UNIT-1

INTRODUCTION

1.1 What is an Embedded System? :-

An embedded system is an electronic/electro-mechanical system designed to perform a specific function and is a combination of both hardware and firmware (software).

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.

1.2. Embedded Systems vs General Computing Systems :-

General purpose computing system	Embedded System
(i) A system which is a combination of generic hardware and a general purpose operating system for executing a variety of applications.	(i) A system which is a combination of special purpose hardware and embedded OS for executing a specific set of applications
(ii) Contains a general purpose operating system (GPOS)	(ii) May or may not contain an operating system for functioning.
(iii) Applications are alterable by the user.	(iii) The firmware of the embedded system is pre-programmed and it is non-alterable by the end-user.
(iv) performance is the key deciding factor in the selection of the system. Always, 'Faster is Better'.	(iv) Application-specific requirements are the key deciding factors.
(v) Response requirements are not time-critical.	(v) For certain category of embedded systems like mission critical systems, the response time requirements is highly critical

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1.3 History of Embedded Systems:

- In the olden days embedded systems were built around the old vaccum tube and transistor technology and the embedded algorithms was developed in low level languages.
- The first recognised modern embedded system is the Apollo Guidance Computer (AGC) developed by the MIT Instrumentation Laboratory for the lunar expedition.
- MIT's original design was based on 4K words of fixed memory (ROM) and 256 words of erasable memory (RAM).

  By June 1963, the figures reached 10K of fixed and 1K of erasable memory.
- The clock frequency of the first microchip proto model used in AGC was 1.024 MHz and it was derived from a 2.048 MHz Crystal clock.
- The user interface unit of AGC is known as DSKY (display/keyboard). DSKY looked like a Calculator type keypad with an array of numerals. It was used for inputting the commands to the module numerically.
- The first mass-produced embedded system was the guidance Computer for the Minuteman-I missile in 1961. It was the 'Autonetics D-17' guidance computer, built using discrete transistor logic and a hard-disk for the main memory.

1.4 Classification of Embedded Systems:-

The classification of embedded systems are:

1. Based on generation
2. Complexity and performance requirements
3. Based on deterministic behavior
4. Based on triggering.

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Classification Based on Generation:-

a) First Generation:- The early embedded systems were built around 8-bit microprocessors like 8085 and Z80, and 4-bit microcontrollers.

* Simple in hardware circuitry with firmware developed in Assembly Code.
* Digital telephone keypads, stepper motor control units etc. are examples.

b) Second Generation:- These are embedded systems built around 16 bit microprocessors and 8 or 16 bit microcontrollers.

* The instruction set is much more complex and powerful than the first generation
* Examples: Data Acquisition Systems, SCADA Systems etc.

c) Third generation:- Embedded system developers started making use of powerful 32 bit processors and 16 bit microcontrollers for their designs.

* A new concept of application and domain specific processors/controllers like Digital Signal processors (DSP) and Application Specific Integrated Circuits (ASICs) came into the picture
* The instruction set of processors became more complex and powerful and the concept of instruction pipelining also evolved.
* processors like Intel Pentium, Motorola 68K, etc. gained attention in high performance embedded requirements.
* Dedicated embedded real time and general purpose operating systems entered into the embedded market.
* Embedded systems spread its ground to areas like robotics, media, industrial process control, networking etc..

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d) Fourth Generation:- The advent of System on chips (SoC), reconfigurable processors and multicore processors are bringing high performance.

+ The SoC technique implements a total system on a chip by integrating different functionalities with a processor core and on an integrated circuit.

+ The fourth generation embedded systems are making use of high perform real time embedded Operating Systems for their functioning.

+ Smart phone devices, mobile internet devices (MIDs) are examples.

2. Classification Based on Complexity and performance:-

a) Small-Scale Embedded systems:- Embedded Systems which are simple in application needs and where the performance requirements are not time critical fall under this category.

+ An electronic toy is a typical example for this.

+ These are usually built around low performance and low cost 8 or 16 bit microprocessors/microcontrollers.

+ It may or may not contain an operating System for its functio

b) Medium-Scale Embedded Systems:- Embedded Systems which are slightly Complex in hardware and firmware (Software) requirements.

+ These are built around medium performance, low cost 16 or 32 bit microproc -ors/ controllers or Digital signal processors.

+ They usually contain an embedded operating system (either general -purpose or real time operating System) for functioning.

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c) Large-Scale Embedded Systems / Complex Systems :-

+ Embedded Systems which involve highly complex hardware and firmware requirements fall under this category.

+ The systems are built around high performance 32 or 64 bit RISC processors/controllers or Reconfigurable System on Chip (RSoC) or multi-core processors and programmable logic devices.

+ They may contain multiple processors/controllers and co-units/hardware accelerators for offloading the processing requirements from the main processor of the system.

+ Decoding/encoding of media, Cryptographic function implementations etc. are examples.

+ Complex embedded systems usually contain a high performance Real Time - Operating System (RTOS) for task scheduling, prioritization and management.

15 Major Application Areas of Embedded Systems :-

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

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

(vii) Card Readers : Barcode, Smart card readers, hand held devices, etc.

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Purpose of Embedded Systems :-

Embedded system is designed to serve the purpose of any one or a combination of the following tasks:

(i) Data collection / storage / Representation. - camera
(ii) Data communication. - wireless NW router
(iii) Data (Signal) processing. - Digital hearing aid
(iv) Monitoring - Monitoring heart beat
(v) Control - AC
(vi) Application specific user interface. - Mobile phone, Electronics enabled Smart running shoes.

(i) Data collection / storage / Representation :-

* Data collection is usually done for storage, analysis, manipulation and transmission. The term "data" refers all kinds of information, 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 signals whereas embedded systems with digital data collection mechanism converts the analog signal to corresponding digital signal using analog to digital (A/D) converters and then collects the binary equivalent of the analog data.
* Analog and digital CROs without storage memory are examples.
* A digital camera is a typical example of an embedded system with data collection / storage / representation of data.
* Images are captured and the captured images may be stored within the memory of the camera.
* The captured image can also be presented to the user through a graphic LCD unit.

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(ii) Data communication :-

* Embedded data communication systems are deployed in applications ranging from complex satellite communication systems to simple home networking systems.
* The transmission is achieved either by a wire-line medium or by a wireless medium.
* A wireless medium offers cheaper connectivity solutions and makes the communication link free from the hassle of wire bundles.
* Data communication units like wireless modules (Bluetooth, Wi-Fi, EDGE, GPRS etc). or wire-line modules (RS-232C, USB, TCP/IP, PS2 etc).

(iii) Data (Signal) processing :-

* The data (voice, image, video, electrical signals and other measurable quantity 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.

(iv) Monitoring :-

* Embedded systems falling under this are specifically designed for monitoring purpose
* They are used for determining the state of some variables using input sensors. They cannot impose control over variables.
* A good example is the electro cardiogram (ECG) machine for monitoring the heartbeat of a patient. It cannot impose control over the heartbeat.
* The other examples are Digital CRO, Digital multimeters, logic analysers etc. used in control & instrumentation applications.

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(v) Control :-

* Embedded systems with control functionality 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 input variable.
* Air conditioner system is the example for embedded systems for control purpose

(vi) Application Specific User Interface :-

* Embedded systems with application-specific user interfaces like buttons, switches, keypad, lights, bells, display units etc.
* Mobile phone is an example for this, the user interface is provided through the keypad, graphic LCD module, system speaker, vibration alert, etc..

1.7 The Typical Embedded System :-

* A typical Embedded System containing a single chip controller, which acts as the master brains of the system.
* The controller can be a Microprocessor (eg. Intel 8085) or a microcontroller (eg: Atmel AT89C51) or a Field Programmable Gate Array (FPGA) device (eg: Xilinx Spartan) or a Digital Signal Processor (DSP) (eg: Blackfin® processors from Analog Devices) or an Application Specific Integrated Circuit (ASIC)

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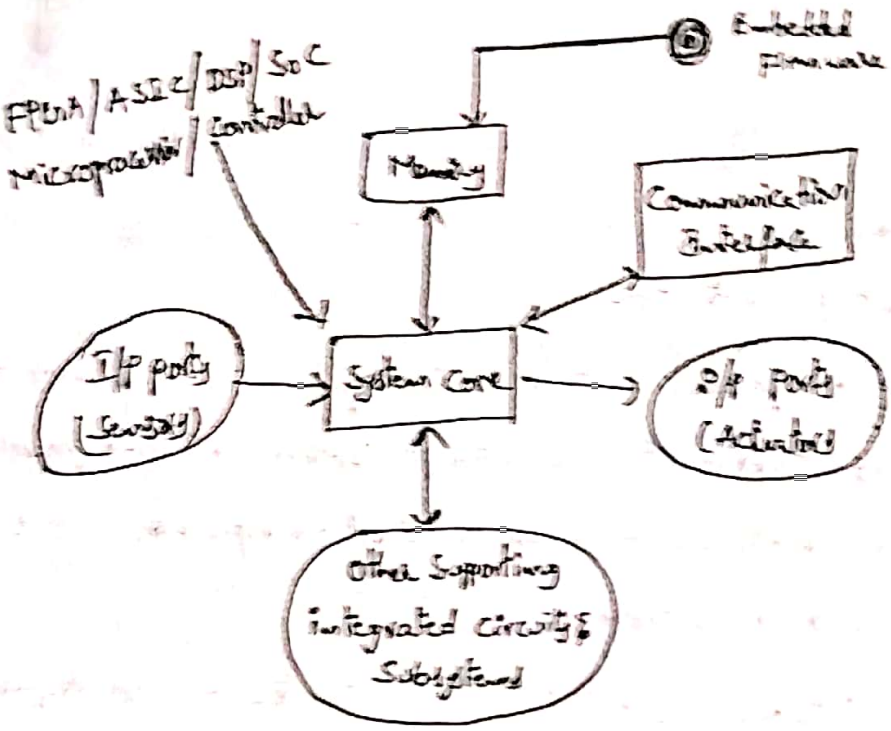


Fig:- Elements of an embedded System.

1.8 Core of the Embedded System:-

* Embedded Systems are domain and application specific and are built around a central Core. The Core of the embedded system falls into any one of the following categories:

(i) General Purpose and Domain Specific processors
  (a) Microprocessors
  (b) Microcontrollers.
  (c) Digital Signal processors
(ii) Application Specific Integrated Circuits (ASICs)
(iii) Programmable Logic Devices (PLDs)
(iv) Commercial off-the-Self Components (COTS)

(i) General purpose and Domain Specific processors:-

* The processor may be a microprocessor or a microcontroller or a digital signal processor, depending on the domain and application.
* The Domains are require signal processing such as Speech coding, Speech-recognization, etc..

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(9) Microprocessors :-

* A Microprocessor is a silicon chip representing a central processing unit (CPU) which is capable of performing arithmetic as well as logic operations according to a predefined set of instructions.
* A Microprocessor is a dependent unit and it requires the combination of other hardware like memory, timer unit, and interrupt controller, etc. for proper function
* Intel claims the credit for developing the first microprocessor unit Intel 4004 a 4 bit processor which was released in November 1971.
  - It featured 1K data memory, a 12 bit program counter and 4K program memory Sixteen 4 bit general purpose registers and 46 instructions.
  - It ran at a clock speed of 740 KHz. It was designed for older day's calculators.
* In 1972, 14 more instructions were added to the 4004 instruction set and the program space is upgraded to 8K. Also interrupt capabilities were added to it.
* It was quickly replaced in April 1972 by Intel 8008 which was similar to Intel 4040, the only difference was that its program counter was 14 bits wide and the 8008 serviced as a terminal controller.
* Immediately after the release of Intel 8080, Motorola also entered the market with their processor, Motorola 6800 with a different architecture and instructions compared to 8080.
* In 1976 Intel came up with upgraded version of 8080 - Intel 8085, with two newly added instructions, three interrupt pins and serial I/O.
* In twentieth century a fast growth in processor technology, 16, 32 and 64 bit processors came into the place of convential 8 bit processors. Clock speed up to 2.4 GHz and also offers high speed, high performance and low cost processors for customer design needs.

