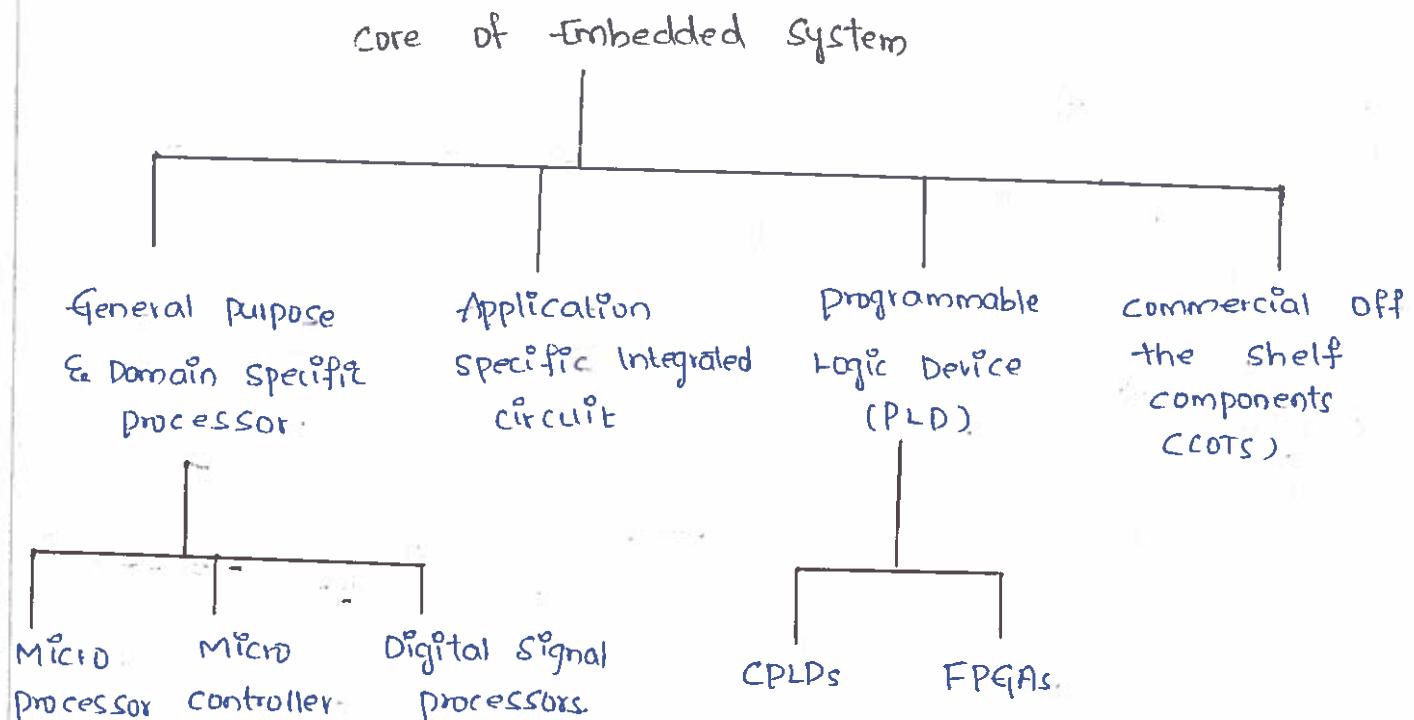


Typical Embedded System.

Core of Embedded System

The classification of Embedded System core is given below.



General purpose & Domain specific processor.

General purpose processor.

General purpose processor consists of arithmetic and logic unit (ALU) and control unit (CU) which are implemented for the operation for general computation tasks.

These general purpose processors are produced in large number and the per unit cost is very low. A typical example of GPP are processor running in laptop.

→ Almost 80% of the ES are processor | controller based.

→ The processor may be

1. micro processor
2. micro controller
3. Digital signal processor

based on the domain and specifications.

→ Most of ES in the industrial control and monitoring applications make use of microprocessors and microcontrollers.

Microprocessor.

- A microprocessor is a silicon chip representing a central processing unit (CPU) which is capable of performing arithmetic and logical operations.
- A microprocessor is a dependent unit and it requires the combination of other hardware like memory, timer unit and interrupt controller etc for proper functioning.
- The first microprocessor unit INTEL 4004, a 4 bit processor released in November 1971.
- In the year of 1972^{April}, the INTEL 8008 microprocessor was replaced which is similar to INTEL 4004. The only difference was that the program counter was 16 bits wide and 8080 served as a terminal controller.
- In April 1974, Intel launched the just 8 bit processor, the INTEL 8008, with 16 bit address bus and program counter and seven 8 bit registers.
- In July 1976, Zilog is a type of microprocessor entered into the market with its Z80 processor, which was designed by an ex-Intel designer, Frederico Faggin.
- Earlier clock speed of processor is 1MHz. But today processor's clock speeds upto 2.4 GHz.

