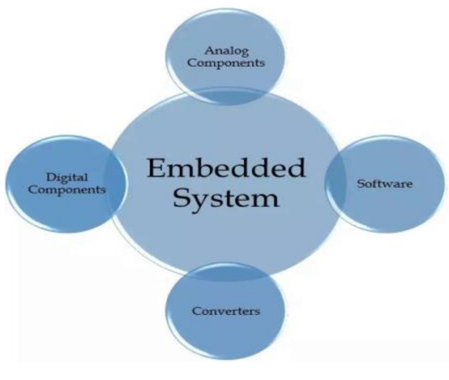
MODULE I
Basics of embedded systems and its architecture

Module Outcomes	Description	Duration (Hours)	Cognitive Level
CO1	Explain the basics of embedded systems and its architecture		
M1.01	Describe embedded system, illustrate difference from general purpose computer	2	Understanding.
M1.02	Classify embedded systems, explain application areas and summarize purpose of embedded systems	2	Understanding
M1.03	Distinguish Hardware and software components of embedded systems	2	Understanding
M1.04	Describe the basic blocks in a typical embedded system	2	Understanding
M1.05	Describe Memory, Sensors, Actuators and I/O sub-systems	2	Understanding
M1.06	Distinguish Communication Interfaces – On board and external interfaces	3	Understanding

Syllabus Content:
Embedded Systems - Definition, difference from general purpose computers -
Classification of embedded systems, Application areas,
Components of embedded system hardware, and Software embedded into the system
Architecture of embedded system – Building blocks of an embedded system , Core of embedded system – categories, Memory –ROM and RAM, Sensors, actuators and I/O sub

Embedded System: An embedded system can be thought of as a computer hardware system having software embedded in it. An embedded system can be an independent system or it can be a part of a large system. An embedded system is 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.



Difference between General Purpose Computer and Embedded System:

Paramater	General Purpose Computer	Embedded System
Basic	It is a general purpose electronic device used to perform different types of tasks.	It is a specialized computer system that used to perform one or a few specific tasks.
System hardware	A computer typically consists of a CPU, storage unit, and I/O units.	Embedded system are designed with a microcontroller which consists of a CPU, memory unit, and I/O interface on a single IC chip.
Processing power	High processing power.	Relatively low processing power.
Storage capacity	High storage capacity or memory to store data and information on the system.	Less memory capacity as compared to computers.
Size	Generally larger in size.	Smaller in size than computers.
Cost	More expensive than embedded systems.	Less expensive.
Operating system	Computers use a full-featured operating system to run.	Embedded systems use a specialized operating system to run.
Software development tools	For computers, the general purpose development tools can be used to develop computer software.	The development of software for embedded systems requires specialized and expert tools.
Maintenance & updates	Computers need regular maintenance and updates.	Embedded systems do not require much maintenance and updates.
Upgradability	Computers are easily upgradable with new hardware and software.	Embedded systems require significant hardware modification for upgradation.
System complexity	Computers involve more complex system design.	Embedded systems are comparatively less complex.
Real time constraints	Computers do not have real-time constraints.	Embedded systems are purposely designed to operate in real time.
Applications	Computers are used for a variety of applications, such as word processing, web browsing, data analysis, scientific simulation, communication, etc.	Embedded systems are used in consumer electronic devices, medical devices, industrial control systems, etc.

Q) List any three differences between embedded system and general purpose computer.(3 marks)
Q) List differences between general purpose computer and embedded system. (7 marks)

Classification of embedded systems:

1) Based on Generation: The classification of embedded systems is based on the generation in which they are evolved from its initial version to the latest version.

