Overview

Sensors

- Introduction to Sensors
- Workflow of a Sensor
- Classification of Sensors
- Sampling DAC and ADC conversion

Actuators

- Workflow of Actuator
- Classification of Actuators

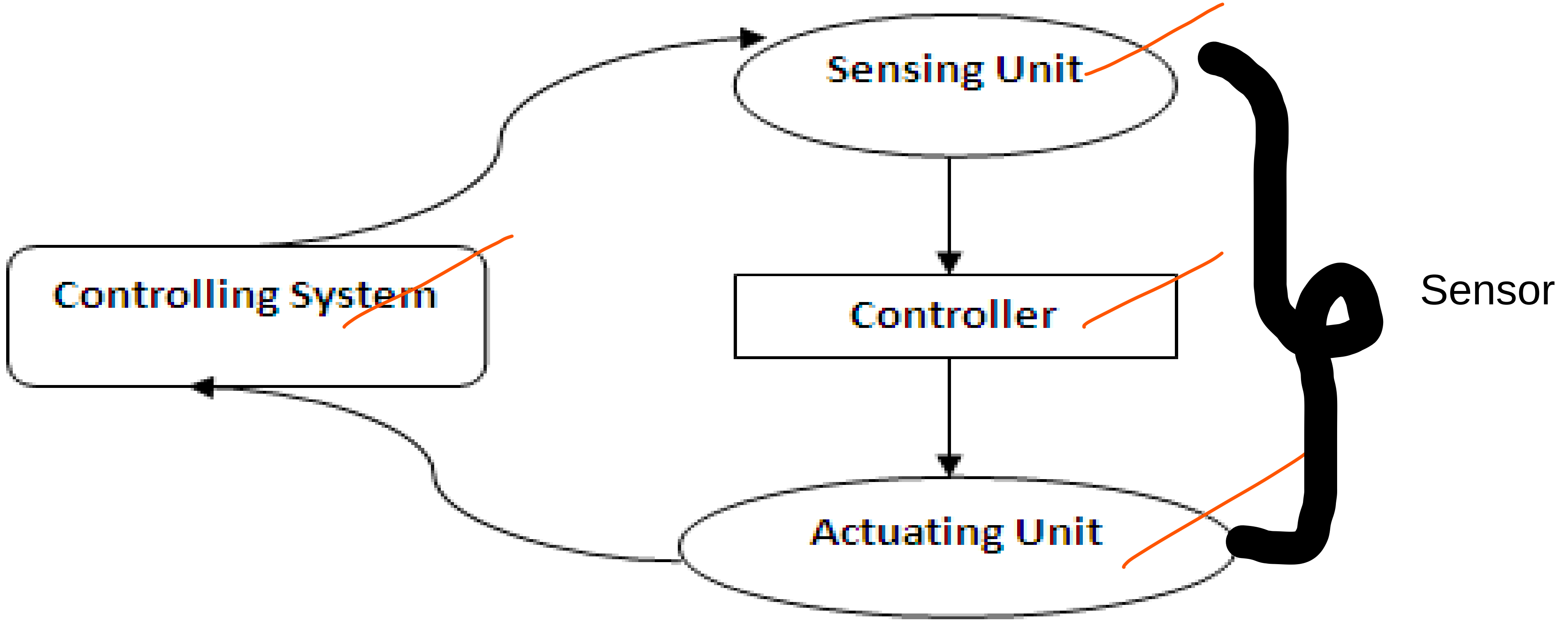
Self-study

- Types of Sensors
- Interfacing concepts to Embedded Systems.

Introduction to sensors

- Sensor is a device which gives a usable yield in response to a specific physical input.
- Sensor takes input as a physical quantity and the output may be optical, electrical or mechanical.
- Usually the output of a Sensor is presumed to be electrical and in rare cases optical or mechanical and Transducer is an active entity of a Sensor.
- A few examples of this are automatic sliding doors at convenience stores, paper towel dispensers in bathrooms, security systems commonly found in the workplace and also in the user interfaces of entertainment systems.
- All sensors fall into one of two categories Digital sensors and Analog sensors.
- Digital sensors speak the language of computers in zeros and ones, while analog sensors convey the world with a wide variance of values which must be converted to a digital number for computers to use.

Workflow of a Sensor in a typical system



Workflow of a Sensor in a typical system

- A system comprises of basically a Sensing unit, Controller and an Actuator.
- A Sensing unit comprises of a single sensor or components such as signal generators, filters, modulators and so on.
- Data generated from a sensing unit is fed in to a controller, controller process the data based on some of the controlling mechanisms to take decisions and outputs the event to the Actuating unit.
- An Actuating unit will consists of an actuator which may or may not be connected to a power supply and comes with a coupling mechanism embedded with actuator

Classification of Sensors

- Sensors identify the presence of energy or changes that occur or to allow the transfer of energy.
- Sensors receives signal through a Transducer and starts responding by converting into validate output to be easily understood.
- Commonly sensors change over a perceived signal into an **analog or digital signal** that is clear.

