MODULE 1: Introduction

Structure

1.1 Introduction: Embedded Systems and general purpose computer systems,
1.2 History, classifications, applications and purpose of embedded systems (Chapter 1 – Text 1)
1.3 Core of Embedded Systems : Microprocessors and microcontrollers,
1.4 RISC and CISC controllers,
1.5 Big endian and Little endian processors,
1.6 Application specific ICs,
1.7 Programmable logic devices,
1.8 COTS, sensors and actuators,
1.9 Communication interface, Embedded firmware,
1.10 other system components, PCB and passive components (Chapter 2 – Text 1)

Objectives

Learning Objectives

1. **Understand Embedded Systems Basics**
    - Differentiate embedded vs. general-purpose computers.
    - Learn history, classification, and applications.
2. **Explore Core Components & Architectures**
    - Study microprocessors, microcontrollers, RISC & CISC, endianness.
    - Understand ASICs, PLDs, and COTS components.
3. **Analyze Hardware & Communication**
    - Learn about sensors, actuators, firmware, and PCBs.
    - Understand communication interfaces and passive components.

1.1 Embedded Systems and General purpose computer systems

Embedded Systems Definition

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).

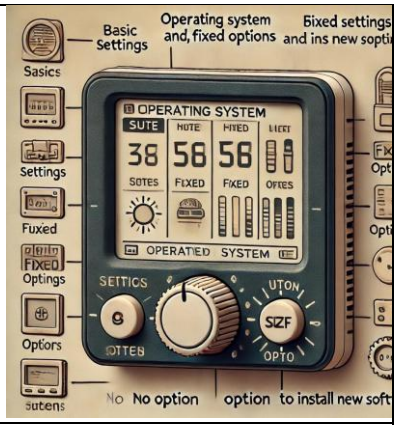
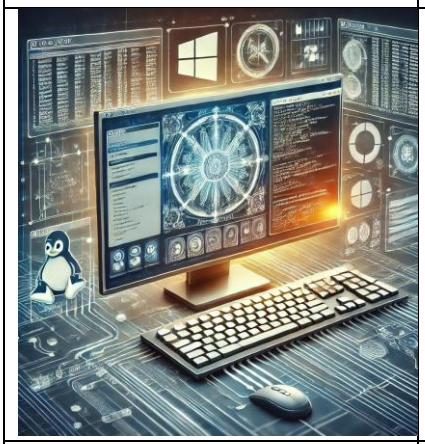
Need:

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.

Comparison Between Embedded Systems and General-Purpose Computing Systems

Feature	Embedded System	General Purpose Computing System
Purpose	Designed for a specific function or task	Designed for multiple applications and tasks
Operating System	Fixed or custom OS, often non-modifiable	User can install or change OS (Windows, Linux, etc.)
Hardware Flexibility	Limited hardware customization	Highly flexible, supports multiple peripherals
User Applications	Cannot install third-party applications	Users can install and run multiple applications
Interfaces	Minimal, task-specific interfaces (e.g., IR remote)	Multiple interfaces (USB, Bluetooth, Wi-Fi, Ethernet, etc.)
Computational Requirements	Real-time processing with strict deadlines	General-purpose processing, not always real-time
Power Efficiency	Optimized for lower power consumption	Higher power consumption due to multitasking capability
Memory Availability	Limited and optimized for function	Large memory (RAM, HDD/SSD) for multiple applications
Software Modification	Not user-modifiable	Users can modify, update, and install new software
Functionality Expansion	Fixed function, cannot be easily repurposed	Can be repurposed for various tasks
Example Devices	DVD Player, Washing Machine, Car ECU	Desktop PC, Laptop, Palmtop, Workstation

Comparison Between Embedded Systems and General Purpose Computing Systems

		
Purpose of an Embedded System: A washing machine with predefined functions.	Purpose of a General-Purpose Computing System: A laptop running multiple applications.	Operating System in an Embedded System: A digital thermostat with a fixed interface.
		
Operating System in a General-Purpose Computing System: A desktop PC with a flexible OS.	Hardware Flexibility in an Embedded System: A microwave oven with fixed buttons.	Hardware Flexibility in a General-Purpose Computing System: A desktop PC with multiple peripherals.
		
User Applications in an Embedded System: A smart thermostat with limited options.	User Applications in a General-Purpose Computing System: A smartphone with multiple third-party apps.	

1.2 History, classifications, applications and purpose of embedded systems

1.2.1

1. Classification Based on Evolution (History)

1. **First Generation**
    - 8-bit microprocessors (8085, Z80) and 4-bit microcontrollers.
    - Simple hardware, firmware in Assembly language.
    - Examples: Digital telephone keypads, stepper motor control units.
2. **Second Generation**
    - 16-bit microprocessors, 8/16-bit microcontrollers.
    - More complex instruction sets, some with embedded OS.
    - Examples: Data Acquisition Systems, SCADA systems.
3. **Third Generation**
    - 32-bit processors, 16-bit microcontrollers, DSPs, ASICs.
    - Instruction pipelining, real-time and general-purpose OS.
    - Examples: Robotics, industrial process control, networking.
4. **Fourth Generation**
    - System-on-Chip (SoC), reconfigurable and multi-core processors.
    - High-performance, miniaturized, real-time OS.
    - Examples: Smartphones, Mobile Internet Devices (MIDs).

2. Classification Based on Complexity and Performance

1. **Small-Scale Embedded Systems**
    - Simple applications, not time-critical.
    - Built on low-cost 8/16-bit microprocessors/microcontrollers.
    - May or may not have an OS.
    - Example: Electronic toys.
2. **Medium-Scale Embedded Systems**
    - Moderately complex hardware and software.
    - Uses 16/32-bit microprocessors/microcontrollers or DSPs.
    - Usually includes an embedded OS.

3. **Large-Scale/Complex Embedded Systems**

    - High-performance, mission-critical applications.
    - Uses 32/64-bit RISC processors, RSoC, multi-core processors.
    - Includes multiple processors, co-processors, and accelerators.
    - Uses high-performance Real-Time Operating Systems (RTOS).
    - Examples: Media encoding/decoding, cryptographic processing.

