ADC:

Analog to Digital Converter and Sensor Interfacing

DAC:

Digital to Analog Converter

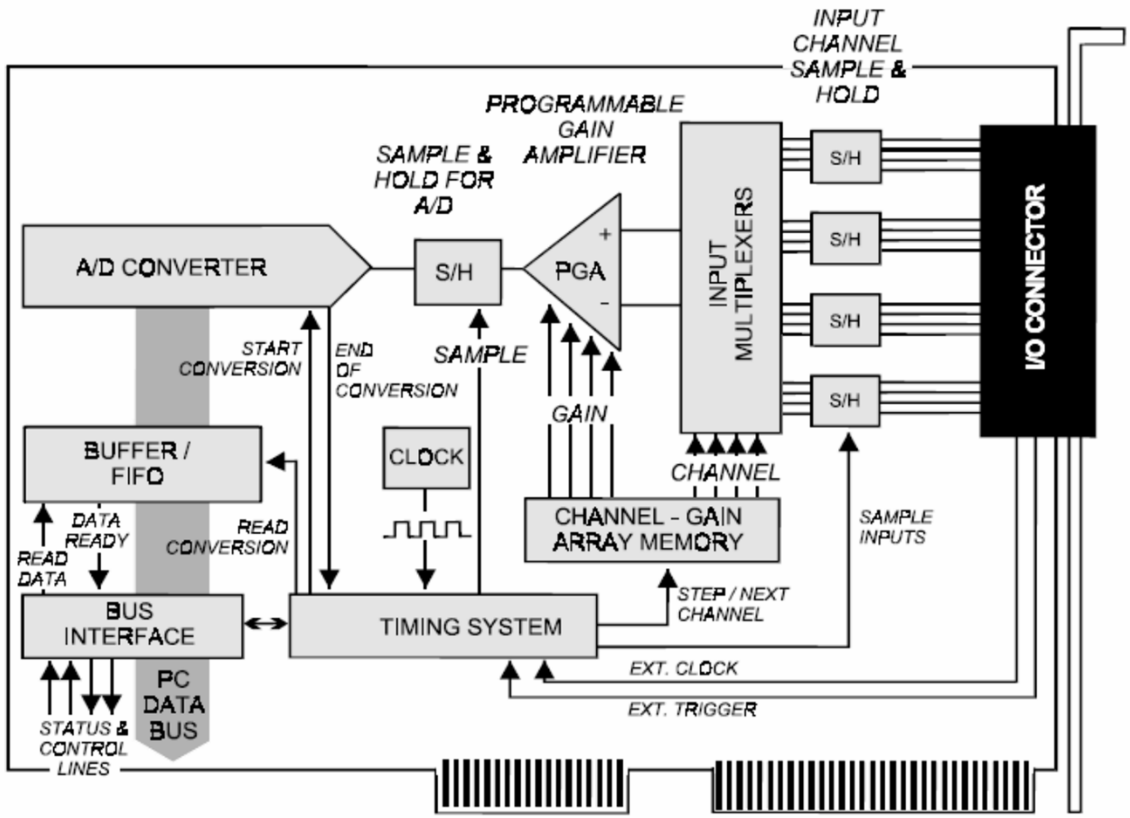
Introduction

- A wide range of plug-in data acquisition and control boards currently on the market are now available, used as multi-purpose plug-in data acquisition boards.
- Examples of these plug-in boards are:
  - Analog input (A/D) boards
  - Analog output (D/A) boards
  - Digital I/O boards
  - Counter/timer I/O boards

A/D boards (ADC)

- Analog input (A/D) boards convert analog voltages from external signal sources into a digital format, which can be interpreted by the host computer.
- The functional diagram of a typical A/D board is shown in figure below and comprises the following main components:
  - Input channel sample and hold circuits (for simultaneous sampling)
  - Input multiplexer
  - Input signal amplifier
  - Sample and hold circuit
  - A/D converter (ADC)
  - FIFO buffer
  - Timing system
  - Expansion bus interface

A/D boards



INPUT CHANNEL SAMPLE & HOLD
PROGRAMMABLE GAIN AMPLIFIER
SAMPLE & HOLD FOR A/D
A/D CONVERTER
S/H
PGA
INPUT MULTIPLEXERS
S/H
S/H
S/H
S/H
I/O CONNECTOR
START CONVERSION
END OF CONVERSION
SAMPLE
GAIN
CHANNEL
BUFFER / FIFO
CLOCK
CHANNEL - GAIN ARRAY MEMORY
SAMPLE INPUTS
DATA READY
READ DATA
READ CONVERSION
BUS INTERFACE
TIMING SYSTEM
STEP / NEXT CHANNEL
EXT. CLOCK
EXT. TRIGGER
PC DATA BUS
STATUS & CONTROL LINES