→ Architectures used for processor design are Harvard or von-Neumann.

(2)

→ Reducing Instruction Set Computing (RISC) and complex Instruction Set computing (CISC) are the two common Instruction Set Architectures (ISA) available for processor design.

Microcontrollers

→ A microcontroller is a highly integrated chip that contains a CPU, scratch pad RAM, special and general purpose register arrays, on chip ROM/FLASH memory for program storage, timer and interrupt control units and dedicated input and output ports.

→ Micro controllers can be considered as a superset of microprocessors.

→ Texas Instruments' TMS 1900 is considered as the world's first microcontroller.

→ TI followed Intel's 8008/8080, 8 bit processor design and added some amount of RAM, ROM and I/O support on a single chip, thereby eliminated the requirement of multiple hardware chips for self-functioning.

→ Intel 8048 is recognised as Intel's first microcontroller and it was the most prominent member in the MCS-8™-family. It is used in the original IBM PC Keyboard.

→ Eventually Intel came out with its most fruitful design in the 8-bit micro controller domain - the 8051 family and its derivatives. It is the most popular & powerful 8 bit microcontroller ever built. It was developed in 1980s and was put under the family MCS-51.

→ Due to low cost, wide availability, memory efficient instruction set, mature development tools and boolean processing capability, 8051 family derivative micro controllers are much used in high volume consumer electronic devices, entertainment industry and other gadgets.

→ 8 bit micro controllers are commonly used in embedded systems where the processing power is not a big constraint.

limit \rightarrow $P = 1/n$.

Digital Signal Processor:

- DSP's are powerful special purpose 8/16/32 bit microprocessors designed specifically to meet the computational demands and power constraint's of today's Embedded audio, video and communication applications
- DSP's are two to three times faster than the general purpose microprocessors in signal processing applications.
- These DSP's implement algorithms in hardware which speeds up the execution, whereas general purpose processors implement the algorithm in firmware and the speed of execution depends primarily on the clock for the processors.
- In general DSP can be viewed as a microchip designed for performing high speed computational operations for 'addition', 'subtraction', 'multiplication' and 'division'.
- DSP includes following key units
 - 1. Program memory - storing program required by DSP to process data.
 - 2. Data memory - storing temporary variables & data to be processed.
 - 3. Computational Engine - It performs the signal processing in accordance with the stored program memory.
 - 4. I/O unit - Acts as an interface b/w the outside world & DSP. It is responsible for capturing signal to be processed and delivering the signal.
- Some of the operations performed by DSP are sum of products calculation, FFT, DFT etc.

General purpose processor

The implementation of general purpose processors is commonly referred as the software implementation. They are designed in such a way that they cover a broad range of applications. In order to accomplish this, the designer need to take care of two main features of processor.

First, the program memory, where in the designer does not build program onto the digital ckt, as he don't know what

Program run by the user on the processor.

(3)

The other is the data path of the processors to carry out a variety of computations.

The benefits GPP are

1. It offers high flexibility because only the program need to be changed in order to change the functionality.
 2. Performs very faster rate when a faster processor & advanced architecture are inherited.
 3. The GPP are sold to too many customers & is user friendly to design.
- ⇒ NRE cost and time-to-market cost is low.
- MOST of Es use either processors or controllers as their GPP in the application areas such as industrial control and monitoring.
- Microprocessor is a typical example of GPP.

Domain Specific processor

Domain Specific processor are generally referred as application specific processors or Application specific instruction set processors (ASIPs). These are designed in such a way that they support a range of applications that share several common features.

For Example, Embedded control, telecommunications or digital signal processing. The data path can be best used for the class of target applications. They can be done by completely removing the rarely used units and adding the common function units.

The benefits of application specific processors are,

1. Good performance.
2. Low power consumption.
3. Small size.
4. Flexible in nature.

The two most commonly used domain specific processors are,

1. Digital signal processors
2. Microcontrollers

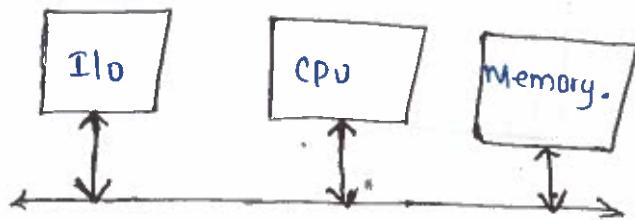
Harvard Architecture.

