EMBEDDED SYSTEMS

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

Example: Aircraft control system, washing Machine, smart phone .

GENERAL COMPUTING SYSTEMS VS EMBEDDED SYSTEMS

GENERAL COMPUTING SYSTEMS	EMBEDDED SYSTEMS
Combination of generic hardware and a general-purpose operating system.	Combination of special purpose hardware and an embedded operating system.
Executes variety of applications.	Executes specific set of applications.
Contains general-purpose operating system (GPOS)	May or may not contain an operating system for functioning.
Upgrading and altering of programs can be done by the end user.	For upgrading and altering of programs you have to go to the manufacturer.
Performance is the deciding factor for the selection of system.	Application-specific requirements like performance, power requirements, memory usage etc are the deciding factor for the selection of system.
Response requirement are not time critical.	Response requirement are highly time critical.
Need not to be deterministic in execution behaviour.	Execution behaviour is deterministic.

CLASSIFICATION OF EMBEDDED SYSTEMS

Embedded systems are classified based on different criteria like

(1) Based on generation
(2) Complexity and performance requirements
(3) Based on deterministic behaviour
(4) Based on triggering.

(1) Classification based on Generation

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

(i) **First Generation:** The earlier first-generation embedded systems were built around 8-bit microprocessors and 4-bit microcontrollers. Such embedded system possesses simple hardware and firmware developed using assembly code.
Example: Digital telephone keypads, stepper motor control units

(ii) Second Generation: After the evolution of the second-generation embedded systems, the 8-bit processor and 4-bit controllers are replaced by 16-bit microprocessors and 8-bit microcontrollers. They are more powerful and complex compared to previous generation processors.

Examples: Data acquisition systems, SCADA systems

(iii) Third Generation: During this period, domain-specific processors/controllers like Digital Signal Processors (DSP), Application-Specific Integrated Circuits (ASICs) and the concept of instruction pipelining, embedded real-time operating system evolved into the embedded system industry.

The embedded system of this period has powerful 32-bit microprocessors and 16-bit microcontrollers. Hence, its operation has become much more powerful and complex than the second generation.

Robotics, industrial process control, embedded networking are examples of the third-generation embedded system.

(iv) Fourth Generation: The recent development of microprocessors and microcontrollers has evolved during these modern days. New concepts like System-on-Chip(SOC), reconfigurable processors, multicore processors, coprocessors also emerged into the embedded market to add more powerful performance in the embedded system.

These systems also make use of the high-performance real-time operating system for their operation. Smart devices, digital cameras, etc are examples of fourth-generation embedded systems.

(2) Based on complexity

The embedded systems are classified into three types based on the complexity of the systems.

(i) Small Scale Embedded Systems: Small Scale Embedded Systems are built with a single 8 or 16-bit microprocessor or controller. The main programming tools used are an editor, assembler, cross assembler and integrated development environment (IDE). The hardware and software complexities in small-scale embedded system are very low. It may or may not contain an operating system for its functioning. An electronic toy is an example for a small-scale embedded system.

(ii) Medium Scale Embedded Systems: The Embedded system with medium performance 16-bit or 32-bit microprocessor or controller, ASICs or DSPs fall under the medium scale embedded systems. They have both hardware and software complexities. The main programming tools used are C, C++, JAVA, Visual C++, RTOS, debugger, source code engineering tool, simulator and IDE.

(iii) **Large scale Embedded Systems:** The embedded systems have highly complex hardware and software, built around 32-bit or 64-bit processors/controllers, RISC processors, SoC, scalable and configurable processors. They are also called sophisticated embedded systems.

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

(3) **Based on deterministic behavior:** It is applicable for Real Time systems. The application/task execution behavior for an embedded system can be either deterministic or non-deterministic

These are classified in to two types

(i) Soft Real time Systems: Missing a deadline may not be critical and can be tolerated to a certain degree

(ii) Hard Real time systems: Missing a program/task execution time deadline can have catastrophic consequences (financial, human loss of life, etc.)

(4) Classification Based on Triggering:

These are classified into two types

(i) Event Triggered: Activities within the system (e.g., task run-times) are dynamic and depend upon occurrence of different events.

(ii) Time triggered: Activities within the system follow a statically computed schedule (i.e., they are allocated time slots during which they can take place) and thus by nature are predictable.