Analog Sensors

- An analog sensor will usually have two or three wires.
- **Three wire** variant has two wires for power and a third as an output for the sensor reading.
- These sensors usually give a voltage proportional to the specific changes in its environment.
- Two wire analog sensor will be connected like a voltage divider, so output will be a varying voltage from usually 0 to 5 volts.
- Depending on the input to the sensor-analog sensors are really great because analog sensors can be easily used without a microcontroller and could hook these analog sensors to trigger things like relays or some other functions.

Analog Sensors

Pros:

- Less quantization errors, low cost and requires less bandwidth because easily constructible by using less preprocessing requirements.
- Accurate since recording data is done through continuous wave forms to represent information.
- Configuring fault components is easier
- Good lifespan
- Low Weather dependencies
- Not expensive and easy to handle
- Easy to manipulate using mathematical formations and calculation.

Analog Sensors

Cons:

- Analog sensors posses’ unwanted variation when noise gets added.
- Analog sensors are measured with a scale henceforth at lower end they are cramped for errors.
- Due to the noise effect its consistence will be reduced and being reduced to its quality also.
- Transmitter and Receiver should be configured if there is a change in the deployment level.
- Security isn’t there for transmitting data.
- Saving data when needed is prone to errors.

Digital Sensors

- In general digital sensors will need to communicate with the microcontroller using a communication protocol.
- The three most common protocols are: **I^{2}C(Inter-Integrated circuit), SPI(serial Peripheral Interface) and 1-wire**.
- There are several others but these three are the most commonly used.
- For digital sensors always needs to find a library for the component that is been used in your application.

Digital Sensors

- In **I^2C protocol** usually it has **power and ground pins** and then it **communicates on two wires on SDA** (Serial Data line) and **SCL** (Serial Clock line) which are easily distinguished by looking at the silk screen on the sensor.
- Two wires don't really seem beneficial at first because some of the sensors that basically communicate on one output wire.
- Considering an example of the sensor which is an accelerometer and a gyro, this sensor has to output the data from the acceleration and the angle of orientation for the x y & z axis.
- So the I^2C is basically helps in reducing six different data points using only two wires, without I^2C two wire needs to take up six wires for micro controller which really want to use minimum amount of analog pins.
- One of the other benefits of I^2C is that, more than one sensor can share the same pair of wires, so accelerometer gyro and a compass and both of these would use the same two pairs.

Digital Sensors

- **SPI** uses a ground and uses four pins to communicate.
- Benefit of SPI is being a lot faster than I^2C and it doesn't require unique addresses.
- SPI can handle a lot more data so they're usually found in more complicated parts like a 2.4 gigahertz transceiver, henceforth it has to process a lot of data really quickly.
- The Pin SS(Slave Select) can be any digital output pin. MISO(Master Input Slave Output) and MOSI(Master Output Slave Input) are specified pins on the microcontroller, just like SDA and SCL.
- Slave select can be any digital output so want to leave that as high in the software and then can pull it low whenever application want to use this specific sensor, so that's how communication with multiple sensors using the same three bus line occurs.

Digital Sensors

- The last most common protocol is **one wire**, one wire is a lot slower than both of the other protocols but it only uses power ground and output wire and which can be seen in basic sensors like digital temperature sensor

Digital Sensors

Pros:

- Easy to implement because they are free from observational errors
- They are noise immune without any deterioration.
- Fast handling, less demanding for storage, solid resistance to noise, parallel preparing plausibility, conceivable outcomes, simple convey ability.
- Flexibility with framework change, utilization of institutionalized receiver and Transmitter.
- Security, you can include great encryption transmission.
- You can spare your information and recover when required.

Digital Sensors

Cons:

- Less accurate because it samples analog wave forms into few numbers and records them.
- Higher cost and depends on weather conditions.
- Have quantization errors, less accurate to finite set of data.
- More immune to noise..
- You can't correct defective parts effectively as there is programming additionally related with chips.
- Highly delicate relying upon dealing with and electrical resistance. Somewhere in the range of few voltage changes could harm the hardware inside couple of moments.
- You couldn't move propel chip innovation as programming is again related.
- Low life traverse as more Dependencies on external source.
- Sampling error is most basic on many cases.