A/D boards (ADC)

A/D converters

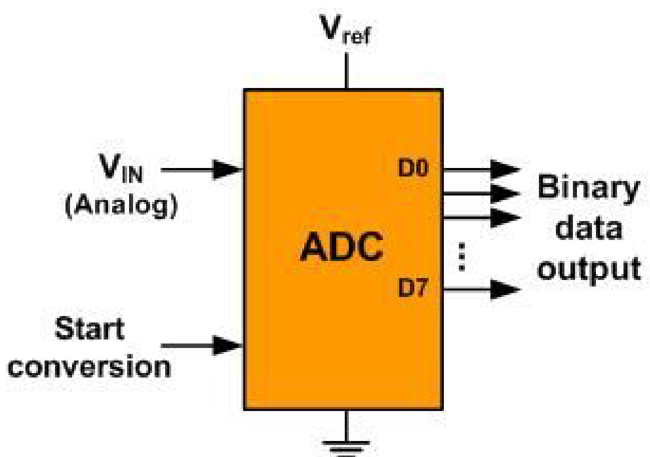
- Analog-to-digital converters (A/D converters, ADCs) measure an analog input voltage and convert this into a digital output format.
- The main types of A/D converters used are:
  - Successive approximation A/D converter
  - Flash A/D converters
  - Integrating A/D converters

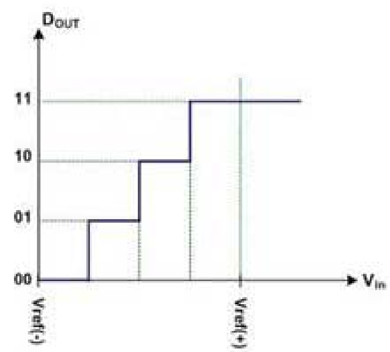
ADC Devices

- ADCs are among the most widely used devices for data acquisition and sensor interfacing.
- Digital computers use binary (discrete) values,
  - but in the physical world everything is analog (continuous).
  - Temperature, pressure (wind or liquid), humidity, and velocity...
- A physical quantity is converted to electrical (voltage, current) signals using a device called a transducer.
- Transducers used to generate electrical outputs are also referred to as sensors.
- Sensors for temperature, velocity, pressure, light, and many others produce an output that is voltage (or current).
- ADC translates the analog signals to digital numbers.
  - ADC takes the magnitude of the voltage and converts it to a binary value representing the magnitude.

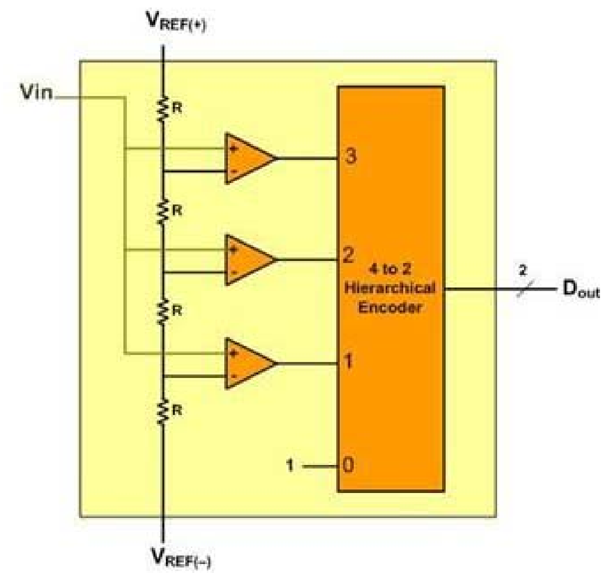
ADC Characteristics: Resolution

- ADC has n-bit resolution,
  - where n can be 8, 10, 12, 16, or even 24 bits.
- Higher-resolution ADCs provide a smaller step size, where step size is the smallest change that can be discerned by an ADC.
- Some widely used resolutions for ADCs are shown in the Table.
- Although the resolution of an ADC chip is fixed in its Design
  - we can control the step size with the help of what is called Vref.





(a) The Relationship between V_{in} and D_{out}



(b) The internal block diagram of a simple 2-bit ADC

ADC Characteristics: Vref

- Vref is an input to the ADC used for the reference voltage.
- Vref along with the resolution of the ADC chip, determine the step size.
- For an 8-bit ADC, the step size is Vref / 256.
- For example, if the analog input range needs to be 0 to 4 volts,
  - Vref is connected to 4 volts.
  - That gives 4 V / 256 = 15.62 mV for the step size of an 8-bit ADC.
- In another case, if we need a step size of 10 mV for an 8-bit ADC,
  - then Vref = 2.56 V, because 2.56 V / 256 = 10 mV.

