ANALOG INTERFACING AND INDUSTRIAL CONTROL (PART I)

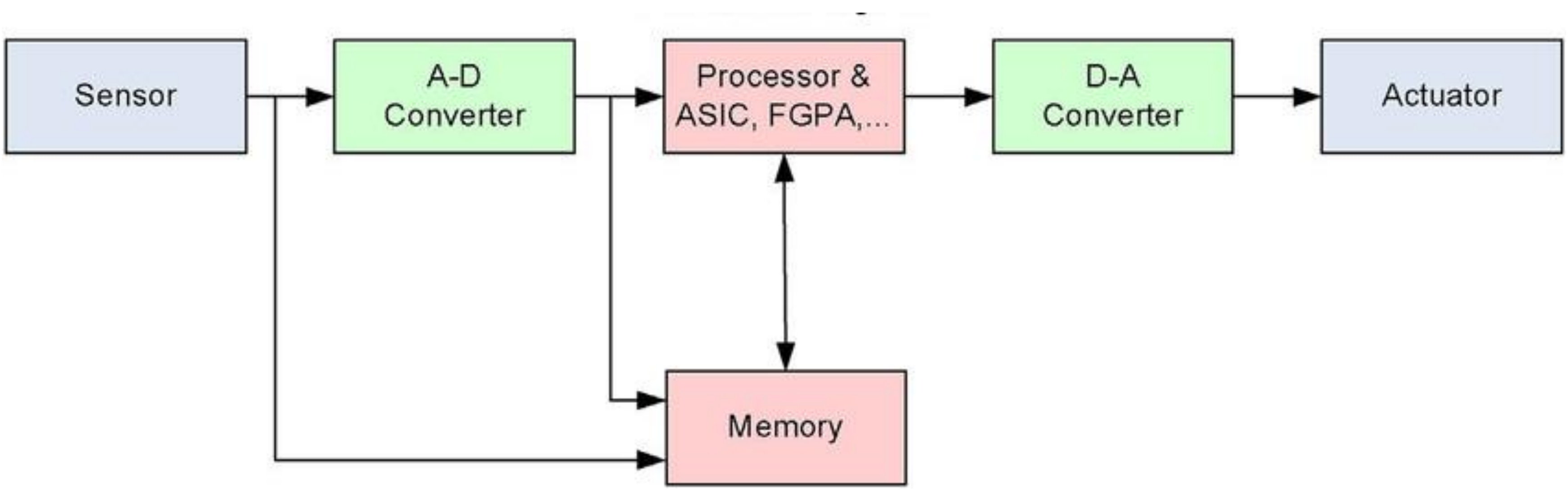
Book: *Microprocessors* and Interfacing-Douglas V. Hall (Chapter 10)

Prepared By: Anika Binte Islam, Lecture, CSE Dept, MIST

Embedded System

- A computer hardware system having software embedded in it.
- An independent system or it can be a part of a large system.
- A microcontroller or microprocessor based system which is designed to perform a specific task.
- For example, a fire alarm is an embedded system; it will sense only smoke.
- An embedded system has three components
  - It has hardware.
  - It has application software.
  - It has Real Time Operating system (RTOS) that defines the way the system works. It sets the rules during the execution of application program.
- We can define an embedded system as a Microcontroller based, software driven, reliable, real-time control system.