1.2.2 Applications of embedded systems

Embedded Systems in Daily Life

Embedded systems play a crucial role in modern technology, evolving from early models like the Apollo guidance computer to advanced smart devices. Their applications span multiple domains, including:

1. **Consumer Electronics** – Camcorders, cameras.
2. **Household Appliances** – TVs, DVD players, washing machines, fridges, microwaves.
3. **Home Automation & Security** – Air conditioners, sprinklers, alarms, CCTV cameras.
4. **Automotive Industry** – ABS, engine control, ignition, automatic navigation.
5. **Telecom** – Cell phones, telephone switches, multimedia applications.
6. **Computer Peripherals** – Printers, scanners, fax machines.
7. **Networking** – Routers, switches, hubs, firewalls.
8. **Healthcare** – Scanners, EEG, ECG machines.
9. **Measurement & Instrumentation** – Digital multimeters, CROs, logic analyzers, PLC systems.
10. **Banking & Retail** – ATMs, currency counters, POS systems.
11. **Card Readers** – Barcode scanners, smart card readers, handheld devices.

1.2.3 Purpose of Embedded Systems

Embedded systems perform various specialized tasks in different domains like consumer electronics, healthcare, automotive, and telecommunications. Their functionalities can be categorized into six major roles:

1. Data Collection/Storage/Representation

- Embedded systems collect and process data from the external environment, which can be in analog or digital form.
- Analog data is converted into digital form using Analog-to-Digital (A/D) converters.
- The collected data may be:

1. Stored for further processing.
2. Represented visually (LCD, LED) or audibly (buzzers, alarms).
3. Deleted after processing.

- Examples: Digital multimeters, ECG monitoring devices, digital cameras (store and display images).

2. Data Communication

- Embedded systems enable communication between devices, either through wired (USB, RS-232, TCP/IP) or wireless (Bluetooth, Wi-Fi, ZigBee) methods.
- Data transmission can be analog or digital, with modern systems favoring digital communication.
- Some embedded systems serve as dedicated transmission units, ensuring secure and efficient data exchange.
- Examples: Network routers, switches, telephone systems, home automation devices.

3. Data (Signal) Processing

- Embedded systems are used in applications requiring signal processing, such as audio, video, and electrical signal manipulation.
- They perform functions like speech coding, audio synthesis, and video encoding.
- Example: Digital hearing aids, which amplify and process sound to improve hearing for individuals with impairments.

4. Monitoring

- Designed to observe variables but not control them.
- Sensors gather real-time data, which is displayed for monitoring purposes without altering the system.
- Common in healthcare and industrial applications.
- Examples:

1. Medical: ECG machines (monitor heartbeat but do not regulate it).
2. Industrial: Digital storage oscilloscopes (CROs), logic analyzers, and multimeters (monitor voltage, current, etc.).

5. Control

- Embedded systems that regulate processes by taking corrective actions based on sensor input.
- These systems consist of sensors (input), actuators (output), and a control unit that adjusts the output to maintain the desired conditions.

- Example: Air conditioners:

    1. The sensor (thermistor) measures the current temperature.
    2. The user input (desired temperature) is set via a remote control.
    3. The actuator (compressor) adjusts airflow to maintain the desired temperature.

1.3 Core of Embedded Systems: Microprocessors and microcontrollers

Microprocessors:

- A **microprocessor** is a CPU on a silicon chip capable of performing arithmetic and logical operations based on predefined instructions.
- Requires additional hardware components like memory, timers, and interrupt controllers for functioning, making it **dependent** and less compact.
- The **evolution of microprocessors** began with Intel's 4004 (4-bit, 1971), followed by Intel 8080, 8085, Zilog Z80, and later 16/32/64-bit processors.
- **Key Features**:
    1. General-purpose usage.
    2. High performance and processing speeds (modern processors reach up to 2.4 GHz).
    3. Based on **Harvard or Von-Neumann architectures** and use either **RISC** or **CISC instruction sets**.
- Used in **high-end markets**, industrial control, and advanced embedded applications.

Microcontrollers:

- A **microcontroller** integrates a CPU, RAM, ROM/Flash memory, timers, I/O ports, and interrupt control units into a single chip.
- **Self-contained** and designed specifically for embedded systems, eliminating the need for external components.
- Early examples include TI's **TMS1000 (1974)** and Intel's **8048 (1977)**, leading to the highly popular **Intel 8051** series in the 1980s.
- **Key Features**:
    1. Application-specific or domain-specific design.
    2. Inexpensive, compact, and power-efficient.
    3. Modern microcontrollers (e.g., ARM11, Atmel AVR) offer advanced features like SPI, I2C, USB, and networking.
- Used in consumer electronics, industrial control, IoT, and automotive applications.

Comparison: Microprocessor vs. Microcontroller

Feature	Microprocessor	Microcontroller
Definition	A silicon chip representing a CPU that performs arithmetic and logical operations.	A highly integrated chip with CPU, RAM, ROM, timers, and I/O ports for embedded systems.
Dependency	Dependent on external hardware (memory, timers, interrupt controllers, etc.).	Self-contained and does not require external hardware for functioning.
Purpose	General-purpose usage in industrial and high-performance computing.	Designed for specific tasks in embedded systems.
I/O Ports	Does not include built-in I/O ports; requires external components like programmable peripheral interface chips.	Includes multiple built-in I/O ports (8, 16, or 32-bit) for direct use.
Applications	Used in computers, servers, and high-performance devices.	Used in IoT, robotics, automotive systems, and consumer electronics.
Architecture	Based on Harvard or Von-Neumann architecture with RISC or CISC instruction sets.	Similar architectures, often domain-specific instruction sets (e.g., AVR for automotive).
Power Efficiency	Less efficient in terms of power consumption.	Optimized for power efficiency and compactness.
Target Market	High-end markets where performance is critical.	Embedded markets, where cost and size are important.
Cost	Expensive due to dependency on external hardware.	Cost-effective, with all required components integrated.

Microcontrollers are ideal for embedded systems due to their compact design, low cost, and energy efficiency, while microprocessors are suited for high-performance, general-purpose applications.

1.4 RISC and CISC controllers,

Feature	RISC (Reduced Instruction Set Computing)	CISC (Complex Instruction Set Computing)
Instruction Set	Lesser number of instructions.	Greater number of instructions.
Instruction Pipelining	Supports instruction pipelining for increased execution speed.	Generally, no instruction pipelining is present.
Instruction Set Orthogonality	Orthogonal instruction set (any instruction can operate on any register or use any addressing mode).	Non-orthogonal instruction set (instructions are instruction-specific regarding registers and addressing modes).
Operations	Operations are performed only	Operations can be performed directly

	on registers; memory operations are limited to load and store instructions.	on registers or memory, depending on the instruction.
Number of Registers	Large number of general-purpose registers are available.	Limited number of general-purpose registers.
Programming	Requires more lines of code as the instructions are simpler and perform smaller operations.	Instructions are like macros in C language, allowing complex operations with a single instruction, reducing the code length.
Instruction Length	Single, fixed-length instructions.	Variable-length instructions.
Hardware Complexity	Uses less silicon and has a lower pin count due to simpler instruction decoding.	Requires more silicon and additional decoder logic to handle complex instruction decoding.
System Architecture	Uses Harvard architecture (separate buses for program and data memory).	Can use either Harvard or Von-Neumann architecture (shared bus for program and data memory).