V_{ref} (V)	Vin Range (V)	Step Size (mV)
5.00	0 to 5	5 / 256 = 19.53
4.00	0 to 4	4 / 256 = 15.62
3.00	0 to 3	3 / 256 = 11.71
2.56	0 to 2.56	2.56 / 256 = 10
2.00	0 to 2	2 / 256 = 7.81
1.28	0 to 1.28	1.28 / 256 = 5
1.00	0 to 1	1 / 256 = 3.90

Note: In an 8-bit ADC, step size is $V_{ref}/256$

n-bit	Number of steps	Step size
8	256	5V /256 = 19.53 mV
10	1024	5V /1024 = 4.88 mV
12	4096	5V /4096 = 1.2 mV
16	65,536	5V /65,536 = 0.076 mV

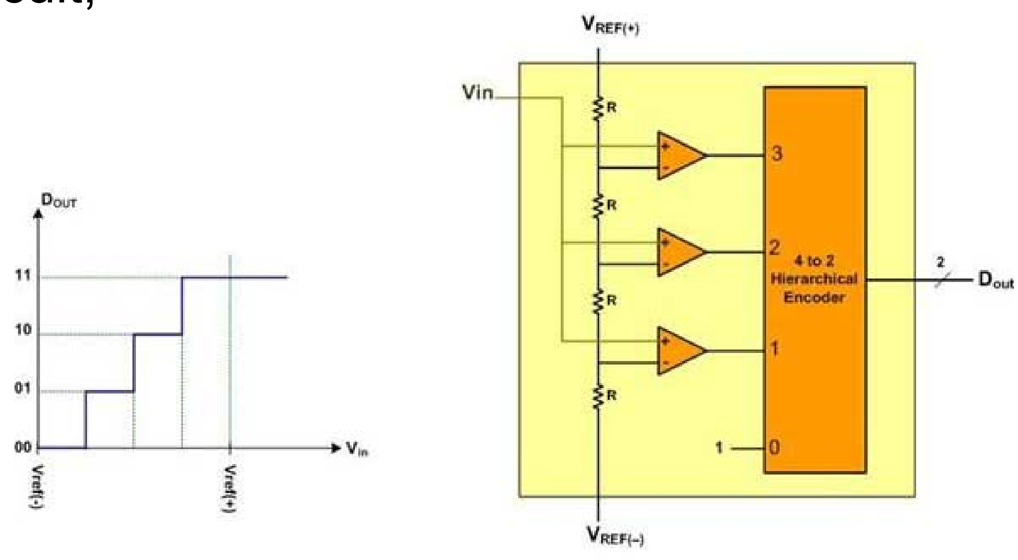
Note: V_{ref} = 5V

ADC Characteristics: Conversion time

- Conversion time is major factor in selecting an ADC, in addition to resolution.
- Conversion time is defined as:
  - the time it takes the ADC to convert the analog input to a digital number.
- The conversion time is dictated by:
  - the clock source connected to the ADC
  - the method used for data conversion
  - technology used in the fabrication of the ADC.
- Start conversion and end-of-conversion signals
  - For the conversion to be controlled by the CPU, there are needs for:
  - start conversion (SC) and
  - end-of-conversion (EOC) signals.
  - When SC is activated, the ADC starts converting the analog input value of Vin to a digital number.
  - The amount of time it takes to convert varies depending on the conversion method.
  - When the data conversion is complete, the end-of-conversion (EOC) signal notifies the CPU that the converted data is ready to be picked up.

ADC Characteristics: Digital data output

- In an 8-bit ADC we have an 8-bit digital data output of D0-D7
- To calculate the output voltage, we use the following formula:
  - DOUT = VIN / StepSize
  - where Dout = digital data output (in decimal), Vin = analog input voltage,
  - step size (resolution) is the smallest change, which is Vref/256 for an 8-bit ADC.
- Ex: simple 2-bit ADC. In the circuit,
  - the voltage between Vref(+) and Vref(-) is divided into 4.
  - As a result, the step size is (Vref(+) - Vref(-)) / 4.