Digital to Analog Converters (DAC)

- **Weighted resistors D/A converter**
- **R–2R ladder D/A converter**

Digital to Analog Converters (DAC)

Weighted resistors D/A converter

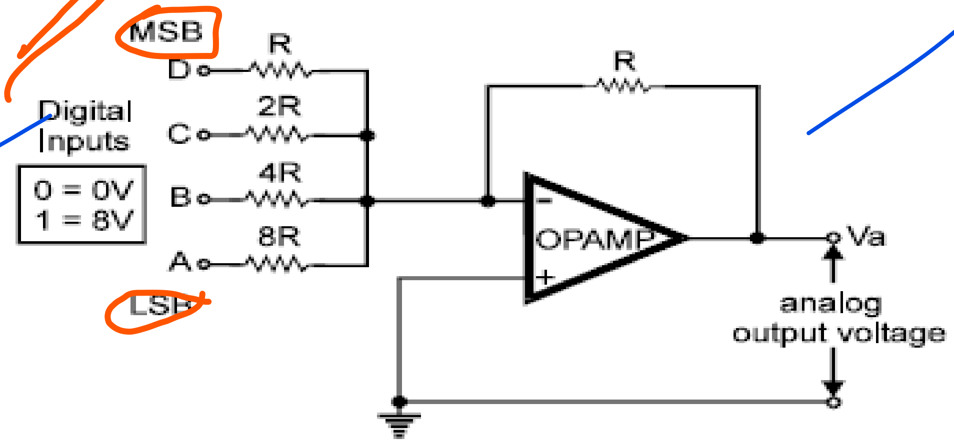
- The circuit of weighted resistors D/A converter is shown in **Figure**
- The circuit uses an summing amplifier which is an opamp here. The circuit uses a variable resistor network at the input terminal of the opamap with four resistors named as R, 2R, 4R and 8R with inputs for the circuit being termed as D, C, B and A.
- In the circuit input D is at MSB and A is at LSB.
- An *V DC voltage is connected to the circuit as level-1 logic assuming 0=0V and 1=8V.
- The circuit is being a summing amplifier; this circuit works as follows with output is given by the equations:

$$\mathbf{V_0 = -R * (D/R + C/2R + B/4R + A/8R)}$$

$$V = R * I$$

Digital to Analog Converters (DAC)

Weighted resistors D/A converter



Digital inputs				Analog output Voltage (V_a)
D	C	B	A	
0	0	0	0	0V
0	0	0	1	–1V
0	0	1	0	–2V
0	0	1	1	–3V
0	1	0	0	–4V
0	1	0	1	–5V
0	1	1	0	–6V
0	1	1	1	–7V
1	0	0	0	–8V
1	0	0	1	–9V
1	0	1	0	–10V
1	0	1	1	–11V
1	1	0	0	–12V
1	1	0	1	–13V
1	1	1	0	–14V
1	1	1	1	–15V

