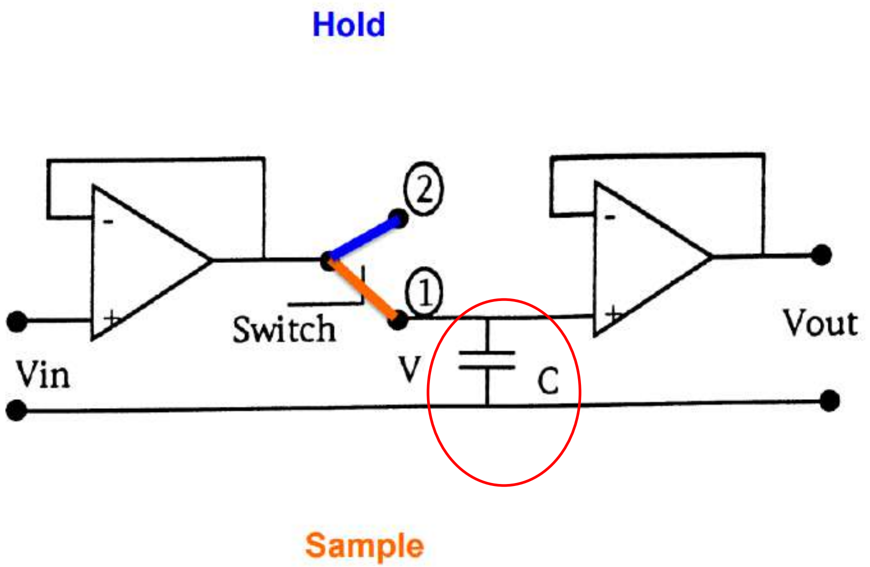


https://slideplayer.com/slide/4584344/

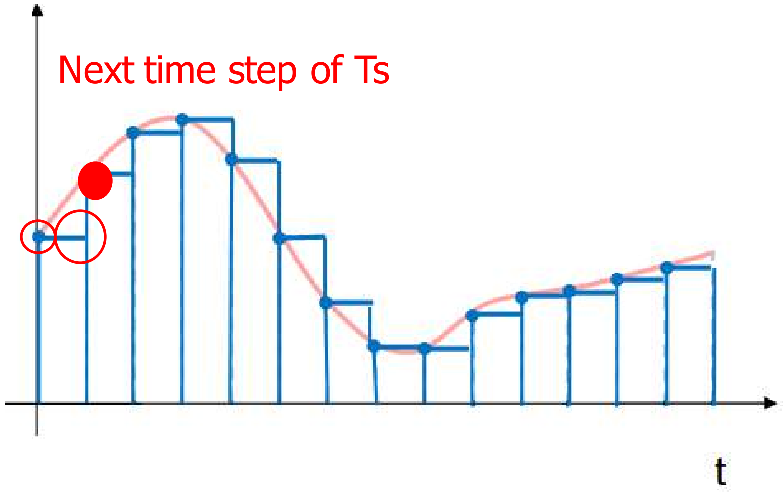
ADC Process

1- Holding

- Reflects sampled and hold signal
- Digital approximation



https://engineering.purdue.edu/ME588/LectureNotes/Unit5a--ADConversion.pdf



https://slideplayer.com/slide/4584344/

Analog to Digital Conversion

- Process of converting an analog signal to a digital number
- Three step procedure
- Sampling (sample and hold)
- Quantization
- Coding

