UNIT - I
Introduction to Embedded Systems.

* Embedded System:-

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

→ Embedded systems are used in all fields including household appliances, telecommunications, medical equipment, industrial control, consumer products, etc.

* Embedded Systems Vs. General computing systems:-

	General purpose computing System	Embedded System
1. Components	A system which is a combination of a generic hardware & a general purpose Operating system for executing a variety of applications.	A system which is a combination of special purpose hardware & embedded OS for executing a specific set of applications.
2. OS	Contains a General purpose Operating System (GPOS)	May or may not contain an OS for functioning.
3. Alterable	Applications are alterable by the user. (It is possible for the end user to re-install the OS, & also add or remove user applications.)	the firmware of ES is pre-programmed & it is non-alterable by the en[d] user. (there may be ex-eptions for system supp-orting OS kernel)

4. Key factor	Performance is the key deciding factor in the selection of system. Always 'faster is better'.	Application specific requirements (like performance, power requirements, memory usage, cost etc) are the key deciding factors
5. Time-critical	Response requirements are not time-critical.	For certain category of ES like mission critical systems, the response time requirement is highly critical.
6. Execution Behaviour	Need not be deterministic in execution behaviour	Execution behaviour is deterministic for certain types of ES like "Hard Real time' systems.

* History of Embedded Systems:-

→ In the olden days, ES were built around the old vacuum tube & transistor technologies & the Embedded algorithm was developed in low level languages.

→ Advances in semiconductor & nano-technology & IT revolution gave way to the development of miniature embedded systems.

→ the first recognised modern ES is the

(1) Apollo Guidance Computer (AGC):-

→ Developed by the MIT Instrumentation laboratory for the lunar expedition, by the charles draper.

→ It has internal guidance systems of both

* Command Module (CM)
* Lunar Excursion Module (LEM)

→ the CM was designed to encircle the moon. → Around 5000 IC's were used in this design.
→ the LEM & its crew were designed to go down to the moon surface & land there safely.
→ the LEM — 18 engines.
— 16 reaction control thrusters.
→ Designed based on — 4k words of ROM
— 256 words of RAM.
→ clk freq. — 1.024MHZ.
→ RTL Logic used in the design.
→ the user interface unit of AGC is known as DSKY (Display / keyboard), used for inputting the commands to module

(2) 'Autonetics 'D-17' Guidance Computer:-
→ the first mass-produced ES was the guidance computer for the Minuteman-I missile in 1961.
→ Built using discrete transistor logic & a hard disk for main memory.
→ NASA — AGC.
US military — Minuteman-II Intercontinental ballistic missile.

* Classification of Embedded Systems:-

Embedded Systems

- Generation
  - → 1st Generation ES
  - → 2nd " "
  - → 3rd " "
  - → 4th " "
- Complexity & Performance Requirements
  - → Small scale ES
  - → Medium " "
  - → Large " " (Sophisticated)
- Deterministic Behaviour
  - → Hard Real time ES
  - → Soft Real time ES
- Triggering
  - → Time triggered ES
  - → Event triggered ES

Based on complexity: (1) (SSI):-

→ System designed using 8-bit µc, or 16-bit µp/µc. → low performance, low cost

→ Complexity low

→ Coding → embedded 'C'

→ Memory → small

→ Simple in application. → May/may not contain OS.

→ Performance not time-critical.

→ Ex:- An electronic toy.

(2) **Medium scale**:-

→ Slightly complex in H/w & firmware requirement

→ Built around medium performance & low cost 16 or 32-bit µp/µc. or DSP's.

→ Usually contain OS → Ex:- Industrial machi[nes], Household applianc[es]

(3) Large - scale :-

→ Highly complex H/w & firmware.

→ Built around 32 or 64-bit RISC μp/μc. or PLDs or Multicore processors.

→ Response is time - critical.

→ Ex:- Antilock - Breaking system.
Mission critical applications.

* Based On Generation:-

① Ist Generation:- (1G)

→ Built around 8-bit μp & μc. (4-bit)

→ Simple in H/w ckt & firmware developed in assembly code

→ Ex:- Digital telephone keypads.
Stepper motor control units etc.

