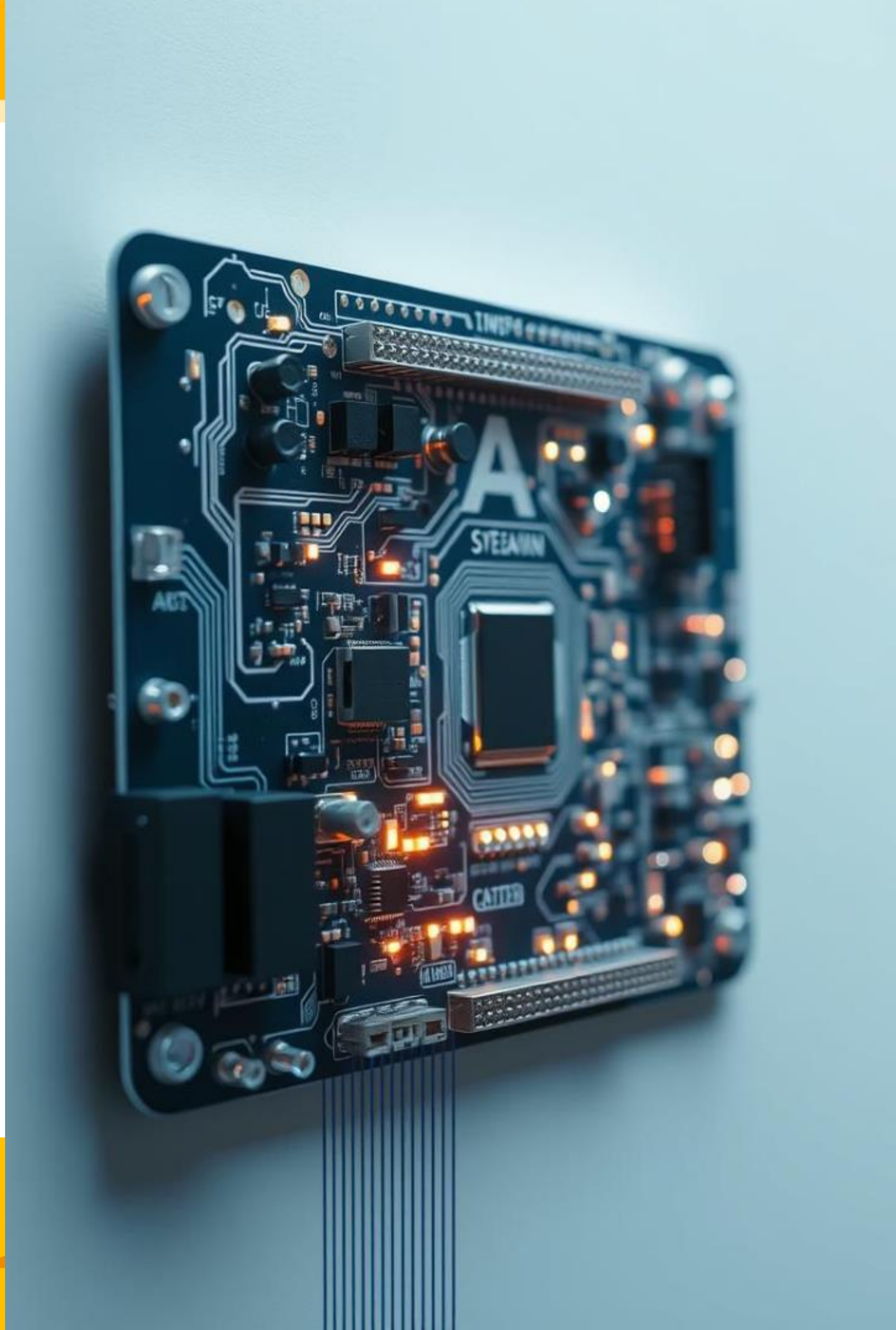
EMBEDDED SYSTEMS (CMPE 30274)