Weighted resistors D/A converter

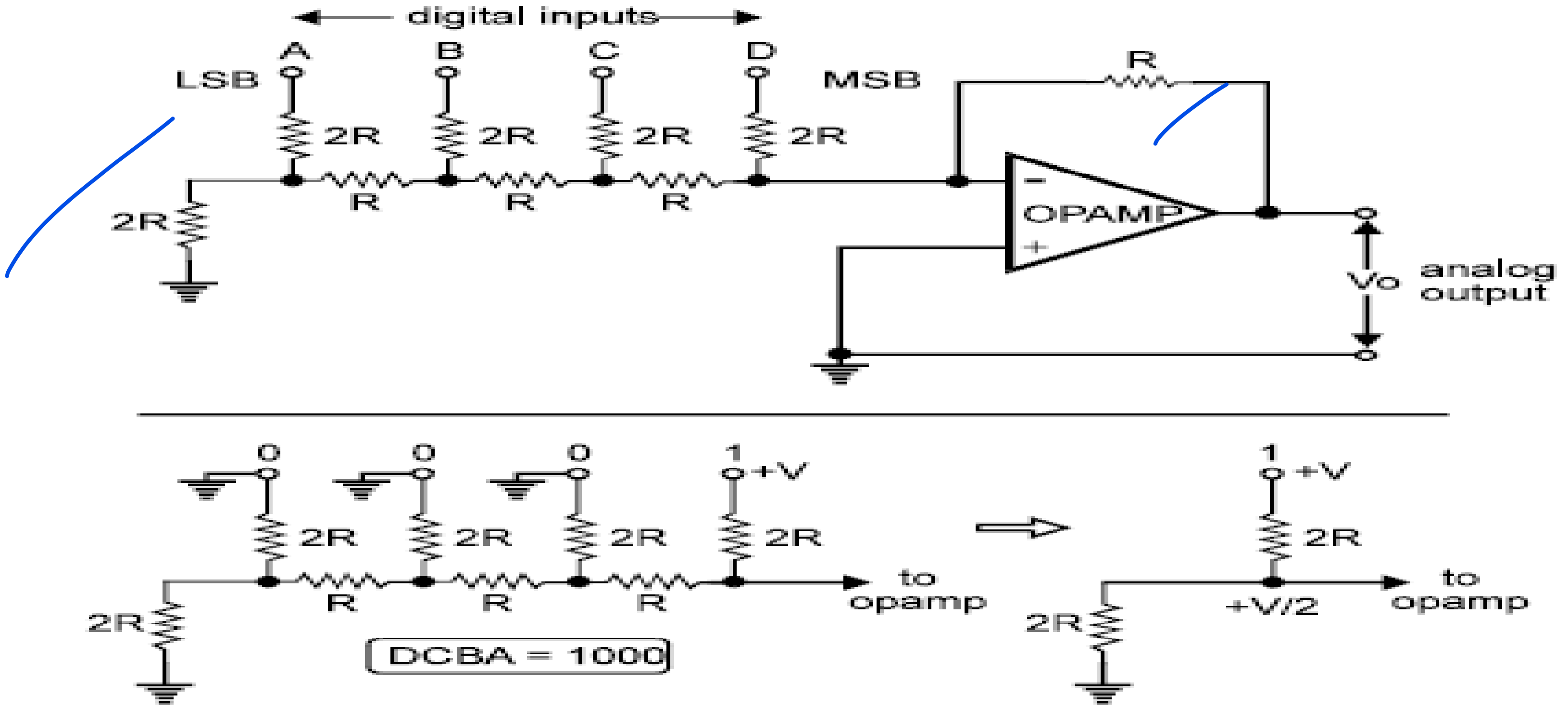
Some disadvantages of the circuit are:

- 1) Each resistor in the circuit has different value.
- 2) So error in value of each resistor adds up.
- 3) The value of resistor at MSB is the lowest. Hence, it draws more current.
- 4) Also, its heat & power dissipation is very high.
- 5) There is the problem of impedance matching due to different values of resistors.

R–2R ladder D/A converter:

R-2R ladder D/A converter is termed as Resistor network which has two resistors with values given as R and 2R, repeats in the entire circuit. In order to scale the output voltage an opamap is used.

like a ladder



R–2R ladder D/A converter:

Working Principle:

- Assuming there is no opamp in the circuit with digital input for DCBA=1000, circuit is reduced to the smallest level by giving its output by the equation below

$$\textbf{Output} = (2R/(2R + 2R)) * (+V) = V/2$$

- If input for DCBA=0100 output will be V/4.
- If input for DCBA=0010 output will V/8.
- If input for DCBA=0001 output will be V/16.
- The general formula for R-2R ladder, including opamp also will be

$$V_0 = --R * (D/2R + C/4R + B/8R + A/16R)$$

- Solving the above equation equation,

$$V_0 = --(V/2 + V/4 + V/8 + V/16)$$

- With this formula, for any combination of digital input its equivalent analog voltage can be calculated.

