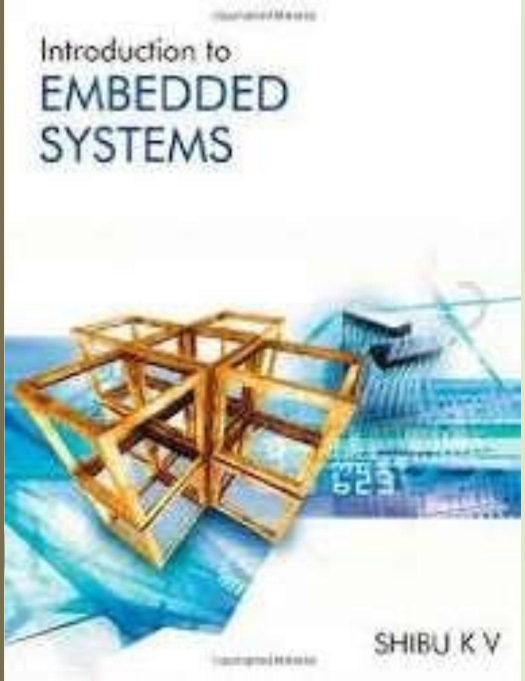


Introduction to

EMBEDDED SYSTEM

(2nd Edition)

SHIBU K V

What is an Embedded System?

- An embedded system is an electronic/electro-mechanical system designed to perform a specific function and a combination of both hardware and firmware (software).
- Every embedded system is unique and the hardware as well as the firmware is highly specialized to the application domain.
- Embedded systems are becoming an inevitable part of any product or equipment in all fields including household appliances, telecommunications, medical equipment, industrial control, consumer products, etc.

Embedded Systems vs General Computing Systems

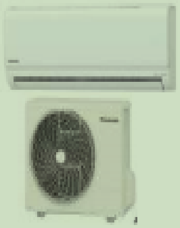
Criteria	General Purpose Computing System	Embedded System
Contents	A system which is a combination of a generic hardware and a General Purpose Operating System for executing a variety of applications.	A system which is a combination of special purpose hardware and embedded OS for executing a specific set of applications.
OS	It contains a general purpose operating system (GPOS).	It may or not contain an operating system for functioning.
Alterations	Applications are alterable (programmable) by the user. (It is possible for the end user to re-install the OS and also add or remove user applications.)	The firmware of the embedded system is pre-programmed and it is non-alterable by the end-user.
Key factor	Performance is the key deciding factor in the selection of the system. Faster is better.	Application specific requirements (like performance, power requirements, memory usage, etc.) are key deciding factors.
Power Consumption	More	Less
Response Time	Not critical	Critical for some applications
Execution	Need not be deterministic	Deterministic for certain types of ES like 'Hard Real Time' systems.

Major Application Areas of ES

The application areas and the products in the embedded domain are countless. A few of the important domains and products are listed below:

i. Consumer electronics: Camcorders, cameras, etc.

ii. Household appliances: Television, DVD players, washing machine, fridge, microwave oven, etc.



iii. Home automation and security systems: Air conditioners, sprinklers, intruder detection alarms, closed circuit television cameras, fire alarms, etc.

iv. Automotive industry: Anti-lock breaking systems (ABS), engine control, ignition systems, automatic navigation systems, etc.

v. Telecom: Cellular telephones, telephone switches, handset multimedia applications, etc.

Major Application Areas of ES (Cont'd)

vi. Computer peripherals: Printers, scanners, fax machines, etc.

vii. Computer Networking systems: Network routers, switches, hubs, firewalls, etc.

viii. Healthcare: Different kinds of scanners, EEG, ECG machines etc.

ix. Measurement & Instrumentation: Digital multi meters, digital CROs, logic analyzers PLC systems, etc.

x. Banking & Retail: Automatic teller machines (ATM) and currency counters, point of sales (POS).

xi. Card Readers: Barcode, smart card readers, hand held devices, etc.

Purpose of Embedded Systems

Embedded systems are used in various domains like consumer electronics, home automation, telecommunications, automotive industry, healthcare, control & instrumentation, retail and banking applications, etc. Within the domain itself, according to the application usage context, they may have different functionalities. Each embedded system is designed to serve the purpose of any one or a combination of the following tasks:

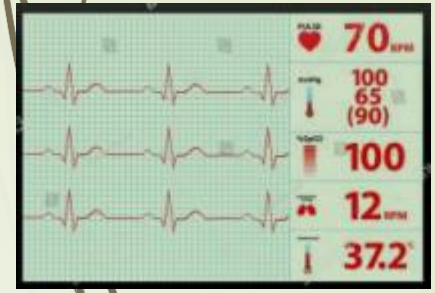
- Data collection/Storage/Representation
- Data Communication
- Data (signal) processing
- Monitoring
- Control
- Application specific user interface

(i) Data Collection/Storage/Representation

- Embedded systems designed for the purpose of data collection performs acquisition of data from the external world.
- Data collection is usually done for storage, analysis, manipulation and transmission.
- The term "data" refers all kinds of information, such as text, voice, image, video, electrical signals and any other measurable quantities.
- Data can be either analog (continuous) or digital (discrete).
- Embedded systems with analog data capturing techniques collect data directly in the form of analog signal whereas embedded systems with digital data collection mechanism converts the analog signal to the digital signal using analog to digital (A/D) converters and then collects the binary equivalent of the analog data.
- If the data is digital, it can be directly captured without any additional interface by digital embedded systems.
- The collected data may be stored directly in the system or may be transmitted to some other systems or it may be processed by the system or it may be deleted instantly after giving a meaningful representation.
- These actions are purely dependent on the purpose for which the embedded system is designed.

(i) Data Collection/Storage/Representation (Cont'd)

- Embedded system designed for pure measurement applications **without storage**, used in control and instrumentation domain, <u>collects</u> data and <u>gives</u> a meaningful representation of the collected data by means of graphical representation or quantity value and <u>deletes</u> the collected data when new arrives at the data collection terminal.
- Analog and digital CROs without storage memory are typical **examples** of this. Any measuring equipment used in the medical domain **for monitoring without storage functionality** also comes under this category.
- A digital camera is a typical **example** of an embedded system with data collection/storage/representation of data. Images are **captured** and the captured image may be **stored** within the memory of the camera. The captured image can also be **presented** to the user through a graphic LCD unit.