- **First Generation:** The first-generation embedded systems were built around 8-bit microprocessors and 4-bit microcontrollers. Such embedded system possess simple hardware and firmware developed using assembly code. Digital telephone keypads, stepper motor control units are examples of the first-generation embedded system.
- **Second Generation:** The second generation embedded systems uses 16-bit microprocessors and 8-bit microcontrollers. They are more powerful and complex compared to previous generation processors. Data acquisition systems, SCADA systems are examples of second-generation embedded systems.
- **Third Generation:** The embedded system of this period has powerful 32-bit microprocessors and 16-bit microcontrollers. Hence, its operation has become much more powerful and complex than the second generation. During this period, domain-specific processors/controllers like Digital Signal Processors (DSP), Application-Specific Integrated Circuits (ASICs) and the concept of instruction pipelining, embedded real-time operating system evolved into the embedded system industry. Robotics, industrial process control, embedded networking are examples of the third-generation embedded system.
- **Fourth Generation**: The recent development of microprocessors and microcontrollers has evolved during these modern days. New concepts like System-on-Chip(SOC), reconfigurable processors, multicore processors, coprocessors also emerged into the embedded market to add more powerful performance in the embedded system. These systems also make use of the high-performance real-time operating system for their operation. Smart phones, digital cameras, etc are examples of fourth-generation embedded systems.

2) Based on Complexity & Performance: The embedded systems are classified into three types based on the complexity & performance of the systems.

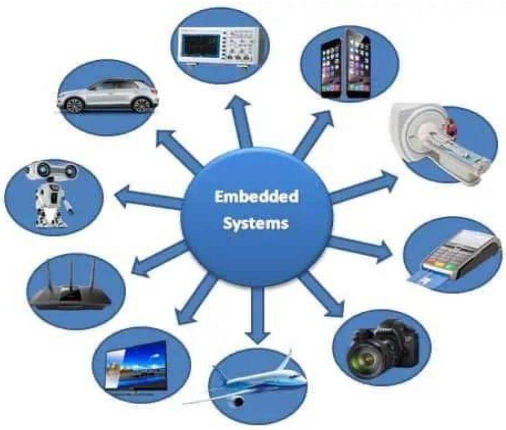
- **Small Scale Embedded Systems:** Small Scale Embedded Systems are built with a single 8 or 16-bit microprocessor or controller. The main programming tools used are an editor, assembler, cross assembler and integrated development environment (IDE). The hardware and software complexities in small-scale embedded system are very low. It may or may not contain an operating system for its functioning. An electronic toy is an example for a small-scale embedded system.
- **Medium Scale Embedded Systems:** The Embedded system with medium performance 16-bit or 32-bit microprocessor or controller, ASICs or DSPs fall under the medium scale embedded systems. They have both hardware and software complexities. The main programming tools used are C, C++, JAVA, Visual C++, RTOS, debugger, source code engineering tool, simulator and IDE.
- **Large scale Embedded Systems:** The embedded systems have highly complex hardware and software, built around 32-bit or 64-bit processors/controllers, RISC processors, SoC, scalable and configurable processors. They are also called sophisticated embedded systems.

They are used for cutting-edge applications that need hardware and software Co-design, where components have to be assembled into the final system. They also contain a high-performance real-time operating system for task scheduling, prioritization and management.

Q) Classify embedded systems based on any two criteria.(7 marks)

Applications of Embedded Systems: Today, embedded systems play a critical role in various sectors.Here are a few examples that make use of embedded technology.

- **Telecommunications systems:** Switches, Routers, Bridges
- **Consumer electronics:** MP3 players, Digital cameras, Mobile phones, Digital watches
- **Household appliances :** Washing machines, Television, Set top Boxes ,Microwave ovens, Dish washer, refrigerators
- **Home automation & Security:** Air condition, CCTV Systems, Intruder alarms, Fire alarms
- **Healthcare:** Different Kinds of Scanners(MRI, CT, PET), EEG & ECG machines
- **Automobiles:** Anti-Lock Braking System (ABS), Traction Control (TCS) and Electronic Stability Control (ESP)
- **Banking & retails:** Automated Teller Machine(ATM), Currency counter
- **Measurements & Instrumentation:** Digital Multimeter, Digital Storage Oscilloscope (DSO), Programmable Logic Controller(PLC) systems.
- **Computer peripherals:** Printer, Scanner, Fax machine
- **Card Readers:** Barcode, Smart Card Readers, Hand held Devices etc.

