A to D and D to A converters

Instructor
Prem Prakash Singh
ECC, Allahabad

Analog signals

- Directly measurable quantities in terms of some other quantity
  - Thermometer – mercury height rises as temperature rises
  - Car Speedometer – Needle moves farther right as you accelerate
  - Stereo – Volume increases as you turn the knob.
- Some characteristics of analog signals
  - Maximum and minimum voltages
  - Precise continuous signals
  - Frequency if not a steady state signal

Digital signals

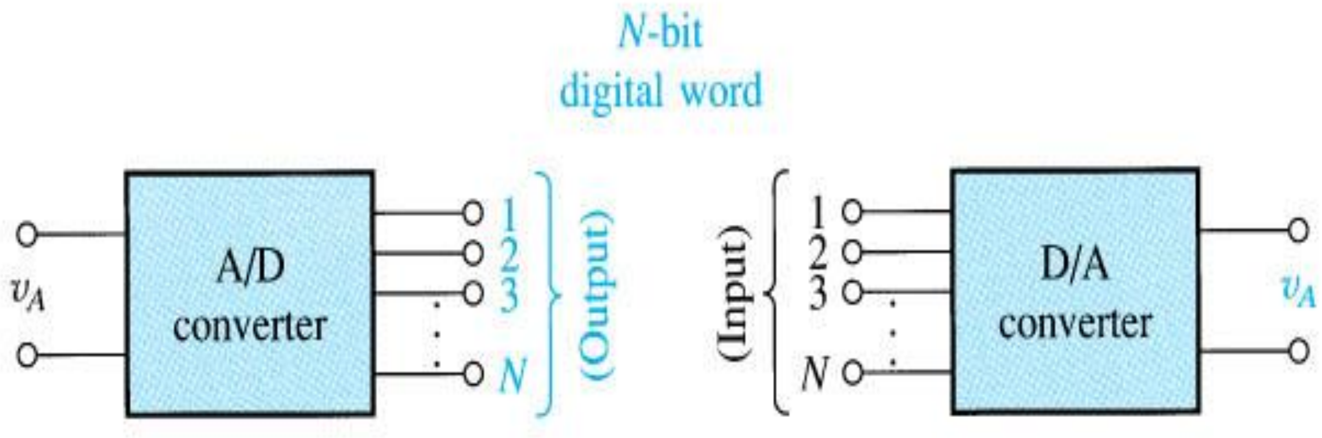
- Having only two states, either 1(ON state) or 0 (OFF state)
  - Light switch can be either on or off
  - Door to a room is either open or closed
- Some characteristics of digital signals
  - Finite
  - Discrete

What converters do

- Converts analog/digital signals to digital/analog
- Continius signal to finite and discrete signals

Why we need converters

- Most transducers and sensors have analog signals as output
- But microcontroller read digital signals

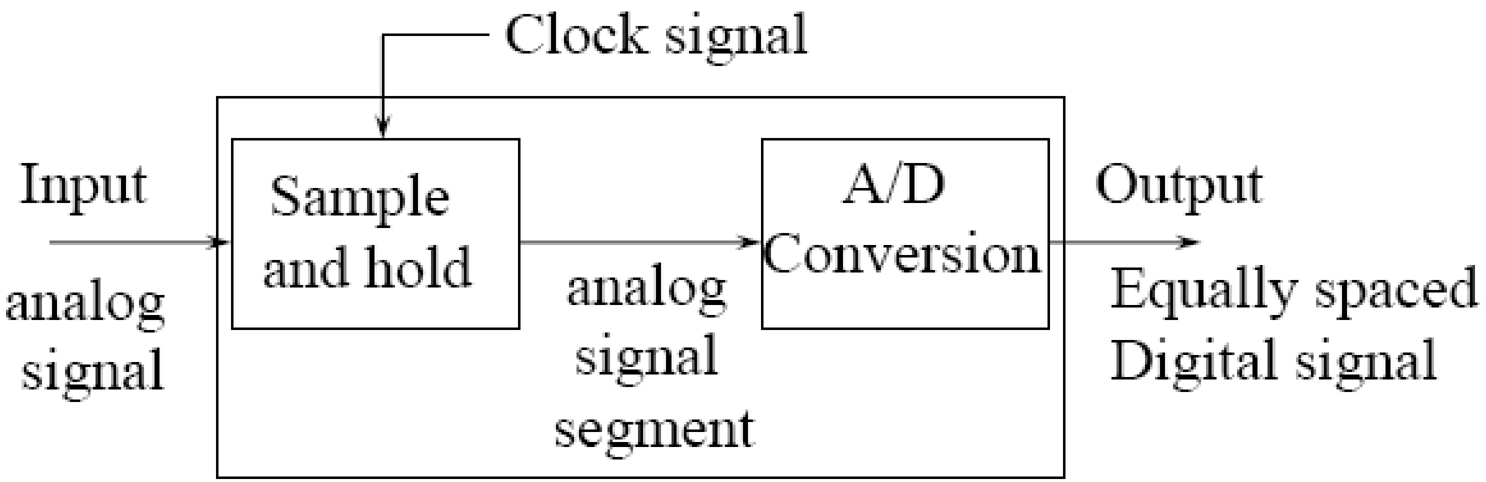


Applications of converters

- **Microphones -** take your voice varying pressure waves in the air and convert them into varying electrical signals
- **Strain Gages -** determines the amount of strain (change in dimensions) when a stress is applied
- **Thermocouple -** temperature measuring device converts thermal energy to electric energy