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(b) General purpose processor (GPP) vs. Application-Specific Instruction set processor (ASIP):-

GPP:-

* A general purpose processor or GPP is a processor designed for general computation - al tasks.
* The example is processor running inside your laptop or desktop.
* The High volume production, the per unit cost for a chip is low compared to ASIC or other specific IC's.
* GPP Contains an Arithmetic and Logic unit (ALU) and Control unit (CU).

ASIP:-

* ASIP's are processors with architecture and instruction set optimized to specific - domain/application requirements like network processing, automotive, telecom, media applications, digital signal processing, control applications, etc.
* The need for an ASIP arises when the traditional general purpose processor are unable to meet the increasing application needs.
* The Embedded systems are built around application specific instruction set processors.
* The examples are microcontrollers (AVR, USB AVR from Atmel), System on chips, digital signal processors etc.

(c) Microcontroller:-

* 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 I/O ports.
* Texas Instrument's TMS1000 is the world's first microcontroller.
* The important family of microcontrollers used in industrial control and embedded applications is the PIC family microcontrollers from Microchip Technology.
* The Instruction set architecture of a microcontroller can be either RISC or CISC.

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(d) Microprocessor vs Microcontroller :-

Microprocessor	Microcontroller
(i) A silicon chip representing a central processing unit (CPU), which is capable of performing arithmetic as well as logical operations according to a pre-defined set of instructions.	(i) A microcontroller is highly integrated chip that contains a CPU, scratchpad RAM, special/general purpose register arrays, on chip ROM/FLASH memory for program storage, timer and interrupt control units and dedicated I/O ports.
(ii) It is a dependent unit. It requires the combination of other chips like timers, program and data memory chips, interrupt controllers, etc. for functioning.	(ii) It is a self-contained unit and it does require external interrupt controller, timer, UART, etc. for its functioning
(iii) Most of the time general purpose in design and operation	(iii) Mostly application-oriented or domain-specific.
(iv) Doesn't contain a built in I/O port.	(iv) Most of the processors contain multiple built-in I/O ports.
(v) Targeted for high end market where performance is important	(v) Targeted for embedded market where performance is not so critical
(vi) Limited power saving options compared to microcontrollers.	(vi) Includes lot of power saving features

(e) Digital Signal processors :- (DSP)

* DSP's are powerful special purpose 8/16/32 bit microprocessors designed specially to meet the audio, video, and communications applications.
* DSP's implement algorithms in hardware which speeds up the execution.
* In general, DSP can be viewed as a microchip designed for performing high-speed computational operations for 'addition', 'subtraction', 'multiplication' and 'division'

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* A typical digital signal processor incorporates the following key units:

Program Memory:- Memory for storing the program required by DSP to process the data.

Data Memory:- Working memory for storing temporary variables and data/signal to be processed.

Computational Engine:- performs the signal processing in accordance with the stored program memory.

* Computational Engine incorporates many specialized arithmetic units and each of them operates simultaneously to increase the execution speed.
* It also incorporates multiple hardware shifters for shifting operands and thereby saves execution time.

I/O unit:- Acts as an interface between the outside world and DSP.
* It is responsible for capturing signals to be processed and delivering the processed signals.

(f) RISC Vs CISC processors / Controllers:-

RISC	CISC
(i) Lesser no of instructions	(i) Greater no of instructions.
(ii) Instruction pipelining and increased execution speed	(ii) Generally no instruction pipelining feature.
(iii) Orthogonal instruction set	(iii) Non-orthogonal instruction set.
(iv) operations are performed on registers only, the only memory operations are load & store	(iv) operations are performed on registers or memory depending on the instruction.
(v) Large no of registers are available	(v) Limited no of general purpose registers.
(vi) Single, fixed length instructions	(vi) variable length instructions.
(vii) with Harvard Architecture	(vii) Can be Harvard or Von-Neuman Archite-

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(9) Harvard Vs Von-Neumann processor/controller Architecture :-

Harvard Architecture	Von-Neumann Architecture
(i) Separate buses for instruction and data fetching.	(i) Single shared bus for instruction and data fetching.
(ii) Easier to pipeline, so high performance can be achieved.	(ii) Less performance compared to Harvard architecture
(iii) Comparatively high cost.	(iii) Cheaper.
(iv) No memory alignment problems.	(iv) Allows self modifying codes.
(v) Data memory & program memory are stored physically in different locations.	(v) Data memory & program memory are stored physically in the same chip.

(ii) Application Specific Integrated Circuits (ASICs) :-

* ASIC is a microchip designed to perform a specific or unique applicatio
* It is used as replacement to conventional general purpose logic chips.
* It integrates several functions into a single chip and there by reduces the system development cost.
* ASIC consumes a very small area in the total system.
* ASICs can be pre-fabricated for a special application or it can be custom fabricated by using the components from a reusable "building block" library.
* ASIC based systems are profitable only for large volume commercial productions.
* Fabrication of ASICs requires a non-refundable initial investment for the process technology and configuration expenses.

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iii) Programmable Logic Devices :-

* Logic devices provide specific functions, including device-to-device interfacing, data communication, signal processing, data display, timing and control operations,
* Logic devices can be classified into two categories - fixed and programmable.
  - Fixed logic devices are permanent, they perform one function or set of funct - once manufactured, they cannot be changed
  - Programmable Logic Devices (PLDs) offers a wide range of logic capacity, features, speed, and voltage characteristics - and these devices can be re-configure to perform any number of functions at any time.
* programmable logic devices, designers use inexpensive software tools to quickly develop, simulate, and test their designs.
* A design can be quickly programmed into a device, and immediately tested in a live circuit.
* The two major types of programmable logic devices are Field programmable - Gate Arrays (FPGAs) and Complex programmable Logic Devices (CPLDs).

Advantages of PLD :-

* PLDs offer customers much more flexibility during the design cycle.
* PLDs do not require long lead times for prototypes or production parts.
* PLDs do not require customers to pay for large NRE costs and purchase expensive mask sets.
* PLDs allow customers to order just the no of parts they need.
* PLD's can be reprogrammed even after a piece of equipment is shipped to a customer.

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(N) Commercial off-the-shelf Components (COTS) :-

* COTS products are designed to provide easy integration and interoperability with existing system components.
* 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.
* Examples of COTS hardware unit are remote controlled toy car control unit including the RF circuitry part, high performance, high frequency microwave-electronics, high bandwidth A to D converters etc.. (2-200GHz)
* Advantage of using COTS is that they readily available in the market, are cheap.
* Drawback of using COTS components may withdraw the product or discontinue the production of the COTS at any time if a rapid change in technology.

1.9 MEMORY :-

* Memory is an important of a processor/controller based embedded system.
  - On-chip memory — processor/controller contain built in memory.
  - Off-chip memory — Do not contain any memory inside the chip.
* The different types of memory used in embedded system applications :
  i) program storage Memory (ROM)
     a) Masked ROM (MROM)
     b) programmable Read only Memory (PROM) (OTP) one time programable Memory
     c) Erasable programmable Read only Memory (EPROM)
     d) Electrically Erasable programmable Read only Memory (EEPROM)
     e) Flash
     f) NVRAM (Non-volatile RAM)

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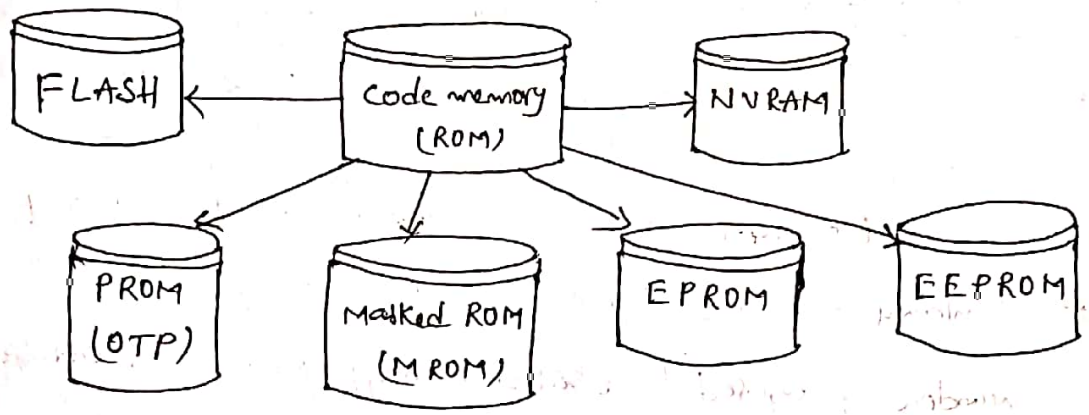


Fig:- classification of program Memory (ROM).

a) Masked ROM (MROM) :-

* Masked ROM is a one-time programmable device.
* Masked ROM makes use of the hardwired technology for storing data.
* The device is factory programmed by masking and metallisation process at the time of production itself, according to the data provided by the end user.
* The advantage is low cost for high volume production.
* Different mechanisms are used for the masking process of the ROM
  - Creation of an enhancement or depletion mode transistor through Channel implant
  - By creating the memory cell either using a standard transistor or a high threshold transistor.

b) programmable Read only Memory (PROM)/(OTP) :-

* One Time Programmable Memory (OTP) or PROM is not pre-programmed by the manufacturer.
* This memory has nichrome or polysilicon wires arranged in a matrix.
* These wires can be functionally viewed as fuses.
* It is programmed by a PROM programmer which selectively burns the fuses according to the bit pattern to be stored.
* Fuses which are not blown/burned represents a logic "1" whereas fuses which are blown/burned represents a logic "0".

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c) Erasable Programmable Read only Memory (EPROM) :-

* Erasable Programmable Read only Memory (EPROM) gives the flexibility to re-prog the same chip.
* EPROM store the bit information by changing the floating gate of an FET.
* EPROM contains a quartz crystal window for erasing the stored informa
* If the window is exposed to ultraviolet rays for a fixed duration, the entire memory will be erased.

d) Electrically Erasable programmable Read only Memory (EEPROM) :-

* The information contained in the EEPROM memory can be altered by using electrical signals at the register/Byte level.
* They can be erased and reprogrammed in-circuit.
* These chips include a chip erase mode and in this mode they can be erased in a few milliseconds.
* It provides greater flexibility for system design.
* Limitation is their capacity is limited when compared to standard ROM (a few kilobytes).

e) FLASH :-

* It combining the re-programmability of EEPROM and the high capacity of standard ROMs.
* FLASH memory is organised as sectors (blocks) or pages.
* FLASH memory stores information in an array of floating gate MOS-FET transistors.
* The erasing of memory can be done at sector level or page level without affecting the other sectors or pages.

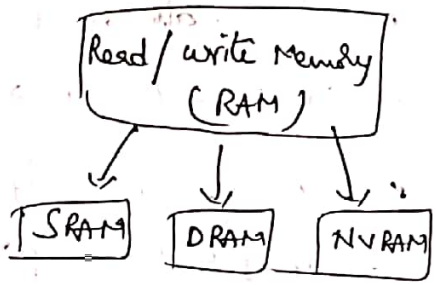
f) NVRAM :-

* Non-volatile RAM is a random access memory with battery backup.
* It contains static RAM based memory and a minute battery for providing supply to the memory in the absence of external power supply.
* The memory and battery are packed together in a single package.
* The life span of NVRAM is expected to be around 10 years.