Basic Structure of An Embedded System



Basic Structure of An Embedded System

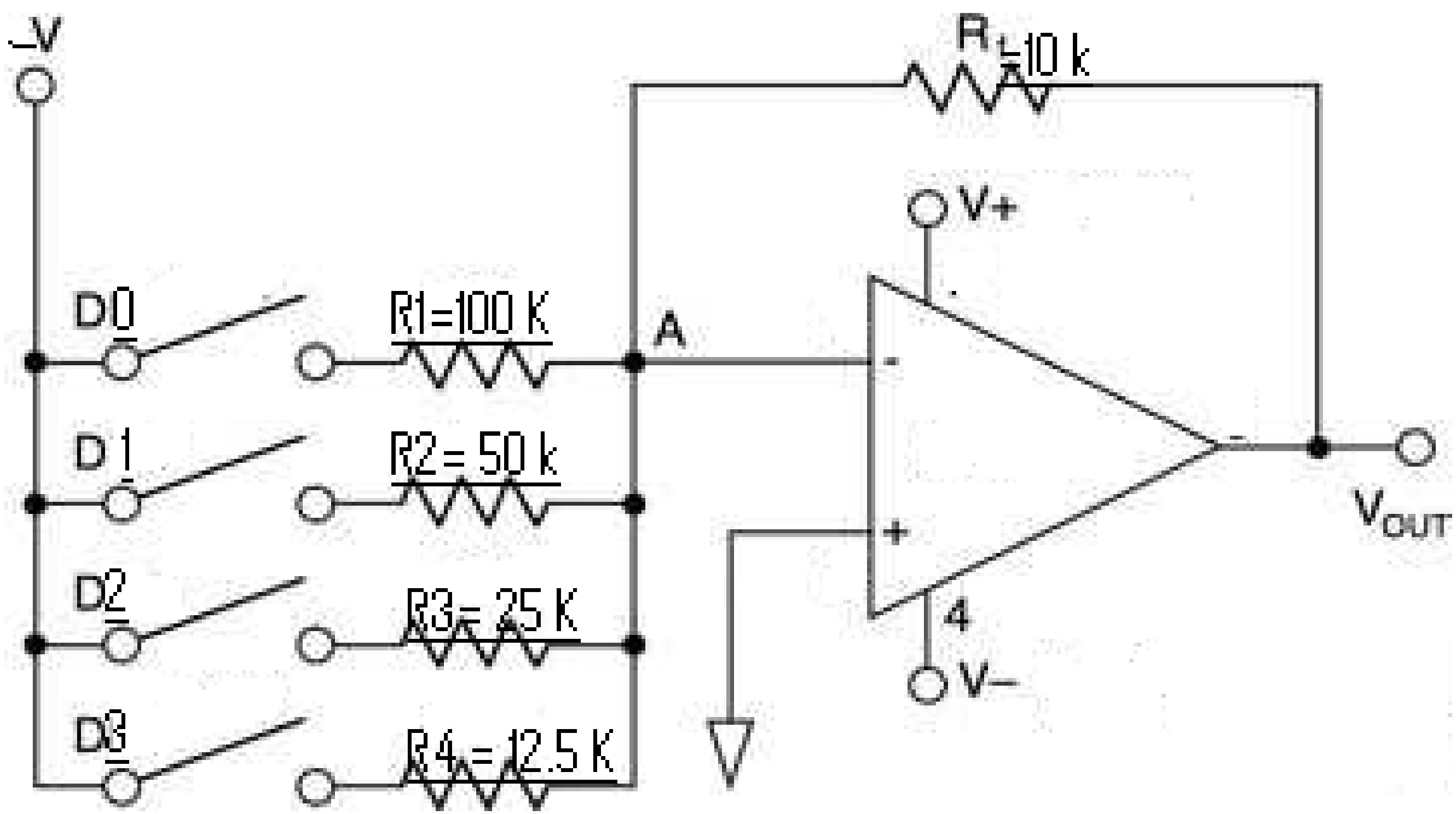
- **Sensor** − It measures the physical quantity and converts it to an electrical signal which can be read by an observer or by any electronic instrument like an A/D converter. A sensor stores the measured quantity to the memory.
- **A-D Converter** − An analog-to-digital converter converts the analog signal sent by the sensor into a digital signal.
- **Processor & ASICs** − Processors process the data to measure the output and store it to the memory.
- **D-A Converter** − A digital-to-analog converter converts the digital data fed by the processor to analog data
- **Actuator** − An actuator compares the output given by the D/A Converter to the actual (expected) output stored in it and stores the approved output.

D/A CONVERTER OPERATION, INTERFACING AND APPLICATIONS

- Why D/A converter?
  - Simpler
  - Several A/D converters have D/A as part of their circuitry.
  - So, we will discuss D/A converters first.

D/A Converter: Operation

- The purpose of a Digital to Analog converter is to convert a binary word to a proportional current or voltage
- In a simple 4 bit D/A converter , inverting input of the circuit is referred to as the summing point
- When one of the switches is closed, current will flow from -V to the summing point
- The equation of O/P voltage, $V_{out} = - Rf/ R (V_{in})$
- If we close the switch D0 , $V_{out} = - 10/ 100(-5) = 0.5$ V
- If we close the switch D0 & D1 , $V_{out} = - 10/ 33.33(-5) = 1.5$ V
- The point here is that, binary weighted resistors produce currents which are summed by the op amp to produce a proportional output voltage
- The heart of a D/A converter is a set of binary weighed current sources which can be switched on or off according to a binary word applied to its input



-V
R1=10 k
V+
D0
R1=100 K
A
D 1
R2= 50 k
D2
R3= 25 K
4
V−
D3
R4= 12.5 K
VOUT

D/A Converter: Characteristics

- **Resolution**
- The minimum possible change at the o/p for any change in the digital i/p.
- This is determined by the number of bits in the input binary word.
- A converter with 8 binary inputs has 2^8 or 256 possible output levels.
- Thus its resolution is 1 part in 256.
- **Example:**
- 12 bit converter has a resolution of 1 part in 2^{12} or 4096.
- Resolution is sometimes expressed in percentage.
- The resolution of an 8 bit converter can be expressed as a percentage is (1/256)*100 percent or 0.39 percent.