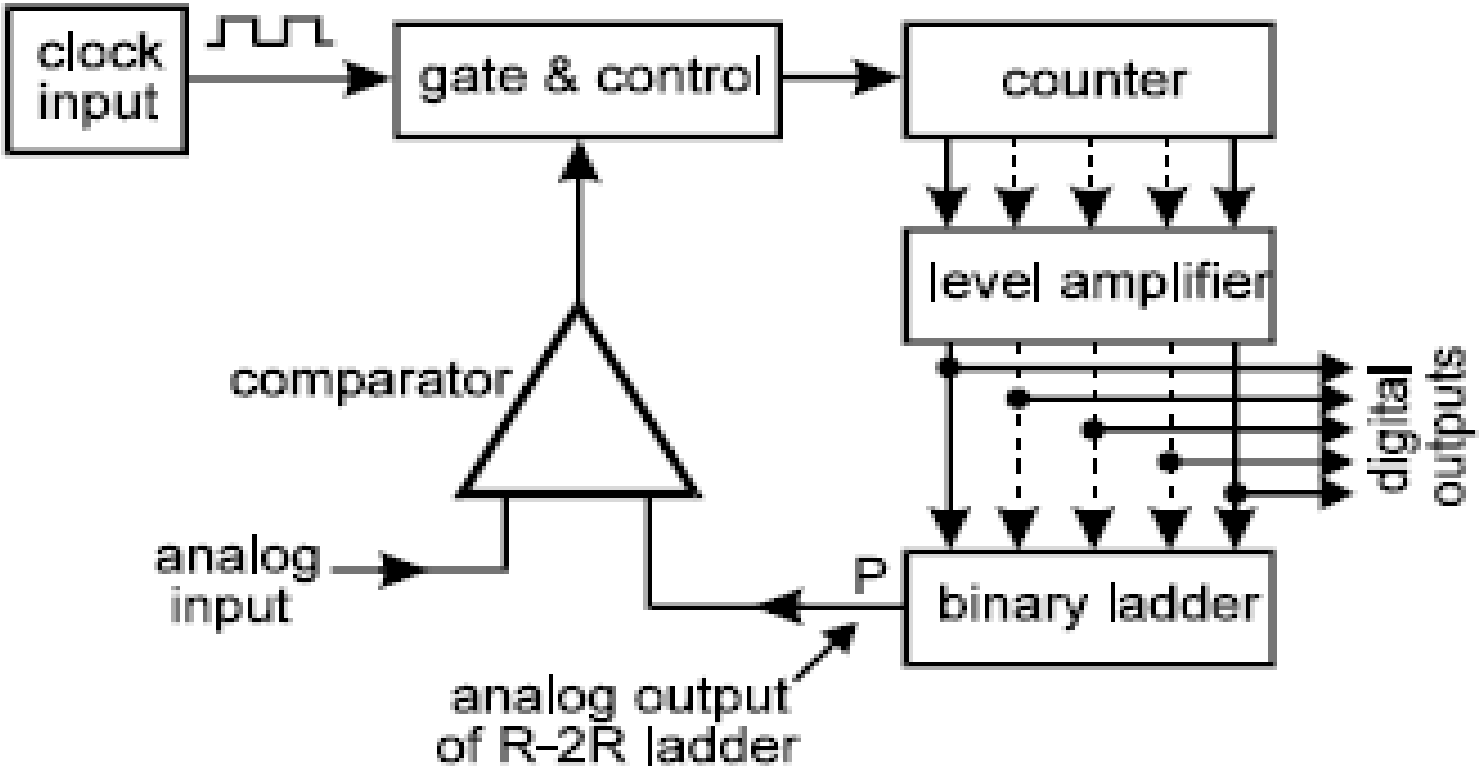
Analog to Digital Converters (ADC)

- **Counter type A/D converter**
- **Successive Approximation Method**

Counter type A/D converter

- In Counter type A/D converter shown a comparator is connected with one analog signal and the other input will be an analog output from the binary ladder.
- The clock generates square waves which are connected to gate-control block.
- When comparator output is HIGH (logic-1), clock pulse is connected to the counter else if comparator output is low (logic-0), clock pulse is cut off.
- These clock pulses are dependent on the analog voltage value.
- If analog voltage value is higher, it results in more number of clock pulses which are counted on the counter, producing a proportionate binary output.
- The output is again fed to level amplifier, which amplifies the counter output voltage and fed to binary ladder, which produces a proportionate analog voltage.