Module 5

Onboard and External Communication in Embedded Systems



Objectives

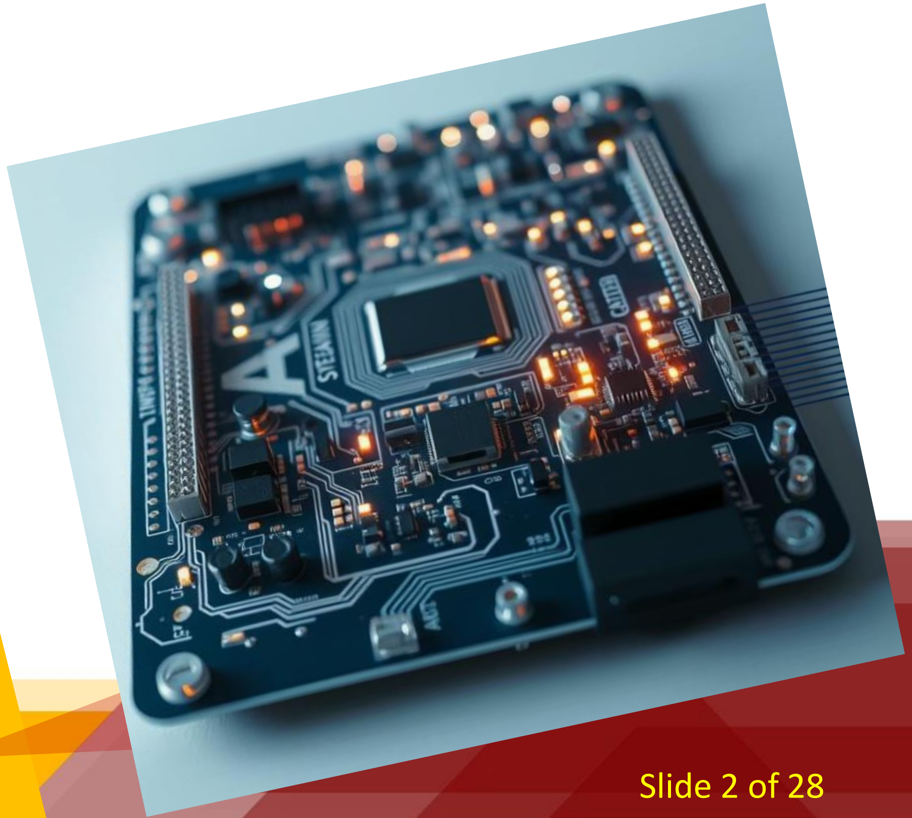
- Understand the differences between onboard and external communication interfaces.
- Identify common communication protocols used in embedded systems.
- Analyze the advantages and disadvantages of various communication interfaces.

Onboard Communication Interfaces

refers to the data exchange that occurs within an embedded system, typically between the microcontroller and its internal components (such as sensors, actuators, and memory).

Key Features:

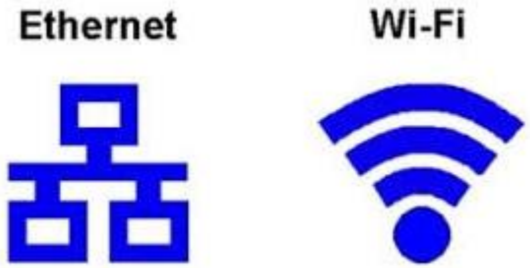
Scope: Short range, typically with the PCB.
Communication within the same device.
Examples: GPIO, I2C, SPI, UART.



External Communication

- involves data exchange between the embedded system and external devices or networks.

- allows the embedded system to interact with the outside world, enabling functionalities such as remote monitoring, control, and data sharing.



Key Features:

Scope: Communication with devices outside the embedded system.
Examples: USB, Ethernet, Wi-Fi, Bluetooth.

On board communication Interfaces

- General-Purpose Input/Output (GPIO)
- I2C (Inter-Integrated Circuit)
- SPI (Serial Peripheral Interface)
- UART (Universal Asynchronous Receiver/Transmitter)

External Communication Interfaces

- USB (Universal Serial Bus)
- Ethernet
- Wi-Fi
- Bluetooth

Onboard Communication Interfaces

General-Purpose Input/Output (GPIO)

•GPIO pins are the simplest form of communication in embedded systems. They can be configured as either input or output, allowing for digital signal transmission.