② 2nd Generation:- (2G):-

→ Built around 16-bit μp & 8-bit μc.

(Instruction set) → they are more complex & powerful than 1G μp & μc. (Instruction set)

→ Ex:- SCADA systems (Supervisory Control & D[illegible] Data Acquisition systems. etc.

③ 3rd Generation:- (3G):-

→ Built around 32-bit μp & 16-bit μc.

→ Concepts like Digital signal processors (DSPs)

→ Application specific Integrated Circuits (ASICs) evolved.

→ Ex:- Robotics, Media etc., networking, Industrial process control

→ Instruction set became more complex & powerful.

* **Based on deterministic behaviour:-**

→ Applicable for "Real time" systems.

→ The task execution behaviour for an ES may be deterministic or non-deterministic.

→ Based on execution behaviour Real time ES are divided into Hard & Soft.

* **Based on Triggering:-**

→ ES which are "Reactive" in nature can be based on triggering".

→ Event triggered, Time triggered.

* **Fourth (4th) Generation (4G):-**

→ The advent of system on chips (SoC), reconfigurable processors & multicore processors are bringing high performance, tight integration & miniaturization into the embedded device market.

→ The SoC technique implements a total system on a chip by integrating different functionalities with a processor core on an integrated ckt.

→ Ex:- Smart phone devices.
Mobile Internet devices.

* Major application Areas of Embedded Systems:-

(1) Consumer electronics:- Camcorders, cameras etc.

(2) Household appliances:- Television, DVD players, washing machine, fridge, microwave oven, etc.

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

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

(5) Telecom:- Cellular telephones, telephone switches, handset multimedia applications, etc.

(6) Computer peripherals:- Printers, scanners, fax machines, etc.

(7) Computer networking systems:- Network routers, switches, hubs, firewalls, etc.

(8) Healthcare:- Different kind of scanners, EEG, ECG machines etc.

(9) Measurement & Instrumentation:- Digital multimete digital CRO's, logic analyzers, PLC systems etc.

(10) Banking & Retail:- Automatic Teller machines (ATM) and currency counters, point of sales (POS)

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

(12) Wearable devices:- Health & Fitness Trackers, Smar phone screen extension for notifications, etc.

(13) Cloud computing and Internet of things (IOT).

(ASICs) evolved.

* Purpose of an Embedded Systems:- (5)

→ Each ES is designed to serve the purpose of any one or a combination of the following tasks:

(1) Data collection/Storage/Representation.
(2) Data communication
(3) Data (signal) processing
(4) Monitoring
(5) Control
(6) Application Specific User Interface.

(1) Data collection/Storage/Representation:

→ ES designed for the purpose of data collection performs acquisition of data from the external world.

→ Data collection is usually done for storage, analysis, manipulation & transmission.

→ Data refers text, voice, image, video, electrical signals & any other measurable quantities.

→ Data can be either analog or digital.

→ The collected data may be stored directly in system or may be transmitted to some other system.

→ ES designed for pure measurement applications without storage, used in control and instrumentation domain.

→ Analog & Digital CRO's without storage memory are examples of this.

→ Some ES store the collected data for processing and analysis.

Ex:- Measuring & Monitoring instruments with storage memory used in Medical applications.

→ A digital camera is an example of an ES with data collection/storage/representation of data.

(2) <u>Data communication</u>:-

→ The data collected by an embedded terminal may require transferring of the same to some other system located remotely.

→ The transmission is achieved either by a wire-line or by a wireless medium.

→ The data communication units are like wireless modules (Bluetooth, ZigBee, Wi-Fi, EDGE, GPRS, etc.) or wire-line modules (RS-232C, USB, TCP/IP, PS2, etc

→ Network hubs, routers, switches etc. are examples of this.

(3) <u>Data (Signal) Processing</u>:-

→ ES are employed in applications demanding signal processing like speech coding, synthesis audio, video Codec, transmission applications e

→ A digital hearing aid is an example, it improves the hearing capacity of hearing impaired persons.

(4) Monitoring :-

→ All Embedded products coming under the medical domain are with monitoring functions only.