(ii) Data Communication

- Embedded data communication systems are deployed in applications from complex satellite communication systems to simple home networking systems.
- The data collected by an embedded terminal may require transferring of the same to some other system **located remotely**.
- The transmission is achieved either by a wire-line medium or by a wire-less medium.
- Wire-line medium was the most common choice in **all olden days embedded systems**.
- As technology is changing, wireless medium is becoming the standard for data communication in embedded systems. It offers cheaper connectivity solutions and make the **communication link** free from **the hassle of wire bundles.**

(ii) Data Communication (Cont’d)

- The data collecting embedded terminal itself can incorporate data communication units like Wireless modules (Bluetooth, ZigBee, Wi-Fi, EDGE, GPRS, etc.) or wire-line modules (RS-232C, USB, TCP/IP, PS2,etc).


- Certain embedded systems act as a dedicated transmission unit between the sending and receiving terminals, offering sophisticated functionalities like **data packetizing**, **encrypting** and **decrypting**.
- Network hubs, routers, switches, etc. are typical examples of dedicated data transmission embedded systems.

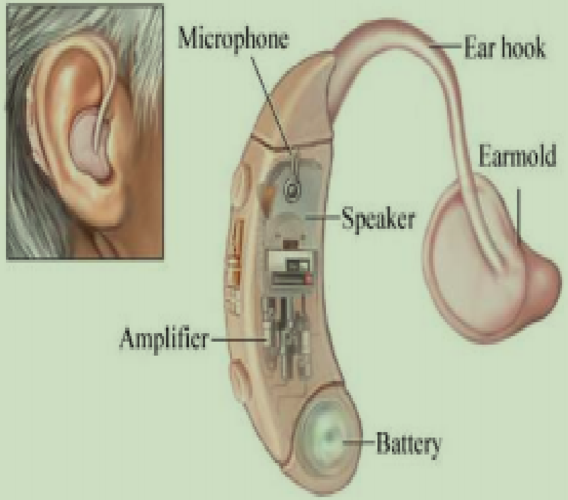


- They act as mediators in data communication and provide various features like **data security**, **monitoring** etc.



(iii) Data (Signal) Processing

- The data (voice, image, video, electrical signals and other measurable quantities) collected by embedded systems may be used for various kinds of data processing.
- Embedded systems with signal processing functionalities are employed in applications demanding signal processing like **speech coding**, **synthesis**, **audio video codec**, **transmission applications**, etc.
- A digital hearing aid is a typical example of an embedded system employing data processing. Digital hearing aid improves the hearing capacity of hearing impaired persons.



(iv) Monitoring

- Almost all embedded products coming under **the medical domain** are with monitoring functions only.
- They are used **for determining the state of some variables using input sensors**. They cannot impose control over variables.
- A very good **example** is the electro cardiogram (ECG) machine for monitoring the heartbeat of a patient. The machine is intended to do the monitoring of the heartbeat of a patient but it cannot impose control over the heartbeat. The sensors used in ECG are the different electrodes connected to the patient's body.
- Other **examples** with monitoring function are measuring instruments **like** digital CRO, digital multimeters, logic analyzers., etc. used in control & instrumentation applications. They are used **for knowing (monitoring) the status of some variables like** current, voltage, etc. They cannot control the variables in turn.

(v) Control

- Embedded systems with control functionalities impose control over some variables according to the changes in input variables.
- A system with control functionality contains both sensors and actuators.
- Sensors are connected to the input port for capturing the changes in environmental variable or measuring variable.
- The actuators connected to the output port are **controlled according to the changes in the input variable** to put an impact on the controlling variable to bring the controlled variable **to the specified range.**
- Air conditioner system used in our home **to control the room temperature** to a specified limit is a typical example for embedded system for control purpose. An air conditioner contains a room temperature sensing element (sensor) which may be thermistor and a handheld unit for setting up (feeding) the desired temperature.

(v) Control (Cont'd)

- The handheld unit may be connected to the central embedded unit residing inside the air conditioner through a wireless link or through a wired link.
- The air compressor unit acts as the actuator. The compressor is controlled according to the current room temperature and the desired temperature set by the end user.
- **The input variable** is the current room temperature and **the controlled variable** is also the room temperature. The controlling variable is cool air flow by the compressor unit.
- If the controlled variable and input variable are not at the same value, the controlling variable tries to equalize them through taking actions on the cool air flow.

(vi) Applications specific user interface

- Buttons, switches, keypad, lights, speakers, display units, etc. are application-specific user interfaces.
- Mobile phone is an example of application specific user interface. In mobile phone, the user interface is provided through the keypad, graphic LCD module, system speaker, vibration alert, etc.

Fig. 1.6 An embedded system with an application-specific user interface (Photo courtesy of Nokia Mobile Handsets (www.nokia.com))

2.3 Sensors and Actuators

- A **sensor** is a transducer device that converts energy from one form to another for any measurement or control purpose.
  - The changes in system environment or variables are detected by the sensors connected to the input port of the embedded system.
- **Actuator** is a form of transducer device (mechanical or electrical) which converts signals to corresponding physical action (motion). Actuator acts as an output device.
  - If the embedded system is designed for any controlling purpose, the system will produce some changes in the controlling variable to bring the controlled variable to the desired value.
  - It is achieved through an actuator connected to the output port of the embedded system.

Cont’d

- If the embedded system is designed for monitoring purpose only, then there is no need for including an actuator in the system.
- For example, take the case of an ECG machine. It is designed to monitor the heart beat status of a patient and it cannot impose a control over the patient’s heart beat and its order. The sensors used here are the different electrode sets connected to the body of the patient. The variations are captured and presented to the user (may be a doctor) through a visual display or some printed chart.

I/O Subsystem

- **The I/O subsystem** of the embedded system facilitates the interaction of the embedded system with the external world.
- The interaction happens through the sensors and actuators connected to the input and output ports respectively of the embedded system.
- The **sensors** may not be directly interfaced to the input ports, instead they may be interfaced through signal conditioning and translating systems like ADC, optocouplers, etc.