MAJOR APPLICATION AREAS OF EMBEDDED SYSTEMS

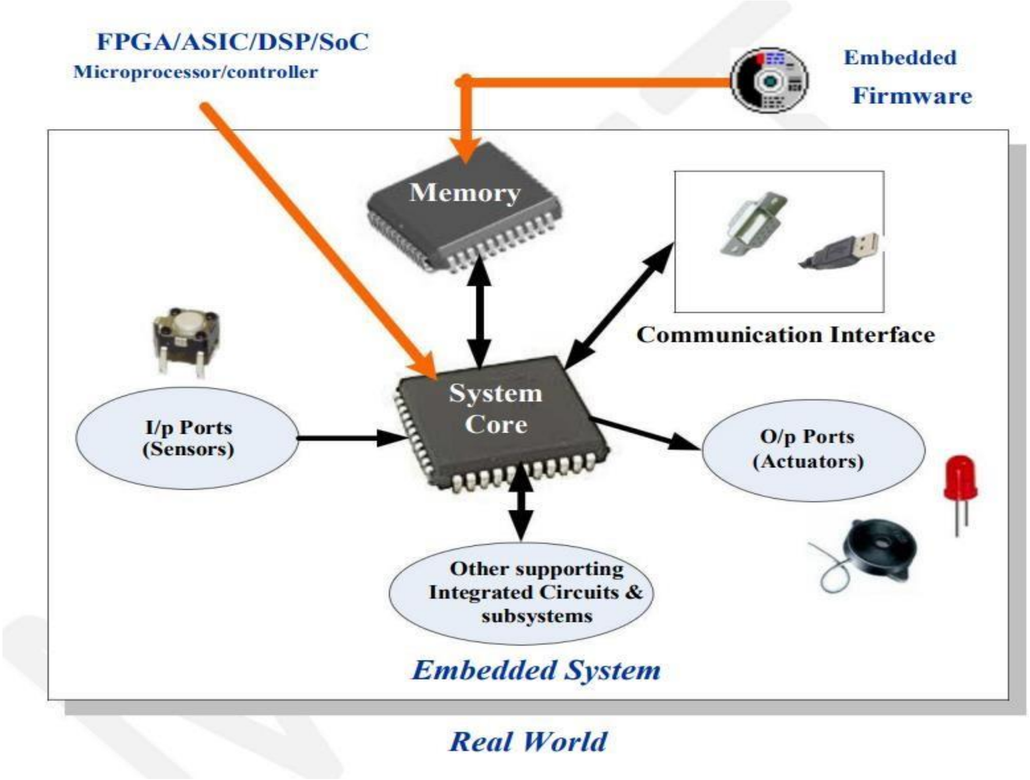
The following table gives the various applications of embedded systems.

EMBEDDED SYSTEM	APPLICATION
Home Appliances	Dishwasher, washing machine, microwave, security system, DVD etc.
Office Automation	Fax, copy machine, smart phone system, modern scanner, printers.
Security	Face recognition, finger recognition, eye recognition, building security system, airport security system, alarm system.

Academia	Smart board, smart room, calculator
Instrumentation	Signal generator, signal processor, power supplier.
Telecommunication	cellular phone, web camera.
Automobile	Fuel injection controller, anti-locking brake system, air-bag system, GPS.
Entertainment	video games
Aerospace	Navigation system, automatic landing system.
Industrial automation	data collection system, monitoring systems on pressure, voltage, current, temperature.
Personal	iPhone, palmtop.
Medical	CT scanner, ECG, EEG, MRI, Glucose monitor, blood pressure monitor.
Banking & Finance	ATM.
Miscellaneous:	Elevators, tread mill, smart card, security door etc.

ELEMENTS OF AN EMBEDDED SYSTEM

An embedded system is a combination of 3 things, Hardware, Software and Mechanical Components and it is supposed to do one specific task only. Diagrammatically an embedded system can be represented as follows:



Fig(): Elements of an embedded systems

System Core: A typical embedded system contains a single chip controller which acts as the master brain of the system.

Embedded systems are basically designed to regulate a physical variable (such Microwave Oven) or to manipulate the state of some devices by sending some signals to the actuators or devices connected to the output port system (such as temperature in Air Conditioner), in response to the input signal provided by the end users or sensors which are connected to the input ports.