- It has separate busses for instruction as well as data fetching.
- There is easier pipeline and the performance of device(CPLD) can be achieved at higher due to easier pipeline.
- The devices^(CPLD) which are designed in the Harvard architecture are very high in cost.
- Since the data memory and program memory are stored physically in different locations, no chances to exist for accidental corruption of program memory.
- There are no memory alignment problems in these types of devices.
- There will be a improved operating Bandwidth
- In this, Program memory is accessed while the data memory can be read and written.
- This architecture requires additional hardware logic for control signal generation.



Von-Neumann Architecture

- It share single common bus for instruction and data fetching.
- This has low performance as compared to harvard architecture.
- The microprocessors/microcontrollers which are designed using von-neumann architecture are cheaper.
- There will be a accidental corruption of program memory may occurs if data memory and program memory are stored physically in the same chip.
- Allows self modifying codes.
- limits operating bandwidth.
- RISC & CISC are the two common instruction set architecture



Endianess.

→ Endianess specifies the order which the data is stored in the memory by processor operations in a multibyte system.

- Based on Endianess Processor can be of two types.
 1. Little Endian processors.
 2. Big Endian processors.

Little Endian.

Little Endian means lower order data byte is stored in memory at the lowest address and the higher order data byte at the highest address.

For Ex: 4 byte long integer Byte3, Byte2, Byte1, Byte0 will be stored in memory as follows.

Base address + 0	Byte 0	Byte 0 (Base address)
Base address + 1	Byte 1	Byte 1 (Base address+1)
Base address + 2	Byte 2	Byte 2 (Base address+2)
Base address + 3	Byte 3	Byte 3 (Base address+3).

Big Endian.

Big-Endian means the higher order data type (MSB) is stored in memory at the lowest address and the lower order data byte (LSB) stored at the highest address.

For Ex:

4 byte long integer Byte3, Byte2, Byte1, Byte0 will be stored in memory as follows.

Base address + 0	Byte 3	Byte 3 (Base Address)
Base address + 1	Byte 2	Byte 2 (Base Address + 1)
Base address + 2	Byte 1	Byte 1 (Base Address + 2)
Base address + 3	Byte 0.	Byte 0. (Base Address + 3).

Load & Store Operations.

The accessing of memory can be done through two operations.

They are

1. Load operation.
2. Store operation.

Load instruction loads the content of operand in memory location to a register.

The store instruction stores the data from register to memory location.

Consider three memory locations p, q, and r in which the contents p and q are added and stored in r. This can be achieved from four instructions as given below.

Load R₁, P.

Load R₂, q.

Load R₃, R₂, R₁

Store R₃, r

In this initially, the contents of memory locations p are stored in R₁ and then the contents of memory locations q are stored in R₂. These two contents are added and result is stored R₃. This content of register R₃ is stored in memory location r.

Application Specific Integrated Circuits (ASICs).

→ Application specific integrated circuit (ASIC) is a microchip which is designed to perform a specific or unique application.

→ It is used as a replacement to conventional general purpose logic chips. It integrates several functions into a single chip and thereby reduces the system development cost.

→ AS a single chip, ASIC consumes a very small area in the total system and thereby helps in the design of smaller systems with high capabilities / functionalities. (5)

→ ASICs can be pre-fabricated for a special application or it can be custom fabricated by using the components from a particular e.g. a reusable 'building block' library of components for a particular customer application.

→ ASIC based systems are profitable only for large volume commercial productions.

→ Fabrication of ASIC's requires a non-refundable initial investment for the process technology and configuration expenses. This investment is known as Non-Recurring Engineering charge (NRE) and it is a one time investment.

→ There are two types of fabrications involved in ASIC's - they are

1. Pre-Fabricated ASIC
2. Custom Fabricated ASIC

Pre-fabricated ASIC

These ASICs are designed for a specific application.

Custom fabricated ASIC

The custom fabricated ASIC are designed by using the components of 'building block' library specifically for user application. An initial one-time and non-refundable investments required for the development of ASIC.

The ASIC's are often referred as Application Specific Standard product (ASSP), if the NRE is invested by a third party and are openly marketed to multiple small number of customers. An example of such ASSP's is the ADE 7760 Energy metric ASIC.

Programmable Logic Devices (PLD's)

- A PLD is an electronic component. It is used to build digital circuits which are reconfigurable.
- Logic devices provide specific functions, including device-to-device interfacing, data communication, signal processing, data display, timing and control operations and almost every other function a system must perform.
- Logic devices are classified into two broad categories
 - i. Fixed
 - ii. Programmable.

Fixed.

- Fixed device as the name indicates, the circuits of fixed devices are permanent and they perform one function or set of functions once manufactured, they cannot be changed.

Programmable.