ADC Essentials

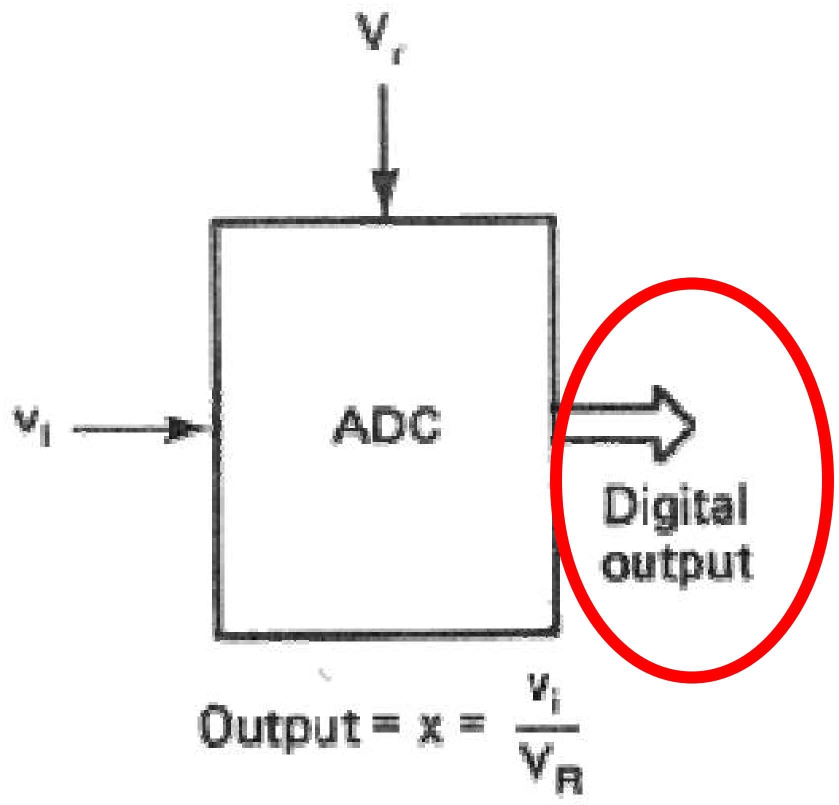
Basic I/O Relationship

ADC is a Rationing System

x =Fraction: 0 ~ 1
Analog input / Reference

n bits ADC

Number of discrete output level : 2^n



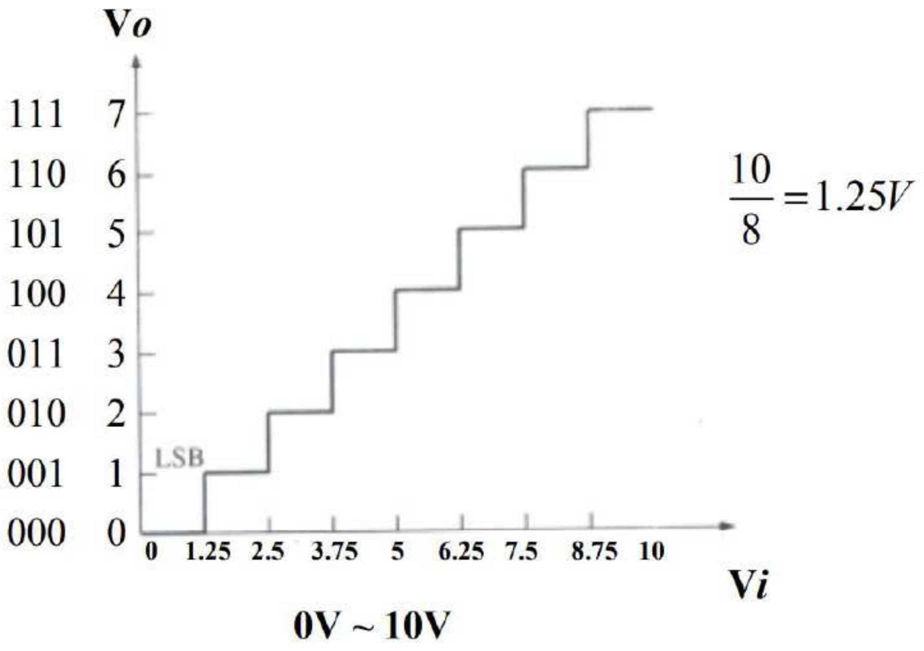
Reference Voltage

Quantization

- Separate the input signal into a discrete states with K increments
-
- $\mathbf{K} = 2^n$ n is the number of bits