Flow chart of A to D converter

- **Step 1 - Quantizing** - breaking down analog value in a set of finite states
- **Step 2 - Encoding -** assigning a digital word or number to each state and matching it to the input signal



Step 1: Quantizing

Example: You have 0-10V signals and 3 bit A/D converter. Separate these signals into a set of discrete states with 1.25V increments.

Why **1.25 V** increments.

The number of possible states that the converter can output is 2^n , where n is the number of bits in the AD converter.

- For 3 bit A/D converter, number of possible states is $2^3 = 8$
- Quantization size is = $(V_{max} – V_{min})$/number of possible states

  i.e. (10-0)/8 = 1.25 V

Output States	Discrete Voltage Ranges (V)
0	0.00-1.25
1	1.25-2.50
2	2.50-3.75
3	3.75-5.00
4	5.00-6.25
5	6.25-7.50
6	7.50-8.75
7	8.75-10.0

Full scale input and Quantization error

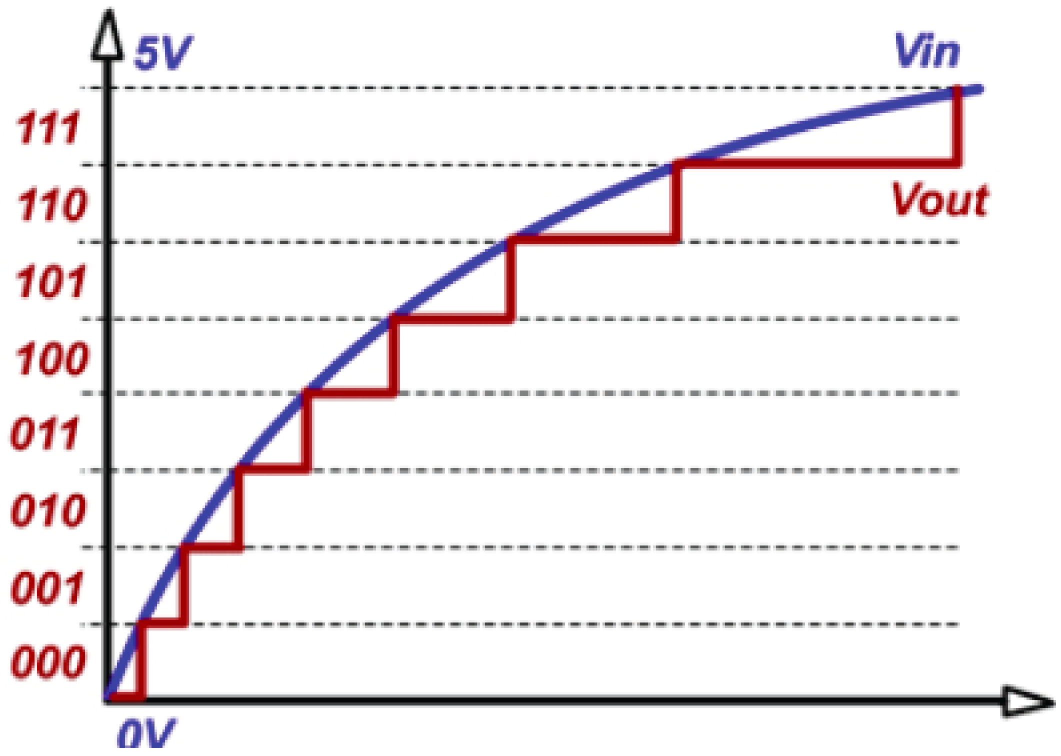
Full scale input – the largest analog voltage that a converter can detect.

Quantization error

- For voltages greater than the Full scale input will result in a converted value of 111---11.
- Similarly inputs less than the minimum input voltage result in 000---00.

Step 2: Encoding

Example: We assign the digital value (binary number) to each state for the computer to read.



Output States	Output Binary Equivalent
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

Accuracy of A/D converter

There are two ways to improve accuracy of A/D converter

- 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.