- Programmable logic devices (PLD's) offers customers a wide range of logic ~~capacity~~ capacity, features, speed and voltage characteristics and these devices can be re-configured to perform any number of functions at any time.
- PLD's are based on re-writable memory technology to change the design, the device is simply reprogrammed.
- PLD's having two major types:
 - i. FPGAs → FPGAs
 - ii. CPLD's.

Field Programmable Gate Arrays.

- The FPGAs offers the highest amount of logic density, the most features, and the highest performance.
- FPGAs are used in a wide variety of applications,

Ranging from data processing and storage, to instrumentation, telecommunications and DSP.

(6)

→ FPGA's performs the operations with a large amount of logic gates i.e., 8 million "system gates" (Ex: xilinx Virtex).

→ The various features of PLD's are:

1. Built in hardwired processors.
2. substantial amount of memory.
3. clock management systems.
4. fast device-to-device signaling technologies..

Complex programmable logic Devices (CPLD's).

→ CPLD's by contrast offer much smaller amounts of logic gates up to 10000 gates.

→ CPLD's offer very predictable timing characteristics and are therefore ideal for critical control applications s. i.e., Xilinx cool runner which require low power.

Advantages of PLD's.

→ PLD's offer customers much more flexibility during the design cycle.

→ PLDs do not require long lead times for prototypes or production parts - the PLD's are already on a distributor's shelf and ready for shipment.

→ PLD's can be reprogrammed even after a piece of equipment is shipped to a customer.

Role of PLD's.

→ PLD's provides it's client a wide range of logic capacity, Speed, flexibility, features, voltage characteristics.

→ The ES designed using PLD's does not impose any NRE cost on customers.

→ In order satisfy customer requirements, PLD based es are reprogrammed and new features are added to the existing product. This offers an advantage of just upgrading system instead of designing a new product.

→ The time of development required for manufacturing a device is reduced.

Commercial off-the shelf components (COTS).

- A commercial off-the shelf (COTS) product is one which is used 'as-is'.
- COTS products are designed in such a way that to provide easy integration and interoperability with existing system components.
- The COTS component itself may be developed around a general purpose or domain specific processor or an application specific integrated circuit or a programmable logic device.
- Typical examples of COTS hardware unit are remote controlled toy car control units; TCP/IP plug-in module.
- The major advantage of using COTS is that they are readily available in market, are cheap and a developer can cut down his/her development time to a great extent.
- The major drawback of using COTS components in embedded design is that the manufacturer of the COTS component may withdraw the product or discontinue the production of the COTS at any time if rapid change in technology occurs.

Advantages :

1. Ready to use.
2. Easy to integrate.
3. Reduces development time.

Disadvantages :

1. No operation or manufacturing standard.
2. Vendor or manufacturer may discontinue production of a particular COTS product.

Memory.

(1)

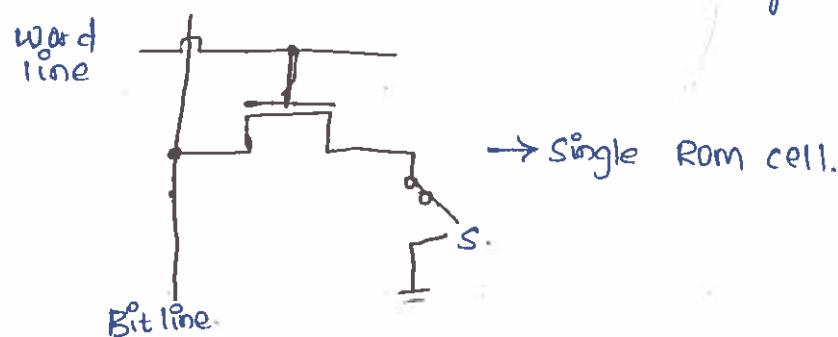
In Embedded System, a processor or a controller contains On-chip memory (built-in memory) or Off-chip memory (External memory). It also contains a memory which temporarily stores the data for certain operations. There are two types of memories. They are:

1. Programmable storage memory (ROM)
2. Random Access memory (RAM).

Programmable Storage memory (ROM).

In ES, Rom is a program or code storage memory which is used to store the instructions of the program. It also referred as non-volatile memory as it not losses the data even if the power is turned off. Hence, by using ROMs, permanent storage of data can be achieved.

Initially, consider the operation of a single ROM cell.



The transistor in this case is connected to ground by means of a switch. hence, whenever the switch is closed, the value of the transistor switches to zero else it remains 1. In order to read the status of a cell, the word line is turned high, and if the switch of the transistor closed, a value '0' flows out of the circuit. similarly, if the switch is open, the transistor supplies a value '1'. No write operation is possible with ROMs since data is added only once during manufacturing.