Input and Output Ports: Keyboards, push button, switches, etc. are examples of common user interface input devices (sensors) and LEDs, LCDs, Piezoelectric buzzers, etc examples for common user interface output devices (actuators) for a typical embedded system.

Memory: The memory of the system is responsible for holding the code (control algorithm and other important configuration details.

There are two types of memories

- **(i)** **Random Access Memory (RAM):** It is a temporary memory and can be changed as per the user requirements. Various types of RAM are SRAM, DRAM etc.
- **(ii)** **Read Only Memory (ROM):** Fixed memory (ROM) is used for storing code or program. The user cannot change the firmware in this type of memory. The most common types of ROM are PROM, EEPROM and FLASH.

Communication Interface: It is used for communicating with various subsystems of the embedded system with the external world. Some of the communicating interface units are UART, Infrared, Bluetooth, WIFI etc.

THE CORE OF THE EMBEDDED SYSTEMS

The core of the embedded system falls into any one of the following categories.

- ➢ General Purpose and Domain Specific Processors
- Microprocessors
- Microcontrollers
- Digital Signal Processors
- ➢ Programmable Logic Devices (PLDs)
- ➢ Application Specific Integrated Circuits (ASICs)
- ➢ Commercial off the shelf Components (COTS).

MICROPROCESSOR VS MICROCONTROLLER

MICROPROCESSOR	MICROCONTROLLER
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.	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.
It is a dependent unit. It requires the combination of other chips like Timers, Program and data memory chips, Interrupt controllers etc for functioning.	It is a self-contained unit and it doesn't require external Interrupt Controller, Timer, UART etc for its functioning.
Most of the time general purpose in design and operation	Mostly application oriented or domain specific.
Doesn't contains a built in I/O port. The I/O Port functionality needs to be implemented with the help of external Programmable Peripheral Interface Chips like 8255.	Most of the processors contain multiple built-in I/O ports which can be operated as a single 8 or 16- or 32-bit Port or as individual port Pins
Targeted for high end market where performance is important	Targeted for embedded market where performance is not so critical (At present this demarcation is invalid)
Limited power saving options compared to microcontrollers	Includes lot of power saving features

RISC (Reduced Instruction Set Computer) V/S CISC (Complex Instruction Set Computer) PROCESSORS/CONTROLLERS.

RISC	CISC
Lesser no. of instructions	More no. of Instructions
Instruction Pipelining and increased execution speed	Generally, no instruction pipelining feature
Orthogonal Instruction Set (Allows each instruction to operate on any register and use any addressing mode)	Non-Orthogonal Instruction Set (All instructions are not allowed to operate on any register and use any addressing mode. It is instruction specific)
Operations are performed on registers only; the only memory operations are load and store.	Operations are performed on registers or memory depending on the instruction.
Large number of registers are available	Limited no. of general-purpose registers

Programmer needs to write more code to execute a task since the instructions are simpler ones.	A programmer can achieve the desired functionality with a single instruction which in turn provides the effect of using more simpler single instructions in RISC
Single, Fixed length Instructions	Variable length Instructions
Less Silicon usage	More silicon usage
With Harvard Architecture	Can be Harvard or Von-Neumann Architecture

HARVARD V/S VON-NEUMANN PROCESSOR/CONTROLLER ARCHITECTURE

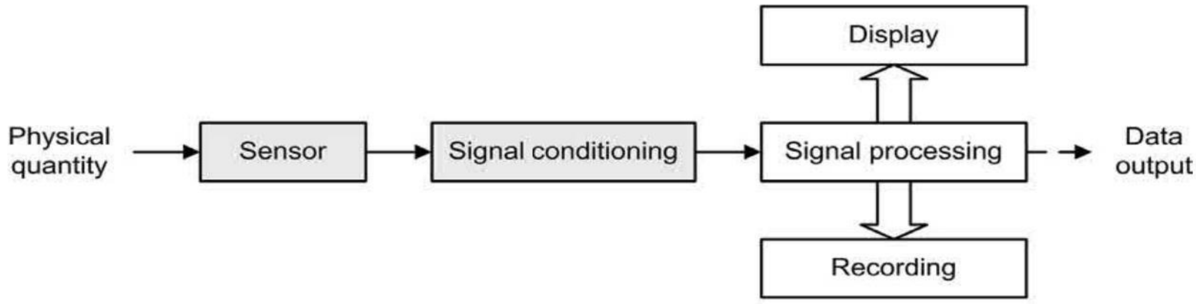
HARVARD ARCHITECTURE	VON-NEUMANN ARCHITECTURE
Separate buses for Instruction and Data fetching	Single shared bus for Instruction and Data fetching
Easier to Pipeline, so high performance can be achieved	Low performance Compared to Harvard Architecture
Comparatively high cost	Cheaper
No memory alignment problems	Allows self-modifying codes
Since data memory and program memory are stored physically in different locations, no chances for accidental corruption of program memory.	Since data memory and program memory are stored physically in same chip, chances for accidental corruption of program memory