Applications:

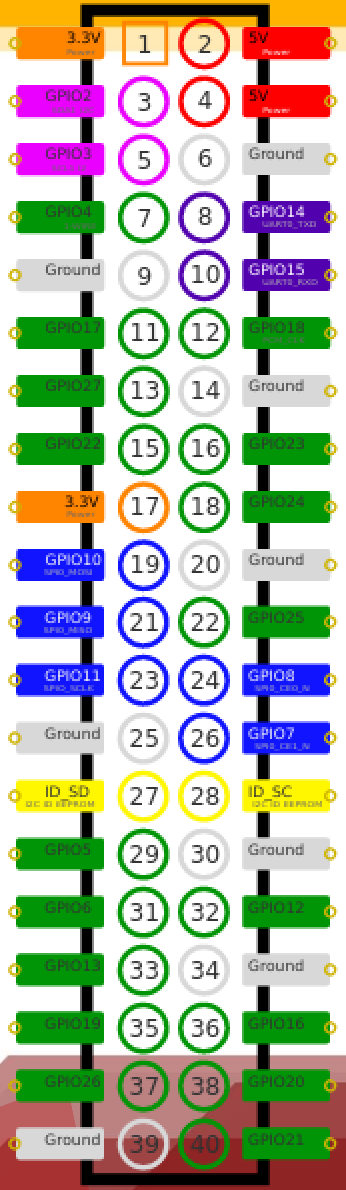
•Used for controlling LEDs, reading button states, and interfacing with simple sensors.

Pros and Cons:

•**Advantages:** Easy to implement; low power consumption; minimal hardware requirements.

•**Disadvantages:** Limited in complexity; not suitable for high-speed data transfer.

•Use Case : LEDs, push buttons, simple sensors



I2C (Inter-Integrated Circuit)

•Synchronous, half-duplex
•I2C is a multi-master, multi-slave protocol that allows multiple devices to communicate over two wires: SDA (data line) and SCL (clock line).

Applications:

•Commonly used in sensor networks, EEPROMs, and RTCs (Real-Time Clocks).

Pros and Cons:

•**Advantages:** Simple wiring; allows multiple devices on the same bus; supports different data rates (standard mode up to 100 kbps, fast mode up to 400 kbps).
•**Disadvantages:** Slower than SPI; limited to short distances (typically less than 1 meter); requires pull-up resistors.
•Temperature sensors, EEPROMs, RTCs (Real-Time Clocks)

SPI (Serial Peripheral Interface)

• Asynchronous, full-duplex

•SPI is a high-speed synchronous protocol that uses four lines: MOSI, MISO, SCK, and SS. It is designed for short-distance communication between a master and one or more slave devices.

Applications:

•Used in applications requiring high data rates, such as SD cards, LCD displays, and sensors.

Pros and Cons:

•**Advantages:** Fast data transfer rates (up to several Mbps); full-duplex communication; simple protocol.

•**Disadvantages:** More complex wiring; requires more pins compared to I2C; no standard addressing scheme.

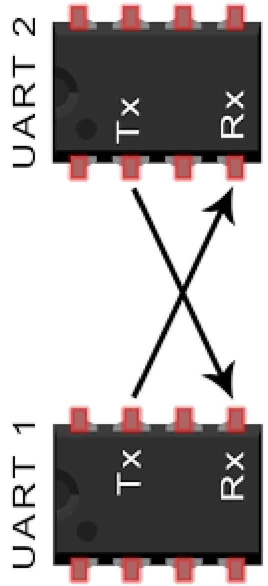
•Use Case : Debugging, GPS modules, Bluetooth

In **SPI (Serial Peripheral Interface)**, the four main signals are:

- MOSI (Master Out, Slave In) – Data line for sending data from the master to the slave.
- MISO (Master In, Slave Out) – Data line for sending data from the slave to the master.
- SCK (Serial Clock) – Clock signal generated by the master to synchronize data transfer.
- SS (Slave Select) – A control signal from the master to select which slave device to communicate with (active low).