Basically, there are may times read-only memories with the differing capabilities they are:

- (i) Masked ROM.
- (ii) Programmable Read only Memory (PROM)
- (iii) Erasable programmable Read only Memory (EPRoM).

- (iv) Electrically Erasable Programmable Read Only Memory (EEPROM)
- (v) Flash memory.
- (vi) NVRAM.

Masked ROM.

- One-time programmable device.
- Used hardwired technologies for storing data.
- masking can be done by
 - (a) creating enhancement or depletion mode transistors through channel input
 - (b) creating memory cell using standard transistor or high threshold transistor.

PROM.

- It is one time programmable memory.
- Nichrome or polysilicon wires are used as fuses.
- program burns the fuses according to bit pattern to be stored.

EPROM.

EPROM facilitates data erasing and writing as many times as possible.

EEPROM.

EEPROM is flexible to erase and reprogram the data. It uses electrical signals at the register or byte level, to store or change the information.

Flash Memory.

Flash memory in Rom technology combines the reprogram ability of EEPROM and the high capacity of standard ROMs.

NVRAM.

Non-volatile RAM is Rom with battery backup. It combines the features of static RAM with an additional usage of minute battery for power supply. NVRAM has a high life span of 10 years.

Random Access Memory (RAM)

(8)

RAM is a data memory which involves reading from or writing data to it. It is a volatile memory as it does not store the data, if the power is turned off. RAM is a direct access memory as the required memory locations can be directly obtained without searching the entire memory.

There are 3 types of RAM, they are

1. Static RAM (SRAM)
2. Dynamic RAM (DRAM)
3. Nonvolatile RAM (NVRAM).

SRAM.

- Memory holds data as long as power is applied.
- Stores data in form of voltage.
- SRAM is made up flipflops.
- It uses 6 transistors. Four for building latch, and 2 for controlling access.
- The main advantages of SRAM are less access time and less volatile.
- The drawbacks of SRAM are low capacity, high cost, more power consumption and more area is occupied as there are 6 no. of transistors.

DRAM.

- It stores the data in form of charge.
- DRAM made up of mos transistor gates.
- It is used for refreshing operation.
- capacity is 1-bit storage unit.
- DRAM advantages are high capacity (density), low cost, less power consumption.
- The drawbacks of DRAM, information stored as charge, so gets leak off with time. hence it is to be periodically refreshed, slow in operation, more volatile.

NVRAM

→ NVRAM consists of static RAM memory & a battery enclosed in a single package. The battery provides backup supply to the memory when the external power supply is unavailable. The life span of NVRAM is approximately 10 years. NVRAM is used to set the flags or store the result of operations that are non-volatile.

Ex:- DS1741 by maxim/dallas.

Selection of Memory & shadowing.

Memory selection.

→ Program memory holds control algorithm or embedded OS and applications designed to run on top of it.

→ Data memory holds variables and temporary data during task execution and memory for holding non-volatile data which is modifiable by application.

→ For selecting the type and size of memory we should identify

1. System requirements
2. word size of memory.
3. Type of processor.

→ RAM is for Execution, ROM is for storing.

→ For processor/controller with 16-bit address bus the max. no. of memory locations that can be addressed is 16 bytes memory range supported by processor/controller is shared b/w I/O, JCS & memory.

→ Word size is no. of bits that can be read/written together at a time word size supported by memory chip should match with data bus width of processor/controller.

→ Flash memory is generally used because it is powerful, and cost effective solid-state storage technology.

Memory Shadowing

(9)

Memory shadowing is defined as the process adopted / implemented to solve the problems of execution speed in a processor based system. In general the execution speed of a RAM is twice the execution speed of ROM.

Usually, computer & video systems are designed by considering ROM which is known as Basic Input Output Configuration ROM (BIOS). In computer systems, BIOS store the information related to address assigned to different serial ports and non-plug 'n' play devices etc.

Thus, the system is configured and read depending on the boot up time. The time required to complete this process is high. So, in order to overcome this problem RAM is used behind the logical layer of BIOS (at the same address) as shadow. During bootup, BIOS is copied to the shadowed RAM and writes to protecting the RAM. Then, disables BIOS reading.

The reason behind the using both RAM and ROM to hold the same data is that, RAM is a volatile and deletes the data when power is off. But, it increases the system performance with the data is accessed from it. ROM is used to hold the data permanently, . . .

Sensors & Actuators

Sensors

A transducer device which is used to convert one form of energy (pressure) into another (electrical) form is known as 'Sensor'. The two major application domains of a sensors are measurement and control.

A sensor is connected to the input part of an EC in order to sense the changes in the system environment.