D/A Converter: Characteristics

- **Full scale output voltage**
- The maximum output voltage of a converter will always have a value 1 least significant bit less than the named value.
- **Example:**
- 12 bit, 10-V converter
- The value of 1 LSB = (10V)/4096 = 2.44mV
- The highest voltage output for the converter when it is properly adjusted will then be : (10 – 0.0024)V or 9.9976V.

D/A Converter: Characteristics

- **Accuracy**
- The accuracy specification for a D/A converter is a comparison between the actual output and the expected output
- It is specified as a percentage of the full scale output voltage or current
- **Example**
- If the converter has a output of 10V and ± 0.2 percent accuracy
- Maximum error for any output will be 0.002 * 10V or 20mV

D/A Converter: Characteristics

Linearity

- Linearity is the measure of how much the output ramp deviates from a straight line as the converter is stepped from no switches on to all switches on
- Ideally the deviation of the output from a straight line should be no greater than ± ½ the value of LSB to maintain overall accuracy

D/A Converter: Characteristics

- **Settling Time**
- When we change the binary word applied to the input of a converter , the output will change to the appropriate new value
- The output may overshoot the correct value, “ring” for a while before finally settling down to the correct value
- The time the output takes to get within ± ½ LSB of the final value is called settling time
- This specification is important, because if a converter is operated at too high frequency, it may not have time to settle to one value before it is switched to the next

D/A Converter: Interfacing to Microcomputers

- The inputs of the D/A circuit can be connected directly to the microcomputer output port
- Thus interfacing an 8 bit converter involves simply connecting the inputs of the converter to an output port
- For some application we need to interface a 12 bit converter to a microcomputer
- If we are working with a system which has an 8 bit data bus
  - The first thought might be – to connect the lower 8 inputs of the 12 bit converter to one output port and upper 4 bits to another port
  - In that case, we could send the lower 8 bits with one write operation and the upper 4 bits with another write operation
  - Time between the two writes introduces a potential problem in this approach

D/A Converter: Interfacing to Microcomputers

Example:

- Suppose we want to change the pattern of a 12 bit converter from 0000 1111 1111 to 0001 0000 0000
- When we will write the lower 8 bits, the output will go from 0000 1111 1111 to 0000 0000 0000
- When we will write the upper 4 bits the output will go back up to the desired 0001 0000 0000
- The point here is that for the time between the two writes the output will go to an unwanted value
- In many systems this could be disastrous
- The cure of this problem is to put latches on the input lines
- The latches can be loaded separately and then strobed together to pass all 12 bits to the D/A converter at the same time