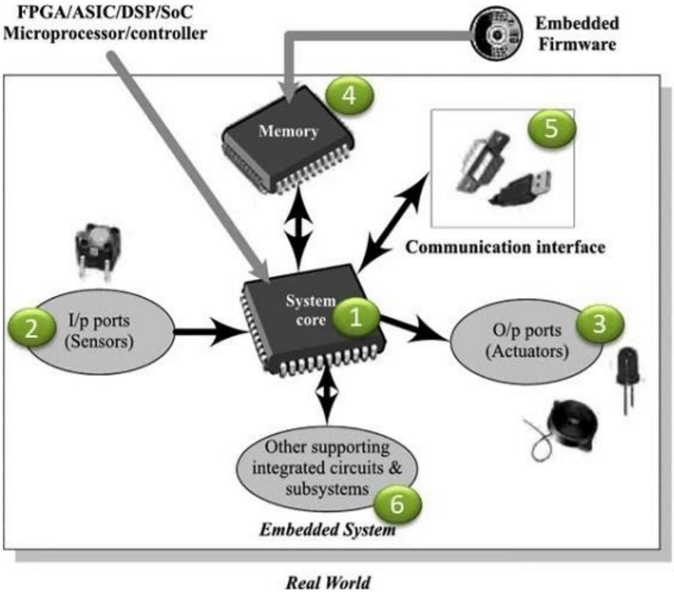


Q) List any two examples of embedded systems.(1 mark)
Q) List any two applications of embedded systems.(1 mark)

Purpose of Embedded Sytems: Each embedded system is designed to serve a specific purpose such as:

1. Data collection/Storage/Representation : Eg.Digital Cameras, Smart TV
2. Data Communication : Eg. Routers, Hub, Switches
3. Data Processing: Eg. Hearing Aids
4. Monitoring: Eg. ECG, EEG, DSO, Digital Multimeter
5. Control: Eg.Air Conditioner System
6. Application Specific User Interface: Eg. Mobile Phones

Elements of Embedded Systems: An embedded system has three components − Hardware, Application Software & Real Time Operating system and it is supposed to do one specific task only. Embedded system hardware/software are designed to regulate a physical variable or to manipulate the state of some devices by sending signals to the actuators or devices connected to the output system, in response to the input signal provided by the end users or sensors which are connected to the input ports.



Hardware components:

1) System Core: A typical embedded system core contains a single chip controller/ Processors which acts as the master brain of the system. The core of the system performs some predefined operations on input data with the help of embedded firmware and sends some actuating signals to the actuator.

2) Input port and Sensors: The input signal provided by the end users or sensors which are connected to the input ports. Keyboards, push button, switches, etc. are examples of input devices

3) Output port and Actuators: The processed control signals is send to the actuators or devices connected to the output port. LEDs, LCDs, Piezoelectric buzzers, etc. are examples for output devices.

4) Memory: The memory of the system is responsible for holding the proram and data. Some controllers may contain internal memory or on-chip memory, while other requires external memory or off-chip memory. There are two types of memory present:

- **Fixed memory:** It is a **Read Only Memory(ROM)** & is used for storing code or program. The user cannot do any modifications in this type of memory. Common types used are PROM, EPROM, EEPROM & Flash memory.
- **Temporary memory or Working memory:** It is a **Random Access Memory**(**RAM**) & is used for performing arithmetic operations. Common types used are SRAM, DRAM and NVRAM.

5) Communication interface: They are used in embedded systems to establish communication with other sub-systems or embedded systems in the external world. There are several communication ports including USB, UART, USB, I2C, SPI, and RS-485.