UART (Universal Asynchronous Receiver/Transmitter)

•UART is a hardware communication protocol used for asynchronous serial communication. It requires only two lines: TX and RX.



Applications:
•Frequently used for serial communication with PCs, GPS modules, and other microcontrollers.

Pros and Cons:
•**Advantages:** Simplicity; no clock signal required; widely supported and easy to debug.
•**Disadvantages:** Limited to point-to-point communication; lower data rates compared to SPI; requires specific baud rate settings.

External Communication Interfaces

USB (Universal Serial Bus)

Asynchronous, serial communication
Speed:
  USB 2.0: 480 Mbps
  USB 3.0: 5 Gbps

Wiring: Uses 4 or more lines (D+, D-, VCC, GND)

•USB is a standard for connecting peripherals to computers and other devices. It supports data transfer, power supply, and device communication.

Pros and Cons:
•**Advantages:** High data transfer rates (up to 10 Gbps); supports hot-swapping; widespread adoption.
•**Disadvantages:** More complex protocol; requires specific drivers; higher power consumption.

Ethernet

Synchronous, packet-based communication
Speed: 10 Mbps, 100 Mbps, 1 Gbps
Wiring: Uses twisted pair cables (Cat5e, Cat6)

•Ethernet is a networking technology for local area networks (LANs) that allows devices to communicate over a wired connection.

Applications:
•Common in industrial automation, smart home devices, and IoT applications.

Pros and Cons:
•**Advantages:** High-speed data transfer; reliable and robust; supports multiple devices on the same network.
•**Disadvantages:** Requires additional hardware (network interface cards); more complex setup; potential for interference.

Wi-Fi

Wireless, packet-based communication
Speed: 2 Mbps – 1 Gbps
Wiring: No physical wiring, uses radio signals

•Wi-Fi is a wireless communication standard that allows devices to connect to a network without physical cables.

Applications:
•Used in smart home devices, mobile applications, and remote monitoring systems.
Pros and Cons:
•**Advantages:** Flexibility and mobility; supports multiple devices; easy to integrate into IoT applications.
•**Disadvantages:** Vulnerable to security threats; affected by range and interference; variable data rates.

Bluetooth (IEEE 802.15.1)

- **Type**: Wireless, short-range communication
- **Speed**: Up to 3 Mbps (Bluetooth Classic), 2 Mbps (BLE)
- **Wiring**: No physical wiring, uses radio signals

- Bluetooth is a short-range wireless communication technology designed for low-power devices.

Applications:

- Commonly used in wearable devices, headphones, and home automation systems.

Pros and Cons:

- **Advantages:** Low power consumption; relatively easy to pair devices; suitable for short-range communication.
- **Disadvantages:** Limited range (typically up to 100 meters); lower data rates compared to Wi-Fi; potential for interference in crowded environments.

Feature	Bluetooth Low Energy (BLE)	Classic Bluetooth
Power Consumption	Very low	Higher
Data Rate	Up to 1 Mbps	Up to 3 Mbps
Connection Range	Typically up to 50 meters	Typically up to 100 meters
Primary Use	IoT devices, wearables	Audio streaming, file transfer
Latency	Lower latency	Higher latency
Programming	Simpler, often event-driven	More complex, stateful connections

LoRa (Long Range Communication)

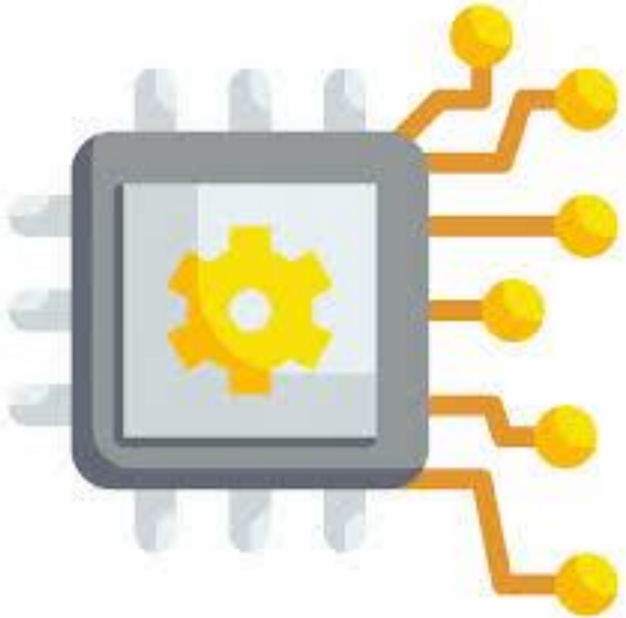
- **Type**: Wireless, long-range communication
- **Speed**: 0.3–50 kbps
- **Wiring**: No physical wiring, uses sub-GHz radio frequencies