Ex:- a hall effect sensor placed at the top of "cushioning element" in a 'smart running shoe' is used to measure the distance from top to bottom of mid sole - soles.

Actuators :

- An actuator is a transducer device which converts an electrical signal into its equivalent physical action (motion). It is connected at the OLP port ES to control the variations in the controlling variable.

for instance, consider an ES used in a controlling application. In order to achieve a specified control value, the controlling variable is varied as desired. This desired variation is accomplished by using an actuator in the system.

Ex:

The micro stepper motor used in the 'smart running shoe' is a typical example for actuator. The purpose of using this actuator is to either lengthen or shorten the positions of a 'plastic-cushioning element'.

I/O Sub System

- The I/O subsystem of ES is used to provide interaction between ES and external world using sensors and actuators.
- The sensors are interfaced through following signal conditioning & translating system to the I/P Port.

LED.

Light Emitting diode in ES is an OLP device used for visual indication of status various signals:

7-segment LED Display.

The 7 segment LED display is an OLP device which is used to display alpha-numeric characters.

Optocoupler.

Optocoupler is a solid state device used to separate two parts of a circuit. Stepper motor A stepper motor is an electromechanical device which is used to produce discrete motion according to dc electric signals.

Keloy.

(9)

Relay is an electro-mechanical device used as a dynamic path selector for signals and power.

push button switch.

Push button switch is of 2 types

1. push to make - In this, ~~if~~ the switch is normally open and when pushed or pressed, it gets closed to make a circuit.

2. push to break - In this, switch is normally closed and when pushed or ~~is~~ pressed, it gets open to break a Ckt.

Piezo buffer.

In ES, piezo buffer is used to generate audio indication Key board.

Keyboard is an I/O device which is used for user Interfacing. Programmable peripheral Interface (PPI).

These devices are used to explain the capabilities of Input/Output of processor controller.

Communication Interfaces with respect to ES.

In ES, communication interfaces is responsible for communication b/w different subsystem & external environment.

There exist 2 major types of communication interfaces available - they are

1. Device/board level communication interface.
2. product level communication interface.

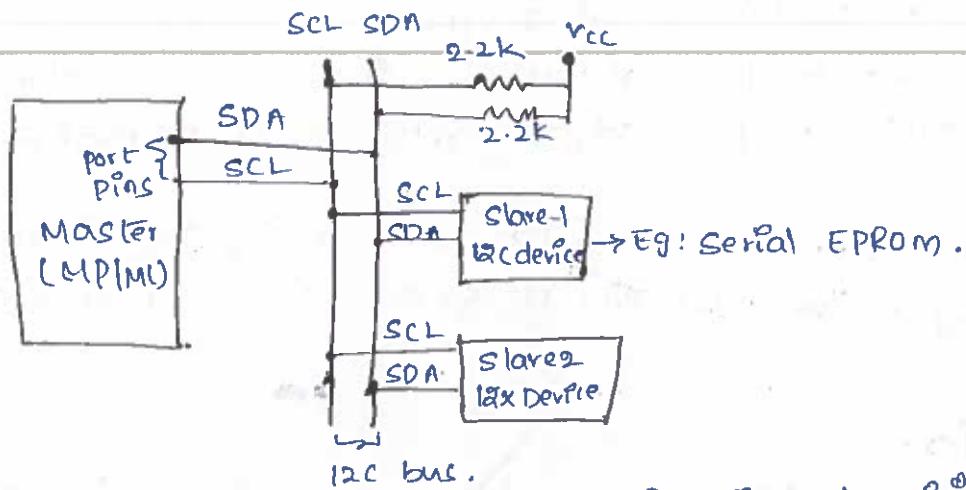
Device/board level communication Interface.

Device board level communication interface act as medium which interconnects the different components on printed Circuit Board (PCB) available in an Embedded devices.

It is known as on board communication interface. The various interfaces of on-board communication are

(i) Inter Integrated circuit (I₂C) Bus.