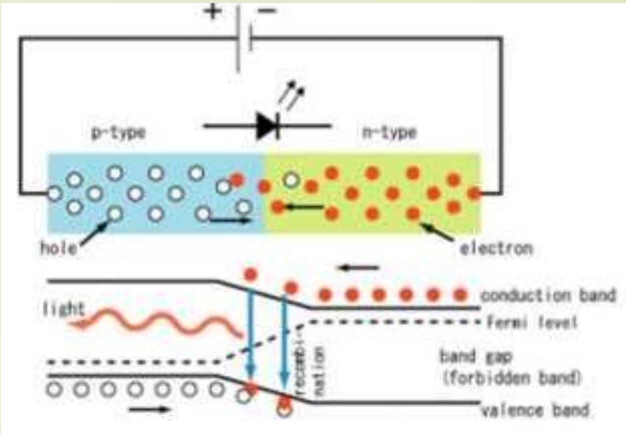
Cont’d

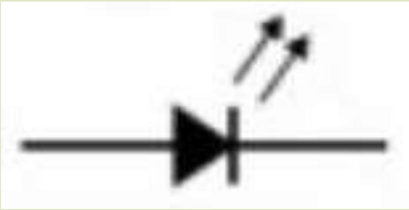
- Light Emitting Diode (LED)
- 7-Segment LED Display
- Optocoupler
- Stepper Motor
- Relay
- Piezo Buzzer
- Push Button Switch
- Keyboard
- Programmable Peripheral Interface (PPI)

Light Emitting Diode (LED)

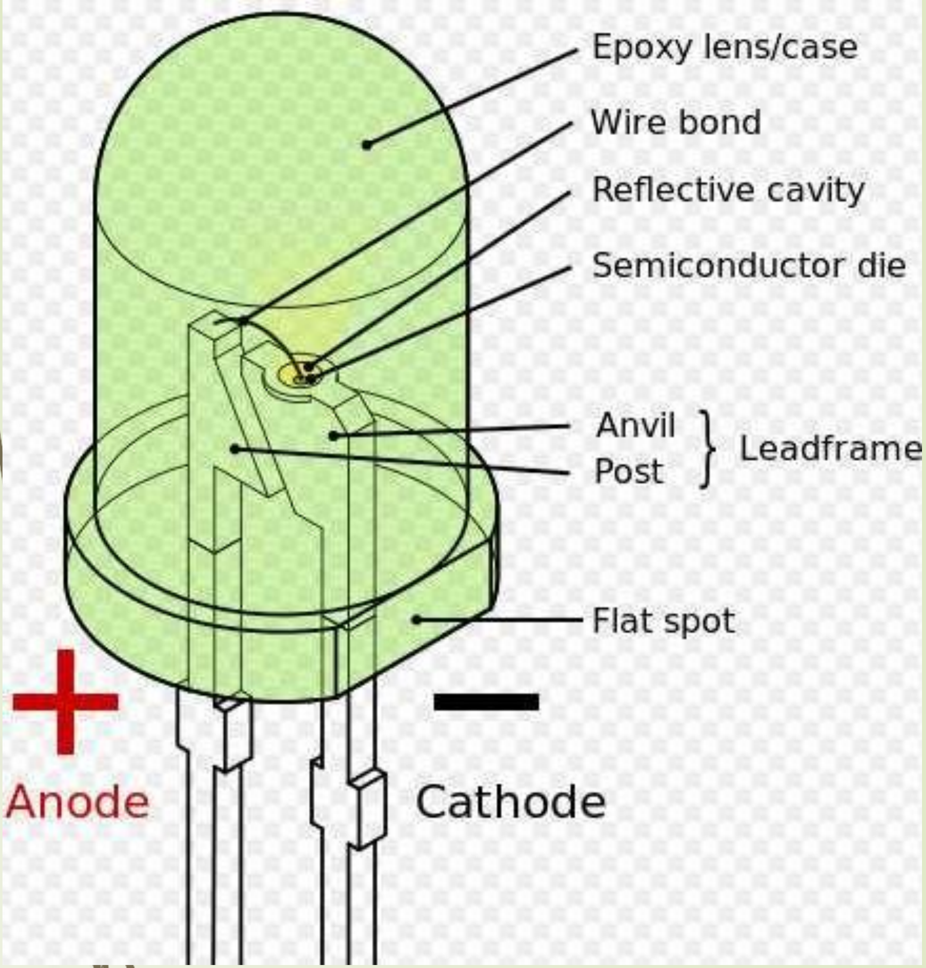
- **LED** is an important output device for visual indication in any embedded system. LED can be used as an indicator for the status of various signals or situations. Typical examples are indicating the presence of power conditions like ‘Device ON’, ‘Battery low’ or ‘Charging of battery’ for a battery operated handheld embedded devices.

- LED is a **p-n junction diode** and it contains an anode and a cathode. For proper functioning of the LED, the anode of it should be connected to +ve terminal of the supply voltage and cathode to the –ve terminal of the supply voltage. The current flowing through the LED must be limited to a value below the maximum current that it can conduct. A resistor is used in series between the power supply and the LED to limit the current through the LED.





Cont'd



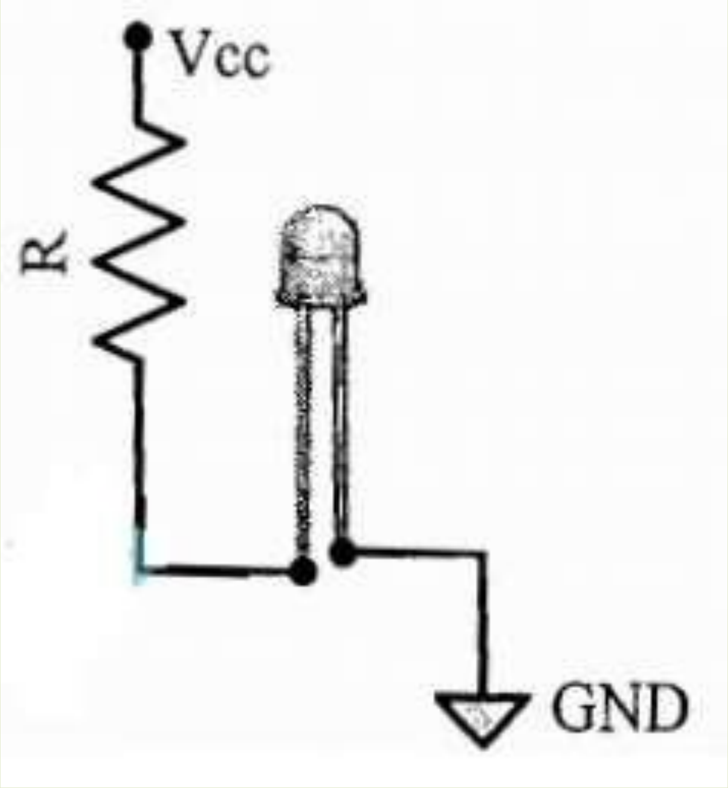
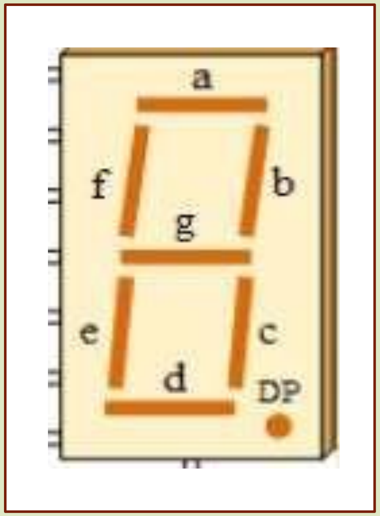