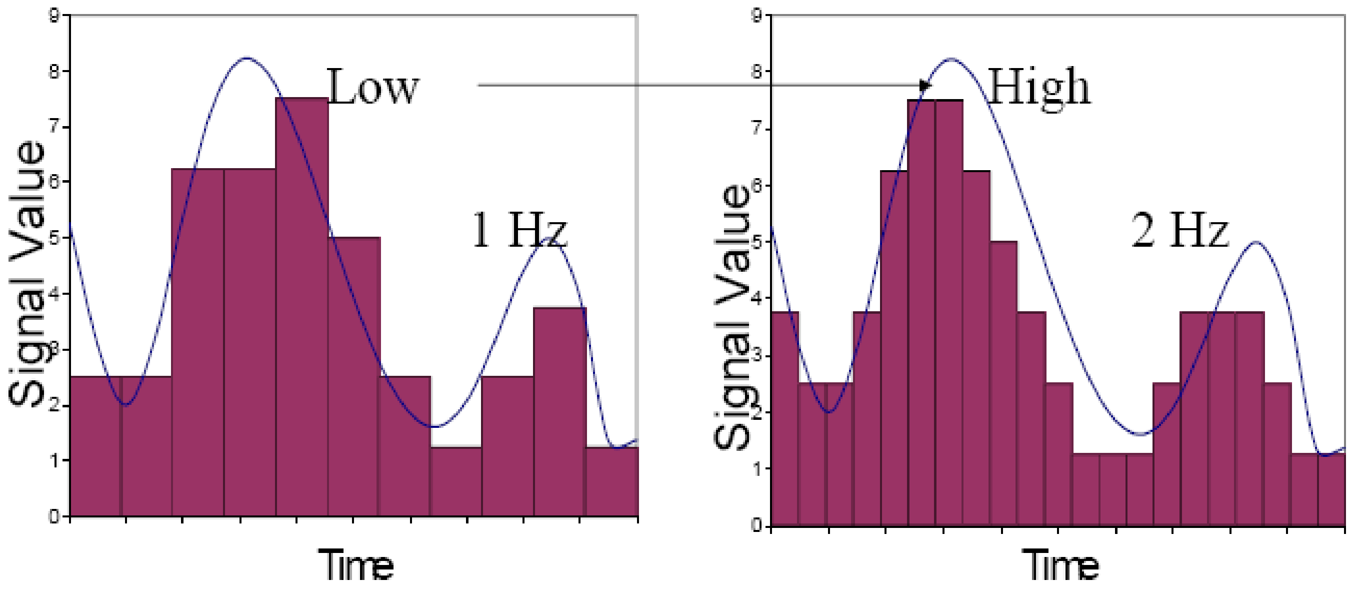
Resolution

- Resolution of a converter is number of discrete values the converter can produce
- Resolution = Analog Quantization size (Q)
- Q = Vrange / 2^n, where Vrange is the range of analog voltages and n is number of bits in A/D converter
- In our previous example: Q = 1.25V, this is a high resolution. A lower resolution would be if we used a 2-bit converter, then the resolution would be 10/2^2 = 2.50V.

limited by signal-to-noise ratio (should be around 6dB)