Counter type A/D converter



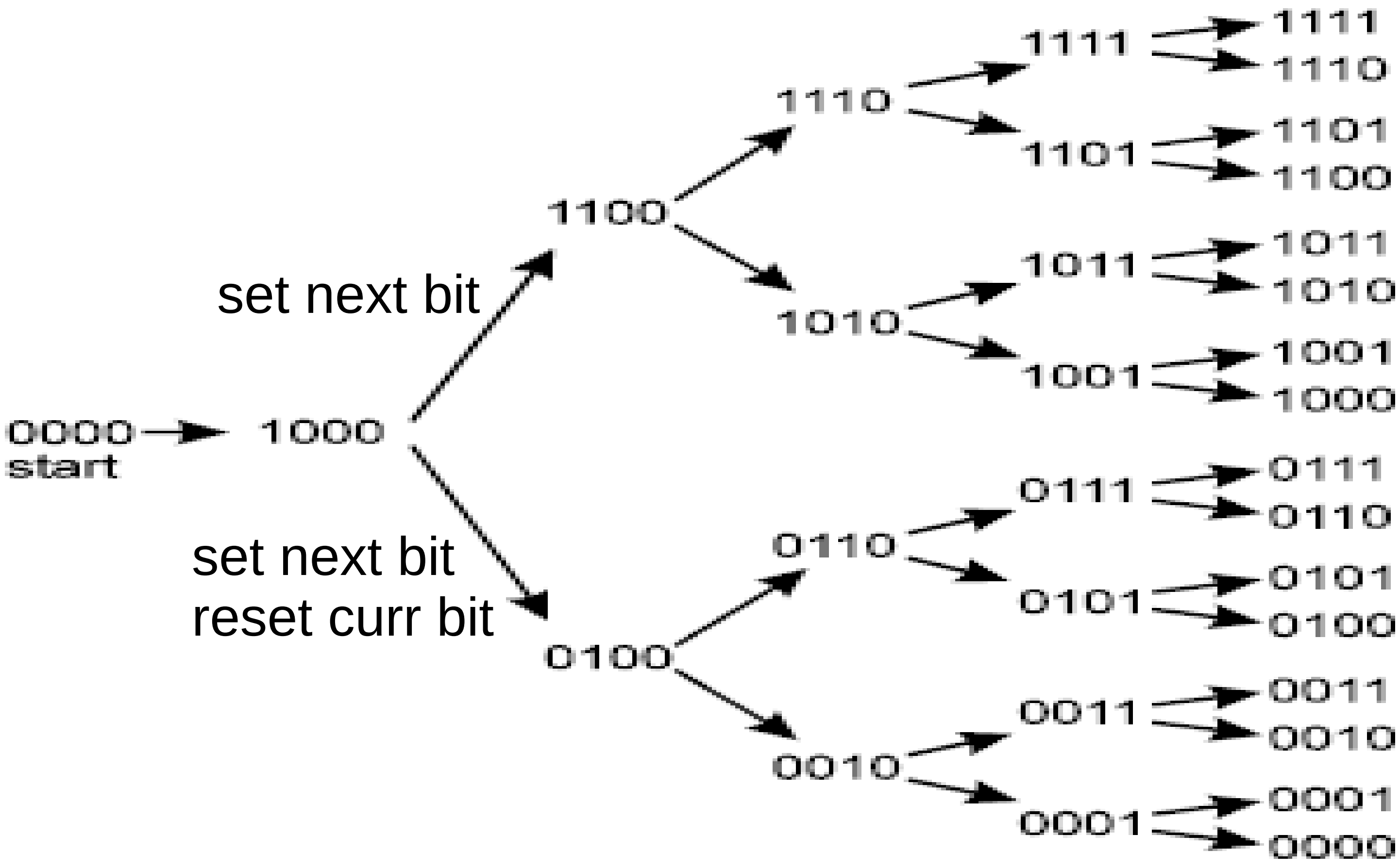
Counter type A/D converter

- Consider if circuit is on with initial value of circuit is 00000. If analog voltage=9V, there will be difference in input voltages of comparator, hence output will be HIGH.
- The counter counts the number of clock pulses generated and producing equivalent binary number whose output gradually changes from 0001, 0010, 0011 and so on.
- Hence the output 1001 is 9V, comparator will have both input voltages of same value resulting in output of LOW, so the gate will cutoff and counter stops counting, with final result is being 1001 In this way, any analog voltage can be converted into its equivalent digital output.

Successive Approximation Method

- Counter method discussed in the previous section requires longer duration for the conversion of analog signal into digital signal, since it starts always from 0000 until corresponding analog voltage is matched. This drawback is overcome by Successive Approximation method.

Successive Approximation Method



Successive Approximation Method

- In Successive approximation method shown in **Figure**, when unknown voltage (V_a) is applied, the circuit starts from 0000 and the output advances with each MSB as shown in Figure.
- The output of SAR does not increase incrementally at every step but it starts from high starting of MSB setting MSB (1000), the second (0100).
- Each time, SAR output is converted by binary ladder to equivalent analog voltage, which is then compared with the unknown voltage V_a. This comparison process goes on until binary equivalent of analog voltage is obtained.
- The comparison process goes on, in binary search style, until the binary equivalent of analog voltage is obtained.

Successive Approximation Method

In this way following steps are carried out during conversion

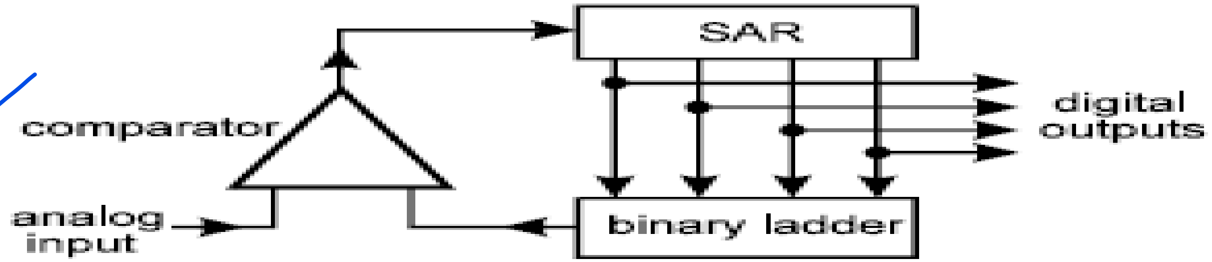
1) The unknown analog voltage (Va) is applied.