(a) The Relationship between V_{in} and D_{out}

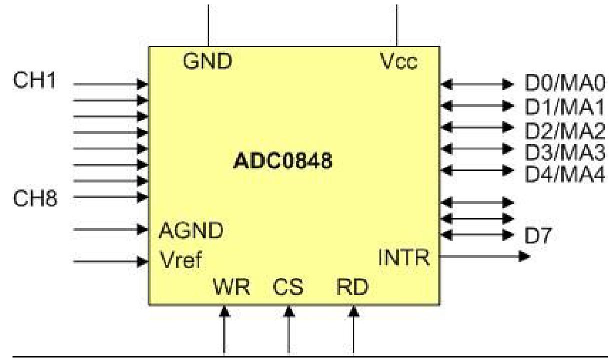
(b) The internal block diagram of a simple 2-bit ADC

ADC Characteristics: Digital data output

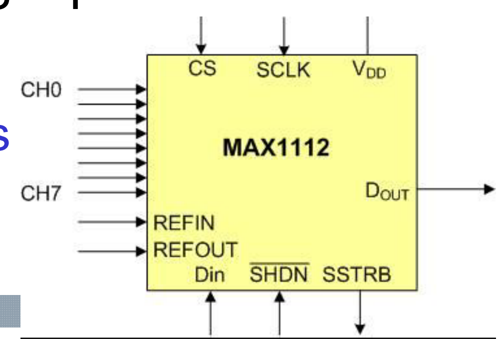
- Ex2: given 8-bit ADC and Vref = 2.56 V.
  - Calculate the D0-D7 output if the analog input is:
  - (a)1.7 V, and (b) 2.1 V.
- Solution:
  - step size is 2.56/256 = 10 mV, we have the following.
  - (a) DOUT = 1.7V/10 mV = 170 in decimal,
  - which gives us 10101010 in binary for D7-D0.
  - (b) DOUT = 2.1V/10 mV = 210 in decimal,
  - which gives us 11010010 in binary for D7-D0

Parallel versus serial ADC

- ADC chips are either parallel or serial.
- In parallel ADC,
  - binary data is sent out with 8 or more pins.
- in serial ADC
  - we have only one pin for data out.

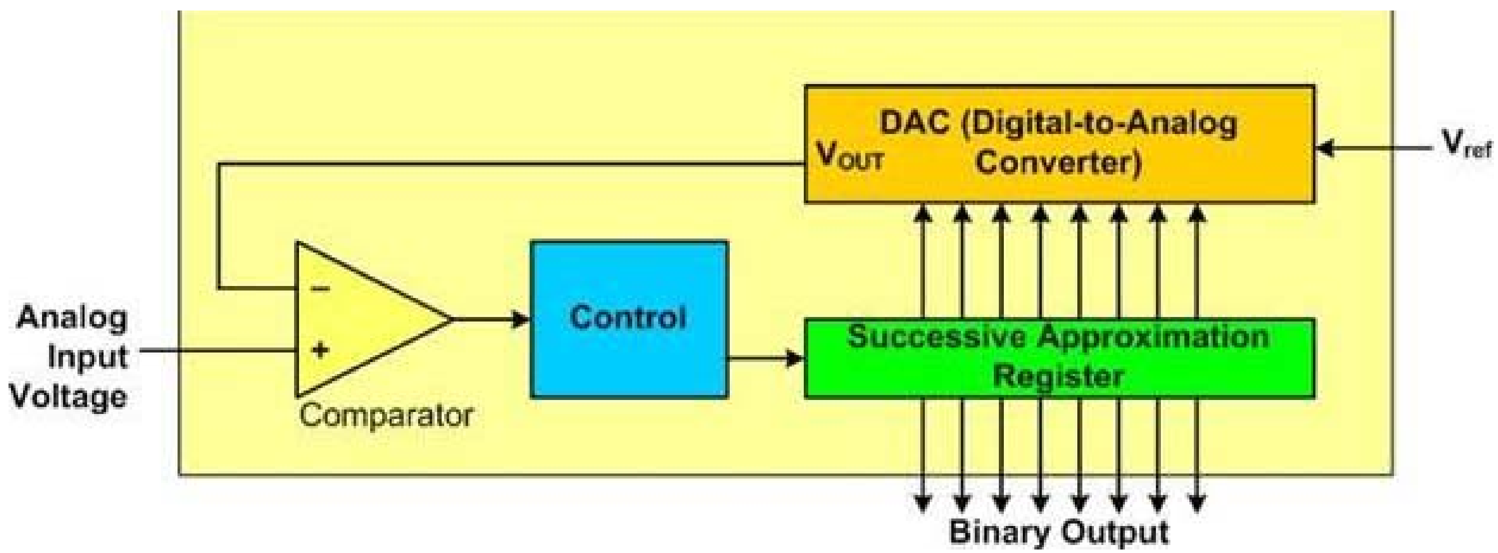


- The D0-D7 data pins of the 8-bit ADC provide an 8-bit parallel data path between the ADC chip and the CPU.
- Since space is a critical issue,
  - serial devices such as the serial ADC are becoming widely used.
- ADC0848 is an example of a parallel ADC with 8 pins for data output
- MAX1112 is an example of a serial ADC with a single pin for Dout.
- Analog Input Channels:
  - Typically, ADC chips has 2, 4, 8, or even 16 channels on a single chip.