Figure. LED Interfacing

$$R = \frac{(V - V_{LED})}{I}$$

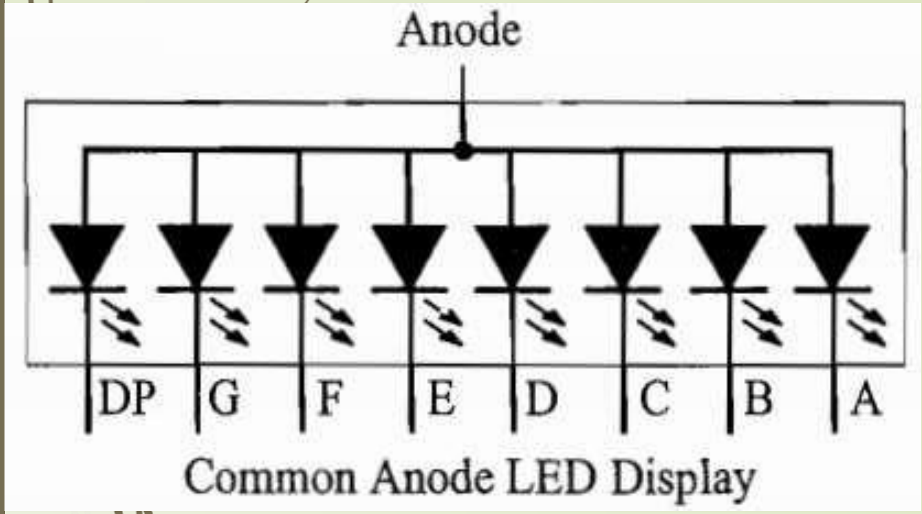
7- Segment LED Display

- The **7-segment LED display** is an output device for displaying alphanumeric characters. It contains 8 light-emitting diode (LED) segments arranged in a special form. Out of the 8 LED segments, 7 are used for displaying alphanumeric characters and 1 is used for representing 'decimal point' in decimal number display.
- The LED segments are named A to G and the decimal point LED segment is named as DP.



Cont'd

- The 7-segment LED displays are available in two different configurations, namely; Common Anode and Common Cathode. In the common anode configuration, the anodes of the 8 segments are connected commonly whereas in the common cathode configuration, the 8 LED segments share a common cathode line.



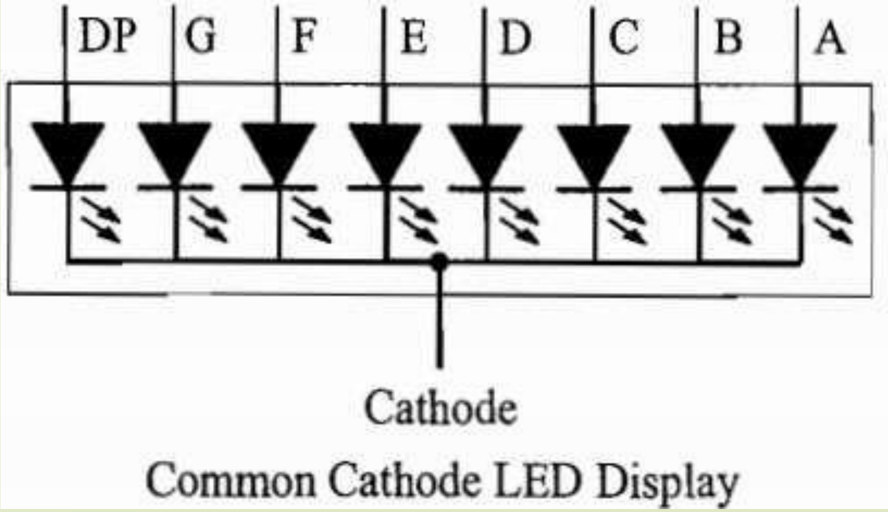
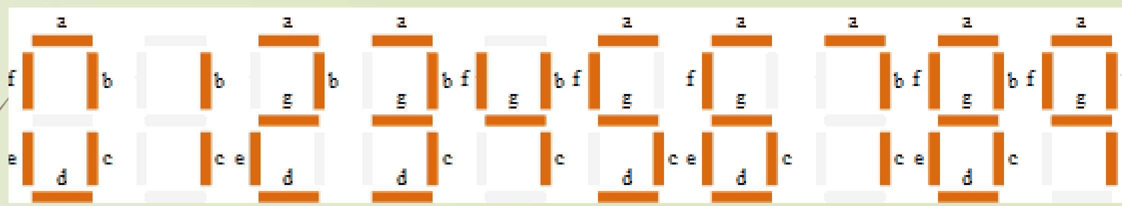
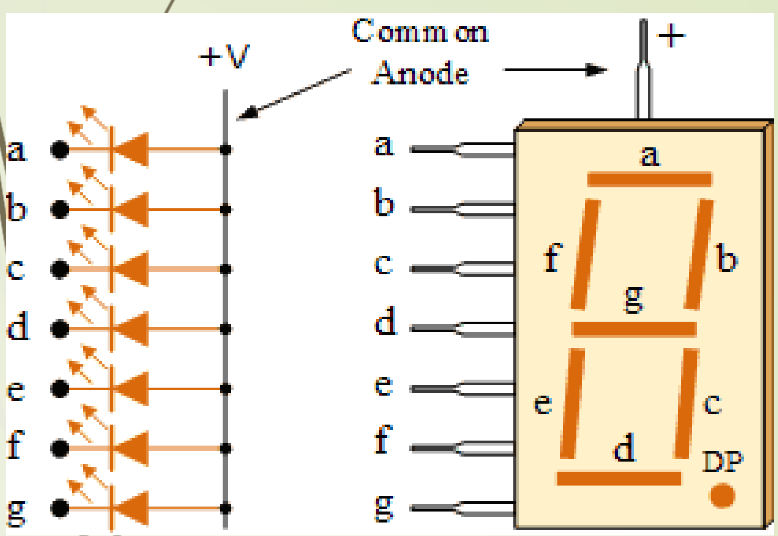