Key Differences in Applications

- **RISC** is commonly used in applications requiring high performance and power efficiency, such as **smartphones, tablets, and embedded systems**.
- **CISC** is suitable for applications requiring complex operations, such as **desktop computers, servers, and legacy systems**.

RISC focuses on simplicity and efficiency, while CISC emphasizes complexity and minimizing the number of instructions a programmer needs to write.

Harvard vs. Von-Neumann Architecture Comparison Table

Feature	Harvard Architecture	Von-Neumann Architecture
Memory Structure	Separate memory for instructions and data	Shared memory for instructions and data
Instruction and Data Fetching	Simultaneous fetching of instructions and data (Pre-fetching)	Sequential fetching of instructions and data
Bus System	Separate buses for instructions and data	Single common bus for instructions and data
Performance	High performance due to parallel execution and pipelining	Lower performance due to sequential fetching
Cost	Comparatively high cost due to separate memory buses	Cheaper due to simpler architecture
Memory Alignment	No memory alignment problems	Memory alignment problems possible
Self-Modifying Code	Does not allow self-modifying code	Allows self-modifying code

Program Memory Corruption Risk	No accidental corruption of program memory	Chances of accidental program memory corruption

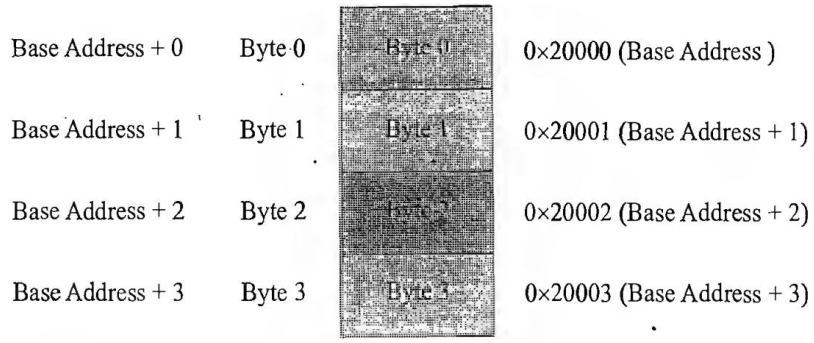
1.5 Big endian and Little endian processors

Endianness in Memory Storage

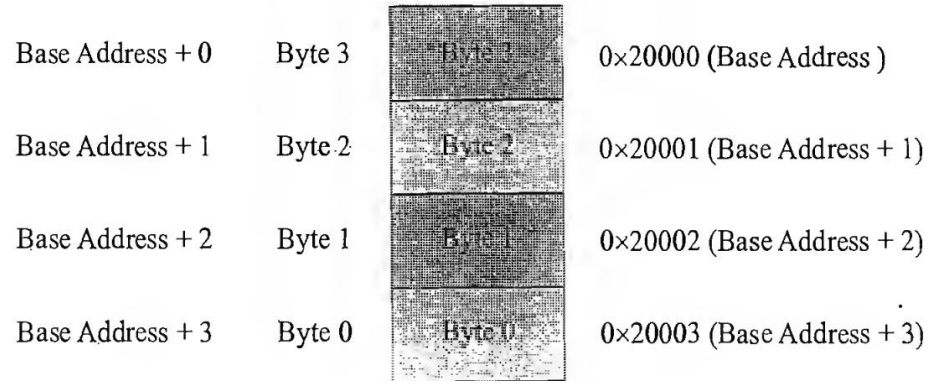
Endianness defines how multi-byte data is stored in memory by a processor. It determines the order in which bytes are arranged in a system where the word size is greater than one byte.

Types of Endianness:

1. **Little-Endian:**
   a. The **lower-order byte** is stored at the **lowest memory address**.
   b. The **higher-order byte** is stored at the **next higher memory address**.
   c. Example (for a 4-byte integer Byte3 Byte2 Byte1 Byte0):
      i. Memory Order: **Byte0 → Byte1 → Byte2 → Byte3** (Lowest to Highest Address).
   d. Commonly used in **Intel x86** processors.



2. **Big-Endian:**
   a. The **higher-order byte** is stored at the **lowest memory address**.
   b. The **lower-order byte** is stored at the **next higher memory address**.
   c. Example (for a 4-byte integer Byte3 Byte2 Byte1 Byte0):
      i. Memory Order: **Byte3 → Byte2 → Byte1 → Byte0** (Lowest to Highest Address).
   d. Used in **Motorola, PowerPC, and some network protocols**.



Key Differences:

- **Little-Endian**: Stores least significant byte first.
- **Big-Endian**: Stores most significant byte first.
- Some architectures, like **ARM and PowerPC**, support both endianness (bi-endian systems).

1.6 Application specific ICs

1. **Definition:**
    - ASIC is a **microchip designed for a specific application** rather than general-purpose use.
    - Replaces conventional logic chips and integrates multiple functions into a **single chip**.
2. **Advantages:**
    - **Reduces system development cost** by integrating multiple functions.
    - **Smaller size** enables compact system designs with **high performance**.
    - **Optimized for specific tasks**, making them more efficient than general-purpose processors.
3. **Types of ASICs:**
    - **Pre-fabricated ASICs:** Designed for **specialized applications**.
    - **Custom ASICs:** Built using reusable components for **specific customer needs**.
4. **Non-Recurring Engineering Charge (NRE):**
    - **One-time investment** for ASIC fabrication costs.
    - **Cost-effective only for large-scale commercial production**.
5. **Application-Specific Standard Product (ASSP):**
    - If an ASIC is made publicly available, it is called an **ASSP**.
    - Marketed like a general-purpose product but for **specific applications**.
    - Example: **ADE7760 Energy Meter ASIC** by Analog Devices.
6. **Proprietary Nature:**
    - ASIC designs are usually **confidential** and **not publicly documented**.
    - Detailed examples are rarely disclosed due to **legal and intellectual property concerns**.

1.7 Programmable logic devices,

1. Definition & Types

- Logic devices perform essential system functions like **data communication, signal processing, and control operations**.

- **Two main categories:**
  - **Fixed Logic Devices:** Permanent circuits, non-changeable once manufactured.
  - **Programmable Logic Devices (PLDs):** Reconfigurable devices with flexible logic capacity and features.