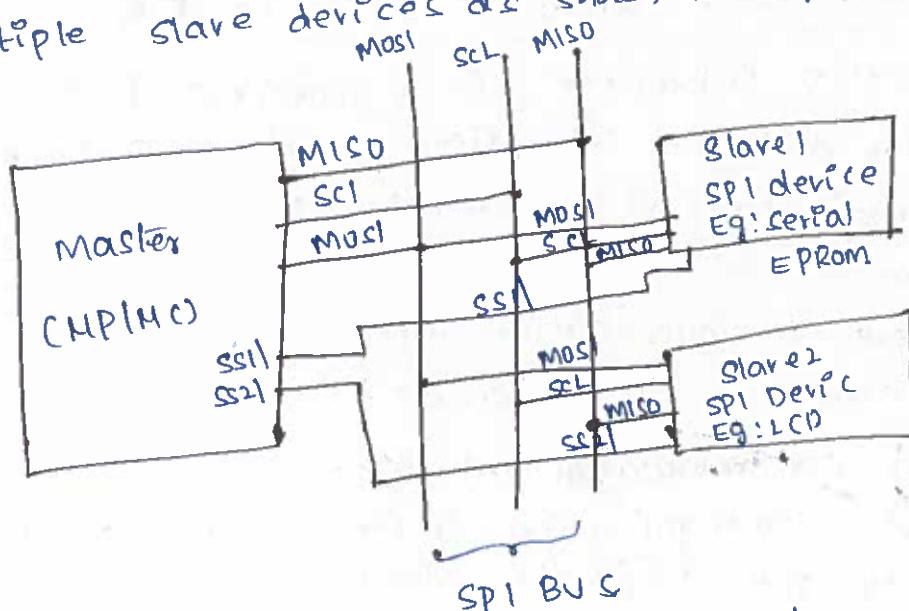
This is a synchronous bidirectional half duplex two wire serial interface bus. It acts as a shared bus system of connecting the master device or slave device as shown in fig.



Master device controls the communication by initiating/ terminating data transfer, sending data etc while slave device waits for permission from master. Both master and slave acts as a transmitter and receiver.

(ii) Serial peripheral Interface (SPI) bus.

This is a synchronous bidirectional full duplex 4 wire serial interface bus. It consists of single master and multiple slave devices as shown in figure.

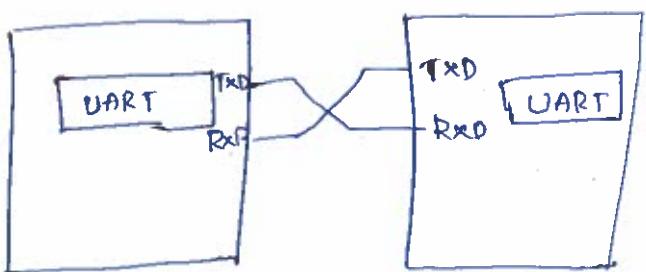


SPI transfers data in streams but does not acknowledge.

(III) Universal Asynchronous Receiver & Transmitter (UART)

This is an asynchronous form of serial data transmission without using synchronised clock signal. The UART interfacing is shown fig.

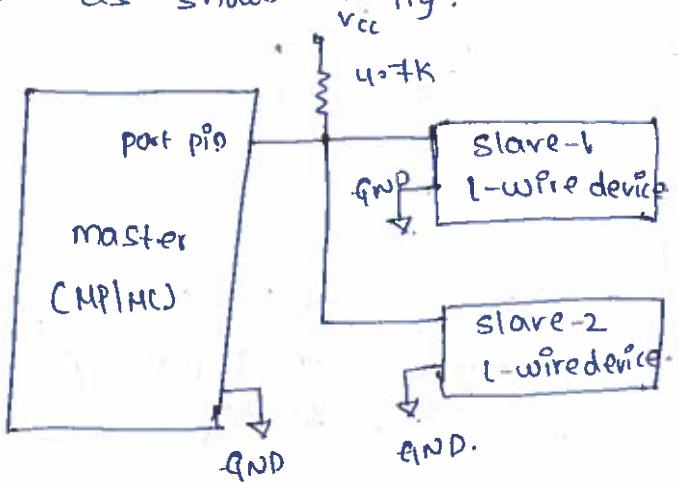
11



This serial communication should possess identical setting for transmission and reception.

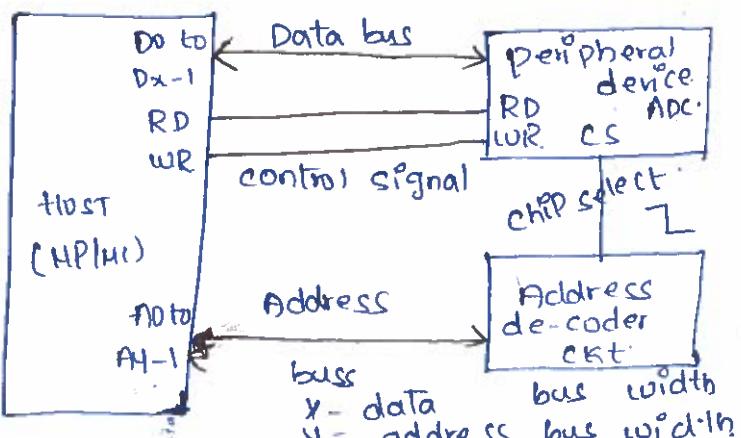
(iv) I-Wire Interface.