6) Other supporting Integrating Circuits(ICs) & Sub-Systems: It includes timers, clock circuits, power supply, Interrupt controller, etc.. for the proper funtioning of an embedded system.

Application Software: Embedded systems software can be defined as specialized programming tools in embedded devices that facilitate the functioning of the system. The main components of software involves editor, compiler, assembler, linker, debugger and emulator.

- The code you write in C, Java, Python programming languages will be saved in a text file in the **editor**.
- A **compiler** is used to translate high level language program into machine code.
- An **assembler** is used to translate an assembly language program into machine code.
- A **debugger** is a tool used for testing and debugging purposes. It scans the code thoroughly and removes the errors and bugs, and identifies the places where they occur.
- A **linker,** also called a link editor, is a tool that takes one or more object files and combines them to develop a single executable code.
- The main task of the **emulator** is to make the embedded system act like a real system in a simulation environment.

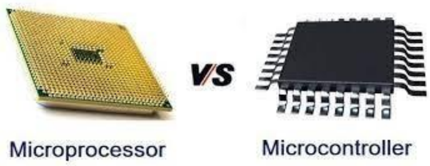
Real Time Operating system (RTOS): It supervises the application software and provide mechanism to let the processor run a process as per scheduling by following a plan to control the latencies. RTOS defines the way the system works. It sets the rules during the execution ofapplication program. A small scale embedded system may not have RTOS.

Q) Explain architecture of embedded system with simple block diagram.(7 marks)
Q) Distinguish hardware and software components in an embedded system. (3 marks)

Core of the Embedded System: The core of the embedded system falls into any oneof the following categories.

1. Microprocessors
2. Microcontrollers
3. Digital Signal Processors(DSP)
4. Programmable Logic Devices (PLDs)
5. Application Specific Integrated Circuits (ASICs)
6. Commercial off-the-shelf Components (COTS)

Microprocessor Vs Microcontroller:



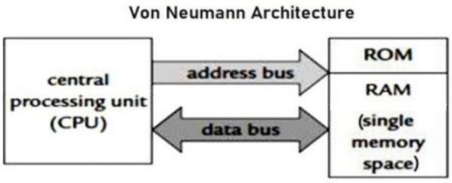
Microprocessor	Microcontroller
• It is a very compact electronic representing a CPU which is capable of performing arithematic & logical operations.	• It is a highly integrated electronic chip which consists of a processing element(CPU), a small memory (RAM, ROM, EPROM), I/O ports, etc. on a single chip.
• The memory and I/O component are connected externally.	• The memory and I/O output component are present internally.

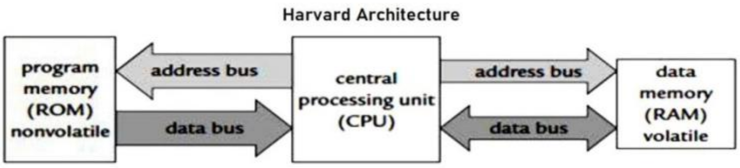
• System requires more hardware and connecting peripherals externally makes the circuit more complex & expensive.	• Most of the peripherals are in-built and internally connected makes the circuit simple & economical.
• Since memory and system buses are provided externally, access times for memory and I/O devices are more, hence processing speed is slower.	• Less access time due to in-built peripherals and hence processing speed is faster.
• It is mainly used for general purpose design & operations.	• It is used for specific purpose design & operations
• Microprocessors are generally used in personal computers.	• Microcontrollers are generally used in washing machines, air conditioners, mobile phones, smart watches, digital cameras etc.
• Eg. Intel 8085, 8086, core i3, i5,i7	• Eg. Intel 8051, PIC, AVR

Digital Signal Processors(DSP): It is a specialized microprocessor chip, with its architecture optimized for the operational needs of audio, image & video applications. They are faster than general purpose microprocessors in digital signal processing. They are often used in as mobile phones, fax/modems, disk drives, radio, printers, medical and health care devices, MP3 players, high-definition television (HDTV), and digital cameras.