2. Advantages of PLDs

- **Fast Development:** No long lead times; immediate testing & deployment.
- **Cost-Effective:** No **Non-Recurring Engineering (NRE) costs** like custom ASICs.
- **Inventory Control:** Order as needed, avoiding surplus or shortage.
- **Field Reprogrammability:** Devices can be updated even after shipping (e.g., firmware updates via the Internet).

3. Types of PLDs

- **Field Programmable Gate Arrays (FPGAs):**
  1. High logic density (millions of gates), high performance.
  2. Used in **data processing, storage, telecommunications, digital signal processing**.
  3. Example: **Xilinx Virtex** with 8M system gates, built-in processors (IBM PowerPC), and high-speed interfaces.
- **Complex Programmable Logic Devices (CPLDs):**
  1. Lower logic density (up to 10,000 gates), predictable timing.
  2. Ideal for **control applications, low-power devices, mobile applications** (e.g., Xilinx CoolRunner series).

4. PLDs vs Fixed Logic Devices

- **PLDs are flexible** – Designs can be **modified & tested instantly** without new hardware.
- **Fixed logic devices are permanent**, requiring custom manufacturing for design changes.

5. FPGA Evolution & Trends

- Older FPGAs: **40 MHz, expensive ($150+), limited gates**.
- Modern FPGAs: **300 MHz, millions of gates, integrated processors & memory, cost <$10**.
- **FPGAs are now the preferred solution** for rapid prototyping and high-performance applications.

1.8 COTS, sensors and actuators,

Commercial Off-the-Shelf (COTS)

- **Definition:** COTS products are **ready-made components** used **as-is** for easy integration into systems.
- **Examples:** Remote control toy car circuits, **high-frequency microwave electronics**, **analog-to-digital converters**, **infrared detectors**, and **TCP/IP plug-in modules** (e.g., WIZnet, Freescale).
- **Advantages:**
  - **Readily available**, reducing development time & cost.
  - **No need for custom design**, firmware is pre-built.

  - **Faster time-to-market** for embedded systems.
- **Disadvantages:**
  - **No universal standards**, leading to **vendor lock-in**.
  - **Compatibility issues** between different manufacturers.
  - **Risk of product discontinuation**, affecting long-term design stability.

Sensors & Actuators

- **Sensor:** A transducer that converts energy from one form to another for measurement or control.
  - Example: **Magnetic Hall Effect Sensor** in a smart running shoe (measures cushion-to-magnet distance).
- **Actuator:** A device that converts signals into physical action (motion).
  - Example: **Micro Stepper Motor** in a smart running shoe (adjusts cushion position).

1.9 Communication interface, Embedded firmware,

Communication Interfaces

1. Types of Communication Interfaces

- **Onboard Communication Interface:** Connects components within an embedded system (e.g., I2C, SPI, UART, Parallel Bus).
- **External Communication Interface:** Connects the embedded system to other devices (e.g., USB, Ethernet, Wi-Fi, Bluetooth, RF, GPRS).

2. Inter-Integrated Circuit (I2C) Bus

- **Type:** Synchronous, bi-directional, half-duplex, **two-wire serial interface** (SCL & SDA).
- **Developed by:** Philips in the **1980s** for microcontroller-to-peripheral communication.
- **Master-Slave Model:**
  - **Master** controls communication, generates clock, and initiates data transfer.
  - **Slave** responds to master's request.
  - **Multi-master support** allows multiple controllers on the same bus.

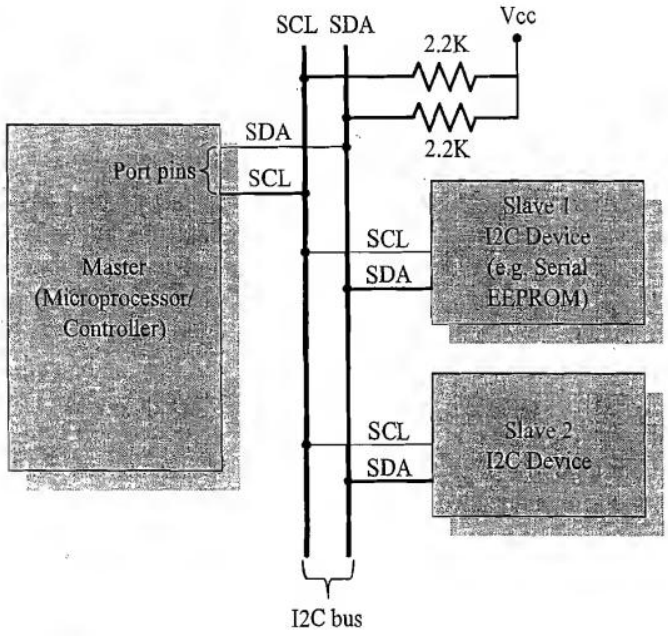
3. I2C Communication Sequence

1. **Start Condition:** Master pulls SDA **LOW** while SCL is **HIGH**.
2. **Addressing:** Master sends **7-bit or 10-bit address** of the slave.
3. **Read/Write Bit:** 1 for **Read**, 0 for **Write**.
4. **Acknowledgment:** Slave acknowledges if the address matches.
5. **Data Transfer:**
   - **Write:** Master sends 8-bit data to Slave.
   - **Read:** Slave sends 8-bit data to Master.
6. **Acknowledgment:** Required after each byte transfer.
7. **Stop Condition:** Master releases SDA **HIGH** when SCL is **HIGH**.

4. I2C Data Rates

- **Standard Mode:** Up to **100 kbps**.
- **Fast Mode:** Up to **400 kbps**.
- **High-Speed Mode:** Up to **3.4 Mbps**.