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(ii) Read-write Memory / Random Access Memory (RAM)

* RAM is the data memory or working memory of the controller/ processor
* Controller/processor can read from it and write to it.
* RAM is volatile, i.e when the power is turned off, all the contents are destroyed
* RAM is direct access memory, we can access the desired memory location directly
* RAM generally fall into three categories:
  - → Static RAM (SRAM)
  - → Dynamic RAM (DRAM)
  - → Non-volatile RAM (NVRAM).



→ Static RAM (SRAM):-

* Static RAM stores data in the form of voltage. They are made up of flip-flops.
* It is the fastest form of RAM available.
* An SRAM cell (bit) is realised using six transistors (or 6 MOSFETs).
* Four of the transistors are used for building the latch (flip-flop) part of the memory cell and two for controlling the access.

→ Dynamic RAM (DRAM):-

* Dynamic RAM stores data in the form of charge.
* They are made up of MOS transistor gates.
* The advantages of DRAM are its high density and low cost compared to SRAM
* The disadvantage is information is stored as charge it gets leaked off with time.

→ NVRAM:-

* Non-volatile RAM is a random access memory with battery backup.
* It contains static RAM based memory and a minute battery for providing supply to the memory in the absence of external power supply.
* The memory and battery are packed together in a single package.

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(iii) Memory According to the Type of Interface :-

* The interface (connection) of memory with the processor/Controller can be of various types.
* It may be a parallel interface or the Serial interface or it may be an SPI (Serial pheripheral interface).
* It can also be of a single wire interconnection
* Serial interface is commonly used for data storage memory like EEPROM.
* The memory density of a serial memory is usually expressed in term of kilobit whereas that of a parallel interface memory is expressed in terms of kilobytes.

(iv) Memory shadowing :-

* Shadowing of memory is a technique adopted to solve the execution speed problem in processor-based systems.
* In computer systems and video systems there will be a Configuration holding ROM called Basic Input output Configuration ROM or simply BIOS
* In personal computers system BIOS stores the hardware Configuration information like the address assigned for various serial ports and other non-plug 'n' play devices, etc.
* It is read and the system is Configured according to it during system booting and it is time Consuming.
* Now the manufactorers included a RAM behind the logical layer of BIOS at its same address as a shadow to the BIOS and the first step that happens during the bootup is copying the BIOS to the shadowed RAM and write protecting the RAM then disabling the BIOS reading.
* RAM is volatile and it cannot hold the Configuration data which is copied from the BIOS when the power supply is switched off
* only a ROM can hold its permanently. i.e But for high system performance it should accessed from a RAM instead of accessing from a ROM.

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(v) Memory selection for Embedded Systems :-

* Embedded systems require a program memory for holding the control algorithm or embedded OS and the applications designed to run on top of it, data memory for holding variables and temporary data during task execution, and memory for holding non-volatile data which are modify by the application.

* The memory requirement for an embedded system in terms of RAM and RO is solely dependent on the type of the embedded systems and the applications for which it is designed.

* There are two parameters for representing a memory. The first one is the size of the memory chip (Memory density expressed in terms of number of memory bytes per chip).

* Memory chips come in standard sizes like 512 bytes, 1024 bytes (1 kilobyte), 2048 bytes (2 kilobytes), 4 Kb, 8 Kb, 16 Kb, 32 Kb, 64 Kb, 128 Kb, 256 Kb, 512 Kb, 1024 Kb (1 megabyte) etc..

* FLASH memory is the popular choice for ROM (program storage memory) in embedded applications.

* FLASH memory comes in two major variants, namely, NAND and NOR FLASH.
  - → NAND FLASH is a high-density low cost non-volatile storage memory.
  - → NOR FLASH is less dense and slightly expensive.

* The EEPROM data storage memory is available as either serial interface or parallel interface chip.

* The memory capacity of the serial EEPROM is usually expressed in bits or kilobits,

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Sensors and Actuators :-

* The changes in systems environment or variables are detected by the sensors connected to the input port of the embedded system.

(ii) Sensors :- A sensor is a transducer device that converts energy from one form to another for any measurement or control purpose.

(iii) Actuators :- Actuator is a forms of transducer device (mechanical or electri which converts signals to corresponding physical action (motion).

* Actuator act as an output device.

(iii) The I/O subsystem :-

* The I/O subsystem of the embedded system facilitates the interaction of the embedded system with the external world.

* The sensors and actuators connected to the input and output ports respective of the embedded system.

a) Light Emitting Diode (LED).
b) 7-Segment LED display.
c) Optocoupler
d) Stepper Motor — Unipolar, Bipolar
e) Relay
f) Piezo Buzzer
g) Push Button Switch.
h) Keyboard
i) Programmable peripheral Interface (PPI)

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(i) Light Emitting Diode (LED) :-

* Light Emitting Diode (LED) is an important output device for visual indicatio in any embedded systems.
* Typical examples are power conditions like 'Device ON', 'Battery low' or, 'charging of battery' for a battery operated handheld embedded devices.
* The 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.
* A resistor is used in series between the power supply and the LED to limit the current through the LED.
* The Ideal LED interfacing circuit is shown in fig.
* LED can be interfaced to the port pin of a processor/ Controller in two ways.
  - → Anode is directly connected to the port pin.
  - → Cathode is connected to the port pin.

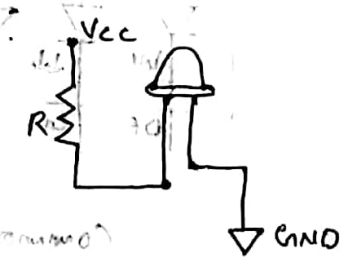


Fig:- LED interfacing

(ii) 7- Segment LED Display :-

* The 7-Segment LED display is an output device for displaying alphanumeri characters.
* It contains 8 light-emitting diode (LED) segments arranged in a special form. Out of this 8, '7' are used for displaying alphanumeric characters and '1' is used for representing 'decimal point' in decimal number display.
* The Fig. shows the arrangement of LED segments in a 7-Segment LED display.

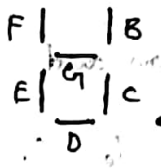
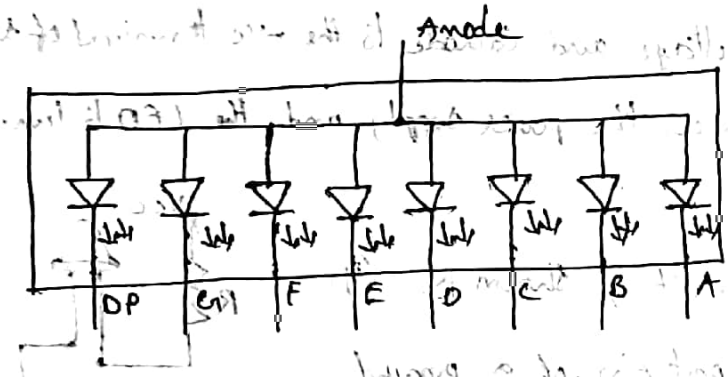


Fig:- 7-Segment LED display

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* The LED segments are named A to G and the decimal point LED segment is named as DP.
* For example, for displaying the number 4, the segments F, G, B and C are li
* The 7-segment LED displays are available in two different configurations namely; Common Anode and Common Cathode.
* The typical value for the current fally within the range of 20mA.



Common Anode LED Display

Similarly Common Cathode LED display.

* It is used in embedded applications like, public telephone call monitoring devic point of sale terminals, etc.

(iii) 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).

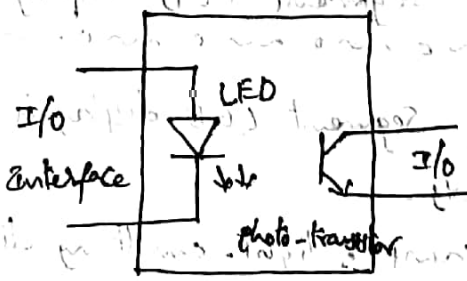


Fig:- An optocoupler device

* In electronic circuits, an optocoupler is used for suppressing interference in data communication, circuit isolation, high voltage separation, simultaneous separation and signal intensification etc.
* Optocoupler can be used in either input circuit or in output circuit.

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(iv) A Stepper Motor :-

* A stepper motor is an electro-mechanical device which generates discrete displacement (motion) in response to dc electrical signals.
* stepper motors are widely used in industrial embedded applications, Consumer-electronics products and Robotics Control systems.
* The paper feed mechanism of a printer/fax makes use of stepper motor for its functioning
* Based on the coil winding arrangement, a two-phase stepper motor is classified into two. They are : 1. Unipolar
2. Bipolar.

Unipolar :- * A unipolar stepper motor contains two windings per phase.
* The direction of Rotation of a stepper motor is Controlled by changing the direction of Current flow.
* It is easy to shift the direction of rotation by just switching the terminals to which the coils are connected.
* The coils are A, B, C & D. Coils A & C carry Current in opposite directions for phase 1. Similarly for phase 2 B & D.

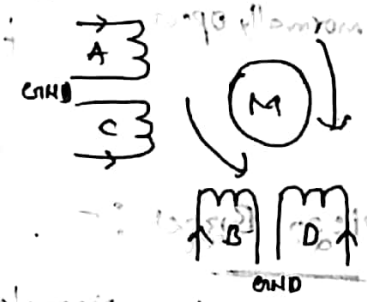


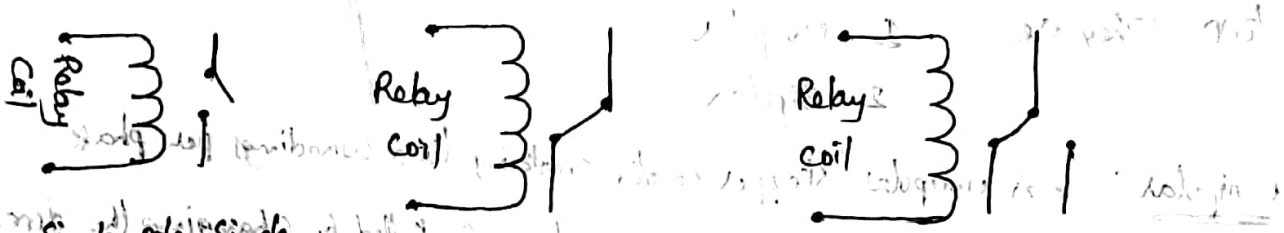
Fig :- 2-phase unipolar stepper motor

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 circuitary for Current flow reversal.

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(v) 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 turns generates magnetic field
* The magnetic field attracts the armature core and moves the contact path



Single pole Single throw normally open

Single pole Single throw normally closed

Single pole double throw.

(vi) Piezo Buzzer:-

* piezo buzzer is a piezoelectronic device for generating audio indications in embedded application.
* It contains diaphragm which produces audiable sound in response to the voltage
* piezoelectric buzzers are in 2 types.
  - → Self driving: It contains all the necessary components to generate sound at a predefined tone
  - → External driving: It generates different tones based on applied variable pulse train.
* A piezo buzzer can be directly interfaced to the port pin of the processor/control

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(vii) Push Button Switch :-

* It is an input device. It has two configurations,
  - ↳ 'push to make'
  - ↳ 'push to Break'.
* In 'push to make' configuration, the switch is normally in the open state and it makes a circuit contact when it pushed or pressed.
* In 'push to Break' configuration, the switch is normally in closed state and it breaks the circuit contact when it is pushed or pressed.
* In embedded application push button is generally used as reset and start switch and pulse generator.
* The fig. shows the push button can be used for generation of 'LOW' and 'HIGH' pulses.