Harvard Vs Von-Neumann Processor/Controller Architecture:

Von Neumann/Priceton architecture	Harvard architecture
• It has single memory storage to hold both program instruction and data.	• It has separate program and data space.
• There is common bus for data and instruction transfer.	• Separate buses are used for transferring data and instruction.
• Comparitively slower operation	• Faster operation
• Eg. Intel 8085, 8086, 80286, 80386	• Eg. Intel 8051, 8052, PIC





Types of Memory:

RAM(Random Access Memory) or Temporary memory: It is the data or working memory of the controller/processor. It retains the content as long as the power is applied to the chip. If the power is turned off then its contents will be lost forever. It is a volatile momory. It is of 2 types:

- **SRAM (Static RAM):** It stores data in the form of voltage. They are made up of flip flops. A typical SRAM cell is made of 6 transistors. It is fast in operations.
- **DRAM (Dynamic RAM):** It stores data in the form of charges. They are made up of MOS transistor gates. A typical DRAM cell is made of one capacitor and one transistor. It has high memory density compared to SRAM. It is slow in operations. A DRAM controller periodically refreshes the data stored in the DRAM. By refreshing the data several times a second, the DRAM controller keeps the contents of memory alive for a long time.
- **NVRAM(Non - Volatile RAM):** It is usually a SRAM with battery backup. When power is turned on, the NVRAM operates just like any other SRAM but when power is off, the NVRAM draws enough electrical power from the battery to retain its content. NVRAM is fairly common in embedded systems. It is more expensive than SRAM.

ROM(Read Only Memory) or Fixed memory: It is the code or program memory of the controller/processor. It retains the content even the power applied to the chip turns off. It is a non - volatile momory. It is of 3 types:

- **Masked ROM:** It is an one time programmable memory. These are hardwired memory devices found on system & are factory programmed. It contains pre-programmed set of instruction and data and it cannot be modified by end user.
- **PROM (PROGRAMMABLE ROM):** It is also an one time programmable memory. This memory device comes in an un-programmed state i.e. at the time of purchased it is in an un-programmed state and it allows the user to write his/her own program or code into this ROM.
- **EPROM (ERASABLE-AND-PROGRAMABLE ROM):** It is same as PROM and is programmed in same manner as a PROM. It can be erased and reprogrammed repeatedly as the name suggests. The erase operation in case of an EPROM is performed by exposing the chip to a source of ultraviolet light, but is a time consuming process.
- **EEPROM(**Electrically Erasable and Programmable ROM). It is same as EPROM, but the erase operation is performed electrically. Any byte in EEPROM can be erased and rewritten as desired. The erasing process is faster compared to EPROM.
- **Flash:** Flash memory is the most recent advancement in memory technology. Flash memory devices are high density, low cost, nonvolatile, fast (to read, but not to write), and electrically reprogrammable. Flash is much more popular than EEPROM and is rapidly displacing many of the ROM devices. Flash devices can be erased only one sector at a time, not byte by byte.

Q) Describe about memory types used in embedded systems.(3 marks)

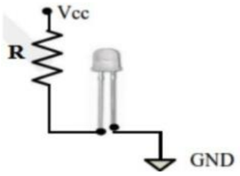
Sensors: A sensor is transducer that is used to generate an input signal to a measurement, instrumentation or control system. The signal produced by a sensor is an electrical analogy of a physical quantity, such as distance, velocity, acceleration, temperature, pressure, light level, etc. Sensors act as an input device. Eg. Temperature sensors, proximity sensors, Accelerometer sensors etc.

Actuators: It is a form of transducer device (mechanical or electrical) which converts signals to corresponding physical action (motion). Actuator acts as an output device.

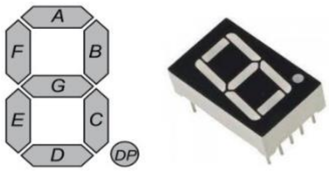
Q) ----- is an example for sensor used in an embedded system. (1 mark)

I/O Sub-systems: It facilitates the interaction of embedded system with external world.