A/D Converter

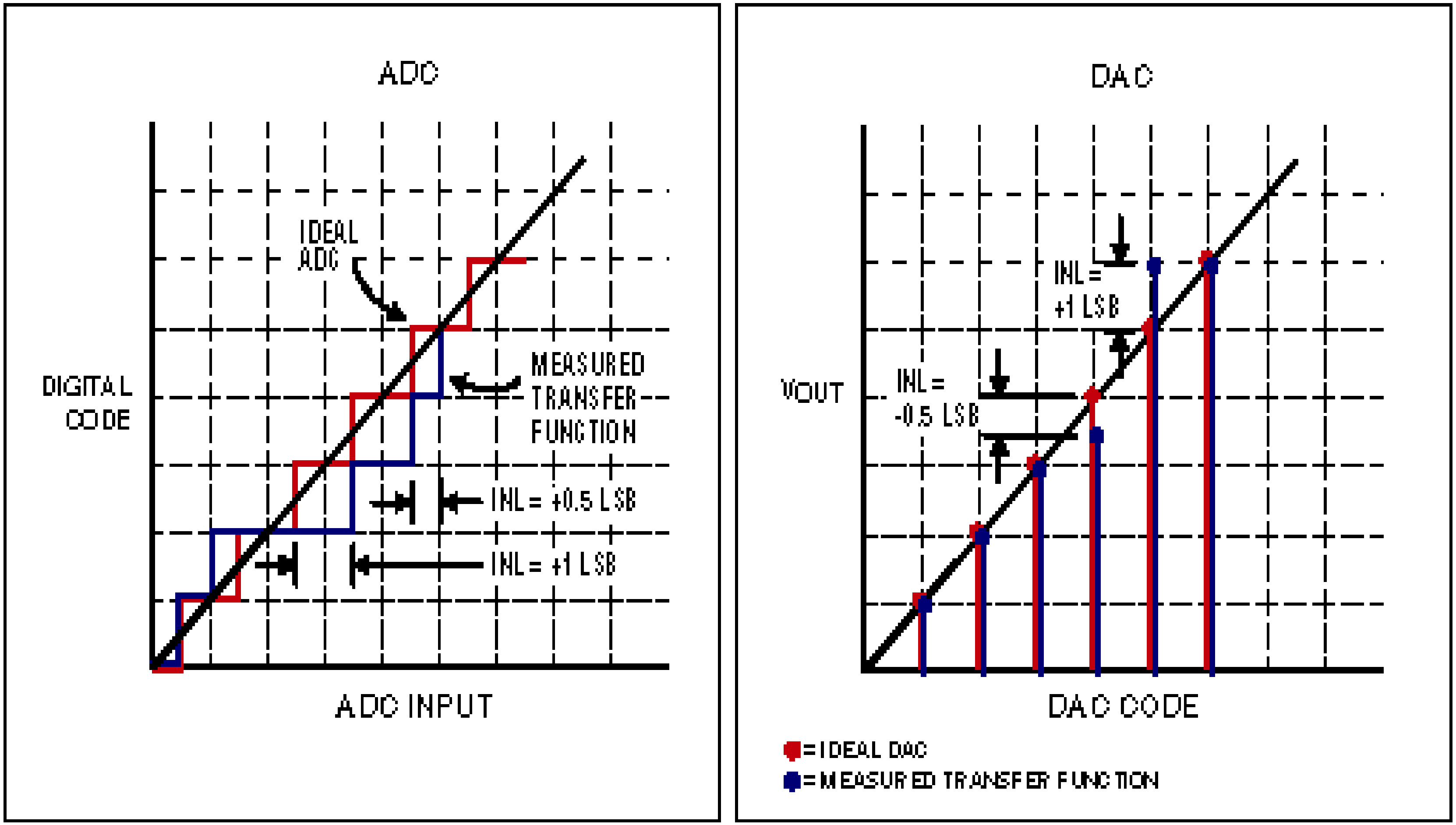
- The function of an A/D converter is to produce a digital word which represents the magnitude of some analog voltage or current

- **A/D converter Specification**

- Resolution: Same as D/A Converter
- Accuracy: Same as D/A Converter
- Linearity: Same as D/A Converter
- Conversion Time

- This is simply the time it takes the converter to produce a valid output binary code for an applied input voltage
- When we refer to a converter as high speed , we mean that it has a short conversion time