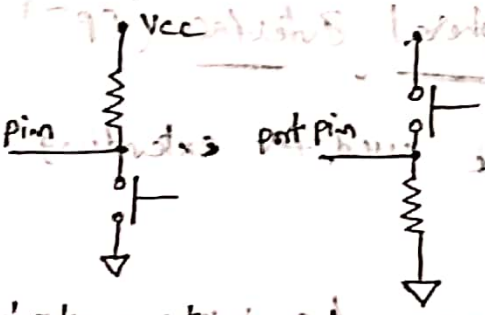
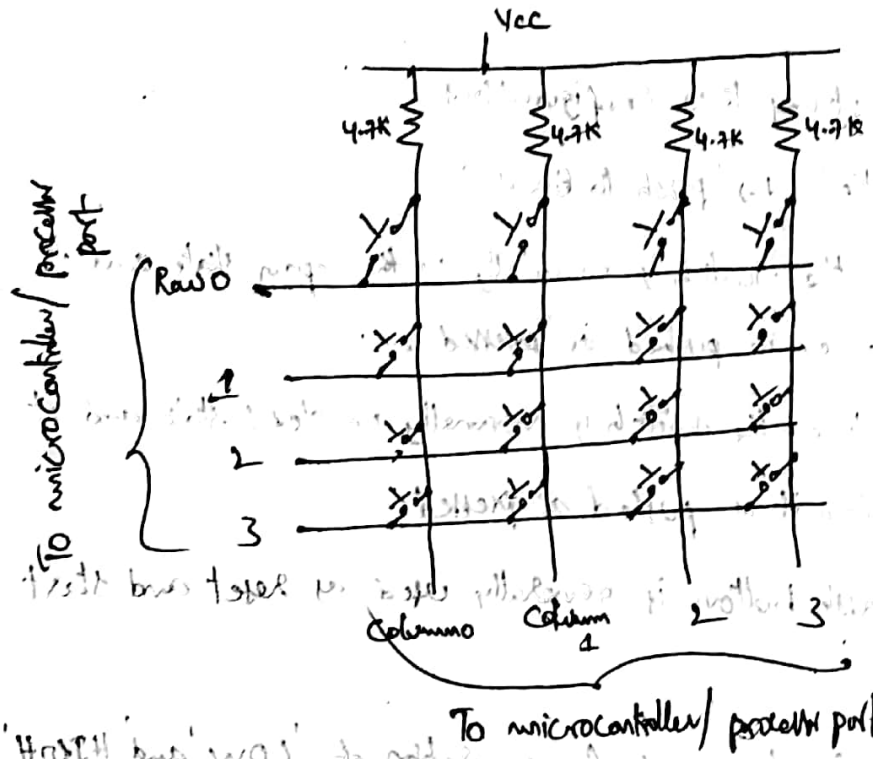


Fig:- push button switch configuration

(viii) Keyboard :-

* Keyboard is an input device for user interfacing.
* It greatly reduces the number interface connections.
* Matrix keyboard is an optimum solution for handling large key requirements.
* Example 16 keys are arranged in a 4 x 4 matrix.
* For detecting a key press, the keyboard uses the scanning technique, where each row of the matrix is pulled low and the columns are read.
* A proper key de-bouncing technique should be applied.
* pull-up resistors are connected to the column lines to limit the current that flows in the row lines when a key is pressed.

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Eg:- Matrix keyboard Interfacing

(ix) programmable peripheral Interface (PPI) :-

* PPI devices are used for extending the I/O capabilities of processor/ Controllers.

* Most of the processors/ Controllers provide very limited number of I/O & data ports and at times it may require more number of I/O ports than the supported by the Controller/ processor

* 8255A supports 24 I/O pins and these I/O pins can be grouped as either three 8-bit parallel ports (port A, B, C) or two 8-bit parallel ports (A with port C in any one of the following configurations

1. As 8 individual I/o pins.
2. Two 4 bit ports namely port C_{UPPER} (C_U) & Port C_{LOWER} (C_L).

This is configured by manipulating the control register of 8255A.

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Communication Interface :-

* Communication interface is essential for communicating with various subsystem of the embedded and with the external world.

* An embedded product, the communication interface can be viewed in two different perspectives;

→ Device/board level communication interface (on board communication Interface)

→ Product level communication interface (External communication Interface

* Serial interfaces like I2C, SPI, UART, 1-wire, etc and parallel bus interfac are examples of 'on board communication interface'.

* The external communication interface can be either a wired media or a wireless media and it can be a serial or a parallel interface.

↳ Infrared (IR), Bluetooth (BT), Wireless LAN (Wi-Fi), Radio Frequency waves (RF), GPRS, etc are examples for wireless communication interface.

↳ RS-232c / RS-422 / RS-485, USB, Ethernet IEEE 1394 ports, parallel port, CF-II interface, SDIO, PCMCIA, etc are examples for wired interfaces.

(i) onboard Communication Interfaces :-

* onboard Communication Interface refers to the different communication channels / buses for interconnecting the various integrated circuits and other peripherals within the embedded system.

a) Inter Integrated Circuit (I2C) Bus :-

* The Inter Integrated Circuit Bus is a synchronous bi-directional half duplex two wire serial interface bus.

* The I2C bus comprise of two bus lines; Serial clock - SCL and Serial data - SDA

→ SCL line is responsible for generating synchronization clock pulses.

→ SDA is responsible for transmitting the serial data across devices.

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* Devices connected to the I2C bus can act as either 'master' device or 'slave' device.

→ The 'master' device is responsible for controlling the communication by initiating/ terminating data transfer, sending data and generating necessary synchronization clock pulses.

→ 'slave' devices wait for the commands from the master and respond upon receiving the commands.

* 'Master' and 'slave' devices can act as either transmitter or receiver.

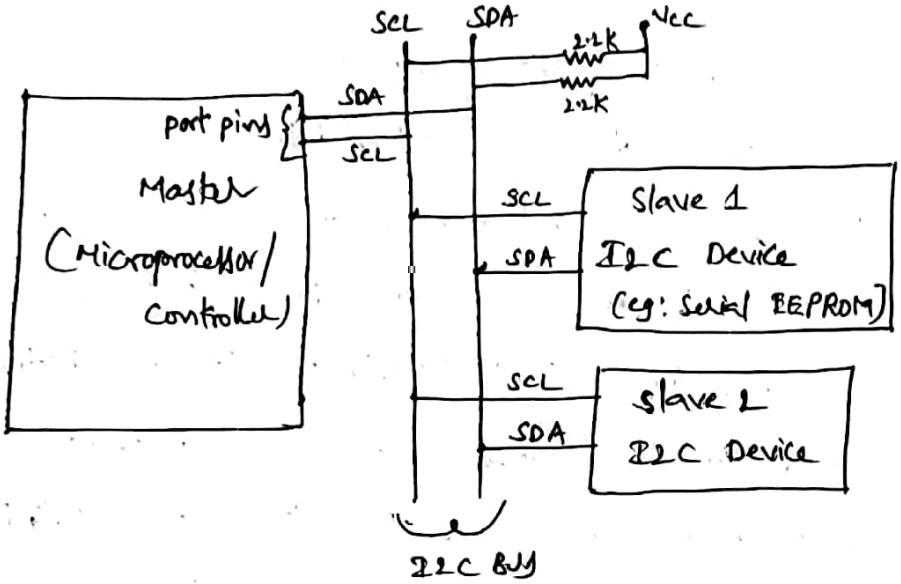


Fig:- I2C Bus Interfacing.

(b) Serial peripheral Interface (SPI) Bus:-

* The Serial peripheral Interface Bus (SPI) is a synchronous bi-directional full duplex four-wire serial interface bus.

* SPI was introduced by Motorola.

* SPI is a single master multi-slave system.

* SPI requires four signal lines for communication.

→ Master out slave In (MOSI): Signal line carrying the data from master to slave device. It is also known as slave Input/slave Data (SI/SDI).

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→ Master In slave Out (MISO) : Signal line carrying the data from slave to master device. It is also known as Slave output (SO/SDO)

→ Serial clock (SCLK) : Signal line carrying the clock signals.

→ Slave select (SS) : Signal line for slave device select. It is an active - low signal.

The following fig. shows the Connection of master and slave devices on the SPI bus.

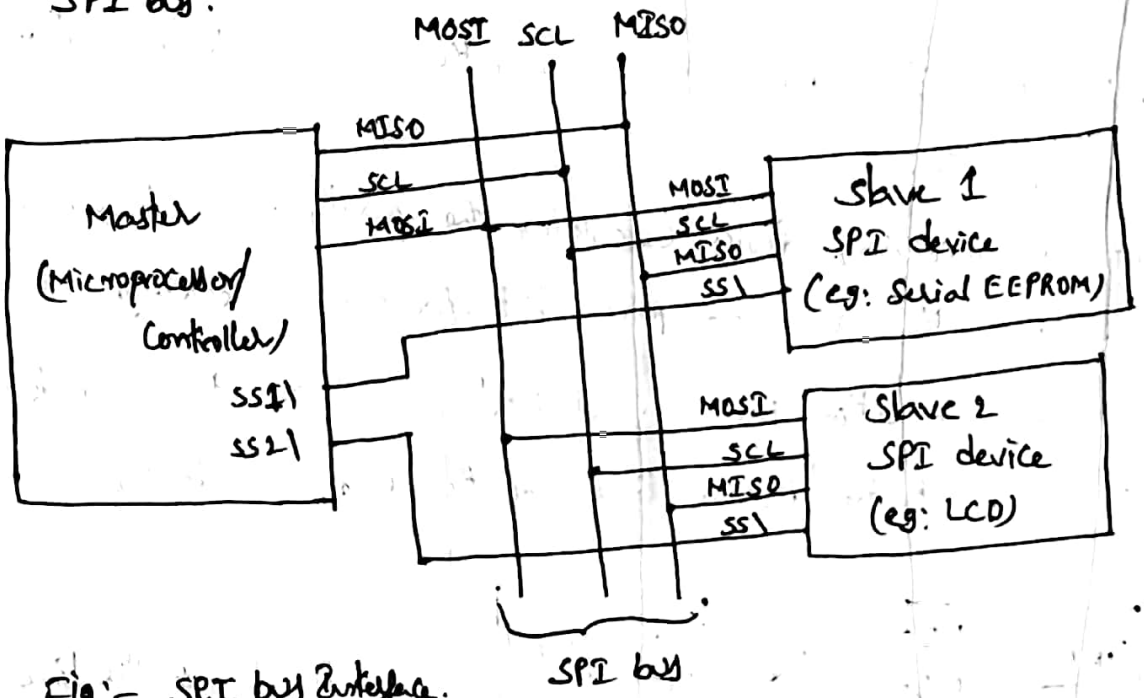


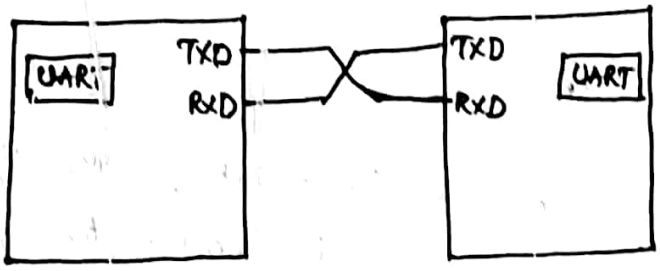
Fig:- SPI bus Interface.