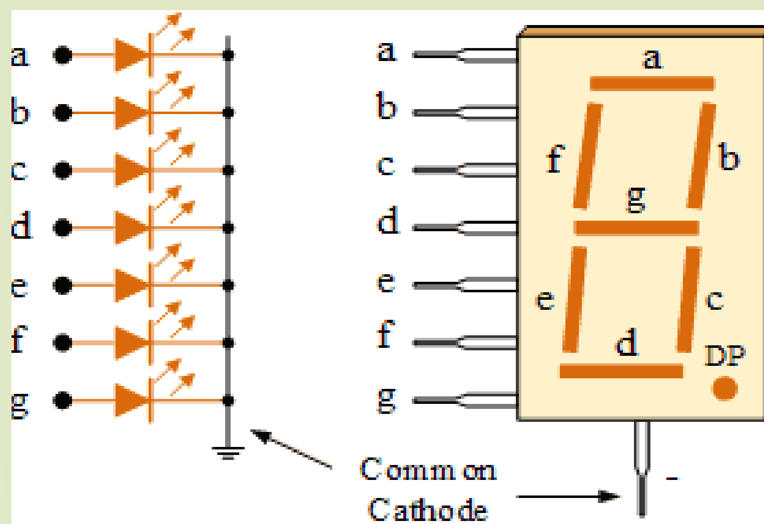
Figure Common anode and cathode configurations of a 7-segment LED Display

Cont’d

- 7-segment LED display is a popular choice for low cost embedded applications like, Public telephone call monitoring devices, point of sale terminals, etc.







Optocoupler

- Optocoupler is a solid state device to isolate two parts of a circuit.
- Optocoupler combines an LED and a photo-transistor in a single housing (package). Figure illustrates the functioning of an optocoupler device.
- Figure illustrates the functioning of an optocoupler device.

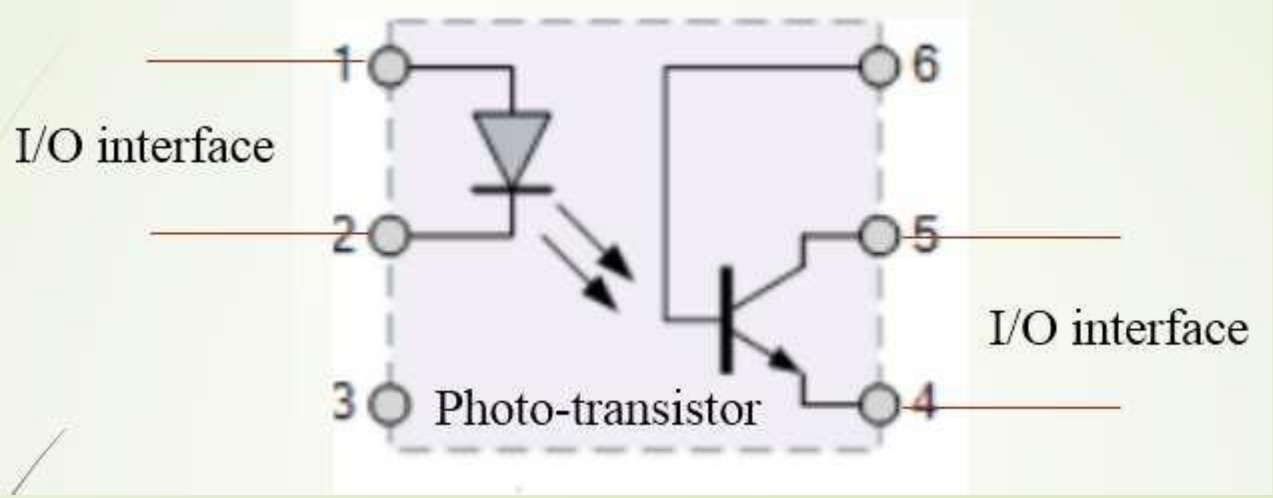


Figure. An optocoupler device

Cont’d

- In electronic circuits, an optocoupler is used for suppressing interference in data communication, circuit isolation, high voltage separation, simultaneous separation and signal intensification, etc.
- Optocouplers can be used in either input circuits or in output circuits.
- Figure illustrates the usage of optocoupler in input circuit and output circuit of an embedded system with a microcontroller as the system core.