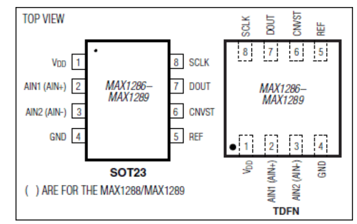
Successive Approximation ADC

- Successive Approximation is a widely used method of converting an analog input to digital output.
- Allows high sampling rates and high resolution
- It has three main components:
  - (a) successive approximation register (SAR),
  - (b) comparator
  - (c) control unit.

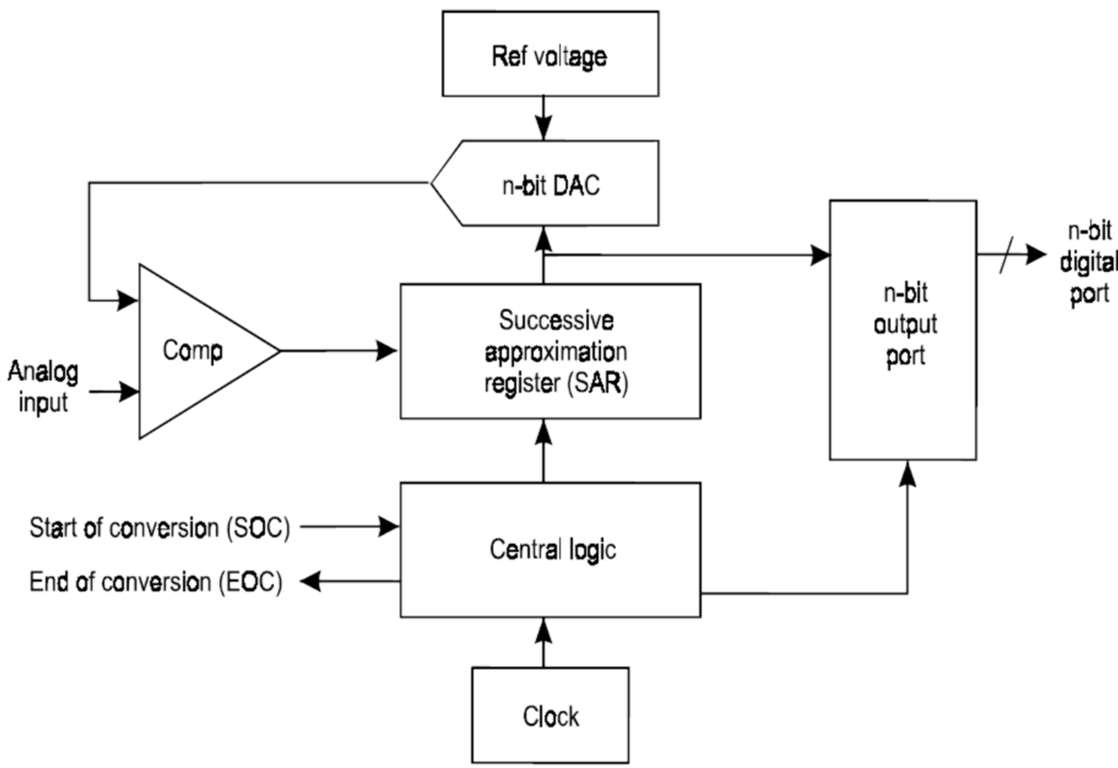


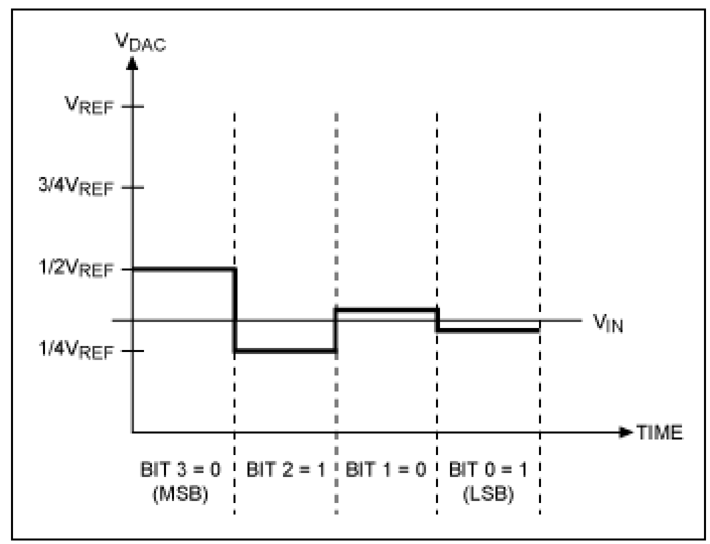
Successive Approximation ADC

- The functional diagram of an n-bit successive approximation A/D converter is shown in Figure.
- Generally speaking, an n-bit SAR ADC will require N comparison periods.