I2C Bus Interfacing

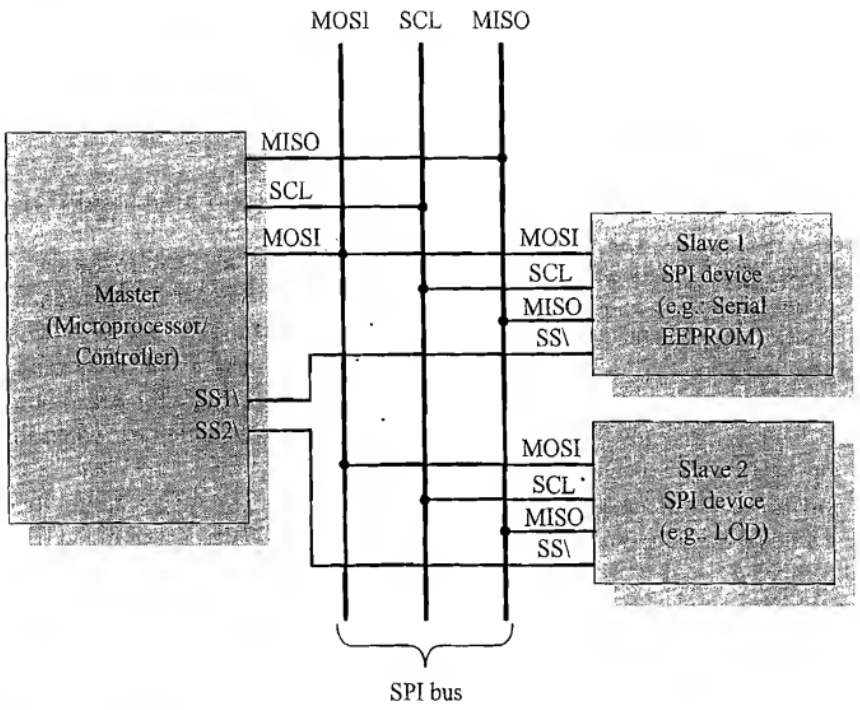


I2C Communication Sequence with a Slave Device

1. **Start Condition:**
   - Master pulls **SDA LOW** while **SCL is HIGH** to signal the start of communication.
2. **Address Transmission:**
   - Master sends a **7-bit or 10-bit slave address** over the **SDA** line.
   - Clock pulses on **SCL** synchronize the transmission.
3. **Read/Write Bit:**
   - Master sends **1-bit command**:
     - 0 → **Write to Slave**
     - 1 → **Read from Slave**
4. **Acknowledgment from Slave:**
   - The addressed slave **acknowledges (ACK) by pulling SDA LOW**.
5. **Data Transfer:**
   - If **writing**, Master sends **8-bit data** to Slave.
   - If **reading**, Slave sends **8-bit data** to Master.
6. **Acknowledgment after Each Byte:**
   - The receiver (Master or Slave) **sends an ACK** after receiving each byte.
7. **Stop Condition:**
   - Master pulls **SDA HIGH** while **SCL is HIGH**, signaling end of communication.

Serial Peripheral Interface (SPI) Bus

- **Definition:** A **synchronous, full-duplex, four-wire serial interface** developed by **Motorola**.
- **Master-Slave System:**
  - **Single master, multiple slaves** (only one master active at a time).
  - Master **generates clock signal** and selects the slave via **Slave Select (SS)**.



SPI Signal Lines:

1. **MOSI (Master Out Slave In):** Data from **Master → Slave**.
2. **MISO (Master In Slave Out):** Data from **Slave → Master**.
3. **SCLK (Serial Clock):** Synchronizes data transfer.
4. **SS (Slave Select):** Activates the selected slave (active LOW).

Working Principle:

- Uses **Shift Registers** for data transfer.
- Data shifts **simultaneously** between Master & Slave via **MOSI & MISO**.
- Configurable settings: Master/Slave selection, baud rate, clock control, LSB/MSB order.

Comparison with I2C:

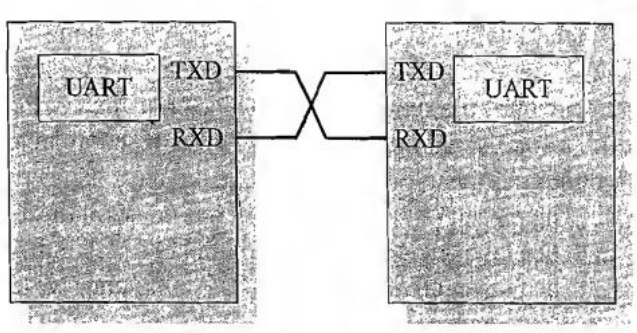
- **Faster** than I2C, ideal for **continuous data transfer (streams)**.
- **No acknowledgment mechanism**, making error detection harder.

Universal Asynchronous Receiver Transmitter (UART):

- **Definition:** UART is an **asynchronous serial communication protocol** that does not require a clock signal for synchronization.

Key Features:

1. **Data Transmission:**
   - Data transmission is based on **pre-defined settings** (baud rate, bits/byte, parity, start/stop bits).
   - Special bits (Start and Stop) indicate the start and end of data transmission.
   - **Parity Bit (optional):** Used for error detection (1 for odd, 0 for even parity).
2. **Operation:**
   - **Start Bit:** Signals the receiver that data is incoming.
   - Receiver polls the line at intervals determined by the baud rate.
   - Discards Start, Stop, and Parity bits to form the data byte.
3. **Connection:**
   - **Transmit (TX)** line of sender connects to **Receive (RX)** line of receiver.
4. **Flow Control:**
   - UART supports **hardware handshaking** for managing data flow.
5. **Implementation:**
   - Early example: **8250 UART** used in IBM PCs.
   - Modern microcontrollers feature **integrated UARTs** for seamless serial communication.



TXD: Transmitter line
RXD: Receiver line

<u>1-Wire Interface</u>

- **Definition:** An asynchronous half-duplex communication protocol developed by Maxim (Dallas Semiconductor).
- **Features:**
  - Uses a **single signal wire (DQ)** for communication and power transmission.
  - Follows a **master-slave model** supporting multiple slave devices.
  - Each device has a **unique 64-bit ID** (8-bit family code, 48-bit serial number, 8-bit CRC).

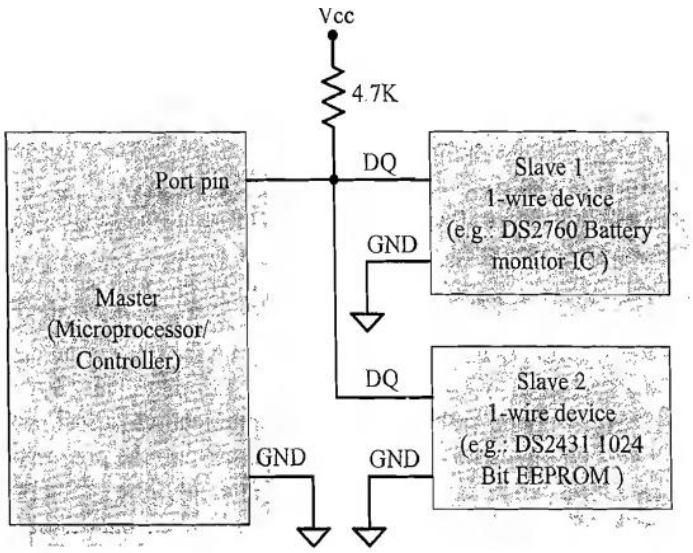
Sequence of Operation:

1. **Reset Pulse:** Master pulls the bus **LOW** for 480 µs to start communication.
2. **Presence Pulse:** Slaves respond with a **LOW pulse** within 60 µs.
3. **ROM Command:** Master sends the **64-bit address** of the slave to address specific devices.
4. **Function Command:** Master sends **read/write commands** to interact with the slave's memory or registers.