- Analog size Quantization

- Q = LSB = ((Vmax-Vmin) =FS) / 2^n
- Q is Resolution

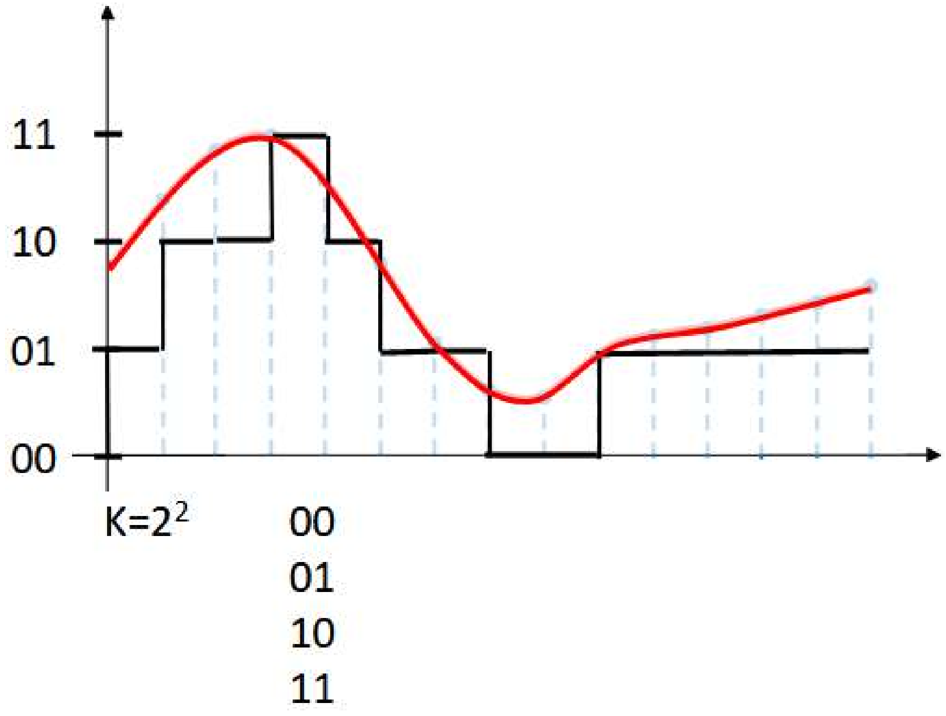


Quantization Error

- + - 1/2 LSB
- Reduced by increasing n

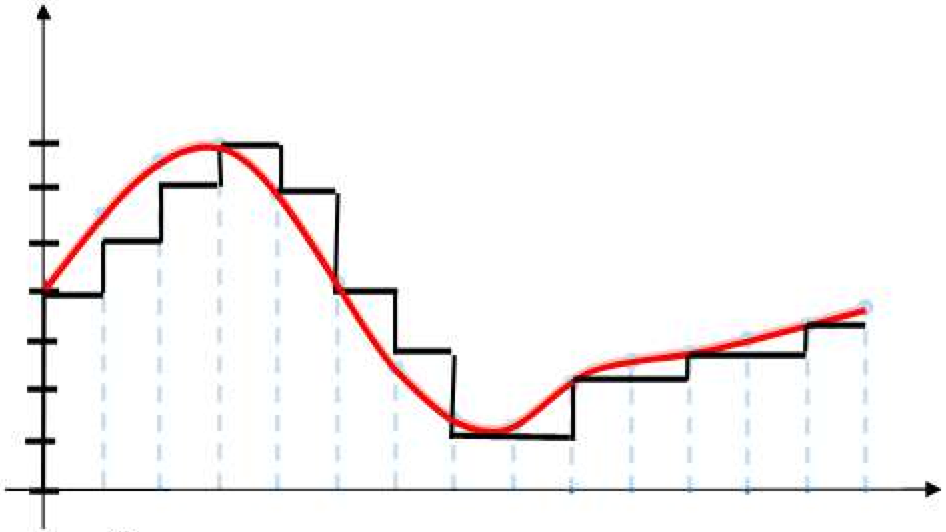
Quantization & Coding

Apply 2 bit coding



Quantization & Coding

Apply 3 bit coding

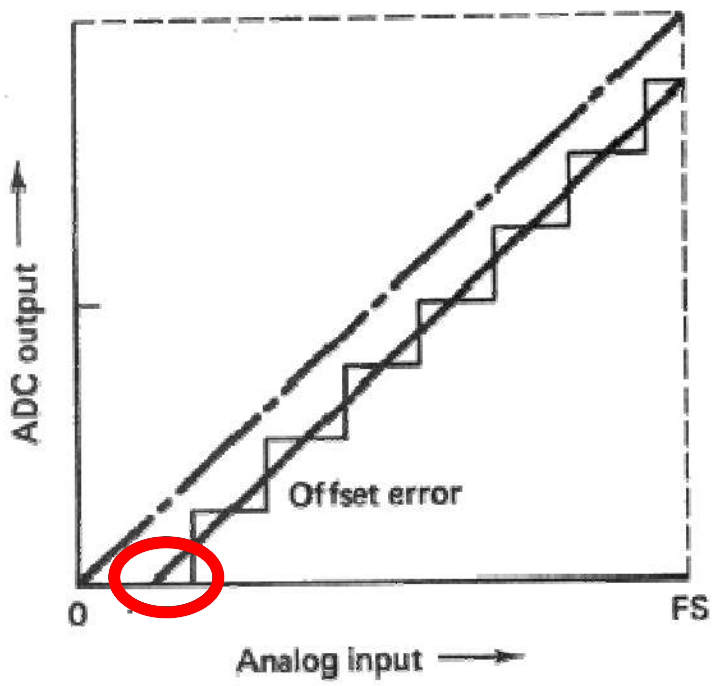


$K=2^3$

000
001
010
011
100
101
110
111

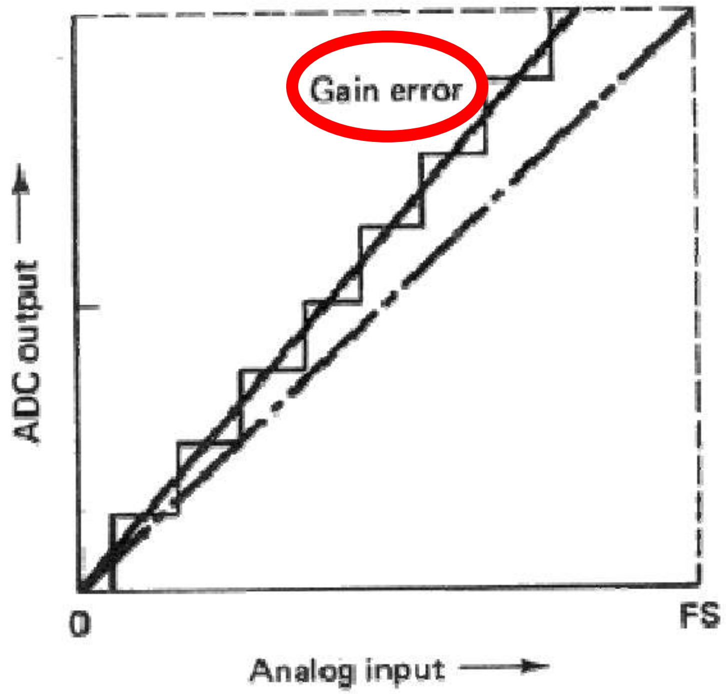
Converter Errors

Offset Error



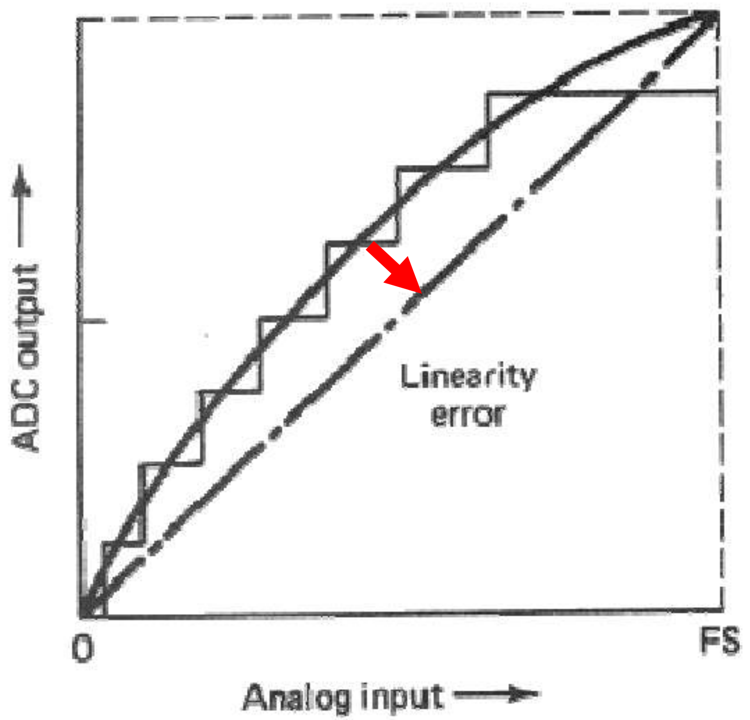
Can be eliminated by initial adjustments

Gain Error

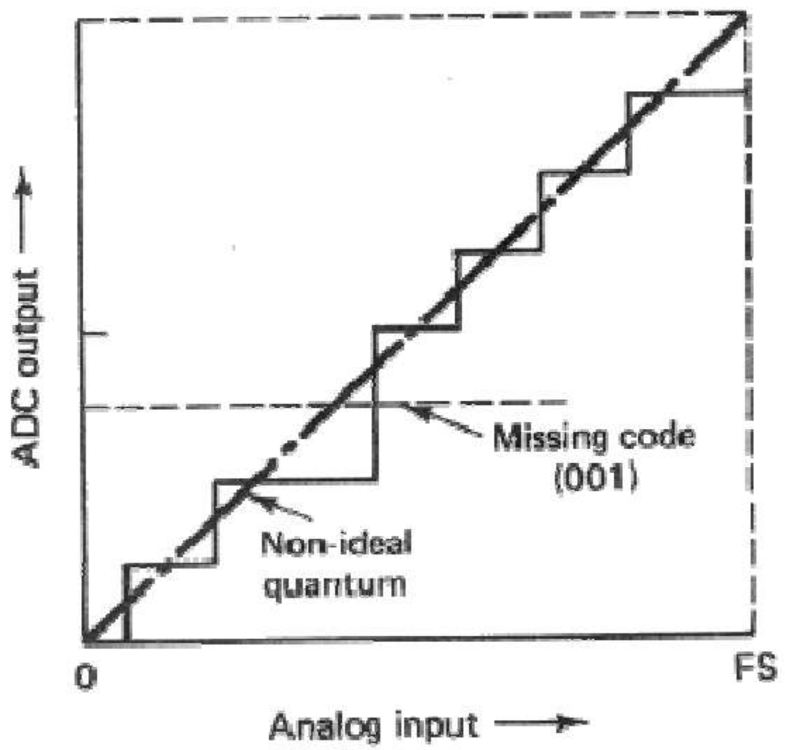


Converter Errors

Integral Linearity Error



Differential Linearity Error



- ❑ Nonlinear Error: Hard to remove

ADC Essentials

Converter Resolution

- The **smallest change required in the analog input** of an ADC **to change its output code** by one level

Converter Accuracy

- The difference between **the actual input voltage** and the full-scale weighted equivalent of the binary output code.
- Maximum sum of all converter errors including quantization error.