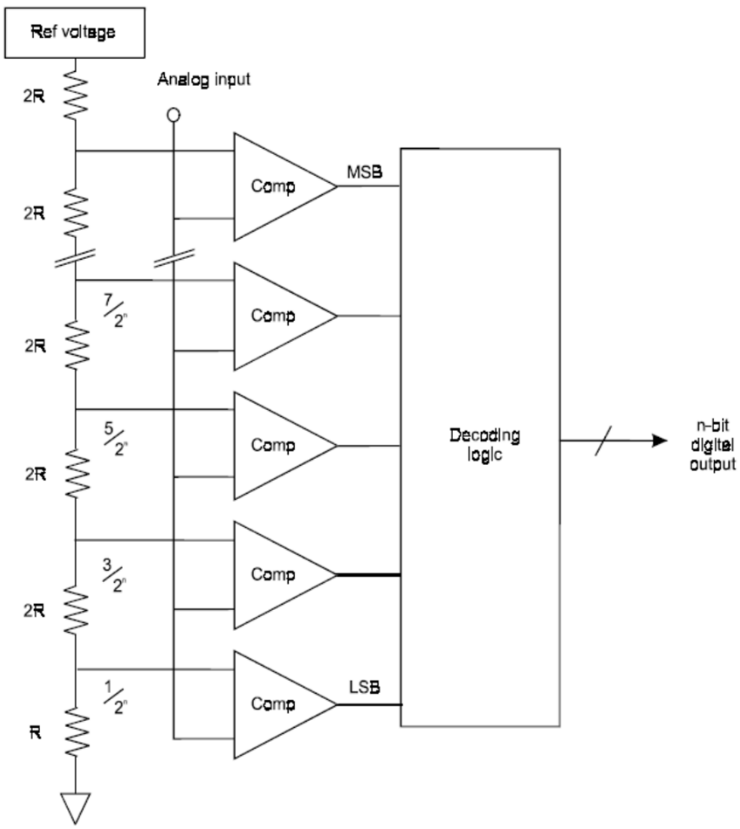
MAX1288/MAX1289
8-bit A/D





A/D boards (ADC)

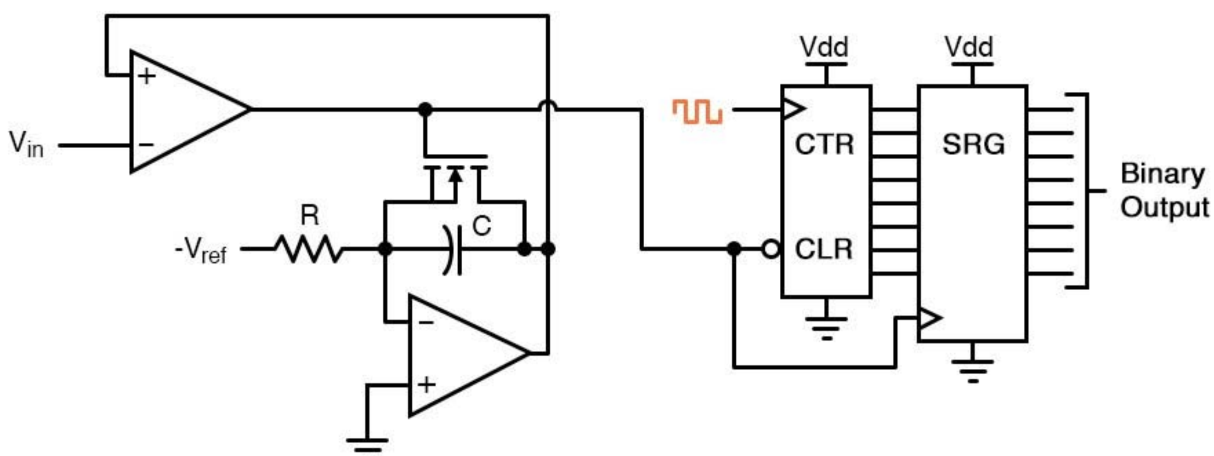
- Flash A/D converters
- Fastest available ADC, operating at speeds up to few GHz.
- Used where extremely high speeds of conversion are required with lower resolution, for example, 8-bits.
- Figure shows the functional diagram of an *n*-bit flash A/D converter.
- Requires 2^n-1 parallel comparators.
- Found in high speed applications such as digital oscilloscopes, DSP and real-time.