INL

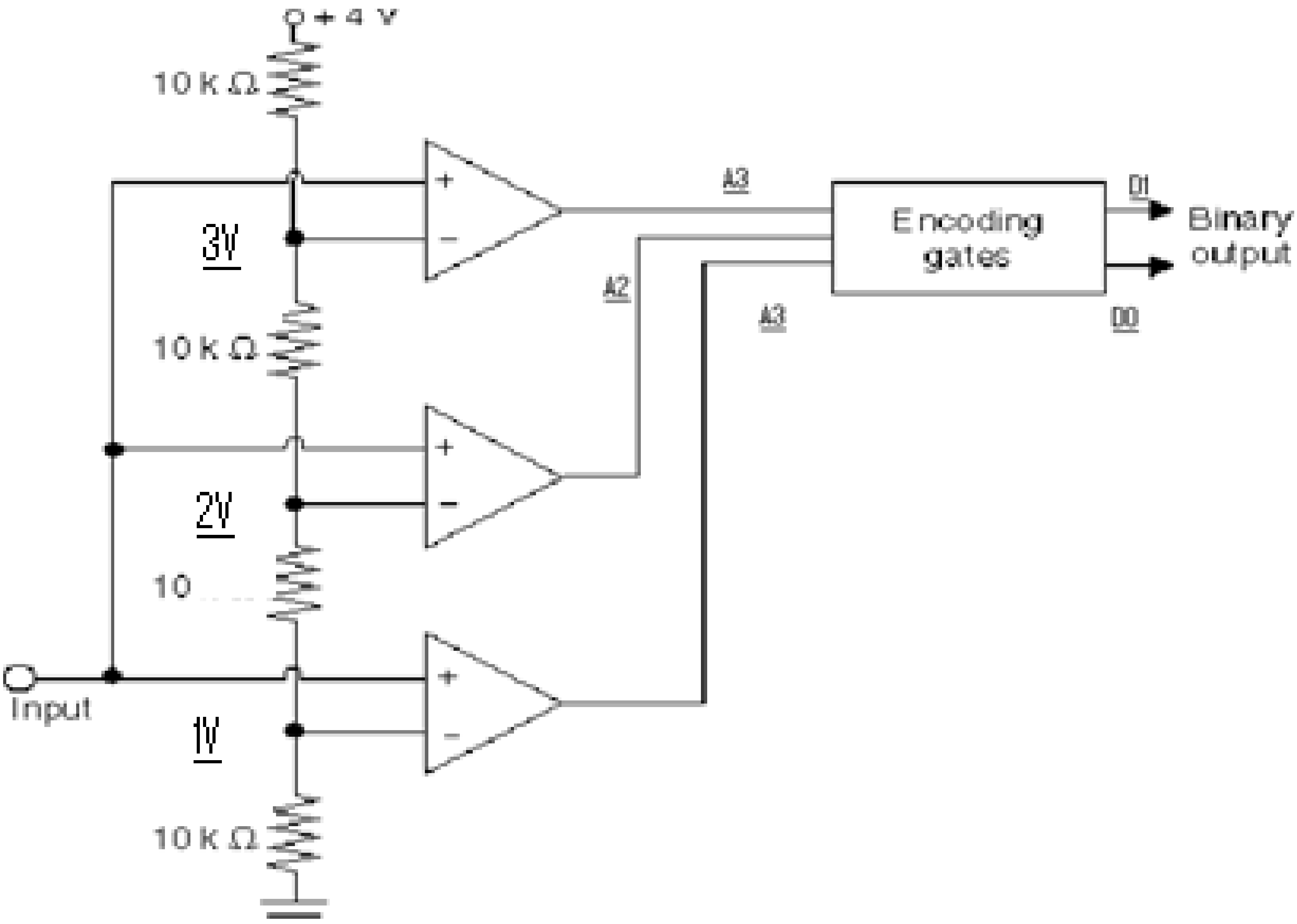

ADC
IDEAL ADC
DIGITAL CODE
MEASURED TRANSFER FUNCTION
INL = +0.5 LSB
INL = +1 LSB
ADC INPUT
DAC
VOUT
INL = +1 LSB
INL = -0.5 LSB
DAC CODE
= IDEAL DAC
= MEASURED TRANSFER FUNCTION

Parallel A/D Converter

- A voltage divider sets reference voltages on the inverting inputs of each of the comparators
- The voltage at the top of the divider represents the full scale value for the comparators
- The voltage to be converted is applied to the non inverting inputs of all the comparators in parallel
- If the input voltage on a comparator is greater than the reference voltage on the inverting input, the output of the comparator will go high
- The outputs of the comparators then give us a digital representation of the voltage level of the input signal

Example:

- With an input voltage of 2.6V , the outputs of comparators A1 and A2 will be high



+ 4 V
10 K Ω
3V
10 K Ω
2V
10
1V
10 K Ω
Input
A3
A2
A3
Encoding gates
D1
D0
Binary output

Parallel A/D Converter

Advantage:

- It is the fastest type of ADC because the conversion is performed simultaneously through a set of comparators, hence referred as flash type ADC. Typical conversion time is 100ns or less.
- The construction is simple and easier to design

Disadvantage:

- It is not suitable for higher number of bits. The number of comparators needed to produce a result with a reasonable amount of resolution
- To produce a converter with N bits of resolution we need (2^N-1) comparators

Dual-Slope A/D Converter

- Control circuitry resets all the counters to zero and connects the input of the integrator to the input voltage to be converted
- When the input voltage is positive, the output of the integrator will ramp negative
  - Comparator output will go high
  - AND gate is enabled and it lets 1 MHz clock to the counter chain
- After a fixed number of counts (typically 1000), the control circuitry switches the input of the integrator to a negative reference voltage and resets all the counters to zero
  - Integrator output ramp positive
- When integrator output crosses 0V
  - Comparator output will drop low
    - Shut of the clock signal to the counters
- The number of counts required for the integrator output to get back to zero is directly proportional to the input voltage