→ Electro Cardiogram (ECG) machine is an example for monitoring the heartbeat of a patient.

→ The sensors used in ECG are different electrodes connected to the patient's body.

→ Digital CRO, digital multimeters, logic analysers. etc. are examples.

(5) Control :-

→ A system with control functionality contains both sensors & actuators.

→ Sensors are connected to i/p port for capturing the changes.

→ The Actuators connected to o/p port are controlled according to changes in i/p variable.

→ Air conditioner system used to control the room ~~the~~ temperature to a specified limit is an example.

(6) Application Specific User Interface :-

→ ES with application - specific user interfaces like buttons, switches, keypad, lights, bells, display unit etc.

→ Mobile phone is an example.

→ In mobile phone the user interface is provided through keypad, graphic LCD module, system speaker, vibration alert etc.

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* Characteristics of Embedded Systems:-

→ Some of the important characteristics of an ES are

(1) Application & domain specific.
(2) Reactive & Real Time.
(3) Operates in harsh environments.
(4) Distributed
(5) Small size & weight
(6) Power Concerns.

(1) Application & Domain Specific:-

→ Each ES is designed to perform a set of defined functions & developed to do intended functions only.

→ They cannot be used for other purpose.

→ For example, we cannot replace the embedded unit control of microwave oven with Air conditioner's embedded control unit.

(2) Reactive & Real time:-

→ ES are must continually react to changes in system's environment.

→ And must compute the results in real time without any delay.

→ ES are in interaction with the Real world through sensors.

→ Ex:- ES which are mission critical, like flight control systems, Antilock Brake Systems etc. are examples of Real time systems.

Ex:- Car cruise control, Air bag in car.
↳ Monitors speed & break sensors

(3) Operates in Harsh environment:-

→ the environment in which ES deployed may be a dusty one / high temp. / vibrations & shock.

→ ES placed in such areas should be capable to withstand all these operating conditions.

→ Power supply fluctuations, corrosion & component aging, etc., shock absorption are the other factors to be considered while designing.

(4) Distributed:-

→ ES is a part of larger systems.

→ An Automatic vending machine, Automatic Teller Machine (ATM) are examples.

→ Each of them are independent embedded units but they work together to perform the overall functions.

(5) Small size & weight:-

→ To buy a new ~~the~~ product, make a comparative study on PROS & CONS.

→ the product size, weight, shape, style etc. are the deciding factors to choose a product.

→ Most of the applications demands small size & low weight.

(6) Power Concerns:-

→ ES should be designed to minimise the heat dissipation by the system.

→ High amount of heat demands cooling requirements like cooling fans which in turn occupies additional space & make the system bulky.

→ Power saving modes & power management also to be considered in design.

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* Quality Attributes of Embedded Systems:-

→ Quality attributes are the non-functional requirements in any system design.

→ the Quality attributes are broadly classified into

1. Operational Quality Attributes.
2. Non-Operational Quality Attributes.

(1) 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 coming under this are

(1) Response
(2) throughput
(3) Reliability
(4) Maintainability.
(5) Security
(6) Safety.

Response:-

→ It is a measure of quickness of the system.
→ Most of the ES demand fast response which should be almost Real time.
→ Ex:- Flight Control application.
→ Any response delay in the system will create potential impact to the safety of the flight as well as passengers.
→ Not necessary that all ES's should be Real time in response.
→ Electronic toy is not at all time-critical.

throughput:-

→ It deals with efficiency of a system.
→ It can be defined as the rate of production or operation of a defined process overastated period of time.
→ the rates can be expressed in terms of units of products, batches produced, or any other meaningful measurements.
→ Ex:- Card Reader, throughput means how many transactions the reader can perform in a minute or in an hour or in a day.

Reliability:-

→ It is a measure of how much % you can rely upon the proper functioning of the system or what is the % susceptibility of the system to failures.
→ 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 allowe to be out of order following a failure, it should be in minutes.

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

A_i = Availability in ideal condition.

Maintainability:-

→ It deals with support & maintainence to the end user or client in case of technical issues & product failures or on the basis of a routine system checkup.