* The master device is responsible for generating clock signal.
* It selects the required slave device by asserting the corresponding slave device's slave select signal 'Low'
* The serial data transmission through SPI bus is fully configurable. SPI device Contain a certain set of registers for holding these configurations.
* The serial peripheral Control register holds the various configurations parameters like master/slave selection for the device, baud rate selection for Communication, Clock signal Control etc..
* SPI works on the principle of 'shift Register'.
* The master and slave devices contain a special shift registers for the data to transmit or receive.
* The limitations in SPI doesn't support an acknowledgement mechanism. //

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(c) Universal Asynchronous Receiver Transmitter (UART) :-

* UART based data transmission is an asynchronous form of serial data transmission.
* It doesn't require clock signal.
* The start and stop are indicated, while sending a byte of data, a start bit is added first and a stop bit is added at the end of the bit stream.
* The least significant bit of the data byte follows the "start" bit.
* If parity bit is enabled for communication, the UART of the transmitting device adds a parity bit.
* The UART of receiving device calculates the parity of the bits received and compares it with the received parity bit for error checking.
* For proper communication, the "transmit line" of the sending device should be connected to the "Receive line" of the receiving device.



TXD: Transmitter line.
RXD: Receiver line.

Fig:- UART Interfacing.

* UART provides hardware handshaking signal support for controlling the serial data flow.
* National Semiconductor's 8250 UART chip is considered as the standard settin UART. It was used in original IBM PC.

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(d) 1-wire Interface :-

* 1-wire interface is an asynchronous half-duplex communication protocol developed by Maxim Dallas Semiconductor. It is also known as Dallas 1-wire protocol
* The key feature of 1-wire bus is that it allows power to be sent along the signal wire as well.
* The 1-wire interface supports a single master and one or more slave devices on the bus.

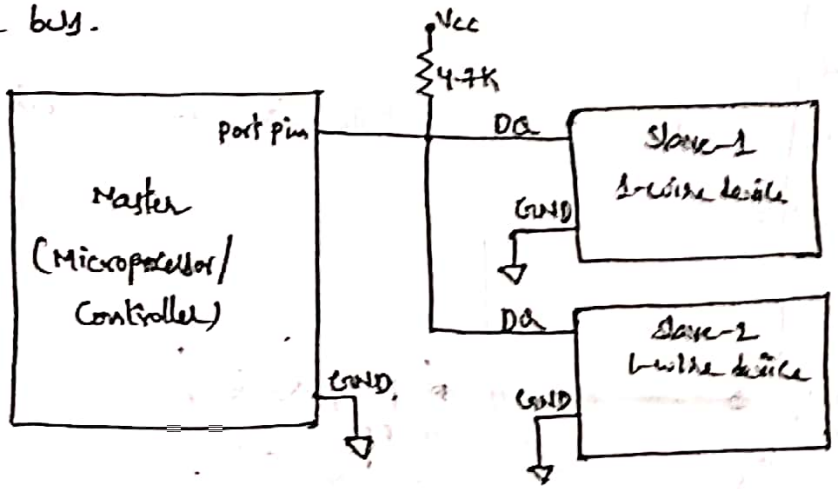


Fig :- 1-wire Interface bus

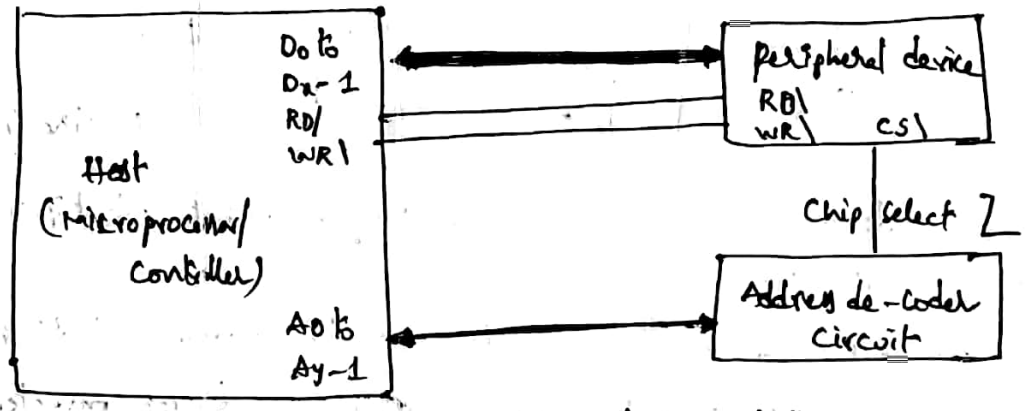
* Every 1-wire device contains a globally unique 64 bit identification number stored within it.
* The unique identification number can be used for addressing individual devices present on the bus in case there are multiple slave devices connected to the 1-wire bus.
* The identifier has three parts : an 8 bit family code, a 48 bit serial number and an 8 bit CRC computed from the first 56 bits.
* The sequence of operation for communicating with a 1-wire slave device is listed as

1. The master device sends a 'Reset' pulse on the 1-wire bus.
2. The slave device(s) present on the bus respond with a 'presence' pulse.
3. The Master device sends a ROM command
4. The master device sends a read/write function command to read/write the internal memory or register of the slave device
5. The master initiates a Read data/ write data from the device or to the device

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(e) parallel Interface :-

* The on-board parallel interface is normally used for communicating with peripheral devices which are memory mapped to the host of the system.
* The host processor/controller of the embedded system contains a parallel bus and that device which supports parallel bus can directly connect to the bus system.
* The 'control signals' for communication includes 'Read/write signal and device select signal.
* The direction of data transfer can be controlled through the control signal lines for 'Read' and 'write'.



x: Data bus width
y: Address bus width.

Fig:- parallel Interface bus

* The width of the parallel interface is determined by the data bus width of the host processor. It can be 4 bit, 8 bit, 16 bit, 32 bit or 64 bit etc
* The bus width supported by the device should be same as that of the host processor.
* The bus interface diagram shown in fig. illustrates the interfacing of the devi through parallel interface.
* parallel data communication offers the highest speed for data transfer.

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(ii) External Communication Interface :-

* The External Communication Interface refers to the different Communicable channel / bus used by the embedded system to communicate with the external world.

a) RS-232 C & RS-485

b) Universal Serial Bus (USB)

c) IEEE 1394 (Firewire)

d) Infrared (IrDA)

e) Bluetooth (BT)

f) Wi-Fi

g) ZigBee.

h) General packet Radio Service (GPRS)

Embedded Firmware :-

* Embedded firmware refers to the control algorithm (program instructions) and or the Configuration settings that an embedded system developer dumps into the Code (program) memory of the embedded system.

* There are various methods available for developing the embedded firmware.

1. write the program in high level language like Embedded C/C++ using an Integrated Development Environment

2. write the program in Assembly language using the instructions supported by your application's target processor/ Controller.

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* The instruction set for each family of processor/ controller is different and the program written in either of the methods given above should be converted into a processor understandable machine code before loading it into the programs memory.

* The process of converting the programs written in either a high level language or processor/ controller specific Assembly code to machine readable binary code is called 'HEX File creation'.

* It is strongly recommended to use the high level language based development techinque, the reason is writing codes in a high level language is easy, the code written in high level language is highly portable which means you can use the same code to run on different processor/ controller with little or less modi-fication.

* Two types of control algorithms design exist in embedded firmware development.

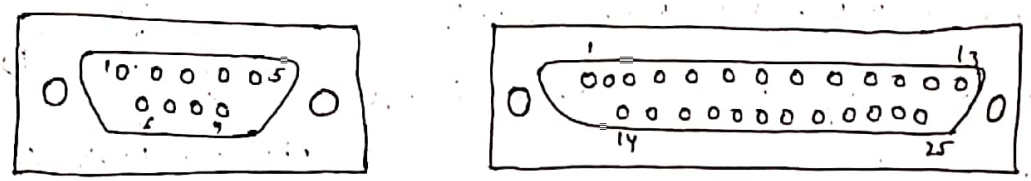
→ The first type of control algorithm development is known as the infinite loop (or) 'super loop' based approach, where the control flow runs from top to bottom and then jumps back to the top of the programs in a conventional procedure.

→ The second method deals with splitting the functions to be executed into tasks and running these tasks using a scheduler which is part of a general purpose or Real Time Embedded Operating System. (OSPOS / RTOS).

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i) RS-232C & RS-485 :-

* RS-232C (Recommended standard number 232, revision C from the Electronic Industry Association) is a legacy, full duplex, wired, asynchronous serial comm-unication interface.
* RS-232 extends the UART communication signals for external data communicati
* RS-232 follows the EIA standard for bit transmission. As per the EIA standard a logic '0' is represented with voltage between +3 and +25 V and a logic '1' is represented with voltage between -3 and -25V.
* Logic '0' is known as 'space' and logic '1' as 'Mark'.
* RS-232 supports two different types of connectors, namely; DB9- 9 pin connector and DB-25 25-pin connector.



DB-9 DB-25

Fig: DB-9 and DB-25 RS-232 Connector Interface

* RS-232 is a point-to-point communication interface and the device involved in RS-232 communication are called 'Data Terminal Equipment (DTE)' and 'Data Communication Equipment (DCE)'.
* Most of the desktop systems are available with DB-9 connectors only.
* RS-232C supports baudrates up to 20Kbps.
* The maximum operating distance supported by RS-232 is 50 feet at the highest supported baudrate.
* RS-232 is not suitable for multidrop communication.
* RS-422 supports data rates up to 100Kbps and distance up to 4000ft. It supports multidrop communication with one transmitter device and receiver devices up to 10.
* RS-485 is supports multi-drop communication with up to 32 tx & Rx driver devices on the L..

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(ii) Universal Serial Bus (USB):-

* Universal Serial Bus is a wired high speed serial bus for data communication
* The first version of USB (USB 1.0) was released in 1995. was created by Intel, Microsoft, IBM, Compaq, Digital and Northern Telecom.
* USB communication system follows a star topology.
* USB host can support connections up to 127, including slave peripheral devices and other USB hosts.
* USB transmits data in packet format.
* There are different standards for implementing the USB host control interface; namely
  - → Open Host Control Interface (OHCI) &
  - → Universal Host Control Interface (UHCI).
* The USB cable supports communication distance of up to 5 meters.

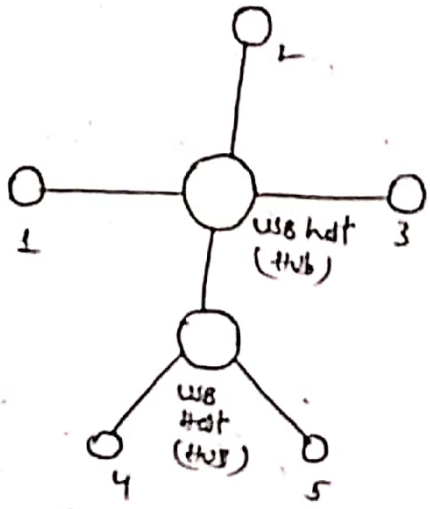


Fig:- USB device connection topology

* The USB standard uses two different types of connectors at the end of the USB cable for connecting the USB peripheral device and host device.
  - → Type A connector is used for upstream connection. Ex:- PC or Laptops.
  - → Type B connector is used for downstream connection.
* USB supports four different types of data transfers,
  - → Control transfer: is used by USB system s/w to query, configure and issue commands.
  - → Bulk transfer: is used to sending a block of data to a device. Doesn't supports error correction & checking.
  - → Isochronous data: Transfer is used for real-time data communication. * data is transmitted as stream of data.
  - → Interrupt transfer: is used for transfering small amount of data.
* Data rates: Low speed (1.5 Mbps), Full speed (12 Mbps), High speed (480 Mbps) & Super speed (4.8 Gbps).