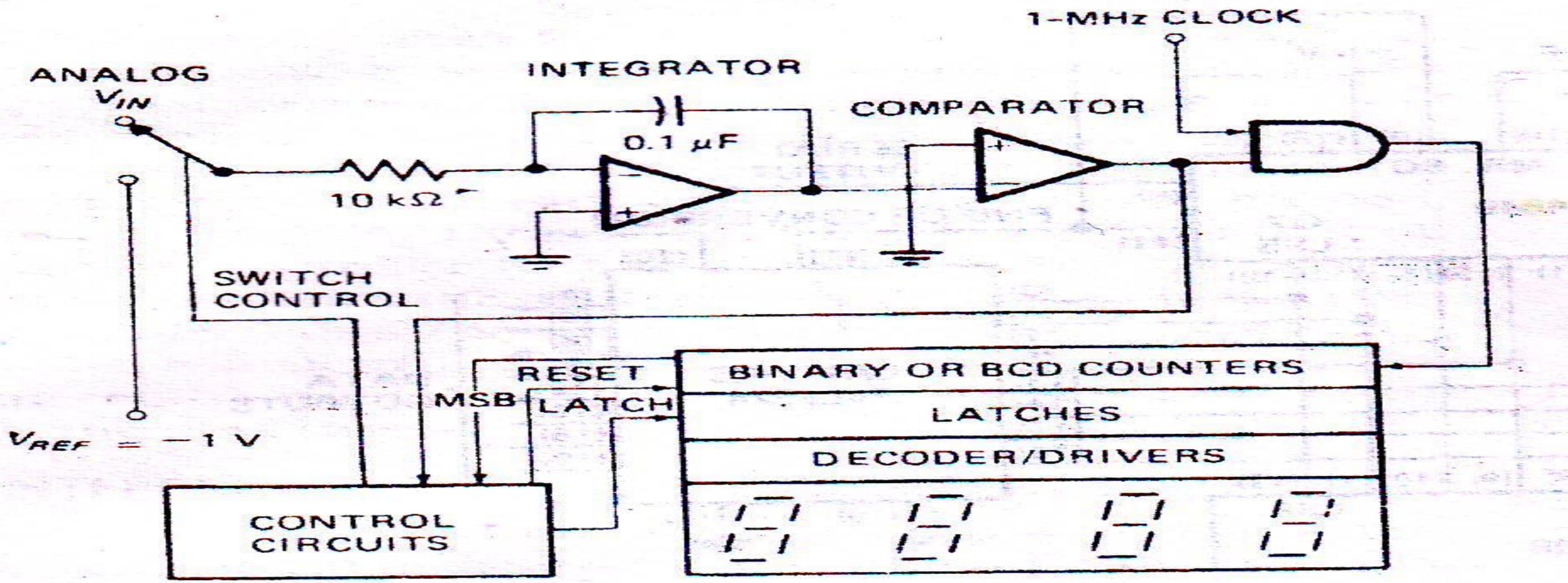
Dual-Slope A/D Converter

Advantage:

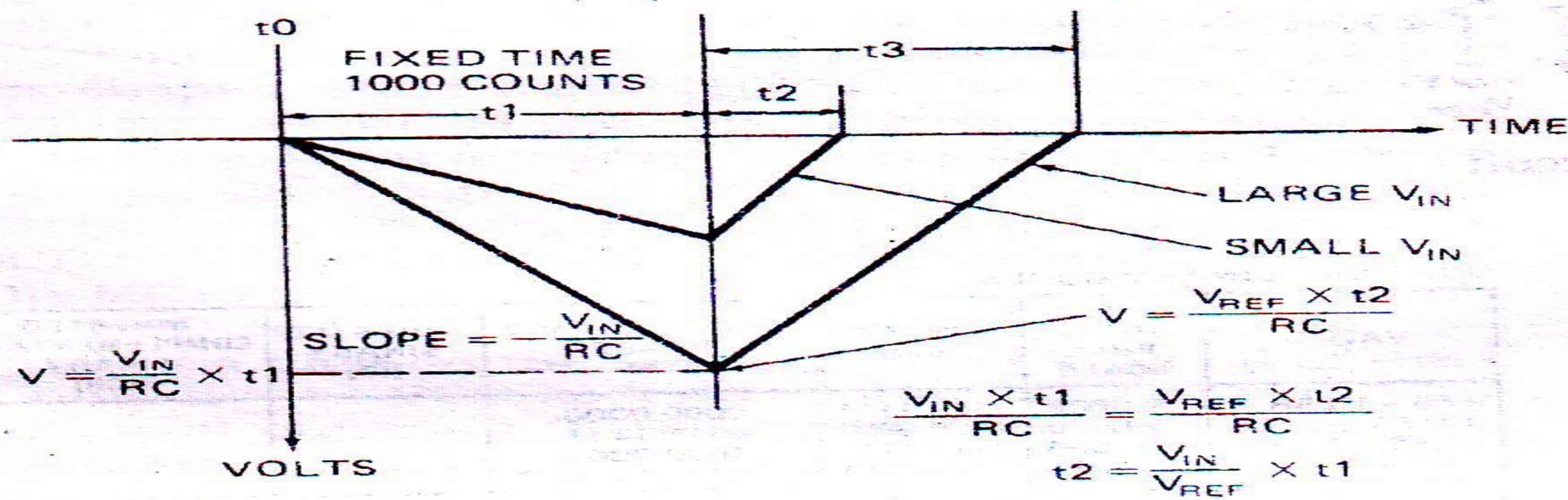
- Large number of bits of resolution at low cost