- **Pros**:
  - Very long range (10+ km)
  - Low power consumption
- **Cons**:
  - Low data rates
- **Use Cases**:
  - Smart agriculture, IoT devices

CAN Bus (Controller Area Network)

- **Type**: Synchronous, message-based protocol
- **Speed**: 1 Mbps (classic CAN), 5–10 Mbps (CAN FD)

- **Wiring**: Uses twisted pair (CAN_H, CAN_L)
- **Pros**:
  - Highly reliable
  - Works well in noisy environments
- **Cons**:
  - More complex software handling
- **Use Cases**:
  - Automotive, industrial automation



Feature	Onboard Communication	External Communication
Scope	Within the same system (PCB)	Between different systems or networks
Range	Short (cm to meters)	Longer (meters to kilometers)
Protocols	SPI, I^2C, UART, GPIO	USB, Ethernet, Wi-Fi, Bluetooth, LoRa
Speed	High speed, low latency	Varies (from low-speed LoRa to high-speed USB 3.0)
Power Consumption	Low	Can be high (e.g., Wi-Fi)

Interface	Type	Speed	Wiring	Use Cases
SPI	Synchronous	Up to 50 MHz	4+ wires	Displays, memory
I^2C	Synchronous	Up to 3.4 Mbps	2 wires	Sensors, RTCs
UART	Asynchronous	Up to 115200 bps	2 wires	Debugging, GPS
GPIO	Digital	Varies	Single pin per signal	LEDs, buttons
USB	Serial	Up to 5 Gbps	4+ wires	Data transfer, peripherals
Ethernet	Packet-based	Up to 1 Gbps	Twisted pair	IoT, industrial
Wi-Fi	Wireless	Up to 1 Gbps	None	IoT, mobile devices
Bluetooth	Wireless	Up to 3 Mbps	None	Wearables, audio
LoRa	Wireless	Up to 50 kbps	None	Long-range IoT
CAN Bus	Message-based	Up to 1 Mbps	2 wires	Automotive, automation

Feature	SPI	I²C	UART	Bluetooth	Wi-Fi	USB
Type	Synchronous	Synchronous	Asynchronous	Wireless	Wireless	Wired
Wires	4 (MOSI, MISO, SCLK, SS)	2 (SDA, SCL)	2 (TX, RX)	Wireless	Wireless	4 (VCC, GND, D+, D−)
Full-Duplex	Yes	No	Yes	Yes	Yes	Yes
Power	Low	Low	Low	Low (BLE), Medium (Classic)	High	Medium-High
Examples	SD cards, ADC/DAC, LCDs	EEPROM, sensors, RTC	Terminals, GPS, BT modules	Headphones, keyboards, wearables	Internet, file transfer, streaming	Flash drives, printers, HDDs

Considerations for Selecting Communication Interfaces

Power Consumption
Power efficiency is crucial, especially in battery-operated devices. Low-power interfaces like Bluetooth Low Energy (BLE) or I2C are often preferred for such applications.

Data Rate Requirements
The choice of interface heavily depends on the required data transfer rates. For high-speed applications, SPI or USB may be more appropriate, while I2C or UART may suffice for lower data rates.

Distance
The physical distance between components influences the selection of communication interfaces. For example, I2C is suitable for short distances, whereas Ethernet or Wi-Fi is better for longer distances.

Complexity and Cost
Simpler interfaces like GPIO or UART may be more cost-effective for basic applications, while more complex interfaces like USB or Ethernet may add to the system's cost and complexity.

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