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(iii) IEEE 1394 (Firewire) :-

* IEEE 1394 is a wired, isochronous high speed serial communication bus.
* 1394 supports peer-to-peer connection and point-to-multipoint communication allowing 63 devices to be connected on the bus in a tree topology.
* It supports a cable length up to 15 feet for interconnection.
* The 1394 standard supports a data rates of 400 to 3200 Mbits/second.
* It supports 3 types of connectors, 4-pin connector, 6-pin connector and 9-pin connector.
* It supports power in the range of 24 to 30 V.
* 1394 is a popular communication interface for connecting embedded devices like Digital Camera, camcoder, scanners to desktop computers for data transfer and storage.

(iv) Infrared (IrDA) :-

* Infrared (IrDA) is a serial, half duplex, line of sight based wireless tech. for data communication b/w devices.
* The remote control of TV, VCD player etc.. works on Infrared data communication principle.
* IrDA supports point-point and point-to-multipoint communication, provided all devices involved in the communication are within the line of sight.
* The typical communication range is 10cm to 1m. The range can be increased by increasing the transmitting power to the IR device.
* IR supports data rate ranging from 9600 bits/second to 16Mbps.
* IR classified into
  (i) Serial IR (SIR) : 9600bps to 115.2 kbps

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(ii) Medium IR (MIR) : 0.576 Mbps and 1.152 Mbps.

(iii) Fasted IR (FIR) : up to 4Mbps.

(iv) Very Fast IR (VFIR) : up to 16Mbps

(v) Ultra Fast IR (UFIR) : Up to 100 Mbps.

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(v) Bluetooth (BT):-

* Bluetooth is low cost, low power, short range wireless technology. for data and voice communication.

* BT First proposed by 'Ericsson' in 1994.

* Bluetooth operates at 2.4 GHz of the radio frequency spectrum and use the Frequency Hopping Spread Spectrum (FHSS) technique for communication.

* It supports a data rate of up to 1Mbps and a range approximately 30 feet for data communication

* Bluetooth enabled devices essentially contain a Bluetooth wireless radio for the transmission and reception of data.

* Each Bluetooth device will have a 48 bit unique identification number.

* Bluetooth supports point-to-point (device to device) and point-to-multipoint (device to multiple device broadcasting) wireless communication.

* When a network is formed with one Bluetooth device as master and more than one device as slaves, it is called a Piconet. A piconet supports a maximum of seven slave devices.

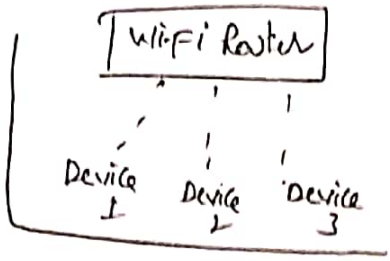
* Bluetooth is the favourite technology for cell phone users as they are the easiest communication channel for transferring ringtones, music files, pictures, media files etc b/w neighbouring bluetooth enabled phones.

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(vi) Wi-Fi :-

* Wi-Fi (or) Wireless Fidelity is the popular wireless communication technology technique for networked communication of device.
* Wi-Fi follows the IEEE 802.11 standard.
* Wi-Fi is intended for network communication and it supports Internet protocol (IP) based communication.
* It is essential to have device identities in a multipoint communication to address specific devices for data communication.
* Wi-Fi based communications require an intermediate agent called Wi-Fi router/wireless access point to manage the communication.
* Wi-Fi enabled devices contain a wireless adapter for transmitting and receiving data in the form of radio signals through an antenna.
* Wi-Fi operates at 2.4GHz or 5GHz of radio spectrum.
* Wi-Fi is turned "on," searches the available networks. If the network is security enabled, a password may be required to connect to a particular SSID. (Service set Identifier)
* Wi-Fi supports data rates ranging from 1Mbps to 150Mbps. depending on standard
* Depending on the type of antenna and usage location, Wi-Fi offers a range of 100 to 300 feet.



(vii) Zig Bee :-

* Zig Bee is a low power, low cost, wireless network communication protocol based on the IEEE 802.15.4 - 2006 standard.
* Zig Bee specifications support a robust mesh network containing multiple nodes.
* Zig Bee operates 2.400 to 2.484 GHz, 902 to 928 MHz & 868.0 to 868.6 MHz

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* ZigBee supports an operating distance of up to 100 meters and a data rate of 20 to 250 Kbps.

* In the ZigBee terminology, each ZigBee device falls under any one of the following ZigBee device category.

→ ZigBee Coordinator (ZC)/ Network Coordinator :- The ZigBee coordinator acts as the root of the ZigBee network. The ZC is responsible for initiating the ZigBee network and it has the capability to store information about the netw

→ ZigBee Router (ZR)/ Full function Device (FFD) :- Responsible for passing informatio from device to another device or to another ZR.

→ ZigBee End Device (ZED)/ Reduced Function Device (RFD) :- End device containing ZigBee functionality for data communication. It can talk only with a ZR or ZC and doesn't have the capability to act as a mediator for transferring data from one device to another

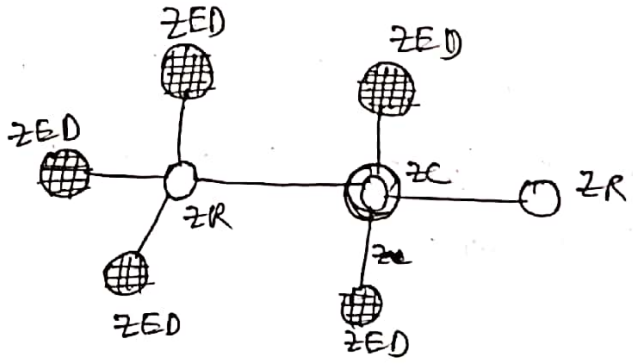


Fig:- A ZigBee network model.

* ZigBee is primarily targeting application areas like home & industrial automation, energy management, home control/ security, medical/patient tracking, logistics & asset tracking and sensor networks & active RFID.

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(viii) General packet Radio Service (GPRS) :-

* GPRS is a communication technique for transferring data over a mobile communication network like GSM.
* Data is sent as packets in GPRS communication.
* The transmitting device splits the data into several related packets. At the receiving end the data is re-constructed by combining the received data packets.
* GPRS supports a theoretical maximum transfer rate of 171.2 kbps.
* The GPRS communication divides the channel into 8 timeslots and transmits data over the available channels.
* GPRS supports Internet protocol (IP), point-to-point protocol (PPP) and X.25 protocol for communication.
* GPRS is mainly used by mobile enabled embedded devices for data communication.

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Other systems components :-

* The other systems components refer to the components / circuits / ICs which are necessary for the proper functioning of the embedded system.

(i) Reset circuit
(ii) Brown-out protection circuit
(iii) Oscillator unit
(iv) Real-Time clock (RTC)
(v) Watchdog Timer.

(i) Reset circuit :-

* The reset circuit is essential to ensure that the device is not operating at a voltage level where the device is not guaranteed to operate, during system power ON.
* The reset signal brings the internal registers and the different hardware systems of the processor / controller to a known state and starts the firmware execution from the reset vector
* The reset signal can be either active high or active low.

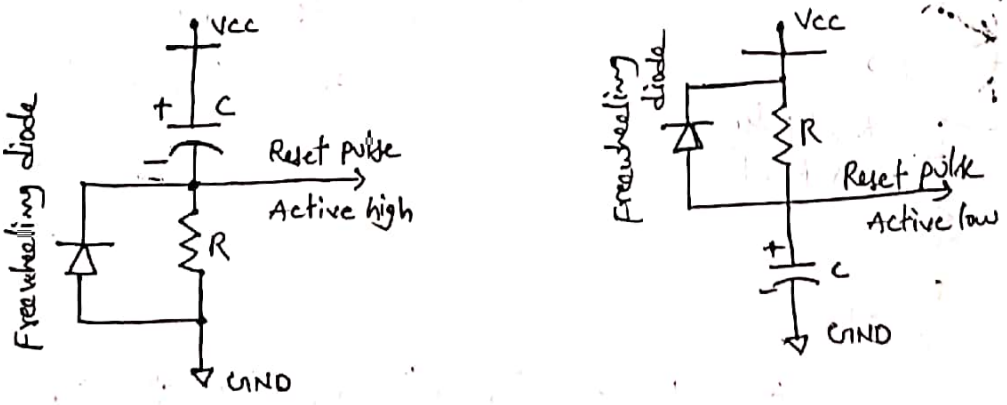


Fig:- RC based reset circuit

* The fig illustrates a resistor capacitor based passive reset circuit for active high and low configurations.

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* Some microprocessors / controllers contain built-in internal reset circuitary and they don't require external reset circuitary.

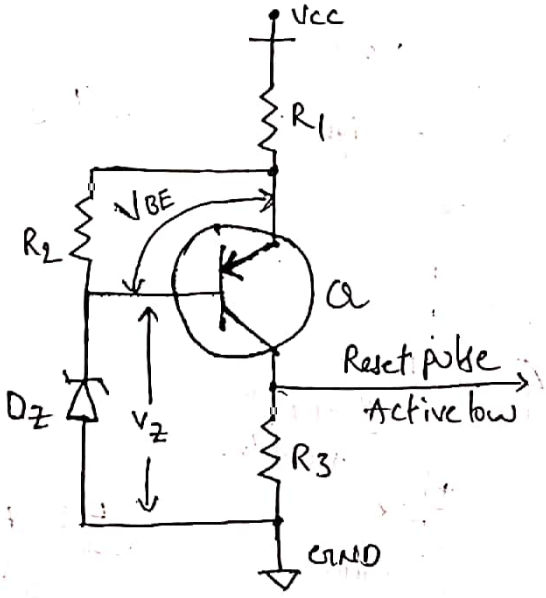
(ii) Brown-out protection circuit :-

* Brown-out protection circuit prevents the processor / controller from unexpected program execution behaviour when the supply voltage to the processor / controller falls below a specified voltage.

* A brown-out protection circuit holds the processor / controller in reset state when the operating voltage falls below the threshold, until it rises above the threshold voltage.

* Certain processors / controllers support built-in brown-out protection circuit, the same can be implemented using external passive circuits or supervisor IC

* The fig.. illustrates a brown-out circuit implementation using zener diode and transistor for processor / controller with active low Reset logic.



* R_1, R_2, R_3 can be selected based on the electrical characteristics.

Fig:- Brown-out protection circuit with Active low output

* The zener diode D_Z and transistor Q forms the heart of this circuit.

* The transistor conducts always when the supply voltage Vcc is greater than that of the sum of V_{BE} and V_Z (Zener voltage).

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(iii) Oscillator unit :-

* The oscillator unit of the embedded systems is responsible for generating the precise clock for the processor.
* certain processors/controllers integrate a built-in oscillator unit and simply require an external ceramic resonator/quartz crystal for producing the necessary clock signals.
* Quartz crystal is normally mounted in a hermetically sealed metal case with two leads protruding out of the case protecting.
* certain devices may not contain a built-in oscillator unit and require the clock pulses to be generated and supplied externally.
* Quartz crystal oscillators are available in the form chips and they can be used for generating the clock pulses in such a cases.
* The total systems power consumption is directly proportional to the clock freq..
* The accuracy of the crystal oscillator or ceramic resonator is normally expressed in terms of +/- ppm (parts per million).
* The fig shows the usage of quartz crystal/ceramic resonator and external oscillator chip for clock generation.