INSTRUMENTATION AND CONTROL SYSTEMS

(Explain with a neat diagram instrumentation and control system)

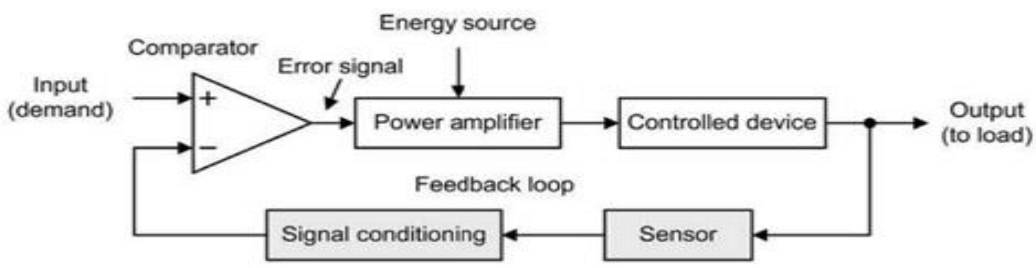
Instrumentation:

- Fig. (a) shows the arrangement of an instrumentation system. The physical quantity to be measured (e.g. temperature) acts upon a sensor that produces an electrical output signal.
- This signal is an electrical analogue of the physical input but note that there may not be a linear relationship between the physical quantity and its electrical equivalent.
- the output produced by the sensor may be small or may suffer from the presence of noise (i.e. unwanted signals) further signal conditioning will be required before the signal will be at an acceptable level and in an acceptable form for signal processing, display and recording.
- Furthermore, because the signal processing may use digital rather than analogue signals an additional stage of analogue-to-analogue conversion may be required.



(a) An instrumentation system

Control Systems:



(b) A control system

- Fig. (b) shows the arrangement of a control system.
- This uses negative feedback in order to regulate and stabilize the output. It thus becomes possible to set the input or demand (i.e. what we desire the output to be) and leave the system to regulate itself by comparing it with a signal derived from the output (via a sensor and appropriate signal conditioning).
- A comparator is used to sense the difference in these two signals and where any discrepancy is detected the input to the power amplifier is adjusted accordingly.

- This signal is referred to as an error signal (it should be zero when the output exactly matches the demand).
- The input (demand) is often derived from a simple potentiometer connected across a stable d.c. voltage source while the controlled device can take many forms (e.g. a d.c. motor, linear actuator, heater, etc.

TRANSDUCERS

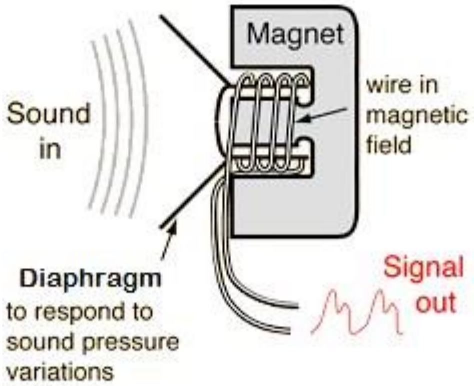
- Transducers are devices that convert energy in the form of sound, light, heat, etc., into an equivalent electrical signal, or vice versa.
- A loudspeaker is a transducer that converts low-frequency electric current into audible sounds. A microphone, on the other hand, is a transducer that performs the reverse function, i.e., that of converting sound pressure variations into voltage or current.
- Loudspeakers and microphones can thus be considered as complementary transducers. Transducers may be used both as inputs and outputs. Loudspeaker is an output transducer and microphone are an input transducer.