Sampling Rate

Frequency at which ADC evaluates analog signals

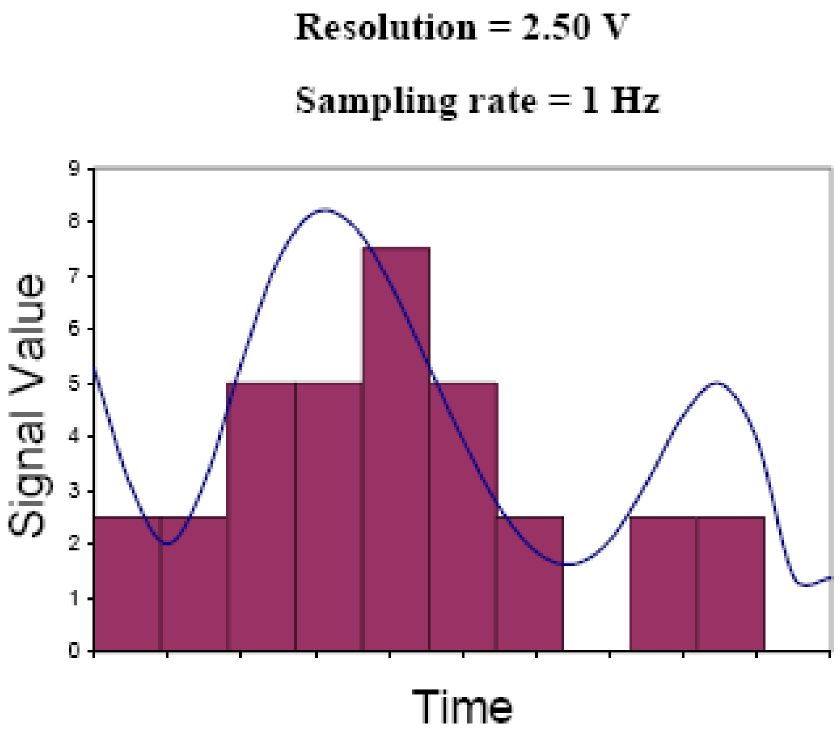


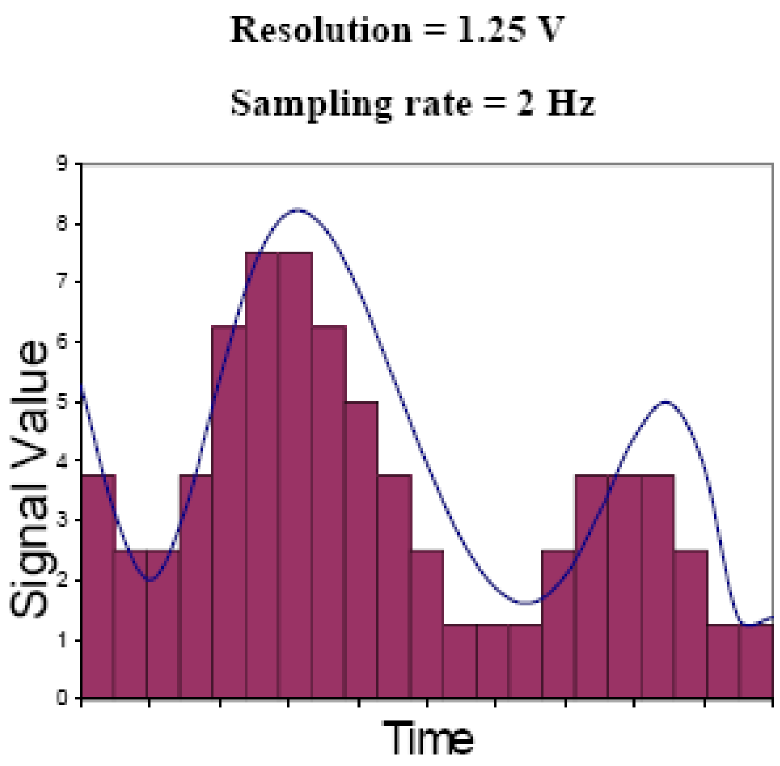
Aliasing

This occurs when the input signal is changing much faster than the sampling rate.
For example, a 2 kHz sine wave being sampled at 1.5 kHz would be reconstructed as a 500 Hz (the aliased signal) sine wave.

Nyquist Rule:
Use a sampling frequency at least twice as high as the maximum frequency in the signal to avoid aliasing.

Overall better accuracy





Increasing both the sampling rate and the resolution, you can obtain better accuracy in your AD signals.

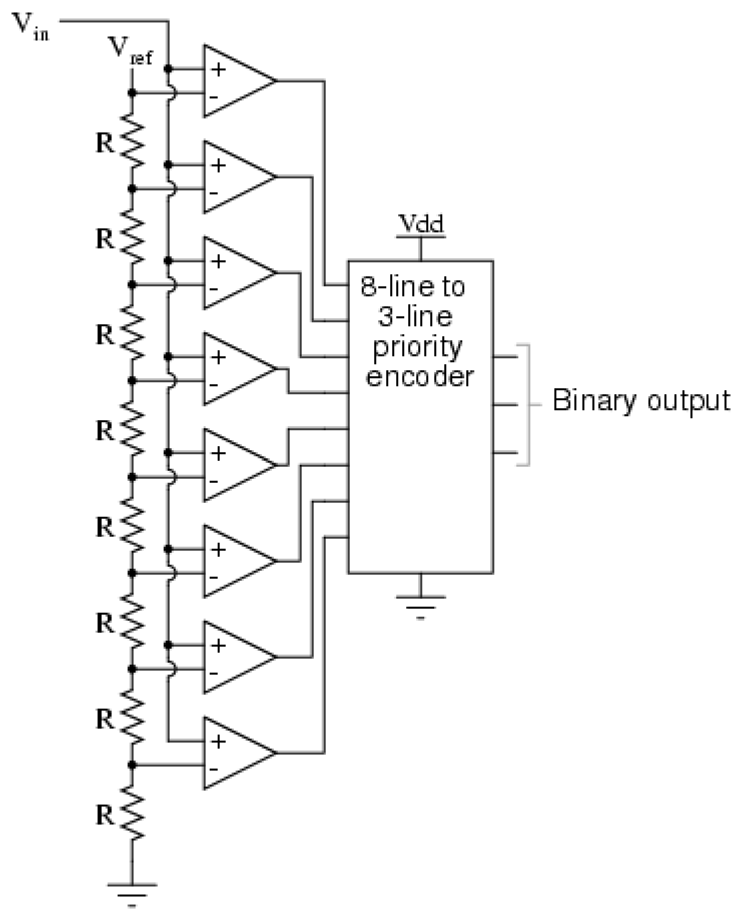
Types of A/D converter

There are four types of A/D converter

- Flash ADC
- Delta-Sigma ADC
- Dual Slope (integrating) ADC
- Successive Approximation ADC