2) Starts up from 0000 and sets up first MSB 1000.

3) If Va > 1000, the first MSB is fixed.

4) If Va < 1000, the first MSB is removed and second MSB is set.

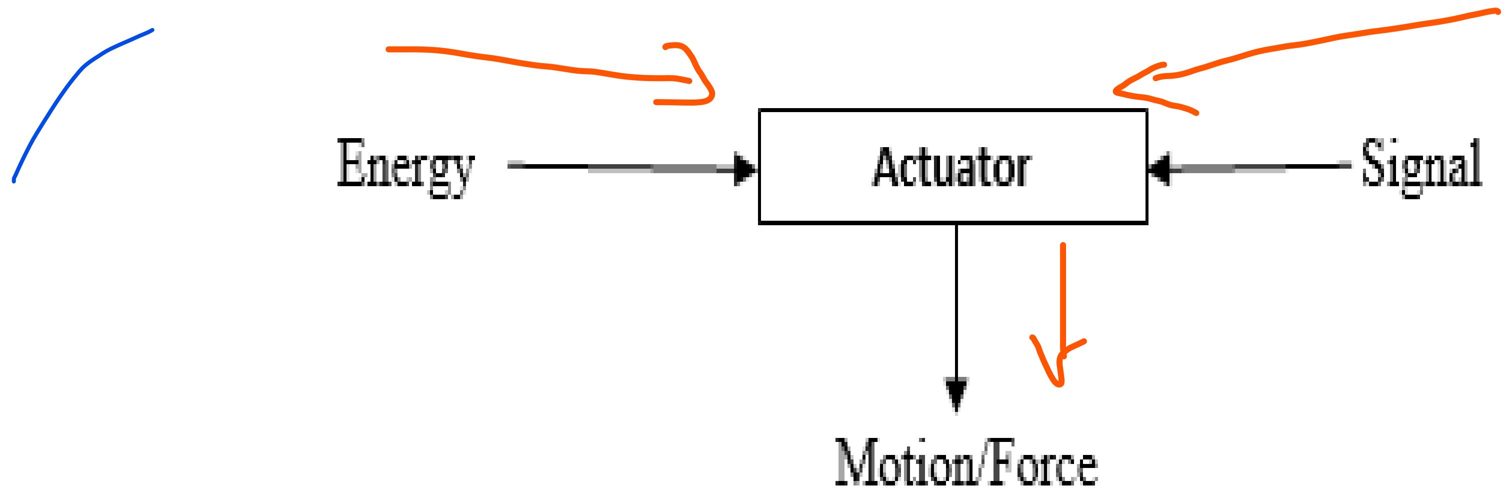
5) The fixing and removing the MSBs continues up to last bit (LSB), until equivalent binary output is obtained. The block diagram of successive approximation A/D converter is shown in **Figure.**



Actuators

- An Actuator is a component of a machine that is responsible for moving or controlling a mechanism or system. An Actuator requires a control signal and a source of energy. The control signal is relatively low energy and may be electric voltage or current, pneumatic or hydraulic pressure or human power.
  - **Hydraulic Actuators**
  - **Pneumatic Actuators**
  - **Electric Actuators**

Workflow of a Actuator in a system



Workflow of a Actuator in a system

- An actuator is a sort of engine that controls or moves instruments or frameworks.
- It takes pressure driven liquid, electric current or different wellsprings of energy and proselytes the energy to encourage the movement.
- Actuators are greatly valuable devices and have an assorted scope of employments in fields, for example, building, electronic designing and can be found in numerous sorts of hardware, for example, printers, autos. Most actuators deliver either direct (straight line), revolving (round) or oscillatory movement.
- Actuators permit more load, compel, control, roughness, speed and obligation cycle to be upheld. Speed is crucial particularly on account of movement control hardware. The way toward changing over wellsprings of energy into vitality has been an extraordinary development to apparatus.
- The productivity realized by actuators make them a practical contrasting option to human operation.

Classification of Actuators

- Hydraulic
- Pneumatic
- Electrical
- The mechanical motion gives an output in terms of linear, rotary or oscillatory motion.

Hydraulic Actuators

- Hydraulic systems are used to control and transmit power.
- A pump driven by a prime mover such as an electric motor creates a flow of fluid, in which the pressure, direction and rate of flow are controlled by valves.
- An actuator is used to convert the energy of fluid back into the mechanical power.
- The amount of output power developed depends upon the flow rate, the pressure drop across the actuator and its overall efficiency.
- Thus, hydraulic actuators are devices used to convert pressure energy of the fluid into mechanical energy.