5. **Data Transfer:** Master initiates **read/write operations**.

Communication Details:

- Time slots: **60 µs per slot**.
- Writing:
  - Bit '1': Master pulls **LOW** for 1–15 µs, then releases.
  - Bit '0': Master pulls **LOW** for 60–120 µs.
- Reading:
  - Slave sends:
    - Bit '1': Releases bus.
    - Bit '0': Holds **LOW** for the rest of the time slot.



Parallel Interface

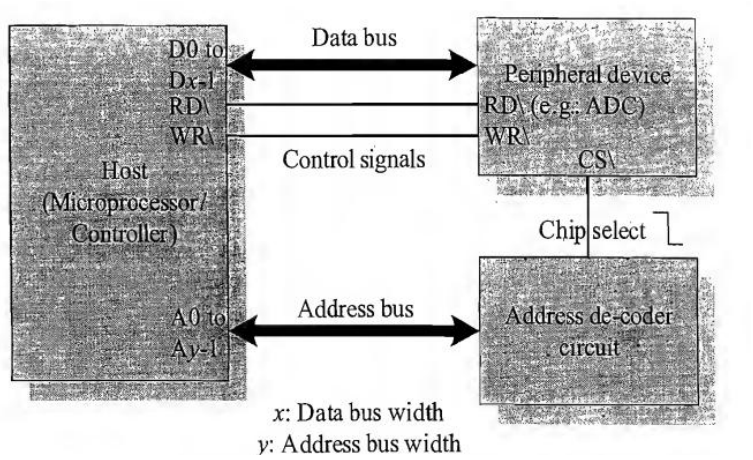
- **Definition:** On-board parallel interfaces are used for communication with peripheral devices **memory-mapped** to the host processor/controller.

Features:

1. **Communication Control:**
   - Controlled by **Read/Write signals** and **Device Select (Chip Select)** signals from the host processor.
   - **Memory Mapping:** Devices are assigned a specific **address range**.
   - **Address Decoder:** Activates the device when the processor selects its address.
2. **Data Transfer:**
   - Direction controlled by **Read (RD)** and **Write (WR)** signals.
   - **Host Initiated:** Communication is always initiated by the host processor.
3. **Interrupt Handling:**
   - Devices can signal the processor using **interrupts** for communication.
   - The device's interrupt line is connected to the host processor's interrupt line.
4. **Bus Width:**

- Matches the **data bus width** of the host processor (e.g., 4-bit, 8-bit, 16-bit, 32-bit, etc.).

5. **Timing:**
   - Parallel communication follows **strict timing protocols** to ensure proper data transfer.



External Communication Interfaces – RS-232, RS-422, RS-485

RS-232:

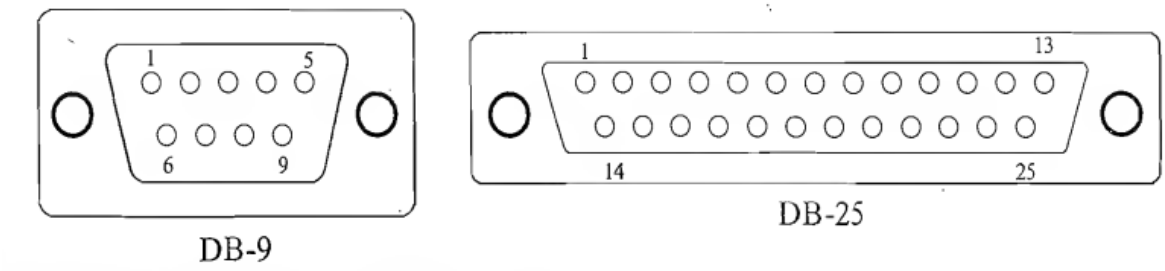
- **Legacy Serial Communication** standard by EIA, supports **point-to-point** communication.
- **Baud Rate:** Up to **19.2 Kbps**, maximum distance **50 ft**.
- Uses **DB-9/DB-25 connectors** and signals logic via **voltage levels (+3 to +25V for 0, -3 to -25V for 1)**.
- Popular in industrial legacy applications, less common now due to USB, Bluetooth, etc.
- Requires **level converters (e.g., MAX232)** for TTL/CMOS logic compatibility.

RS-422:

- Differential data communication, supports up to **100 Kbps** over **400 ft**.
- Allows **multi-drop communication** with **1 transmitter** and up to **10 receivers**.
- Requires RS-232 to RS-422 conversion for use.

RS-485:

- Enhanced RS-422, supports **multi-drop communication** with up to **32 transmitters** and **32 receivers**.
- Uses **addressing mechanism** to identify slave devices.
- Ideal for long-distance and multi-device communication in industrial applications.



RS-232 Connector Pin Details (DB-9 and DB-25)

Key Notes:

- **DB-9 connectors** are more common in modern systems, while **DB-25 connectors** are mostly obsolete.
- For simple data transmission, only **TXD, RXD, and GND** are essential.
- Here are all the pins for **RS-232 connectors (DB-9 and DB-25)**:

Pin Name	Pin Number (DB-9)	Pin Number (DB-25)	Description
TXD	3	2	Transmit Data: Sends serial data.
RXD	2	3	Receive Data: Receives serial data.
RTS (Request to Send)	7	4	Signals readiness to send data.
CTS (Clear to Send)	8	5	Acknowledges readiness to send/receive data.
DSR (Data Set Ready)	6	6	Indicates the device is ready.
DTR (Data Terminal Ready)	4	20	Host signals it is ready to communicate.
DCD (Data Carrier Detect)	1	8	Indicates the presence of a valid carrier signal.
RI (Ring Indicator)	9	22	Indicates an incoming call on a telephone line.
GND (Ground)	5	7	Signal ground: Provides common reference for signal levels.
Secondary TXD (STXD)	-	14	Secondary transmit data for extended configurations.
Secondary RXD (SRXD)	-	16	Secondary receive data for extended configurations.
Secondary RTS (SRTS)	-	19	Secondary request to send signal.
Secondary CTS (SCTS)	-	13	Secondary clear to send signal.
SDCD (Secondary DCD)	-	12	Secondary data carrier detect.
RC (Receiver Clock)	-	17	Timing signal for receiving devices.
TC (Transmission	-	15	Timing signal for transmitting

Clock)			devices.
Signal Ground (FG)	-	1	Frame ground.
NC (No Connection)	9, 10, 11, 18, 23, 24, 25	9, 10, 11, 18, 23, 24, 25	Not connected (reserved).