Flash A/D converter

- Flash ADC consists of a series of comparators, each one comparing the input signal to a unique reference voltage.
- Flash ADC uses these comparators in parallel
- The comparator outputs connect to the inputs of a priority encoder circuit, which produces a binary output
- 2^N-1 comparators for N-bits



How Flash A/D converter works

- As the analog input voltage exceeds the reference voltage at each comparator, the comparator outputs will sequentially saturate to a high state.
- The priority encoder generates a binary number based on the highest-order active input, ignoring all other active inputs

Advantages

- Simplest in terms of operational theory
- Most efficient in terms of speed, very fast
- Capable of gigahertz sampling rates
- limited only in terms of comparator and gate propagation delays

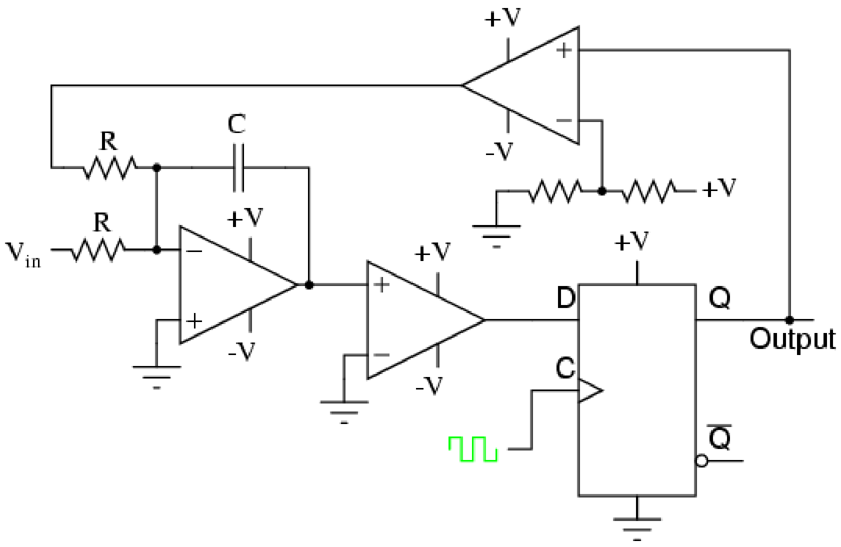
Disadvantages

- Lower resolution, only 8 bits
- Expensive
- A large die size and high power dissipations
- A high input capacitance
- For each additional output bit, the number of comparators is doubled

  i.e. for 8 bits, 256 comparators needed

Sigma Delta A/D converter

- Ideal for converting analog signals over a wide range of frequencies, from DC to several megahertz.
- Can also be used to convert high bit-count and low frequency digital signal into lower bit-count and higher frequency digital signals
- Consist of an oversampling modulator followed by a digital filter that together produce a high-resolution data-stream output.
- The internal DS modulator coarsely samples the input signal at a very high rate into a 1-bit stream.
- The digital filter then takes this sampled data and converts it into a high-resolution, slower digital code.



How Sigma Delta A/D converter works

- **Over sampled input signal by a large factor -** An analog signal applied to the input of the converter needs to be relatively slow so the converter can sample it multiple times
- **Filtration for the desired signal band -** Each individual sample is accumulated over time and "averaged" with the other input-signal samples through the digital/decimation filter.
- **DS modulator -** is responsible for digitizing the analog input signal and reducing noise at lower frequencies. In this stage, the architecture implements a function called noise shaping that pushes low frequency noise up to higher frequencies where it is outside the band of interest. Noise shaping is one of the reasons that DS converters are well-suited for low-frequency, high accuracy measurements.