Disadvantage:

- Slow speed


1-MHz CLOCK
ANALOG
V_IN
INTEGRATOR
0.1 μF
COMPARATOR
10 kΩ
SWITCH
CONTROL
RESET
MSB
LATCH
BINARY OR BCD COUNTERS
LATCHES
DECODER/DRIVERS
V_REF = −1 V
CONTROL
CIRCUITS

(a)


t0
FIXED TIME
1000 COUNTS
t1
t2
t3
TIME
LARGE V_IN
SMALL V_IN
V = (V_REF × t2) / RC
SLOPE = − V_IN / RC
V = V_IN / RC × t1
(V_IN × t1) / RC = (V_REF × t2) / RC
t2 = V_IN / V_REF × t1
VOLTS

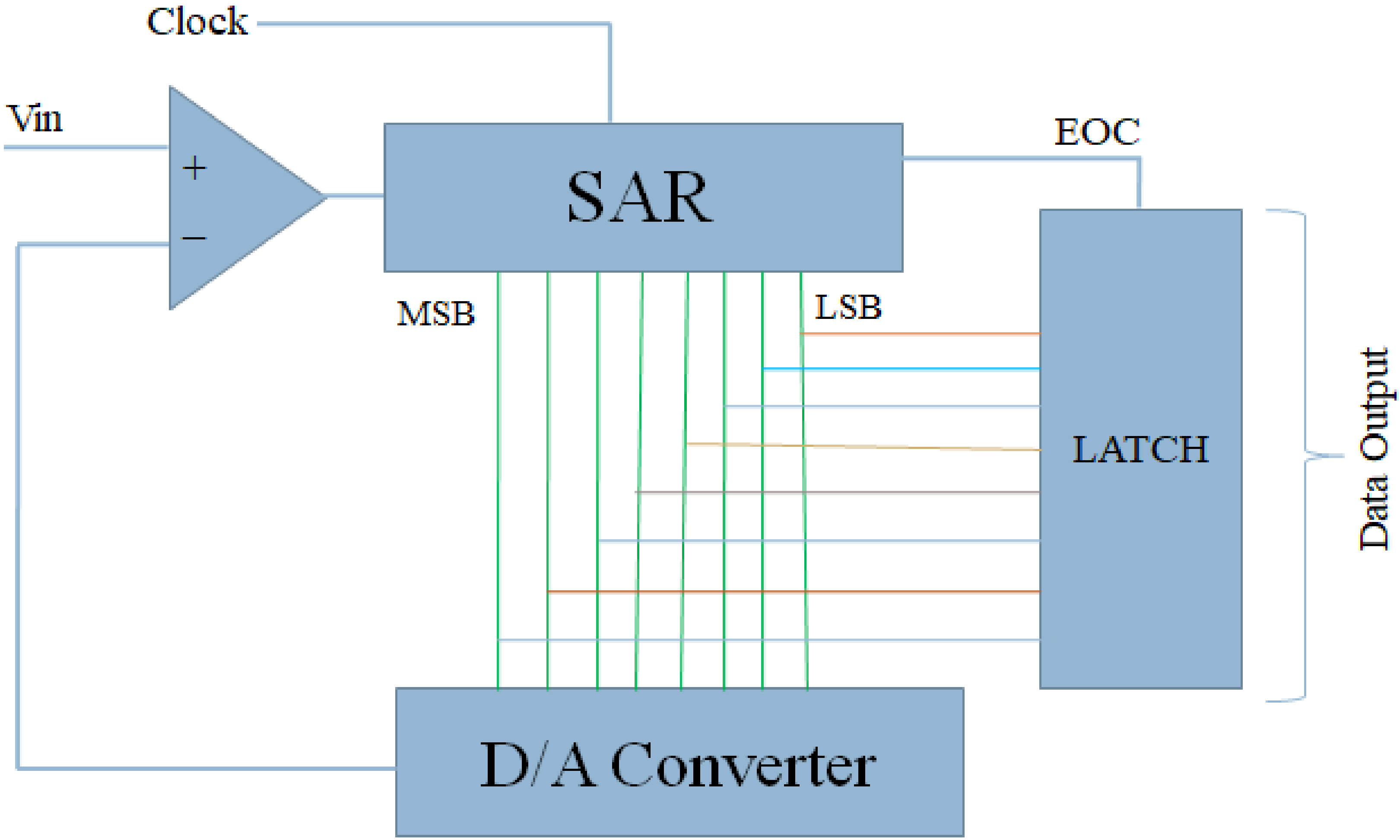
(b)

Successive Approximation Resister (SAR)