SENSORS

- A sensor is a special kind of transducer that is used to generate an input signal to a measurement, instrumentation or control system.(Sensors acts as input device).
- The signal produced by a sensor is an electrical analogy of a physical quantity, such as distance, velocity, acceleration, temperature, pressure, light level, etc.
- Sensors can be categorized as either active or passive. An active sensor generates a current or voltage output. A passive transducer requires a source of current or voltage and it modifies this in some way (e.g. by virtue of a change in the sensor's resistance).
- Sensors can also be classed as either digital or analogue. The output of a digital sensor can exist in only two discrete states, either 'on' or 'off', 'low' or 'high', 'logic 1' or 'logic 0', etc. The output of an analogue sensor can take any one of an infinite number of voltage or current levels. It is thus said to be continuously variable.
    - Eg. Hall Effect Sensor which measures the distance between the cushion and magnet in the Smart Running shoes from adidas
    - Example: IR, humidity , PIR(passive infra red) , ultrasonic , piezoelectric , smoke sensors.

Example:
Physical quantity: **sound**
Input transducer: **Microphone**

Diaphragm attached to a coil is suspended in a magnetic field.
Movement of the diaphragm causes current to be induced in the coil.

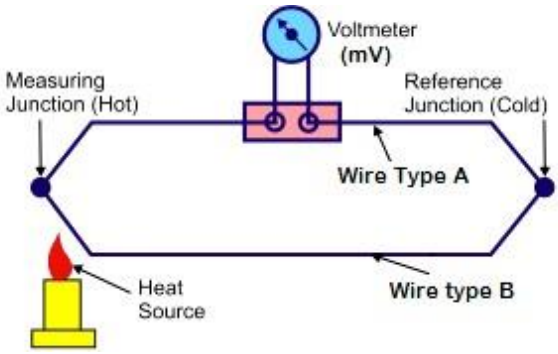


Example :

Physical quantity: Temperature

Input transducer: Thermocouple

Small e.m.f (mV) generated at the junction between two dissimilar metals (e.g. copper & constantan). Requires reference junction (cold) and compensated cables for accurate measurement.



ACTUATOR:

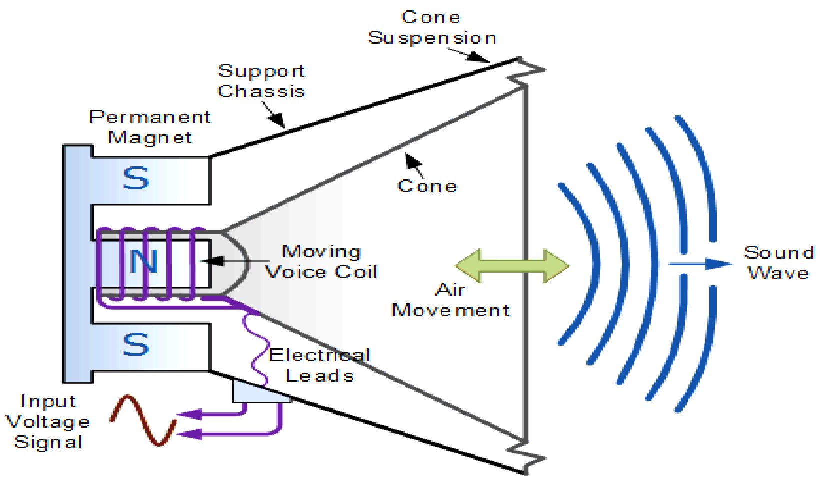
- A form of transducer device (mechanical or electrical) which converts signals to corresponding physical action (motion). Actuator acts as an output device
- Eg. Micro motor actuator which adjusts the position of the cushioning element in the Smart Running shoes from adidas.

Example

Physical Quantity: **Sound** (pressure change)

Output transducer: **Loudspeaker**

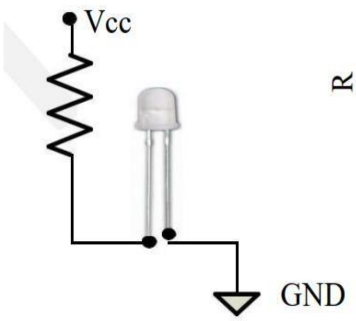
Diaphragm attached to a coil is suspended in a magnetic field. Current in the coil causes movement of the diaphragm which alternately compresses and rarefies the air mass in front of it.