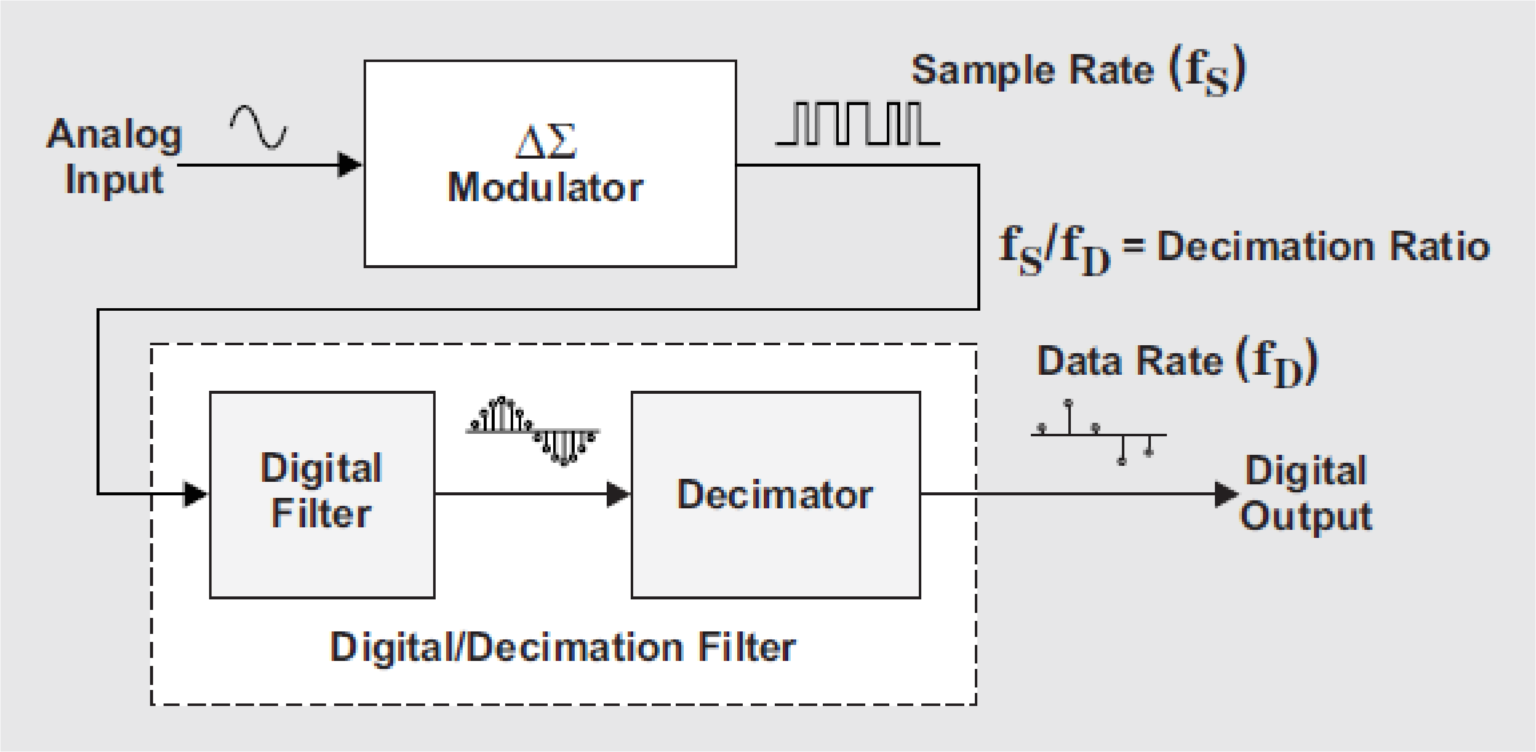
Advantages

- High resolution
- No precision external components needed

Disadvantages

- Slow due to oversampling

Block diagram of Sigma Delta A/D converter



Dual slope A/D converter

- In dual slope type ADC, the integrator generates two different ramps, one with the unknown analog input voltage V_{in} and another with a known reference voltage $-V_{ref}$. Hence it is called a s dual slope A to D converter.
- Vin is applied for fixed time and V_{ref} is applied for variable time
- Used in digital voltmeter or multimeter

