Task 2

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UART

- UART (Universal Asynchronous Receiver–Transmitter) operates on the principle of asynchronous serial communication, where data is transmitted bit-by-bit without a shared clock line. (can be parallely received)
- It works by framing each data packet with a start bit, data bits, optional parity, and stop bits, allowing the receiver to synchronize with the sender based solely on the agreed baud rate.
- UART is advantageous because it requires only two main wires (TX and RX), is simple to implement, widely supported by microcontrollers, and ideal for low-speed point-to-point communication.
- Its disadvantages include limited data rate, short transmission distance, susceptibility to noise without differential signaling, and inability to support multiple devices on the same line.
- UART is commonly used in microcontroller communication, debugging, GPS modules, GSM/Bluetooth modules, and serial peripheral devices.
- In terms of efficiency, UART offers low overhead and reliable communication for small data packets but becomes inefficient for high-speed or multi-device systems.
- Alternatives include **SPI** for high-speed full-duplex communication, **I2C** for multi-device two-wire communication, and **RS-485** for long-distance differential serial links.
- Examples include onboard UART ports of Arduino, STM32, ESP32, and external USB-to-UART converters like **FT232RL** and **CH340G**.

SPI

- SPI (Serial Peripheral Interface) operates on the principle of synchronous serial communication using a dedicated clock line to ensure precise timing between devices.
- It works in a master–slave architecture with four main lines: SCK (clock), MOSI (master out), MISO (master in), and CS/SS (chip select), allowing the master to send and receive data simultaneously in full duplex as the clock shifts bits in and out of the devices.
- SPI is advantageous because it offers very high data rates, low latency, full-duplex capability, and reliable communication over short distances, making it ideal for performance-critical peripherals.
- Its disadvantages include the need for more wires than other protocols, limited scalability for many slaves due to multiple chip select lines, and the absence of device addressing.
- SPI is widely used in displays (TFT, OLED), SD cards, sensors, ADC/DAC modules, wireless transceivers, and high-speed data converters.
- In terms of efficiency, SPI is extremely fast and efficient for continuous data streaming or real-time communication, but wiring complexity increases as more devices are added.
- Alternatives include **I2C** for multi-device communication with fewer wires, **UART** for simple point-to-point links, and **QSPI** for higher-bandwidth flash memory interfaces.
- Common examples of SPI-based devices include the **NRF24L01 wireless module**, **MAX7219 display driver**, **LSM9DS1 IMU**, and **W25Qxx flash memory chips**.

I2C

- I^2C (Inter-Integrated Circuit) operates on the principle of synchronous serial communication using only two wires—SCL (clock) and SDA (data)—to connect multiple devices on the same bus through unique addressing.
- It works in a master–slave architecture where the master controls the clock, initiates communication, and sends or requests data, while slaves respond based on their assigned 7-bit or 10-bit address.
- I^2C is advantageous because it supports many peripherals with minimal wiring, offers good reliability, and simplifies PCB design, making it ideal for sensor networks and low-speed peripherals.
- Its disadvantages include slower speeds compared to SPI, susceptibility to noise due to open-drain signaling, limited bus length, and shared bandwidth among all devices.

- I^2C is commonly used in IMUs, EEPROMs, temperature sensors, RTC modules, OLED displays, and configuration chips where moderate speed and multi-device communication are required.
- In terms of efficiency, I^2C is highly efficient for short-range, multi-sensor systems but not suitable for high-speed data transfer or long-distance communication.
- Alternatives include SPI for faster, low-latency operation, UART for simple point-to-point communication, and CAN bus for robust long-distance multi-device networks.
- Common I^2C-compatible components include the MPU6050 IMU, DS3231 RTC, BMP280 sensor, AT24C04 EEPROM, and SSD1306 OLED display.

Parameter	**UART**	**I^2C**	**SPI**
Communication Type	Asynchronous	Synchronous	Synchronous
Clock Line	Not required	Shared clock	Dedicated clock
Duplex Mode	Full duplex	Half duplex	Full duplex
Number of Wires	2 (TX, RX)	2 (SDA, SCL)	4 (MOSI, MISO, SCLK, CS)
Topology	Point-to-point	Multi-master, multi-slave	Single master, multi-slave
Device Selection	Fixed connection	Address-based	Chip Select based
Addressing	Not supported	7-bit / 10-bit	Not supported
Speed	Low	Medium	High
Protocol Overhead	Start/stop bits	Address and ACK	Minimal
Error Detection	Parity (optional)	ACK/NACK	None
Hardware Complexity	Very low	Medium	Medium
Scalability	Poor	Excellent	Poor
Distance	Long	Short	Very short
Typical Applications	Serial debug, GSM	Sensors, RTC, EEPROM	Displays, SD cards