Conversion Time

- **Required time (tc) before** the converter can provide valid output data

Converter Throughput Rate

- The number of times the input signal can be sampled maintaining full accuracy
- Inverse of the total time required for one successful conversion
- Inverse of Conversion time if No S/H(Sample and Hold) circuit is used

Analog Input Signal

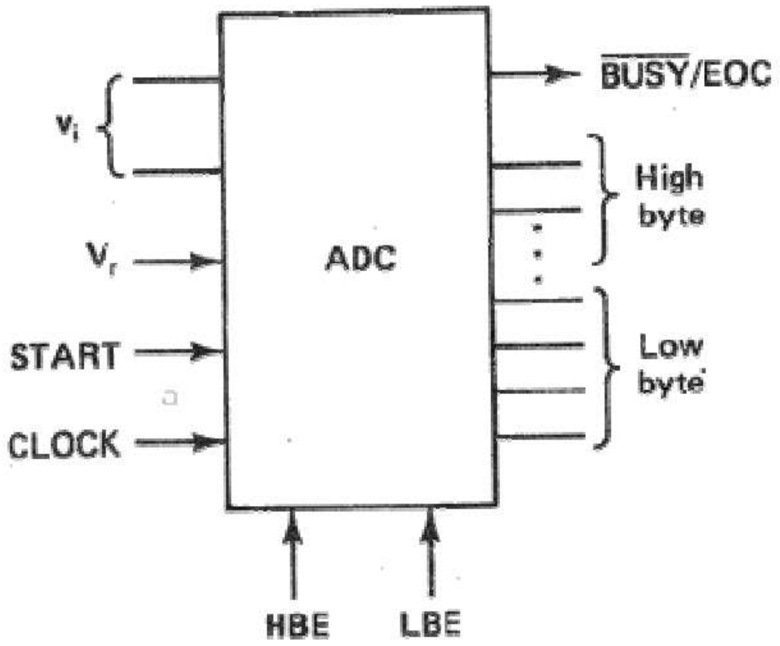
- Typically, Differential or Single-ended input signal of a single polarity
  - Typical Input Range 0 ~ 10V and 0 ~ 5V

- Matching input signal and input range
  - Pre-scaling input signal using OP Amp
  - In a final stage of preconditioning circuit

- By proportionally scaling down the reference signal
  - If reference signal is adjustable

Inputs/Outputs and Analog Reference Signal

I/O of typical ADC



ADC output

- ❑ 8 and 12 bits are typical
- ❑ 10, 14, 16 bits also available

Errors in reference signal

- **From**
  - Initial Adjustment
  - Drift with time and temperature
- **Cause**
  - Gain error in transfer characteristics

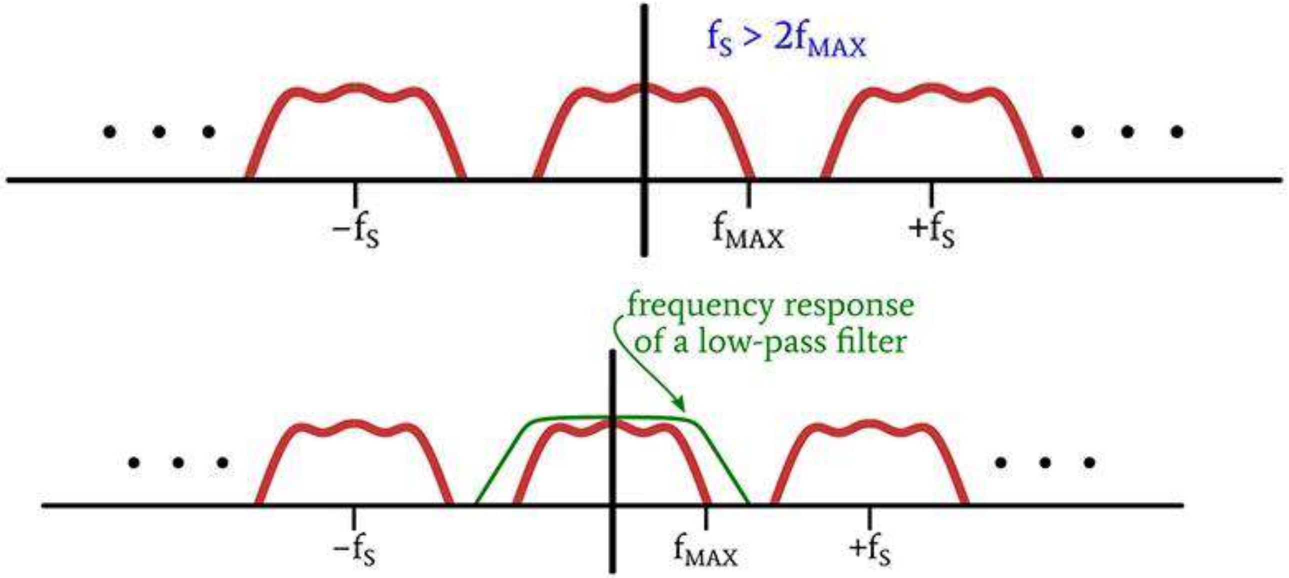
Sampling rate:

- Sampling occurs when the input signal is changing much faster than the sample rate

Nyquist rule:

- Use a sampling frequency at least twice as high as the maximum frequency in the signal to avoid aliasing

$$Fsample > (2 * Fsignal)$$



https://www.allaboutcircuits.com/technical-articles/the-nyquistshannon-sampling-theorem-exceeding-the-nyquist-rate/

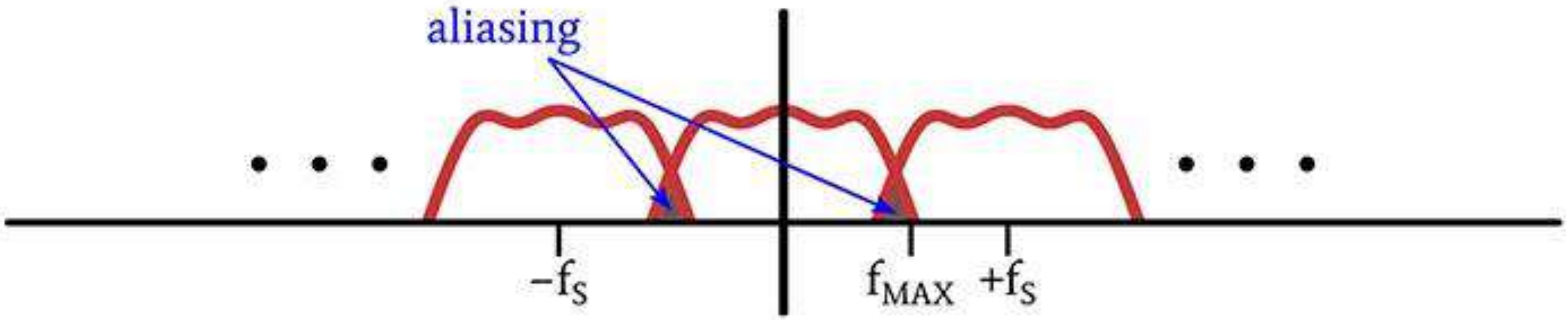
QUEEN'S UNIVERSITY BELFAST

Nyquist rule:

- Aliasing $Fsample < (2 * Fsignal)$

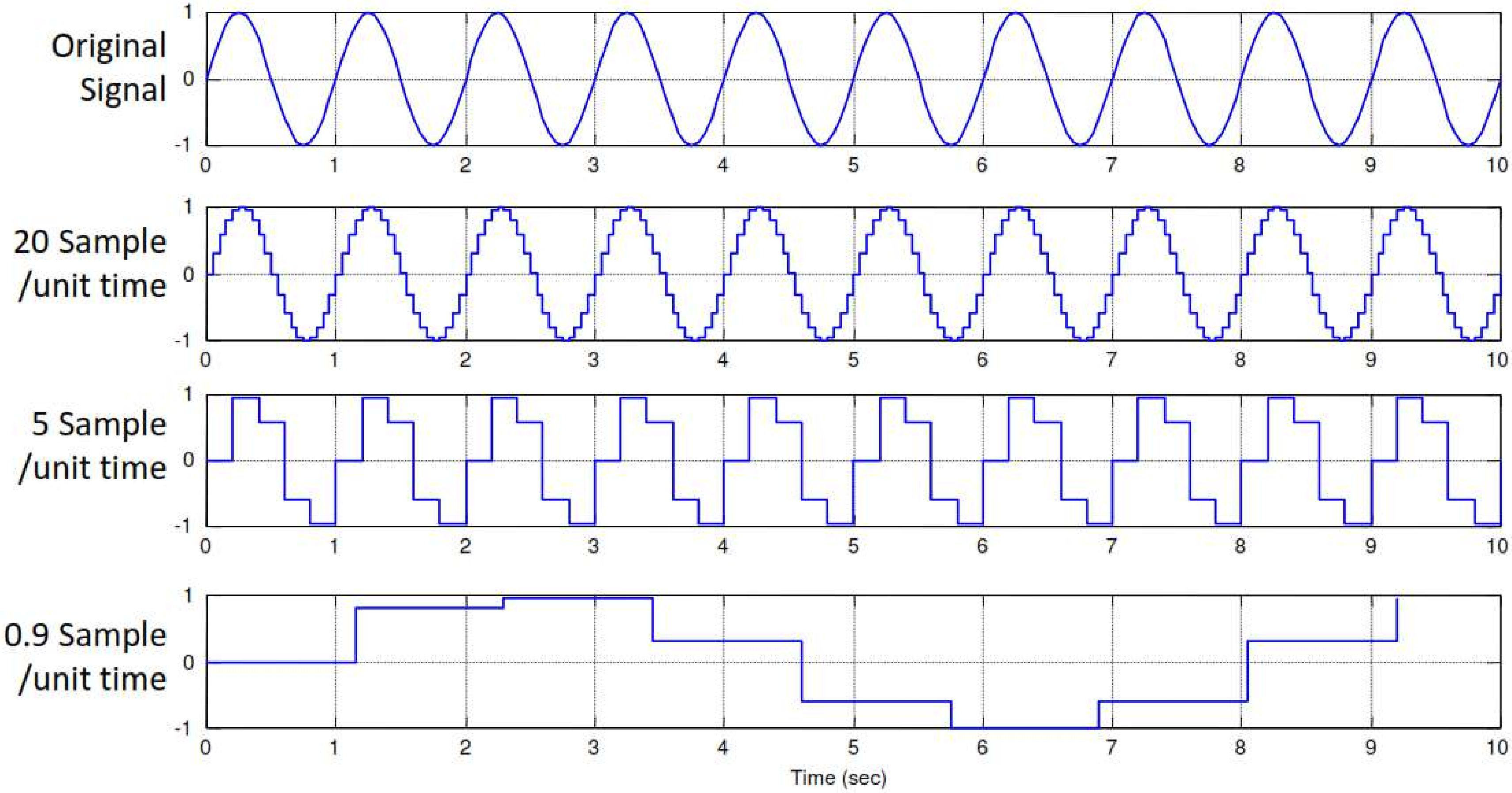
Sampling and Aliasing

- we see that aliasing happens when the sampling frequency (fs) is less than twice the maximum signal frequency (fmax), we will have overlap in signal.



https://www.allaboutcircuits.com/technical-articles/the-nyquistshannon-sampling-theorem-exceeding-the-nyquist-rate/

Example



https://engineering.purdue.edu/ME588/LectureNotes/Unit5b--DAConversion.pdf

❑ Rule of Thumb

- ❑ For control, sample (20 x) faster than signal.
- ❑ For data analysis, sample at least (2 x) faster than signal.

Successive Approximation ADC

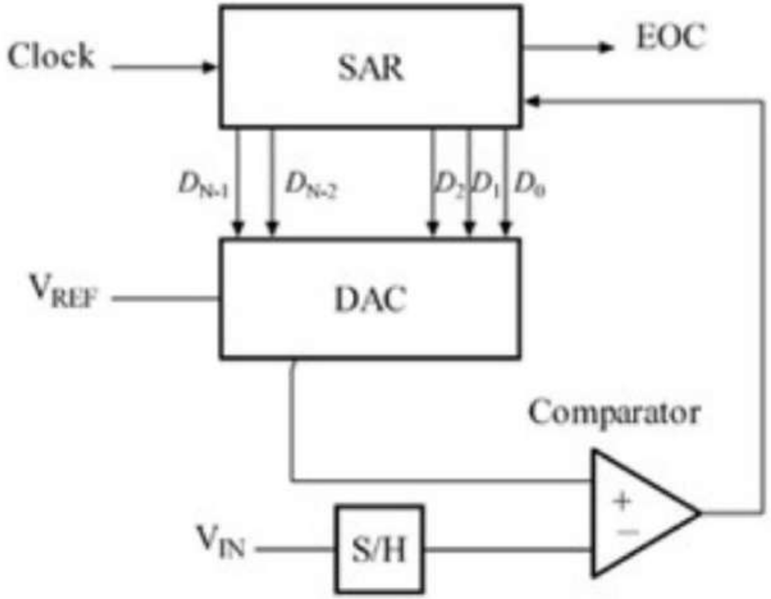
Conversion Time

- ❑ Maximum n+1 clock for an n-bit ADC
- ❑ Fixed conversion time

Serial Output is easily generated

- ❑ Bit decision are made in serial order

- ❑ EOC: End of conversion
- ❑ SAR: Successive Approximation Register
- ❑ Vref: Reference voltage
- ❑ V_{IN}= Input voltage
- ❑ S/H: Sample and hold circuit