- **Light emitted Diode (LED):** It is an output device & is used as an indicator for the status of various signals or situations. LED is a p-n junction diode and it contains an anode & 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 supply voltage. A resistor is used in series between the power supply and the resistor to limit the current through the LED.

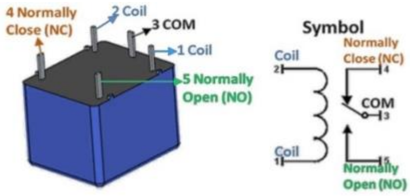


- **7-Segment LED Display:** It is an output device for displaying alpha numeric characters & contains 8 LED segments arranged in a special form. Out of the 8 LED segments, 7 are used for displaying alpha numeric characters. LED segments are named A to G and the decimal point LED segment is named as DP. The current flow through each of the LED segments should be limited to the maximum value supported by the LED display unit by connecting a current limiting resistor.



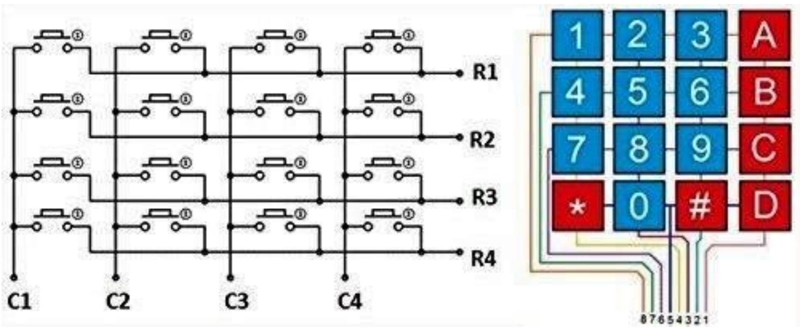
- **Stepper Motor:** It is an electro mechanical device which generates discrete displacement (motion) in response to DC electrical signals. It differs from the normal DC motor in its operation. The DC motor produces continuous rotation on applying DC voltage whereas a stepper motor produces discrete 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.

- **Relay:** It is an electro mechanical device which 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 an armature with one or more contacts. It works on electromagnet 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. The Relay is normally controlled using a relay driver circuit connected to the port pin of the processor/controller.



- **Push button switch:** It is an input device. Push button is used for generating a momentary pulse. In embedded application push button is used as reset, start switch & pulse generator.

- **Matrix Keyboard:** It is an input device to provide input data. In a matrix keyboard, the keys are arranged in matrix fashion. To detect which key is pressed from the matrix keyboard, the row lines are to be made low one by one and read the columns. Pull-up resistors are connected to the column lines to limit the current that flows to th row line on a key press.

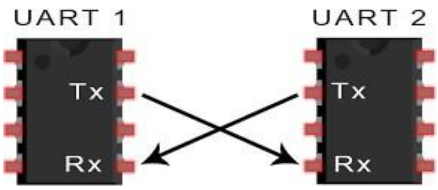


- **Piezo Buzzer:** It is a piezoelectric device for generating audio indications in embedded applications. A Piezo buzzer contains a piezoelectric diaphragm which produces audible sound in response to the voltage applied to it.

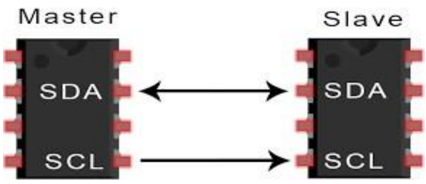
Communication Interface: They are essential for communicating with various subsystems of the embedded system and with the external world.The communication interface can be of two types:

- **Onboard Communication Interface:** The communication interface channel which interconnects the various components within an embedded system. Eg: Serial interfaces like I2C, SPI, UART, 1-Wire etc and Parallel bus interface.
- **External Communication Interface:** It is responsible for data transfer between the embedded system and other devices or modules. The external communication interface can be either wired media or wireless media and it can be a serial or parallel interface. Eg: Infrared (IR), Bluetooth (BT), Wireless LAN (Wi-Fi), Radio Frequency waves (RF), GPRS etc. (wireless) and RS-232, USB, Parallel port etc. (wired).