I-wire interface is an asynchronous half duplex communication protocol which uses only single line or wire for communication. It supports single master and many slaves as shown in fig.



(V) Parallel Interface.

It is used to communicate with peripheral devices that are memory mapped to host of the system. The bus interface of Parallel interface illustrated in fig.



Product Level Communication Interface:

It is also known as External communication interface. These interfaces provide communication b/w an ES and External device. The product level communication interface is available either of the following form.

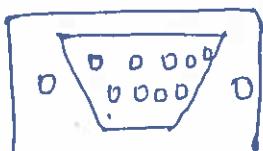
(i) Serial or Parallel interface.

(ii) wired or wireless interface.

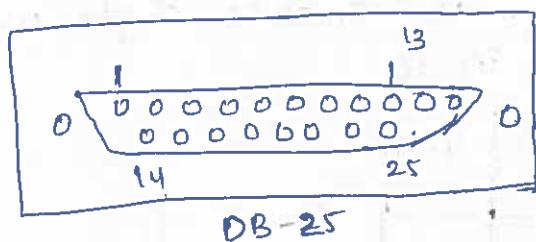
The various ~~8~~ interfaces of External communication interface ~~are~~ are

RS-232.

RS-232 is an asynchronous full duplex wired serial communication that extends the UART communication for external data communication. The connector details of DB-9 and DB-25 are shown in fig.



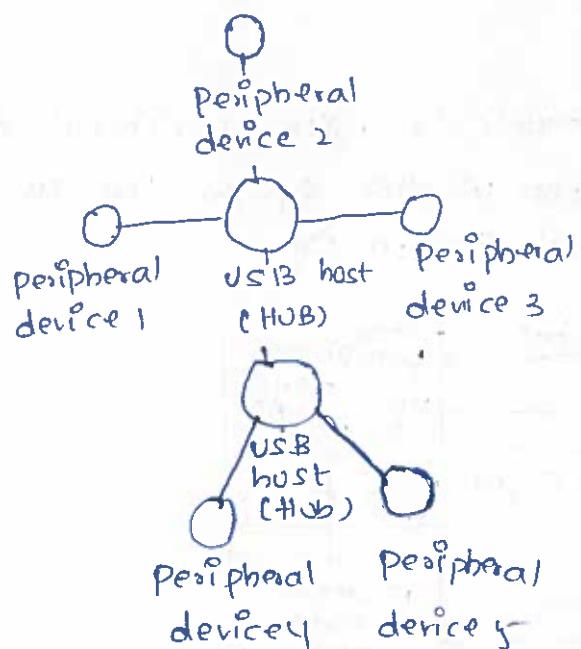
DB-9.



DB-25

Universal Serial Bus (USB).

It is a wired high speed bus used to transmit data in packet format. USB supports star topology using host slave peripheral devices as shown in fig.



It is a wired, isochronous high speed serial communication bus.

Infrared (IrDA)

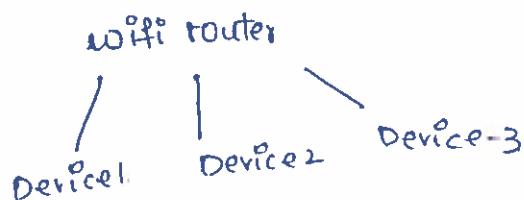
It is a half-duplex serial line based wireless topology used for data communication between devices. It acts as an interface for file exchange and data transfer.

Bluetooth

Bluetooth is a wireless short range technology used for data and voice communication.

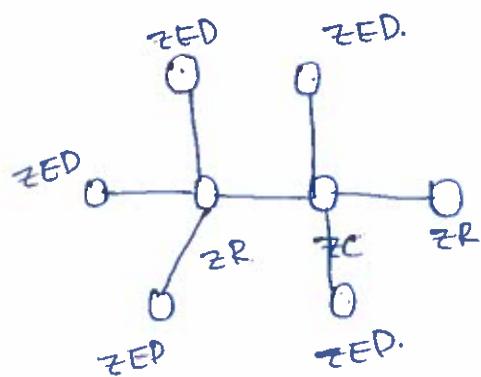
Wi-Fi

Wireless Fidelity is a wireless communication technique used for network communication of devices. The communication depends on an intermediate agent called Wi-Fi router as shown in fig.



ZigBee

ZigBee is a wireless networks communications protocol which depends on IEEE 802.15.4 - 2006 standard. It contains mesh network with multiple nodes as shown in fig.



ZC - ZigBee coordinator, ZR - Zigbee Router.

ZED - Zigbee End device.

General packet Radio Service (GPRS).

GPRS is used for communication by transferring data in the form of packets over mobile communication network.