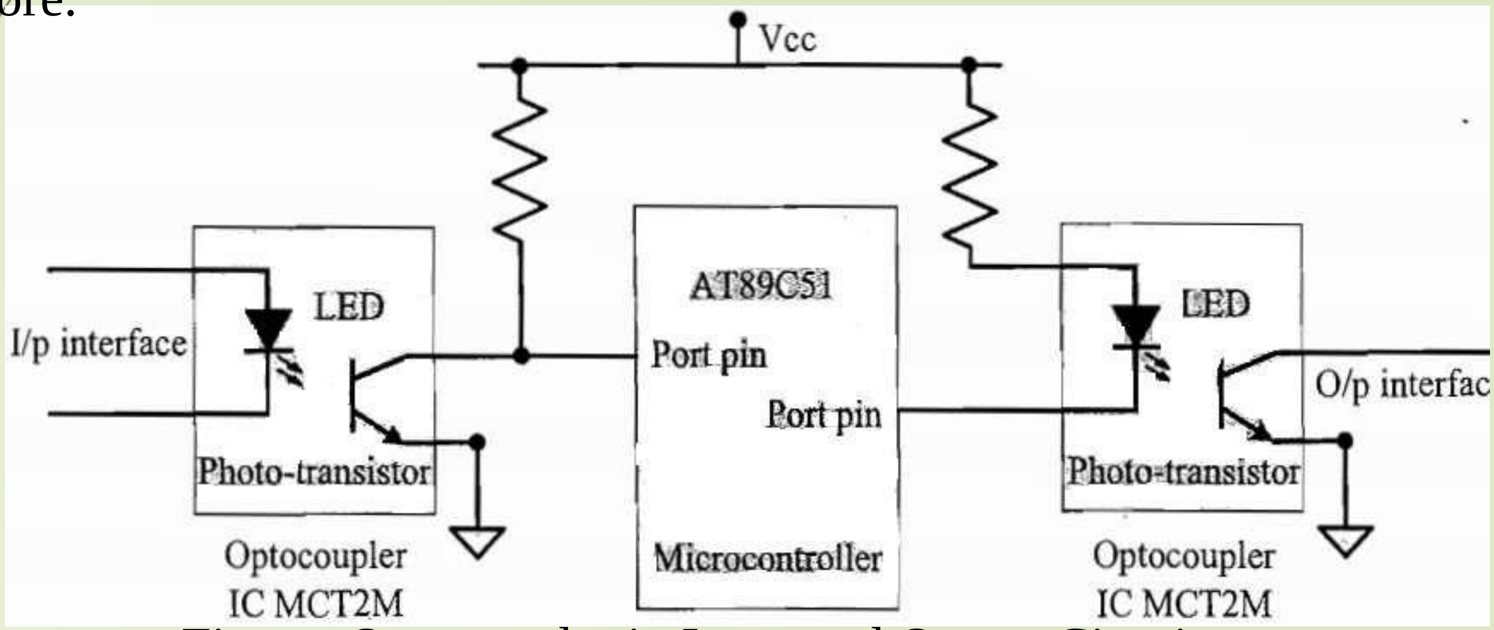


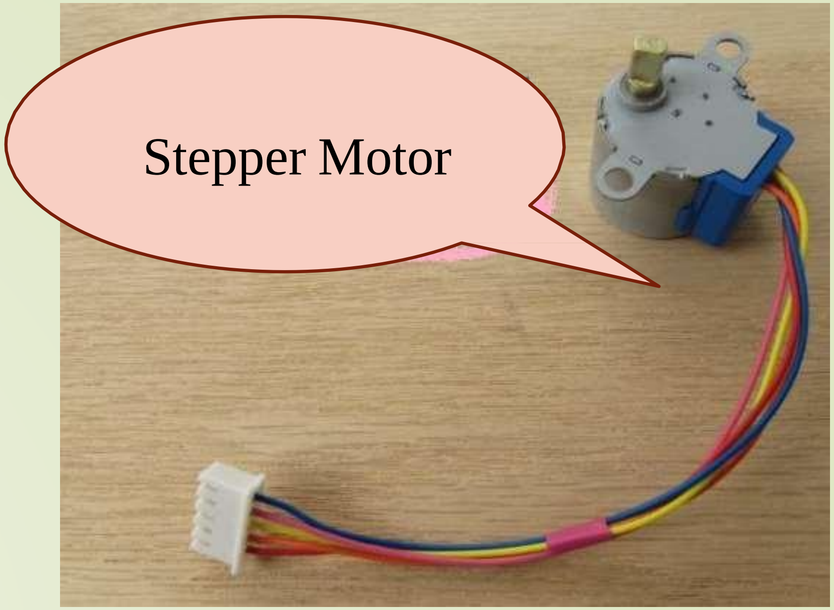
Figure. Optocoupler in Input and Output Circuit

Stepper Motor

- A stepper motor is an **electro-mechanical device** which generates discrete displacement (motion) in response to dc electrical signals.
- It **differs from the normal dc motor** in its operation.
- The dc motor produces continuous rotation on applying dc voltage whereas a stepper motor produces discrete rotation in response to the dc voltage applied to it.
- Stepper motors are widely used in industrial embedded applications, consumer electronic products and robotics control systems.
- The paper feed mechanism of a printer/fax makes use of stepper motors for its functioning.

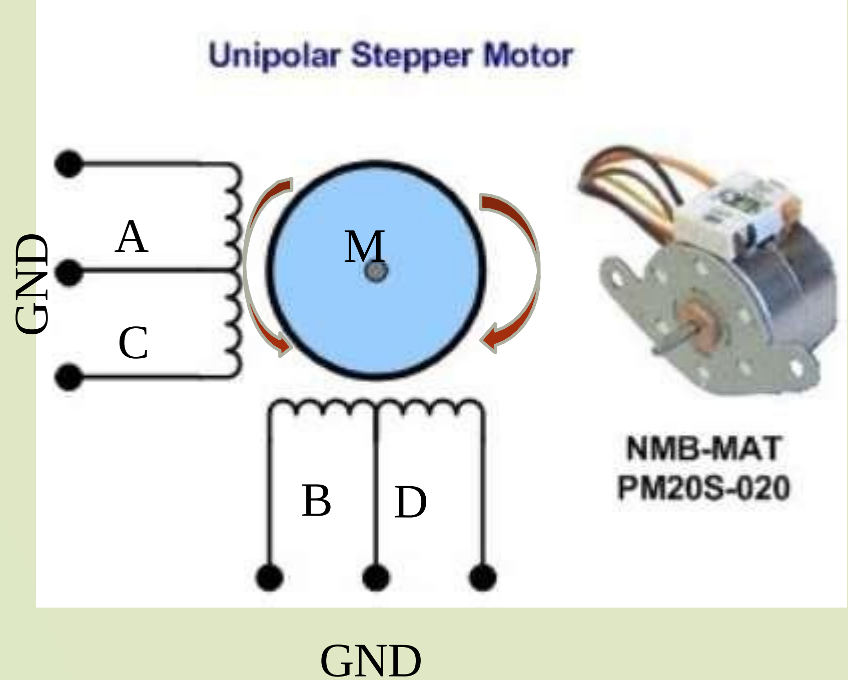
Cont’d

- Based on the coil winding arrangements, a two-phase stepper motor is classified into two. They are:
  - Unipolar
  - Bipolar



Unipolar

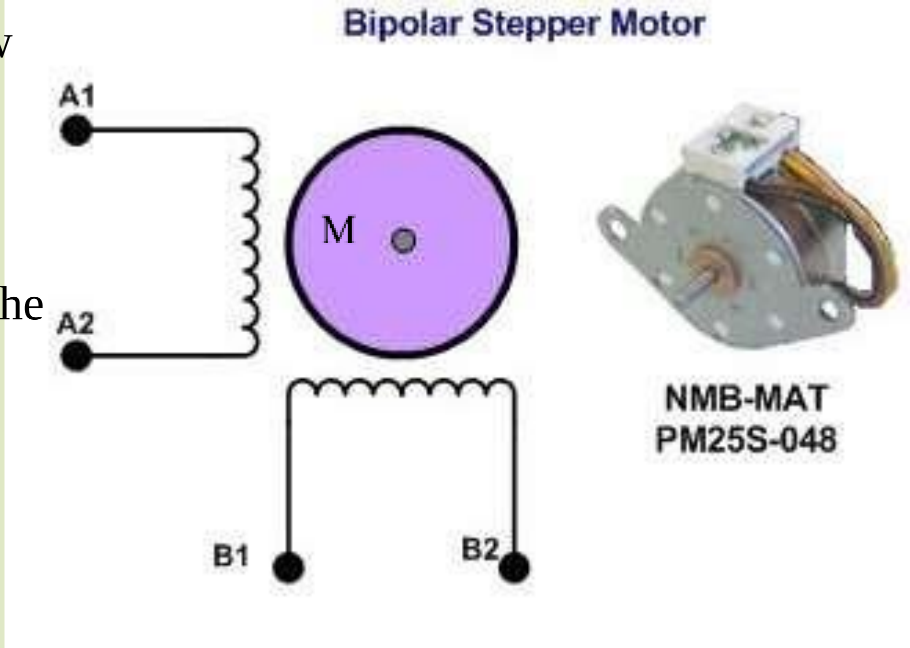
- A unipolar stepper motor contains two windings per phase.
- The <u>direction</u> of rotation (clockwise or anticlockwise) of a stepper motor is controlled by changing the direction of current flow.
- Current in one direction flows through one coil and in the opposite direction flows through the other coil.
- It is easy to shift the direction of rotation by just switching the terminals to which the coils are connected.
- Figure illustrates the working of a two-phase unipolar stepper motor.