Hydraulic Actuators

- Depending on the type of actuation, hydraulic actuators are classified as follows:

1. **Linear actuator**: For linear actuation (hydraulic cylinders).
2. **Rotary actuator**: For rotary actuation (hydraulic motor).
3. **Semi-rotary actuator**: For limited angle of actuation (semi-rotary actuator).

Hydraulic Actuators

- Hydraulic linear actuators, as their name implies, provide motion in a straight line.
- The total movement is a finite amount determined by the construction of the unit. They are usually referred to as cylinders, rams and jacks.
- All these items are synonymous in general use, although ram is sometimes intended to mean a single-acting cylinder and jack often refers to a cylinder used for lifting.
- The function of hydraulic cylinder is to convert hydraulic power into linear mechanical force or motion. Hydraulic cylinders extend and retract a piston rod to provide a push or pull force to drive the external load along a straight-line path.
- Continuous angular movement is achieved by rotary actuators, more generally known as a hydraulic motor. Semi-rotary actuators are capable of limited angular movements that can be several complete revolutions but 360^0 or less is more usual.

Pneumatic Actuators

- Pneumatic actuators are the devices used for converting pressure energy of compressed air into the mechanical energy to perform useful work.
- In other words, Actuators are used to perform the task of exerting the required force at the end of the stroke or used to create displacement by the movement of the piston.
- The pressurized air from the compressor is supplied to reservoir. The pressurized air from storage is supplied to pneumatic actuator to do work.

Pneumatic Actuators

- The air cylinder is a simple and efficient device for providing linear thrust or straight line motions with a rapid speed of response.
- Friction losses are low, seldom exceeds 5 % with a cylinder in good condition, and cylinders are particularly suitable for single purpose applications and /or where rapid movement is required.
- They are also suitable for use under conditions which preclude the employment of hydraulic cylinders that is at high ambient temperature of up to 200 to 250.
- Their chief limitation is that the elastic nature of the compressed air makes them unsuitable for powering movement where absolutely steady forces or motions are required applied against a fluctuating load, or where extreme accuracy of feed is necessary. The air cylinder is also inherently.

Pneumatic Actuators

- Pneumatic cylinders can be used to get linear, rotary and oscillatory motion. There are three types of pneumatic actuator: they are

i) Linear Actuator or Pneumatic cylinders

ii) Rotary Actuator or Air motors

iii) Limited angle Actuators

Electric Actuators

- An electric actuator is basically a geared motor.
- The motor can be of various voltages and is the primary torque-generating component.
- To prevent heat damage from overwork or excessive current draw, electric actuator motors are usually equipped with a thermal overload sensor embedded in the motor windings.
- This sensor is wired in series with the power source and opens the circuit should the motor be overheated, then closes the circuit when the motor reaches a safe operating temperature.

Electric Actuators

- An electric motor consists of an armature, an electrical winding, and a gear train.
- When power is supplied to the winding, a magnetic field is generated causing the armature to rotate.
- The armature will rotate as long as there is power to the windings when the power is cut, the motor stops.
- Standard end of travel limit switches, which are a necessity for an electric actuator, handle this task.

Electric Actuators

- **Types of Motors:** There are two types of motors used for electric actuators: unidirectional and bidirectional (commonly known as reversing motors).
- **Unidirectional motors** are motors in which the armature rotates in one direction, causing the valve to rotate in one direction. These actuators are typically used with a ball valve and rotate in 90 or 180 degree increments strictly for an on/off type of service.
- **Reversing motors** are motors in which there are two sets of windings allowing the armature to rotate in either direction depending on which set of windings is powered. One set of windings controls the clockwise direction for closing a valve, while the other set of windings controls the counter-clockwise direction for opening the valve. A major benefit of a bidirectional actuator is precise flow control, as the actuator is not required to travel the full stroke to begin the reverse stroke.

Electric Actuators

- Electric actuators rely on a gear train, which is coupled directly from the motor to enhance the motor torque and dictate the output speed of the actuator.
- The only way to change the output speed is to install a cycle length control module. This module allows an increase in cycle time only. If a decrease in cycle time is required, an alternate actuator with the desired cycle time and proper output torque must be used.

Self-Study

Types of Sensors

- **Acoustic and sound sensors**
- **Automotive sensors**
- **Chemical Sensors**
- **Environmental Sensors**

Interfacing concepts to embedded systems

- **Characteristics of Embedded Systems**