A/D boards (ADC)

Integrating ADC

- Integrating analog-to-digital converters (ADCs) provide high resolution analog-to-digital conversions, with good noise rejection. These ADCs are ideal for digitizing low bandwidth signals, and are used in applications such as digital multi-meters and panel meters.



Basic integrator of a single-slope integrating ADC

Sampling rate and the Nyquist theorem

Sampling rate and the Nyquist theorem

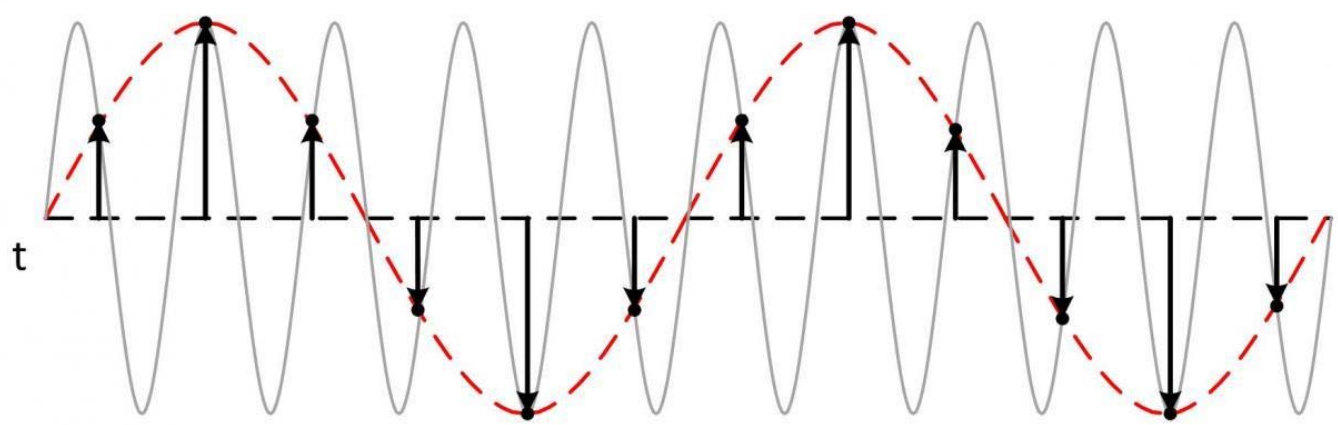
- How fast should the A/D board sample the data to be able to represent and reconstruct the input signal accurately.

Nyquist's theorem

Nyquist's sampling theorem states that:

*"An analog band-limited signal that has no spectral components at or above a frequency of f Hz can be uniquely represented by samples of its values spaced at uniform intervals that are no more than ½*f seconds apart or sampled at a frequency of no less than 2*f Hz."*

- The max. sampling period, *T*=1/(2*f), is known as the Nyquist interval, while the min. sampling frequency, 2*f, is known as the *Nyquist sampling frequency,* or *rate.*



Digital-to-Analog (DAC) converter

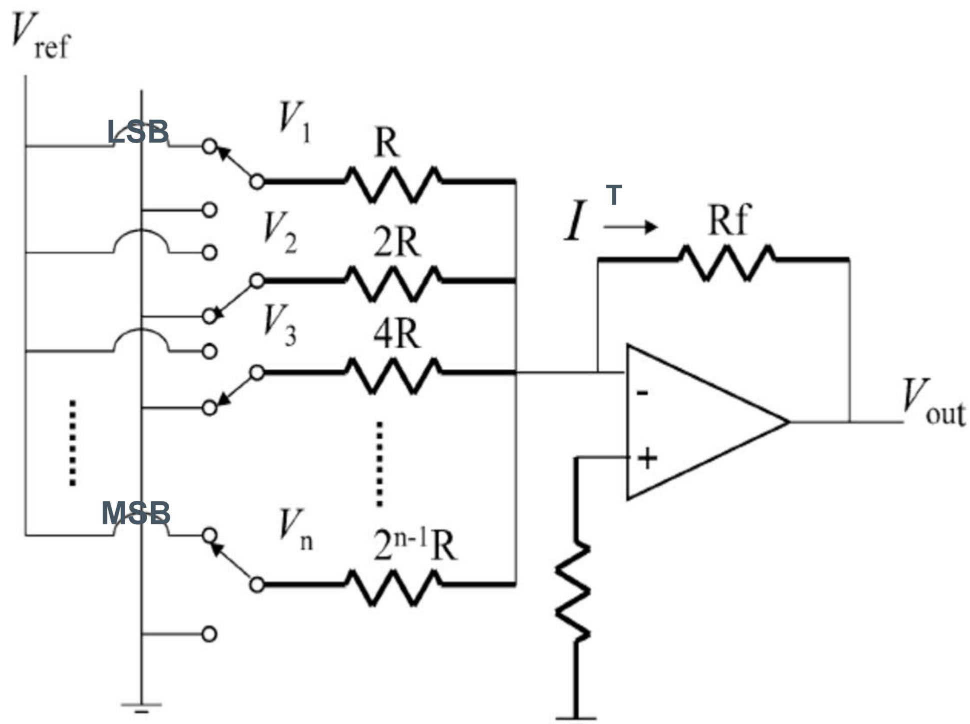
- D/A boards (DAC)
- Convert digital signals from a host computer into an analog format for use by external devices such as actuators in controlling or stimulating a system or process.
- Digital to analog converters (D/A converters or DACs) accept an n-bit parallel digital code as input and provide an analog current or voltage as output.
- The primary output value is a current, however, this is easily converted to a voltage using an operational amplifier.