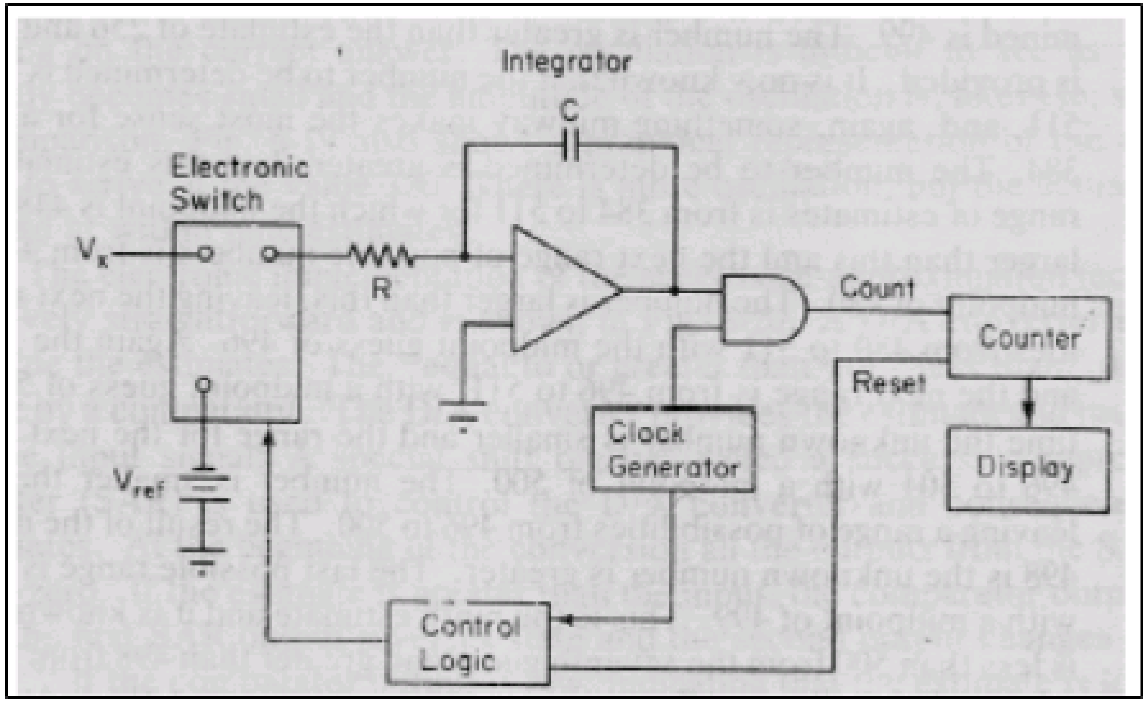
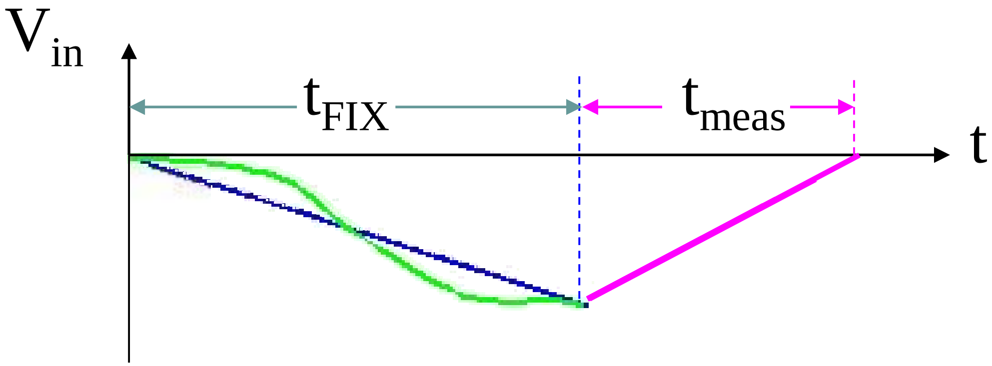


Figure 5 - Bock Diagram of Dual Slope ADC



How Dual slope A/D converter works

- When switch for V_{in} is ON, the sampled signal charges a capacitor for a fixed amount of time. This charging is fast.
- When switch for V_{ref} is ON, the sampled signal discharges a capacitor for a fixed amount of time. This discharging is slow.
- By integrating over time, noise integrates out of the conversion
- Then the ADC discharges the capacitor at a fixed rate with the counter counts the ADC’s output bits. A longer discharge time results in a higher count

Advantages

- Input signal is averaged
- Greater noise immunity than other ADC types
- High accuracy

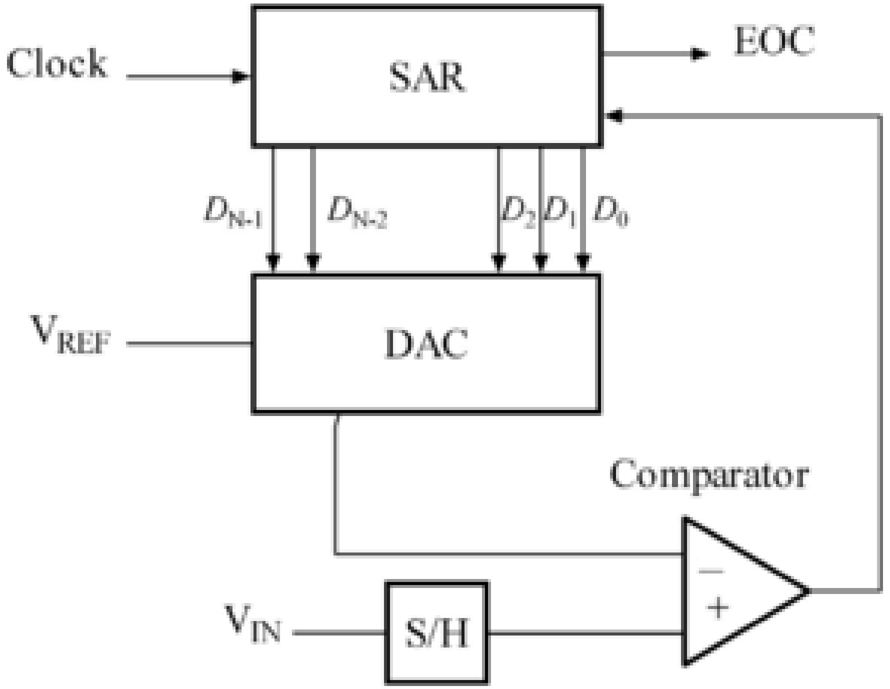
Disadvantages

- Slow
- High precision external components required to achieve accuracy

Successive approximation A/D converter

How Successive approximation A/D converter works

- A Successive Approximation Register (SAR) is added to the circuit
- Instead of counting up in binary sequence, this register counts by trying all values of bits starting with the MSB and finishing at the LSB.
- The register monitors the comparators output to see if the binary count is greater or less than the analog signal input and adjusts the bits accordingly