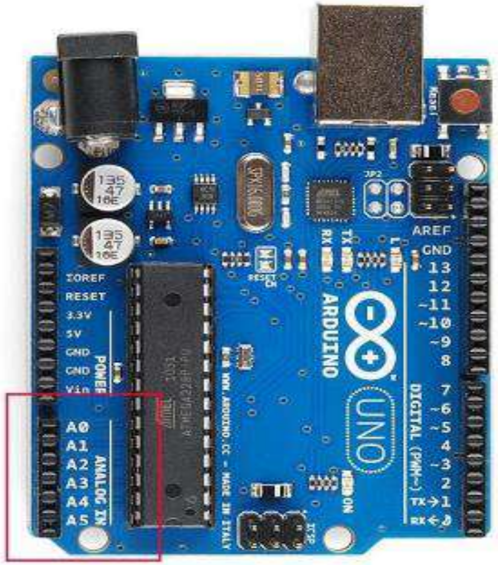
https://slideplayer.com/slide/4584344/

Successive Approximation ADC

- Usually used with a Multiplexer– many channel feed to a single converter
- Effective conversion speed for multiplexed ADC depends on number of channels used.

Arduino ADC

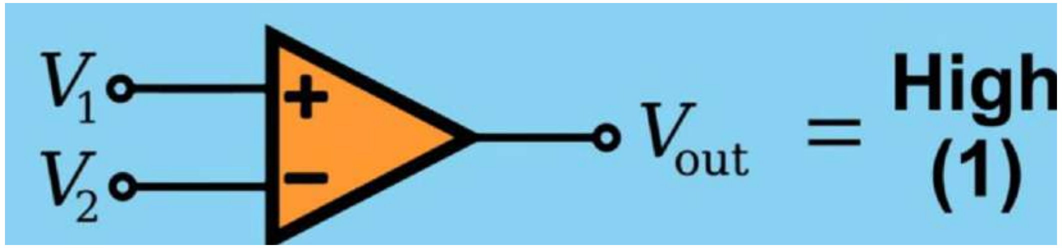
6-channel 10-bit ADC



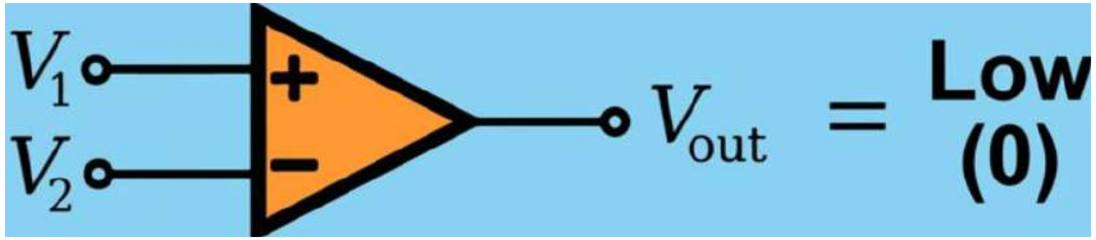
Analog to Digital Converter Flash

1. Uses comparators to determine input voltage range.
2. First type of ADC we can see how a comparator is responsible for each step change.
3. A comparator has two inputs if the positive input is greater the output is a high (1).
4. if the negative input is greater the output is a low (0).