Digital-to-Analog (DAC) converter

- The digital-to-analog converter (DAC) is a device widely used to convert digital signals to analog signals.
- Two methods of making a DAC:
  - binary weighted and R/2R ladder.
- The vast majority of integrated circuit DACs, including the DAC0808, use the R/2R method
  - It can achieve a much higher degree of precision.
- The first criterion for selecting a DAC is:
  - its resolution, which is a function of the number of bits of the digital input.
  - The common ones are 8, 10, and 12 bits.
- The number of digital input bits decides the resolution of the DAC
  - since the number of analog output levels is equal to 2^n, where n is the number of digital input bits.
  - Therefore, the 8-bit DAC such as the DAC0808 provides 256 discrete voltage (or current) levels of output.

D/A boards (DAC)

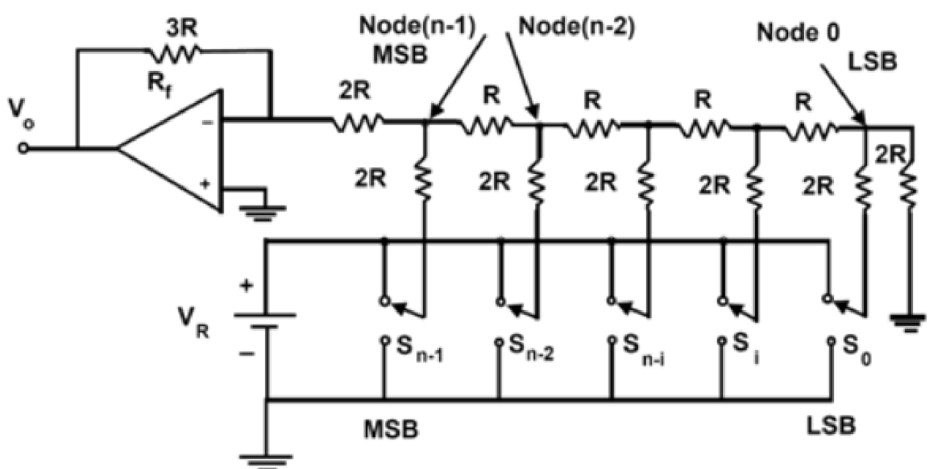
- *Binary Weighted Resistor D/A converters*
- This method creates an output current, I_T, which is the summation of the weighted currents from each of the parallel transistor sources; the current contributed by each transistor set by the resistances R, $2R$, $4R$, $8R$, etc.
- The output is $V_0 = -I_T\, R/2$ the output voltage is directly proportional to the voltage reference according to the equation $V_0 = V_{REF}\,(B_0 2^{-1} + B_1 2^{-2} \ldots + B_{n-1} 2^{n-1})$



D/A boards (DAC)

R-2R ladder D/A converters

- A D/A converter which uses resistors of only two values, *R* and 2*R*.
- The DAC produces an output current I_T, proportional to the input code and the voltage reference source.
- The output is given by: $$V_0 = -V_R 2^{-n} \sum_{i=0}^{n-1} a_i 2^i ; where\ a_i \in \{0,1\}$$
- The output voltage at node n-1 is: $V_{n-1} = V_R/3$
- The main advantages, are
  - easy matching of resistances (*R* or 2*R*),
  - constant and low resistance can be used, thus ensuring high-speed.



D/A boards (DAC)

Parameters of D/A converters

- Resolution
  - Output for 1bit change
  - The greater the number of input bits the smoother the output voltage
- Output range
  - Current
  - Voltage
- Input data code
  - binary, binary offset, two's complement, BCD, arbitrary, etc

DAC connection to the MCU