Universal Serial Bus (USB)

- **Definition:** High-speed, wired serial bus for data communication, introduced in **1995** by Intel, Microsoft, IBM, and others.
- **Topology:** Star topology with a **USB host** supporting up to **127 devices**.
- **Connectors:**
  - **Type A:** Upstream (host).
  - **Type B:** Downstream (slave).
  - Includes **Mini** and **Micro USB** for small devices.
- **Data Transmission:**
  - Packet-based, **host-initiated** with standards like **OHCI** and **UHCI**.
  - Differential signals for noise immunity; supports up to **5m cable length**.
- **Power Supply:** Provides **5V, 500mA** to connected devices.
- **Device Identification:** Uses **Product ID (PID)** and **Vendor ID (VID)** for driver identification.
- **Data Transfer Types:**
  - **Control:** Device configuration.
  - **Bulk:** Block data (e.g., printers).
  - **Isochronous:** Real-time streaming (e.g., audio).
  - **Interrupt:** Small data (e.g., mouse, keyboard).
- **Data Rates:**
  - **USB 1.0:** Low (1.5 Mbps), Full (12 Mbps).
  - **USB 2.0:** High (480 Mbps).
  - **USB 3.0:** Super Speed (4.8 Gbps).

USB Connector Pin Details

Pin	Signal Name	Description
1	VBUS	Power Supply (+5V).
2	D−	Data Line (Negative).
3	D+	Data Line (Positive).
4	GND	Ground.

This pin configuration is applicable for **Type A**, **Type B**, **Mini USB**, and **Micro USB** connectors.

IEEE 1394 (FireWire)

- **Definition:** High-speed, **isochronous serial communication bus** developed by **Apple in 1985**, standardized by **IEEE in 1995**.
- **Other Names:** FireWire (Apple), i.LINK (Sony), Lynx (TI).
- **Topology: Peer-to-peer, point-to-multipoint** (supports **up to 63 devices** in a tree structure).
- **Cable Length:** Up to **15 feet**.
- **Data Rates: 400 Mbps to 3.2 Gbps**.

- **Differential Data Transfer:** Uses **twisted-pair cables** for **better noise immunity**.
- **Connectors:**
  - **4-pin:** Data only.
  - **6-pin (Alpha):** Data + **Power (24-30V)**.
  - **9-pin (Beta):** Higher speeds, **Power (9-12V for battery devices)**.
- **Use Cases:** Digital cameras, camcorders, scanners, **direct device-to-device communication** (e.g., scanner to printer).
- **Comparison with USB:** Faster than **USB 2.0**, **no host required**, but **costlier**.

Wireless Communication Interfaces

Infrared (IrDA):

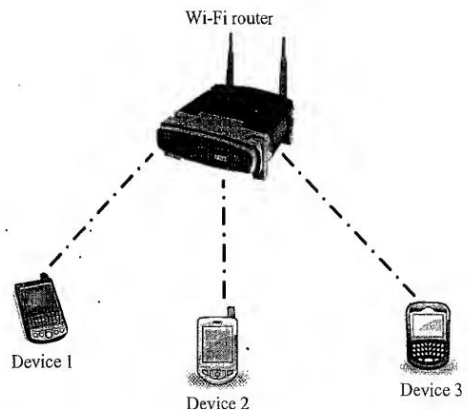
- **Half-duplex, line-of-sight wireless communication**.
- **Range: 10 cm – 1 m**, extendable with higher power.
- **Data Rates: 9.6 kbps – 16 Mbps** (SIR, MIR, FIR, VFIR, UFIR).
- Uses **IR LED for transmission** and **photodiode for reception**.
- **Used in:** TV remotes, file transfer, mobile phones (before Bluetooth).

Bluetooth (BT):

- **Short-range, low-power wireless communication (2.4 GHz RF band)**.
- **Range: ~30 feet**, Data Rate: **Up to 1 Mbps**.
- **Supports: Point-to-point and point-to-multipoint (Piconet, max 7 slaves)**.
- **Profiles:** GAP (connection setup), SPP (serial data), FTP (file transfer), HID (keyboards/mice).
- **Popular in:** Phones, headsets, speakers, wearables.

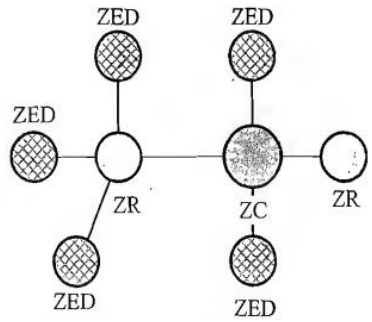
Wi-Fi (IEEE 802.11):

- **Wireless networking communication, IP-based.**
- **Range: 100-300 feet**, **Data Rates: 1 Mbps – 150 Mbps**.
- Requires **Wi-Fi Router** for managing connections.
- **Security Protocols:** WEP, WPA, WPA2.
- **Used in:** Internet access, smart devices, IoT.



ZigBee (IEEE 802.15.4):

- **Low-power, low-data-rate WPAN (Wireless Personal Area Network)**.
- **Range: Up to 100 meters**, **Data Rate: 20 – 250 Kbps**.
- **Network Roles:**
  - **Coordinator (ZC):** Initiates and manages the network.
  - **Router (ZR):** Passes data between devices.
  - **End Device (ZED):** Communicates but doesn't route.
- **Used in:** Home automation, smart meters, IoT, industrial monitoring.



Zigbee Network Model

GPRS (General Packet Radio Service):

- **Packet-switched mobile data communication over GSM networks.**
- **Max Data Rate: 171.2 kbps**.
- **Uses:** IP, PPP, X.25 protocols.
- **Replaced by:** EDGE, HSDPA, LTE for higher speeds.
- **Used in:** Mobile internet, GPS trackers, M2M communication.