V1 > V2

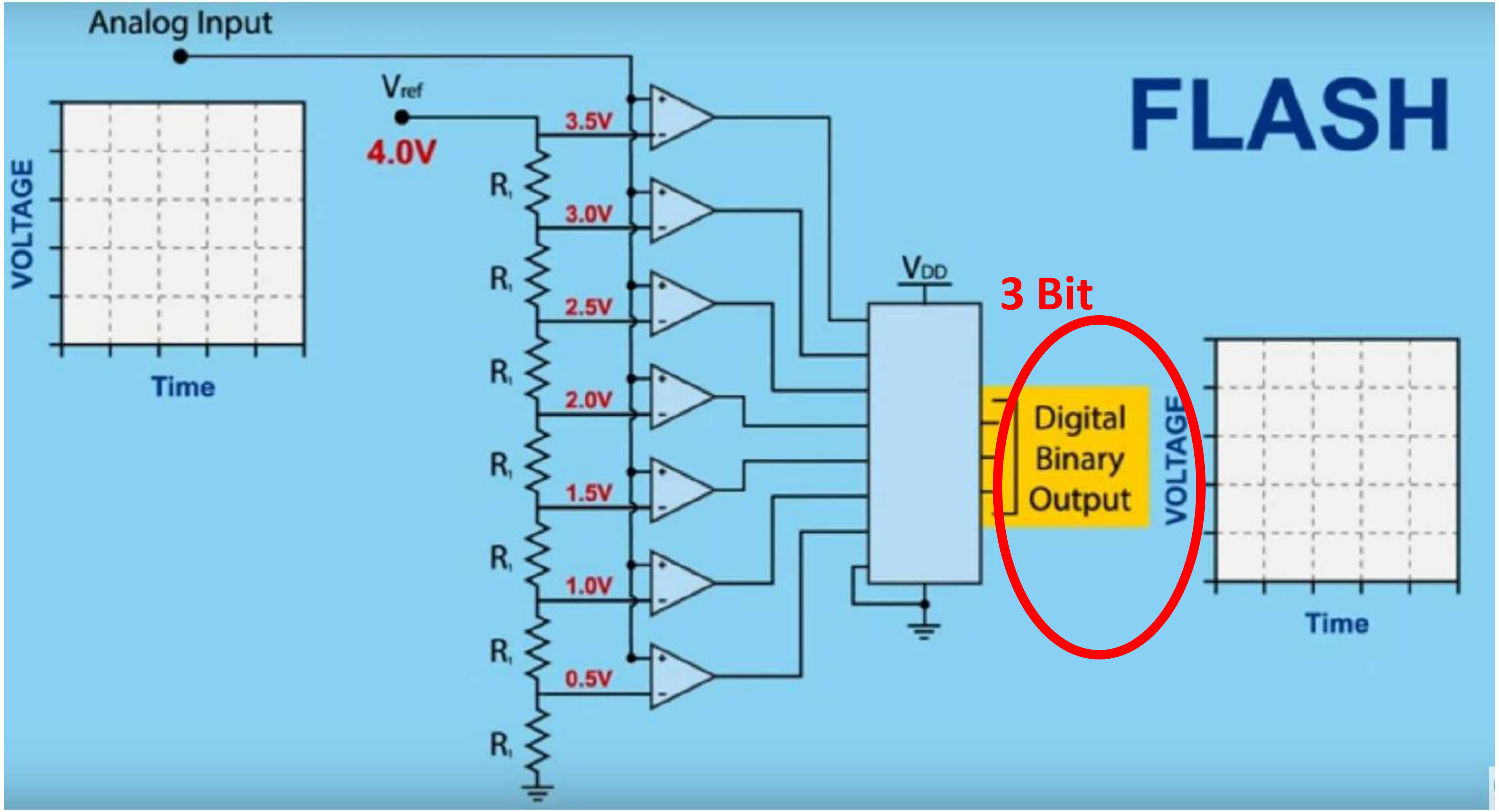


V1 < V2



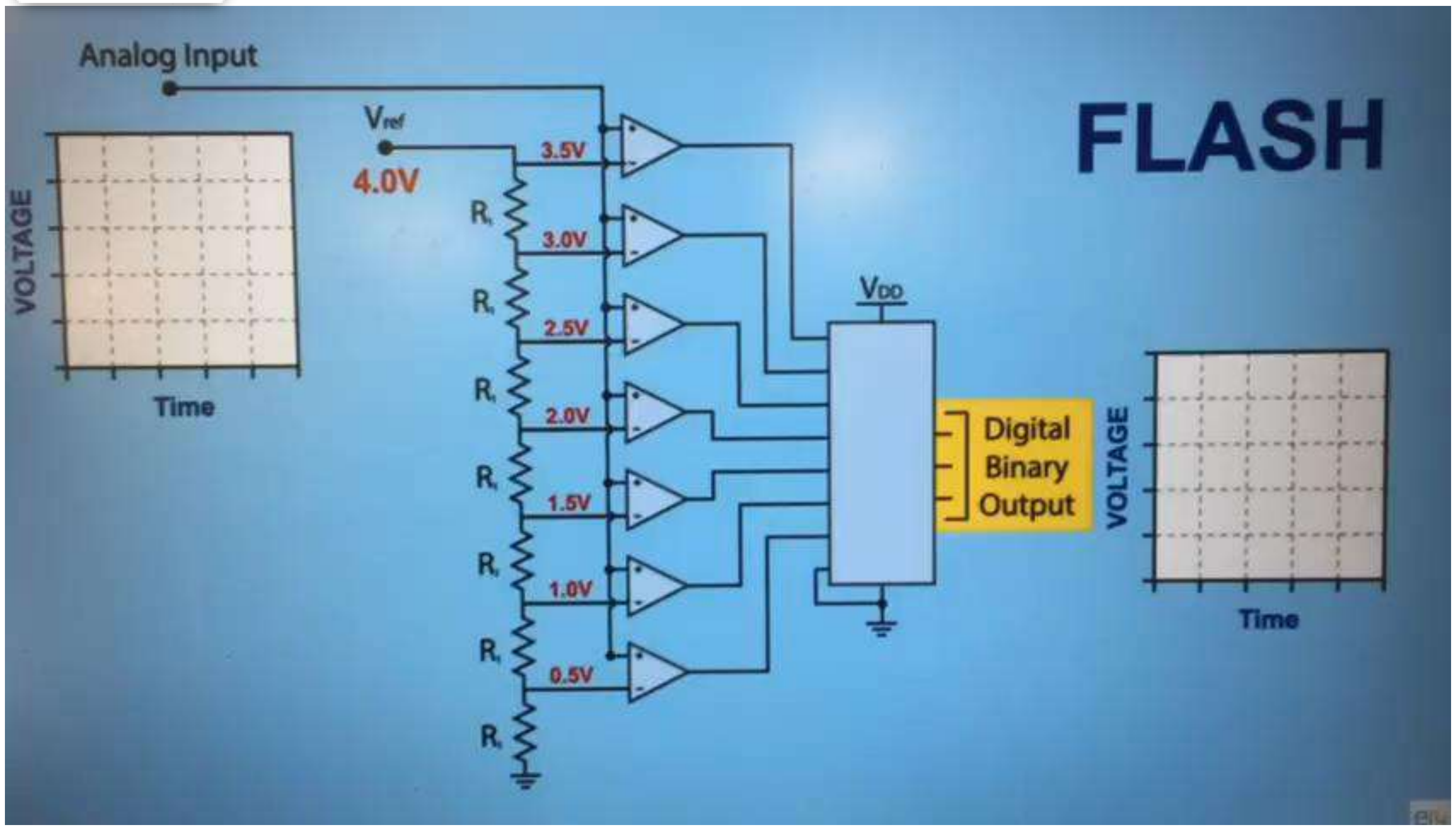
https://www.youtube.com/watch?v=g4BvbAKNQ90