→ A more reliable system means a system with less corrective maintainability requirements & vice versa.

→ As the reliability of system increases, the chances of failures & non-functioning also reduces, thereby the need for maintainability is also reduced.

→ Maintainability can be classified into two categories

① Scheduled or periodic Maintainance (preventive maintainance)

② Maintainance to unexpected failures (corrective maintainance)

→ A printer is a typical example.

→ An inkjet printer uses ink catridges, the end user replace the catridge after each 'n' no.of printouts to get quality prints. — Ex. for scheduled or periodic maintainance.

→ If the paper feeding part of the printer fails the printer fails to print & it requires immediate repairs to rectify the problem. — Ex. for Maintanance to unexpected failure.

→ Maintanance is simply an indication of the availability of the product for use.

Security:-

→ Confidentially, Integrity, and availability are the three major measures of information security.

→ Confidentially deals with the protection of data & application from unauthorised disclosure.

→ Integrity deals with the protection of data & application from unauthorised modification.

→ Availability deals with protection of data and application from unauthorised users.

→ EX:- Personal Digital Assistant (PDA).

→ If it is shared one there should be some mechanism in the form of a user name & password to access into a particular person's profile —— Ex. of Availability

→ Also all data & applications present in the PDA need not be accessible to all users. Some of them are specifically accessible to administrators only.

→ For achieving this, Administrator & user levels of security should be implemented – Ex. of Confidentiality

→ Some data present in the PDA may be visible to all users but there may not be necessary permissions to alter the data by the users. that is Read Only access is allocated to all users — EX. of Integrity.

Safety:-

→ It deals with the possible damages that can happen to the operators, public and the environment due to the breakdown of an embedded system or due to the emission of radio-active or hazardous materials from the embedded products.

→ The breakdown of an embedded system may occur due to a hardware failure or a firmware failure.

(2) 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.

1. Testability & Debug-ability
2. Evolvability
3. Portability
4. Time to prototype & market
5. Per unit & total cost.

(1) Testability & Debug-ability:-

→ Testability deals with how ~~man~~ easily one can test the design, application & by which means he/she can test it.

→ For an embedded product, testability is applicable to both embedded hardware & firmware.

→ Hardware testing ensures that the peripherals & total hardware functions in desired manner.

→ Firmware testing ensures that the firmware is functioning in the expected way.

→ Debug-ability means debugging the product for figuring out the probable sources that create unexpected behaviour in the total system.

→ Debug-ability has two aspects:

1. Hardware level debugging:- used for figuring out the issues created by hardware problems
2. Firmware debugging:- employed to figure out the errors that appear as a result of flaws in the firmware.

② **Evoluability:-** Evoluability is referred as the non-heritable variation.

→ It refers to the ease with which the embedded product (including firmware & Hardware) can be modified to take advantage of new firmware or H/w technologies.

③ **Portability:-**

→ It is a measure of 'System independence'.

→ An Embedded product is said to be portable if the product is capable of functioning in various environments, target processors/controllers & embedded operating system.

→ A standard embedded product should always be flexible and portable.

→ In embedded products, the term 'porting' represents the migration of the embedded firmware written for one target processor to a different target processor.

④ **Time-to-prototype and Market:-**

→ Time-to-market is the time elapsed between the conceptualisation of a product & the time at which the product is ready for selling or use.

→ Prototyping is an informal kind of rapid product development in which the important features of the product under consideration are developed. The time to prototype is also another critical factor.

⑤ **Per unit cost and Revenue:-**

→ Cost is a factor which is closely monitored by both end user & 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. (10)