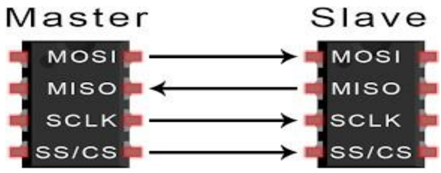
Universal Asynchronous Receiver Transmitter (UART): It is an asynchronous form of serial data transmission. It doesn't require a clock signal to synchronize the transmitting end and receiving end for transmission. Instead UART uses start and stop bits with actual data bits, which defines the start and end of data packet. For proper communication, the Transmit line (TX) of the sending device should be connected to the Receive line (RX) of the receiving device. UART works under full duplex communication mode meaning it can transmit and receive data at same time.



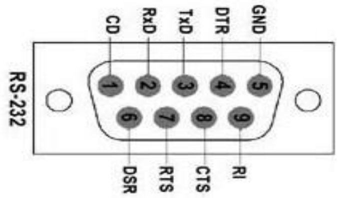
Inter-integrated-circuit (I2C): Inter Integrated Circuit (I2C) is a serial communication interface developed by Philips Semiconductors. The main purpose is to provide connection between peripheral chips with microcontroller. I2C interface is a master to slave communication interface. Each slave is been provided with unique address.
I2C interface has two wires SDA (Serial Data Line) and SCL (Serial Clock Line) to carry information between devices. Data is transferred bit by bit along a single wire (the SDA line). Thesetwo active wires are said to be bidirectional. It is a synchronous form of serial data transmission.



Serial Peripheral Interface (SPI): It is one of the serial communication interface developed by Motorola. It is a 4-wire protocol namely MOSI (Master Out Slave In), MISO (Master In Slave Out, SS (Slave Select), and SCLK (Serial Clock). MOSI and MISO are the data lines.
As I2C protocol, SPI is also a master to slave communication protocol. In SPI, the master device first configures the clock at a particular frequency. Furthermore the SS line is used to select the appropriate slave by pulling the SS line low where it is normally held high. The communication is established between the selected slave and the master device as soon as appropriate slave device is selected. SPI is a full duplex communication interface. It is a synchronous form of serial data transmission.



RS232 (**Recommended Standard 232**): It is a full duplex, wired, asynchronus mode serial communication interface developed by Electronics Industrial Assosiation(EIA). It extend the UART communication signal for external data communication.



Universal Serial Bus (USB): It is a common interface that allows the connection between external devices and controllers. It connects peripheral devices including digital cameras, mice, keyboards, printers, scanners, media devices, external hard drives, and flash drives. USB protocol sends and receives the data serially between host and external peripheral devices through data signal lines D+ and D-. Apart from two data lines, USB has V_{CC} and Ground signals to power up the device.

Bluetooth: it is a Low-cost short-distance radio communications standard. Bluetooth is wireles and replaces cable technology. It uses radio waves for transmitting and receiving data. It operates at 2.4GHz of radio spectrum.

Wireless Fidelity(Wi-Fi): It is the popular wireless communication technique for networked communication of devices. Wi-Fi operates at 2.4GHz or 5GHz of radio spectrum. Wi-Fi supports Internet Protocol (IP) based communication. In an IP based communication each device is identified by an IP address, which is unique to each device on the network. Wi-Fi enabled devices contain a wireless adaptor for transmitting and receiving data in the form of radio signals through an antenna (Wi-Fi Radio).

Q) Give two examples for on-board communication interfaces in a common embedded system hardware. (1 mark)
Q) Describe different types of communication interfaces in an embedded system. (7 marks)