Sensor	Actuator
It converts physical quantity into electrical signals.	It converts electrical signals into physical quantity.
It takes input from environment.	It takes input from the electric or electronic system.
Sensor generates electrical signals.	Actuator generates heat, motion, vibration,etc.
It is placed at input port of the system.	It is placed at output port of the system.
It is used to measure the physical quantity.	It is used to measure the continuous and discrete process parameters.
It gives information to the system about environment.	It accepts command from the system to perform a function.
Example: Photo-voltaic cell which converts light energy into electrical energy.	Example: Stepper motor where electrical energy drives the motor.

LIGHT EMITTING DIODE (LED):

- Light Emitting Diode (LED) is an output device for visual indication in any embedded system. LED can be used as an indicator for the status of various signals or situations.
- Typical examples are indicating the presence of power conditions GND like „Device ON‟, „Battery low‟ or „Charging of battery‟ for a battery-operated handheld embedded device
- LED is a p-n junction diode and it contains an anode and a cathode. For proper functioning of the LED, the anode of it should be connected to +ve terminal of the supply voltage and cathode to the –ve terminal of supply voltage
- The current flowing through the LED must limited to a value below the maximum current that it can conduct.
- A resistor is used in series between the power supply and the resistor to limit the current through the LED.



- ➢ LED can be interfaced to the port pin of microcontroller in two methods:
- ➢ **Method:1-** (current sourcing) Anode of LED is connected to port pin. Cathode is connected to ground (0V) through resistor. When port pin of microprocessor goes logic 1, the LED is forward biased and emits light. When the port pin goes 0, LED is *off*. That means port pin *sources* current to LED.
- ➢ **Method:2-** (current sinking) Cathode of LED is connected to port pin. Anode is connected to external supply through resistor. LED turns *on* when the port pin is at logic 0. Here port pin *sinks* current, such that the brightness of LED can be increased to the required level. See fig.

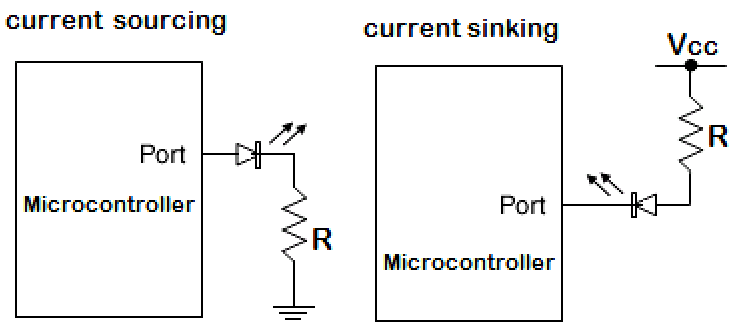
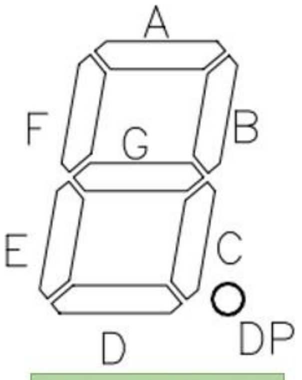


Fig: LED interfacing to the port pin of microcontroller

7-SEGMENT LED DISPLAY

- The 7 – segment LED display is an output device for displaying alpha numeric characters. It contains 8 light-emitting diode (LED) segments arranged in a special form.
- Out of the 8 LED segments, 7 are used for displaying alpha numeric characters.
- The LED segments are named A to G and the decimal point LED segment is named as DP.
- The LED Segments A to G and DP should be lit accordingly to display numbers and characters.



7-Segment Display

- For example, to display 4, the segment F,G,B and C are lit and to display character C A, F,E and D are lit.
- The 7 – segment LED displays are available in two different configurations, namely; Common anode and Common cathode

- In the Common anode configuration, the anodes of the 8 segments are connected commonly whereas in the Common cathode configuration, the 8 LED segments share a common cathode line

- Based on the configuration of the 7 – segment LED unit, the LED segment anode or cathode is connected to the Port of the processor/controller in the order „A" segment to the Least significant port Pin and DP segment to the most significant Port Pin.
- The current flow through each of the LED segments should be limited to the maximum value supported by the LED display unit.