* Product life Cycle:- (PLC):-

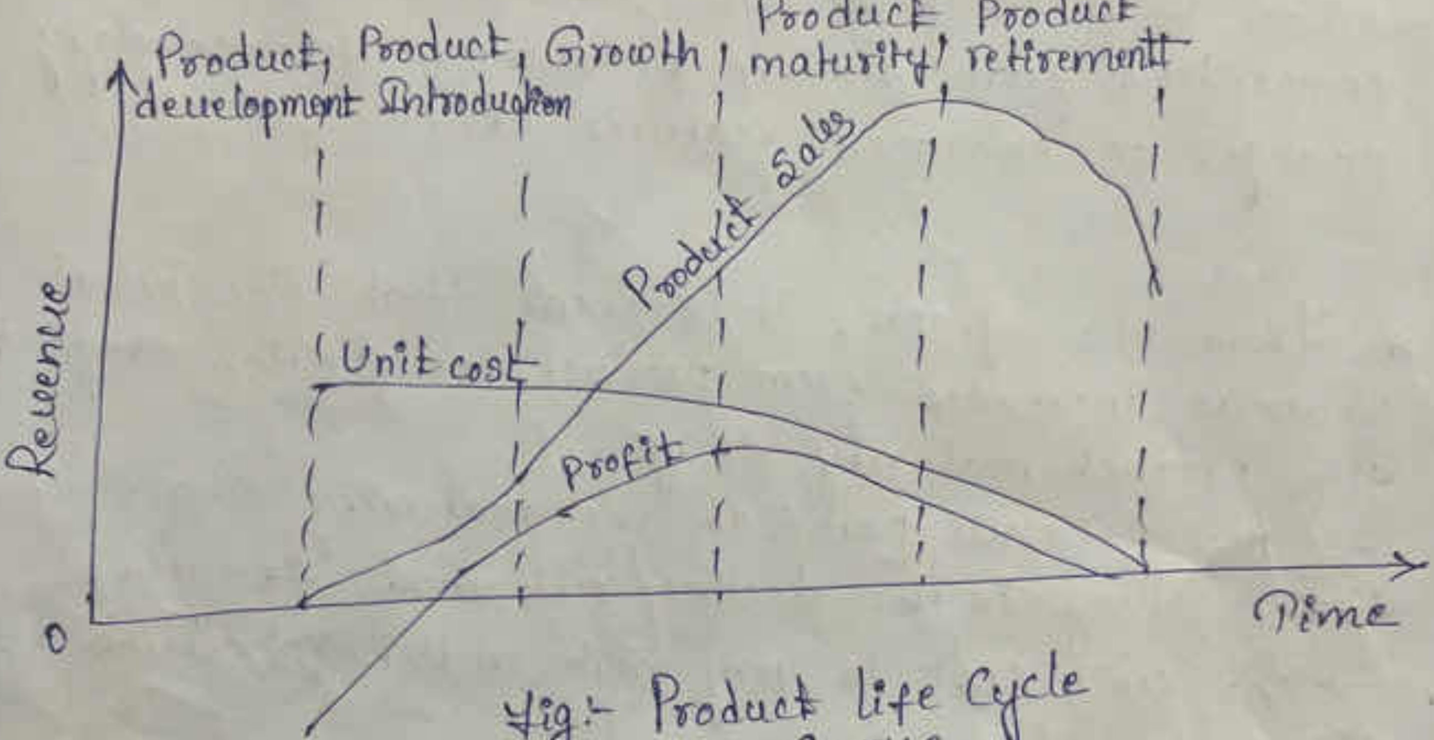

Fig:- Product life Cycle Curve.

→ Every embedded product has a product life cycle which starts with the design & development phase.

→ The product idea generation, prototyping, Roadmap definition, actual product design & development are the activities carried out during this phase.

→ During the design & development phase there is only investment & no returns.

→ Once the product is ready to sell, it is introduced to the market. This stage is known as the product Introduction stage. During the initial period the sales & revenue will be low.

→ In the growth phase, the product grabs high market share.

→ During the maturity phase, the growth & sales will be steady & the revenue reaches at its peak.
→ The product retirement/ Decline starts with the drop in sales volume, market share & revenue.
→ The decline happens due to various reasons like competition from similar product with technology changes or enhanced features etc.

* From the graph, it is clear that the total revenue increases from product introduction stage to the product maturity stage.
→ The revenue peaks at the maturity stage & starts falling in the decline/ retirement stage.
→ The unit cost is very high in the introductory stage.
→ The profit increases with increase in sales & attain a steady value & then falls with a dip in sales.