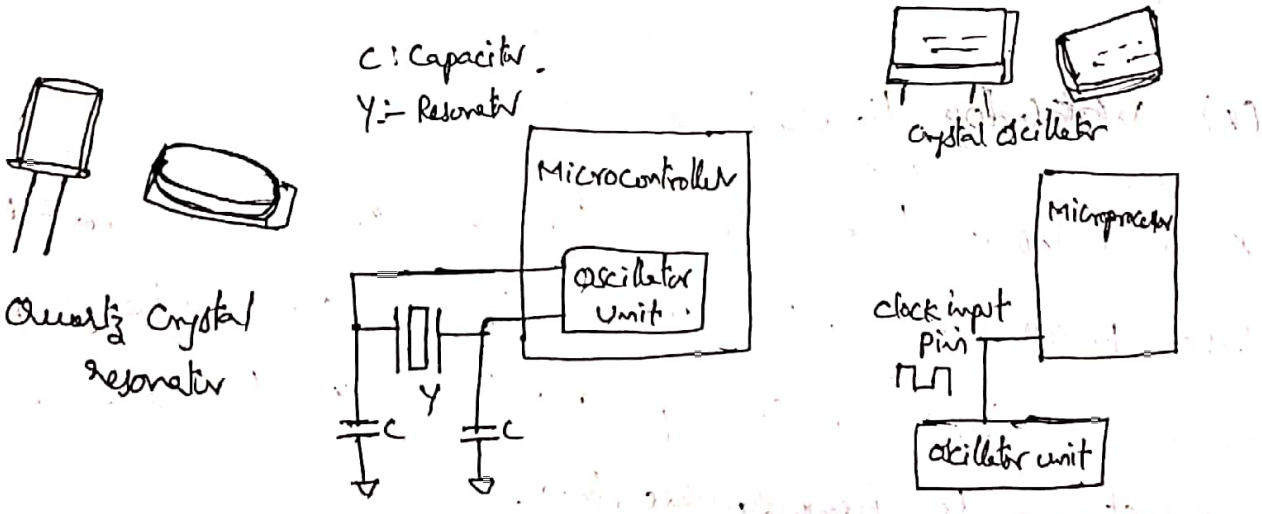


Fig:- Oscillator circuitary using quartz crystal and quartz crystal oscillator

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(iv) Real-Time Clock (RTC):-

* Real-Time Clock (RTC) is a system component responsible for keeping track of time.
* RTC holds information like current time in 12 hour/24 hour format, date, month, year, day of the week, etc. and supplies timing reference to the system.
* RTC is intended to function even in the absence of power.
* The RTC chip contains a microchip for holding the time and date related information and backup battery cell for functioning in the absence of power, in a single IC package.
* For operating system based embedded devices, a timing reference is essential for synchronizing the operations of the OS kernel.
* The OS Kernel identifies the interrupt in terms of the Interrupt Request (IRQ) number generated by an interrupt controller.
* one IRQ can be assigned to the RTC interrupt and the Kernel can perform necessary operations like system date time updating, managing software timers etc when an RTC timer tic interrupt occurs.

(v) Watchdog Timer:-

* A watchdog to monitor the firmware execution and reset the system processor/microcontroller when the programs execution hangs up.
* A watchdog timer, or simply a watchdog, is a hardware timer for monitoring the firmware execution.

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* If the watchdog counter is in the enabled state, the firmware can write a zero to it before starting the execution of a piece of code and the watchdog will start counting.
* If the processor/controller doesn't contain a built in watchdog timer, the same can be implemented using an external watchdog timer IC circuit.
* The fig illustrates the implementation of an external watchdog timer based microprocessor supervisor circuit for a small scale embedded syst.

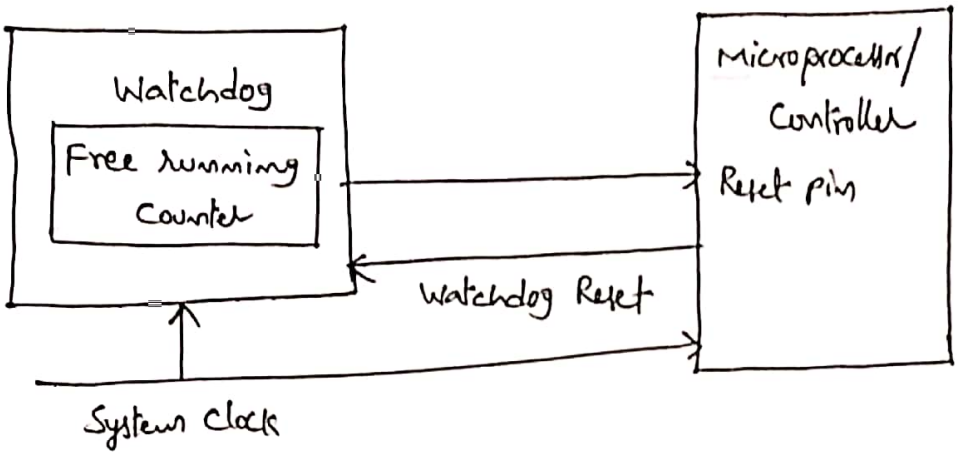


Fig:- Watchdog timer for firmware execution supervision.

PCB and Passive Components :-

* Printed Circuit Board (PCB) is the backbone of every embedded system.
* After finalising the components and the inter-connection among them, a schematic design is created and according to the schematic the PCB is fabricated.
* It acts as a platform for testing your embedded firmware.

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* Apart from the above-mentioned important subsystems of an embedded system, you can find some passive electronic components like resistor, capacitor, diodes etc on your board.

* They are the co-workers of various chips contained in your embedded hardware.

* They are very essential for the proper functioning of your embedded system.

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UNIT-2

Characteristics and Quality Attributes of Embedded Systems

1. Characteristics of An Embedded System :-

The important characteristics of an embedded system are

(i) Application and domain specific
(ii) Reactive and Real Time.
(iii) Operates in harsh environments.
(iv) Distributed.
(v) Small size and weight
(vi) Power Concerns.

(i) Application and Domain Specific :-

+ The embedded system is having certain functions to perform and they are developed in such a manner to do the intended functions only.
* They cannot be used for any other purpose. It is the major criterion which distinguishes an embedded system from a general purpose system.
* For example, you cannot replace the embedded control unit of your microwave - oven with your air conditioner's embedded control unit, because the embedded control units of microwave oven and airconditioner are specifically designed to perform certian specific tasks.

(ii) Reactive and Real Time :-

+ Embedded systems are in constant interaction with the Real world through sensors and User-defined input devices which are connected to the input port of the system.

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* The event may be a periodic one or an unperiodic one.
* Embedded systems produce changes in otput in response to the changes in the input. So they are generally referred as Reactive systems.
* Real Time systems operation means the timing behavior of the systems should be deterministic; meaning the systems should respond to requests or tasks in a known amount of time.
* It is not necessary that all embedded systems should be Real Time in operation
* Flight Control systems, Antilock Break systems (ABC) etc. are examples of Real Ti - Systems.

(iii) Operates in Harsh Environment :-

* The environment in which the embedded system deployed may be a dusty one or a high temperature zone or an area subject to vibrations and shock.
* The design should take care of the operating conditions of the area where the systems is going to implement.
* For example, if the systems needs to be deployed in a high temperature zone, then all the components used in the systems should be of high temperature grade
* power supply fluctuations, corrosion and Component aging etc are the other factors that need to be taken into consideration for embedded systems to work in harsh environments.

(iv) Distributed :-

* The term distributed means that embedded systems may be a part of larger systems.
* Example is Automatic Teller Machine (ATM). An ATM Contains a Card reader embedded unit, responsible for reading and validating the User's ATM card, transaction unit for performing transactions, a currency

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counter for dispatching/vending currency to the authorised person and a printer unit for printing the transaction details.

* we can visualise these an independent embedded systems. But they work together to achieve a common goal.

(v) Small size and weight :-

* product aesthetics is an important factor in choosing a product.
* For example, when you plan to buy a new mobile phone, you may make a comparative study on the pros and corns of the products available in the market.
* Definitely the product aesthestics (size, weight, shape, style, etc.) will be one of the deciding factors to choose a product.
* In embedded domain also compactness is a significant deciding factor.

(vi) power Concerns :-

* power management is another important factor that needs to be considered in designing embedded systems.
* Embedded systems should be designed in such a way as to minimize the heat dissipation on the systems.
* Nowadays, ultra low power components are available in the market.
* Low power components like low dropout regulators, and Controllers/processors with power saving modes.
* The more the power consumption the less is the battery life.

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2. Quality Attributes of Embedded Systems :-

* Quality attributes are the non-functional requirements that need to be documented properly in any system design.
* They are classified into two, namely
  - → Operational Quality Attributes.
  - → Non-operational Quality Attributes.

→ Operational Quality Attributes :-

* The operational quality attributes represent the relevant quality attributes related to the embedded system when it is in the operational mode or 'online' mode.
* The important quality attributes are :
  - (i) Response
  - (ii) Throughput
  - (iii) Reliability
  - (iv) Maintainability
  - (v) Security
  - (vi) Safety.

(i) Response :-

* Response is the measure of quickness of the system.
* It gives you an idea about how fast your system is tracking the changes in input variables.
* For example, an embedded systems demand fast response in real time manner is flight control application - Any response delay in the system will create potential damages to the safety of the flight as well as the passengers.
* It is not necessary that all embedded systems should be Real Time in response
  Ex:- An electronic toy is not a all time-critical.

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(ii) Throughput :-

* Throughput deals with the efficiency of a systems.
* In general it can be defined as the rate of production or operation of a defined process over a stated period of time.
* The rates can be expressed in terms of units of products, batches produced, or any other meaningful measurements.
* In the case of a CardReader, throughput means how many transactions the reader can performs in a minute or in an hour or in a day.

(iii) Reliability :-

* Reliability is a measure of how much % you can rely upon the proper functioning of the systems or what is the % susceptability of the systems to failure.
* Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) are the terms used in defining system reliability.
* MTBF gives the frequency of failures in hours/weeks/months.
* MTTR specifies how long the system is allowed to be out of order following a failure.

(iv) Maintainability :-

* Maintainability deals with support and maintenance to the end user or client in case of technical issues and product failures or on the basis of a routine system checkup.
* A more reliable systems means a system with less corrective maintainability requirements and vice versa.
* Maintainability can be broadly classified into two categories, namely, 'scheduled or periodic Maintenance' and 'Maintenance to unexpected failures'.

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* A typical example is

→ An inkjet printer uses ink cartridges, which are consumable components and as per the printer manufacturer the end user should replace the cartridge after each 'n' number of printouts to get quality prints. This is an example for 'Scheduled or periodic maintenance'.

→ If the paper feeding part of the printer fails the printer fails to print and it requires immediate repair to rectify this problem. This is an example of 'Maintaince to unexpected failure'.

* The maintainability is simply an indication of the availability of the product for use.

Availability is expressed as

$$A_i = \frac{MTBF}{(MTBF + MTTR)}$$

where A_i = Availability in the ideal Condition.

MTBF = Mean Time Between Failures.

MTTR = Mean Time TO Repair.

(v) Security :- 'Confidentiality', 'Integrity', and 'Availability' are three major measures of information security.

* Confidentiality deals with the protection of data and applications from unauthorised disclosure
* Integrity deals with the production of data and applications from unauthorised modification
* Availability deals with protection of data and application from unauthorized users.
* An example is Personal Digital Assistant (PDA).

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(vi) Safety :-

* Safety deals with the possible damages that can happen to the operators, public and the environment due to the breakdown of an embedded systems.
* The breakdown may occur due to hardware failure or firmware failure
* Safety analysis is a must in product engineering to evaluate the anticipated damages and determine the best course of action to bring down the consequences of the damages to an acceptable level.

→ Non-operational Quality Attributes :-

The quality attributes that needs to be addressed for the product 'not' on the basis of operational aspects are grouped under this category.

(i) Testability & Debug-ability
(ii) Evolvability
(iii) portability
(iv) Time to prototype and market
(v) per unit and total cost.