Successive approximation A/D converter

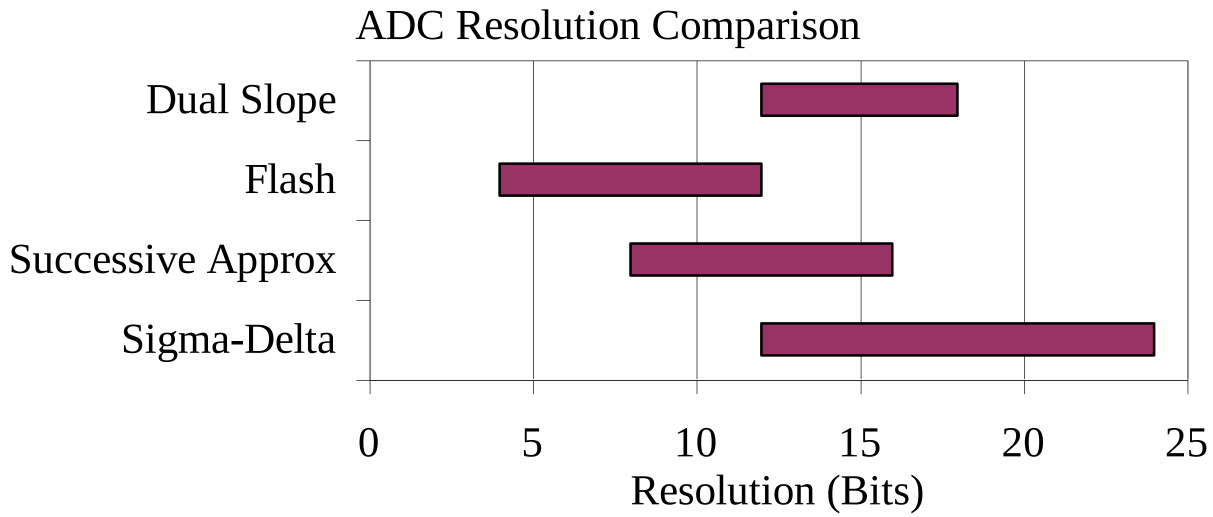
Advantages

- Input 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

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

Overall comparison of A/D Converters



Type	Speed (relative)	Cost (relative)
Dual Slope	Slow	Med
Flash	Very Fast	High
Successive Appox	Medium – Fast	Low
Sigma-Delta	Slow	Low

Successive Approximation Example

- 10 bit resolution or 0.0009765625V of Vref
- Vin= .6 volts
- Vref=1volts
- Find the digital value of Vin

Bit	Voltage
9	.5
8	.25
7	.125
6	.0625
5	.03125
4	.015625
3	.0078125
2	.00390625
1	.001952125
0	.0009765625

Successive Approximation

- MSB (bit 9)
  - Divided V_{ref} by 2
  - Compare $V_{ref}/2$ with V_{in}
  - If V_{in} is greater than $V_{ref}/2$, turn MSB on (1)
  - If V_{in} is less than $V_{ref}/2$, turn MSB off (0)
  - V_{in} =0.6V and V=0.5
  - Since V_{in}>V, MSB = 1 (on)

1									

Successive Approximation

- Next Calculate MSB-1 (bit 8)
  - Compare V_{in}=0.6 V to $V=V_{ref}/2 + V_{ref}/4$= 0.5+0.25 =0.75V
  - Since 0.6<0.75, MSB is turned off
- Calculate MSB-2 (bit 7)
  - Go back to the last voltage that caused it to be turned on (Bit 9) and add it to $V_{ref}/8$, and compare with V_{in}
  - Compare V_{in} with $(0.5+V_{ref}/8)$=0.625
  - Since 0.6<0.625, MSB is turned off

1	0	0							

Successive Approximation

- Calculate the state of MSB-3 (bit 6)
  - Go to the last bit that caused it to be turned on (In this case MSB-1) and add it to $V_{ref}/16$, and compare it to V_{in}
  - Compare V_{in} to $V = 0.5 + V_{ref}/16 = 0.5625$
  - Since 0.6>0.5625, MSB-3=1 (turned on)

MSB	MSB-1	MSB-2	MSB-3	…					
1	0	0	1						

Successive Approximation

- This process continues for all the remaining bits.

•Digital Results:

MSB	MSB-1	MSB-2	MSB-3	…					LSB
1	0	0	1	1	0	0	1	1	0

•Results: $\frac{1}{2}+\frac{1}{16}+\frac{1}{32}+\frac{1}{256}+\frac{1}{512}=.599609375\text{ V}$