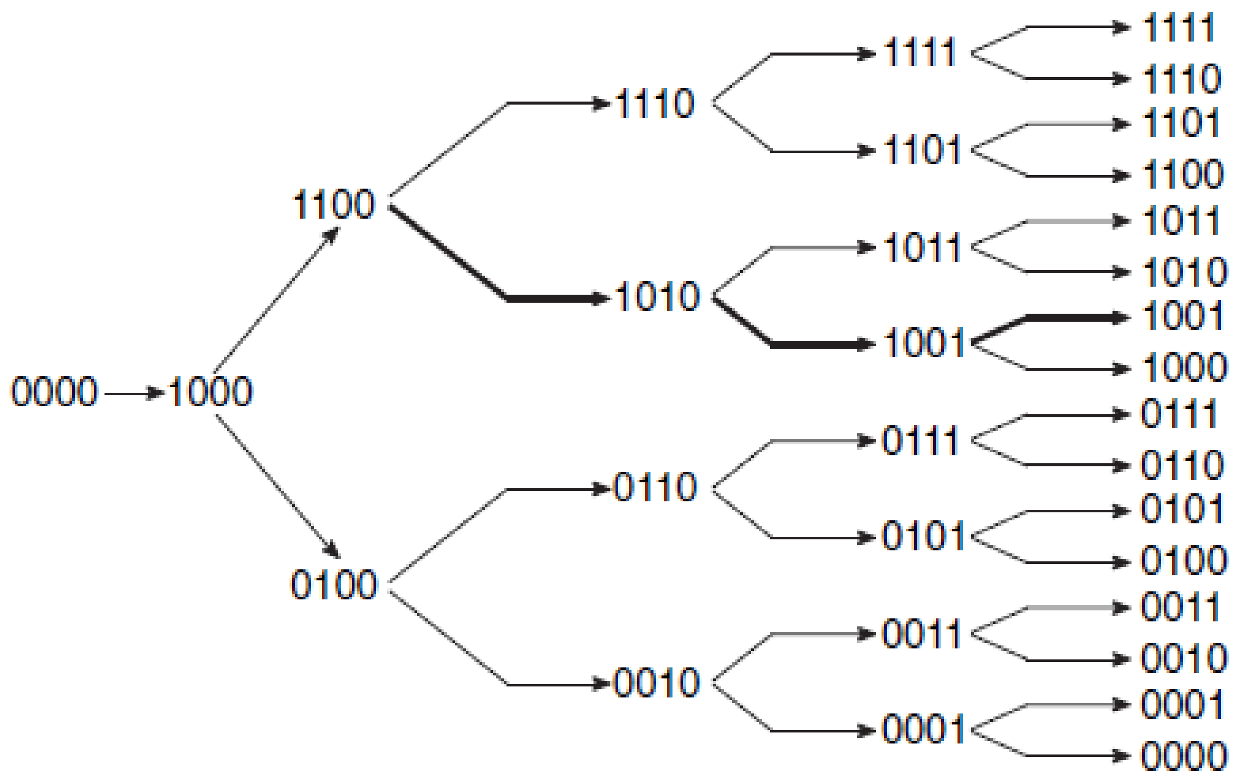
- The heart of this converter is *Successive Approximation Resister (SAR)*
- On the first clock pulse, at the start of a conversion cycle, the SAR outputs a high on its most-significant bit to the D/A converter
- The D/A converter and the amplifier convert this to a voltage and apply it to one input of a comparator
- If this voltage is higher than the input voltage on the other input of the comparator, the comparator output will go low and tell the SAR to turn off that bit- because it is too large
- If the voltage from the D/A converter is less than the input voltage, then the comparator output will be high , which tells the SAR to keep that bit on
- When the next clock pulse occurs, the SAR will turn on the next most-significant bit to the D/A converter

Successive Approximation Resister (SAR)

- Based on the answer this produces from the comparator , the SAR will keep or Reset this bit
- SAR will proceed in this way on down to the Least-significant bit adding each bit to the total in turn and using the signal from the comparator to decide whether to keep that bit in the result
- Only 9 clock pulses are required to do the actual conversion
- When the conversion is complete , binary results will be now on the parallel outputs of SAR
- SAR sends out an End-of-conversion(EOC) signal to indicate the conversion is complete
- EOC is used to strobe the binary result into latches , where it can be read by a microcomputer



8 Bit Successive approximation A/D converter



Conversion process in a successive approximation type A/D converter.

Successive Approximation Resister (SAR)

- **Advantages:**
  - Conversion time is very small.
  - Conversion time is constant and independent of the amplitude of the analog input signal VA.

- **Disadvantages:**
  - Circuit is complex.
  - The conversion time is more compared to flash type ADC.