3 Bit Flash ADC



3 Bit Flash ADC

video

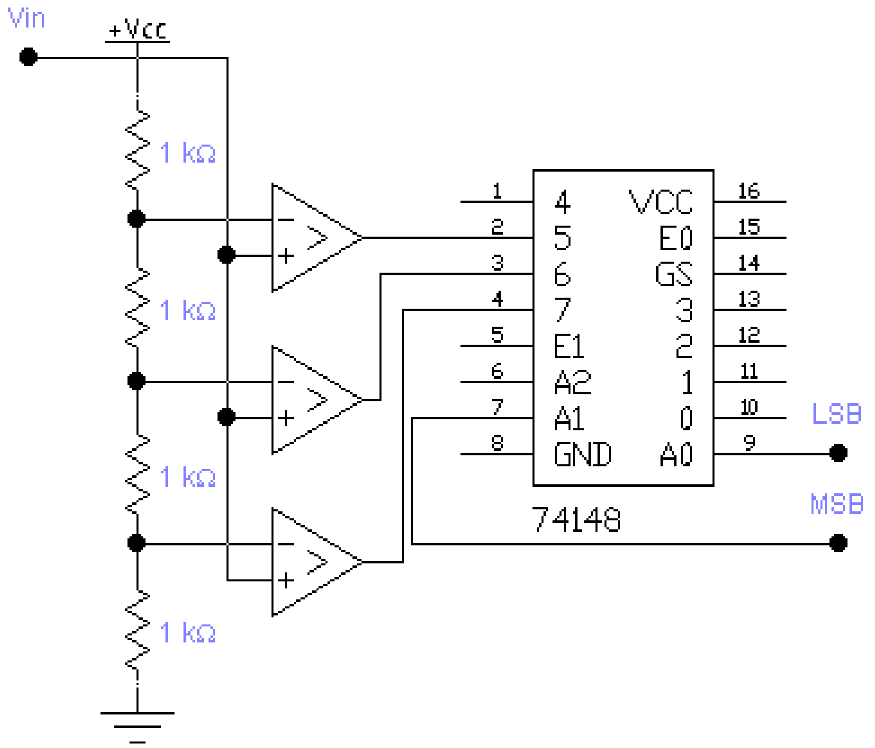


https://www.youtube.com/watch?v=g4BvbAKNQ90

Analog to Digital Converter Flash (Direct converter ADC)

- Also Known as a Parallell ADC

1. Uses comparators to determine input voltage range.
2. Gate logic converters comparator output to digital value.
3. Fast; Typical conversion time: 10- 500 nSec

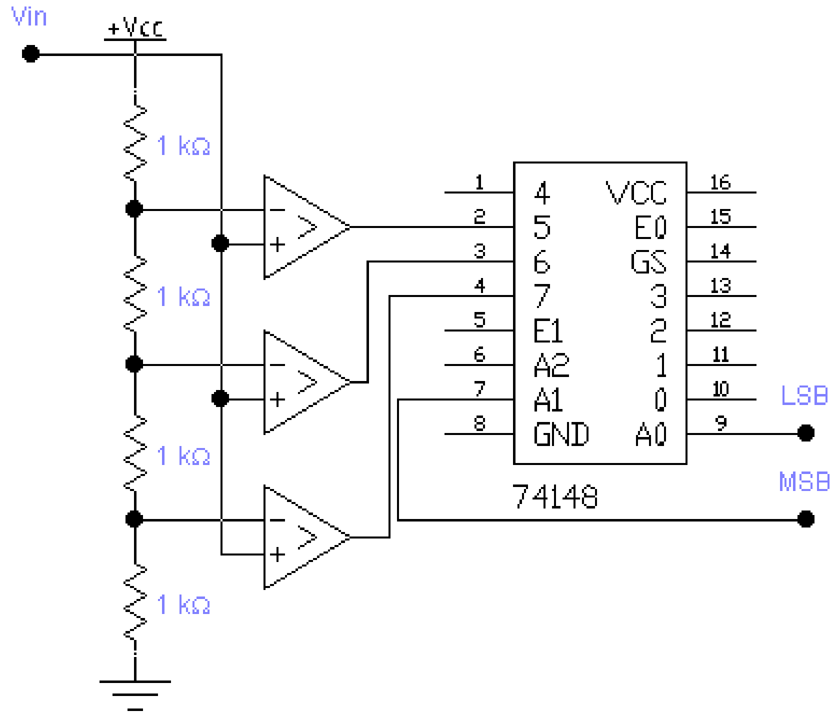


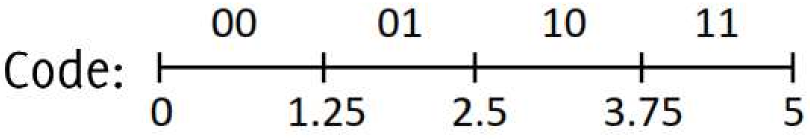
https://engineering.purdue.edu/ME588/LectureNotes/Unit5b--DAConversion.pdf

Analog to Digital Converter Flash (Direct converter ADC)

- Example: 2 bit Flash ADC

C3	C2	C1	MSB	LSB
0	0	0	0	0
0	0	1	0	1
0	1	0	X	X
0	1	1	1	0
1	0	0	X	X
1	0	1	X	X
1	1	0	X	X
1	1	1	1	1





- **Needs a 3 comparators**

C1: V > 1.25

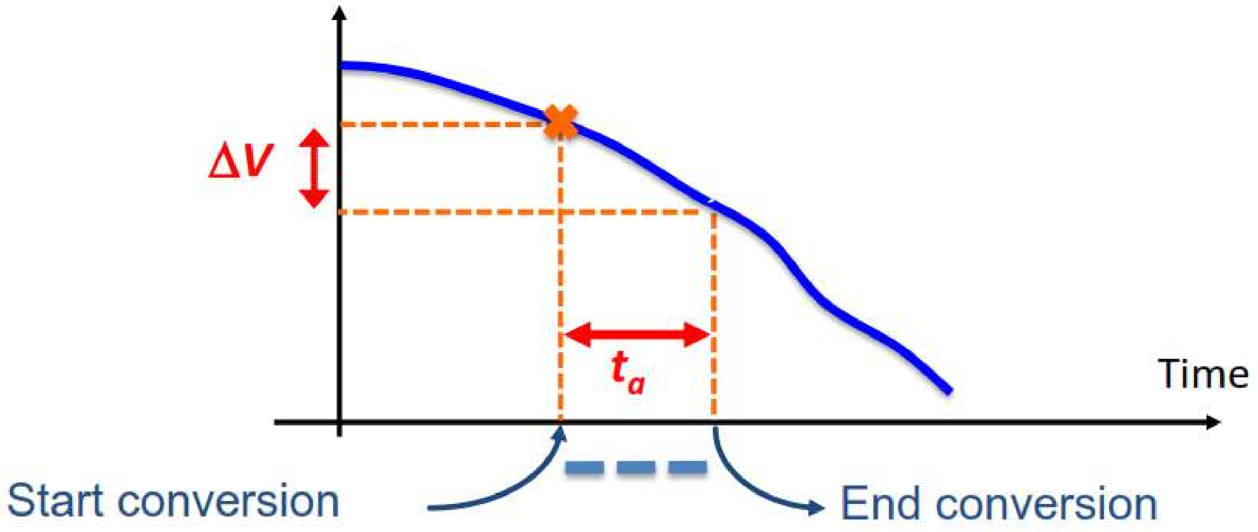
C2: V > 2.5

C3: V > 3.75

ADC is not instantons

Aperture Time

- ❑ Time needed for an ADC to convert a voltage to a binary code, during which input signal may change.



https://engineering.purdue.edu/ME588/LectureNotes/Unit5a--ADConversion.pdf

- ❑ Want ΔV to be small.

$$\Delta V < Q$$

Thank You For Your Attention!

Any Question?