(i) Testability & Debug-ability :-

* Testability deals with how easily one can test his/her design, application and by which means he/she can test it.
* For an embedded product, testability is applicable to both the embedded hardware and firmware.
  → Embedded hardware testing ensures that the peripherals and the total hardware functions in the desired manner.
  → Firmware testing ensures that the firmware is functioning in the expected way

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* Debug-ability has two aspects in the embedded systems development context, namely, hardware level debugging and firmware level debugging.

→ Hardware debugging is used for figuring out the issues created by hardware problems.

→ whereas firmware debugging is employed to figure out the probable errors that appear as a result of flaws in the firmware

(ii) Evolvability :-

* Evolvability is a term which is closely related to Biology.
* Evolvability is referred as the non-heritable variation.
* For an embedded systems, the quality attribute 'Evolvability' refers to the ease with which the embedded product can be modified to take advantage of new firmware or hardware technologies.

(iii) Portability :-

* portability is a measure of 'system independence'.
* An embedded product is said to be portable if the product is capable of functioning 'as such' in various environments, target processors/controllers and embedded operating systems.
* The term 'porting' represents the migration of the embedded firmware written for one target processor to a different target processor.
* If the firmware is written in a high level language like 'c' with little target processor-specific function, it is very easy to port the firmware
* If the firmware is written in Assembly Language for a particular family of processor, it will be very difficult to translate the assembly language instructions to the new target processor specific language and so the portability is poor

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(iv) Time-to-prototype and Market :-

* Time-to-market is the time elapsed between the conceptualisation of a product and the time at which the product is ready for selling or use.
* There may be multiple players in the embedded industry who develop products of the same category.
* If you come up with a new design and if it takes long time to develop and market it, the competitor product may take advantage of it with their product.
* Embedded technology is one where rapid technology changes is happening.
* product prototyping helps a lot in reducing time-to-market.
* prototyping is an informal kind of rapid product development in which the important features of the product under consideration are developed.

(v) per unit cost and Revenue :-

* Cost is a factor which is closely monitored by both end user and product manufacturer.
* Any failure to position the cost of a commercial product at a nominal rate, may lead to the failure of the product in the market.
* proper market study and cost benefit analysis should be carried out before taking a decision on the per-unit cost of the embedded product.
* The budget and total systems cost should be properly balanced to provide a marginal profit.
* Every embedded product has a product life cycle which starts with the design and development phase.

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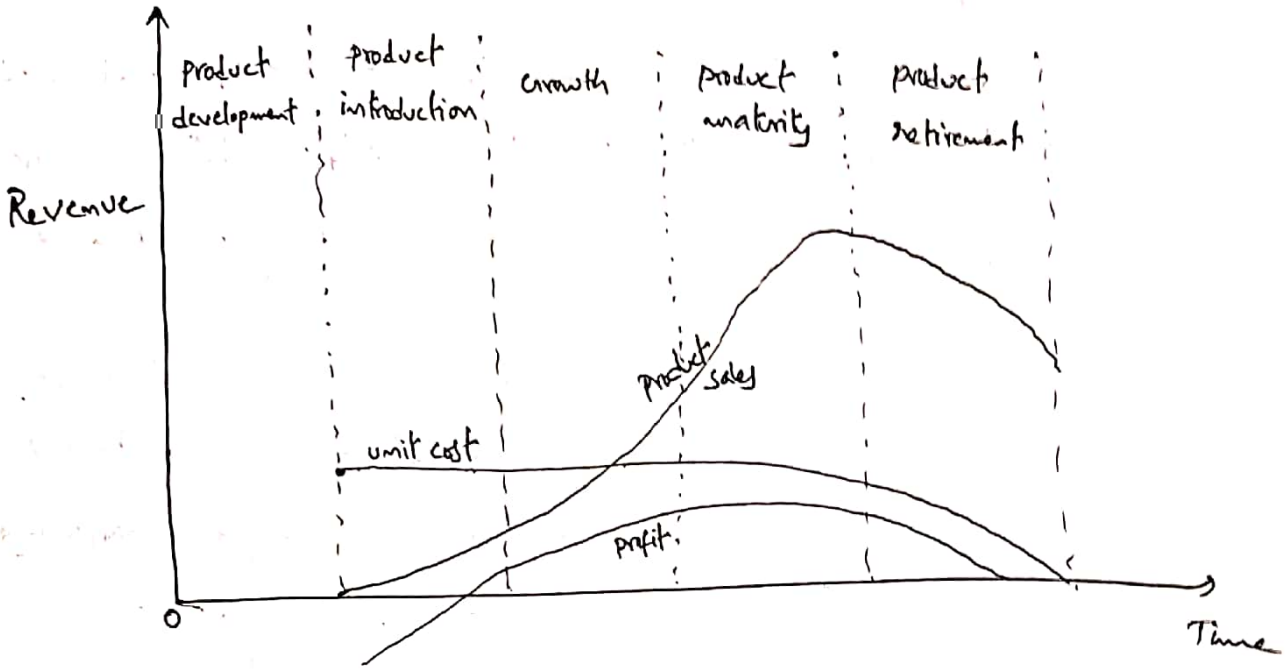
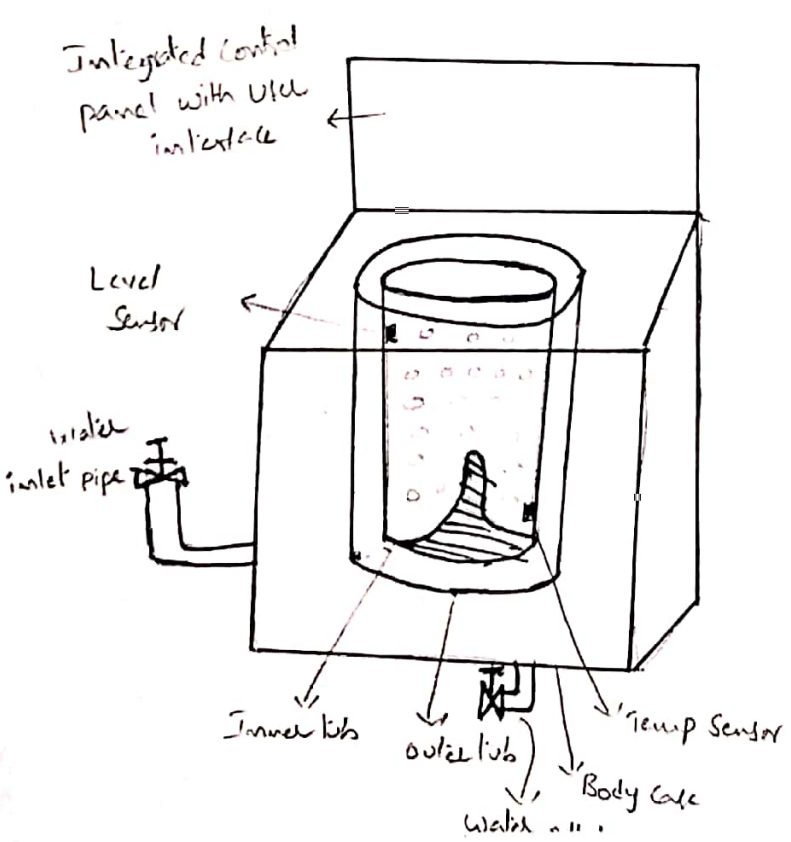


Fig :- product life cycle (PLC) curve.

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Washing Machine – Application-Specific Embedded System

* An embedded systems contains sensors, actuators, control unit and application-specific user interfaces like keyboards, display units, etc..
* All these components are used in washing machine, some of them are visible and some of them may be invisible.
* The actuator part of the washing machine consists of a motorised agitator, tumble tub, water drawing pump and inlet valve to control the flow of water into the unit.
* The sensor part consists of the water temperature sensor, level sensor etc.
* The control part contains a micro processor/ controller based board with interfaces to the sensors and actuators.
* The control unit also provides connectivity to user interfaces like keypad for setting the washing time, selecting the type of material to be washed like light, medium, heavy duty etc..



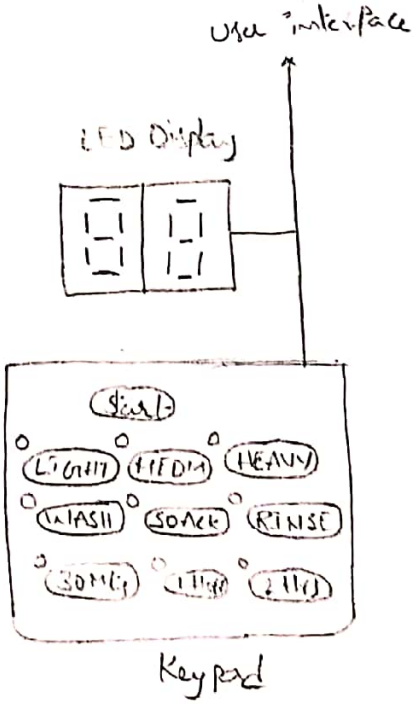


Fig:- Washing machine – Functional block diagram

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* Washing machine comes in two models, namely top loading and front loading machines.

→ In top loading model the agitator of the machine twists back and front and pulls the cloth down to the bottom of the tub. and work their way back up to the top and repeats the mechanism.

→ In front loading machines, the clothes are tumbled and plunged into the water over and over again.

This is the first phase of washing.

* The second phase of washing, water is pumped out from the tub and the inner tub uses centrifugal force to wring out more water from the clothes by spinning at several hundred rotations per minute (RPM). This is called a 'Spin phase'.

* The keyboard panel contains three buttons * Wash, Spin and Rinse. to configure the washing stages.

* The cloth type selector namely * Light, Medium, Heavy duty and washing time setting, etc..

* The output interface consists of LED/LCD displays, status indication LEDs e connected to the I/o bus of the controller.



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Automotive – Domain Specific examples of Embedded Systems

The major application domains of embedded systems are Consumer, industrial, automotive, telecom, etc.. of which telecom and automotive industry holds a big market share.

1. Inner workings of Automotive Embedded Systems:

* Automotive embedded systems are the one where electronics take control over the mechanical systems.
* Automotive embedded systems are normally built around microcontrollers or DSPs or hybrid of the two and are generally known as Electronic Control units (ECUs)
* The no of embedded controllers in an ordinary vehicle varies from 20 to 40 whereas a luxury vehicle like Mercedes S and BMW 7 may contain 75 to 100 no's of embedded controlers.
* The first embedded systems used in automotive application was the microprocessor based fuel injection system introduced by Volkswagen 1600 in 1968.
* Electronic Control units (ECU's) are classified into two
  - (i) High-Speed Electronic Control units (HECU's)
  - (ii) Low-Speed Electronic control units (LECU's)

(i) High-Speed Electronic Control units :- (HECU's)

→ These units require fast response. They include fuel injection systems, antilock brake systems, engine control, electronic throttle, steering controls, transmission control unit and central control unit.

(ii) Low-Speed Electronic Control units :- (LECU's)

→ These are deployed in applications where response time is not so critical.
→ Ex: Audio controllers, passenger and driver door locks, door glass controls (power windows

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Tools and platform providers are manufacturers and suppliers of various kinds of development tools and Real Time Embedded Operating Syste for developing and debugging different control unit related applications.

(i) ENEA
(ii) The Math Works
↳ MATLAB
(iii) Keil Software
(iv) Lauterbach
(v) ARTISAN
(vi) Microsoft.

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1. Instrumentation
2. Engine Control
3. Fan control
4. Fuel injection control
5. Headlamp control
6. ABS Control
7. Wiper Control
8. Supension control
9. Centrized locking
10. Power windows
11. Mirror Control
12. Seat control
13. Airbag Control
14. Power steering
15. Air conditioner

CAR

Fig: Embedded System in the Automotive Domain

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