Infrared (IrDA) Communication

Bluetooth (BT) Communication

Wi-Fi Communication

ZigBee Communication

GPRS Communication

Embedded Firmware

- **Definition:** Embedded firmware consists of **program instructions** and **configuration settings** stored in an embedded system's memory.
- **Development Methods:**
    1. **High-Level Languages (C/C++)** – Uses **IDEs** like Keil for coding, compiling, debugging, and simulation.
    2. **Assembly Language** – Uses **processor-specific instructions** but is **harder to write and debug**.
- **HEX File Creation:** Converts code into machine-readable **binary format** using **cross-compilers** or **vendor utilities**.
- **Recommended Approach: High-level languages** are preferred due to **ease of coding, portability, faster debugging, and team collaboration**.
- **Control Algorithm Approaches:**
    1. **Super Loop (Infinite Loop)** – Runs continuously like while(1){}.
    2. **Task Scheduler (RTOS/GPOS)** – Splits functions into tasks managed by an **operating system**.

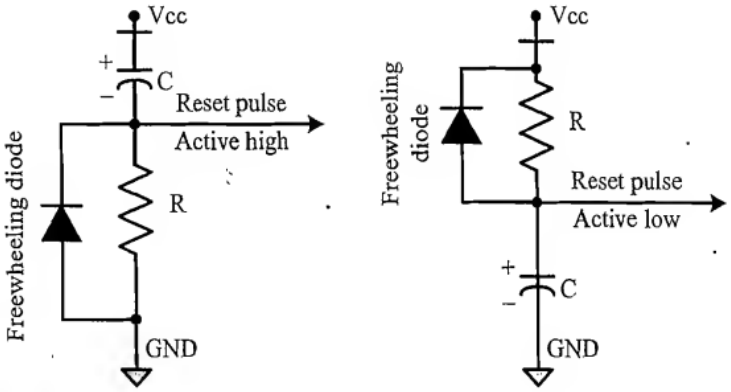
1.10 Other system components, PCB and passive components

Other System Components – Key Points

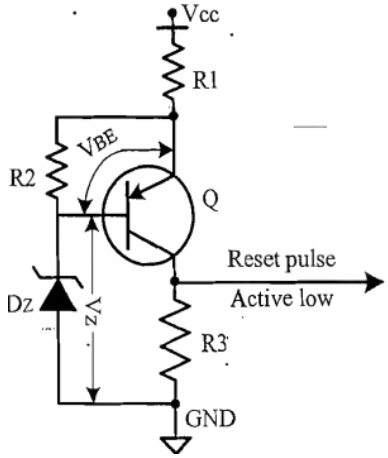
- **Definition:** Essential **circuits/ICs** required for proper **functioning** of an embedded system.
- **Examples:**
  - **Watchdog Timer** – Prevents system hang-ups.
  - **Reset IC/Circuit** – Ensures proper system startup.
  - **Brown-out Protection** – Prevents malfunction during power drops.
- **Integration:** Some **controllers/SoCs** have these built-in; others require **external components**.
- **Additional Components: Level translators, specific function ICs**, and interface circuits as needed.

Essential System Components – Key Points

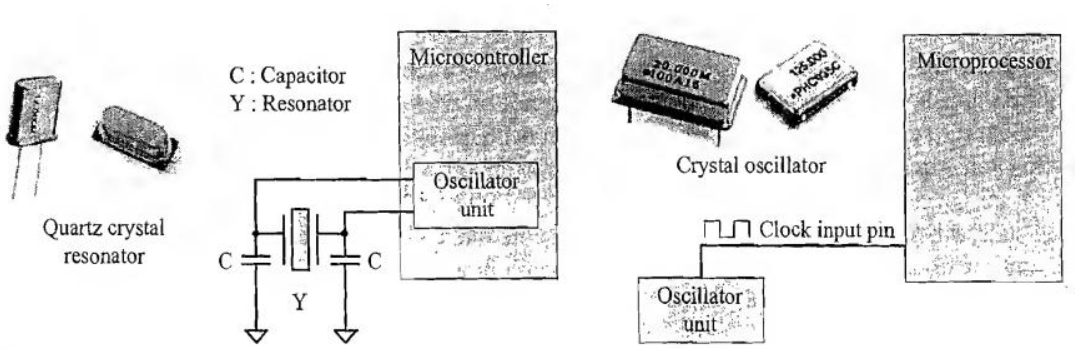
- **Reset Circuit:** Ensures proper startup by resetting the processor to a known state at power-on. Uses **passive RC circuits or Reset ICs**.



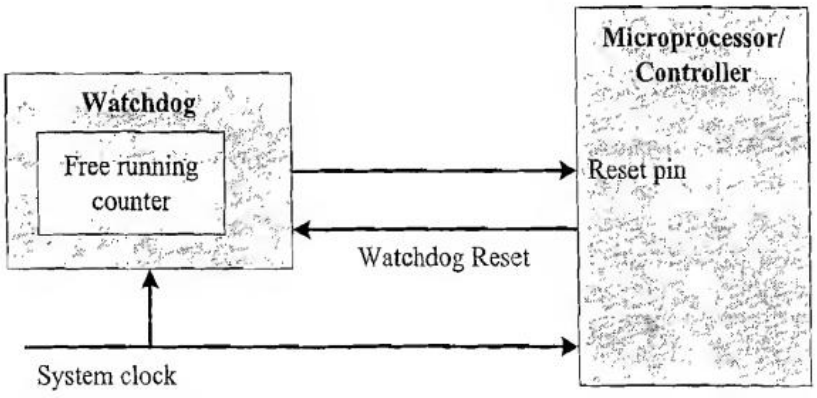
- **Brown-out Protection:** Prevents malfunction when voltage drops below a threshold. Implemented using **Zener diodes, transistors, or supervisor ICs**.



- **Oscillator Unit:** Generates clock signals for processor operation. Uses **quartz crystals, ceramic resonators, or external oscillator chips**.



- **Real-Time Clock (RTC):** Maintains system time, date, and alarms. Essential for **OS-based systems** for time synchronization.
- **Watchdog Timer:** Monitors firmware execution and resets the system if it **hangs or malfunctions**. Built-in in most processors or available as **external ICs**.



PCB and Passive Components – Key Points

- **Printed Circuit Board (PCB):** The **foundation** of an embedded system, designed based on schematics and used for **component mounting and firmware testing**.
- **Passive Components:** Essential **supporting elements** like **resistors, capacitors, diodes**, etc., ensuring stable operation.
    - **Example:** Regulator IC with **filter capacitors** for a stable, ripple-free power supply.

Outcomes

At the end of the module, students will be able to:

CO-1: Explain characteristics of Embedded System design [L2]

TEXT BOOKS:

Shibu K V, "Introduction to Embedded Systems", Second Edition, McGraw Hill Education

Reference Books/ Link

NPTL Lectures: https://nptel.ac.in/courses/108102045
Embedded Systems, IIT Delhi, Prof. Santanu Chaudhary