2-Phase unipolar stepper motor

Bipolar

- A bipolar stepper motor contains single winding per phase.
- For reversing the motor rotation the current flow through the windings is reversed dynamically.
- It requires complex circuitry for current flow reversal.
- There is one disadvantage of unipolar motors. The torque generated by them is quite less. This is because the current is flowing only through the half the winding. Hence they are used in low torque applications.
- On the other hand, bipolar stepper motors are a **little complex to wire** as we have to use a current **reversing H bridge driver IC like an L293D**. But the advantage is that the **current will flow through the full coil**. The resulting torque generated by the motor is larger as compared to a uni-polar motor.



Cont’d

- The stepping of stepper motor can be implemented in different ways by changing the sequence of activation of the stator windings. The different stepping modes supported by stepper motor are explained below.
- **Full Step**: In the step mode both the phases are energized simultaneously. The coils A, B, C and D are energized in the following order:

Step	Coil A	Coil B	Coil C	Coil D
1	H	H	L	L
2	L	H	H	L
3	L	L	H	H
4	H	L	L	H

- It should be noted that out of the two windings, only one winding of a phase is energized at a time.

Cont’d

- **Wave Step**: In the wave step mode only one phase is energized at a time and each coils of the phase is energies alternatively. The coils A, B, C and D are energized in the following order:

Step	Coil A	Coil B	Coil C	Coil D
1	H	L	L	L
2	L	H	L	L
3	L	L	H	L
4	L	L	L	H

Cont'd

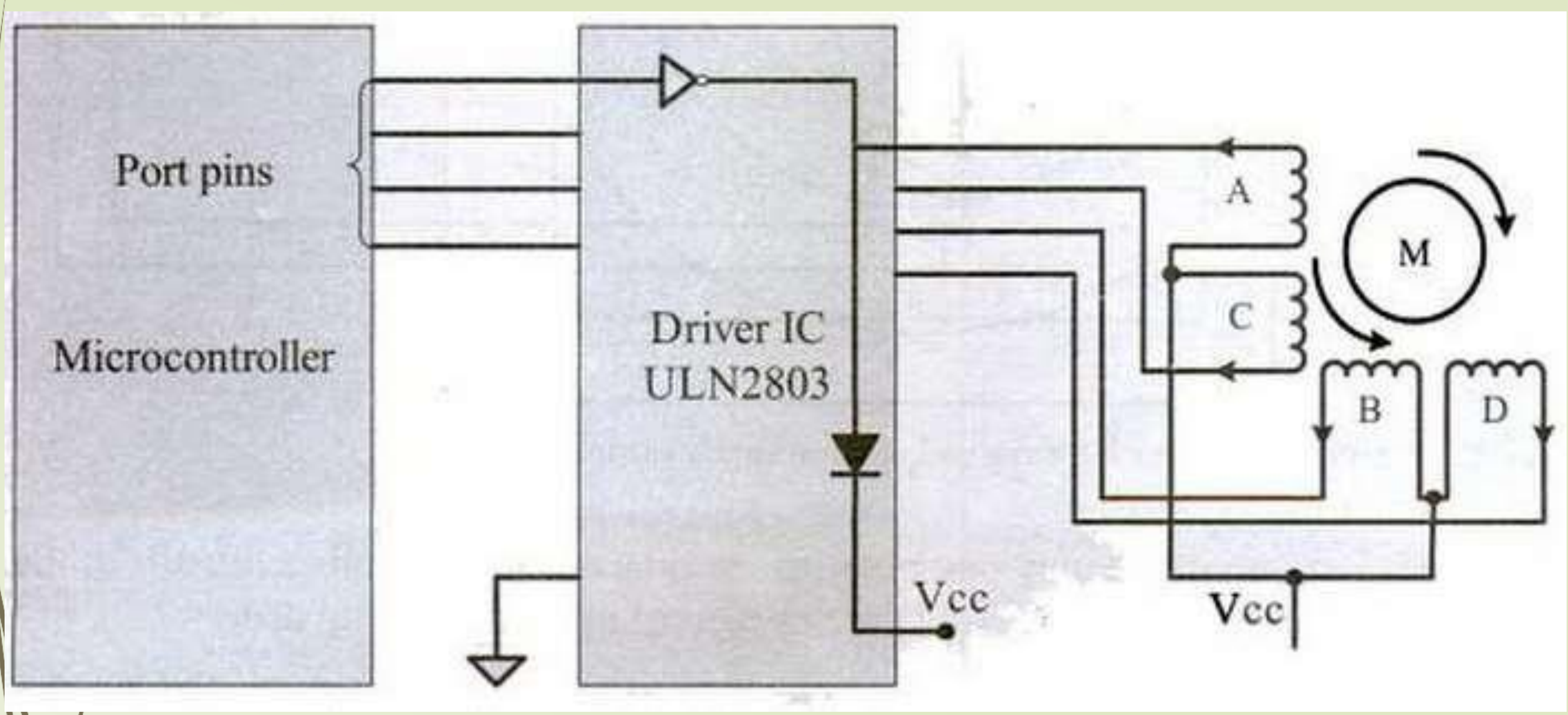
- **Half Step** : It uses the combination of wave and full step. It has the highest torque and stability. The coil energizing sequence for half step is given below.

Step	Coil A	Coil B	Coil C	Coil D
1	H	L	L	L
2	H	H	L	L
3	L	H	L	L
4	L	H	H	L
5	L	L	H	L
6	L	L	H	H
7	L	L	L	H
8	H	L	L	H

Cont'd

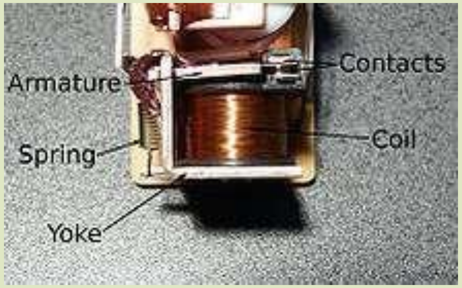
- The rotation of the stepper motor can be reversed by reversing the order in which the coil is energized.
- Two-phase unipolar stepper motors are the popular choice for embedded applications.
- The current requirement for stepper motor is little high and hence the port pins of a microcontroller/processor may not be able to drive them directly.
- Also the supply voltage required to operate stepper motor varies normally in the range 5V to 24 V.
- Depending on the current and voltage requirements, special driving circuits are required to interface the stepper motor with microcontroller/processors.
- The following circuit diagram illustrates the interfacing of a stepper motor through a driver circuit connected to the port pins of a microcontroller/processor.

Cont'd



Interfacing of stepper motor through driver circuit

Relay



- Relay is an **electro-mechanical device**. In embedded application, the ‘Relay’ unit acts as **dynamic path selectors** for signals and power.
- The ‘Relay’ unit contains **a relay coil** made up of insulated wire on a metal core and a metal armature with one or more contacts.
- ‘Relay’ works on electromagnetic principle. When a voltage is applied to the relay coil, current flows through the coil, which in turn generates **a magnetic field.**
- The magnetic field attracts **the armature core** and moves **the contact point**. The movement of the contact point changes the power/signal flow path.
- ‘Relays’ are available in different configurations. Figure given below illustrates the widely used relay configurations for embedded applications.

Cont'd

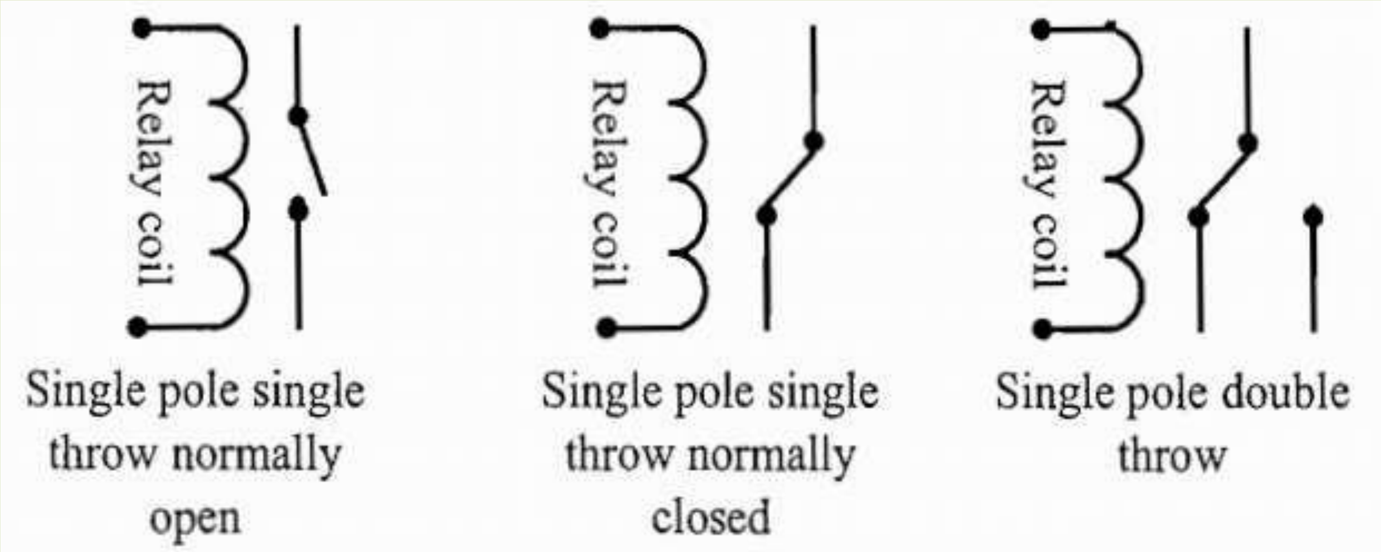


Figure Relay Configurations

- The **Single Pole Single Throw** configuration has only one path for information flow. The path is either open or closed in normal condition. For normally **Open** Single Pole Single Throw relay, the circuit is normally open and it becomes closed when the relay is energized. For normally **closed** Single Pole Single Throw configuration, the circuit is normally closed and it becomes open when the relay is energized. For **Single Pole Double Throw Relay**, there are two paths for information flow and they are selected by energizing or de-energizing the relay.

Understanding Test Questions IV

1. Which of the following is (are) example(s) for the input subsystem of an embedded system dealing with digital data?

   (a) ADC (b) Optocoupler (c) DAC (d) All of them

   (e) only (a) and (b)

2. Which of the following is (are) example(s) for the output subsystem of an embedded system dealing with digital data?

   (a) LED (b) Optocoupler (c) Stepper Motor (d) All of them

   (e) only (a) and (c)

3. Which of the following is true about optocouplers

   (a) Optocoupler acts as an input device only

   (b) Optocoupler acts as an output device only

   (c) Optocoupler can be used in both input and output circuitry

   (d) None of these

Cont'd

4. Which of the following is true about a unipolar stepper motor

   (a) Contains only a single winding per stator phase

   (b) Contains four windings per stator phase

   (c) Contains two windings per stator phase

   (d) None of these

5. Which of the following is (are) true about normally open single pole relays?

   (a) The circuit remains open when the relay is not energized

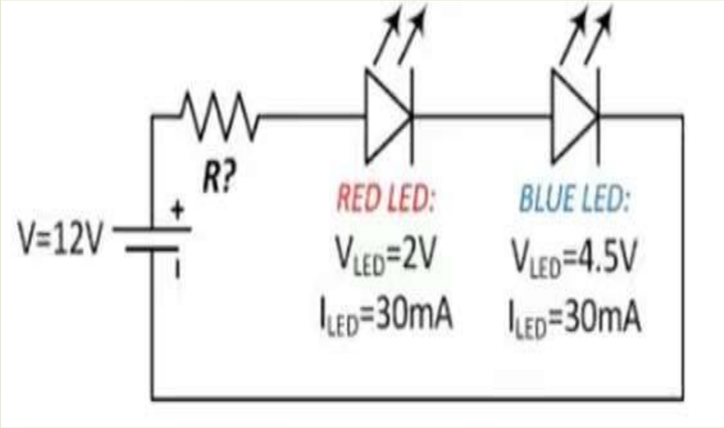
   (b) The circuit remains closed when the relay is energized

   (c) There are two output paths

   (d) Both (a) and (b) (e) None of these

Reviewed Questions IV

1. What is Sensor? Explain its role in Embedded System Design? Illustrate with an example.
2. What is Actuator? Explain its role in Embedded System Design? Illustrate with an example.
3. Calculate the resistance in the following circuit.



4. What is stepper motor? How is it different from ordinary dc motor?
5. Explain the role of Stepper motor in embedded applications with examples.
6. What is Relay? What are the different types of relays available?